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AN APPLICATION OF A LINEAR PROGRAMMING MODEL TO SPATIAL PLANNING OF FOREST RESOURCES IN THE KALAMAZOO RIVER BASIN OF MICHIGAN

By

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ABSTRACT

AN APPLICATION OF A LINEAR PROGRAMMING MODEL
TO SPATIAL PLANNING OF FOREST RESOURCES
IN THE KALAMAZOO RIVER BASIN OF MICHIGAN

By

Craig Dennis Osteen

The U.S. Forest Service is interested in developing an integrated land inventory and evaluation system useful for river basin planning. The system is called the Multiple Use Management Simulator (MUMS). The objective of the study is to examine the feasibility of building an integrated land inventory and evaluation system for river basin planning studies. The location aspect of the model is emphasized.

Important issues considered in conceptualizing the system include the spatial and time aspects of demand, production, and environmental impacts; the openness of the river basin economy; and the transfer of goods through the economy. The conceptualized system consists of a set of components. The first component is the land evaluation system which generates acreages of land management strategies, which are combinations of land practices which produce goods, to meet various requirements for goods at different locations. This component also locates strategies and their outputs in space. This component consists of a psuedo-dynamic regional linear programming model with transportation and environmental diffusion components incorporated into the production component. This model allocates production requirements among regions and generates pat-

terns of land management. A multiple land use assignment model allocates management strategies among grid cells which make up a region.

The second component is the land inventory component which stores information needed by the land evaluation system. Location information, raw resource data, and resource classes are stored. The third component is the constraint generator which constrains the land evaluation system with decisions made outside of the system. Alternative flowcharts are presented.

The fourth component is goals for outputs and land use. The fifth component includes land management strategy data. Information is generated by relationships based on resource data, land practices, and time. The sixth component consists of displays which include tables and maps produced by computer graphics.

A portion of the system was tested. A pseudo-dynamic regional linear programming model with the transport component incorporated was constructed for the forest sector of the Kalamazoo River Basin. Six time periods, four commodities, four regions inside the river basin, and eight regions outside of the river basin were considered. A transport system connects the regions. Requirements for the goods were estimated over time. Production in regions outside of the river basin was estimated. Importing and exporting was included in the model. Production and transport costs were estimated. The model minimizes production and transportation costs subject to land constraints and requirements for goods at different locations.

Five computer runs were completed. Assumptions associated with these runs were as follows:

A. No growth in timber and hunterday requirements over time.

B. Growth in timber requirements in regions with pulpmills.

C. Growth in timber and hunterday requirements.

D. Growth in hunterday requirements and a higher rate of growth of timber requirements.

E. Growth in hunterdays and no growth in timber requirements.

Land management patterns, levels of production, quantities received at different locations, and flows between regions were discussed. It was found that all lands capable of producing timber during the time period of analysis should be converted to intensive management as soon as possible, given the assumptions and objectives of the model. All non-timber producing lands in the adequate condition class should be converted to intensive management as soon as possible. Non-timber producing lands in the non-adequate condition classes have the lowest priority for intensive management. Important factors affecting allocation of land management strategies include: 1) levels of requirements for goods produced, 2) trade-offs between investments in land to increase outputs and transportation and importing costs to bring goods into a region, 3) time distribution of production, and 4) time period of analysis.

OBERS demands for the river basin for the present and 1990 cannot be met given the assumptions of this model. Possibilities for growth of timber-using industries are limited by small amounts of commercial forest land, conversion of forest land to urban use, and the dispersed, private ownership of forest land.

Problems with the model are discussed. The assumptions of linear programming, assumptions concerning behavior of social and natural systems, and assumptions that reduce data needs make the model simpler than reality. The model does not seem to be well suited to predicting land use patterns in the Kalamazoo River Basin which is made up of small, scattered, privately-owned tracts of land. The model appears to be better suited to planning management of publicly-owned land or for setting guidelines for management practices to be encouraged through extension programs. Important management options were not included in the model. Bias could be introduced into the solution as a result. Including the dimensions of time and space greatly increase the size of the tableau and costs of solving the model.

It is feasible to construct a linear programming model of the forest resource of a river basin which includes spatial and temporal ecologic and economic dimensions. However, it is costly to operate and difficult to construct. It is difficult to link the tested model to the currently used USDA model. Data in the Kalamazoo River Basin are not precise enough in spatial and management terms to support a gridded data system. Data that could be used in demand and supply projection models are also scarce. Data submitted by the U.S. Forest Service were poorly documented. More documentation of these data is desirable.

PREFACE

This dissertation is the final report of a research project funded by the Northeastern Area, State and Private Forestry, Forest Service, U.S.D.A The research study was called the "Multiple Use Simulator (MUMS)."

The problem statement, study objectives, research approach, and description of the study area are presented in Chapter I. The ideal model is conceptualized in Chapter II. The model which tested and the data collected for the model are discussed in Chapter III. Chapter IV discusses the results of testing. The model is criticized in Chapter V. Chapter VI contains the summary, conclusions, and recommendations. Appendix AA contains flowchart symbols. Appendices B through CC contain information used as input to the model. Appendices CC through FF contain results of testing the model. Appendix GG is a glossary of terms.

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CHAPTER I

INTRODUCTION

Statement of the Problem

The U.S. Forest Service is interested in developing an integrated land inventory and evaluation system useful for river basin planning. It is called the Multiple Use Management Simulator (MUMS). The system should have the capability to handle land uses and outputs of land uses and be useful to other agencies of the U.S. Department of Agriculture involved in river basin planning. Important aspects of river basin planning are the location of land management strategies and the location of outputs and impacts of land management strategies. The objective of the U.S. Forest Service is to investigate the feasibility of building a system that uses land resource information, allocates land management strategies in space, and displays the impacts of these strategies over space.

There are alternative models and system designs to inventory land resource data, allocate management strategies in space, and display impacts by location. General types of models that could be used for the land evaluation system include input-output models, linear programming models, simulation models, and hybrid models. There are other systems that can be used to store land data and input it to the land evaluation system. The output of the land evaluation system must also be handled. Part of the problem is to identify the alternatives, since there is some uncertainty as to which alternatives exist and which are best.

The problem exists in a context. MUMS may be used to satisfy the information needs of river basin planning. The model could be used to test various land use plans and project what is likely to occur. In the planning process, objectives for production of goods and services and environmental conditions are defined. They could be based on 1) national and regional economic conditions that are likely to impact on a region over time, and 2) the participation of various levels of government and the public. Alternative objectives for goods, services, and environmental conditions could be used in different runs of the model. Comparisons of results could then be made. Current and future levels of achievement are to be projected in the planning process. The resources of the river basin are inventoried and their capabilities appraised. The inventory defines the availability of resources to satisfy current and future levels of objectives. Planning is concerned with how to use these resources to achieve objectives.

The Water Resources Council has defined a set of goals for planning land and water resources in river basins. MUMS will be concerned with evaluating land use plans to meet these objectives. The Water Resources Commission defines four basic sets of objectives: a) enhancement of national economic development, b) enhancement of environmental quality, c) regional development, and d) social well-being (Water Resources Council, 1972). Alternative plans can be developed, each of which favor one objective over the others.

National economic development deals with the value of output of goods and services and national economic efficiency. Beneficial effects of the plan include: a) value to users of increased outputs of goods and services, and b) value of output resulting from external economies. Adverse effects include: a) value of resources required for or displaced by the plan and b) losses in output resulting from external diseconomies.

Environmental quality is evaluated in terms of physical or ecological criteria or dimensions, including qualitative aspects. This objective is concerned with the effects on areas of natural beauty; water, land, and air quality; biological resources and selected ecosystems; geological, archeological, and historical resources; and irreversible or irretrievable commitments of resources to future use.

The regional development aspect deals with the subnational effects and thus may deal with distributional effects over space and between social groups. Beneficial income effects include: a) value of increased output of goods and services within relevant regions, and b) value of output resulting from externalities occurring within relevant regions. Adverse income effects include: a) values of resources within relevant regions required for or displaced by the plan, and b) losses in output resulting from externalities within relevant regions. Other effects include the number and types of jobs, effects on population distribution within and among regions, and effects on the region's environment.

Social well-being seems to be a category inserted to deal with that which was not covered in the above categories. It includes real income distribution; life health, and safety effects; educational, cultural, and recreational opportunities; and emergency preparedness.

The U.S. Forest Service believes that it is desirable for MUMS to have the capability to be linked to the existing Economic Research Service's least cost linear program that will generate impacts of alternative land management strategies and agricultural outputs. A land inventory system based on the Soil Conservation Service Conservation Needs Inventory already exists. New sectors are being added to the model. These sectors are the forest and pasture sectors. The model excludes urban land. The heart of the model is a set of management strategies. These management strategies produce a set of products called a product-package which includes both positive and negative aspects. Each product has a row coefficient. Each row can be constrained to meet a particular demand. Each management strategy is assigned a cost for producing the product-package. The model then minimizes total production costs of meeting certain demands and shows various impacts of the solution. The model is not permitted to change land use from crop to forest to pasture, etc. Land use transfers of this type can occur only when specified before the model is run. Management strategies on cropland or forest land are allowed to change.

Demands are incorporated into the model in the form of constraints. The initial set of demands are regional food and fiber projections based on OBERS projections. Requirements for other products in each product-package can be developed with representatives of the public in a river basin. The model projects the acreages of various management strategies required to meet projected needs in the years 2000 and 2020.

The river basin linear program is essentially spaceless. It does not account for the costs of bringing consumers and products together nor does it account for the spatial distribution of resources.

Study Objectives

The primary objective of this study is to examine the feasibility of building an integrated land inventory and evaluation system for river basin planning studies. Recommendations concerning the structure and development of the model are to be made. This will involve conceptualizing the system, including the types of questions with which to deal, and analyzing the problems in and the feasibility of building such a system. Specific goals of the study are listed:

1. Survey the literature to find existing models and concepts that can be incorporated into the land inventory and evaluation system. The emphasis is put on the location model.
2. Study the feasibility of developing a location model that can be linked to a production model, such as the Economic Research Service's least cost linear programming river basin model. Linkages to the production model must also be conceptualized. The Forest Service is interested in several specific points in this area of emphasis:
    a. Identification of key variables to form sub-regions of river basins. These variables should be important variables for river basin planning.
    b. If possible, an estimate of bias caused by forcing sub-regions to conform to political boundaries should be made.
    c. The distribution of key variables should be displayed using a method that can be adapted to the Economic Development Administration's two minute by two minute national grid.

3. Conceptualize and study the feasibility of developing other parts of the system.
4. Examine the suitability of the model for land use, specifically river basin, planning by U.S.D.A.
5. Test the location model on the forest sector of the Kalamazoo River Basin and generate alternative land use plans from it.

Research Approach

The focus of this research project is model building. This project is divided into a series of steps: 1) conceptualization of the system and its components, 2) testing of some of the components, specifically the location model, 3) analysis of the results of testing, and 4) discussion of the suitability of the system for land use planning and policy-making. The activities undertaken in each step are briefly discussed below. The details of these activities will be elaborated in later chapters.

Conceptualization of the System

The questions to be approached by the system and the issues to be considered in answering them are defined. Once this is done, a search for models and concepts to be used is undertaken. The system and its components are conceptualized by defining the components, the purpose of each component, and the models that could be used in each component. The system and its components are then specified in mathematical form and flowcharts. Variables, relationships, and assumptions are defined. The linkages between the components are also defined.

Testing

During this stage, the location model is tested to discover the extent to which it meets the purpose for which it was designed. Alternative questions and assumptions concerning future land use in the Kalamazoo River Basin are developed to be considered by the system. Data for the system are then collected. The computer model is constructed. Computer runs are made to test the hypotheses and consider various land use questions.

Analyses of the Tests

In this stage results of the computer runs are presented and analyzed. Impacts of results on the hypotheses and questions are discussed. Land use plans developed by the system are compared and the validity of the structure and data are analyzed. Changes that could be made in the system are recommended.

Discussion of System Suitability

The suitability of the system for land use planning and policy-making is analyzed. Shortcomings, limitations, and strengths are pointed out. Recommendations as to the feasibility and suitability of the system to land use planning and policy-making are discussed.

Description of the Study Area

The model was tested on the forest sector of the Kalamazoo River Basin in southwestern Michigan. The Kalamazoo River Basin was chosen because the U.S. Forest Service is participating in a planning study for the river basin. Data were made available by the Forest Service and other U.S. Department of Agriculture personnel. Most of the work on the river basin study was undertaken in East Lansing, Michigan, on the Michigan State University campus making cooperation easier than if the work was spread out at various locations. Modelling the entire river basin system appears to be too large a task given the funds and time allocated to the research project. The forest sector was chosen rather than the agriculture or pasture sectors since the project was being funded by the U.S. Forest Service.

The Kalamazoo River Basin study covers the Kalamazoo, Black, and Paw Paw river basins. These rivers drain into Lake Michigan. The hydrological basin covers portions of eleven counties: Allegan, Barry, Berrien, Calhoun, Eaton, Hillsdale, Jackson, Kalamazoo, Kent, Ottawa, and Van Buren. The river basin is west of Detroit and northeast of Chicago. The Economic Research Service, which is conducting the economic analysis, eliminated Kent county since only a small portion of the county is in the river basin. The river basin was divided into four sub-basins by the Economic Research Service. These sub-basins will be used in this study. The river basin is outlined on the map in Figure 1-1 and includes regions one through four. Region 1 includes portions of Calhoun, Eaton, Hillsdale, and Jackson counties. Region 2 includes portions of Allegan, Barry, and Kalamazoo counties. Region 3 includes portions of Berrien and Van Buren counties. Region 4 contains portions of Allegan, Ottawa, and Van Buren counties.

Regions were defined for this research project outside of the river basin. These regions (5-12) serve as suppliers of goods and demanders of goods produced by the forest sector. This project, however, is not concerned with land use planning for those regions. Region 5 contains Muskegon county and a portion of Ottawa county. Region 6 is Kent county. Region 7 contains Clinton and Ionia counties and portions of Berrien and Van Buren counties. Region 9 contains Branch and

Figure 1-1.--Map of Regions in the Study Area.

St. Joseph counties and portions of Calhoun, Hillsdale, and Kalamazoo counties. Region 10 contains Ingham county and a portion of Jackson county. Region 11 contains Lake, Mecosta, Newaygo, and Osceola counties. Region 12 contains Montcalm and Gratiot counties. Regions outside of the river basin are defined along county lines whenever possible. Figure 1-1 illustrates the regions.

Population

The population of the ten county area in which the Kalamazoo River Basin is located increased from 1960 to 1970. Table 1-1 contains the population figures for 1960 and 1970 and the percentage changes in population for those ten counties. Population of the ten county region increased by 14.7 percent from 1960 to 1970. Barry, Eaton, and Ottawa counties increased by more than 20 percent. Allegan, Kalamazoo, and Van Buren counties increased between ten percent and twenty percent, while the rest of the counties increased less than ten percent. Population density of the ten county area in 1970 was 167 people per square mile.

The Economic Research Service compiled 1970 population figures for the hydrological basin. These are shown in Table 1-2. The population of the hydrological basin in 1970 was 187 people per square mile.

The counties in the ten county area vary in their urban-rural population distribution. Table 1-3 illustrates the urban-rural population distribution. More than 50 percent of the population of Allegan, Barry, Eaton, Hillsdale, and Van Buren counties live outside of urban areas or places of 1000-2500 population.

The Economic Research Service also estimated the urban population in the hydrological basin. This is shown in Table 1-4.

Table 1-1.--Population Figures for 1960 and 1970 and Percentage Change for Counties in the Kalamazoo River Basin.

County	Population 1970	Population 1960	Percent Change
Allegan	66,575	57,729	15.3
Barry	38,166	31,738	20.3
Berrien	168,875	149,865	9.3
Calhoun	141,963	138,858	2.2
Eaton	68,892	49,684	38.7
Hillsdale	37,171	34,742	7.0
Jackson	143,274	131,994	8.5
Kalamazoo	201,550	169,712	18.8
Ottawa	128,181	98,719	29.8
Van Buren	56,173	48,395	16.1
Total	1,045,820	911,436	14.7

Source: Michigan State University, Cooperative Extension Service, County and Regional Facts, Regions II, III, IV, VI, and VIII.

Table 1-2.--1970 Population for the Hydrological River Basin.

Region	Population
1	158,959
2	234,218
3	74,575
4	88,626
Total	556,378

Table 1-3.--Urban-Rural Population Distribution, 1970.

County	Urban	Percent of Population Places of 1000-2500	Other
Allegan	22.6	4.6	72.8
Barry	17.0	8.9	73.9
Berrien	46.4	0.8	45.6
Calhoun	59.6	3.8	36.6
Eaton	42.1	6.1	51.8
Hillsdale	20.8	11.8	67.4
Jackson	54.8	2.8	42.4
Kalamazoo	75.5	2.9	21.6
Ottawa	48.3	3.4	48.3
Van Buren	21.6	12.0	66.4

Source: Michigan State University, Cooperative Extension Service, County and Regional Facts, Region II, III, IV, VI, and VIII.

Table 1-4.--Urban Population in Sub-basins of the Kalamazoo River Basin, 1970.

Region	Urban Population	Percent Urban
1	92,820	58.4
2	147,923	63.2
3	30,646	41.1
4	40,256	45.4

These figures indicate that regions 1 and 2 are the most populous regions in the basin and have predominately urban populations while regions 3 and 4 have predominately rural populations. The urban population of region 2 is concentrated in Kalamazoo county while it is concentrated in Calhoun county in region 1.

The incorporated cities in the hydrological basin are listed in Table 1-5.

Table 1-5.--Population of Incorporated Cities, 1970.

Region	City	Population
1	Albion	12,112
	Battle Creek	38,931
	Marshall	7,253
	Springfield	3,994
	Charlotte	8,244
2	Allegan	4,516
	Otsego	3,957
	Plainwell	3,195
	Wayland	2,054
	Galesburg	1,355
	Kalamazoo	85,555
	Parchment	2,027
	Portage	35,590
3	Benton Harbor	16,481
	Coloma	1,814
	Watervliet	2,059
	Hartford	2,508
	Paw Paw	3,053
4	Holland	26,337
	Bangor	2,050
	South Haven	6,471

Kalamazoo is the only city in the river basin larger than 50,000. There are only six cities larger than 10,000. The basin population lives largely in medium-sized and small towns, unincorporated exurban places, and in rural areas.

The population regions outside of the river basin is presented in Table 1-6. Regions 5, 6, and 10 are the most populous and contain such cities as Muskegon and Holland in region 5, Grand Rapids in region 6, and Lansing and Jackson in region 10. Regions 11 and 12 are the least populated.

Economy

Table 1-7 lists the total earnings of each county in the ten county area and the contribution of each sector. Total earnings are the sum of

Table 1-6.--Populations of Regions Outside of the River Basin, 1970.

Region	Population
5	230,737
6	411,044
7	173,503
8	165,585
9	162,422
10	391,894
11	76,483
12	78,906

Source: Michigan State University, Cooperative Extension Service, County and Regional Facts, Regions II, III, IV, VI, and VIII.

total wage and salary disbursements, other labor income and proprietor income. No figures were available for Eaton and Ottawa counties. Manufacturing accounts for less than 40 percent of total earnings only in Allegan and Van Buren counties and more than 50 percent of total earnings only in Berrien county. Agriculture makes its greatest contribution in Van Buren and Allegan counties and its least contribution in Calhoun county. However, manufacturing is the most important sector in terms of earnings for all of the counties.

Table 1-8 will help to give some perspective into the importance of the timber economy in the area. This table lists the value added by manufacturing in each county and an estimate of value added by wood products manufacture in 1970. It also gives an estimate of value of roundwood produced in each county.

The manufacture of wood products appears to be quite important in Allegan, Berrien, and Kalamazoo counties. The portion of value added by manufacturing attributed to wood products is greater than 30 percent for these three counties. Berrien and Kalamazoo counties rank high in

Table 1-7.--Total Earnings and Percentage Contributions from Each Sector in 1969.

County	Total Earnings ($1000)	Percent of Total Earnings: Sector 1	2	3	4	5	6	7	8	9	10
Allegan	113842	8.8	17.0	39.3	1.2	4.9	3.1	14.1	0.9	10.1	0.5
Barry	68101	6.1	18.9	43.9	*	3.7	3.1	10.5	*	10.5	0.4
Berrien	521339	3.7	7.9	54.4	*	4.4	3.7	12.3	*	10.6	0.3
Calhoun	477293	1.4	14.9	45.3	0.1	4.0	5.0	12.0	5.6	11.3	0.3
Hillsdale	75482	7.6	18.6	40.2	*	3.3	3.2	15.4	*	7.9	0.6
Jackson	466677	1.7	10.4	45.7	0.1	5.2	10.1	12.8	2.4	11.5	0.1
Kalamazoo	648994	0.8	12.5	47.6	0.1	7.5	3.8	13.5	2.8	11.3	0.1
Van Buren	107620	12.5	15.3	36.0	*	8.3	2.6	13.7	1.6	9.3	0.8

Sector Code

Sector Code	Sector
1	Farming
2	Government
3	Manufacturing
4	Mining
5	Construction
6	Transportation, communications, and public utilities
7	Wholesale and retail trade
8	Finance, insurance, and real estate
9	Service
10	Other

Source: Michigan State University, Cooperative Extension Service, County and Regional Facts, Regions II, III, IV, VI, and VIII.

value added by manufacturing. The value of roundwood produced by all ten counties is very small. In all counties, the value of roundwood is less than one percent of the total earnings. The roundwood harvested in these counties is primarily sawlogs and veneer logs. In 1970, Marquette county had the greatest value of roundwood production in Michigan with $3,183,000. Only Barry county's roundwood production

Table 1-8.--Value Added by Manufacturing and Wood Products Manufacturing and Value of Roundwood Production in 1970.

County	Value Added by Manufacture ($1000)	Value Added by Wood Products Manufacture ($1000)	Percent Wood Products of Total	Value of Roundwood Produced ($1000)
Allegan	67,300	24,060[2]	35.8	160
Barry	47,800	0	0	327
Berrien	363,900	115,337	31.7	115
Calhoun	473,400	44,322	9.4	198
Eaton	34,500	5,128	14.9	291
Hillsdale	39,600	3,503	8.8	136
Jackson	277,900	D	0	192
Kalamazoo	510,200	235,537[1]	46.2	162
Ottawa	227,200	32,945	14.5	110
Van Buren	70,000	5,446	7.8	173

[1]Excludes wood, furniture, and fixtures due to disclosure possibilities.

[2]Excludes pulp and paper due to disclosure possibilities.

D--Excluded by the Census Bureau to avoid disclosure of firms' operations.

Sources: Bureau of the Census, County and City Factbook, and Robert S. Manthy, Lee M. James, and Henry H. Huber, "Michigan Timber Production--Now and in 1985."

exceeds ten percent of that value. These ten counties, then, are relatively small producers of roundwood in Michigan. However, the production of roundwood can be an important source of income to landowners. Barry and Eaton counties had the largest value of roundwood production in 1970.

Table 1-9 lists the number and type of primary wood-using plants in each county in 1974. There is a total of 36 plants, consisting of one pulpmill, four veneer mills, and 31 sawmills. Only nine of these sawmills have a capacity of more than 500,000 board feet per year. Only two mills have a capacity greater than 3,000,000 board feet per year.

Table 1-9.--Primary Wood-Using Plants in Each County in 1974.

County	Pulp-mill	Veneer	Sawmills (MBF) <100	100-500	500-1000	1000-3000	3000-5000	5000-7500	7500+
Allegan	1	*	*	1	1	1	*	*	*
Barry	*	*	1	6	*	1	*	*	1
Berrien	*	2	*	2	1	*	*	*	*
Calhoun	*	*	2	1	*	*	*	*	*
Eaton	*	*	*	1	*	1	1	*	*
Hillsdale	*	*	1	1	*	1	*	*	*
Jackson	*	*	*	*	1	*	*	*	*
Kalamazoo	*	1	1	1	*	*	*	*	*
Ottawa	*	*	*	1	*	*	*	*	*
Van Buren	*	1	1	2	*	*	*	*	*

Source: 1974 Directory of Primary Wood Using Plants in Michigan.

There is a predominance of small sawmills in these counties. These mills use primarily hardwoods.

1970 per capita income varies from $2149 in Hillsdale county to $3355 in Kalamazoo county. Per capita incomes are higher in counties containing relatively large cities and having high values added by manufacturing. Per capita incomes are lower in rural and agricultural counties. Table 1-10 illustrates the per capita incomes for each county. In Kalamazoo county, which ranked first in per capita income, and Berrien county, ranked fourth, wood products manufacturing is an important part of the manufacturing sector. Allegan county which ranks ninth in per capita income also has an important woods products sector.

The timber economy of regions outside of the river basin will be briefly discussed. The value added due to wood products manufacturing and the value of roundwood produced in each county are presented in Table 1-11. Kent, Muskegon, and St. Joseph counties are relatively

Table 1-10.--Per Capita Income for Counties in the River Basin, 1970.

County	Per Capita Income ($)
Allegan	2649
Barry	2849
Berrien	3031
Calhoun	3309
Eaton	3332
Hillsdale	2149
Jackson	3198
Kalamazoo	3355
Ottawa	3002
Van Buren	2680

Source: Bureau of the Census, County and City Factbook.

Table 1-11.--Value of Wood Production in Counties Outside of the River Basin in 1970.

County	Value Added From Wood Products Manufacturing ($1000)	Value of Roundwood Production ($1000)
Branch	3,524	195
Cass	8,351	281
Clinton	*	207
Gratiot	*	372
Ingham	2,499	374
Ionia	*	399
Kent	288,266	327
Lake	*	1,493
Mecosta	*	393
Montcalm	*	405
Muskegon	27,349[a]	341
Newaygo	*	838
Osceola	*	617
St. Joseph	85,036	79

[a]Excludes pulp and paper due to disclosure possibilities.

Source: Robert S. Manthy, Lee M. James, and Henry H. Huber, "Michigan Timber Production--Now and in 1985."

large manufacturers of wood products. The value added by wood products manufacturing in Kent county is larger than any county in the ten county area of the Kalamazoo River Basin. St. Joseph county is larger than eight of the ten counties. Muskegon county is larger than six of the ten counties. However, the large pulpmill in Muskegon is excluded from the value added figures because of the disclosure problems. Values of roundwood production in Gratiot, Ingham, Ionia, Kent, Lake, Mecosta, Montcalm, Muskegon, Newaygo, and Osceola counties are all larger than for any of the counties in the ten county river basin area. Lake, Mecosta, Newaygo, and Osceola counties are important producers of pulpwood for the Menasha Corporation of Allegan county in region 2.

Table 1-12 lists the primary wood-using plants in counties in regions outside of the river basin.

Table 1-12.--Primary Wood-Using Plants in Counties Outside of the River Basin, 1974.

County	Pulpmill	Veneer	Sawmills (MBF) 100	100-500	500-1000	1000-3000	3000-5000	5000-7500	7500+
Branch	*	*	*	*	*	1	1	*	*
Cass	*	*	3	1	1	*	*	*	*
Clinton	*	*	*	*	*	1	*	*	*
Gratiot	*	*	*	2	*	*	*	*	*
Ingham	*	*	1	2	1	*	*	1	*
Ionia	*	*	1	1	1	2	*	*	*
Kent	*	*	*	*	*	1	1	*	*
Lake	*	*	*	1	2	2	*	*	*
Mecosta	*	*	*	*	*	*	*	*	*
Montcalm	*	*	*	1	*	2	*	*	*
Muskegon	1	*	*	1	1	2	*	*	*
Newaygo	*	*	*	2	2	1	1	*	*
Osceola	*	*	*	2	2	*	*	*	*
St. Joseph	*	*	1	*	*	*	*	*	*

Source: 1974 Directory of Primary Wood-Using Plants in Michigan.

Land Use

In terms of total acreage, agriculture is the predominant land use in all ten counties as shown in Table 1-13. Agricultural land use is less than 50 percent only in Ottawa county. Agricultural land use exceeds 70 percent in Eaton and Hillsdale counties. Kalamazoo, Calhoun, and Berrien counties are the most urbanized counties with 16.0, 6.7, and 10.6 percent urban land respectively. None of the other counties exceed three percent urban land. Allegan, Barry, Calhoun, Jackson, Kalamazoo, Ottawa, and Van Buren counties all have more than 20 percent forest land. Allegan, Barry, and Van Buren counties exceed 25 percent forest land. In all counties, forest land is the second largest land use in terms of acreage. Recreation land use exceeds five percent only in Allegan and Barry counties with 8.4 percent and 7.0 percent respectively. These two counties are also the most forested and among the least urban.

Table 1-13.--Percentages of County Land in Each Land Use, 1970.

County	inland water	forest	agri-culture	transpor-tation	recre-ation	urban	other
Allegan	1.3	28.4	52.2	3.6	8.4	2.9	4.5
Barry	2.9	26.4	55.9	4.4	7.0	0.8	5.5
Berrien	0.7	18.7	58.2	5.2	0.5	10.6	6.9
Calhoun	1.0	21.8	63.7	4.3	0.3	6.7	3.2
Eaton	0.2	15.3	71.1	3.8	0.1	2.2	7.5
Hillsdale	0.6	18.2	72.6	3.2	0.7	1.8	3.6
Jackson	2.6	21.4	57.8	4.2	3.4	2.0	11.2
Kalamazoo	3.2	21.8	51.5	4.9	2.7	16.0	3.1
Ottawa	1.5	24.5	49.0	4.8	0.6	2.4	18.7
Van Buren	2.0	25.8	58.4	3.9	0.1	2.4	9.3

Source: Michigan State University, Cooperative Extension Service, County and Regional Facts.

The U.S. Forest Service has compiled acreages of forest ecosystems for the hydrological basin. Five ecosystems are present in the river basin: conifer, oak-hickory, maple-beech-birch, elm-ash-cottonwood, and aspen-birch. Table 1-14 lists these acreages.

Table 1-14.--Acres of Each Ecosystem in Each Region in the River Basin, 1966.

	Acres				
Ecosystem	Region 1	Region 2	Region 3	Region 4	Total
Conifer	4,376	9,812	2,529	8,901	25,618
Oak-Hickory	30,828	66,385	23,681	38,965	159,860
Elm-Ash-Cottonwood	25,062	39,650	19,022	25,120	108,859
Maple-Beech-Birch	14,619	30,038	12,647	19,964	77,269
Aspen-Birch	10,942	21,927	8,905	12,060	53,834
Total	85,827	167,813	66,784	105,010	425,434

Source: Economic Research Service, Unpublished Data, 1974.

Forest land is approximately 22 percent of the area of the hydrologic river basin area. Oak-hickory is the largest ecosystem in all regions followed by elm-ash-cottonwood, maple-beech, birch, aspen-birch and conifer. Urbanization will probably reduce the amount of forest land in the river basin in the future. Table 1-15 lists the net volumes of growing stock and sawtimber in each of the ten counties in 1966. Volume of growing stock is the volume of sound wood in the bole of sawtimber and poletimber trees from the stump to a minimum four inch top diameter outside bark or to the point where the central stem breaks into limbs. Volume of sawtimber is the volume of the sawlog portion of live sawtimber trees in board feet, International 1/4-inch rule, from stump to a minimum seven inch top diameter outside bark for softwoods and nine inches for hardwoods (Chase, Pfeiffer, and Spenser, 1970).

Table 1-15.--Net Volume of Growing Stock and Sawtimber, 1966.

County	Growing Stock (MMCF)	Sawtimber (MMBF)
Allegan	85.8	245.7
Barry	64.1	187.7
Berrien	48.2	144.6
Calhoun	66.6	178.8
Eaton	36.0	104.2
Hillsdale	48.5	148.3
Kalamazoo	45.4	127.1
Ottawa	46.5	123.4
Van Buren	58.6	167.4

Source: Clarence D. Chase, Ray E. Pfeifer, John S. Spenser, Jr., The Growing Timber Resource of Michigan, 1966.

Forest land in the river basin is largely unmanaged for timber purposes. Only 40 percent of the stands are considered medium to fully stocked. Another 30 percent of the stand area is occupied by inhibiting vegetation that will preclude establishment of a fully stocked stand by natural means. Another 40 percent is considered either fair or unfavorable in stocking. Rough and rotten trees occupy much of the available growing space. Poletimber is the dominant size class. Removals, mostly sawtimber, exceed allowable cut by 80 percent (Shroeder, 1974). Much of this removal may occur during the clearing of land for residential development. Due to the age distribution of timber stands, sawtimber removals may decrease in the future. Most stands are in the poletimber size class. Sawtimber removals may again increase when poletimber trees increase in size to sawtimber trees.

Ownership of land in the ten county area is largely private. Table 1-16 lists the acreages of land and percentages of land in each county owned by the Michigan Department of Natural Resources and the U.S. Forest Service. In no case is more than ten percent of the land in the county publically owned. Only in Allegan and Barry counties is more than one percent of the land publically owned with 8.3 percent and 6.65 percent in public ownership respectively. The U.S. Forest Service owns only 11 acres in the ten county area, in Barry county. The rest of the public ownership is by the Michigan Department of Natural Resources. Most forest land in the ten county area is privately owned. Maps drawn by the Michigan State University Remote Sensing Project for the Upper Kalamazoo Watershed, which corresponds closely to region 1 show that forest land occurs in small blocks scattered over the watershed area. Forest land appears to be interspersed among agricultural, marsh and brushy land. This pattern suggests that ownership is highly fragmented with most woodlots being owned by farmers. (See Figures 1-2,

Table 1-16.--Public Ownership of Land in the River Basin, 1974.

County	DNR (acres)	% of county	U.S.F.S. (acres)	% of county
Allegan	44,046.32	8.3	0	0
Barry	23,357.50	6.65	11	.003
Berrien	880.56	.24	0	0
Calhoun	132.19	.029	0	0
Eaton	7.70	.002	0	0
Hillsdale	2,424.64	.63	0	0
Jackson	13,492.12	2.90	0	0
Kalamazoo	2,722.80	.75	0	0
Ottawa	1,207.02	.33	0	0
Van Buren	831.68	.21	0	0

Source: Michigan State University, Graduate School of Business, Michigan Statistical Abstract, 1974.

1-3, 1-4, and 1-5.) A survey of recently printed platbooks indicates that most rural ownerships are less than 640 acres. Very few of these are larger than 160 acres. Figure 1-6 is a typical township plat map located in Eaton county in the Upper Kalamazoo Watershed. This township, Walton township, T1N-R5W, is located in an area with a relatively large amount of forest land in the Upper Kalamazoo. The ownership is highly fragmented. The map lists the owner and the size of the tract. It appears that much of the forest land is located along streams in the area.

Land Characteristics

The U.S. Forest Service has classified the forest soils into five groups for the river basin study. Following is a description of the soil groups.

Soil Group A. Well-drained and moderately well-drained loamy and clayey soils with slopes from 0-18 percent. Hardwood production on these soils is high relative to softwood production.

Soil Group B. Well-drained and moderately well-drained sandy and gravelly soils with slopes from 0-18 percent. Conifers are favored on this soil.

Soil Group C. Somewhat poorly-drained to very poorly-drained sandy, loamy, and clayey soils with slopes from 0-12 percent. Neither hardwoods nor softwoods grow well on this soil.

Soil Group D. Very poorly drained organic and mineral soils. Growth of both hardwoods and softwoods is limited, although some species may grow well.

Soil Group E. Well-drained and moderately well-drained loamy, clayey, and sandy soils with slopes from 18 to 35 percent. Growth of hardwoods and softwoods is probably better than on groups C and D.

Table 1-17 gives the acreage of each soil group for each region in the river basin and the entire river basin. Only forest land is

Figure 1-2.--Land Cover: Active Agricultural Land Use, 1972.

Source: Michigan State University, Project for the Use of Remote Sensing in Land Use Policy Formulation, "Upper Kalamazoo Watershed Land Cover Inventory," 1973.

Figure 1-3.--Land Cover: Forested Land, 1972.

Source: Michigan State University, Project for the Use of Remote Sensing in Land Use Policy Formulation, "Upper Kalamazoo Watershed Land Cover Inventory," 1973.

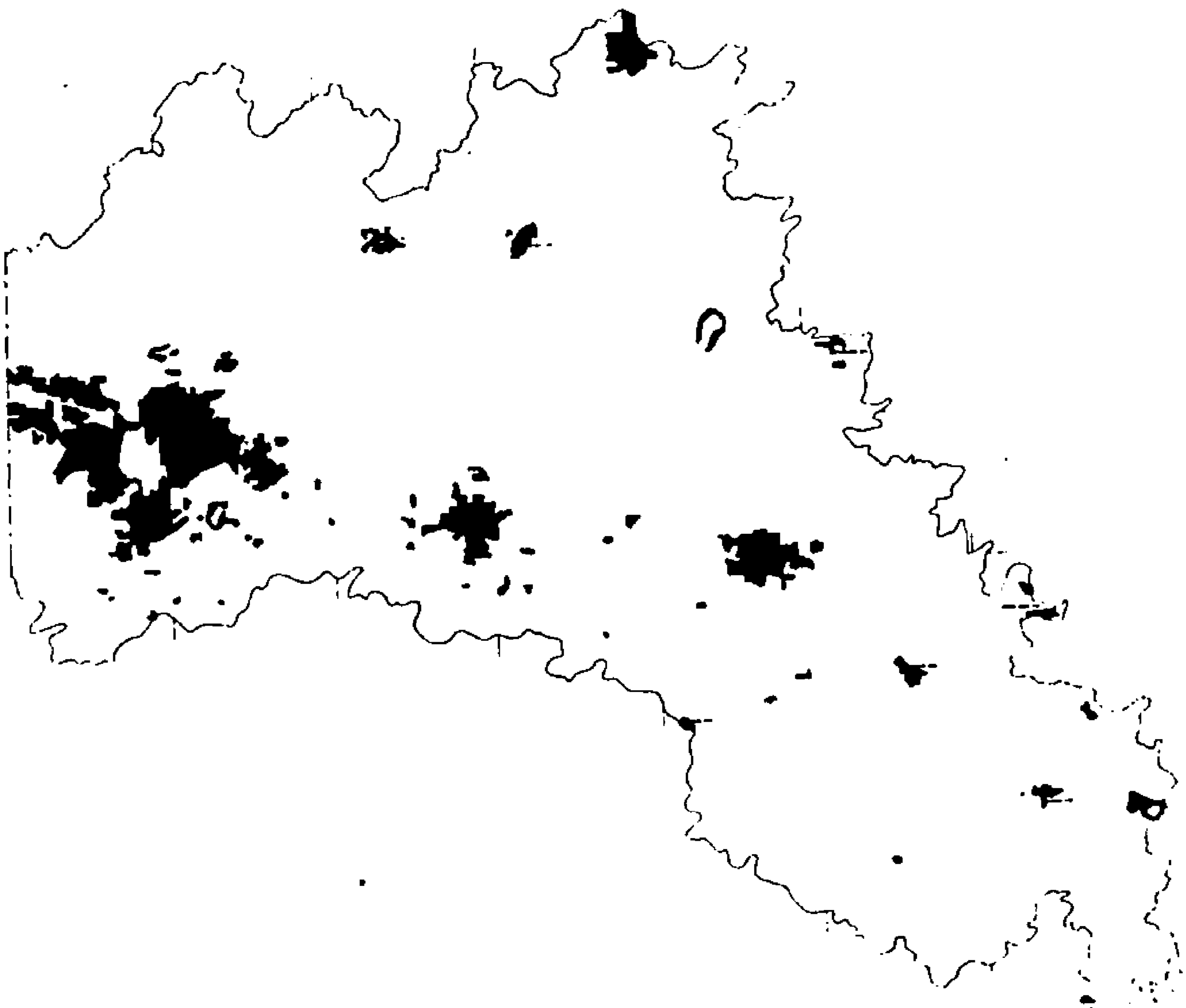


Figure 1-4.--Land Cover: Developed Land, 1972.

Source: Michigan State University, Project for the Use of Remote Sensing in Land Use Policy Formulation, "Upper Kalamazoo Watershed Land Cover Inventory," 1973.

Figure 1-5.--Other Open Lands, 1972.

Source: Michigan State University, Project for the Use of Remote Sensing in Land Use Policy Formulation, "Upper Kalamazoo Watershed Land Cover Inventory," 1973.

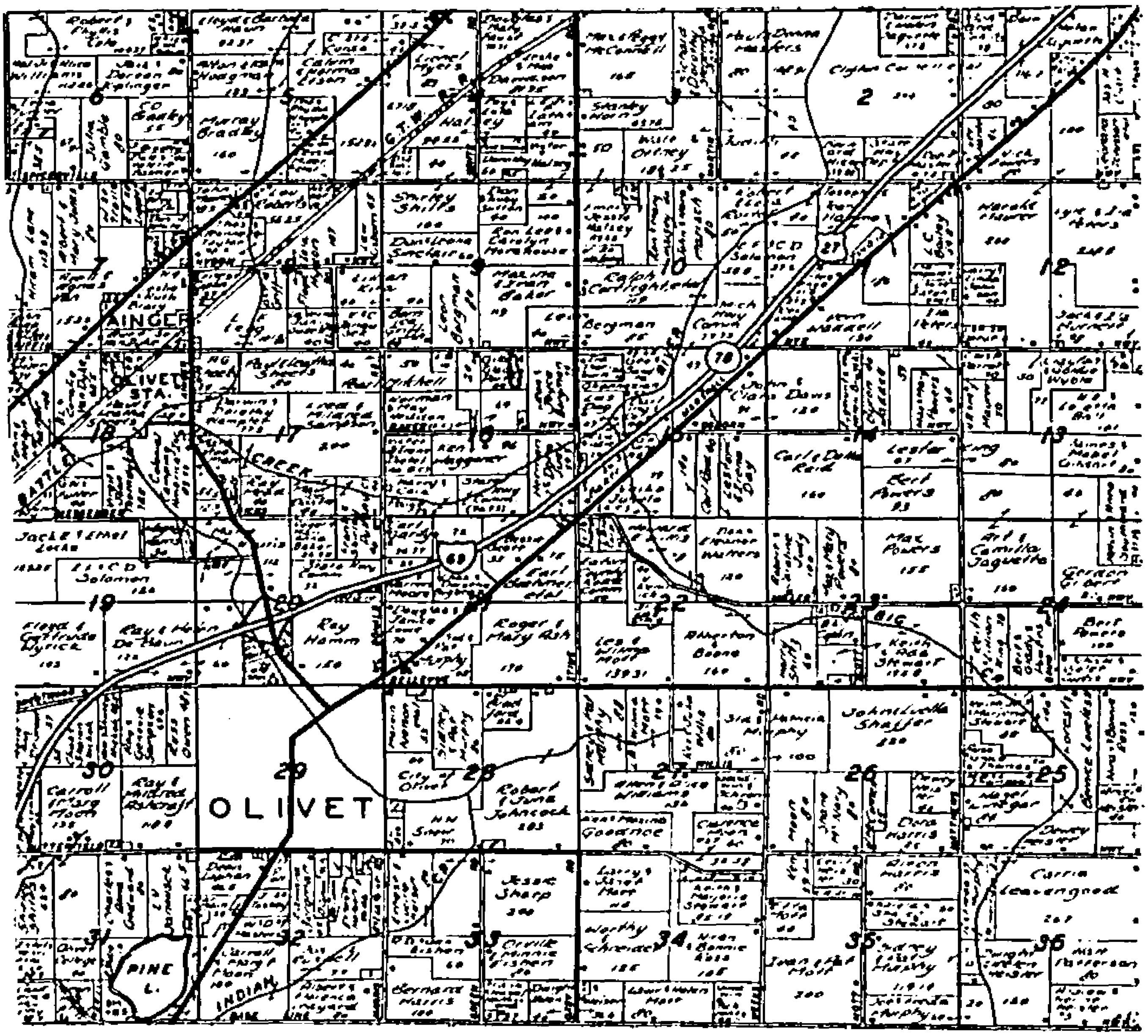


Figure 1-6.--Plat Map of Walton Township in Eaton County, T.1N.-R.5W.

Source: Eaton County Platbook, 1973.

Table 1-17.--Acreage of Each Forest Soil Group in the River Basin, 1974.

Soil Group	Region 1	Region 2	Region 3	Region 4	Total
A	29,087	16,481	8,215	3,557	57,699
B	11,663	61,214	17,890	28,528	119,269
C	16,313	48,288	23,211	41,882	129,695
D	24,805	20,761	8,504	4,340	58,409
E	3,959	20,709	8,964	26,703	60,335
Total	85,827	167,813	66,784	105,010	425,434

included. Soil group A has the most acreage in region 1. Soil group B has the most acreage in region 2. Soil group C has the most acreage in regions 3 and 4. Soil group C has the most acreage in the river basin followed by soil groups B, E, D, and A.

CHAPTER II

CONCEPTUAL BASIS OF THE SYSTEM

The purpose of this chapter is to discuss the issues to be considered by the MUMS system, to discuss the components of the system, to list alternatives that could be incorporated into each component, and to make recommendations for the ideal system.

Issues Considered by the System

The purpose of the MUMS system is to allocate land management strategies and locate their outputs and impacts in space. Issues must be considered in developing this system. Basically, these issues fall into three categories: economic, institutional, and ecological. Each category has dimensions of space and time. Important issues to be considered by the system will now be reviewed.

Demand

Requirements are desired levels of outputs of goods and services. An important question is what goods and services to consider. Both market and non-market goods, including external effects, both positive and negative, also could be considered. Market goods, that is, goods for which markets have not developed, might include hunterdays, maximum levels of erosion, aesthetics, and water quality.

Demand has a spatial dimension. People and firms which demand goods are distributed over space. Population and production are not evenly distributed over space. People have different tastes, desires, and demands. Industries and firms are not evenly distributed over space. Absolute levels of demands for various goods and services will vary over space. Relative levels of demand for various goods and services may also vary over space.

Demand also has a time dimension. The levels of desired outputs of various goods and services may increase, decrease, or remain constand over time. Projecting demands over time is a difficult task since there is uncertainty as to what factors affect demand and how these factors change over time.

Environmental Impacts

A subset of the outputs to be considered are the environmental impacts. Environmental impacts can be positive or negative to various groups. Environmental impacts could include such things as erosion, sedimentation, impacts on aesthetics, and impacts on wildlife habitat.

Environmental impacts have a spatial dimension. First, these impacts may have a pattern over space resulting from the pattern of production or land use. Second, some of these impacts may be nonstationary, that is, thay may move through space. Examples are air pollutants and water pollutants.

Environmental impacts also have a time dimension. A land practice may have a changing set of environmental impacts over time.

Production

Production enters the model through management strategies. An important problem is to determine what outputs should be produced on a given type of land resource by a set of land practices at what cost.

Market goods and services, non-market goods and services, and environmental impacts could be produced by a management strategy. An important aspect of the problem is in defining what characteristics of the land resource affect production and how these characteristics vary over space. This is a problem of land classification. Land classification must be related to the problem of how costs and production will change as characteristics of the land resource change. Production is constrained by characteristics of the land resource base. Therefore, classes of land must be developed to property constrain production.

Production has a spatial dimension. The land resource varies over space. The spatial distribution of land resources will affect the pattern of production over space and the potentials for production over space.

Production also has a time dimension. Time is particularly important to the forest resource. It takes a number of years for a stand of timber to mature and produce merchantable timber. Today's management must take tomorrow's demands for timber into consideration. Forest management takes place over a number of years.

Distributional Effects

An important problem is who receives what benefits, who bears what costs, when, and where. Different patterns of production may well change the distribution of costs and benefits among various groups of people, both in space and time. Levels of requirements, both over time and space, are normative statements that may have differential impacts on different groups. Requirement levels might well favor one group over others. Different regions might be favored by different plans. Impacts on various groups or regions may appear at different points in time.

Defining Regions

The spatial dimension enters through the definition of regions. The river basin can be divided into regions to allow variations in demand and the characteristics of the land resource to be expressed. Any region is an aggregation and is essentially treated as a point in space. Regions can be defined by three methods. 1) Homogeneity, where all areas which are similar in various criteria are aggregated into a region. An example would be definition of soil associations. 2) Nodality, where regions are defined according to the relationship of certain areas to nodes, usually cities. This method is concerned with economic linkages and usually focuses on market areas. 3) Policy regions, where boundaries are defined by existing political boundaries. This type of region is usually used because much data are collected in areas defined by political boundaries. Secondary data sources are an important source of resource, production, and consumption information and regions may be defined to be consistent with data collection units.

Requirements and acreages of land classes are to be assigned to regions. In this way, spatial aspects of both demand and supply will be expressed.

Openness of the River Basin System

The river basin probably is not a self-contained economic and ecologic system. The smaller the river basin, the less realistic it is to assume that the river basin is self-contained. Thus goods, services, and residuals may flow in and out of the system.

With an open system, demands in the river basin could be met by production outside of the river basin. Production in the river basin could satisfy demands outside of the river basin. Demand and supply areas outside of the basin and limits on demands and supplies in these areas would have to be considered. With a closed system, the river basin would be assumed self-sufficient so that all demands within the river basin would be met by production in the river basin.

Transfer of Goods Through the Economy

Goods often are not produced and consumed at the same site. Either the good is transferred to the consumer or the consumer goes to the good. A cost is the transfer cost and includes any cost of bringing a good, once it has been produced, and the user together in space. These costs could include loading, transporting, and unloading a good or the movement of users to a production site. Origins, destinations, transport modes, and routes must be considered.

Components of the MUMS System

MUMS should have the capability to relate acreages of management strategies required to meet various demands and their outputs and impacts to locations within a river basin. A management strategy is a land practice or combination of land practices. A management strategy produces a product-package and has costs associated with it. Such factors as soil type, climate, topography, vegetative cover, precipitation, and water courses can affect the quantities of commodities produced and costs. Components of the system and the purpose of each are discussed below.

Land Evaluation System

The land evaluation system should be capable of generating acreages of management strategies required to meet various demands and locate these strategies and their outputs and impacts in space. Conversely, management strategies may be located in space by decisions exogenous to the model. The model should be able to accept these as inputs and generate impacts of these management strategies on the river basin. The land evaluation system should have economic, ecologic, and spatial linkages. This system is broken down into two components: 1) the production component and 2) the location component.

Production Component. This component calculates acreages over which management strategies will be applied to meet demands for products subject to the constraints of the land resources. The Economic Research Service's least cost linear program could be used as the production component (Bull and Sutton, 1974).

Location Component. Space enters the model by including aspects of production and consumption and by bringing in transport costs. Land resource and demand information are allocated over space. Transport costs enter since they are costs of overcoming the barriers of space, transport routes are defined. Goods may move from production areas to demand points over these transport routes and incur transport costs. This component will allocate management strategies generated by the production component and their outputs and impacts over space. This component can also trace the movement of residuals through space.

Land Management Strategy Data

Land management strategy data are processed into information which is used as input to the production component. These data include costs and product-packages of the management strategies and the types of land resources required. Models may be needed to calculate quantities of each product in the product-packages and the costs.

Goals for Output and Land Use

This component contains the objectives for land management. These objectives include requirements for various outputs, by location if necessary, maximum acceptable levels of environmental impacts, and limitations on land uses. This information could be derived from demand projections, land use plans, Water Resources Council directives, OBERS projections, and the demands of various interest groups.

Constraint Generator

Land management decisions can be made exogenous to the land evaluation system. These exogenous decisions cause a certain spatial distribution of management strategies. This component provides these exogenous decisions as inputs to the land evaluation system and constrains the allocation of management strategies to meet demands for products.

Land Inventory System

A land inventory system is required to meet information needs of the land evaluation system. Such a system stores data for the land evaluation system and contains data on location, qualities, and quantities of land resources. Data sources include Soil Conservation Service Conservation Needs Inventory (CNI) soil and land use inventory data, state and local soil data, and NASA photo-mapping data. All data required to differentiate management strategies in space are stored. Besides storing data necessary for the land evaluation system, the land inventory system interfaces with the land evaluation system by defining acreage constraints on management strategies within a region.

Displays

Outputs of the land evaluation system must be recorded and stored. Alternative media include maps, tables, graphs, computer cards, and tapes. Characteristics of the land resource and management strategies could be mapped.

Figure 2-1 is a schematic diagram of the components in the MUMS system.

Defining the Ideal Model for the Land Evaluation System

The remainder of this chapter will discuss and evaluate alternatives for each component. First, the land evaluation system will be discussed and defined. All other components are tailored to the needs of the land evaluation system. The land evaluation system is the primary component of the system since it must allocate land management strategies in space while considering the issues discussed earlier in this chapter.

Alternatives for the Land Evaluation System

The land evaluation system must have economic, ecological, and spatial linkages. The system will deal basically with the management of land but should indicate some of the impacts on the economy and resource base of the river basin in spatial terms. It is not necessary that all sectors of the regional economy be included in the land evaluation system.

Several alternatives exist for developing models that consider economic and ecological linkages in spatial terms. There appear to be four classes of models representing economic-ecologic linkages (Pompi and Chappelle, 1974). The first is the traditional static input-output

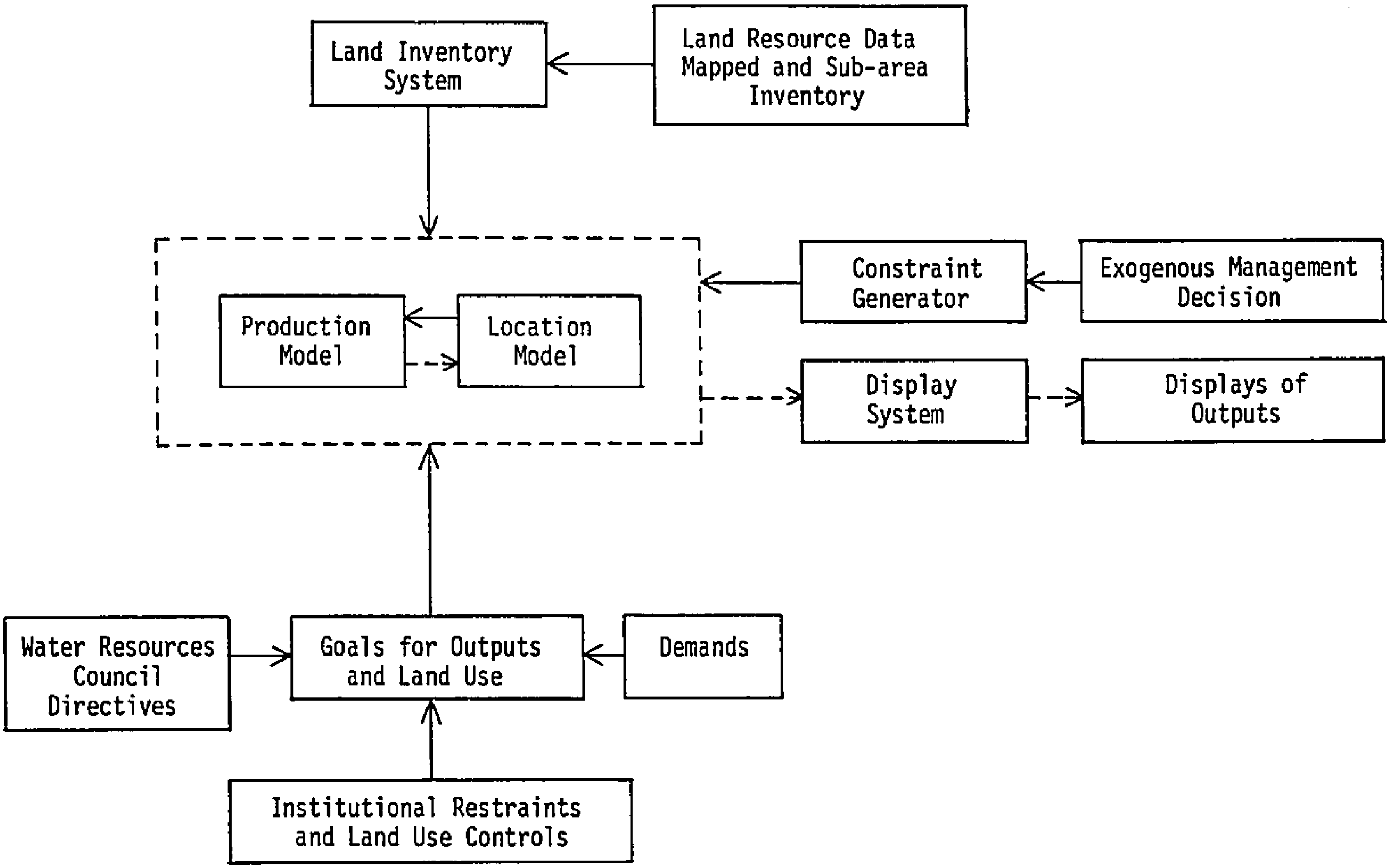


Figure 2-1.--Diagram of an Integrated Land Inventory and Evaluation System.

or inter-industry model. This type of model has a transactions matrix representing transactions between different sectors of the economy. It solves for total requirements in terms of output from each unit in the processing sector necessary to meet exogenously determined final demands. There are several ways in which environmental linkages can be made. These linkages provide estimates of the amounts of materials contributed to the ecosystem by processing sectors to meet final demands. The spatial aspect can be included by going to an interregional type of model, each region having an input-output matrix. Interactions between regions would have to be accounted for within the model.

The second class is the linear programming model which optimizes an objective function. In this approach, activities can have input, output, and residual coefficients. An objective function and constraints must be explicitly specified. The ecological linkages are included by coefficients in the activity columns. The spatial dimension is included by dividing the study area into a set of regions, defining activities according to these regions. Interactions between these regions can be specified. Closely related to this class of models are transportation, land assignement, spatial equilibrium, and quadratic programming models.

The third class is the simulation model. This type of model is highly flexible and can be tailored to specific problems. Simulation models are non-optimizing. The user has to make value judgments about alternative outputs. This approach is best for variables that change over time. This type of model is usually recursive. Multiple runs are required to generalize solutions and make comparisons. The spatial aspects can be added to this system by defining regions and generating values for each region.

Hybrid models are combinations of the above approaches. Any of the approaches can be best suited to a certain part of the problem. This kind of approach allows different models to be linked in order to better handle the problem. Simulation is often included in a linear programming approach. Hybrid models are usually specially tailored to fit certain types of problems. The spatial dimension can be added in the same way as it was in the other approaches.

Dynamic programming is a fifth possibility (Agrawal and Heady, 1972). Dynamic programming optimizes over time. Each time period could be a stage. Each stage has a number of possible states that can be allocated to it. Dynamic programming uses a recursive relationship to optimize. It starts at the last time period and works backward to the present finding the optimum state for each stage. Space would be introduced by defining regions. Essentially, a dynamic program would be defined for each region and each class of resource. Stages and states would be defined for each region and resource class. Alternatively, dynamic programming could also optimize over space and resource class given one time period. Each region and resource class could be a stage with a number of states, which would be management strategies, to be allocated to it. A dynamic program would be required by each time period.

Accounting for the spatial dimension requires more than defining regions. Barriers to mobility caused by distance must be considered in the model. These barriers can be accounted for by including transport costs or by including a gravity model. Including transfer costs is particularly easy in a linear programming model. Activities for transferring goods can be devised and the transfer costs are then included in the objective function. With a gravity model, the attraction between two points is stressed. The attraction between two points (which could be the flow of goods between two points) is directly proportional to the product of the magnitudes of some dimension of each of two points and inversely proportional to the distance between two points. Both approaches may give similar results. However, the gravity approach might be more easily adaptable to some types of problems.

Input-output does not seem to be a viable alternative for the problem defined for study in Chapter I. Input-output deals more explicitly with trade between sectors rather than land management. Much time and money would be spent on data not really critical to land use planning. To account for a subregion of a river basin, that is, to introduce the spatial dimension, an input-output model would be required for each sub region thus raising costs of data collection. Flows between regions would also have to be included.

Linear programming seems to be a good approach to the problem being dealt with in the land evaluation system. Its optimization qualities can be useful to planners showing the best solution among a set of alternatives, provided that the proper objective function and constraints have been specified. Applications of linear programming have already been made to similar types of problems. Hence, there are examples to be followed which show that linear programming might be well suited to the problem. The Economic Research Service's model to which the location model developed in this study is to be linked is a least cost linear program. Linkages of the location model to the Economic Research Service model might be easier if the location model is also a linear programming model.

Simulation might be well suited to certain parts of the problem that are non-optimizing and would not fit well into the linear programming model.

Dynamic programming might be difficult to use since each type of problem requires a special algorithm. An algorithm would probably have to be specially developed for this problem. This task could be very difficulty and expensive. It would also be difficult to keep track of multiple outputs and constrain the solution by the acreages of the land resource.

Past and Current Work

The work discussed in this section deals with the land evaluation system, emphasizing the location component, and the types of problems to be encountered.

Isard and Ostroff discuss general interregional equilibrium (Isard and Ostroff, 1970). They define a system of a number of one-point regions and commodities. There are producers and consumers in a region. Consumers have initial holdings of commodities that can be consumed or traded. There is a world trader to ship commodities between any two regions. Each producer in each region has a production function. Each consumer in each region has a utility function which is a function of final demands. Prices are defined for each commodity in each region. Assets can flow between regions to provide a balance of payments equilibrium.

For the system of regions to be in equilibirum, the following equilibrium conditions must hold: 1) Each producer uses inputs such that the marginal rate of technical substitution between inputs is equal to the ratio of input prices and produce output until marginal costs equals price. 2) Each consumer maximizes utility subject to a budget constraint by equating the marginal rate of substitution between two goods to ratio of prices of the goods. 3) The difference between prices of a commodity in two regions equals the cost of transporting the commodity between the regions when there is trade between the two regions. This assumes that the world is a competitive market. 4) Final demands in a region plus exports, including resources for transport, equals the initial holdings plus production in the region plus imports. (Supply equals demand for each good in each region.) 5) The balance of trade must be in equilibrium for each region. The difference between the value of exports and imports is just offset by the flow of assets between regions. The number of independant equations in the system is equal to the number of unknowns.

Once equilibrium prices are given, an equilibrium set of shipments and asset transfers can be determined by a computation similar to a linear program. The total set of imports and exports are determined when equilibrium prices are set. Maximum gains from trade are defined by minimizing total transport costs. Once the pattern of exports and imports is set, the flow of assets is determined to balance trade.

Supplies and requirements of transport services must be equal under conditions of interregional equilibrium, given a positive transport cost. After all consumers and producers have been furnished with intraregional requirements of transport services, the available world supply of transport requirements must be exactly equal to transport requirements to effect a minimum cost interregional shipment program which corresponds to a maximum gain from trade.

Isard and Ostroff point to several problems likely to be encountered when dealing with a regional or interregional system. Regions are not closed systems. Flows of goods, flows of assets, and transportation costs must be dealt with. Demands and supplies are distributed in space. Price differentials can exist because of the lack of perfect mobility. Regions need not be self-sufficient, they can export and import to equilibrate supply and demand. In a competitive system, price differentials in two regions will be no greater than the transport costs between two regions in equilibrium. Location of production can change in space as supply and demand parameters change in space, as can interregional flows. The system also indicates that inputs, as well as outputs, can move between regions.

R. A. King and W. R. Henry claim that it is a challenge to develop a model that is useful in explaining and predicting particular lines of production (King and Henry, 1959). The concept of comparative advantage developed by the classical economists says that the location of production is determined by relative, rather than absolute, costs of production. The concept does not explicitly incorporate costs of transporting commodities among regions. Factor costs are point values rather than price-quantity relationships.

The transportation model is the simplest form of point-trading model. A surplus or deficit must be specified for each region. Representative shipping and receiving points and the unit costs of transferring the commodity from each surplus region to each deficit region must be specified. The market is cleared with the minimum outlay for total transfer costs. This situation would tend to evolve in a competitive market.

In the space model, interregional commodity transfer costs are composed only of transportation costs, that is, they deal only with the dimension of space. Information about the costs of production, processing, and intra-market distribution can be added. Multi-dimensional transportation models consider other types of transfer costs. In competitive markets, transportation costs set upper limits to the separation of commodity prices in the space dimension, storage costs set upper limits to the separation of commodity prices in the time dimension, and other marketing charges set upper limits to the separation of commodity prices by level of production and marketing (form dimension). The space-form model allows production of more than one good at an origin. Each receiving point has requirements for each product. Transfer costs include costs of processing (transfer costs in the form dimension) and transport costs (transfer costs in the space dimension). Processing capacity for each good in each supply region can be calculated. The space-time model deals with transferring commodities between time periods. The costs of transfer are the costs of storage and preserving the commodities (transfer costs in the time dimension). Estimates of storage capacity by location can be calculated. Hence the space-form-time model considers the costs of transferring goods in space, form, and time.

J.C. Day has made an important application of a linear programming model, in the form of land assignment model, to flood plain management (Day, 1972). It appears to be highly applicable for river basin projects with some modification. The model employs a recursive linear program for allocating specific parts of the flood plain according to a productivity index that takes into account the hazard and susceptibility of the use to damage. The community is viewed as a single entrepreneur desiring to use scarce land resources in an economically efficient way. The objective was to choose the most economically productive spatial distribution of land use activities which includes employment of site elevation and flood-proofing techniques given resources and expected economic growth and development. The objective function maximized relates to the aggregate value of goods and services produced by land uses. Non-efficiency objectives are expressed by constraints.

Given a statement regarding land use requirements, non-structural damage control alternatives are evaluated in terms of their economic feasibility and effects on economic rents. An optimal spatial ordering of land use activities is then selected for various planning periods. The model is designed to deal only with future development of vacant land. Land uses considered are residential, commercial, and industrial. The structure and approach of the model are much more important than the actual land uses.

The model uses recursive linear programming, which is a sequence of linear programming problems in which the objective function constraint matrix and/or right-hand side parameters depend upon the primal and/or dual solution variables of the preceding linear programming problems in the sequence. Each linear program in the sequence solves for a planning period.

The state conditions are expected rents to land use activities at the end of the period, stock of land to accommodate growth, and urban planning criteria regarding the intensity of land use. Endogenous ties between sequences include 1) the current right-hand side and previous land use elements and 2) the current value of the objective function coefficients and previous land use assignments. Exogenous data include:

1) preselected assignment of activities, 2) determinants of activity rents, 3) land use requirements, and 4) forecasted community growth. Rent determinants are recalculated at each step of the recursive linear program. Rents can be readjusted for interdependencies between time periods.

The activities take the form of $X_{ifp}{}^{k}(t)$.

$X_{ifp}{}^{k}(t)$ = number of acres devoted to each (ifp^k) combination in time period t

i identifies the specific type of land use

k refers to the geographic location in the planning area

f and p are special indicies.

Alternative locations for planning purposes may be defined by grid zones or other bounded land units within which net productivity is relatively homogeneous for each ith use. The total number of locations to be considered as alternatives depends upon the particular economic and physical factors that influence the productivity of land in alternative employment. Constraints include 1) upper bounds on land to be developed in planning zones, 2) constraints (upper or lower) on the amount of growth to be accommodated, 3) non-negativity requirements for each activity, and 4) special constraints for flood control problems.

The model is basically concerned with maximizing rent but does not account for problems of overcoming space, mainly transportation costs.

R.L. Patterson has discussed constrained optimization models for land assignment (Patterson, 1972). He was concerned with linear integer programming, but many aspects he discussed are relevant to land use linear programming models. There is a variety of ways and means of limiting land use. Patterson feels that it is obvious that no single model is adequate to cover all combinations of possible constraints. There can be objective and subjective criteria to compare alternative patterns of land use. Different groups' criteria can conflict. Development always occurs over time in a sequential pattern, so that no single agency can identify at any particular time the set of interested users, their set of preferred alternatives, or their criteria for choice. Planning or regulatory agencies dannot "optimize" land use decisions for other independant users.

Patterson describes a simplified land use assignment problem. Parcels of land are specified, each of which is capable of sustaining any one of several alternative uses. The problem is to assign exactly one use to each parcel in such a way that some measure of user satisfaction is maximized given constraints on land use. Grid parcels are specified. Alternative land uses are assigned. Values are assigned to each land use for each parcel. Following is the model which requires a linear integer programming algorithm:

$$\text{maximize} \sum_{i=1}^{M} \sum_{j=1}^{N} x_{ij} v_{ij} \qquad (1)$$

M = number of feasible sites

N = needs (land uses)

x_{ij} = parcel i in land use j

v_{ij} = value of land use j at site i

subject to:

$$\sum_{j=1}^{N} x_{ij} = 1 \qquad (i = 1,\ldots,M) \qquad (2)$$

This constraint limits one land use to a parcel.

$$\sum_{i=1}^{M} x_{ij} = r_j \qquad (j = 1,\ldots,M) \tag{3}$$

r_j = number of parcels of land use j required.

This equation requires that requirements for land use be met.

$$x_{ij} \geq 0 \tag{4}$$

This is the nonnegativity requirement for activities.

Patterson also describes a multiple land use assignment problem. One or more land uses are permitted simultaneously in a parcel. The amount of usable land in a parcel varies. Upper limits are set for 1) the area in a parcel available for assignment and 2) the area in a parcel suitable for a given land use. Following is the model:

$$\text{maximize} \sum_{i=1}^{M} \sum_{j=1}^{N} x_{ij} v_{ij} \tag{5}$$

subject to:

$$\sum_{j=1}^{N} x_{ij} = a_i \qquad (i = 1,\ldots,M) \tag{6}$$

This constraint limits the area of the parcel that can be assigned.

$$\sum_{i=1}^{M} x_{ij} = r_j \qquad (j = 1,\ldots,N) \tag{7}$$

This constraint requires that land use needs be met.

$$0 \leq x_{ij} \leq c_{ij} \qquad (i = 1,\ldots,M) \quad (j = 1,\ldots,N) \tag{8}$$

This constraint puts an upper limit on land use j in parcel i and also requires non-negativity.

Patterson cites several problems. If values are placed on specific patterns of land use the objective function becomes non-linear. A linear objective function assumes that the degree of preference of one assignment of uses to sites is the sum of the individual "values" derived from assigning uses to each site separately. No value is placed on particular patterns of land use per se. Subjective criteria can cause similar problems. This type of land assignment problem is inadequate to solve location-allocation problems. In the location-allocation problem, a decision is made concerning where to locate a number of land parcels, each of a specified size for specific uses, in an optimal manner, subject to possible land use constraints. In the location-allocation problem, the area required for each of a fixed number of uses is specified in advance. Possible sites are specified in advance. The problem is to locate the uses in an optimal manner.

There are also difficulties in specifying cell sizes. The smaller the land unit area, the more homogeneous its characteristics and the more uniform its numerical description. However, increasing the number of cells increases the total number of constraint equations and computational costs. Small cells also tend to "sprinkle" land uses, that is, there may be an unrealistic amount of intermixing. These types of models do not account for minimum requirements on size of local areas assigned to a given use.

Takayama and Judge (1964) discuss spatial price equilibrium in a closed system of n regions. Within a framework of interconnected competitive markets with appropriate linear dependencies between regional supply, demand, and price, it is possible to convert the Samuelson-Enke spatial price equilibrium problem into a quadratic programming problem. The competitive optimal solution for regional prices and quantities and interregional flows can be obtained from the program. Interdependencies between markets or regions in the production, pricing, and use of commodities are considered. Interdependencies between commodities are disregarded.

Each region is characterized by a linear demand function for each commodity (there can be more than one commodity) which is a function of the prices of all other commodities in the region. Prices of each commodity in each region are a function of interregional commodity flows. Prices and interregional commodity flows are non-negative.

Net social payoff is maximized. Net social payoff is the sum of consumers' and producers' surpluses for all commodities minus transport costs incurred in shipping costs between regions. The problem is formulated as follows:

$$\text{maximize } f(P) = P'C - \tfrac{1}{2}P'QP$$

subject to:

$$G'P \leq T$$

$$P \geq 0$$

where:

P = the vector of each non-negative price of each commodity in each demand and each supply region

C = the vector of demand and supply equation intercept values

Q = a symmetric, positive, semi-definite matrix composed of demand and supply behavior coefficients

T = the vector of transport costs for shipping each commodity between each region

G = a vector of 1's, -1's, and 0's that allows demand and supply relationships to be included in the program. The transverse guarantees that the prices in different regions are not separated by more than the costs of transporting goods between them.

The quadratic problem can be reduced to a linear programming problem including both primal and dual formulations that can be solved by the simplex algorithm:

$$\text{maximize } g(X,P,V)=[C-QP]'P-TX=[GX]'P-[G'P+V]'X=-V'X \; 0$$

subject to:

$$G'P + V = T$$

$$GX + QP = C$$

$$P,V,X \geq 0$$

X = a vector of non-negative interregional commodity flows

V = a vector of interregional transport costs minus interregional price differentials

The model solves for prices in each region and flows between each region. Information is provided to solve for the quantities of commodities supplied and demanded in each region. The program can be modified to handle the case of fixed regional demands or supplies. When both are fixed, the problem will degenerate to a classical transportation problem.

This formulation provides a basis for the analysis of interregional activity models when the regional demands for final commodities are represented by well-behaved linear functions and output is limited by geographical distribution of resources, processing facilities, etc. The model could be modified to handle both time and space dimensions. Time periods, carrying costs or storage costs, and flows between time periods would have to be included. Other market formulations besides competitive formulations could be assumed.

The preceding discussion deals with the spatial aspect of the land evaluation system. Now it is appropriate to discuss the economic-ecologic linkages. Pompi and Chappelle discuss a model proposed by Clifford S. Russell and Walter O. Spofford of Resources for the Future (Pompi and Chappelle, 1974). It is one of the most complete hybrid approaches and must be considered an "ideal" approach to the problem of economic-ecologic linkages. The components of the model are 1) a linear programming inter-industry model, 2) an environmental diffusion model, and 3) a set of receptor-damage functions.

The linear programming inter-industry model relates inputs and outputs of various production processes and consumption activities at specific locations in a region which includes the amounts of various residuals generated by a unit of production, the costs of transforming residuals from one to another, the costs of transporting residuals, and the costs of any final discharge related activity.

Environmental diffusion models describe the fate of various residuals after their discharge into the environment. These models predict ambient concentrations in different locations throughout the system. They deal with diffusion, dilution, transformation, and accumulation of residuals.

The set of receptor damage functions relate concentration of residuals in the environment to resulting damages. Damages may be sustained directly by humans or indirectly through plants and animals in which man has a commercial, scientific, or aesthetic interest.

Russell and Spofford viewed all relationships as linear. In order to do this they had to assume: 1) The economic world is static so that time does not enter as a decision variable in the production model; 2) Relationships in the model are deterministic and steady state; 3) No interaction takes place between residuals; 4) The environment cannot be modifed to change its waste assimilation capabilities.

The model is run in an iterative fashion, the linear program is solved with no restrictions or prices on the discharge residuals. The residuals generated are entered as inputs to the environmental diffusion models and resulting ambient concentrations enter receptor-damage functions. Ambient concentrations and damage values are used to calculate marginal damages attributable to each residual discharge. These marginal damages are then applied as interim effluent charges on discharge activities in the industry model which is then re-solved. Figure 2-2 is a schematic diagram of the Russell-Spofford model.

Earl O. Heady has played an important role in developing linear programming models for agricultural production problems and land use planning (Heady, 1976). Heady devoted much effort to developing the current Economic Research Service model. In recent efforts at Iowa State University, he has incorporated a transportation model into the production model developed for the entire continental United States. The United States is divided into 27 consumption regions. Each consumption region is subdivided into supply regions such that the United States is divided into 223 supply regions. A total of 51 water supply regions were developed in the western U.S. The objective function minimizes the total costs of production of commodities, costs of transporting commodities between regions, and costs of purchasing water to produce

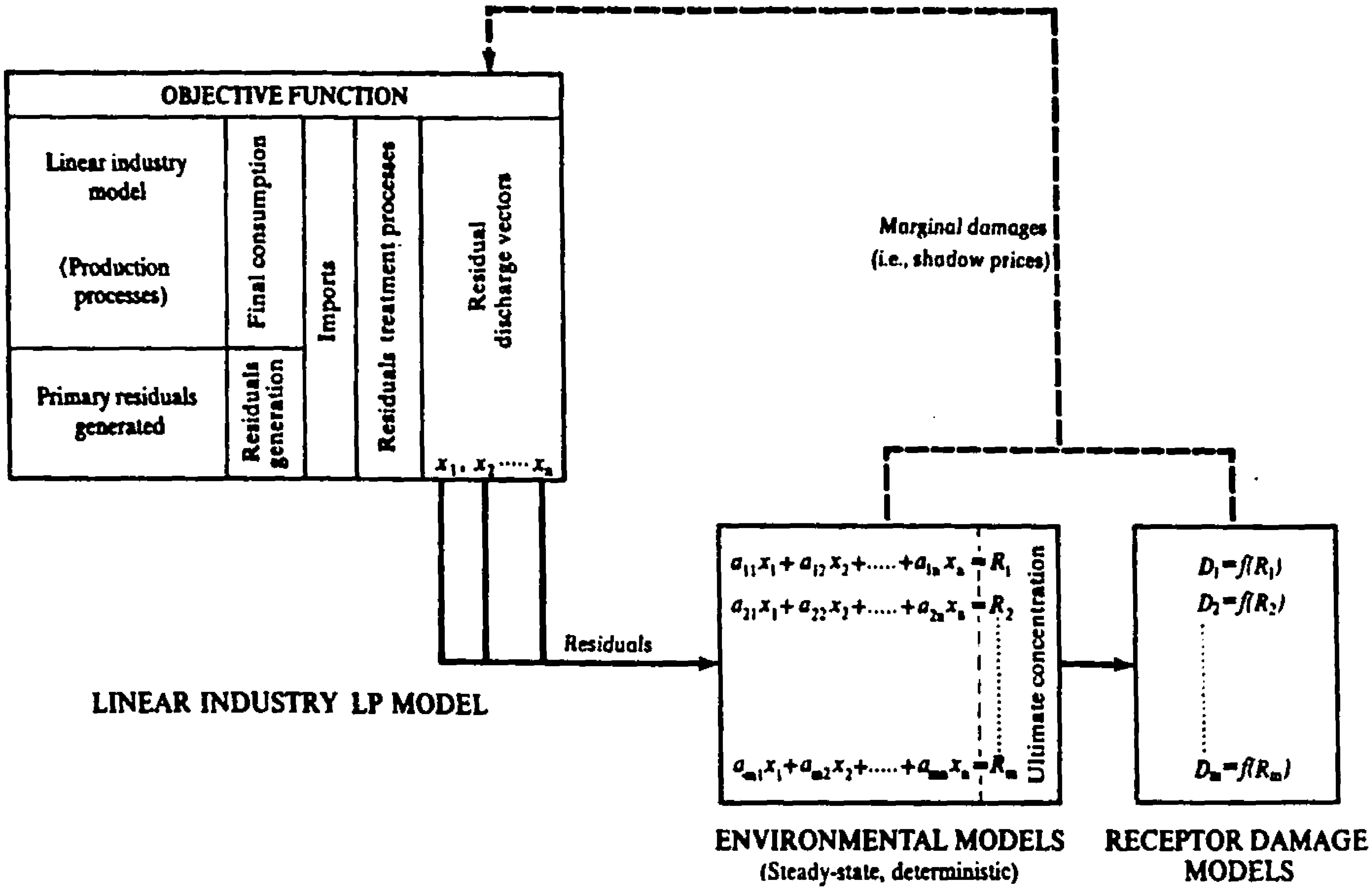


Figure 2-2.--Schematic Diagram of the Russell-Spofford Residuals-Environmental Quality Planning Model.

Source: Russell and Spofford, 1972.

crops. One set of demand equations from the total set of equations in the Heady model appears to be useful to spatial analysis. This equation determines surpluses, deficits, and the flows of goods between regions. Production relationships are included through production variables. Population, livestock, and national exports affect consumption. Goods are allowed to flow between regions to satisfy requirements. Production and transport patterns are solved simultaneously given requirements and land constraints. The demand equation follows:

$$\sum_{i=k} \left[\sum_{j=1}^{21} y_{ij} X_{ij} - b_{iq} N_i \right] - \sum_{j=22}^{25} F_{kjq} - e_{kq} E_q$$

$$- \sum_{p=1}^{5} f_{kpq} G_p + \sum_{k=1}^{27} \left[T_{qk'k} - T_{qkk'} \right] \geq 0$$

i = producing area = (1,...,223)

j = type of endogenous crop or livestock activity = (1,...,25)

k = consuming region = (1,...,27)

p = type of endogenous livestock activity = (1,...,5)

q = type of commodity = (1,...,12)

b_{iq} = per capita consumption of qth commodity in ith producing region

e_{kq} = proportion of exports of qth type commodity exported historically from kth consuming region

E_q = national export activity for qth type commodity

f_{kpq} = amount of qth type crop commodity consumed by pth type exogenous livestock activity in kth consuming region

F_{kjq} = amount of qth type of commodity transformed into feed for use by the jth type of livestock in the kth consuming region

G_p = national activity for pth type of livestock

N_i = population-industry activity in the ith producing region

$T_{qk'k}$ = amount transported of jth commodity from kth consuming region to k'th consuming region where k and k' must be contiguous except for long hauls

X_{ij} = level of the jth product activity in the ith producing region

Y_{ij} = yield per acre or per unit of activity of jth crop or livestock activity in the ith producing area

Choice of General Alternatives for the Land Evaluation System

The discussion of the previous sections suggests three general alternatives to provide answers for the issues to be considered in the land evaluation system. They are based on linear programming and simulation since input-output and dynamic programming do not seem to be well suited to the problem. Following are the three alternatives:

1.a. A regional linear program which is divided into sub regions calculates the acreages on which management strategies are applied.

b. Spatial economic and environmental components can be included directly into the production model directly influencing the allocation of management strategies.

c. Management strategies can be allocated to grid subdivisions of sub regions by using a multiple land use assignment model.

2.a. A multiple use or single land use assignment model calculates the acreages of management strategies in individual grid cells.

b. Spatial economic and environmental impacts are taken into consideration but do not influence the allocation of management strategies.

3.a. The acreages of management strategies are calculated outside of the model. The results are put into a simulation model to generate the production of various products.

b. Spatial economic and environmental impacts are considered but do not affect the allocation of management strategies.

Criteria are needed to evaluate these alternatives. An ordinal scale is used to rate each alternative according to each criterion. It is felt that a quantitative answer cannot be calculated.

Louis Pompi suggested several criteria to evaluate alternative models (Pompi, 1975). The first criterion is information output which asks if the information needs of the user are met. Information is needed in this model for the issues to be considered. The second criterion is data input which includes quantity and quality, that is, level of detail, of required data. The third criterion is the provision of policy guidelines. This is similar to the first criterion except that it considers how easily policy guidelines are developed from the output of the model. The fourth criterion is the relevance of necessary assumptions. The fifth criterion is the capacity for dealing with the temporal dimension. The sixth is the capacity to deal with the spatial dimension. The seventh criterion is generality which concerns itself with the extent to which the model can be generalized to a variety of problems. The eight is specificity which concerns itself with how easily the model can be adapted to specific problems. The first six and the eighth criteria are applicable for this problem. A specific problem for application has been defined. The question here is how well the alternative is suited for the defined problem.

Specific criteria have been developed based on Pompi's criteria to evaluate these alternatives. The criteria are now discussed. The criterion of information output has been more specifically defined in this problem. It is a problem of how well the model accounts for the spatial economic and environmental aspects. The first criterion, then, is spatial economic impact. If the allocation of management strategies is affected by the spatial economic impact, the alternative receives the highest rating, 1. The reason for this rating is that transport costs will affect the landowner's decision of how to manage land. If the spatial economic impacts are generated but do not affect the allocation of management strategies, the alternative receives a poorer rating, 2. With this situation, it is assumed that transport costs do not affect the landowner's decision of how to manage land. Alternative 1 has a rating of 1 while alternatives 2 and 3 have ratings of 2.

The second criterion is spatial environmental impact. If the allocation of management strategies is influenced by the spatial environmental impact, the alternative receives the highest rating, 1. If the spatial environmental impact is accounted for but does not influence the allocation of management strategies, the alternative receives a lower rating of 2. It is felt that the generation of environmental impacts should affect land management decisions. Alternative 1 has a rating of 1 while alternatives 2 and 3 have ratings of 2.

The criterion of data input, as stated previously, includes both quantity and quality aspects (Pompi, 1975). The third criterion, then, is quantity of data required. In general, it appears that simulation models require more data than linear programming models (Pompi, 1975). Alternative 3, then has the lowest rating, 3. It also appears that alternative 1 requires more data than alternative 2, since management strategies are allocated to grids in a second step in alternative 1. Alternative 2 receives a rating of 1 and alternative 1 receives a rating of 2.

The fourth criterion is data quality. Simulation models may be able to use data of lower quality, in the sense of measurement scales, than linear programming models (Pompi, 1975). Alternative 3 receives a rating of 1. Alternatives 1 and 2 receive ratings of 2.

The fifth criterion is the provision of policy guidelines. Linear programming models with their capacity to provide optimal solutions require less judgement to translate output into policy guidelines (Pompi, 1975). Alternatives 1 and 2 receive ratings of 1 while alternative 3 receives a rating of 2.

The sixth criterion is the relevance of necessary assumptions. The assumptions of linear programming are generally more restrictive than those of simulation. In the case of simulation, it is impossible to say what the assumptions are except in the specific case (Pompi, 1975). Alternative 3 receives a rating of 1 while alternatives 1 and 2 receive ratings of 2.

The seventh criterion is the capacity to deal with time. While linear programming is static in nature, time can be incorporated in a variety of ways. These methods will be discussed later. Simulation, however, is easily adapted to the time dimension (Pompi, 1975). Alternative 3 receives a rating of 1 while alternatives 1 and 2 receive ratings of 2.

Criteria for this specific problem have also been added. The eighth criterion is compatibility of the system with systems presently used in U.S.D.A. river basin planning. Alternative 3 seems to be the most remote in relation to existing systems. Alternative 2 puts the production model on a smaller grid than current practice. Alternative 1 uses the same size subdivisions. In all cases, the economic and environmental dimensions, as well as the time dimension, are added. Alternative 1 seems to be the most closely related to presently used systems, so it receives the highest rating of 1. Alternative 2 receives a lower rating of 2. Alternative 3 receives the lowest rating of 3.

The ninth criterion is the cost of operating the model. This cost must include any manual work. It is felt that due to the large number of iterations involved, operating a linear programming model would be more costly than operating a simulation model. Due to the increased number of steps involved in getting down to the grid level and the fact that spatial aspects affect solution of the production model, alternative 1 is felt to be more expensive than alternative 2. Alternative 3 requires substantial amounts of work done outside of the computer. It is felt that if this work is done in much detail, the cost could easily be greater than the cost of making a linear programming run. Alternative 2 receives a lower rating of 2. Alternative 3 receives the lowest rating of 3. Table 2-1 contains a summary of the rating of the alternatives.

Alternative 1 receives the highest rating the most times. These ratings occur in the criteria felt to be most important to the study, the spatial impacts and the compatibility with present systems. The assumptions of linear programming can be limiting, but in many cases can

Table 2-1.--Rating of Alternatives for the Land Evaluation System.

Criterion	Alternative		
	1	2	2
Spatial economic impact	1	2	2
Spatial environmental impact	1	2	2
Quality of data	2	1	3
Provision of policy guidelines	1	1	2
Relevance of necessary assumptions	2	2	1
Capacity to deal with time	2	2	1
Compatibility with present systems	1	2	3
Operating cost	2	1	3

1 = highest   2 = lower   3 = lowest

be overcome. It is also felt that the other criteria can be dealt with without too much trouble. Alternative 1 is the favored alternative and the subject of further investigation in this project. Further investigation of other alternatives could be pursued in other studies, however.

Possible Structure of the Land Evaluation System

The land evaluation system contains two components: 1) the production component and 2) the location component. The production component will be a linear programming model. The model is broken down into regions. An activity is defined for each management strategy on each class of land in each region. Each activity will produce a set of products and will be constrained by the acreage of land available to it. Demands for products are defined at various locations.

The location component can be broken down into three subcomponents: 1) the transportation component, 2) the environmental diffusion component, and 3) the land assignment component. The transportation component is a series of linear programming activities which relate production in each region to demand for products at various locations. The environmental diffusion component is a series of equations which simulate the movement of residuals produced by management strategies through space. The land use assignment component takes acreages of management strategies and allocates them to subdivisions of each region. The transportation component and the environmental diffusion component could be incorporated directly into the production component. These components would then directly affect the solution of the production model. Either or both of these two components could also be separate components. They would just show the impacts of solutions of the production model. If the transportation component was removed, production to meet regional consumption would be required in each region and would appear in the production model. The land use assignment component could not be included into the production model. The land use assignment model would have no impact on the allocation of management strategies among regions in the production model. Its purpose would be to locate management strategies in space more precisely according to another set of criteria.

Any or all of these location components could be eliminated from the land evaluation system. If they are all eliminated, the consideration of location would be eliminated from the land evaluation system. Following are alternative combinations of components:

1. All location components included, the transportation and environmental diffusion components are incorporated into the production model.
2. Land use assignment model excluded, the transportation and environmental diffusion components are incorporated into the production model.

3. Environmental diffusion component excluded, the transportation component is incorporated into the production model.
4. Environmental diffusion and land use assignment models excluded, the transportation component is incorporated into the production model.
5. Environmental diffusion component excluded, the transportation component is separate.
6. Land use assignment and environmental diffusion components excluded, transportation component is separate.
7. Transportation component is excluded, the environmental diffusion component is incorporated into the production model.
8. Transportation and land use assignment components excluded, the environmental diffusion component is incorporated into the production model.
9. Transportation component excluded, the environmental diffusion component is separate.
10. Transportation and land use assignment components excluded, the environmental diffusion component is separate.
11. All location components included, the transportation and environmental diffusion components are separate.
12. Land use assignment model excluded, the transportation and environmental diffusion components are separate.
13. All location components excluded.

Incorporating the Time Dimension into Linear Programming

The time dimension presents special problems for linear programming which is static by nature. The time dimension must be considered for the forest resource due to the separation in time between planting, thinning, or other cultural activities and production of merchantable timber. Models with many agricultural crops do not have this problem since production occurs in a single growing season. Timber growth, from establishment of a stand to harvest of timber, occurs over a large number of years.

Several alternatives exist for incorporating time into linear programming: polyperiod linear programming, recursive linear programming, and pseudo-dynamic linear programming. Recursive linear programming solves for each time period separately (Day, 1972). The first time period is optimized. This solution then constrains the solution of the next time period. The solution for each time period is always constrained by the solution of the previous time period. This process of sequential optimization was deemed undesirable for this problem since it does not optimize over the entire time period. It does not really seem well suited to the problem of investment to meet a stream of demands over time. This method could be desirable when considering what cultural operations, such as planting, thinning, or fertilization to undertake in a year, given the practices undertaken in previous years. Timber growth and the impacts of cultural practices on growth would have to be considered when moving from one time period to the next by the use of models outside of the recursive linear program. These models would have to account for timber growth and changes in wildlife habitat. The impacts of past and present cultural and harvest operations on timber stand growth and development would have to be included. The amounts of timber and hunterdays available for harvest at different locations would become inputs to the model for the next time period. Polyperiod linear programming considers the transfer of goods and the costs of doing so (Duvick, 1970). The transfer of goods between time periods is not being considered in the model being developed. However, this potential could be incorporated into the approach to be used, pseudo-dynamic linear programming. Pseudo-dynamic linear programming appears to be the best approach when considering investment problems (Buller, 1965). Costs and returns are discounted to the present for the objective function value. Because of this discounting, time is implicit. Products and constraints for each time period can be entered. There would be a coefficient in the activity for each product in each time period. A particular problem with this method is that all alternatives must be evaluated over the same time period. The time period and the sequence of cultural activities must be explicitly stated.

This time problem makes inclusion of the forest sector into the current Economic Research Service's least cost linear programming model difficult. If impacts of cultural practices on wood production are to be considered in the Economic Research Service's model, all other sectors must be changed to include the time dimension . This could become quite complicated for agriculture since conversions between crops or crop rotations over the period of analysis would have to be considered. If the forest sector is included into the current Economic Research Service's model, only cultural practices and the products that they affect in the same time period could be included. Individual cultural practices would be the activities rather than combinations of practices over a period of time as is the case in pseudo-dynamic linear programming. The effects of cultural practices on later yields of merchantable timber and other products at later times could not be easily accounted for. Effects that could be included are the immediate effects on sedimentation, erosion, animal populations, and amounts of timber that could be harvested from stands ready to be cut. The time dimension is not easily handled in the current Economic Research Service model.

Choosing Among Alternative Structures

Criteria are needed to choose among alternative structures for the land evaluation system. These criteria are based on those proposed by Pompi that were discussed earlier in this chapter (Pompi, 1975). There are several criteria for which all of the alternatives will have identical results. They all have identical capacities to deal with time since all alternatives use pseudo-dynamic linear programming. The relevance of necessary assumptions will also be the same as will generality and and specificity since the same linear programming format is being used. The quality of data needed will also be the same due to the same basic linear programming framework.

There are some differences, however. The quantity of data needed will vary by alternative. The information output and the capacity to provide policy guidelines will also vary. Variation in these two criteria is related directly to the manner in which space is handled. The costs associated with alternatives will also vary.

Three criteria will be defined that deal with space. The first is the ability to deal with the spatial economic aspects. If the allocation of management strategies is affected by the transportation costs, that is, if the transportation component is incorporated into the production component, the alternative receives the highest rating of 1. If the spatial economic impact is accounted for but does not affect the allocation of management strategies, that is, the transportation component is separate, the alternative receives a lower rating of 2. If the spatial economic aspect is not considered, that is, the transportation component is excluded, the alternative receives the lowest rating of 3.

The second criteria is the ability to deal with spatial environmental impacts. If the movement of residuals affects the allocation of management strategies, that is, if the environmental diffusion model is included, the alternative receives the highest rating of 1. If the movement of residuals is accounted for but does not affect the allocation of management strategies, that is, the environmental diffusion model is separate, the alternative receives a lower rating of 2. If the movement of residuals is not accounted for, that is, the environmental diffusion model is excluded, the alternative receives the lowest rating of 3.

The third criteria is the spatial specificity of allocating management strategies. If a multiple land use assignment model is included which allocates the management strategies in a region to a grid network, the alternative receives a rating of 1. If the land assignment model is excluded, the alternative receives a lower rating of 2.

The fourth criteria is the cost of constructing the model. The major component of this cost is obtaining the data to input to the model. All alternatives have the same production component which is the most expensive part. The rating is based on the components that must be added on. The most expensive component that can be added on is the multiple land use assignment model. Large amounts of data are necessary for this component. The construction cost of this component is much greater than the construction cost of other components. The construction costs of components incorporated into the production component are greater than the costs of those excluded. More data and modelling effort is required for components incorporated into the production component since all time periods must be explicitly considered. The construction cost of the environmental diffusion model will be assumed to be greater than that of the transportation component. The environmental diffusion relationships could be much more complex than the transport relationships. The transportation relationships include transport routes, mileages, and cost per mile for each commodity. Environmental diffusion relationships would include characteristics of the transfer media, factors affecting the transfer media, and factors affecting the movement of residuals through the media. For a stream, speed of the current and water temperature might be very important. Interactions between residuals could be difficult to account for. Much time might be required to specify the environmental diffusion relationships. Data collection could also be expensive. The order of construction cost of each component from highest to lowest follows: a) land use assignment model, b) incorporated environmental diffusion model, c) incorporated transportation model, d) separate environmental diffusion model, and e) separate transportation model. The alternative with the lowest cost has the highest rank of 1 in Table 2-2. The remaining alterantives receive a rating equal to their rank in construction cost.

The fifth criteria is operation cost. The operation cost of the production component, included in all alternatives, is assumed to be the same for all alternatives. The ranking of operation cost will depend upon the operation cost of components added. The land use assignment model has the largest cost due to its large size. It probably requires a large number of iterations to calculate a solution. Its cost will be assumed greater than the sum of the costs of any combination of trans-

Table 2-2.--Rating of Alternative Model Structures.

	Alternative												
Criterion	1	2	3	4	5	6	7	8	9	10	11	12	13
transportation impact	1	1	1	1	2	2	3	3	3	3	2	2	3
environmental diffusion impact	1	1	3	3	3	3	1	1	2	2	2	2	3
spatial specificity	1	2	1	2	1	2	1	2	1	2	1	2	2
construction cost	13	7	11	5	8	2	12	6	9	3	10	4	1
operation cost	13	7	12	6	9	3	11	5	8	2	10	4	1

1 = highest rating

portation and environmental diffusion components. The cost of incorporated components will be assumed much larger than the cost of separate components because time must be considered. The operation cost of the transportation component will be assumed larger than that of the environmental diffusion component because of the large number of iterations needed to solve a transportation model. The ranking of operation cost of each component from highest to lowest follows: a) land use assignment model, b) incorporated transportation model, c) incorporated environmental diffusion model, d) separate transportation model, and e) separate environmental diffusion model. The alternative with the lowest cost has the highest ranking of 1 and the alternative with the highest cost has the lowest ranking of 13. These rankings apply to Table 2-2. The following table presents the results of rating each alternative according to each criterion. Alternative 1 has the highest rating for each of the three policy criteria. It also has the lowest rating for each of the two cost criteria. For picking an ideal model, cost will be ignored. Alternative 1 will be considered to be the ideal. When describing the structure later, the alternative structures will also be discussed.

Description of the Ideal Land Evaluation System and Possible Changes

Objective Functions

A linear program requires an objective function. Alternatives include: 1) linear objective functions of which there are two types: gain-maxmizing and cost-minimizing and 2) quadratic objective functions which require a special mathematical programming formulation.

With a cost-minimizing linear objective function, costs must be calculated. A minimum level of demands must be satisfied. The algorithm minimizes the costs to meet these demands. The advantages of this approach for MUMS include: 1) Prices or price-quantity relationships do not have to be calculated. Implicit assumptions about prices are made, however. 2) The Economic Research Service's model, a cost minimizing model, already has costs calculated. The disadvantages include: 1) Only one set of requirements is considered, and 2) The approach is essentially a requirements approach.

With a gain-maximizing linear objective function, a fixed net return must be calculated for each activity. Resource constraints must be calculated for each activity. Resource constraints on productive capacities are required. The algorithm maximizes net gain subject to resource constraints. The Economic Research Service's model could be converted to a gain-maximizing model by calculating a price for products and subtracting costs to obtain a net revenue. Both demands for products and resource constraints exist. The advantages of this approach are: 1) Price-quantity relationships do not have to be calculated, 2) Computation costs are comparable to a cost-minimizing approach, and 3) It is not restricted to a single set of demands. The disadvantages include: 1) Prices must be fixed, 2) It may be difficult to calculate prices for many of the commodities, and 3) Prices are not calculated for the Economic Research Service model.

When the location component is separate from the production component, the production component would be gain-maximizing. The location model would minimize transfer costs subject to the solution of the production component. When the two models are incorporated into one linear program, price minus production and transfer costs would be maximized.

Under a quadratic formulation, as put forth by Takayama and Judge, net social payoff is maximized. A modified simplex algorithm is required. Price-quantity relationships and inter-regional flows are considered. Supply or demand can be assumed fixed. The advantage of this formulation is that price-quantity relationships can be included and an economy can be simulated in greater detail. The disadvantages are: 1) The Economic Research Service's model cannot be incorporated into the Takayama and Judge formulation since the units of production activities are expressed in acreages of management strategies rather than in quantities of commodities produced. 2) Higher computation costs will result because of the large linear programming format required, and 3) There will be costs involved in estimating the price-quantity relationships. The Economic Research Service's model cannot be incorporated into the Takayama and Judge formulation. Before a quadratic model can be considered, a primal problem must first be formulated.

The cost minimization approach is the favored alternative, since this approach would require the least amount of work in constructing the model.

Nature of the Linear Programming Activity

As has been stated previously, a management strategy is a combination of activities that can be practiced on a single acre of land. The management strategy is a column, that is, a linear programming activity, in the production component of the model. These activities produce a number of products at a given cost. These activities take place over a period of time. The cultural practices can occur at different points in time, which must be explicitly stated. Coefficients in the linear programming activity are specified for each product in each time period as well as for the amount of land required for the activities. Costs are also incurred at different points in time when the cultural practices are undertaken. These costs are discounted to the present and are the objective function values of the activities. Conversions of management strategies can also take place in the linear programming activity. The time of the conversion, the cultural practices involved, and the costs incurred must also be explicitly stated.

Definition of Variables

i = demand point = $(1,2,3,\ldots,I)$

i' = demand point outside of the river basin

j = supply area = $(1,2,3,\ldots,J)$

J' = supply area outside of the river basin

a = management strategy = $(1,2,3,\ldots,A)$

when:

$a = (b,\ldots,h)$ are management strategies for forest land

$a = (i,\ldots,p)$ are management strategies for agricultural land

$a = (q,\ldots,z)$ are management strategies for pasture land

k = component (product) of a product-package = $(1,2,3,\ldots,K)$

$k = (a,\ldots,p)$ are market and non-market goods

$k = (q,\ldots,s)$ are stationary residuals

$k = (t,\ldots,v)$ are non-stationary residuals

r = class of forest resource = $(1,2,3,\ldots,R)$

r^* = class of non-forest land

input variables:

K_{arj} = production cost of management strategy a on resource class r in region j discounted to the present

K_{rr^*j} = cost of converting resource class r in region j to resource class r* in region j

n_{kijt} = transfer coefficient of residual k from site j to site i in time period t

T_{kijt} = transport cost for good k from supply area j to demand point i in time period t

X_{kit} = demand for component k at demand point i in time period t

X_{kjt} = constraint on production of product k in region j in time period t

Z_{arj} = limit on management strategy a on resource class r in region j

δ_{akrjt} = amount of component k produced by one acre of management strategy a or resource class r in region j in time period t output variables:

C_{it} = transport cost of meeting demands at demand point i in time period t

C_{jt} = transport cost of goods produced in supply area j in time period t

V_{r*rj} = acreage of resource class r in region j converted to resource class r* in region j

W_{rr*j} = acreage of resource class r* in region j converted to resource class r in region j

X_{arj} = acres of management strategy a practiced on resource class r in supply area j

X_{kijt} = amount of component k shipped from supply area j to demand point i in time period t

X_{kjt} = amount of component k produced in time period t

X_{rj} = acres of resource class r in supply area j

Y_{kjt} = amount of product k at supply point j in excess of the production requirement on that region in time period t

Discussion of the Production, Transportation, and Environmental Diffusion Components and Linkages

This section will discuss the mathematical specification of the production, transportation, and environmental diffusion components and the linkages between components. The first alternative combination of components to be considered is the incorporation of the transportation and environmental diffusion components into the production model. (Alternatives 1 and 2). The linkage of a land assignment model will be discussed in a later section.

Equations

objective function:

Minimize total production, transportation, and land conversion costs:

$$\sum_a \sum_r \sum_j K_{arj} X_{arj} + \sum_k \sum_i \sum_j \sum_t T_{kijt} X_{kijt} + \sum_r K_{rr*j} W_{rr*j} + \sum_{r*} K_{r*rj} V_{r*rj} \qquad (9)$$

constraints:

A) Product k is the same for all product packages. Product k is summed across all management strategies and shipped to any i at which there is a demand for k. Both market and non-market goods are considered.

$$\sum_a \sum_r \delta_{akrjt} X_{arj} - \sum_i X_{kijt} = 0 \qquad (10)$$

for k = (a,...,p), all j, and all t

B) Residual k is also the same for all product packages. This equation set sums the residuals produced in each supply area.

$$\sum_a \sum_r \delta_{akrjt} X_{arj} - X_{kjt} = 0 \qquad (11)$$

for k = (q,...,s), all j, and all t

X_{kjt} has an objective function value of 0.

C) Some of the residuals might not be stationary. They might move through the system. The set of equations simulates the movement of residuals through the system and allows quantities of residuals at various locations to be constrained:

$$\sum_j n_{kijt} X_{kjt} \leq X_{kit} \qquad (12)$$

for k = (t,...,v), all i, and all t

If no limit is placed on a residual, equation (12) is changed to (12a) to sum the quantity received at each site:

$$\sum_j n_{kijt} X_{kjt} - X_{kit} = 0 \qquad (12a)$$

X_{kit} would have a value of 0 in the objective function.

Equation set (12) or (12a) is the environmental diffusion component.

D) This equation set requires that projected demands at various points in the river basin be met.

$$\sum_j X_{kijt} + \sum_{j'} X_{kij't} \geq X_{kit} \qquad (13)$$

for k = (a,...,p), all i, and all t

This equation set allows products to be imported to the river basin to meet demands in the river basin.

E) Demand points outside of the river basin with a negative excess supply of a good will have a capacity to absorb excess production of products in the river basin. They cannot buy infinite amounts, however. Their demands do not have to be satisfied by river basin production, either.

$$\sum_j X_{kijt} \leq X_{ki't} \qquad (14)$$

for k = (a,...,p), all i' with a negative excess supply, and all t

F) There is also a limit on the amount of goods that a region outside of the river basin with positive excess supplies can export to meet river basin demands.

$$\sum_i X_{kij't} \leq X_{kj't} \qquad (15)$$

for k = (a,...,p), all j' with positive excess supplies, and all t

G) Demands could also be made directly on the production of a region, that is a region could be required to produce a certain quantity of a given good. The following equation set will accomplish this:

$$\sum_i X_{kijt} \geq X_{kjt} \qquad (16)$$

for a given k, for all j, and all t

H) There are resource limitations to production on each resource class in each region. It is also possible for resource classes to be converted to another class. Forest land can be converted to non-forest land and vice-versa. The following equation set constrains production and allows conversions of resource classes to occur.

$$\sum_a X_{arj} - \sum_{r*} W_{rr*j} + \sum_{r*} V_{r*rj} \leq X_{rj} \qquad (17)$$

for each r and j

If conversions between resource classes do not occur, the equation set changes to (17a).

$$\sum_a X_{arj} \leq X_{rj} \qquad (17a)$$

for all r and j

I) Transfer costs can be summed at the locations where they are captured to study distributional effects. This equation set sums the costs, at each demand point, of transporting products from supply areas to meet demands at that point.

$$\sum_j \sum_k T_{kijt} X_{kijt} - C_{it} = 0 \qquad (18)$$

for all i and t

C_{it} has an objective function value of 0.

J) This equation set sums the cost, at each supply region, of transporting goods to demand points.

$$\sum_{i}\sum_{k} T_{kijt}X_{kijt} - C_{jt} = 0 \qquad (19)$$

for j and t

C_{jt} has an objective function value of 0.

K) Other constraints on land use by location can be put in the model by using this general form:

$$X_{arj} \leq Z_{arj} \qquad (20)$$

Greater than or equal to constraints or equal to constraints could also be put in. These equations allow constraints to be put on management strategies by decisions exogenous to the model. Figure 2-3 illustrates these equation sets.

The environmental diffusion component can be removed. (Alternatives 3,4,5, and 6). Equation set (12) or (12a) would be removed. Equation set (11) could be changed to:

$$\sum_{a}\sum_{r} \delta_{arkj}X_{arj} \leq X_{rjt} \qquad (11a)$$

for k = (q,...,v), all j, and all t

Removal of the transportation component is more complex. (Alternatives 6,7,8,9, and 10). Variables C_{kit}, C_{kjt}, T_{kijt}, X_{kijt}, and X_{kit} are removed. Requirements cease to be specific to demand points. Requirements on production by the river basin or sub-basins are then made. With these alternatives, the objective function is changed to:

$$\text{minimize} \sum_{a}\sum_{r}\sum_{j} K_{arj}X_{arj} + \sum_{r} K_{rr*j}W_{rr*j} + \sum_{r*} K_{r*rj}V_{r*rj} \qquad (21)$$

Demands are made for the products by each supply region:

$$\sum_{a}\sum_{r} \delta_{akrjt}X_{arj} \geq X_{kjt} \qquad (22)$$

for k = (a,...,p), all j, and all t

9) Minimize $\sum_{a}\sum_{r}\sum_{j} K_{arj}X_{arj} + \sum_{k}\sum_{i}\sum_{j}\sum_{t} T_{kijt}X_{kijt} + \sum_{r} K_{rr*j}W_{rr*j}$

$$+\sum_{r*} K_{r*rj}V_{r*rj}$$

10) $\sum_{a}\sum_{r} \delta_{akrjt}X_{arj} - {}_{i} X_{kijt} = 0$

11) $\sum_{a}\sum_{r} \delta_{akrjt}X_{arj} - X_{kjt} = 0$

12) $\sum_{j} n_{kijt}X_{kjt} \leq X_{kit}$

13) $\sum_{j} X_{kijt} + \sum_{j'} X_{kijt} \geq X_{kit}$

14) $\sum_{j} X_{kijt} \leq X_{ki't}$

15) $\sum_{i} X_{kij't} \leq X_{kj't}$

16) $\sum_{i} X_{kijt} \geq X_{kjt}$

17) $\sum_{a} X_{arj} - \sum_{r*} W_{rr*j} + \sum_{r*} V_{r*rj} \leq X_{rj}$

18) $\sum_{j}\sum_{k} T_{kijt}X_{kijt} - C_{it} = 0$

19) $\sum_{i}\sum_{k} T_{kijt}X_{kijt} - C_{jt} = 0$

20) $X_{arj} \leq Z_{arj}$

Figure 2-3.--The Production Model with Transportation and Environmental Diffusion Components Incorporated.

The environmental diffusion model is included in alternatives 7 and 8 through equation sets (11) and (12). Equation set (19) contrains the acreage of each resource class. Equation set (20) allows exogenous constraints to be made on management strategies. Equation sets (13), (14), (15), (16), (18), and (19) are not included.

The environmental diffusion model could be eliminated in alternatives 5 and 6. This is done by removing equation set (4) or (4a). Equation set (11) could be changed to (11a). With alternatives 9 and 10, the environmental diffusion model is separated but included. This separation will be discussed in the next paragraph. With alternative 13, both the transportation and environmental diffusion models are separated.

The transportation and environmental diffusion components could be included but made separate from the production component. To separate the environmental diffusion component, equation (12) or (12a) is removed. (Alternatives 7, 8, 9, and 10). Equation (11) would be left in the production model. Equation set (25) would be solved separately using information from equation set (11):

$$\sum_j n_{kij} X_{kjt} = X_{kit} \qquad (25)$$

for k = (q,...,v), all i, and all t

The production of residuals could be constrained by substituting equation set (24) for equation set (11):

$$\sum_a \delta_{akrjt} X_{arj} + Y_{kjt} = X_{kjt} \qquad (24)$$

for k = (q,...,v), all j, and all t

Equation (25a) would be substituted for equation (25):

$$\sum_j n_{kij} [X_{kjt} - Y_{kjt}] = X_{kit} \qquad (25a)$$

for k = (q,...,v) all i, and all t

The transportation component would be separated by changing equation set (10) to equation (23):

$$\sum_a \delta_{akrjt} X_{arj} - Y_{kjt} = X_{kjt} \quad (23)$$

for k = (q,...,v), all j, and all t

Equations (13), (14), (15), (16), (18), and (19) are then removed from the production model.

The transportation model is then solved separately using a linear programming format.

objective function:

Minimize total transportation costs:

$$\text{minimize} \sum_k \sum_i \sum_j \sum_t T_{kijt} X_{kijt} \quad (26)$$

constraints:

The total amount of products produced in the production component must be shipped:

$$\sum_i X_{kijt} = X_{kjt} + Y_{kjt} \quad (27)$$

Equation sets (13), (14), (15), (18), and (19) are then included in the transportation component to account for the shipment of products between regions. (Alternatives 5, 6, 11, and 12).

Linking a Land Assignment Model

It might be desirable to allocate management strategies to subdivisions within a region. Problems are caused when more than one management strategy is allocated to a resource class and more than one regional subdivision contains some acreage of the resource class. It is impossible to uniquely assign management strategies to regional subdivisions by defining the locations of the resource class. Additional criteria will be needed to choose the regional subdivision to which the management strategies are allocated. The subdivisions would be single grid cells in which land information is stored.

At this point in time, criteria have not been defined. A land assignment model would be used to allocate the management strategies among the grids (Patterson, 1972). A scale of priority for all management strategies would have to be developed for each resource class and location. A priority would have to be defined within a cell and between cells. Some of the possible criteria include: accessibility, desired patterns, ownership, historic land use patterns, and relationships to land forms and features. Each management strategy at each location could be assigned a value from 0 to 10 or 0 to 100 depending upon the criteria and weights on the criteria.

This priority system would be used to define objective function values. A value would be defined for each management strategy for each resource class in each grid. The value would show the relative priority of the strategies in each grid and between grids. A multiple land use assignment model would be used to maximize the total value of the objective function for the river basin.

Variables

j^* = subdivision of j region, that is, a grid cell

V_{arj^*} = value assigned to management strategy a practiced on resource class r in region j^* (from priority scale)

X_{arj^*} = acreage of management strategy a practiced on class r in region j^*

X_{arj} = acreage of management strategy a practiced on resource class r in region j which is calculated in the location model

X_{rj*} = acres of resource class r in region j*

Z_{arj*} = limit of management strategy a on resource class r in region j*

Equations:

objective function:

Maximize the total value of the objective function.

$$\text{Maximize} \sum_a \sum_r \sum_{j*} V_{arj*}X_{arj*} \tag{26}$$

constraints:

A) The acreage of any management strategy must be constrained by the acreage of its resource class in any given region. Management strategies are allocated to every acre of the resource class and the following equation accomplishes this:

$$\sum_a X_{arji*} = X_{rj*} \tag{27}$$

for all r and j*.

B) The total acreage of each management strategy on each resource class in each j region, which is determined in the production component, must be allocated. The management strategies must be summed over each j* in each j region.

$$\sum_{j*} X_{arj*} = X_{arj} \tag{28}$$

for all a, r, and j.

C) The acreage of a management strategy in any j* region could be constrained by decisions made exogenous to the model by use of the following types of equations:

$$X_{arj*} \leq Z_{arj*} \tag{29}$$

Greater than or equal to constraints or equal to constraints could also be used.

The linkage between this multiple land use assignment model and the location component occurs through X_{arj} for all a, r, and j. Each X_{arj} is calculated in the location model and then constrains the solution of the land use assignment model.

Land Management Strategy Information

An important problem with this system is that of determining the product coefficients, the δ_{akrjt}'s. Relationships must be determined to calculate these coefficients. These relationships must account for physical resource data, the dimensions of resource class r, the practices of management strategy a, and the point in time:

$$\delta_{akrjt} = f_k\ (a,r,t)$$

f_k = relationship to determine coefficient for product k

These relationships will not be prescribed in this study. These relationships are best determined by practitioners in the fields specializing in each of the products. Relationships used in this study will be described in a later chapter.

Goals for Land Use Management

Requirements for products are important goals for land use management. Calculating these requirements is a problem. Requirements are normative statements concerning what ought to be produced. Defining relationships to calculate the requirements on a micro-scale, such as, subdivisions of a river basin, could be quite difficult. The levels of requirements which are projected are affected by the form of the relationships, the variables included in the realtionships, and the assumptions behind the relationships. Relationships used in this study will be described in the next chapter. Factors to be considered for calculating requirements for timber are current consumption, growth potentials for industries using roundwood, locational advantages, technology, and prices of roundwood and its substitutes. Variables to be considered for calculating recreation and hunterday requirements include population and population changes, current levels of economic activity, prices, income, availability of substitutes, and potentials for change. Constraints on environmental impacts should consider desired uses to be made of the resource needed for those uses.

Linking the Land Evaluation System to the Land Information System

Purpose of the Linkage Between the Location Model and the Land Information System

Each management strategy is labelled according to its resource class, r, and its region, j. The purpose of the land information system is to provide the information for the calculation of X_{rj}, the acreage of resource class r in region j, and X_{rj*}, the acreage of resource class r in region j*. These acreages constrain the acreage of management strategies a = (1, 2, 3,...,A) on resource class r in any region.

Region j could be defined as a set of grid cells. Each grid cell would contain acreages of various resource classes. The acreages stored in these grids would be summed by the j region and resource class to calculate the acreage of each resource class in each region.

The land inventory system serves basically the same purposes for the land assignment model. The system provides information to calculate the acreage of resource class r in grid cell j*, X_{rj*}.

The purpose of the linkage is to provide the resource constraints needed for the production component and the land assignment model. The land information system must contain the data to classify the land resource classes and stored by grid cells. The grid cells must be referenced to allow retrieval of this information. The land information system could also be used to generate maps of the resource classes or specific items of land information.

Resource Classification

The classification system is based on the concept of a multi-dimensional landtype (Lacate, 1961). Dimensions to be used in classifying the resource are those important to decision-making, in the case, those important to allocating management strategies in space. Classification of each dimension should be based on management needs. There must be a concern with the current cover type or land use and characteristics of the cover type or land use. As an example, the Forest Service is defining management strategies using forest ecosystem, soil association, and stand size class and condition. Other data might also be important if land use conversions are to be considered, such as, slope, topography, climate, bedrock depth, the presence of minerals, and soil series. For the purposes of this model, only characteristics of the current cover type are necessary since the Economic Research Service's model does not consider land use conversions. Land could be classified for each potential use if conversion is to be considered.

Each resource class r is defined as being a combination of one class of each of n dimensions. There are R classes of resources. Each class of each dimension is defined such that the cost or product-package of a management strategy does not change. For the forest sector, there are four dimensions each with a set of classes:

b = 1,...,5 = forest ecosystem

c = 1,...,4 = stand size class

d = 1,...,5 = soil association

e = 1,2 = stand condition

The maximum number of forest resource classes in this study is 200. Some combinations may not exist.

There are two ways to define these resource classes and their locations. Each dimension and its classes could be surveyed and mapped separately. The resource class could then be defined by the use of overlays or computer techniques. Each resource class would be defined by one class of each dimension and would have its boundaries defined on a map. The other method would be an integrated survey where a group goes out into the field and defines each multi-dimensional class and maps each. If each dimension is mapped and classified in a desired manner, the first method will probably be used. The second method becomes more desirable if the desired data does not exist.

Grids

A system of grids is not the only way to store and map land use information. However, it is the most common and perhaps the easiest method (Murray et. al., 1971). A system of grids is recommended because of the more widespread use and the probability that technology using this system is better developed.

The size of the grid is an important problem. The sizes fall into two categories. The first size is small enough to allow definition of only one resource class, that is, only one resource class is assigned to a cell. The cell size allows each resource dimension to be classified and mapped separately. Each dimension can then be combined into a resource classification of each cell, perhaps by a computer program. The second size is too large to allow the definition of only one resource class. The acreage of each class must be assigned to each cell. The acreage of resource classes must be determined outside of the land information system and assigned to each cell. Whether or not a cell is too large depends upon the resolution or accuracy desired by the analyst. Computer capacity and available budget can constrain the number of cells handled and thus may affect the size of the grids.

If the grid cell is small enough to allow the classification of only one resource class to a grid, the task of the land information is defined as follows: 1) Land information is stored by grid cell for each dimension by class needed to define a resource class. 2) This information is processed by a computer algorithm to classify each grid cell. 3) The acreage of each grid cell constrains the land assignment model and is aggregated by j region to constrain the location model. Figure 2-4 illustrates the steps in this process.

If the grid cell is large enough to allow classification of more than one resource class to a grid, the task of the land information system changes: 1) Land information is collected and mapped. 2) Land resource classes are defined and mapped from the land information. 3) The grid system is overlaid and acreages of each class are assigned to each grid cell. 4) The acreages of each grid cell constrain the land assignment model and are aggregated by j region to constrain the location model. Figure 2-5 illustrates the steps in this process.

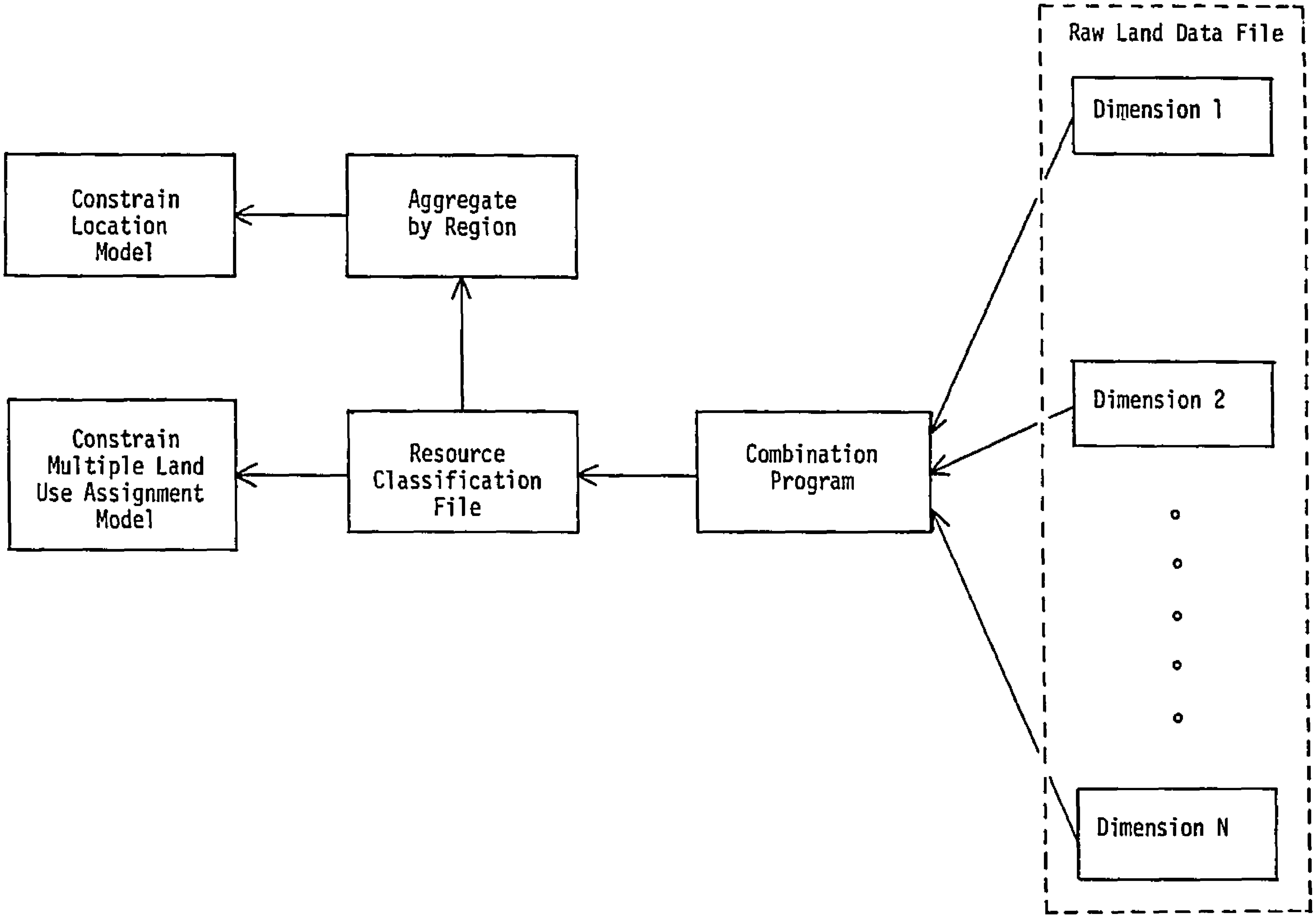


Figure 2-4.--Steps from Storing Land Information to Constraining the Location Model, Given a Grid Cell Small Enough to Classify Only One Resource.

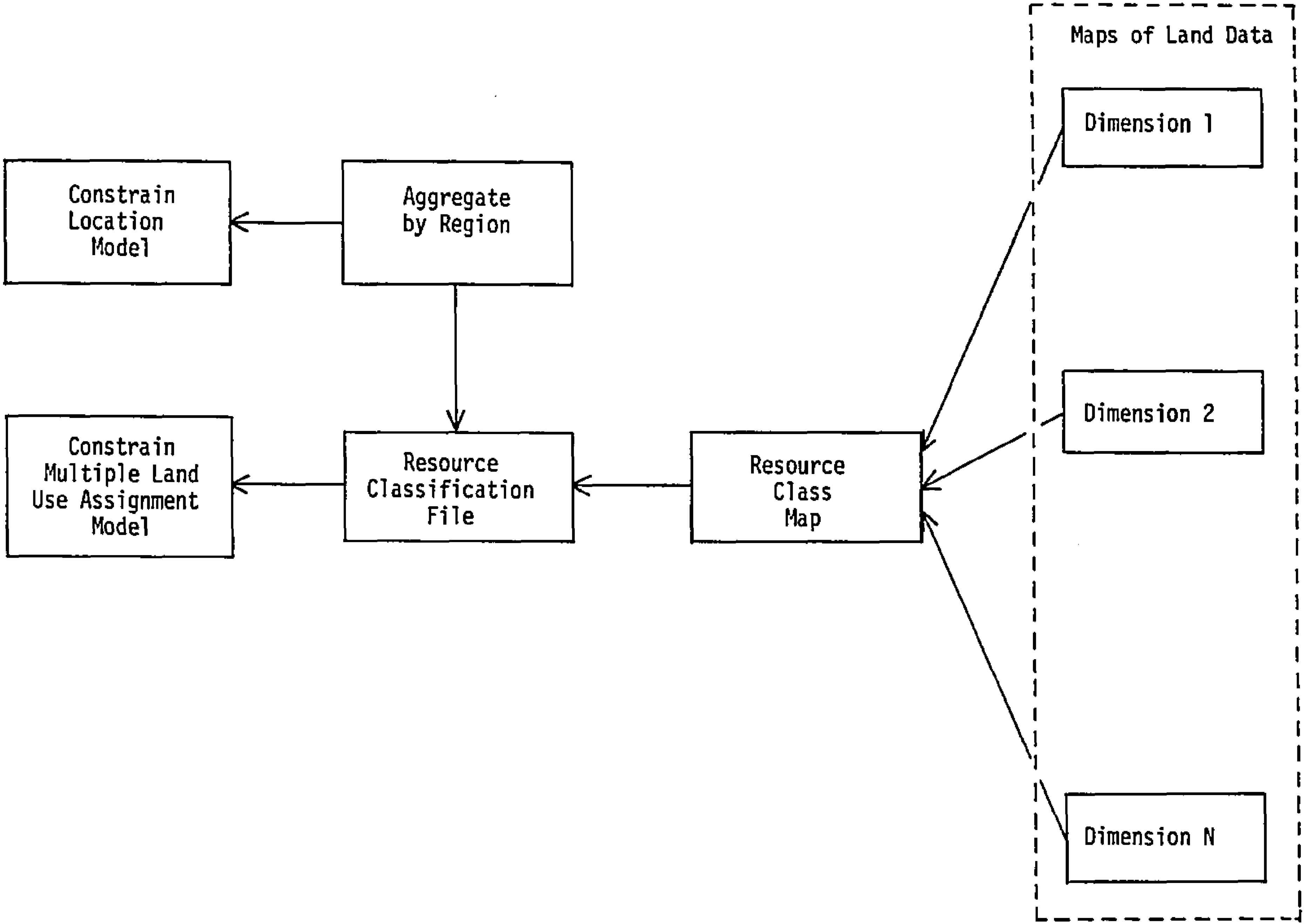


Figure 2-5.--Steps in Constraining the Location Model from Land Information, Given a Grid Cell Small Enough to Classify Only One Resource.

Choosing a Grid Cell Size

The grid cell size is an important factor in developing a land inventory system. The advantages of a large or small grid cell are discussed below. A small grid cell is a cell to which only one resource class can be assigned. A large grid cell is a cell to which more than one resource class can be assigned. These two terms are relative to the accuracy of the data collected and the desired accuracy of mapping the data. Given a level of accuracy of data, there is a threshhold in area above which a grid cell is large and below which it is small for a desired level of accuracy of mapping. As the desired level of accuracy increases, given a level of data accuracy, the smaller is the threshhold area. As data become more accurate, the desired level of accuracy of mapping can increase thus decreasing the threshhold area between a large and small grid.

Criteria must be developed to choose a grid cell size. The cost of collecting data is assumed independant of grid cell size. The accuracy of data and the quantity will determine the cost of collection. The size of a grid cell is relative, given the accuracy of the data and the desired accuracy of mapping the data.

The first criteria is the cost of classifying resources. With the small grid cell, the process can be computerized. With the large grid cell, the process might have to be done manually. If the process for a large grid cell is computerized, it would be more complex than the classification of resources given a small grid. It would appear that the cost of classifying resources on a small grid would be lower than the cost of classifying them on a large grid. A rating of 1 is assigned to the grid cell size with the lower cost of classifying resources, while a rating of 2 is assigned to the grid cell size with the higher cost. A lower cost of classification is preferred to a higher cost of classification. The small grid receives a higher rating of 1 and the large grid receives a lower rating of 2.

The second criteria is the ease of displaying maps of resource classes or resource dimensions. With a small grid cell, resource classes or a single resource dimension can be mapped for all cells on a single map. With a large grid cell, more than one map will probably be required since more than one resource class could be assigned to a cell. The small grid cell receives a higher rating of 1 while the large grid cell receives a lower rating of 2.

The third criteria is the ease of mapping management strategies allocated to grid cells by the land use assignment model. This mapping will be more difficult since more than one management strategy can be assigned to a grid cell. With a small grid cell, resource classification will not be a complicating factor as it will be in a large grid cell. The small grid cell receives a higher rating of 1 while the large grid cell receives a lower rating of 2. Table 2-3 displays the results of these three criteria.

Table 2-3.--Rating Grid Cell Size

criterion	grid cell size large	grid cell size small
Cost of classifying land resources	2	1
Ease of mapping resources	2	1
Ease of mapping management strategies	2	1

1 = high 2 = low

Geographic Referencing

Geographic referencing is also an important problem. Several possible systems include: 1) latitude-longitude, 2) Universe Transverse Mercator, 3) state plane coordinates, and 4) the rectangular survey. The Universe Transverse Mercator system seems to be favored in the literature (Murray et, al, 1971 and State Planning Division, 1972). This system has several advantages: 1) each grid unit is square and uniform in size, 2) the system is global, 3) the system is metric, and 4) other referencing systems can be converted to it by use of computer programs. It seems advantageous for units of the federal government to use one system of geographic referencing so that data collected by different agencies are compatible. Therefore, it is desirable that data collected for river basin planning be based on a Universe Transverse Mercator grid. Once laid out, grids can be labelled by an X-Y coordinate system to reference data collected by the grid. Availability of data, however, may force use of the rectangular survey. The land evaluation system and the land information system could be based on a variety of grid systems, including the Economic Development Agency's two minute by two minute national grid.

File Structure

There are several ways to organize data files. The first is sequential organization where the records are stored in the specific order in which they are processed. This is the most common method of storage. The second is random organization where data are stored and retrieved on the basis of a predictable relationship between the key of the record and the direct address of the location. This method has been used in the LUNR system and seems to offer advantages in the speed of retrieval when there are large numbers of cells. The third method is list processing where pointers are used to divorce the logical organization from the physical organization (Murray et. al., 1971). Any of these methods of organizing and storing data can be adapted to the land inventory system. The critical problem is the amount of data to be stored and the cost involved in retrieving data.

Media of storage include cards, tapes, and discs. The disc offers advantages in total volume of storage. More records can be stored and more data items can be stored in each record. When combined with a method a random organization, the disc offers one of the most advanced methods of storing land data. A prime example is the LUNR system developed at Cornell University (Shelton and Liang, 1973). Cards and tapes can also be useful in smaller systems. Tapes usually are more advantageous than cards since they can be rewound to allow the file to be read several times for various operations in the same program. Sequential organization is the easiest method to implement.

The data file is a means of storing data records for each cell. The record for each cell should be structured in such a way as to allow several operations to be performed using the file as a data base. The record contains several types of information useful to various operations. Each piece of information is stored in a field. Blank fields may be left in the record to allow new data items to be included in the record at later times (Hardy and Shelton, 1970).

When the grids are small enough to allow classification of only one resource, several types of information should be contained in the record: 1) location information, 2) basic resource data, that is, raw measurements of the land resource, and 3) resource classes for different land uses. The location information should contain the number of the j region, the number of the grid cell (j*), and the coordinates of the grid cell. The first two location data items are helpful in developing acreage constraints. All location items are integer fields. The basic resource data could include such things as soil association, stand size class and condition, ecosystem, climate, topography, bedrock depth, geologic data, land use, and other data concerning cover type. These data can be used to develop resource classifications for each use to be considered by the grid. The MIADS combination program could be used for this purpose (Amidon, 1964). When no land use conversions are considered, only one resource class is included. The location data and basic resource data may be put into the record first. Operations may then be performed to define the resource classes which are then put into the records. The resource classes are to be integer fields. Blank fields may be left in the record for the inclusion of more resource data and classifications. An example of such a record could be:

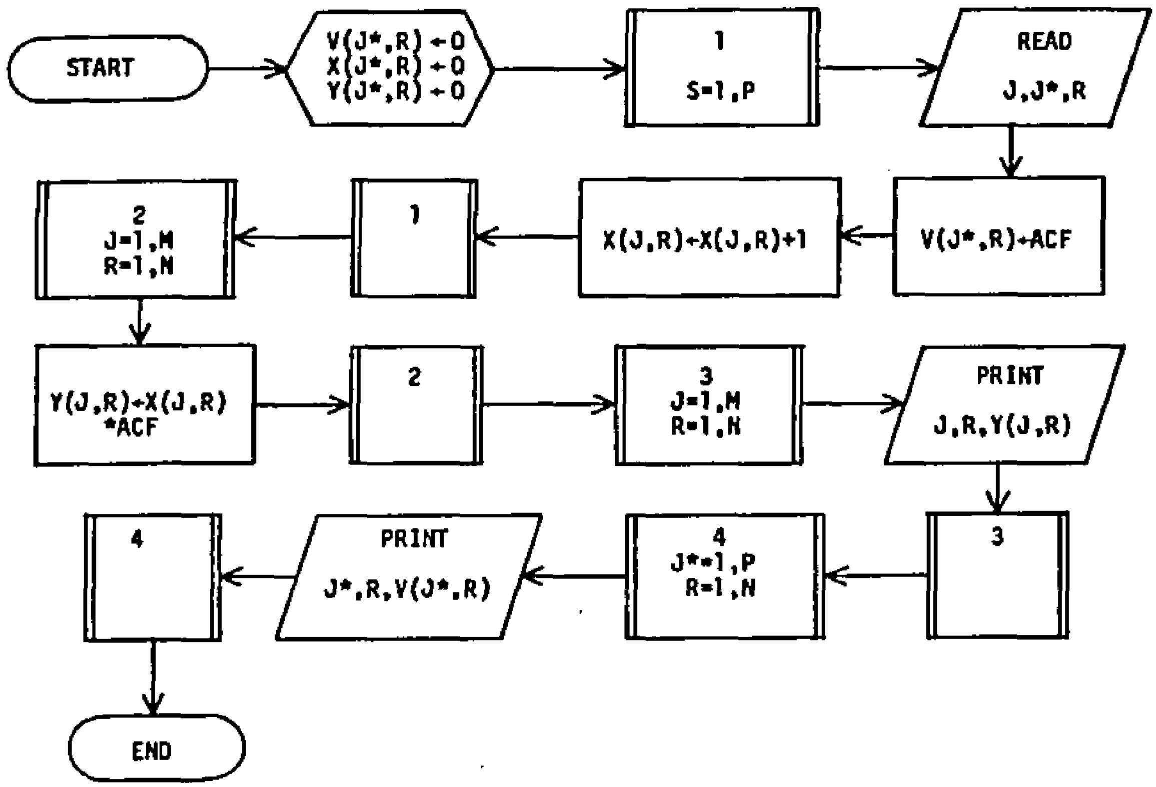
```
  J     J*     X     Y       A . . . . . N      1 . . . . . R    Blank
(I2)  (I2)  (I2)  (I2)     Real or Integer    (I2) . . . . (I2)  Fields
                                Fields
 \__________________/        \___________/      \____________/
    Location Data            Resource Data    Resource Classes
```

The X-Y integer fields are the coordinates of the X-Y coordinate system.

When the grids are large enough to allow more than one resource to be classified, the record is different. Again the number of the j region, the grid cell (j*), and the coordinates of the grid cell must be included. Resource data could be included. More than one class of each dimension could be included in a grid. Each class of each dimension would have a field in units such as acres. Resource classes are also included. However, even if no conversions are considered, there could be more than one resource class for each grid. Thus a field would be required for each resource class, with the acreage of each recorded. The location data would remain in the integer fields. Both the resource data fields and the resource class fields would be real fields, since real numbers, which are non-integer numbers, would be stored in them.

Constraining the Location Model and the Multiple Land Use Assignment Model

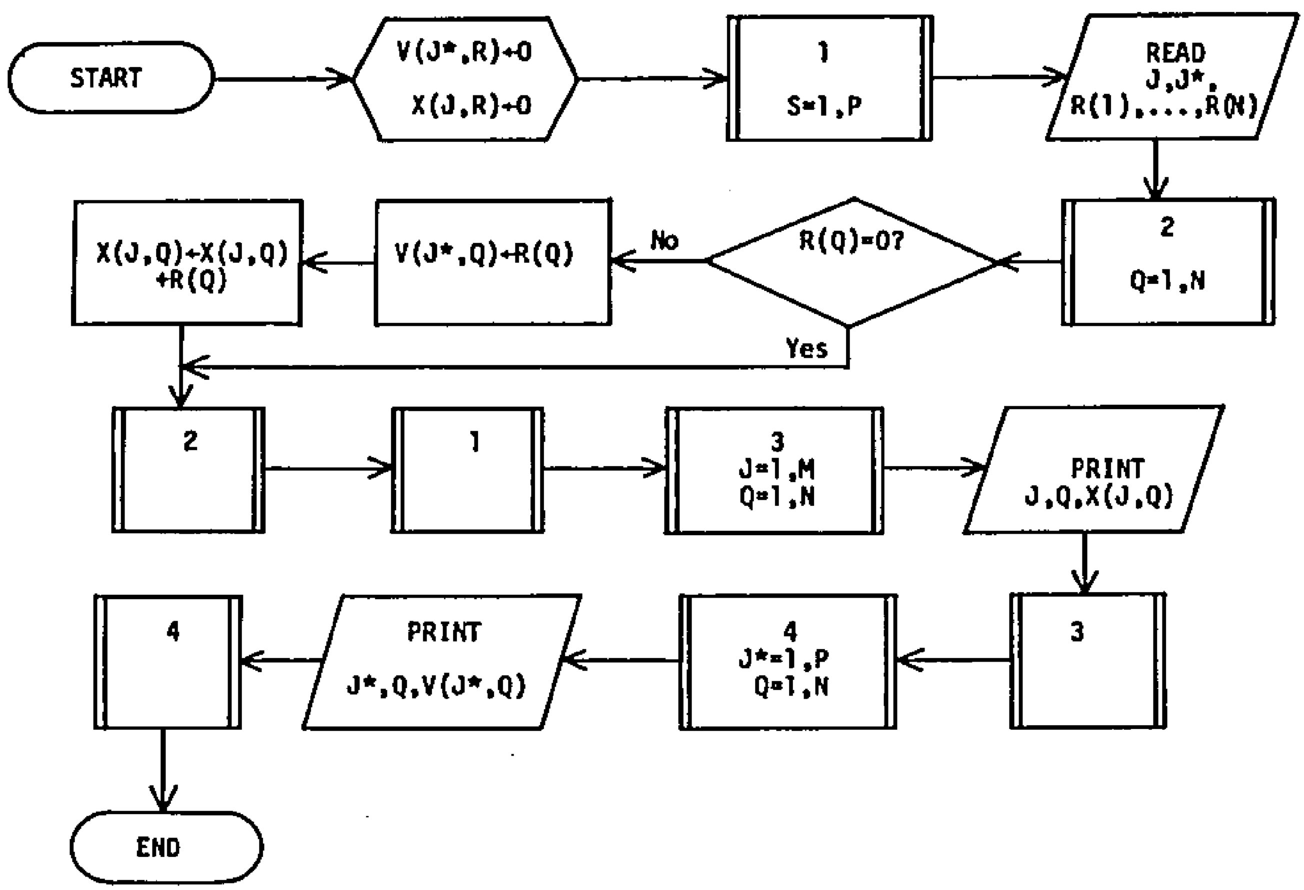
A computer program could be developed to read resource class information, perform operations to calculate acreages of resource classes and constrain the location model and the land use assignment model. To constrain the location model, the acreage of each resource class in each grid would be summed to calculate and print the total acreage of each resource class in each j region. To constrain the land assignment model, the acreage of each resource class in each grid is found and printed out. The actual constraints of the location model and the land assignment model are read from a computer printout and punched onto cards or other storage media. The cards could be punched as output from the computer program. See Figure 2-6 for a flowchart of an algorithm that calculates and prints acreages of resource classes by region and grid cell. See Appendix A for the set of flowchart symbols. Figure 2-6 assumes that the grids are small enough to classify only one resource. Since a small grid cell is favored over a large grid cell, this algorithm is favored over one that assumes a large grid cell. Figure 2-7 illustrates an algorithm that assumes a large grid cell.



ACF = Acreage of Grid Cell
J = Region = (1,...,M)
J* = Grid = (1,...,P)
R = Resource = (1,...,N)
S = Grid being processed

V(J*,R) = Acreage of resource R in grid J*
X(J,R) = Number of grids in resource R in region J
Y(J,R) = Acreage of resource R in region J

Figure 2-6.--Flow Chart of an Algorithm to Generate Acreage Constraints for the Location Model and the Multiple Land Use Assignment Model, Given a Grid Small Enough to Classify Only One Resource Class.



J = Region = (1,...,M)
J* = Grid = (1,...,P)
Q = Resource class = (1,...,N)
S = Grid being processed

R(Q) = Acreage of Resource Q
V(J*,Q) = Acreage of Resource Q in grid J*
X(J,Q) = Acreage of Resource Q in grid J

Figure 2-7.--Flow Chart of an Algorithm to Generate Acreage Constraints for the Location Model and the Multiple Land Use Assignment Model, Given a Grid Large Enough to Classify More Than One Resource Class.

Linking a Constraint Generator to the Land Evaluation System

The purpose of this component is to constrain the land evaluation system by land management decisions made exogenously to the model. These exogenous land management strategies define a spatial pattern of land management strategies which could be mapped. This mapped information could be used to determine Z_{arj}, the limit on management strategy a on resource class r in region j, for the production component or Z_{arj*}, the limit on management strategy a on resource class r in grid cell j*, for the land assignment model.

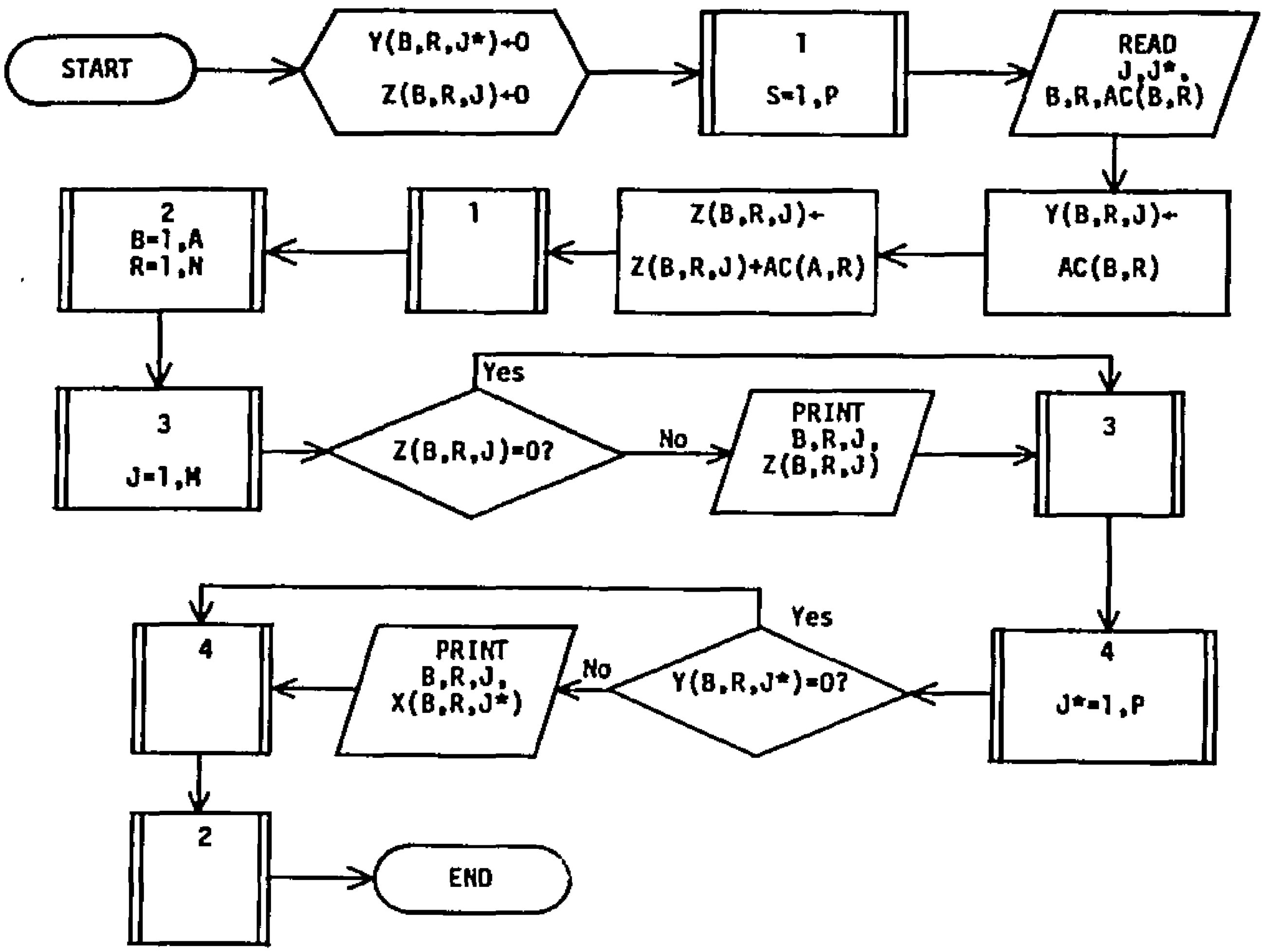
In some instances, the decision to manage land in a given manner would be based on the resource or dimension classification. A map of resource classes or desired resource classes could be generated from the land information system to assist in making such decisions. The exogenous decision would then simultaneously determine the resource class and the management strategy. The management strategies could be assigned to grid cells. If more than one management strategy could be assigned to a grid cell, the acreage of each strategy in the cell would have to be determined. The acreages of the cell could be obtained by using a planimeter or a digitizer. In this case, the acreage of a grid cell would have to be broken up among management strategies when summing over grid cells. If more than one resource can be classified in a grid cell which is not a favored alternative, the acreage of each management strategy on each resource class would have to be assigned to a grid cell and then summed to constrain the location model. If a small number of grids were involved the summations could be done manually. However, if a large number of grids are involved or the task is to be done many times, the acreage of each management strategy on each resource class in each grid cell could become input to a computer algorithm. This algorithm would then sum the acreages to constrain the producton model. A listing of each Z_{arj} and Z_{arj*} could be obtained which then could be used to constrain the models. Cards could be produced to be used as constraint cards in the linear programming algorithm. Figure 2-8 illustrates a flowchart to do this task.

Land management decisions also could be made exogenously to the land evaluation system without consulting the resource classification. In such a case, management strategies would have to be compared to the classified land use to determine the Z_{arj}'s and the Z_{arj*}'s. If the grid is small enough to allow only one resource class which is the favored alternative, the task is relatively simple. The resource class must be determined and the acreages divided among the alternative management strategies. Figure 2-9 is a flowchart to accomplish this.

If more than one resource class is assigned to a grid which is not the favored alternative, the process changes. Assumptions have to be made concerning how to distribute management strategies among resource classes. If the number of grids is small enough, the process could be carried out manually. With a large number of grids, a computer program would be helpful in completing this task. Figure 2-10 illustrates a flowchart of such an algorithm. It assumes that management strategies will be evenly distributed among resource classes.

Mapping

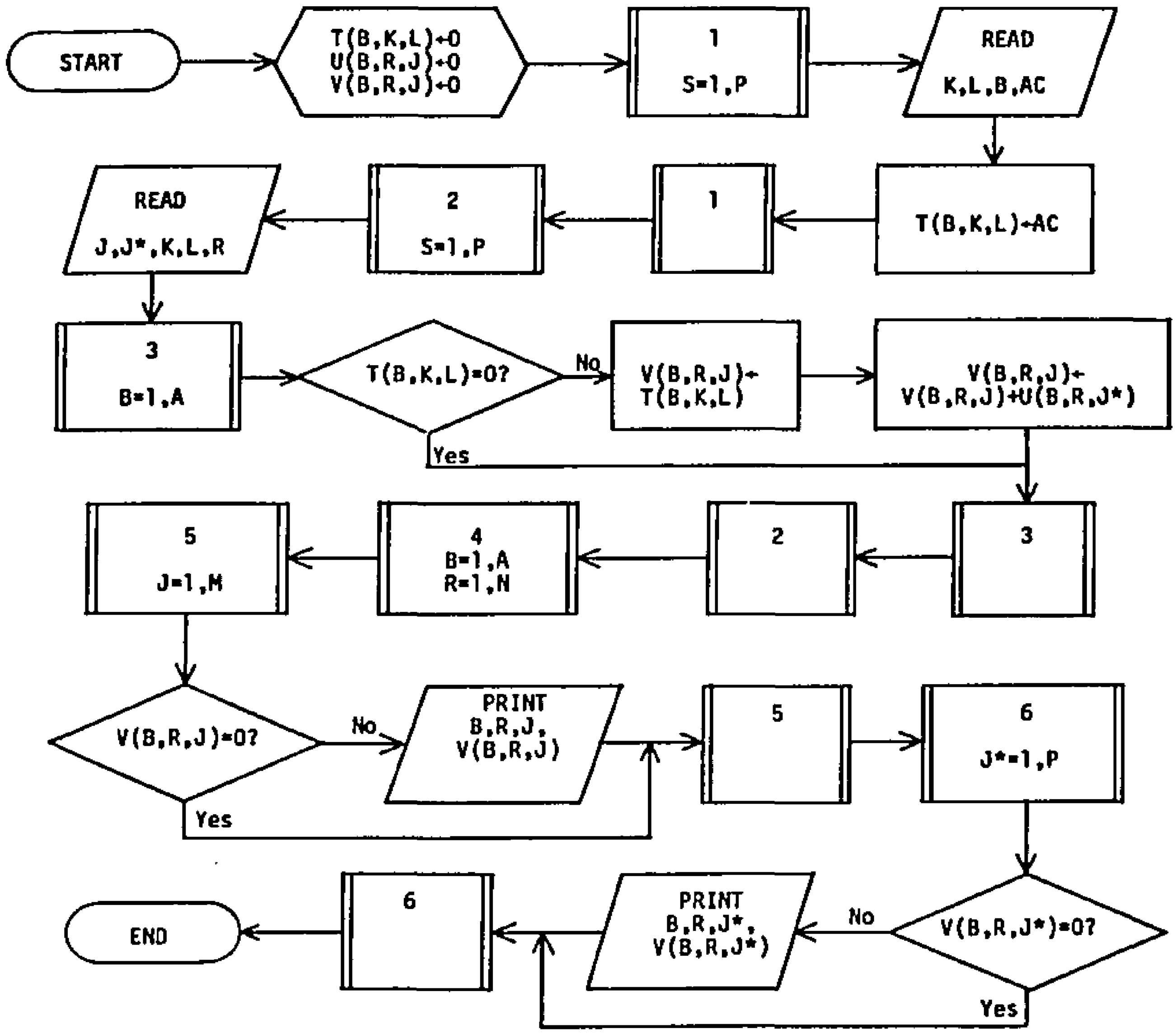
Three mapping routines were investigated. The investigation was restricted to printing routines operable on the MSU computer. Printing routines contain as much information as plotter routines and are cheaper to use. Also, handling gridded data on small grids will become very



J = Region = (1,...,M)
J* = Grid = (1,...,P)
B = Management Strategy = (1,...,A)
R = Resource Class = (1,...,N)
S = Grid being processed = (1,...,P)

Z(B,R,J) = Acreage of Management Strategy B on resource class R in region J
AC(B,R) = Acreage of Management Strategy B on resource class R
X(B,R,J) = Acreage of Management Strategy B on resource class R in region J
Y(B,R,J*) = Acreage of Management Strategy B on resource class R in grid J*

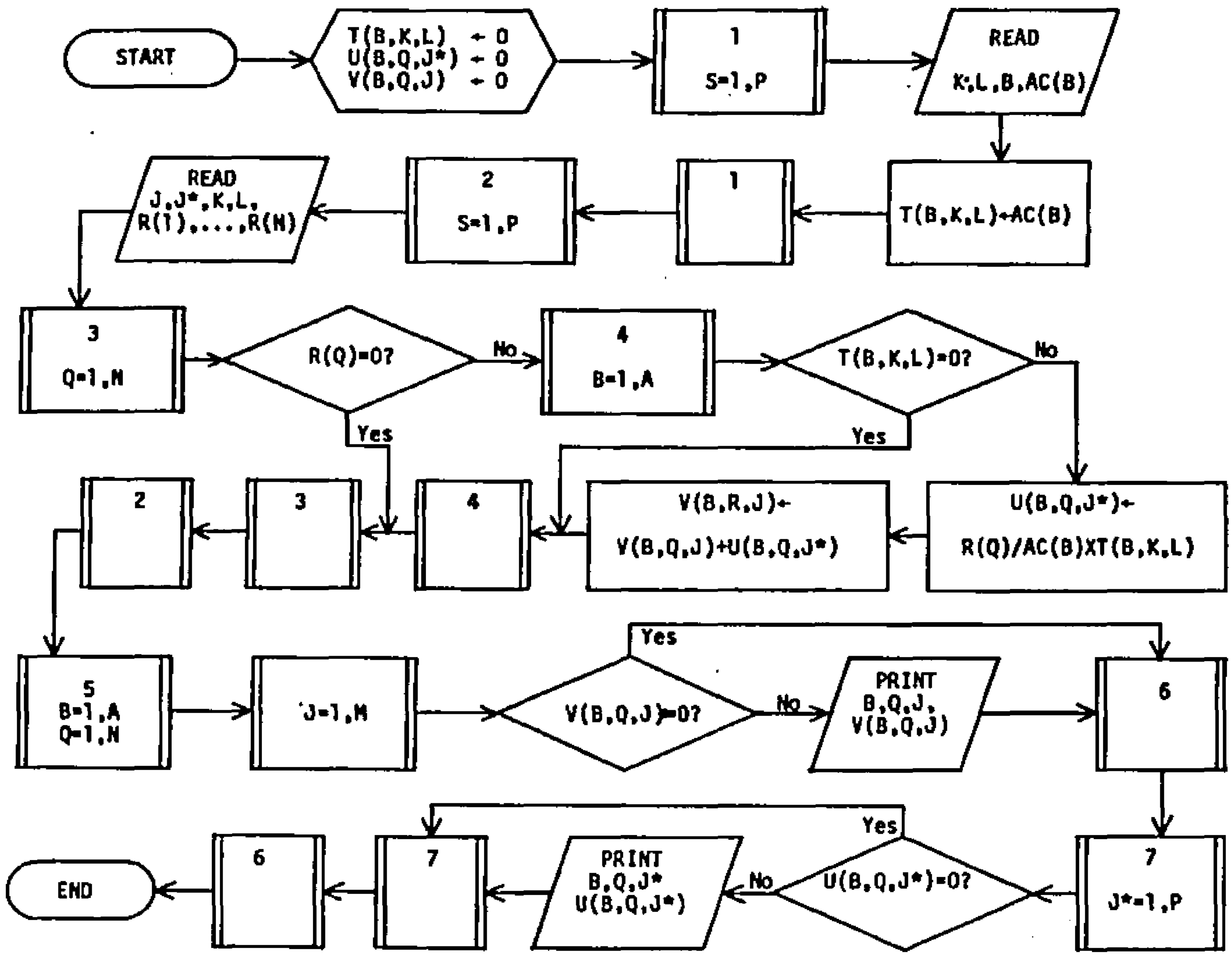
Figure 2-8.--Flow Chart of the Constraint Generator, Assuming that Management Strategy, Resource Class, and Location are Specified.



K,L = Coordinates
B = Management Strategy = (1,...,A)
R = Resource Class = (1,...,R)
J = Region = (1,...,M)
J* = Grid = (1,...,P)
S = Grid being processed

AC = Acreage
T(B,K,L) = Acreage of Management Strategy B at coordinates K,L
U(B,R,J*) = Acreage of Management Strategy B on resource R in grid J*
V(B,R,J) = Acreage of Management Strategy B on resource R in grid J

Figure 2-9.--Flow Chart of the Constraint Generator, Assuming a Small Grid Cell and Unspecified Resource Classes.



K,L = Coordinates
B = Management Strategy = (1,...,A)
J = Region = (1,...,M)
J* = Grid = (1,...,P)
S = Grid being processed
Q = Resource Class = (1,...,N)
R(Q) = Acreage of resource class Q

AC(B) = Acreage of Management Strategy B
T(B,K,L) = Acreage of Management Strategy B at coordinates K,L
U(B,R,J*) = Acreage of Management Strategy B on resource R in grid J*
V(B,R,J) = Acreage of Management Strategy B on resource R in grid J

Figure 2-10.--Flow Chart of the Constraint Generator, Assuming More Than One Management Strategy Can be Assigned to a Grid Cell.

expensive with plotter routines. The routines are 1) GRIDS (Murray et.al., 1971), 2) SYMAP (Young, 1972), and MIADS (Amidon, 1964). SYMAP can be used to map large areas but is not well suited to grid data. An outline must be specified for each subdivision. Data is assigned to the subdivision. This would be a difficult process for a large number of grids. A maximum of ten classes of data can be mapped. The program prints out a symbol for a particular class of data in the grid. The symbols are combinations of characters which allow shading. A region is mapped entirely with the symbol of the data value assigned to it. GRIDS is a routine developed at Harvard to specifically handle data stored in a grid network. The format of input data can be specified by the user allowing the program to be adjusted to any type of storage media and record formate. GRIDS could be easily adapted to the file structure discussed earlier. A maximum of ten classes of data can be allocated to the map grids. GRIDS uses symbols similar to SYMAP. MIADS allows a large number of data classes to be mapped. MIADS I can map 98 classes, while MIADS II can map many more. MIADS, however, does not shade in the way that SYMAP and GRIDS do. An alphanumeric is assigned to each class of data. The alphanumeric symbol is printed on the map. MIADS can handle a large number of grids.

Resource Data

Maps showing classes of different resource characteristics, that is, the dimensions of resource classes, could be printed. For each resource dimension, a map could be printed showing classes of the dimensions. These maps draw on the raw resource data fields of the data file. GRIDS appears to be a good choice since the input format can be written to read the proper data from the resource file. If resource data is stored on tape or disc, maps of several resource dimensions could be printed in succession. However, a maximum of ten classes of each dimension can be printed. If more classes are desired, MIADS would have to be used. The shading provided by GRIDS has a better visual effect than MIADS. SYMAP is not well suited to this task since an outline would have to be described for each grid cell. GRIDS is the favored alternative when the number of resource classes is less than or equal to ten. MIADS is the only alternative when the number of classes is greater than ten.

Maps of resource classes could also be printed. If only one resource class is assigned to a cell, all classes could be put on one map. Only MIADS could do the job since there are more than ten resource classes. The input problems of MIADS are not all that serious since only one map is required. A printout of resource classes by grid could be produced. Once the grid is coded and the cards are punched, many maps could be printed. If conversions are to be considered, a map could be printed for each land use class, that is, agriculture, forest, or pasture. MIADS is the only alternative investigated that is capable of doing the desired task.

If more than one resource class could be assigned to a grid cell, some problems in mapping resource classes would occur. One map could not display resource classes unless the grid cell size is small enough to classify only one resource. Both the classes of resources and the acreages would have to be mapped. This would be difficult. It might be possible to set up an algorithm to rank the resource classes and then print a map for each rank. However, acreages would not be listed. Again, only MIADS could do this job. A tabular printout of the acreage of each resource class in a grid cell might provide as adequate a description as a map. However, there would be no visual impact.

Listings of resource data and classes could be useful to guide exogenous management strategy decisions as well as being useful in determining constraints to be generated.

Output

Tables and maps can be printed for the location and the multiple land use assignment components. Each management strategy, a = (1,...,A), can be mapped. A map would be printed for each management strategy. A symbol could be assigned to a range of acreages. For the multiple land use assignment model, GRIDS and MIADS are the only viable alternatives. With less than ten management strategies, GRIDS is the favored alternative. MIADS can do the same job, but the visual effect is better with GRIDS. If GRIDS is used, a special program could be used to put output on a tape that could be read by GRIDS. This would be desirable only if a large number of maps were to be printed.

If output from the production model is to be mapped, SYMAP becomes the favored alternative. The output of the location model would be mapped if the multiple land use assignment model could not be developed as was the case of the Kalamazoo River Basin. With SYMAP, each subdivision would be outlined. A set of symbols could be developed for the percentage of forest land in each general management strategy which could then be mapped by region. GRIDS and MIADS could be adapted to the same job, but SYMAP is particularly well suited to this job.

In summary, 1) the GRIDS program is particularly well suited to mapping data from the resource data file and output from the land use assignment model. 2) MIADS is well suited to mapping resource classes and output from the land use assignment model. 3) SYMAP is well suited to mapping results from the production model. Tables could be printed for the regions. It is not necessary to produce maps for the regions if results from the land use assignment model are mapped. Figure 2-11 shows the output produced by components of the system and the algorithms used.

Tabular output could be developed for information besides the location of management strategies. The quantities of products produced in each region, the shipments of products between regions, and the excess of products received over demands could all be presented in tabular form to indicate the impacts of alternative land use plans.

Summary

This chapter discusses the issues to be considered by the MUMS system and the components of the system. Alternatives for the components of the system were discussed. These alternatives were evaluated and choices were made among them. Recommendations for the ideal model were made. The recommendations for each component follow.

Land Evaluation System

The recommended system is a regional linear programming model with the transportation and environmental diffusion components incorporated into the production component. The solution of the model is directly affected by including the transportation and environmental diffusion into the environmental diffusion component. The structure of this model was explicitly discussed. A multiple land use assignment model is linked to allocate management strategies among cells in a grid network when regions are subdivided into a grid network.

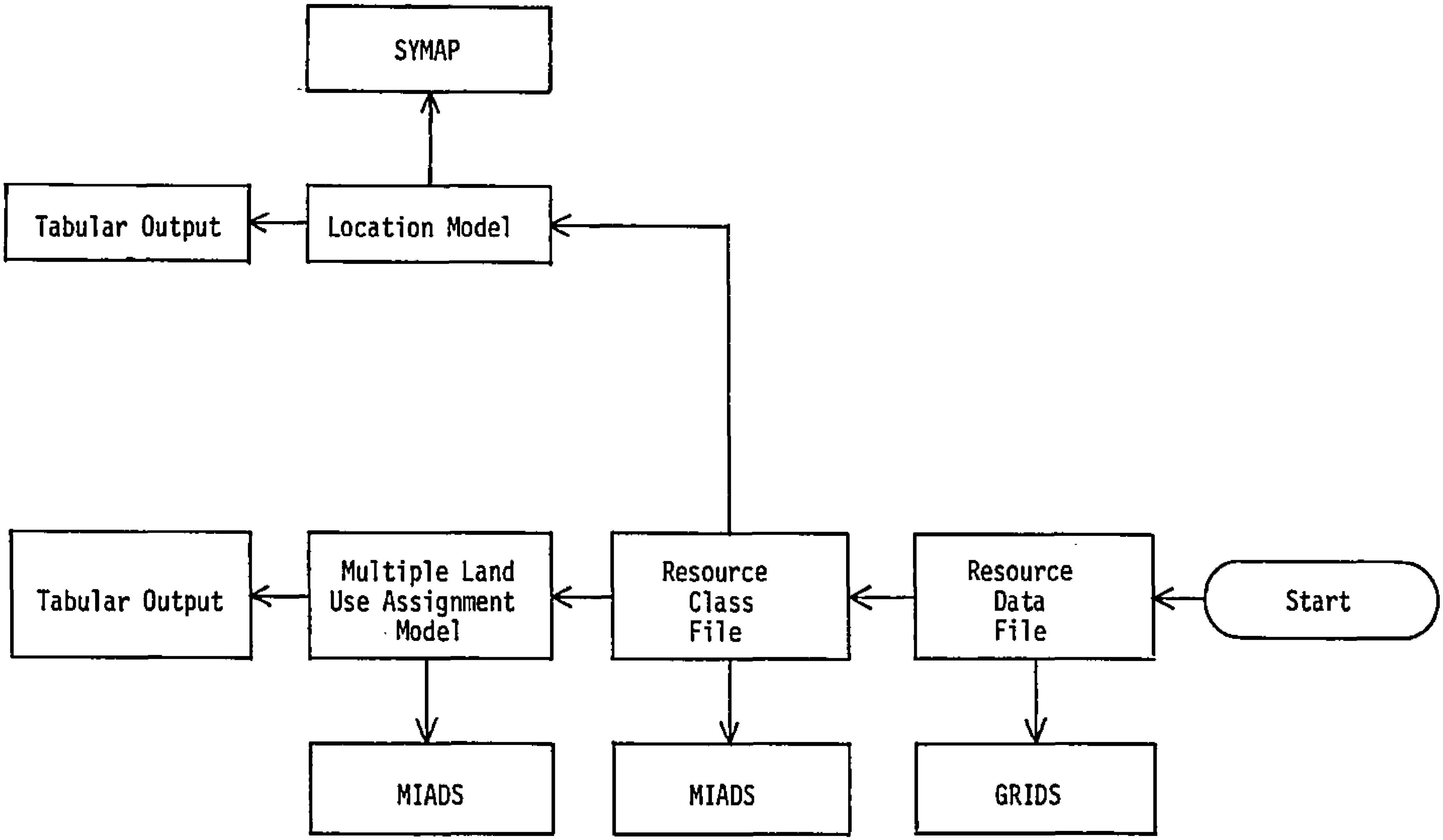


Figure 2-11.--Outputs from System Components.

Forms of relationships to calculate product coefficients and requirements are not being recommended in this study.

Land Inventory System

The classification of resources should be based on the landtype concept. A grid cell should be small enough to allow classification of only one resource class in the cell. Geographic referencing should be based on the Universe Mercator (UTM) system. Other systems are available and could easily be used. Existing storage technology and storage media should be adapted to the data needs of the problem. Recommendations for the structure of the record were made.

Constraint Generator

Flow charts of recommended algorithms were presented. The favored alternatives are based on the assumption that a grid cell is small enough to allow only one resource class. One flowchart assumes that the location of resource classes is determined prior to determining the location of the management strategy. Another assumes that the location of resource classes are not determined prior to determining the location of the management strategy.

Displays

Mapping routines are also recommended. Only printer routines operable on the MSU system were discussed. GRIDS is recommended for mapping resource data by grid cell. MIADS is recommended for mapping resource classes and the output produced by the multiple land use assignment model. SYMAP is recommended for any mapping based on regions or the river basin,that is, large areas with irregular boundaries.

CHAPTER III

MODEL TO BE TESTED AND DATA USED

The purpose of this chapter is to discuss the model to be tested and data to be used in testing the model.

As previously stated, the model is to have economic, ecologic, and spatial linkages. However, when dealing with forest resources time is also an important dimension. A number of years often pass between the application of cultural practices such as thinning, planting, or fertilization, and the production of merchantable timber. Growing timber is an investement process extending over many years. Time must be considered when planning forest resources.

The linear programming format will be retained in this study. Time will be incorporated through pseudo-dynamic linear programming since it is well suited to investment problems. With pseudo-dynamic linear programming, all costs incurred over time by each activity are discounted to the present. A planning period is specified for the analysis. Products and constraints at various points in time can be accounted for in different rows. A single tableau is constructed for the entire period of analysis. Time is an implicit variable because all costs are discounted to the present.

The objective function will be to minimize the present value of the sum of production costs (costs of management strategies) and transportation costs. Only forest land is being considered. Four products will be produced by the management strategies: merchantable timber, big game hunter days, small game hunter days, and erosion. Six time periods will be considered: 1966-1975, 1976-1985, 1986-1995, 1996-2005, 2006-2015, and 2016-2025. The management strategies produce quantities of each product in each time period. Coefficients for each product are averages for each time period. The river basin is divided into four regions. There are also eight regions outside of the basin which can supply or demand products. The outside regions can supply or demand timber and hunter days. Production of erosion can be constrained in the four regions contained in the river basin. Products can be transported between regions. Transport routes have been defined between each of the four regions in the river basin and from each of those to each of the eight outside regions.

The management strategy is a combination of land practices on an acre of land which generates a set of outputs. The combination of outputs, the timing of outputs, and the costs are affected by the land practices and the characteristics of the land resource. The forest resource is divided into classes. Each resource class is defined by one sub-division of each of the dimensions of forest ecosystem, soil group, stand size class, and stand condition. The subdivisions of the forest ecosystem dimension are: conifer, oak-hickory, maple-beech-birch, elm-ash-cottomwood, and aspen-birch. There are five soil groups: A,B,C,D, and E. There are four stand size classes: non-stocked, seedling-sapling, poletimber, and sawtimber. There are two stand condition classes: 1) adequate condition for the practice of intensive management and 2) timber stand improvement needed to practice intensive management. Intensive management involves investment in forest stands through the application of cultural practices to increase wood yields and economic returns. For example, one resource class may consist of the following classes of each dimension; ecosystem: oak-hickory; soil group: B; stand-size class: poletimber; stand condition: adequate.

The availability of data for the Kalamazoo River Basin is an important consideration. Soil associations are defined and mapped by the Soil Conservation Service. However, maps of soil series do not exist for the entire river basin. Acreages of forest ecosystems and stand size classes are estimated for four regions in the river basin by the Forest Service using Forest Survey data. Conditions of stands are also available from forest inventory data. Forest Survey data are collected using areal samples and maps have not been produced. Remote sensing data have been obtained from the Michigan State University remote sensing project. Forest land maps have been drawn. However, these data do not provide enough information to allocate management strategies to locations. The classes of forest land include: deciduous, coniferous, mixed, and brush. This is not enough detail for Forest Service management purposes. At the present time, the data base for forest land in the Kalamazoo River Basin cannot support a land information system based on grids smaller than a region. Other river basins may contain this type of information. In some National Forests in the Western U.S., even stand size classes are mapped. More precise spatial data will have to be collected if mapping is to take place on the Kalamazoo River Basin. Because of this scarcity of data, it is not possible to estimate the bias caused by forcing regions to conform to political boundaries. Data are available either on a region or county basis.

Structure of the Model to be Tested

Variables

Some variables are redefined from Chapter II and new variables are added.

$k = 1$ = timber

$k = 2$ = deer hunter days

$k = 3$ = small game hunter days

$k = 4$ = erosion

Input Variables:

h_{kjt} = amount of product k produced on land to be converted to urban use in region j and time period t.

M_{kjt} = cost of producing product k on land to be converted to urban use in region j and time t.

l_{kj} = supply of good k available to meet requirements in region j when all production of good k in the the river basin and the eight outside regions is consumed.

N_{kjt} = cost of meeting requirements for good k in region j in time t when all production in the river basin and the eight outside regions is consumed.

Output Variables:

H_{kjt} = amount of product k produced on lands to be converted to urban use in region j in time t.

L_{kjt} = extra supplies of product k brought in to meet requirements in region j and time t when all production in the river basin and eight outside regions is consumed.

Equations

Objective Function:

Minimize sum of total production costs, transportation costs, costs of bringing products produced on forest land to be converted to urban use into the river basin system, and costs of bringing in any extra supplies to meet final demands.

$$\text{Min} \sum_a \sum_r \sum_j K_{arj} X_{arj} + \sum_k \sum_i \sum_j \sum_t T_{kijt} X_{kijt} + \sum_k \sum_j \sum_t M_{kjt} H_{kjt} + \sum_k \sum_j \sum_t N_{kjt} L_{kjt} \qquad (30)$$

Constraints:

A) Each product is summed across all management strategies and resource classes in region 1 through 4 and can be shipped to any demand point where there is a demand for the product. Production of products on any land to be converted to urban use are accumulated during each time period for each region.

$$\sum_a \sum_r \delta_{akrjt} X_{arj} + H_{kjt} - \sum_i X_{kijt} = 0 \qquad (31)$$

for k = (1,2,3), j = (1,...,4), and all t.

B) Erosion is summed across all management strategies and resource classes in region 1 through 4. Production of erosion on lands to be converted to urban use are accumulated during each time period for each region.

$$\sum_a \sum_r \delta_{akrjt} X_{arj} + H_{kjt} - X_{kjt} = 0 \qquad (32)$$

for k = 1, j = (1,...,4), and all t

Environmental diffusion will not be considered in testing the model.

C) Projected demands at various points in the river basin must be met. A special variable is included to guarantee that demands are met by providing extra supplies once all production of a good in the river basin and all outside regions is consumed. These supplies are provided at a cost much higher than the cost of importing goods from the outside regions. When such a variable enters the solution it shows that the river basin production is not meeting demands.

$$\sum_j X_{kijt} + \sum_{j'} X_{kij't} + L_{kjt} \geq X_{kit} \tag{33}$$

for k = (1,2,3), all i, and all t

Products can be imported to the river basin from outside the river basin to meet demands in the river basin.

D) Demand points outside of the river basin with a negative excess supply for a product will have a capacity to absorb excess production in the river basin. They cannot buy infinite amounts, however. Their demands do not have to be satisfied by river basin production.

$$\sum_j X_{kijt} \leq X_{ki't} \tag{14}$$

for k = (1,2,3), all i' with a negative excess supply, and over all t

E) There is also a limit on the amount of goods that regions outside of the river basin can export to meet river basin demands. These regions will have positive excess supplies for a given product.

$$\sum_i X_{kij't} \leq X_{kj't} \tag{15}$$

for k = (1,2.3), all j' with a positive excess supply, and all t

F) Requirements for the production of timber in the river basin regions will be made in some runs of the model. These requirements will be OBERS demands. These requirements are not assigned to a specific demand point.

$$\sum_i X_{kijt} \geq X_{kjt} \tag{16}$$

for k = 1, j = (1,...,4), and t = (1,3,6)

G) There are resource limitations to production on each resource class in each region.

$$\sum_{a} X_{arj} \leq X_{rj} \qquad (34)$$

for all r and j

H) The following equation set requires that all goods produced on forest lands which will be converted to urban use or on forest lands which are managed intensively at the present be brought into the system to satisfy requirements.

$$H_{kjt} = h_{kjt} \qquad (35)$$

for all k, j = (1,...,4), and all t

I) The amounts of products that can be purchased to meet requirements in the river basin if production cannot meet these products is limited in the following equation.

$$\sum_{t} L_{kjt} \leq l_{kj} \qquad (36)$$

for k = (1,2,3), and j = (1,...,4)

J) Costs of transferring products from supply areas to meet demands are summed at demand points.

$$\sum_{j} \sum_{k} T_{kijt} X_{kijt} - C_{it} = 0 \qquad (18)$$

for all i and t

C_{it} has an objective function value of 0.

K) Costs of transferring products to demand points are summed at each supply point.

$$\sum_{i} \sum_{k} T_{kijt} X_{kijt} - C_{jt} = 0 \qquad (19)$$

for all j and t

C_{jt} has an objective function value of 0.

L) Other constraints on land use by location can be put in the model by using this general form:

$$X_{arj} \leq Z_{arj} \qquad (20)$$

Greater than or equal to constraints or equal to constraints could also be inserted.

All activities are subject to non-negativity constraints since no activity can have a negative value.

Calculating Requirements for Roundwood

Pulpwood

There appear to be two demand points for pulpwood produced in the Kalamazoo River Basin: 1) The Warren Company in Muskegon, Michigan, and 2) The Menasha Corporation in Otsego, Michigan. The Menasha Corporation is in region 2 of the Kalamazoo River Basin. The yearly consumption of pulpwood by each plant is not published or made available by the plants. However, Lockwood's Directory of the Paper and Allied Trades has published an average daily consumption of pulpwood for some plants in Michigan. The figures published for the Warren Company are 430 cords per day and for the Menasha Corporation are 150 cords per day (Lockwood's Directory of the Paper and Allied Trades, 1970).

These daily consumption figures are not published for all plants in Michigan, but they are published for all plants in the Lower Peninsula of Michigan. Pulpwood production in the Lower Peninsula was allocated among pulpmills in the Lower Peninsula. The decision to do this based on two assumptions; 1) The proportion of total Lower Peninsula production purchased by each plant each year is constant, and 2) The Lower Peninsula is self-sufficient in pulpwood production, that is, there are no imports or exports. The second assumption is supported by U.S. Forest Service figures. Most exports have gone to Wisconsin and most imports have come from Canada in the past 24 years (Blythe, Boelter, and Danielson, 1975). It is being assumed that most of the exports and imports are occurring in the Upper Peninsula. Also, little pulpwood is hauled between the Upper and Lower Peninsulas due to tolls on the Mackinac Bridge (Leushner, 1972).

The average daily pulpwood purchase figures for each plant in the Lower Peninsula were found in Lockwood's directory and summed to 1730 cords per day (Lockwood's Directory of Paper and the Allied Trades, 1970). A ratio was calculated for each plant by dividing its daily consumption by 1730. The fraction of total Lower Peninsula pulpwood consumption is 0.249 for the Warren Company and 0.087 for the Menasha Corporation. The yearly production of pulpwood in the Lower Peninsula was obtained from Michigan Pulpwood Production printed each year by the Michigan Department of Natural Resources (DNR). A time series of purchases by the two plants was generated by multiplying annual pulpwood production in the Lower Peninsula by the fraction of total Lower Peninsula pulpwood production for each plant. A seven year average was calculated to estimate present requirements. Each of these seven years is included in the first time period. The estimates were converted from cords to cubic feet. Table 3-1 presents the seven-year time series and the average for the Lower Peninsula, the Warren Company, and the Menasha Corporation.

Sawlogs and Veneer Logs

Requirements for roundwood for the four regions in the river basin were based on 1972 consumption levels. 1972 estimates were chosen rather

Table 3-1.--Estimated Pulpwood Consumption by the Menasha Corporation and the Warren Company in Time Period 1.

Year	Lower Peninsula (Ccf)	Warren Co. (Ccf)	Menasha Corp. (Ccf)
1966	519,771	129,423	45,220
1967	400,303	99,676	34,826
1969	461,334	114,872	40,136
1970	488,493	121,635	42,499
1971	476,703	118,699	41,473
1972	499,502	124,376	43,457
1973	506,915	126,222	44,102
	seven year average	119,271	41,673

Source: Forestry Division, Michigan DNR, Michigan Pulpwood Production.

than averages to eliminate the effects of new plants entering business and other plants going out of business. It seems that the most recent consumption rates would be the best indicator of requirements since few plants are likely to leave or enter in a short period of time. Figures to calculate consumption in 1972 have been recorded by the U.S. Forest Service. Production of lumber or purchases of sawlogs were not recorded at the county or region level. However, residuals produced were recorded in Table 27 of Primary Forest Products Industry and Timber Use, Michigan, 1972 (Blyth, Boelter, and Danielson, 1975). A constant was calculated to estimate roundwood purchased from residuals produced. Total Michigan receipts of hardwood and softwood roundwood are found in Table 4 of the same report. Total wood and bark residues produced in Michigan, excluding residues from pulpwood, came from Table 27. Roundwood receipts, excluding pulpwood, were divided by total wood and bark residues, excluding pulpwood residues. The constants are 1.65 for hardwoods and 2.10 for softwoods. The units are cubic feet of purchases per cubic feet of residues. These constants were asumed to hold for all acreas of the state, all processes, and all species. Roundwood purchases for each county, excluding pulpwood, were calculated by multiplying hardwood and softwood residues produced in each county by the appropriate constant. County production data are found in Appendix B.

The figures for each region were then calculated from the county figures. This was done by estimating the lumber producing capacities of each region. The Forestry Division of the Michigan DNR inventories mills by county and lists their mailing addresses (Forestry Division, Michigan DNR, 1974). The mailing addresses were used in conjunction with county maps to place the mills into regions. Sawmills are classfied into size classes in terms of annual lumber production (thousand board feet). Other primary wood-using plants are not classified this way. The high production figure of the range for each plant was used to sum the maximum lumber production for each county. The same was done for each portion of the county allocated to each region. A fraction of lumber production allocated to each region from each county was calculated by dividing the lumber production allocated to each region from the county by the total county production. These fractions are recorded in Appendix C. Roundwood purchases were allocated to regions by multiplying total county roundwood purchases by the fraction of county lumber production occurring in each region. This assumes that roundwood purchases are directly related to lumber production. Purchases of roundwood allocated to each region were summed by region to estimate regional roundwood purchases. Weaknesses of this method include: 1) The ranges of lumber production in a given class are wide which means the estimates of lumber production allocated to a given region are not very precise, and 2) Roundwood using plants other than sawmills do not have size classes so they are not included in the calculations of the fractions thereby causing biased estimates.

Requirements for sawlogs and veneer logs in regions outside of the river basin were calculated by averaging estimated purchases in 1972, 1969, and 1965. The average was chosen because these demands were to be used in calculating the difference between production of roundwood and purchases by mills in the region, that is, an excess supply of roundwood by region. It was felt that local production would respond to local demand, so that the effects of plants leaving and entering business would not hurt the estimates of excess supply. The 1972 figures were calculated using the same method as that used for figures for regions in the river basin. The figures on residuals were not available for 1965 and 1969. However, in 1965 and 1969, the Michigan DNR collected figures on lumber production by county in thousand board feet (Forestry Division, Michigan DNR, 1969, and Forestry Division, Michigan DNR, 1965). This was converted to an estimate of hundred cubic feet of roundwood purchased by multiplying lumber production by 1.667. These county estimates are in Appendix B. These county estimates were aggregated into regions in the same way in which the 1972 figures were. The 1965 and 1969 estimates are biased in that they leave out veneer production. The estimates of consumption in 1965, 1969, and 1972 were averaged to estimate present requirements and veneer logs. Table 3-2 contains requirements for sawlogs and veneer logs by region for time period 1.

Projecting Roundwood Requirements Into the Future

Making future projections is always a difficult task. Assumptions must be made. In this study, several alternative sets of assumptions will be made. Future projections are based on projections made in the

Table 3-2.--Requirements for Sawlogs and Veneer Logs by Region in Time Period 1.

Region	Quantity (Mcf)
1	872
2	828
3	201
4	227
5	913
6	1455
7	3198
8	542
9	1125
10	859
11	2103
12	671

Outlook for Timber in the United States (Forest Service, USDA, 1973). The Forest Service projections were based on assumptions concerning how relative prices behave in the future. The Forest Service assumed three levels of population growth and growth of economic activity with three sets of price assumptions for each. All projections in this study will be based on medium level projections of population growth and economic activity.[1] The two sets of price assumptions to be used in this study are 1970 relative prices and rising relative wood prices.[2] The study makes projections only for 1980, 1990, and 2000. The last two time

[1]The medium level assumes that population in the U.S. rises to 281 million in the year 2000. GNP rises at a rate of 4.0% per year. Labor productivity increases at a rate of 3.4% per year. Technological changes that appear likely in the various timber using sectors have been accounted for.

[2]With rising relative prices, the prices of wood products increase faster than the 1970 rate. Lumber increases at a rate of 1.5% per year faster than 1970 prices; plywood, miscellaneous products, and fuelwood increase at a rate of 1% per year, and paper and board increase at a rate of 0.5% per year.

periods must also be accounted for. It is assumed that the rates of population and economic growth will continue through time periods 5 and 6.

The levels of demand for sawlogs, veneer logs, and pulpwood were calculated. First, relative levels of demand were calculated by dividing projected quantities demanded for 1980, 1990, and 2000 by the quantities demanded in 1970. These trends were then projected to 2010 and 2020. Not all the projections by the Forest Service are straight line projections from 1970 to 2000. To account for the curvilinear nature of the trends, the first order rate of change of demand per year was calculated from 1970 to 1980, 1980 to 1990, and 1990 to 2000 (Δ demand/Δ time). A straight line was then fitted to these points using least squares regression. The rate of change for each time period was then estimated from the trend line. This first derivative trend line was then integrated to estimate the relative levels of demand for each time period. These relative levels were then multiplied by the 1970 levels of consumption of each commodity in each region to get estimated absolute levels of consumption. Under these assumptions, each region behaves the same as the nation. Regional advantages and disadvantages are not taken into account. Appendix D shows the relative levels of demand and Appendix E shows the absolute levels of demand for each product. Requirements for each product in each region were then summed to get total roundwood requirements. Appendix F shows these requirements. The requirements are in cubic feet per year. It is assumed that these are average figures for each ten-year time period.

Roundwood Production Outside of the River Basin Available for Use in the River Basin

Pulpwood

County figures on pulpwood production were obtained from annual data put out by the Michigan DNR (Forestry Division, Michigan DNR). Some years are skipped, however. Only oak, birch, aspen, and other hardwoods were summed since these are species used by the Menasha Corporation, the only pulpmill in the river basin. The harvest of these species was summed to get county production of pulpwood. Data on pulpwood production was obtained from 1966 to 1973.

County production was allocated to regions. It was assumed that the timber resource is distributed uniformly over the counties. The percentage of a county in a region was found. For the most part, regions outside of the river basin follow county lines. However, some counties are divided into areas inside and outside of the river basin. The proportion of each county's acreage in the river basin was obtained from the Soil Conservation Service. This acreage was subtracted from total county acreage to obtain the acreage of the county outside of the river basin (Michigan State University, Cooperative Extension Service, 1973). The acreage of a county in a particular region was divided by total county acreage to get the portion of the county in the region. These proportions are in Appendix G. County pulpwood production was multiplied by this ratio to estimate pulpwood production of that portion of the county in a particular region. Estimates of county pulpwood production allocated to regions were summed over the region to calculate the regional pulpwood production.

These estimates were made for each region for each year. A seven year average for those years in time period 1 was computed for each region. Table 3-3 contains the estimates of pulpwood production for each region outside of the river basin in time period 1.

Table 3-3.--Estimates of Pulpwood Production in Outside Regions.

Region	Average pulpwood production (Ccf)
5	2461
6	210
7	295
8	117
9	181
10	0
11	50,195

Source: Forestry Division, Michigan DNR, Michigan Pulpwood Production.

Sawlogs

Sawlog production is not recorded annually. The years 1972, 1969, and 1965 were chosen because these were years in which purchases of sawlogs by mills in a county could be estimated. The 1972 data by county were found in Table 15 of Primary Forest Products Industry and Timber Use, Michigan, 1972 (Blythe, Boelter, and Danielson, 1975). The 1969 data were found in Michigan Commercial Sawlog, Veneer Log, and Lumber Production, 1965 (Forestry Division, Michigan DNR, 1969). The 1965 data were found in Michigan Sawlog and Lumber Production, 1965 (Forestry Division, Michigan DNR, 1965). These figures were tabulated for each county of interest and each year. The counties' sawlog production was allocated to regions by the same method used to allocate pulpwood production to regions. An average of the three years was calculated for each region to be used as an estimate of sawlog production. Table 3-4 contains the sawlog production by region.

Table 3-4.--Estimated Sawlog Production in Outside Regions.

Region	Production (Mcf)
5	726
6	1051
7	2400
8	799
9	1105
10	1291
11	2822
12	1534

Sources: Blyth, Boelter, and Danielson, Primary Forest Products Industry and Timber Use, 1972, Forestry Division, Michigan DNR, Michigan Commercial Sawlog, Veneer Log, and Lumber Production, 1965, and Forestry Division, Michigan DNR, Michigan Sawlog and Lumber Production, 1965.

Veneer Logs

Data on veneer log production by county is available only for 1972 and 1969. The data for 1972 were obtained from Table 21 of Primary Forest Products Industry and Timber Use, Michigan, 1972 (Blyth, Boelter, and Danielson, 1975). The 1969 data were obtained from Michigan Commercial Sawlog, Veneer Log and Lumber Production (Forestry Division, Michigan DNR, 1969). These data were tabulated by county and allocated to regions in the same way as sawlogs and pulpwood. Appendix I contains veneer log production. Units were converted from board feet to cubic feet. An average of the production for two years was calculated for each region and used to estimate the veneer log production for the present. Table 3-5 contains the estimates of veneer log production.

Table 3-5.--Estimated Veneer Log Production in Outside Regions.

Region	Veneer Log Production (Mcf)
5	15
6	18
7	67
8	86
9	24
10	32
11	45
12	12

Source: Blythe, Boelter, and Danielson, Primary Forest Products Industry and Timber Use, 1972, and Forestry Division, Michigan DNR, Michigan Commercial Sawlog, Veneer Log, and Lumber Production.

Excess Supply

Estimated requirements for roundwood purchased by mills in regions outside of the river basin were subtracted from the estimated production of roundwood to calculate an excess supply of roundwood available for use in the river basin. When excess supply is negative, the region can accept roundwood produced in the basin. When excess supply is positive, the region makes roundwood available to the river basin. Sawlogs and veneer logs were summed since requirements for the two could not be separated. For pulpwood, all the excess supplies are in terms of roundwood available to the Menasha Corporation.

Excess supplies for all regions outside of the river basin for different price assumptions are found in Appendix J.

Calculating Requirements for Hunterdays

Deer

Requirements for hunter days by region were calculated by using the following formula:

$$\text{regional population} \times \frac{\text{hunters}}{\text{person}} \times \frac{\text{hunter days}}{\text{hunter}} = \text{hunter days for the region}$$

It is assumed that hunter days per hunter equals four (Jordan and Baker, 1973). The number of hunters per person was calculated by finding the average number of hunters from 1963 to 1972 in a Michigan DNR zone and dividing this average by the population of the zone (Ryel, 1974). All Michigan DNR zones follow county lines so that population figures based on the 1970 census are readily available (Michigan State University, Cooperative Extension Service, 1973). It is assumed that hunters in these regions are local, that is, they live in the region. Any long distance travelling is assumed to be going to the northern half of the Lower Peninsula. Table 3-6 contains the number of hunters per person and hunter days per person for each of the Michigan DNR zones that affect the river basin area.

Table 3-6.--Hunters per Person, Hunterdays per Hunter, and Hunterdays per Person for Each DNR Zone.

Zone	Hunters/Person	Hunterdays/Hunter	Hunterdays/Person
13	.028	4	.112
14	.035	4	.140
17	.031	4	.124
18	.039	4	.156

Source: Ryel, The 1973 Deer Seasons.

The population of regions inside the river basin were calculated by the Economic Research Service. These figures are illustrated in Table 1-2 on page 10 in Chapter I. Figures for population in regions outside of the river basin were calculated and are illustrated in Table 1-5 on page 12 in Chapter I. The requirements for hunterdays were obtained by multiplying population times hunter days per person for each portion of each county in each region. These requirements were then summed to obtain requirements for regions. Appendix K contains the requirements for hunterdays by county and region. Table 3-7 gives the requirements for deer hunterdays by region in time period 1. These requirements are an average for each year in the ten year period.

Table 3-7.--Requirements for Deer Hunterdays in Each Region in Time Period 1.

Region	Hunterdays
1	19,958
2	36,537
3	11,634
4	11,524
5	25,842
6	46,037
7	23,418
8	25,832
9	22,587
10	52,771

Small Game

The same formula for calculating deer hunterdays was used to calculate small game hunterdays. Small game includes squirrels and cottontails. The number of hunters per person was calculated by averaging the number of hunters for cottontails and squirrels from 1963 to 1973 in DNR Region III and dividing by the population of DNR Region III (Hawn, 1974). The number of hunterdays per hunter was recorded by the Michigan DNR for the state (Hawn, 1974). It is assumed that these figures would hold for hunters in Michigan DNR Region III. Hunters per person was multiplied by hunterdays per hunter to get hunterdays per person as shown in the following formula:

$$\text{hunters per person} \times \frac{\text{hunterdays}}{\text{hunter}} = \text{hunterdays per person}$$

Table 3-8 shows these figures.

Table 3-8.--Hunters per Person, Hunterdays per Hunter, and Hunterdays per Person by Species.

Species	hunters/person	hunterdays/hunter	hunterdays/person
Squirrel	0.021	6.8	0.143
Cottontail	0.030	10.1	0.303

Source: Hawn, Michigan Small Game Kill Estimates, 1973.

Requirements for squirrel and cottontail hunterdays were calculated in the same way as deer hunter days. Population was calculated for each region as stated previously. Requirements for hunterdays for both species were found for each part of each county in each region by multiplying population times hunterdays per person. The requirements were then summed by region to get requirements by region. Table 3-9 contains the requirements for hunterdays by region.

Projecting Future Requirements for Hunterdays

Requirements for hunterdays must be projected for future time periods. Hunterdays per person and hunterdays per hunter were assumed to remain constant over all time periods. Requirements for hunterdays, then, increase at the same rate as population. The Economic Research Service projected population for the river basin. It is assumed that the population of the regions increases at the same rate. Population projections were made for 1990 and 2020. Population was assumed to in-

Table 3-9.--Requirements for Small Game Hunterdays by Region in Time Period 1.

Region	Small Game Hunterdays
1	70,735
2	104,227
3	33,186
4	39,439
5	102,678
6	182,915
7	77,209
8	73,685
9	72,278
10	174,393

crease linearly between the present and 1990 and between 1990 and 2020. Multipliers were calculated for each time period. The hunterdays required for each region in time period 1 were multiplied by the multiplier in each time period to get the requirements for that time period. Appendix L includes the requirements for deer and small game hunterdays for each region and time period. Table 3-10 contains the multipliers for each time period.

Table 3-10.--Population Multipliers for Each Time Period.

Time Period	Multiplier
1	1.00
2	1.10
3	1.20
4	1.27
5	1.34
6	1.41

Source: Economic Research Service, Unpublished Data, 1974.

Supplies of Hunterdays in Regions Outside of the River Basin

The supplies of hunterdays were estimated for cottontails, squirrels, and deer by using the following formula:

$$\text{regional game kill} \times \frac{\text{hunter}}{\text{kill}} \times \frac{\text{hunterdays}}{\text{hunter}} = \text{hunterdays}$$

Deer

The average buck kill per square mile figures for 1963 to 1972 for Michigan DNR Region III zones 13, 14, 17, and 18 were taken from Michigan DNR figures (Ryel, 1974). There were 0.5 bucks killed per square mile for zones 14, 17, and 18 and 0.7 bucks killed per square mile for zone 13. These figures were assumed to be valid for estimating deer kills for each region outside of the river basin. The DNR zones are groups of counties. The kill per square mile figures were not available for counties. Deer habitat is assumed to be homogeneously distributed over the DNR zones. These kill figures per square mile were converted to kills per acre. For does, the kill from 1968 to 1973 for Michigan DNR region III was averaged and divided by acreage of Region III to get the doe kill per acre. The doe kill estimates are probably less reliable than the buck kill figures for two reasons: 1) The doe figures are calculated for a larger area than the buck figures, and 2) The doe season is highly controversial and it is difficult to know how many doe permits will be issued in any given year. Table 3-11 illustrates the kill per acre for bucks and does.

These kill per acre figures were multiplied by the acreage of a county in a region to estimate the kills in that portion of the county in the region. The appropriate zone was chosen for each county. Appendix M contains the kill per county in each region.

Table 3-11.--Deer Kills per Acre.

Sex and Region	Kill per Acre
Does in 13,14,17,18	0.000234
Bucks in 14,17,18	0.000781
Bucks in 13	0.001093

Source: Ryel, The 1973 Deer Seasons.

The number of hunters per kill was the reciprocal of the average kill per hunter. The average kill per hunter was found by averaging the success rates of deer hunters from 1968 to 1973 in Michigan DNR Region III. The number of hunters per kill is 9.34 (1/0.107) (Ryel, 1974). It is assumed that hunters are satisfied with this rate of success and will continue to hunt. The number of hunterdays per hunter is assumed to be four (Jordan and Baker, 1973). The number of hunterdays per kill is 4/0.107 or 37.4. The number of hunterdays supplied by each county in each region was computed using the following formula:

$$\frac{\text{hunterdays}}{\text{county}} = \frac{\text{kill}}{\text{county}} \times 37.4$$

These county figures were then summed by region to estimate the supply of hunter days by region outside of the river basin. Appendix N shows the hunterdays supplied by each county in each basin. Table 3-12 shows the supply of hunterdays in regions outside of the river basin.

Small Game

Small game kills by each county in each region were calculated. The kills for cottontails and squirrels from 1969 to 1973 in Michigan DNR Region III were averaged (Hawn, 1974). The average kill was divided by the acreage of Michigan DNR Region III to estimate kill per acre.

Table 3-12.--Supplies of Hunterdays in Regions Outside of the River Basin.

Region	Supply of Deer Hunterdays
5	30,257
6	25,095
7	51,732
8	25,282
9	48,845
10	26,430

Table 3-13 shows these estimates.

Table 3-13.--Small Game Kills per Acre in DNR Region III.

Species	Kill per Acre
Cottontail	0.068
Squirrel	0.043

Source: Hawn, Michigan Small Game Kill Estimates, 1973.

The kill per acre was multiplied by the acreage of the region to get kill per region. An even distribution of game habitat in DNR Region III is assumed. Appendix N contains the game kills for each region.

The number of hunters per kill was the reciprocal of kill per hunter. The number of hunterdays per hunter was also found for each species (Hawn, 1974). Both of these figures were found for 1973 and were assumed to be representative for projection purposes. The number of hunterdays per kill was estimated by multiplying hunters per kill by hunterdays per hunter. Table 3-14 contains hunters per kill, hunterdays per hunter, and hunterdays per kill for each species.

Table 3-14.--Estimates of Hunters per Kill, Hunterdays per Hunter, and Hunterdays per Kill for Each Small Game Species.

Species	Hunters/Kill	Hunterdays/Hunter	Hunterdays/Kill
Cottontail	1/5.6	10.1	1.8
Squirrel	1/4.4	6.82	1.55

Source: Hawn, Michigan Small Game Kill Estimates.

The number of hunterdays supplied by each region was computed by multiplying kill per region by hunterdays per kill to get hunterdays per region. Table 3-15 shows estimates of hunterdays supplied by each region outside of the region.

Table 3-15.--Estimates of Small Game Hunterdays Supplied by Regions Outside of the River Basin.

Region	Squirrel Hunterdays	Cottontail Hunterdays	Total
5	40,714	74,771	115,485
6	37,025	67,995	105,020
7	83,295	152,970	236,265
8	44,403	81,543	125,946
9	85,819	157,600	243,419
10	47,261	86,793	134,054

Excess Supplies of Hunterdays

Excess supplies were calculated for hunterdays to estimate the amount that might be available to the river basin from regions outside of the river basin. Excess supply was calculated for big and small game hunterdays for each time period by subtracting each region's requirements from its supply in each time period. Small game hunterday requirements were calculated by summing the requirements for squirrel and cottontail hunterday requirements. The supply of hunterdays was assumed constant for each time period. Requirements for small game hunterdays were projected by using the population multipliers that were used to project big game hunterdays. Appendix L contains the requirements for each time period and region. When excess supply is negative, the region can consume surpluses of hunterdays produced by the river basin. When excess supply is positive, the quantity is available to the river basin. Appendix O contains the excess supplies of big and small game hunterdays available in each region.

Defining Regions

Regions have been defined to account for spatial differentiation of the economy and of land resources. Figure 1-1 on page 7 in Chapter I outlines the regions. Regions 1 through 4 are identical to regions defined by the Economic Research Service and make up the river basin. Regions 5 through 12 are outside of the river basin. These regions can supply goods to the river basin and can purchase goods produced in the river basin. An attempt was made to approximate a square when defining a region while following county lines and river basin boundaries. The river basin was surrounded with regions. These regions include what appear to be important supply and demand areas for goods produced in the region. Regions 5 through 10 can supply and demand timber, deer hunter days, and small game hunter days. Regions 11 and 12 were defined specifically to supply roundwood to the Menasha Corporation. These two regions supply only timber. The Menasha Corporation purchases large quantities of timber in region 11. Region 12 was added because it was almost surrounded by regions 6, 7, and 11. Representative demand points were defined in these regions. In regions 1 through 4, demand points were defined near the center of the region close to the junction of two major highways. The regions and the representative demand points are listed in Table 3-16.

Table 3-16.--Representative Demand Points in the River Basin.

Region	Demand Point	Junction
1	Marshall	I69,I94
2	Plainwell	US131,M89
3	Paw Paw	M40,I94
4	Holland	US31,M43

The irregular shape of region 4 presents problems. Most of the population and demanders of wood products are situated near Holland at the north end of the region. However, when goods are supplied to regions outside of the region outside of region 4, they will follow a route from a supply point located at South Haven, situated near the geographic center of the southern portion of region 4.

Representative demand points are also defined for regions outside of the river basin. These demand points are located at cities which are relatively large demanders of roundwood for the regions. These demand points for roundwood are assumed to be representative demand points for hunterdays. These demand points are located as close to the junction of two major highways where possible. These representative points are listed in Table 3-17. Regions 11 and 12 are net exporters of timber so that a demand point was not defined for either region.

Calculating Transfer Costs

General Concepts

Transfer costs are the costs of overcoming the barrier of dis-

Table 3-17.--Representative Demand Points for Regions Outside of the River Basin.

Region	Demand Point	Junction
5	Muskegon	I69,US131
6	Sparta	on M37
7	Portland	on I96
8	Cassopolis	M60,M62
9	Union City	on M60
10	Mason	US127,M36

tance between the location of production and the location of the consumer. Timber is transferred from a forest resource assumed to be distributed evenly over the region to demand points that process roundwood which may be in the region or other regions. Hunterdays are consumed at the site of production. Hunters travel from points of population concentration to the forest resource, again assumed to be evenly over the region. Timber is hauled by truck while hunters travel in automobiles. All travel is over highways. Conversations with the U.S. Forest Service personnel at Cadillac, Michigan, indicate that most roundwood is hauled to the mill by truck.

Defining Transport Routes

Transportation Between Regions:

Routes of travel are chosen to link supply areas to demand points. Each route extends from the demand point to the edge of the supply area, where it links into the transportation network of the supply area. The roads chosen were fastest or the shortest routes between two points. There were several classes of roads defined for travel between regions: 1) interstate, 2) U.S. highway, 3) state highway, four lane, and 4) state highway, two lane. Wherever possible, interstate or other four lane highways were chosen. The area is well knit with such roads.

Transportation routes were plotted between each supply area and demand point in the river basin and between each demand point and supply area in the river basin and demand points and supply areas outside of the river basin. Each route was numbered and coded. Appendix P contains all of the transportation routes. Two routes are required whenever goods are required to be moved two ways between regions. In total, 68 such transportation routes were defined. The mileage was calculated by measuring the distance of each road on a route on county maps with a map-measuring wheel. The length in inches was then converted to mileage.

Transportation Between Regions:

The transportation system in each region was divided into classes. Report No. 162 of the Michigan Highway Department of State Highways and Transportation contains in Table 2-3 the mileage of various classes of highways by county (Michigan Department of State Highways and Transportation, 1975). These classes do not correspond to classes of highways defined by the U.S. Forest Service. U.S. Forest Service classes of roads are based on travel speeds. The State of Michigan classifies roads on the basis of surface materials and condition of surface. Classes of surface materials include: 1) mixed bituminous surface on concrete or brick, 2) concrete or brick, 3) mixed bituminous surface on gravel, 4) bituminous surface treated gravel, 5) gravel and similar materials, 6) graded and drained earth, 7) graded and drained earth, and 8) unimproved earth. Conditions of the road surface include: 1) adequate for use by expected traffic, and 2) inadequate for use by expected traffic. Traffic speeds are assumed to be higher on hard surface roads, which are concrete, brick, and bituminous surfaces, than on gravel roads. The travel speeds on gravel roads are, in turn, assumed to be greater than those on unimproved earth roads. Travel speeds are assumed to be greater on adequate condition roads than on inadequate condition roads for any type of road surface. Classes of State highways which are based on road surface material and surface conditions were allocated among U.S. Forest Service classes of highways which are based on travel speeds as follows:

Forest Service Classes	State Highway Classes
High-Speed:	concrete or brick--adequate, mixed bituminous surface on concrete or brick--adequate, mixed bituminous surface on gravel--adequate, bituminous surface treated gravel--adequate.
1:	concrete or brick--inadequate, mixed bituminous surface on concrete or brick--inadequate, mixed bituminous surface on gravel--inadequate, bituminous surface treated gravel--inadequate.
2:	gravel--adequate, graded and drained earth--adequate.
3:	gravel--inadequate, graded and drained earth--inadequate.
4:	unimproved earth.
5:	private logging road. No mileage is recorded for this class.

The high-speed class was further broken down into three sub-classes:

Transportation Network: Each region is criss-crossed with a north-south road and an east-west road that intercept roads between regions.

Trunkline Roads: This mileage is found in Report No. 162, Table 2-1, the mileage of the transportation network was subtracted since the transportation network is made up of trunkline highways.

Non-Trunk Highways: Residual of High-Speed Class.

Mileages of each class were then allocated to regions. The transportation system was assumed to be evenly distributed over the county. The proprotion of the area of a county in a region was multiplied by the mileage in each class to compute the mileage of each class allocated to a region. The mileage from each county allocated to each region was summed to get the mileage of each class in each region.

The mileage figures by each class were tabulated in order to compute an average of the number of miles travelled on each class of road to reach the transportation network. The following formula developed by Hamilton was used to compute the average mileage travelled on each class of highway (Wynd and Manthy, 1971):

$$X_i = \frac{1}{M_{i=1}} - \sum_{j=0}^{n-i-1} X_{n-j}; \; i=n,\ n-1,\ n-2, \ldots, 1$$

X_i = miles travelled on class i

i = class of highway = 1,...,n

n = total number of classes = 8

X_{n-j} = miles travelled on class n-j; X_{n-j} = 0, when i=n=8

M_{i-1} = accumulated miles of road per square mile for all roads in classes higher than that under consideration.

To calculate M_{i-1}, the miles of each class of highway in a region was divided by the region's area in square miles to compute miles in each class per square mile. The accumulated miles per square mile for class is the sum of the miles of each class from 1 to i where class 1 is the transportation net work and class n is private logging roads, that is:

$$M_i = \sum_{k=1}^{i} m_k$$

m_k = miles per square mile of class k

X_i cannot be calculated for class 1, that is, the transportation network, since no M_{i-1} is available. However, an average mileage travelled is computed for each class including private logging roads. Appendix Q lists the mileage travelled on each class of road.

Estimating the distances travelled on the transportation network presents a bit of a problem. The region is assumed to be a square with the forest resource distributed evenly over the region. There is a north-south, east-west transportation network which intersects the demand node at the center of the region. See Figure 3-1.

Hamilton's formula calculates the average distance travelled to reach the transportation network. Given the uniform distribution of the forest resource, once timber reaches the route to the demand point, it will be uniformly distributed along that route. The average distance travelled to leave the region, that is, to link up to a route going to an outside demand point, will be distance a in Figure 3-1 which is one-fourth of the total mileage of the transportation network. To compute the average distance travelled to leave the region, the total mileage of the transportation network is divided by four. Appendix Q contains this information for each region.

The average distance to the demand node in the region is found by finding a square containing one-half of the forest resource with the demand node as a center. This is square HIJK in Figure 3-1. Distance d is the average distance travelled to reach the demand node in the region. One-half of the forest resource is inside square HIJK while one-half is outside. The distance is now derived.

By definition: $d = 1/2\ e$

The area of HIJK is: $A_1 = e^2$

A_1 = area of HIJK

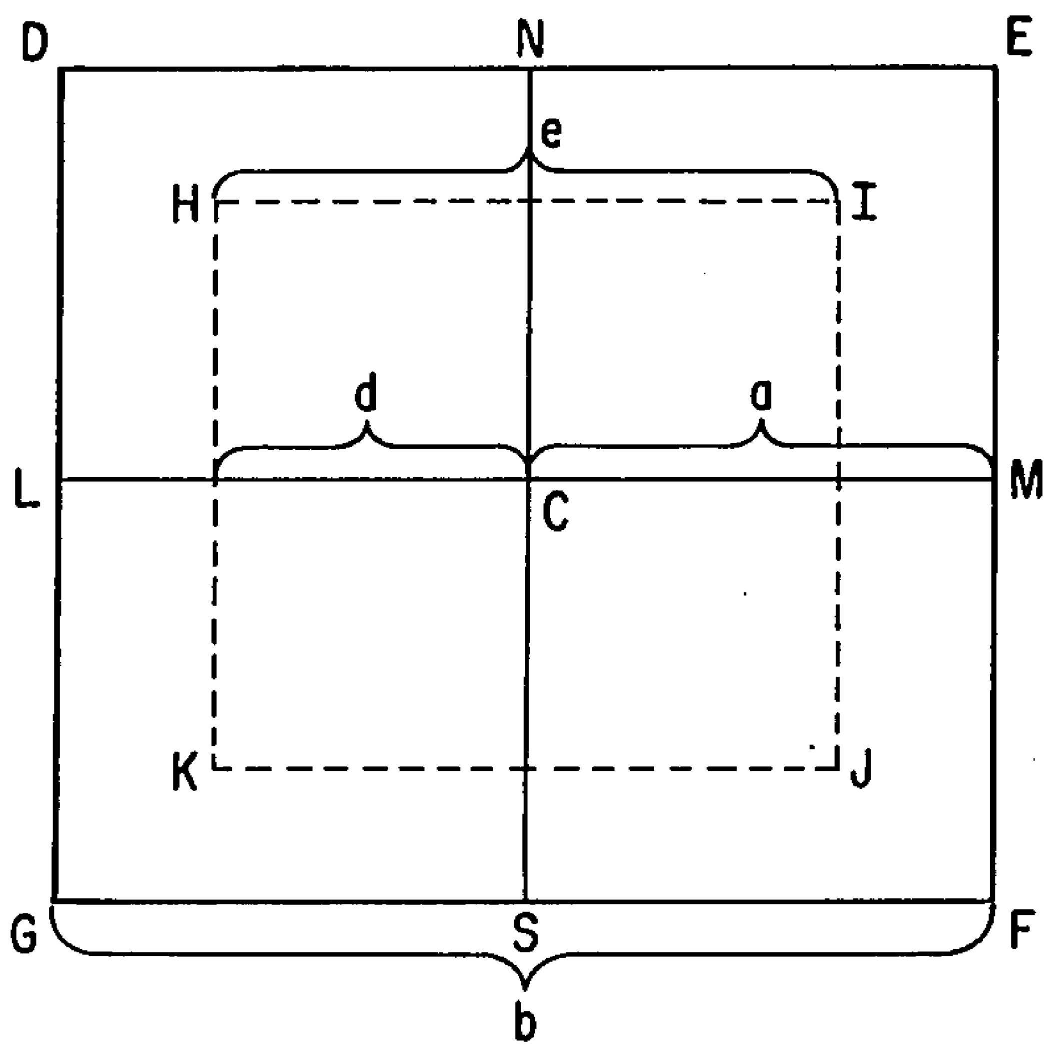


Figure 3-1.--Square DEFG is the region. Point C is the demand point. Lines NS and LM are the roads in the transportation network. b is the length of one side of square DEFG. a=1/2b. e is the length of one side of square HIJK. d=1/2e. The area of HIJK is one-half the area of DEFG.

The area of the DEFG is: $A_0 = b^2$

A_0 = area of DEFG

By definition: $A_1 = 1/2A_0$

Thus: $e^2 = 1/2b^2$

As a result: $e = \frac{b}{\sqrt{2}}$

Since $d = 1/2e$ and $a = 1/2b$, $d = a/\sqrt{2}$.

To compute the average distance travelled on the transportation network to reach the demand node in the region, the mileage of the transportation network is divided by $4\sqrt{2}$. Appendix Q contains this information.

There are several problems with using this method to estimate distances travelled on the transportation network: (1) The regions defined in this study are not square, but this problem is unavoidable; (2) The demand node often is not in the center; (3) The transportation network defined in the study may not be the major roads for hauling timber or for hunters travelling to hunting spots; (4) Travel might not occur over the shortest distance from the forest resource to the transportation network; and (5) The forest resource is probably not evenly distributed over the region.

Calculating Timber Transportation Costs

Transportation costs per mile per cubic foot were obtained from the U.S. Forest Service office at Cadillac, Michigan. The costs are differentiated by truck class and highway class. The class of truck chosen was the same as that used by Wynd and Manthy (Wynd and Manthy, 1971). The truck chosen was a six foot by four foot flatbed with tandem axle and self unloader that weighs 37,000 pounds, combined gross weight. The costs for each class are roundtrip and are listed in Table 3-18.

Table 3-18.--Hauling Costs for Timber in Michigan, 1975.

Road Class	Speed (mph)	Cost per Mile per Ccf
Highspeed	45	$0.12
I	35	$0.17
II	25	$0.25
III	16	$0.35
IV	8	$0.63
V	4	$1.15
Standby, delay, load, unload		$2.09

Source: U.S. Forest Service, personal correspondence, 1975.

First, the cost of reaching the transportation network was calculated for each region. The mileage of each class of highway was multiplied by the cost per mile per hundred cubic feet of that class to calculate the cost per hundred cubic feet for each road class in the region. The cost per hundred cubic feet was summed for each road class and summed to standby costs to compute to calculate the cost per hundred cubic feet to reach the transportation network.

The transportation network was assumed to be in the highspeed class. The mileage to leave the region was multiplied by cost per mile per hundred cubic feet for the highspeed class. The cost per hundred cubic feet on the transportation network to reach the demand point in the region was added to the cost per hundred cubic feet to reach the transportation network to compute the cost per hundred cubic feet to haul timber from the forest resource to the market in the region.

The route connecting each supply region to demand points outside the region were assumed to be in the high-speed class. The total mileage of each route was multiplied by the cost per mile per hundred cubic feet for the high speed class to compute the cost per hundred cubic feet on the route. The cost per hundred cubic feet to reach the transportation network, the cost per hundred cubic feet on the transportation network to leave the region, and the cost per hundred cubic feet on the route to the demand point were summed to get the cost per hundred cubic feet to haul timber from the forest resource in the supply region to a demand point outside of the region. The cost per hundred cubic feet was calculated for all routes between supply areas and demand points. These costs are contained in Appendix R.

Calculating Transportation Costs for Hunterdays

The cost per mile per hunterday was estimated for both big and small game hunting. It is assumed that all hunters travel in automobiles. First, a cost per mile of operating an automobile was calculated. The U.S. Department of Transportation has developed cost per mile figures for operating automobiles. The figures were derived for standard-sized cars, compacts, and sub-compacts. Not all costs included by the Department of Transportation are used in this study. Only operating costs were included. These costs include depreciation, repairs and maintenance, replacement tires, gas, oil, and taxes on gas, oil, and tires.

Assumptions were used to calculate the cost per mile of operating an automobile. First are the descriptions of the cars:

1. Standard-sized car: 1972 4-door sedan, Equipment: V-8 engine, automatic transmission, power steering and brakes, air conditioning, tinted glass, radio, clock, white-wall tires, body molding.

2. Compact: 1972 2-door sedan. Equipment: 6-cylinder engine, automatic transmission, power steering, radio, body molding.

3. Sub-compact: 1972 2-door sedan. Equipment: standard equipment plus radio and body molding.

Repairs and maintenance are required and include: lubrication, repacking wheel bearings, flushing cooling system, aiming headlamps, replacement of sparkplugs, fanbelts, radiator hoses, distributor caps, fuel filter, pollution control filter, brake jobs, water pumps, carburetor overhaul, universal joints, and valve jobs. Tires must be replaced, so it is assumed that seven new regular tires and four new snow tires are purchased during the life of the car. Accessories include floor mats purchased during the first year, seat covers purchased in the sixth year, and some miscellaneous items. Gasoline consumption is assumed to be 13.6 miles per gallon for a standard-sized car, 15.97 miles per gallon for a compact car, and 21.43 miles per gallon for a sub-compact car. Oil consumption is assumed to be 1 gallon of oil for 186 gallons of gas for a compact car, and 1 gallon of oil for 135 miles of gas for a sub-compact. A car is assumed to operate for ten years and 100,000 miles and then be scrapped (U.S. Department of Transportation, 1972).

The Department of Transportation report gave all prices in 1972 prices. Inflation and increases in gasoline prices have changed these prices. It is assumed that gasoline $0.52 per gallon and oil cost $0.90 per quart. Federal taxes were held constant. The 1972 cost per mile figures for depreciation, repairs and maintenance, replacement tires, and accessories were summed and inflated to 1975 prices. The inflator was based on U.S. Bureau of Labor Statistics reports. The consumer price index rose by 3.3% in 1972, 6.2% in 1973, and 10.6% in 1974. (U.S. Bureau of Labor Statistics, 1974 and Dennis, 1974). The 1972 cost was inflated to 1973, the 1973 figure inflated to 1974, and the 1974 figure was inflated to 1975. Table 3-19 shows the 1972 figures to be inflated, the 1975 figures after inflation, and the 1975 cost per mile for each car class. The cost per mile figures are doubled to get round trip figures.

Table 3-19.--Cost per Mile Figures for Operating an Automobile.

car class	1972 costs (excludes gas and oil) (cents)	1975 costs (excludes gas and oil) (cents)	1975 costs (includes gas and oil) (cents)
standard	6.97	8.46	12.75
compact	4.88	5.92	9.59
sub-compact	4.21	5.11	7.86

The next step was to get an average cost per mile by aggregating over all classes of cars on the road. Figures on car production were obtained from the Motor Vehicle Manufacturers Association of the U.S., Inc. Production figures were kept from 1968 to 1974 (Motor Vehicle Manufacturers Association, 1974). These figures were not aggregated according to standard compact, and sub-compact classes, however. The Motor Vehicle Manufacturers Association figures were allocated to classes in the following manner:

1. standard: high, regular, intermediate, passenger van
2. compact: compact, sport
3. sub-compact: sub-compact, import

The proportion of each of these classes was calculated from 1968 to 1974. A set of weights was developed to be multiplied by these proportions. First, the rate of removal of cars was taken into consideration. The Department of Transportation stated that 50% of the cars produced in a given year are still on the road after ten years. After ten years, they are assumed scrapped. It is assumed that 100% of the cars built in 1974 are still on the road, while 50% of the cars built in 1965 are still on the road. It is assumed that the rate of removal is constant over the ten year period. The percentage of a given year's cars on the road was decreased by a constant amount from the following year's proportion.

A set of automobile production weights was also calculated to account for differences in yearly production. 1974 was assigned a weight of 1.0. The production of each years was divided by 1974 production to get a relative weight. Production in 1965, 1966, and 1967 was assumed to be identical to 1968. The removal weight and the production weight were multiplied together to get a total weight. These weights are listed in Appendix S. The proportion of each class of car produced in each year was multiplied by this weight. The weighted percentage of each class was summed over the ten year period. The percentage of each car class produced in each year is listed in Appendix T. The total weighted percentage for each class was divided by the total of all classes to get a percentage of each class of car on the road at the present time. The proportion of each class of car was found to be: sub-compact--18%, compact--17%, and standard--65%.

The next step was to find the number of hunters in a party for small game and big game. The number of passengers per car was found in a publication printed by the U.S. Department of Interior. There were 2.46 passengers per car for big game. This figure is assumed to hold for deer hunters in the river basin area. There were 2.17 passengers per car for small game. This figure was assumed to hold for squirrel and rabbit hunters in the river basin area. The same publication provided information to calculate the number of days per trip. The number of hunting days was divided by the number of days per trip. The number of hunting days was divided by the number of hunting trips to calculate the number of hunterdays per trip. There is 1.37 days per trip for big game and

1.09 days per trip for small game. These national figures were assumed to hold for hunters in the river basin area (U.S. Department of Interior, 1971).

Cost per mile per hunterday for small and big game were calculated for each class of automobile according to the following formula:

cost per mile ÷ passengers per car ÷ days per trip

Table 3-20 shows the results in terms of round trip costs.

Table 3-20.--Cost per Mile per Hunterday for Each Class of Car.

Class of Car	Small Game (cents)	Big Game (cents)
Standard	10.78	7.56
Compact	8.11	5.69
Sub-compact	6.64	4.66

Each class of car was multiplied by the proportion of each class on the road and summed to get an average round trip cost per mile for big game and small game. For big game, the cost per mile per hunterday was estimated to be 6.72 cents. For small game, the cost per mile per hunterday was estimated to be 9.58 cents.

The cost per mile per hunterday figures were assumed to hold for all classes of road. The total mileage travelled from any demand point to any supply areas was summed and multiplied by the cost per mile per hunterday to get the costs per hunterday for both big game and small game. The same mileage figures were used as those calculated for timber. Appendix R contains these costs.

Transport Costs for the Linear Program

Transportation costs were calculated for each good for each transport route and each time period. The future value at the end of a ten-year period was calculated for the transport cost per unit of commodity incurred in each year of the ten-year period. The future values for each year in the ten-year period then were summed to compute the future value of all transport costs per unit of commodity incurred in the ten-year period. This future value was discounted to the present which in this model is assumed to be 1965. The future value was discounted over ten years for time period 1, 20 years for time period 2, 30 years for time period 3, 40 years for time period 4, 50 years for time period 5, and 60 years for time period 6. A discount rate of 5.88% was used. These costs are the present value of transportation costs in each time period.

These costs are objective function values for transportation activities in the linear programming model. Activities that transfer timber from regions outside of the river basin to regions inside the river basin have an added cost, the cost of harvesting timber. This cost is added since the cost of harvesting timber in the region is accounted for in the objective function values of the production activities. If these added harvesting cost were not accounted for, the model would choose to import timber to meet river basin requirements rather than produce timber in the region. The true cost of importing timber would not be calculated if the harvesting cost was not fully considered.

Generating Forest Production Activities

Aggregating Management Strategies and Resource Classes

Large amounts of data are used in this model. It is time-consuming and costly to calculate product coefficients for each management strategy on each resource class. Costs of deriving a solution to a linear programming model increases as the number of coefficients in the model increases. If the problem becomes too large, it is possible to exceed the core limits of the computer. To reduce costs, time involved in calculations, and computer core requirements, management strategies and resource classes were aggregated.

If was found that the coefficients calculated by the U.S. Forest Service for the intensive fiber and multiple use management strategies were very similar. To conserve on computer time, it was decided to aggregate these two management strategies. Usually, the hunterday coefficients were identical. The greatest information loss occurred in fiber production and erosion. The coefficients were aggregated by averaging. The aggregated management strategy is renamed intensive management. The current use and environmental emphasis management strategies remain.

It was decided that, in some cases, resource classes could be aggregated. As a result, the total number of activities is reduced. Resource classes were aggregated by soil group and, in some cases, condition classes. However, stand size classes were not aggregated. Table 3-21 shows the aggregated soil groups, the original soil groups contained in the aggregation, and the condition classes included in each resource class.

Each of these 13 groups has four stand size classes associated with it. Appendix V shows the range of values for each of the fiber production coefficents in each of these groupings. The management strategies were aggregated by averaging the coefficients from each resource class which was aggregated.

Time

Time presents a special problem in defining activities. A rotation

Table 3-21.--Aggregation of Soil Groups and Condition Classes.

Ecosystem	Aggregated Soil Group	Soil Groups	Condition
Conifer	1	A,B,E	Adequate
	1	A,B,E	TSI
	2	C	Both
	3	D	Both
Oak-Hickory	1	A,B,D,E	Adequate
	1	A,B,C,E	TSI
	2	D	Both
Elm-Ash-Cotton-wood	1	A,B,C,D,E	Both
Maple-Beech-Birch	1	A,B,C,E	Adequate
	1	A,B,C,E	TSI
	2	D	Both
Aspen-Birch	1	A,B,E	Both
	2	C,D	Both

time must be defined for each management strategy on each resource class. Time periods must also be defined for each stand size class. Rotation lengths were defined for intensive management by consulting The Growing Timber Resource of Michigan, 1966 and the staff of the Manistee National Forest (Chase, Pfeiffer, and Spenser, 1969). The recommended rotation length for the current use management strategies for each resource group was defined by taking a period somewhere between the current rotation length and the oldest age class of the resource group found in Michigan's Lower Peninsula. When the rotation age for the intensive management strategy and the oldest age class are the same, the rotation age for the current use management strategy is the same. When the recommended rotation age for the intensive management strategy is in the second oldest age class of the resource group found in the Southern Lower Peninsula, the rotation age for the current use management is the highest age of the oldest age class.

Defining the relationship between age class and stand size class was more difficult. The acreage of each ecosystem in each stand size class was found for the southern half of the Lower Peninsula in The Growing Timber Resource of Michigan, 1966. The acreage of each ecosystem in various age classes was determined for the whole state. The same information was found for subdivisions of the state in Michigan DNR publications for each region. However, there was no information for the southern half of the Lower Peninsula. The acreage of the ecosystem in each age class was found by subtracting the acreage of the rest of the state from the acreage for the entire state. The residual was allocated to the southern half of the Lower Peninsual. The acreage of each ecosystem in each stand size class is shown in Appendix W. The acreage of each ecosystem in each age class was shown in Appendix X.

It was assumed that the age distribution within an age class was even. Non-stocked areas were allocated evenly among the stand size classes. Age classes were summed, starting with the youngest, until the acreage of the seedling-sapling class was approximated. The same was done for poletimber and sawtimber. When it was necessary to subdivide on age class, which occurred only with the seed-sapling age class, the acreage of the stand size class was divided by the acreage of age class 0-20. This ratio was multiplied by 20. The product of the last year in the age distribution of the stand size class. This was rounded to the nearest multiple of five. This process yielded a cross-sectional relationship of age-classes in the stand size classes. The relationship was assumed to hold over time thus giving the time period, in years, a stand spends in a stand size class.

Table 3-22 shows the rotation age and stand size class time periods for each management strategy in each ecosystem. These times were assumed to hold for every resource class.

Table 3-22.--Rotation Age and Time Periods in Each Stand Size Class.

Ecosystem	Management Strategy	Rotation Age	Time Period in Each Stand Size Class		
			Seed-Sapling	Pole-timber	Saw-timber
Conifer	CU	120	15	25	80
	IM	120	15	25	80
Oak-Hickory	CU	120	15	35	70
	IM	140	15	35	90
Elm-Ash-Cottonwood	CU	140	15	35	90*
Maple-Beech-Birch	CU	140	20	40	80
	IM	140	20	40	80
Aspen-Birch	CU	50	15	25	10
	IM	60	15	25	20

CU = Current Use Management Strategy

IM = Intensive Use Management Strategy

*Intensive management is not considered because Dutch Elm Disease makes this ecosystem non-commercial.

The forest resource is conceptualized as a set of age cohorts moving through time. There will be a set of ten-year age cohorts from zero through rotation age. Each cohort will age by ten years after the passing of a ten-year time period. For example, there is a 0-10 cohort in 1966. In 1975, that cohort will be 10-20 in 1985, 20-30 in 1995, 30-40 in 2005, etc. The age cohorts will move smoothly through time so that in 1970, the age class actually is 5-15. At the end of rotation, the cohorts will move back to 0-10 after timber removals. This technique will be used to calculate how much timber becomes available in different time periods. Each age class can be traced through time in this manner.

Linear Programming Production Activities

The production activities are a statement of the outputs produced over time by the combinations of land management practices. The coefficients of the time period reflect the management strategy applied to a given class of land during the production period. A given parcel of land can remain in one management strategy for the entire period of analysis. However, conversion of a management strategy on a parcel of land can also occur. An activity has to be formulated for each combination of management strategies over time. Simplifying assumptions are made concerning when conversion decisions can be made and what conversion decisions can be made in order to limit the number of activities. The simplifying assumptions are:

1. Once a tract of land is devoted to the intensive management or environmental emphasis management strategies, no conversions can be made. Conversions can only be made from the current use management strategy to intensive management or environmental emphasis. Land devoted to environmental emphasis will be set aside in parkland. Most parklands are removed from timber production. Land is assumed to be devoted to intensive management after a deliberate decision-making process by the landowner in which he weighs the costs and benefits of intensive management in terms of his own goals over time. It is being assumed that the landowner will not change his goals during the period of analysis.

2. A conversion decision can be made only once for a stand size class and will take place at the juncture with the following stand size class or at the present. Conversion can take place at:

    a. present

    b. seedling-sapling--poletimber juncture

    c. poletimber--sawtimber juncture

    d. just before the stand is cut

    e. after the stand is cut

3. Once a cut has been made, no conversions can take place. No conversions are made after a cut since it is assumed that the landowner will decide after timber is harvested whether to devote land to intensive management or to leave the land unmanaged. Land devoted to intensive management before harvest remains in intensive management. It is then assumed that the landowner will not change his goals during the period of analysis.

4. Conversion of non-stocked land to seedling-sapling can occur only at the present or the year 2000.

5. Conversion from current use to the intensive management strategy on land needing timber stand improvement can occur only with an investment and conversion to the adequate condition class.

6. When the needs-timber-stand-improvement and adequate condition classes are aggregated the conversion from current use to intensive management will require an investment.

7. For non-stocked forest land, only conversion to intensive man-

agement will be considered. In most cases, the quantities of timber and hunterdays produced over time on non-stocked land or non-stocked land converted to intensive management are greater than or equal to the amounts of these commodities produced on non-stocked land converted to current use.

8. Conversions of forest land to urban land will be handled outside of the model. Products produced on lands to be converted during each time period will be added into the model. Products produced on lands currently in the intensive management strategy will be handled in the same way.

Appendix Y contains a list of the activities for the resource classes.

Calculating Timber Coefficients

Data were provided by the U.S. Forest Service concerning the outputs of products by management strategies on each resource class. Coefficients were provided for the annual growth of wood fiber for each forest ecosystem, stand size class, stand condition class, soil group and management strategy. These fiber coefficients cannot be used directly in this model since the product in this model is timber that can be sold to the mill. A model is proposed that will calculate timber production. It assumes that all timber to be sold is cut at the end of the rotation. It also assumes that timber growth per year figures provided by the U.S. Forest Service are accurate. It also assumes that the relationships will hold constant over time. The model is:

$$MVH_{ar} = [\sum_{s=1}^{3} G_{sar} T_{sar}] C_{ar}$$

MVH_{ar} = merchantable volume of timber harvested per acre by manage-strategy a on resource class r at the end of the rotation.

s = state size class

when s = 1, the stand size class is seed-sapling

when s = 2, the stand size class is poletimber

when s = 3, the stand size class is sawtimber

G_{sar} = net growth of total fiber per acre per year in stand size class s with management strategy a on resource class r.

T_{sar} = number of years that the stand is in stand size class s with management strategy a on resource class r.

C_{ar} = amount of merchantable timber produced per unit of total volume of fiber with management strategy a on resource class r at the rotation age.

C_{ar} is calculated from the following product:

Growing stock volume ÷ total fiber volume

x Growing stock harvest ÷ growing stock volume

x Merchantable volume ÷ growing stock harvest

Growing stock harvest/growing stock volume for the current use management strategy is calculated by dividing growing stock removals per year by growing stock available for harvest. This was approximated by 1966 data. Growing stock removals were divided by the allowable cut of growing stock (Chase, Pfeiffer, and Spenser, 1969). Allowable cut is the growing stock available for commercial use in a given year. These figures are shown for softwoods and hardwoods in Table 3-23. For the intensive management strategy, growing stock harvest/growing stock volume is assumed to be one.

Table 3-23.--Calculating Growing Stock Harvest/Growing Stock Volume.

	softwood	hardwood
Growing stock removals (MCF)	50,002	156,461
Growing stock allowable cut (MCF)	127,612	252,339
removals/allowable cut	.392	.620

Merchantable volume/growing stock harvest was calculated by dividing industrial roundwood production by timber removals from growing stock. These figures were calculated for 1966 and 1972. The figures for 1966 are shown in Table 3-24 (Chase, Pfeiffer, and Spenser, 1969). The figures

Table 3-24.--Merchantable Volume/Growing Stock Harvest, 1966.

	hardwood	softwood
Output of roundwood products (MCF)	149,051	47,622
Timber removals from growing stock (MCF)	156,463	50,002
Output/removals	.953	.952

for 1972 are shown in Table 3-25 (Blythe, Boelter, and Danielson, 1975).

Table 3-25.--Merchantable Volume/Growing Stock Harvest, 1972.

	hardwood	softwood
Volume of industrial roundwood (MCF)	43,601	140,305
Growing stock removals for industrial roundwood	46,041	148,300
Roundwood/removals	.947	.946

The average for both years is .95 for both hardwoods and softwoods. This figure will be used.

Calculating the volume of growing stock/total volume of fiber was more difficult since this type of information is not readily available. The volume of growing stock is the volume of timber up to a four-inch top. Gardner and Hahn studied 176-year-old lodgepole pine (National Materials Policy Commission, 1974). They found that there were 6174 cubic feet per acre of fiber up to a six-inch top while there were 4333 cubic feet per acre of residue. The residue was 41% of total volume. 82% of the residue was between six inches and three inches in diameter, while 97% was between six inches and 0.06 inches in diameter. To calculate the portion of a tree up to a four-inch top, the tree was assumed to be a cone. It was calculated that the volume portion of a cone with a 6 inch base between a diameter of six inches and four inches was 70% according to the following calculations:

Volume of a cone with a six-inch base:

$$\frac{\Pi}{3} 3^2 h = 3\Pi h$$

Volume between six inch diameter and four inch diameter of the cone:

$$\frac{\Pi}{3} 3^2 h - \frac{\Pi}{3} 2^2 \frac{2}{3} h = 2.11\Pi h$$

The ratio of the two volumes is 2.11 h/3 h = 0.70.

The portion of the whole lodgepole pine in a volume with a six-inch bottom and a four-inch top is .41 x .7 = .29. The volume of the tree up to a four-inch top is .59 + .29 = .88 which is growing stock volume/total fiber volume.

Samuel F. Gingrich did similar work with shortleaf pine (Gingrich, 1972). He presented an equation to calculate the portion of a shortleaf pine up to a four-inch top. The values approach 98%. A pine with a height of 50 feet and a dbh of nine inches would have 93% of the total volume in that portion up to a four-inch top. A tree 54 feet high with a dbh of 12 inches would have 96% of the volume in that portion up to a four-inch top. Bryce Schlagel did similar work with quaking aspen. Merchantable volume up to a three-inch top and five-inch top both approach 98.6% of total volume (Sclagel, 1971). It was decided to set growing stock volume/total fiber volume at 92% for this study.

The values of C_{ar} were calculated and are presented in Table 3-26.

Table 3-26.--Merchantable Volume/Total Fiber Volume.

Management Strategy	C_{ar} Hardwood	Softwood
Intensive Management	0.87	0.87
Current Use	0.54	0.34

Once the merchantable volume of timber per acre produced at the end of the rotation for each management strategy is calculated, special weights must be devised to show what relative amounts will be available at different time periods. Acreage constraints are developed for stand size classes, not age cohorts. The distribution of age cohorts within a resource class must be accounted for when calculating the amount of timber that is available in a given time period. The portion of the age class in a resource class is calculated by using the age class in a resource class is calculated by using the age distribution table in Appendix AA. The ratios between age cohorts and resource class acreages will be the same as those shown in that table. When a particular age cohort reaches rotation age, its portion of the total acreage of the resource class is multiplied by merchantable volume of timber per acre. The timber production figure also is an annual average for a ten-year period. The volume of timber is produced by an age class over a ten-year period.

The timber produced per acre must be multiplied by 1/10. This is summarized by the following equation:

$TPC_{acr} = 1/10 \times p_{cr} \times MVH_{ar}$

p_{cr} = portion of resource class r at rotation age at time period c

TPC_{acr} = Timber harvest per year by management strategy a on resource class r in time period c.

Appendix AA contains the proportion of each stand size class reaching rotation age in each time period.

Calculating Coefficients for Other Products

The coefficients for other products will also be averages for ten-year periods. The ten-year age cohort will move completely into the next ten-year age class at the end of the period. The coefficient for the ten-year period is an average of the coefficients of the age classes existing at the beginning and end of the time period. When an age class extends over 20 years, the ten-year divisions have a frequency equal to 1/2 of the total of the 20 year age class. These coefficients must be averaged for each cohort in the stand size class. Each cohort is multiplied by the acreage proportion of that cohort in the stand size class. The resulting product for each cohort in the stand size class is then summed together. When a conversion between management strategies occurs in an activity, the coefficient of the appropriate stand size class and management strategy is used for each time period. For example, when current use is converted to intensive management at the juncture between the seedling-sapling and poletimber stand size classes, the coefficients for current use is used for the seedling-sapling class and the coefficients for intensive management are used for the poletimber class. The following equation expresses the calculation of coefficients for hunterdays and erosion.

$$CO_{br} = \sum_{c}^{f} p_{cr} \left(1/2CO_{ac} + 1/2CO_{ac+1}\right)$$

CO_{br} = coefficient for activity b on resource class r

CO_{ac} = coefficient of cohort c in management strategy a

c = cohort

f = last cohort in resource class r

p_{cr} = proportion of acreage of resource class r in cohort c

The coefficients for each cohort are taken from the data provided by the U.S. Forest Service. The coefficient for cohort c is the coefficient for the stand size class of which cohort c is a member in a particular time period. Some of the stand size classes extend over a period of 15 years rather than multiples of ten. The coefficients of the first ten-year period are seedling-sapling coefficients. The coefficients of the second ten-year period are the averages of the seedling-sapling coefficients and the poletimber coefficients. Appendix Z lists the coefficients in terms of multiples of stand size class coefficients for each resource class at each period in time.

Calculating Costs for Production Activities

Two types of costs were developed by the U.S. Forest Service: 1) production costs and 2) development costs. Production costs are the costs of harvesting timber. Development costs are the costs of managing a stand. The production cost per year was calculated by multiplying the cubic feet per year of merchantable timber harvested per acre by the production cost in dollars per cubic foot. All production costs for a management strategy were discounted to the present. The planning horizon extends from 1965 to 2025, a period of 60 years. No costs beyond that time were considered. The discount rate is 5.88% as determined by the Water Resources Council in August 1974. The future value of production costs at the end of a ten-year period incurred in each year of the ten year period was calculated. Annual future values were then summed to compute the future value at the end of the ten-year period for all costs incurred in the ten-year period. The future value at the end of the ten year period was discounted to the present, which is 1965 in this study. The present values of costs for each ten-year period were summed to compute the present value of production cost for each activity.

The development costs are the costs of managing a stand. These costs must also be spread over time. since these costs are incurred only when a stand is converted to the adequate condition class, they are incurred at junctures between stand size classes. Since the junctures are spread over time, the costs must also be spread over time. The portion of a stand size class in an age cohort is multiplied by the development cost and divided by the number of years in the cohort to compute a development cost per year. A present value of development costs incurred in a management strategy incurred in a management strategy is calculated for each age cohort and discounted back to 1965 at 5.88%. The present value for each age cohort in a stand size class to calculate a discounted development cost for each management strategy. Only costs incurred between 1965 and 2025 are considered. The total cost for each production activity is the sum of production and development costs incurred. Appendix BB contains these costs for each production activity.

Land Conversion

Conversion of forest land to urban use is handled exogenous to the model. The acres converted during the time period of analysis were removed from each resource class. The amount of each product produced on each class of land were calculated and summed for each region and each time period.

In order to calculate these products, a conversion rate was required. The Economic Research Service projected the conversion of forest land to urban use from the present to 1990 and 2020. Table 3-27 contains the acreage of forest land converted in each region during each time period and the proportion of total 1966 forest land converted.

Table 3-27.--Conversion of Forest Land to Urban Use by Region.

Region	1967-1990 (acres)	% of 1967 forest land	1967-2020 (acres)	% of 1967 forest land
1	181	.21	1401	1.63
2	2982	1.78	5116	3.05
3	1934	2.90	2997	4.49
4	2753	2.62	4758	4.53

Proportions of total 1967 forest land converted by the end of each time period were calculated. A straight line relationship was assumed from 1966 to 1990 and from 1990 to 2020 for each region. This is shown in Figure 3-2. The proportion for the last year in each time period was calculated by taking the appropriate point from these relationships. Table 3-28 contains these proportions. It is assumed that all resource classes in a region are converted at the same rate. The acreage converted during each time period was calculated by multiplying the acreage of each resource class in a region and time period by the region's conversion proportion in that time period. This acreage was subtracted from the total acreage converted from 1966 to 2025 to compute the acreage not yet converted in that time period. The acreage not yet converted for one

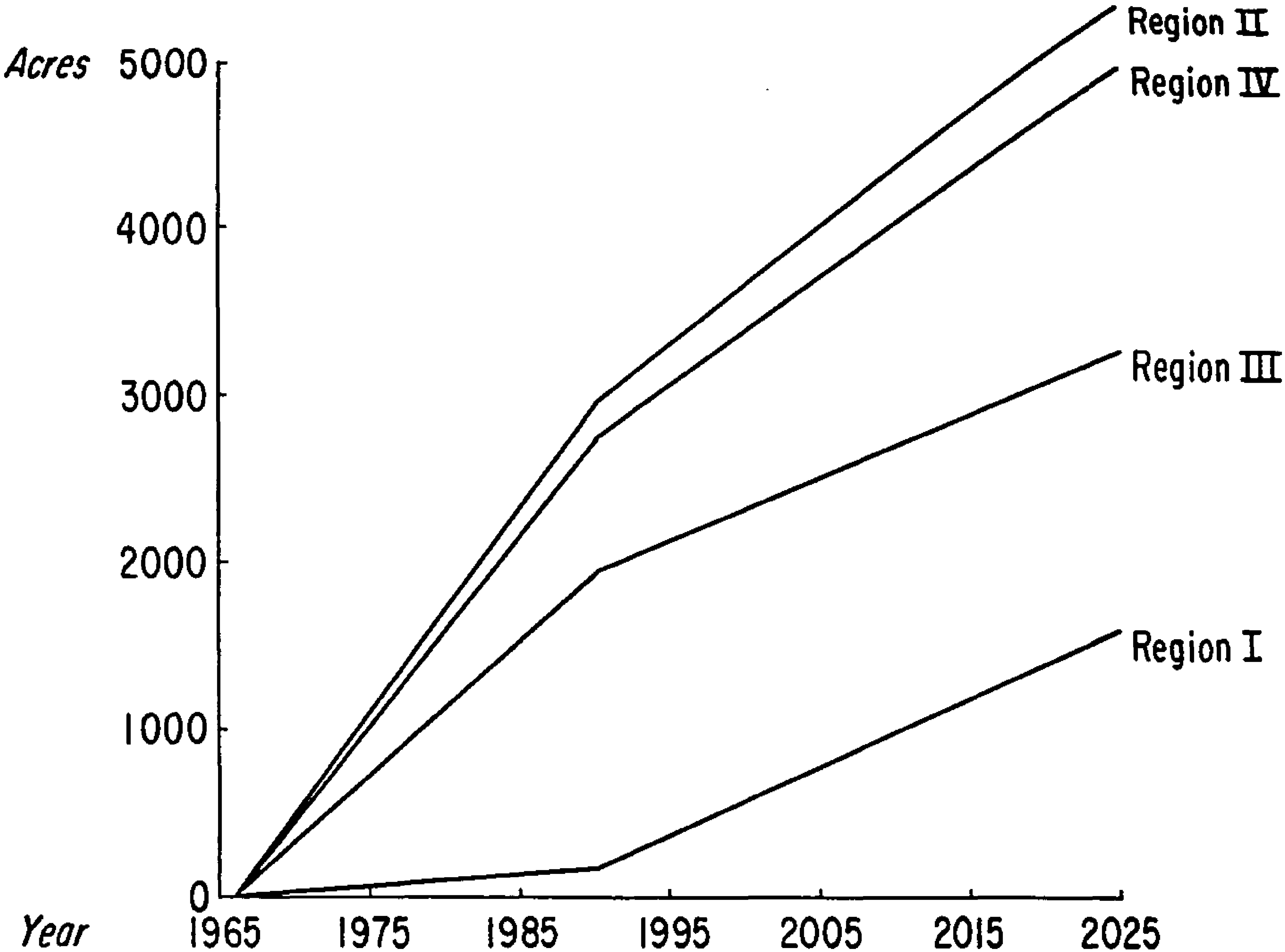


Figure 3-2.--Acres of Forest Land Converted to Urban Use Over Time.

Table 3-28.--Projected Percentage of 1967 Forest Land Converted through Each Time Period.

Region	Time Period					
	1	2	3	4	5	6
1	.088	.176	.447	.920	1.393	1.866
2	.742	1.484	3.262	3.685	4.108	4.531
3	1.208	2.416	4.755	5.285	5.815	6.345
4	1.092	2.184	4.849	5.486	6.123	6.760

time period was averaged with the acreage at the end of the next time period to get the average number of acres in production during that time period. This average was multiplied by the coefficients of the current use management strategy to get the products produced during each time period on each resource class. All products produced in a region were summed. Appendix CC contains this information.

Lands currently in intensive management and environmental emphasis are handled exogenously, also. Acreages currently in intensive management were calculated for each resource class. These acreages were multiplied by coefficients for each product in each time period to calculate quantities of products produced in each time period. These products were then summed with those produced on land converted to urban use and added into the model through a special activity. The cost of adding in timber was the harvest cost per cubic foot. All other products have no cost of adding the products into the model. These products can be shipped to demand points like goods produced in the production component.

Extra Supplies

In order to prevent infeasible solutions in meeting requirements, supplies of goods that can be purchased from outside the 12 region area of analysis by each region in the river basin are made available at a cost much higher than any importing cost from other regions. Due to this high cost, this supply of goods is a last resort. A pool of these goods is made available for each region in the river basin that can be drawn upon in each time period. Table 3-29 list these pools of supplies.

Table 3-29.--Extra Supplies of Goods Available to Each Region from Outside the 12 Region Area of Analysis.

Region	Good	Amount
1	Timber (MCF)	6,391,000
1	Deer Hunter Days	145,893
1	Small Game Hunter Days	517,073
2	Timber (MCF)	83,164,100
2	Deer Hunter Days	267,086
2	Small Game Hunter Days	761,900
3	Timber (MCF)	1,472,000
3	Deer Hunter Days	85,044
3	Small Game Hunter Days	242,591
4	Timber (MCF)	1,664,000
4	Deer Hunter Days	84,240
4	Small Game Hunter Days	288,298

Summary

This chapter has discussed the model to be tested and the data to be used in the model. Variables were defined and equations were presented and discussed. Data requirements and the methods of obtaining these data were discussed. Requirements for timber and hunterdays for regions in the river basin were calculated over all time periods. Excess supplies of timber and hunterdays for regions outside of the river basin were calculated for all time periods. The procedure for defining regions was discussed. Transfer costs for timber and hunterdays were calculated. Definition of representative transfer routes was discussed. Costs per mile were calculated for timber and hunterdays. Calculating coefficients for linear programming production activities were also discussed. Assumptions were presented. Management strategies and resource classes were aggregated. Methods for calculating each product coefficient for each timber period were presented. Methods of calculating costs for production activities were discussed. Problems associated with land conversion and supplying extra quantities of products were also discussed.

CHAPTER IV

ANALYSIS AND RESULTS

The purpose of this chapter is to present and analyze the results of testing the model. Particular problems with the model will be pointed out. Recommendations for land management will be discussed.

Types of Computer Runs Made

Five runs were made on the Michigan State University Control Data Corporation 6500 computer using APEX I, a linear programming algorithm developed by Control Data Corporation. These runs represent different levels of requirements for timber and hunterdays over time. The methods of projecting these requirements over time were discussed in Chapter III. Short descriptions of these five runs follow.

A. This baseline run assumes that timber and hunterday requirements remain constant over time. No growth in economic activity or population is assumed. However, conversion of forest land to urban use is assumed to continue.

B. Requirements for timber grow only in regions with pulpmills, that is, regions 2 and 5. Requirements for timber in the other regions and requirements for hunterdays in all regions remain constant. Requirements for timber in regions 2 and 5 grow at rates assumed with rising relative timber prices, as discussed in Chapter III. The purpose of this run is to show the effects of uneven growth rates of timber requirements over space on land management.

C. In this run, timber requirements in all regions grow at rates associated with rising relative timber prices. Requirements for hunter-days grow at the same rate as projected population growth. The purpose of this run is to show the impact of growth of both timber and hunterday requirements on land management.

D. Timber requirements grow at rates associated with 1970 prices. Hunterday requirements grow at the same rate as the population. The purpose of the run is to show the impact of an even higher rate of growth of timber requirements on land management.

E. Timber requirements remain constant over time. Requirements for hunterdays grow at the same rate as population. The purpose of this run is to show the impact of no growth in wood products industry while population continues to grow.

Discussion and Analysis of Land Management Results

The purpose of this model is to provide recommendations for land management planning and provide information concerning the impacts of alternative plans. This section will include discussion of the land management results of these five runs.

The land management activities can be divided into two groups: 1) timber-producing and 2) non-timber-producing. Timber producing activities produce merchantable timber during the period of analysis. These activities include the current use management strategy and the conversion from current use to the intensive management strategy on the following resource classes: 1) conifer, oak, and maple sawtimber size classes in adequate stand condition classes, 2) conifer, oak and maple sawtimber size classes in stands requiring timber stand improvement to convert from current use to intensive management, 3) conifer sawtimber size classes in which condition classes are not differentiated but produce merchantable timber, and 4) aspen-birch seedling-sapling, poletimber, and sawtimber size classes. Groups 2 through 4 will be referred to as non-adequate condition classes since the condition of these classes is not currently adequate to convert from current use to intensive management. Non-adequate condition classes include those classes where timber stand improvement is needed to convert from current use to intensive management and where condition classes are not differentiated.

Non-timber producing activities do not produce timber during the time period of analysis. Some stand size classes will not reach harvest age during the time period of analysis. Some resource classes will not produce merchantable timber at any age. Environmental emphasis management strategies will not allow removal of any timber, so they are non-timber producing strategies. Current use and the conversion from current use to intensive management strategies on the following resource classes are non-timber producing: 1) conifer, oak, elm, and maple seedling-sapling and poletimber size classes and 2) conifer, oak, elm, and maple sawtimber size classes which produce no merchantable timber.

Timber-producing lands are classes of land capable of producing timber during the time period of analysis. The environmental emphasis management strategy, a non-timber producing management strategy, can be applied to timber producing land. Non-timber producing lands are classes of land which are not capable of producing timber during the time period of analysis. Both timber-producing and non-timber producing lands can be in adequate or non-adequate stand condition classes.

Timber-Producing Activities

Timber-producing activities will be discussed first. There are two levels of timber production among these five different runs. Runs A and E have identical land management patterns in the lower level of production. Runs B, C, and D have identical land management patterns in the higher level of production. More timber is produced in time periods 4 and 5 at the higher level of production than at the lower level of production. Timber production is equal at both levels of production in time periods 1, 2, 3, and 6.

The results of runs A and E will now be discussed. All timber-producing stands in adequate condition classes are converted to intensive management before they are cut, at the earliest possible time. The same is true of timber-producing stands requiring timber stand improvement. Classes in which condition classes are not differentiated are more complex. All sawtimber classes, both conifer and aspen-birch, are converted to intensive management before the harvest. Aspen-birch poletimber size classes are all converted to intensive management at the earliest possible time. However, aspen-birch seedling-sapling size classes are all converted to environmental emphasis in which there is no timber production. Production of timber in the aspen-birch seedling-sapling size classes is concentrated in time periods 4 and 5. All requirements for timber in time periods 4 and 5 in runs A and E are satisfied by management strategies on other classes of forest land. These management strategies also produce timber in other time periods. Aspen-birch seedling-sapling size classes are kept out of timber production to reduce costs without decreasing production in time periods 1, 2, 3 and 6. If other classes of timber producing land were kept out of production, requirements in time periods 1, 2, 3 and 6 could not be satisfied.

There is no spatial variation in this pattern for runs A and E. The only spatial variation in acreages is due to variations in the land resource.

The results of runs B, C, and D are identical except for the seedling-sapling size classes of aspen-birch. With these runs, aspen-birch seedling-sapling size classes are converted from current use to intensive management at the present, the earliest conversion possible.

The only difference between the runs at the higher level of timber production and the runs at the lower level of timber production is the status of seedling-sapling classes of aspen-birch. In runs at the lower level of timber production all classes of timber-producing lands, except aspen-birch seedling-sapling classes are converted from current use to intensive management at the earliest possible time. In runs at the higher level of timber production, all classes of timber-producing land are converted from current use to intensive management at the earliest possible time. At the higher level of timber production, requirements for timber are not satisfied in time periods 4 and 5 even though aspen-birch seedling-sapling size classes are converted to intensive management at the earliest possible time.

Timber requirements appear to be the most difficult requirements to meet. All timber requirements are met only when there is no growth in timber requirements. As soon as there is growth in timber requirements in regions with pulpmills, any unused timber-producing potential is forced into the most intensive form of management.

Two factors emerge which appear to seriously affect the pattern of land management. The first factor is the time distribution of production, that is, how much timber is produced in each time period by a management strategy on a resource class. The second factor is the cost per unit of timber. Included are harvesting and development costs. Development costs are the only differentiating factor. Harvesting cost per unit of timber are equal for all management strategies.

The time distribution of production seems to be the most important factor in determining the pattern of management of timber producing land. The production of timber in the aspen-birch seedling-sapling classes is concentrated in time periods 4 and 5. When there is no growth in timber requirements, timber production can exceed requirements in time periods 4 and 5 . As a result, timber producing capacity is not fully utilized. Timber-producing activities other than the aspen-birch seedling-sapling classes spread timber production over more time periods. As a result, it is difficult to remove these other activities from production since timber requirements in other time periods can no longer be met. With growth in timber requirements, requirements in the river basin can no longer be met, even when timber-producing capacity is fully utilized. All timber producing classes are converted to intensive management in an attempt to satisfy these timber requirements.

Costs also seem to be important. With adequate condition classes, the cost per unit of timber which may include harvesting and development costs is the same regardless of the management strategy since development costs are not necessary, according to Forest Service personnel. The most efficient form of management on the adequate classes is conversion to intensive management at the earliest possible time. Development costs are incurred by all classes requiring timber stand improvement to convert to intensive management and by classes in which stand condition classes are not differentiated. Under certain circumstances, these development costs could keep acreages out of intensive production. Poletimber and sawtimber classes of the aspen-birch ecosystem have no development costs, so intensive management would be the most efficient use of these classes.

The combination of development costs and time distribution of production appears to keep the seedling-sapling classes of the aspen-birch ecosystem out of production when there is no growth in timber requirements. When there is growth in timber requirements over time in runs B, C, and D, timber requirements are not satified in time periods 2 through 6. As a result, the model will incur any cost in an attempt to increase timber production. The time distribution of production will not cause the model to keep lands capable of producing timber out of timber production.

Acreages of land in each management strategy are presented in Appendix DD.

Non-Timber Producing Activities

The pattern of land management strategies is more difficult to discuss because each run is different. However, production potential of hunterdays currently is not being used to its limit. Importing potentials from regions outside of the river basin are not being fully utilized, either. Other factors, besides those affecting timber production, will have an effect on land management.

The results of the runs on non-timber producing lands will be reviewed and analyzed. Refer to Appendix DD for the acreages of each management strategy on each resource class in each region. First, the results of run A will be discussed. Changes in the other runs will follow. All ecosystems with adequate stand conditions are converted to intensive management. All are converted to intensive management at the present except for the seedling-sapling size class of oak which is converted to intensive management at the juncture between seedling-sapling and poletimber size classes. The remaining classes are in current use, except for some classes in regions 2 and 3. In region 2, the elm poletimber size class is converted to intensive management and the elm seedling-sapling size class is converted to intensive management at the juncture between poletimber and sawtimber. In region 3, the conifer poletimber size classes in all non-adequate classes are converted to intensive management. The oak poletimber size class when stand condition classes are combined and no merchantable timber is produced is also converted to intensive management. The elm seedling-sapling size class is converted to intensive management at the juncture between poletimber and sawtimber.

With run B, there is a movement toward less intensive management. On adequate condition classes, there is a trend toward conversion to intensive management at later time periods. In region 1, the maple-beech-birch seedling-sapling size class converts to intensive management at the juncture between poletimber and sawtimber rather than at the present. The same is true for the oak seedling-sapling size class in regions 2 and 4. There are no changes in classes requiring timber stand improvement. In classes where stand condition classes are combined and which can also produce merchantable timber, there is also a trend toward less intensive management. Some of the acreage of the conifer poletimber size class in region 3 remains in current use while some converts to intensive management. In run A, all the acreage of the conifer poletimber class converts to intensive management. There is also a change toward less intensive management when both condition classes are combined and no merchantable timber can be produced. All of the elm seedling-sapling size class acreage remains in current use. In run A, all of this acreage is converted to intensive management at the juncture between poletimber and sawtimber size classes.

In run C, there is a movement toward less intensive management of some classes and toward more intensive management in other classes relative to A. In the adequate condition classes, the changes are the same as B. In the stands requiring timber stand improvement there is a movement toward more intensive management. The oak poletimber size class converts from current use to intensive management, while in run A it remains in current use. When both condition classes are combined and merchantable timber can be produced, there is no change from run A. When no merchantable timber can be produced, there are changes in both directions. In region 2, the elm seedling-sapling class remains in current use while remaining from current use to intensive management in run A. The conifer poletimber size class converts from current use to intensive management, while remaining in current use in run A.

Run D has only one change as compared with C. In region 2, only a portion of the acreage of the oak poletimber size class in the condition class requiring timber stand improvement is converted from current use to intensive management. The remaining acreage is in current use. In run C, all the acreage of this class is converted from current use to intensive use.

Run E moves toward more intensive management of non-timber-producing lands than run A. All changes are made in classes where both condition classes are combined and no merchantable timber can be produced. In region 2, the oak poletimber size class converts from current use to intensive management. In run A, this class remains in current use. In region 3, the oak seedling-sapling size class converts from current use to intensive management at the juncture between poletimberand sawtimber. In run A, this class remains in current use. In region 4, the oak poletimber size class converts from current use to intensive management. In run A, this class remains in current use.

Timber-producing management strategies also produce big and small game hunterdays. In general, more hunterdays are produced with intensive management than with current use. Non-timber-producing management strategies will react to changes in intensity of management on timber-producing lands and specifically to changes in production and time distribution of production of hunterdays from timber-producing management strategies. Timber-producing management strategies do not produce enough hunterdays to meet requirements. Non-timber-producing management strategies produce the remaining quantities of hunterdays needed to satisfy hunterday requirements. Given fixed demands for hunterdays, intensity of managing non-timber-producing lands should decrease as intensity of timber management increases. This result should occur because the production of hunterdays increase on timber-producing lands as management becomes more intensive. With fixed requirements, fewer hunterdays must be produced on non-timber producing lands to meet hunterday requirements. As a result, the non-timber-producing lands can be managed less intensively. This result occurs in run B. Management of nontimber-producing lands will also react to changes in time distribution of timber-producing lands to meet the requirements for hunterdays.

Total import potential is not utilized. Maximum production of hunterdays in the river basin does not occur. As a result, there is an important trade-off between costs of importing and development costs. Development costs are costs of converting lands from current use to intensive management in order to increase production of goods to meet requirements. In some cases, it may be cheaper to import than to intensify management of non-timber-producing lands. In other cases, it may be cheaper to intensify management than to import. Problems associated with the time distribution of production may complicate the trade-off, however.

All adequate condition class stands are converted to intensive management in run A. This occurs because development costs are zero. It costs no more to convert lands to intensive management than to leave them in current use. According to Forest Service personnel developing these coefficients, the basic difference is landowner intent concerning how to use these lands. It is difficult to see, however, how landowner intent changes land productivity unless some positive, costly action is taken. The problem of time distribution seems to explain why the oak seedling-sapling class converts at a later time in region 1 than the other regions in run A. Different time distributions of production are possible in these adequate condition class stands at the same costs. Therefore, more than one optimal solution is possible for a given set of requirements. Surpluses could be produced in earlier time periods at the same cost if all conversions of seedling-sapling classes took place at the present.

The problem of importing versus conversion to intensive mangement becomes more important on non-adequate stand condition classes in run A. Region 4 exports hunterdays; there is no need to incur development costs to increase production to meet requirements in that region. Region 1 imports hunterdays, but no conversion of these lands to intensive management occurs. It would seem that the costs of importing hunterdays is too cheap to justify incurring development costs to intensify production to meet requirements in region 1.

The model forces some of the non-adequate stand condition classes into intensive management. Big-game hunterdays are imported from inside and outside the basin. Flows of all goods will be discussed in a later section. Small game hunterdays are imported only from inside the river basin. It would seem that some importing costs are high enough to cause conversions to intensive management to occur. Costs of importing small game hunterdays are greater than costs of importing big game hunterdays. Also, small game hunterdays are not imported from outside the river basin. It would seem that the costs of importing small game hunterdays cause development costs to be incurred to intensify management. It is cheaper to incur development costs to intensify management than to import small game hunterdays from outside the region.

The model also forces non-adequate stand condition classes into intensive management in region 3. This region imports big game hunterdays in some time periods from region 4 but exports them in time period 6. Small game hunterdays are imported from inside and outside the river basin. This region is farther from big game hunterday exporting regions outside of the river basin than small game hunterday exporting regions outside of the river basin. It would appear that the conversion of non-adequate stand condition classes into intensive management is needed to meet requirements for big game hunterdays at lower cost.

It appears that land productivity, development costs, importing costs, and the time distribution of production all seem to be important factors in converting non-adequate stand condition classes to intensive management. The resulting pattern is difficult to explain. The problem of joint production associated with linear programming may complicate the pattern of land management. It is important, however, to point out that

that there is a spatial differentiation of land management patterns of non-timber-producing lands in the non-adequate stand condition classes. Costs of importing, an important factor in bringing space into this model, appear to have an impact on "optimal" land management patterns because they trade-off with development costs.

In run B, there is more intensive timber management activity resulting from growth in timber requirements in region 2. There is no growth in hunterday requirements. Non-timber-producing lands move into a less intensive state of management. Changes in time distribution of hunterday production by timber-producing management strategies result in later conversions to intensive management thereby reducing surpluses of hunterdays in earlier time periods. As stated earlier, more hunterdays could be produced at the same cost on adequate condition classes. Non-adequate stand condition class stands changed to current use in regions 2 and 3 in order to decrease development costs while meeting requirements for hunterdays.

In run C, the only difference as compared with run A occurs in the non-adequate condition classes. Some changes are toward more intensive management while others are toward less intensive management. This result reflects a change in the time distribution of hunterday requirements. Requirements are higher in later time periods. Also, region 4 begins to import small game hunterdays thus decreasing its export potential. As a result, more production at later time periods is required in both regions 2 and 3. The cost of intensive production seems to be less than the cost of importing.

In run D, there is a slight change in the management pattern as compared with run C. A small portion of the acreage of oak poletimber size class in the non-adequate stand condition classes remains in current use, while the remainder is converted to intensive management. This change is not easily explained.

In run E, the management of non-timber-producing lands is more intensive than in the case of run A. All increases in management intensity beyond the situation in run A occur in classes where both condition classes are combined. More intensive production is needed to meet growth in hunterday requirements. The model forces some of the acreage of non-adequate stand condition classes into intensive management for the first time in region 4. Regions 2 and 3 also increase intensity of management. Both regions 2 and 3 import from region 4. It appears to be cheaper to intensify management in regions 2, 3, and 4 than to import from outside the river basin. Region 1 continues to import from outside the river basin without intensifying management. It appears to be cheaper to import hunterdays than to intensify management to increase production of hunterdays.

Run E shows that it is cheaper to intensify management of non-timber-producing classes of land than on timber-producing classes of land in order to meet increases in hunterday requirements when timber requirements remain constant. In this way timber harvesting costs are not incurred. In order to minimize costs, the model converts land in condition classes requiring timber stand improvement with relatively low development costs from current use to intensive management.

Factors Affecting Location of Activities

Patterns of managing timber-producing classes of land do not vary between regions. Timber requirements are high relative to the productive capacity of the land. If timber requirements are to be met, all classes of timber-producing land must be managed intensively. In runs A and E, surpluses of timber are produced in time periods 4 and 5. As a result, the aspen-birch seedling-sapling size classes are removed from timber production. In runs B, C, and D which produce no surpluses of timber, the aspen-birch seedling-sapling size classes are converted to intensive management. To meet these high levels of timber requirements, regions must import timber, if possible, and timber-producing lands must be managed intensively. The only factor which differentiates the spatial distribution of management strategies is the spatial distribution of land resources. Important factors that determine the pattern of management are development costs, harvesting costs, the time distribution of production, and the level of timber requirements over time.

The patterns of managing non-timber-producing lands are more complex. There is differentiation of patterns of management between regions. Non-timber-producing management strategies produce the residual of hunterdays not produced by timber producing management strategies to meet hunterday requirements. Spatial factors besides the distribution of land resources seem to be important. Transportation costs become an important factor. There is a trade-off between incurring costs of importing goods and incurring development costs to increase production of goods in the river basin. Increasing levels of requirements cause these trade-offs to be made. When a region cannot support its requirements for hunterdays, it must intensify management or import hunterdays, that is, hunters must go outside of the region to hunt. The algorithm used in this model will choose the cheapest way to meet requirements. A region may import all hunterdays available from another region without intensifying management and without satisfying requirements. A trade-off between importing and intensifying must again be evaluated. This trade-off is complicated by the time distribution of production and the problem of joint production of big and small game hunterdays.

The level of requirements is the factor that ultimately determines whether there will be spatial differentiation in patterns of land management. It seems that land management patterns will become more sensitive to transport costs as levels of requirements decrease. Timber requirements are high relative to the productive capacity of the region. Transport costs have no impact on the spatial distribution of land management on timber-producting classes of land. The only variations in the pattern of management are caused by the time distribution of production and the spatial pattern of land resources. Import potentials are depleted in some time periods even at the lowest levels of requirements therefore requiring intensification of management to meet requirements regardless of cost. At lower levels of timber requirements, production potential is greater than requirements in some time periods. As a result, aspen-birch seedling-sapling classes are removed from production to avoid harvesting costs. However, as soon as there is growth in requirements, the most intensive form of management is required. Importing potentials are depleted so that management becomes more intensive to meet timber requirements. In fact, even the most intensive form of management cannot meet these requirements.

Requirements for hunterdays, however, are low relative to the productive capacity of the land. As a result, costs of intensive management must be compared to costs of importing. Intensive management will be located in areas with relatively high requirements in order to lower transportation costs. The trade-off between costs of importing and costs of intensive management is important only when the capacity to import has not been depleted. However, given a level of development costs, intensive management becomes more attractive as the costs of importing increase.

Receipts of Goods

The amount of goods received at each region in the basin will be discussed in this section. Surpluses above and deficits below requirements will be pointed out. Appendix EE contains the deficits and surpluses.

In runs A and E, all requirements were met in all time periods and regions. There was a surplus of timber in regions 1 and 4 in time period 5. In run B, there were deficits of timber in region 2 in time periods 2 through 6. All other timber requirements were met. The deficit of timber in region 2 brings about the change in management of aspen-birch seedling-sapling size classes from environmental emphasis to intensive management. There was a surplus of hunterdays in region 4 in time period 1. In run C, there is a deficit of timber in region 1 in time period 3 and region 2 in timber periods 2 through 6. All other timber requirements are met. All requirements for hunterdays are met. There is a surplus of small game hunterdays in region 4 in time period 1. In run D, there are timber deficits in region 1 in time periods 3, 4, and 6 and region 2 during time periods 2 through 6. All other timber requirements are met. All requirements for hunterdays are met. There is a surplus of small game hunterdays in region 4 in time period 1.

Timber deficits in runs B, C, and D indicate that if projected timber requirements are to be met, timber purchases will have to be made from areas outside of the regions included in this analysis during certain time periods. Region 2 will have to make these purchases in time periods 2 through 6 in runs B, C, and D. These deficits indicate that the pulp-mill in region 2 might have difficulty in obtaining timber supplies to expand pulp-making capacity. Region 1 would have to make these purchases in time period 3 in run C and time periods 3, 4, and 6 in run D. Timber surpluses in runs A and E are of short duration. These surpluses represent an export potential for that time period rather than an opportunity for growth of timber-using industries. These surpluses occur in regions 1 and 4 in time period 5 in runs A and E. Hunterday surpluses indicate possibilities for increased consumption by people in the region or an export potential. These surpluses are of short duration. The surpluses are in region 4 in time period 1 in runs B, C, and D. All these surpluses remain in the region in which they were produced. The algorithm minimizes costs by not incurring transportation costs.

Production

The actual quantities of goods produced will not be presented in this section, but rather are shown in Appendix FF. Tables will be used to show the orders of runs in the production of various goods. First, production in the river basin will be discussed. Next, production in the regions will be discussed.

River Basin Production

Table 4-1 ranks each plan according to the amount of each commodity produced in each time period.

In order to make comparisons of the runs easier, a rating system was used to evaluate these patterns over time. Each run receives a rank of 1 through 5 in each time period. A rank of 1 goes to the run with the highest production of the commodity in the time period. A rank of 5 goes

Table 4-1.--Ranking of Runs for Production of Commodities in the Kalamazoo River Basin

Time	Timber	Big Game Hunterdays	Small Game Hunterdays	Erosion
1	A=B=C=D=E	E>A>C>D>B	D>C>B>A>E	B>C>A>E>D
2	A=B=C=D=E	D>C>B>A>E	D>B>C>E>A	A>C>D>E>B
3	A=B=C=D=E	C>D>E>B>A	D>C>B>E>A	A>E>C>D>B
4	B=C=D>A=E	C>D>E>B>A	C>D>B>E>A	E>A>C>D>B
5	B=C=D>A=E	D>C>E>A>B	C>B>D>A>E	A>E>C>D>B
6	A=B=C=D=E	E>C>D>A>B	B>C>D>E>A	A>E>C>D>B

to the run with the lowest production in the time period. The rank of the run in time periods 1 through 6 is summed to get a total score and the run with the lowest total score gets a rank of one. Each successively higher score gets the next highest rank up to 5. Each time period is weighted equally in this rating system. These rankings are calculated for each commodity. Table 4-2 contains these ratings.

Table 4-2.--Ranking of Total River Basin Production for Each Commodity.

Commodity	Ranking
Timber	B=C=D>A=E
Big Game Hunterdays	B>D>E>A>B
Small Game Hunterdays	C=D>B>A=E
Erosion	A>E=C>D>B

Regional Production

The relative levels of production of all commodities in all time periods in all regions will now be discussed.

Timber. Runs A and E are identical in all time periods. Runs B, C, and D are identical in all time periods. The only difference between the two groups is that production is greater in the fourth and fifth time periods for runs B, C, and D than runs A and E.

Big Game Hunterdays. This pattern is more difficult to describe. There is much more differentiation in time and space than with timber production. Table 4-3 gives these rankings for the four regions in each time period. Because of the large volume of information, these results are not contained in an appendix. The same ranking used to rank river

Table 4-3.--Ranking of Big Game Hunterday Production by Run in Each Time Period.

Time	1	2	3	4
1	B=C=D>A=E	E>A>C>D>B	A=B=C=D=E	E>A>C>D>B
2	B=C=D>A=E	E>A>C>D>B	A=E>C=D=B	E>C>D>B>A
3	B=C=D>A=E	C>D>B>E>A	C=D>D>E>A	C>D>B>A>E
4	D=C=D>A=E	C=D>E>B>A	C=D>B>E>A	D>C>E>B>A
5	B=C=D>A=E	C>D>E>A>B	C=D>E>B>A	D>E>C>B>A
6	B=C=D>A=E	C>D>E>A>B	C=D>B>E>A	E>C>D>B>A

basin production over time was used to rank regional production. The results of this ranking are presented in Table 4-4.

Table 4-4.--Ranking of Overall Big Game Hunterday Production by Run for Each Region.

Region	Ranking
1	B=C=D>A=E
2	C>D=E>A>B
3	C=D>B>E>A
4	C=E>D>B>A

Small Game Hunterdays. This pattern of production is also difficult to explain. There is much differentiation of production in time and space. The pattern of small game hunterday production is different that the pattern of big game hunterday production. Table 4-5 illustrates the ranking for each region in each time period. Because of the large amount of data, these results are not contained in an appendix. Each run was ranked

Table 4-5.--Ranking of Small Game Hunterday Production by Region for Each Time Period.

	Region			
Time	1	2	3	4
1	B=C=D>A=E	C>D>B>E>A	B=C=D>A=E	A>D>C>B>E
2	B=C=D>A=E	E>A>C>D>B	B=C=D>A=E	D>B>E>C>A
3	B=C=D>A=E	C>D>B>E>A	D>B>C>A>E	C>D>B>E>A
4	B=C=D>A=E	C>D>E>A>B	C=D>B>E>A	C>D>B>E>A
5	B=C=D>A=E	C>B>D>E>A	B=C>A>D>E	B>C>D>E>A
6	B=C=D>A=E	D>C>B>E>A	B>C=D>E>A	C>D>B>E>A

for each region by using the same method used in the previous two sections. These results are shown in Table 4-6.

Table 4-6.--Ranking of Small Game Hunterday Production Over All Time Periods for Each Region.

Region	Ranking
1	B=C=D>A=E
2	C>D>B>E>A
3	B=C>D>A>E
4	C=D>B>E>A

<u>Erosion</u>. Regions one and three have identical patterns. Regions two and four are more difficult to describe. Table 4-7 ranks the production of erosion in each time period for each run. Because of the large amount of information, these results are not contained in an appendix. The overall production of erosion was also ranked. The ranking is

presented in Table 4-8.

Table 4-7.--Ranking of Production of Erosion by Run in Each Time Period.

	Region		
Time	1,3	2	4
1	A=E>B=C=D	B=C=D>A=E	B=C=D>A=E
2	A=E>B=C=D	C>D>B>A>E	A>E>B=C=D
3	A=E>B=C=D	A=E>C>D>B	A>E>B=C=D
4	A=E>B=C=D	C>D>E>A>B	A>E>C>D=B
5	A=E>B=C=D	C>D>E>B>A	A>C>B=D>E
6	A=E>B=C=D	C>D>B>E>A	A>C>B=D>E

Table 4-8.--Ranking of Production of Erosion Over All Time Periods for Each Run in Each Region.

Region	Ranking
1,3	A=E>B=C=D
2	D>C>B>E>A
4	A>C>B=D>E

OBERS Demands

The river basin cannot meet Series C OBERS demands for sawtimber removals as calculated by the Economic Research Service (Economic Research Service, personal correspondence, 1975). Series C projections are relatively low projections compared to other series. The only run made which included OBERS demands as constraints was found to be infeasible. Table 4-9 lists OBERS demands by time period and the production in those time periods in the infeasible run. OBERS demands are met only in time period 6. Infeasibilities occur in time period 1 in regions 2, 3, and 4 and time period 3 in regions 3 and 4.

Table 4-9.--OBERS Demands and River Basin Production in the Infeasible Run.

Time	OBERS Demand (cf)	Basin Production (cf)
1	4,956,100	4,899,604
3	5,718,506	5,334,562
6	5,439,500	6,145,187

Source: Economic Research Service; personal correspondence, 1975.

Runs in which OBERS demands are not active cannot meet these requirements either. Runs A through E have identical results in time periods 1, 3, and 6. These results are listed in Table 4-10. Runs A through

Table 4-10.--River Basin Timber Production in Time Periods 1, 3, and 6 for Runs A Through E.

Time	Basin Production
1	4,545,604
3	3,366,448
6	6,145,187

E fall short of OBERS demands in time periods 1 and 3. These results show, however, that the time distribution of production of timber can be changed.

Flows of Goods Between Regions

The transportation component is the mechanism through which production requirements are allocated over space. The flows of goods between regions will be a function of the production and the time distribution of production in regions, costs of production, requirements and growth of regional requirements, transport costs, and surpluses and deficits of commodities in regions outside of the river basin. The actual volumes of the flows are not contained in an appendix because of the large amount of information.

Timber

Run A is the baseline run to which all other runs are compared. Regions from which goods are imported and to which goods are exported were identified by time period. However, actual quantities are not shown to conserve space. Table 4-11 indicates origin regions from which a region imports timber and destination regions which export timber, by time period.

Table 4-11.--Exports and Imports of Timber for Run A.

Region	Imports From Region	During Time Periods
1	9	1
	10	2-4
2	1	2,3,4,6
	3	1-6
	4	1-6
	8	1-4,6
	11	1-3
	12	1-4
3,4	-	-

Region	Exports to Region	During Time Periods
1	2	2-4,6
2	-	-
3	2	1-6
4	2	1-6

Region 2 imports only. Regions 3 and 4 export only. Region 1 imports and exports simultaneously in time 2 through 4. This pattern must be caused by a slight cost advantage such that it is cheaper to move goods to region 2 through region 1. Region 2 imports from all other regions in the river basin. Imports to region 2 decrease in time period 5 due to relatively high production. Region one does not import in time period 5. Regions 3 and 4 appear to be preferred importing regions over region 1. Region 1 exports to region 2 only in poorer production years. High production in regions 3 and 4 in time periods 5 and 6 result in imports from regions 11 and 12 stopping while imports from region 8 continue. It appears that region 8 is preferred to regions 11 and 12 for importing by region 2, because the costs of importing from region 8 are lower than the costs of importing from regions 11 and 12.

Changes in the importing and exporting factors brought about in run B are shown in Table 4-12.

Table 4-12.--Changes in Imports and Exports of Timber in Run B.

Region	Imports From Region	During Time Periods
1	10	2-6
2	1	3-6
	9	1
	11	1-6
	12	1-6
4	8	5

Region	Exports To Region	During Time Periods
1	2	3-6

These results show the importance of changes in requirement growth and production patterns. Region 5 is no longer a surplus region because of growth in pulpwood requirements. Region 4 imports from region 8 while exporting its total product to region 2. Total requirements in region 4 in time period 5 are imported from region 8. Total quantities of timber moving to region 2 increase because of increased requirements in that region over time. Import potentials are exhausted.

Changes in the import and export potential brought about in run C are shown in Table 4-13. Requirement growth in all regions and reduction in import potentials change the pattern of imports and exports. Import potentials are exhausted earlier. Region 1 imports from region 11 in time period 2.

Table 4-13.--Changes in Imports and Exports of Timber in Run C.

Region	Change in Imports From Region	During Time Period
1	10	2-6
	11	2
2	1	3-6
	9	1
	11	1-6
	12	1-6
4	8	5

Region	Change in Exports To Region	During Time Period
1	2	3-6

The changes in the import and export pattern brought about by run D are shown in Table 4-14.

Requirements increase in run D and reduce surpluses available for importing even further. Less timber is imported from outside regions as a result. Region 10 can export only in time periods 1 and 2. Region 8

Table 4-14.--Changes in Exports and Imports of Timber in Run D.

Region	Change in Imports From Region	During Time Period
1	10	2
	11	2
2	1	5
	8	1-3
	11	1-6
	12	1-6

Region	Change in Exports To Region	During Time Period
1	2	5

can export only in time period 1 through 3. These increases in requirements result in regions in the the river basin exporting less in order to meet their own requirements.

Run E is identical to run A. Requirements and timber production are identical, so the flow patterns should be identical.

Big Game Hunterdays

Run A is again the baseline run. The pattern of imports and exports of big game hunterdays is presented in Table 4-15. Regions 1, 2, and 3 import, while region 4 exports to regions 2 and 3. Region 3 exports to region 2 in time period 6. Regions 5, 7, and 9 are the only regions outside of the river basin with surpluses. Regions 5 and 9 seem to be preferred by region 1 which does not import from regions inside the river basin. Region 2 prefers to import from regions 2, 3, and 9. Region 3 imports only from region 4. Region 3 has a surplus to export to region 2 in time period 6.

Table 4-15.--Big Game Hunterday Imports and Exports in Run A.

Region	Imports From Region	Time Periods
1	5	1-6
	7	5
	9	1-4,6
2	3	6
	4	1-6
	9	1-6
3	4	2-5
4	-	-
Region	**Exports To Region**	**Time Periods**
3	2	6
4	2	1-6
	3	2-5

The changes brought about by run B are illustrated in Table 4-16.

Table 4-16.--Changes in Imports and Exports of Big Game Hunterdays Brought About by Run B.

Region	Change in Imports From Region	During Time Period
2	3	-
3	4	2-4
Region	**Change in Exports To Region**	**During Time Period**
3	2	-
4	3	2-4

This pattern reflects a surplus of production in region 3 in time period 5 without an increase in requirements. The surplus results from more intensive timber production.

The changes in the import and export pattern brought about by run C are illustrated in Table 4-17.

Table 4-17.--Changes in Imports and Exports of Hunterdays Brought About by Run C.

Region	Changes in Imports From Region	During Time Period
1	5	1,2
	7	4-6
	9	1-3
2	1	2-6
	3	-
	4	1,6
	9	1-6
3	4	2-6
4	5	6
Region	**Changes in Exports To Region**	**During Time Period**
1	2	2-6
3	2	-
4	2	1-6
	3	2-6

Region 5 exports only in time periods 1 and 2 because of increases in requirements for hunterdays. Region 7 picks up the slack. Region 1 begins to export to region 2. Region 3 ceases to export and must import in all time periods. Region 4 begins to import in time period 6. Increases in requirements for hunterdays cause the river basin regions to import more.

Changes brought about by run D on the pattern of imports and exports are shown in Table 4-18. These changes are rather surprising since the pattern of production is similar to run C while requirements at all locations remain the same.

Table 4-18.--Changes in Imports and Exports of Big Game Hunterdays Caused by Run D.

Region	Changes in Imports From Region	During Time Period
1	5	1,2
	7	3,5,6
	9	1-3
2	1	3-6
	3	-
	4	1,5,6
	9	1-6
3	4	2-6
	5	6
Region	**Changes in Exports to Region**	**During Time Period**
4	2	1,5,6

Changes in the imports and exports of big game hunterdays caused by run E from run A are shown in Table 4-19. Region 4 begins to import in time period 6. Region 3 imports for a longer period of time. These changes reflect increases in requirements for big game hunterdays without increasing demands for timber. A different pattern of production develops as a result.

Small Game Hunterdays

Run A is again the baseline run. Table 4-20 illustrates the pattern of imports and exports. Region 1 imports and exports simultaneously. Region 1 imports only from outside regions. Region 2 imports from regions 1, 3, and 4 inside of the river basin and from region 8 outside of the river basin. Region 3 imports and exports simultaneously. Region 3 imports from inside and outside the river basin. Region 4 exports to

Table 4-19.--Changes in Imports and Exports of Big Game Hunterdays Caused by Run E.

Region	Changes in Imports From Region	During Time Period
1	5	1,2
	7	3
	8	6
	9	1,2,5
2	1	2-6
	4	1,6
3	4	2-6
4	5	6

Region	Changes in Exports To Region	During Time Period
1	2	2-6
4	2	1,6
	3	2-6

Table 4-20.--Imports and Exports of Small Game Hunterdays in Run A.

Region	Imports From Region	During Time Period
1	9	1-6
2	1	1
	3	2-6
	4	1-6
	8	1
3	4	1
	8	1-6
4	-	-

Region	Exports To Region	During Time Period
1	2	1
3	2	2-6
4	2	1-6
	3	1

regions 2 and 3. The only imports into the river basin come from regions 8 and 9. Regions 1 and 2 export small game hunterdays to each other simultaneously. This result is difficult to explain. A problem in model specification or in the solution algorithm could be possible causes of this result.

The changes in the import and export pattern brought about by run B are illustrated in Table 4-21. The river basin imports fewer small

Table 4-21.--Changes in the Pattern of Imports and Exports of Small Game Hunterdays Caused by Run B.

Region	Changes in Imports From Region	During Time Period
2	8	-
3	8	2-6

game hunterdays. Requirements for hunterdays have not increased. Increased timber production increases production of small game hunterdays.

The changes in patterns of imports and exports that occur in run C are illustrated in Table 4-22. Region 4 ceases to export after time period 1 and begins to import. Region 1 and 2 again import from each other in time period 1. Regions 1 and 4 increased importing from region 8. Region 1 exports to region 2 while importing from regions 8 and 9. This change in the pattern of imports and exports reflects the increase in requirements for hunterdays. Import potentials are decreased. Regions must keep more of the production in the region to satisfy requirements. As a result importing is increased.

The changes in import and export patterns brought about in Run D are shown in Table 4-23. Region 1 increases importing from region 2 in

Table 4-22.--Changes in the Pattern of Imports and Exports Caused by Run C.

Region	Changes in Imports From Region	During Time Period
1	2	1
	8	2-6
2	1	1-6
	4	1
4	8	2-6

Region	Changes in Exports To Region	During Time Period
2	1	1
4	2	1

Table 4-23.--Changes in the Pattern of Imports and Exports of Small Game Hunterdays Caused by Run D.

Region	Changes in Imports From Region	During Time Period
1	2	1,5
2	1	2-6
	4	3
	8	-
3	4	1
	8	2-6
4	8	3-6

Region	Changes in Exports To Region	During Time Period
1	2	2-6
2	1	1,5
4	2	3

time period 5. Region 4 exports to region 2 in time period 3 while importing from region 8. Region 2 imports from region 1 in time periods 2 through 6. This change in pattern is rather surprising. The level of requirements is the same as run C and the pattern of production is similar.

The changes in the patterns of imports of hunterdays are caused by run E are shown in Table 4-24. Region 2 imports from region 1 during more time periods than run A. Region 2 also imports from regions 3 and 4 over fewer time periods. Region 3 ceases to import from region 4.

Table 4-24.--Changes in the Patterns of Imports and Exports of Small Game Hunterdays Caused by Run E.

Region	Changes in Imports From Region	During Time Period
2	1	1-6
	3	1-4
	4	2
3	4	-

Flows

An important observation is that the river basin does not export to regions outside of the river basin. All surpluses stay in the river basin. It appears that the only way to cause surpluses to be exported is to require that exports occur when defining the inequalities.

There appear to be some important factors affecting the pattern of flows. The most obvious factor is transportation costs, one aspect of the objective function to be minimized. The growth of requirements and the availability of imports over time are also very important. These two factors determine how much of a commodity can be imported into the river basin and how much of a commodity is required at any location. The time pattern of production is also an important factor. The time pattern of production determines how much of a commodity is available in the region to transfer to other regions. Production, however, is a function of the requirements at the various locations, the availability of imports, the levels of transportation costs, and the levels of production costs. As stated previously, the allocation of management strategies appears to be sensitive to the relative levels of transportation costs and development costs.

Costs

The objective function was adjusted by subtracting the costs of meeting deficits in requirements from the pools of extra supplies. The costs of importing goods into the river basin, the costs of transporting goods within the river basin, and the costs of producing goods were calculated. These costs are presented in Table 4-25. It is important

Table 4-25.--Costs Incurred in the River Basin for Each Run.

Run	Costs of Importing	Transport Costs in the Basin	Production Costs in the Basin
A	15,535,952.18	13,677,593	237,284,833.54
B	22,534,487.63	14,606,691	238,667,515.30
C	21,207,846.19	14,925,737	239,105,766.80
D	17,959,466.68	14,827,427	238,697,590.30
E	16,862,907.50	14,224,689	237,551,699.50

to realize that the costs of importing in runs B, C, and D are underestimated because the requirements for timber are not being completely met at these costs.

The impacts of run E on costs relative to A are discussed first.

Hunterday requirements increase while timber requirements remain constant over time in run E. Importing costs are greater in run E than in run A. More costs are incurred by people living in the river basin to leave the river basin to hunt. However, it is difficult to estimate the amount spent in the river basin and the amount spent outside of the river basin. Itemizing of costs would be required to become more specific. However, even then it would still be difficult to state how much of the total import bill was spent inside and outside of the river basin. Itemizing would increase the size of the linear programming matrix which would eventually cause problems with the amount of computer core available and this could increase costs. Non-transportation costs spent outside of the river basin are not taken into account. Improved analysis of leakages of money due to importing would probably be better carried out as a side study rather than attempting to handle all aspects within the linear program. In that way actual patterns of spending could be studied with the results being applied to costs generated by the model.

The costs incurred in the river basin are greater for run E than run A. This reflects more intensive management of land and increased flows of hunters between regions in the river basin. Both transport and production costs are greater in run E than in run A. A major problem is that the means by which landowner costs are to be covered is not specified. Landowners might not invest in land strictly for wildlife purposes unless they can charge for hunting, receive financial assistance, or receive a tax break.

The costs of runs B, C, and D relative to A are now discussed. In these runs, timber requirements are increased over run A. However, importing costs in these runs do not account for costs of importing from regions outside of the area of analysis to meet timber requirements. Deficits are greatest in run D, run C is in the middle, and run B involves the smallest deficits. More costs will have to be incurred to meet deficits such that run D will have greater importing costs than run C which in turn will have greater costs than run B. In these runs, it is also difficult to determine who is receiving the importing costs and where they are located. First, both costs of importing hunterdays and timber is combined. Second, the location of haulers and cutters is not specified. Third, the cost of harvesting timber in outside regions are combined with the costs of transporting the timber into the river basin. These problems probably would be handled best outside of the model.

Run C has greater costs within the region than run D which in turn is greater than run B. Both transport and production costs in the river basin follow this trend. It would seem that runs C and D should have very similar costs since production patterns are similar. The handling of deficits may have an impact. There are,as a result,fewer flows between regions as requirements increase. Flows decrease because more of the production is needed to satisfy the producing region's requirements. More timber must be imported. Much of this importation is handled by the pool of extra supplies.

The implication is that the order of importing costs for these five runs is, from highestto lowest: D, C, B, E, and A. Leakages undoubtedly occur while importing. It would seem that leakages would increase as importing increases such that the order of leakages from highestto lowest is also D, C, B, E, and A.

Recommendations for Land Management

Ultimately the purpose of this type of model is to provide recommendations for land management. These recommendations will be based on the results of this study. It appears likely that timber requirements will increase over time. In order to satisfy these requirements in an economically efficient manner as defined in the model, all timber-producing lands in current use management should be converted to a more intensive form of management as soon as possible. All lands in environmental emphasis or intensive management at the beginning of the study remain in those uses as assumed in Chapter III. Lands converted to urban use remain in current use as assumed in Chapter III.

Recommendations for non-timber producing lands are more complicated. Growth in requirements for hunterdays will probably increase. Priorities are set on non-timber-producing lands to satisfy requirements for hunterdays in an economically efficient manner. The first priority on non-timber-producing lands is to convert all adequate condition class lands in current use to intensive management as soon as possible. Lands to be converted to urban use are excluded.

Efforts on non-adequate class lands, the second priority, should be concentrated in regions 2, 3, and 4 on certain key land classes. When there is no growth in timber and hunterday requirements, the elm poletimber class in region 2 and the elm seedling-sapling class should be converted to intensive management while they are in the poletimber size class. In region 3, all conifer poletimber classes in non-adequate condition classes and the elm seedling-sapling class should be converted to intensive management while they are in the poletimber size class. All lands to be converted to urban use are excluded.

Changes in management guidelines must be made when timber requirements increase. When timber requirements increase in region 2 and all others remain constant over time, the elm seedling-sapling class remains in current use rather than being converted to intensive management as occurs when there is no growth in timber requirements. When there is growth in both timber and hunterday requirements, other changes are made from when there is no growth. The oak poletimber class requiring timber stand improvement to be converted to intensive management converts to intensive management in region 2. In region 4, the conifer poletimber class which produced no merchantable timber is converted to intensive management.

Changes in the pattern of land management caused by increasing wildlife requirements over time while keeping timber requirements constant are contrasted with the land management pattern associated with no growth in requirements. In region 2, the oak poletimber class producing no merchantable timber is converted to intensive management while it is in the poletimber class. In region 3, the oak seedling-sapling class producing no merchantable timber should be converted to intensive management when the stand is in the seedling-sapling class. In region 4, the elm seedling-sapling class should be converted to intensive management when the stand is in the poletimber class. The oak poletimber class which can produce no merchantable timber should be converted to intensive management while it is still in the poletimber class.

It is important to point out that the conversion to intensive management of non-timber producing lands in the adequate condition classes takes place earlier than conversions to intensive management on non-adequate class lands. Conversion of adequate condition class lands should take place at the earliest possible times, according to the results of the model. Seedling-sapling classes on non-adequate condition class lands that are converted to intensive management are converted after they grow into the poletimber size class.

These recommendations are based on the period of analysis and the selected discount rate. Increasing the time period of analysis will increase the number of resource classes which are capable of producing timber. Forestland in the non-timber-producing classes in one time period of analysis can become timber-producing in a longer time period of analysis. The impact of lengthening the time period could be to increase the number of classes of land in current use which should be converted to intensive management as soon as possible, assuming the same trends of requirements used in this study. However, a smaller percentage of remaining non-timber-producing lands might be converted to intensive management. Hunterday requirements might be supplied more completely on timber-producing lands. Lands which are not capable of producing merchantable timber, than, might not receive any intensive management if the time period of analysis is lengthened. Increasing discount rates, given a time period of analysis, will encourage postponement of investments in land.

Impacts of Land Management on Regional Growth

Some growth in timber-using industries in the region can be accommodated by intensifying management, given the technologies assumed in this analysis. The relatively small amount of commercial forest land, the conversion of forest land to urban use, and the status of land tenure limits possibilities for growth in the timber-using industries. Much growth in wood consumption in the river basin is supplied by importing from outside of the river basin and from outside of the 12 region area of analysis.

Increasing output from the pulpmill in the river basin, the Menasha Corporation, would seem to be severely limited. Growth of this firm would have to be supplied increasingly by timber in the northern lower peninsula of Michigan outside of the 12 region area of analysis. This would appear to put the Menasha Corporation at a competitive disadvantage relative to other mills located closer to the timber resource. This firm's profit margin would decrease relative to the other firms due to the longer hauling distances. Given the weight losing characteristics of timber-using industries, growth in these industries would probably be encouraged closer to the large timber esource in the northern lower peninsula of Michigan. It would seem that output of the Menasha Corporation would increase at a rate lower than the outputs of other firms in the lower peninsula. Factors that might combat this trend could be the availability of labor and capital and economies of scale. Short-rotation popular culture might rapidly increase supplies of pulpwood in the region by taking advantage of sub-marginal farmland. The potentials for growth of pulpmills could be encouraged as a result.

Growth of smaller operations could probably be accommodated. These smaller mills produce specialty products and use hardwoods for the most part. While the supply of timber is limited, high quality hardwood timber can be produced because of the climate and the fertility of the soil. Increased silvicultural practices could improve the quality of the timber produced and concentrate growth in higher quality trees.

There appears to be much potential to increase the supplies of hunterdays, given the information and assumed technologies in the model.

Supplies, it appears, could be increased faster than projected population growth, both through intensive management and importation. Surpluses could be easily created in earlier time periods. The basic problem is providing incentives to the landowner to manage his woodlot and to provide access to the public.

Applicability of Results to Other River Basins

It appears difficult to apply the results of this study to other river basins. The most productive lands, it would seem, still ought to be converted to intensive management as early as possible (that is, the adequate condition class lands). The marginal classes of non-adequate forest land to be converted from current use to intensive management which were defined in this study cannot be applied to other river basins. The marginal class of forest land will vary from river basin to river basin. Each river basin will have its unique set of location factors. The level of requirements of different commodities relative to the productive capacity of the land probably will not be the same from river basin to river basin. Given projected high levels of demand for timber products by the U.S. Forest Service, timber producing land ought to be converted to intensive management as soon as possible. The productivity and spatial distribution of land resources will not be the same for every river basin. The costs of transportation and the transportation network will be different for each river basin. Development costs might vary by ecosystem and land type. The location and levels of requirements will also vary. There are a large number of spatial features unique to every region that can affect the spatial distribution of land management strategies. The presence of these factors which are unique to every region makes it difficult to apply these results to other river basins.

Discussion of Problems Encountered During Testing

Problems in Using the Model

Silvicultural practicies to change the age or size distribution of stands and forests were not considered in the model. Impacts of prices and costs on desired rotation lengths, desired stocking levels, and merchantable tree diameters and forms were not considered. It may be desirable to include such factors to meet various demands over time and to meet forest management goals for area and age distributions. Including such factors, however, would increase the size of the linear programming matrix and could, perhaps, cause problems by exceeding computer core limits. Sustained yield of the entire river basin was not an explicit goal because of the nature of land tenure. With a large number of small tracts owned by a variety of people, the concept of sustained yield management of the entire river basin might mean little to the owner, given his time preferences and scale of production. The conversion of forest land to urban use also discourages this point of view.

It is difficult to interpret costs from the cost equations defined in the model. The costs of importing individual goods could not be obtained since all costs were summed. It was also difficult to specify the location of spending. More specific definition of costs could increase the size of the linear programming problem greatly, resulting in computer core limits being exceeded.

Erosion was not constrained for the river basin or for individual regions. As shown in Chapter II, erosion could easily be constrained. However, constraints were difficult to define. The Economic Research Service did not have erosion constraints defined for forest land in its analysis. Economic Research Service personnel indicated that forest land is not an important contributor to erosion in this study. Erosion, thus, was summed, not constrained.

Production surpluses in the river basin were not exported. It appears that the only way to force exporting to occur is to require that a certain amount of a commodity be sent to a region. In this application, regions with negative excess supplies could have been eliminated from the analysis thus reducing the size of the problem.

Changing patterns of production in regions outside of the river basin were not considered. Production was assumed to remain constant in every time period. It was difficult to project production patterns over time in these outside basins due to lack of data, time, and money.

Environmental diffusion relationships were not considered as stated in Chapter III. This component was excluded because of a lack of data, expertise, and time. This could be included as shown in Chapter II. Inclusion, however, could require computer core beyond what is available.

More than one optimal solution is possible in runs B, C, and D. This occurs because development costs on adequate condition class, non-timber producing lands are zero regardless of the time of conversion to intensive management. Surpluses of hunterdays could be produced in some time periods with no changes in total cost. It is difficult to understand, however, why changes in output of hunterdays on these lands would occur with no investment in the land. Forest Service personnel did not provide an explanation for this when the data were obtained. This problem with the optimal solution could be overcome by allowing conversion to intensive management at only one point in time on these adequate condition class, non-timber producing lands.

It was difficult to test alternative structures for the transportation component. When designing these possibilities, it was decided that the OBERS demands would be the requirements for the production component when the transportation component was separate. However, the OBERS demands could not be met. It makes no sense to use existing levels of production because the results would be identical to results already calculated.

The effect of differential access to supplies of hunterdays on privately owned lands was not included. It was assumed that all supplies of hunterdays were accessible by consumers. However, no trespassing signs are commonplace on private lands in Michigan. As a result, supplies available for consumption might be overestimated in this study.

Problems with the Algorithm

APEX I was the linear programming algorithm used on the Control Data Corporation 6500 computer at Michigan State University. Available computer core limits the size of problems that can be solved. The maximum field length on the CDC 6500 at Michigan State is $170{,}000_8$. The recommended field length calculated for this model is $161{,}000_8$. As a result, there is not much room to expand this model while using APEX I. It is, then, difficult to include more regions, time periods, goods, management strategies, environmental relationships, cost equations, or land use sectors.

The only way to overcome this problem on the CDC 6500 is to use APEX II. This algorithm was designed to handle much larger problems. This algorithm is more expensive to run and more difficult to use. Also, few runs have been made at Michigan State using this algorithm. therefore it is reasonable to expect that problems might still exist in APEX II.

There was also a problem with an APEX I option which exists to change the structure of the linear programming initial tableau. The option allows technical coefficients, row constraints, and objective function values in the tableau to be changed. Equations and variables can be added to and deleted from the tableau. The changes are made by requesting the option on the APEX I control card and including the changes at the end of the input deck. There was a bug in the option which required special programming to overcome. Changing the tableau became more expensive and time consuming. As a result, APEX I became less flexible.

Costs of Modelling

Costs of Developing the Model

One year was spent in collecting data and preparing the model for the runs. For approximately six months, twenty hours per week were spent. For the remaining six months, forty hours per week were spent. So, approximately three-quarters of one man-year was spent to implement this model once it was conceptualized. Keypunching was contracted out at a cost of $300. The following tasks were undertaken during this year: 1) collection of data, 2) calculation of coefficients, costs, requirements, and acreage constraints, 3) coding, 4) checking of punched cards, 5) correction of punched cards, 6) creation of card file on tape, 7) rechecking of card file using APEX I, and 8) recorrection of card file and remaking of tape.

Costs of Running the Model

Following are the costs of obtaining the initial infeasible solution which served as a starting basis for runs A through E. Computation costs were at the lowest priority rate group at Michigan State to economize resources:

Computation costs:	$49.11
Printing costs:	$10.17
Total:	$59.28

The computation costs of runs A through E varied from $3.71 to $12.66. The printing cost for each run was $3.60. The total costs of making runs A through E is $54.05. However, costs of using permanent files, purchasing a tape, creating a card file on tape, and unsuccessful runs are not included in these figures.

Changes Recommended for the Model After Testing

Testing this model indicated that some changes could be made in the model to improve it or simplify it. For example, the number of conversions from current use to intensive management on timber producing lands could be reduced. All conversions on timber producing lands took place at the earliest possible time. Conversions in later time periods could have been eliminated. It is possible that in other river basins conversions at later time periods might occur. However, given growth rates in demands for timber as projected in the Timber Outlook Study (U.S. Forest Service, 1973), conversion to intensive management as soon as possible appears to be the favored alternative in an optimizing model such as this one. Conversions on adequate condition class lands in the seedling-sapling size class could also be reduced. Conversions from current use to intensive management at the present produces the most hunterdays in every time period at the same costs as other conversions. Reducing the number of conversions would reduce the number of activities and would reduce the amount of computer core required.

Changes could also be made in the area of cost analysis. The equations could be made more specific in reference to product and location of spending if more specific analysis of costs was desired. Outside studies would probably still be required to estimate impacts on regional growth. More complete specification of costs would require additional equations which could greatly increase computer core requirements. If less specific cost analysis was desired, cost equations could be eliminated completely.

In some linear programming algorithms, such as APEX I, summation of activities for erosion and costs could be eliminated. Rows for erosion and costs could be defined so that they are set greater than or equal to zero. The algorithm will sum all row activites so that production of erosion or costs could be summed without using special activities.

Summary

Results of testing the model were presented in this chapter. Trends in land management, production, consumption, flows of goods, and costs were discussed and analyzed. Recommendations for land management were made. The costs of constructing and running the model were discussed.

Several conclusions follow from this chapter. A linear programming model which fully accounts for time and space in forest land planning is feasible to construct and run. It is difficult to construct and costly to use. The model developed in this study does allocate production requirements for timber among regions given requirements at demand points and the productive capacity of various regions. Several important factors are identified which affect land management patterns: costs of management, costs of transportation, locations of requirements, time distribution of production, joint production, and spatial distribution of land resources. An important trade-off between costs of intensive management and costs of importing is discussed. The time period of analysis and the rate of interest also could have important impacts on land management patterns.

CHAPTER V

CRITICAL ANALYSIS OF THE MODEL FOR POLICY ANALYSIS AND ITS USEFULNESS TO LAND USE PLANNING

The purpose of the model is to locate land management strategies in space given requirements for products and resource information in USDA river basin planning studies. River basin planning must concern itself with national economic development, environmental quality, regional development, and social well-being. River basin planning studies recommend land use plans to meet future demands for products.

The study area to which this approach is being applied is a rural area in which agriculture and forests are the largest land uses. Agriculture is an important income producing sector. Land in the study area is largely privately owned and highly parcelized. There is little public ownership of land in the river basin.

The model being proposed can be applied to several types of problems. 1) It can be used by federal or other government agencies to help develop land management plans on public lands managed by the agency. 2) It can be used by federal or other government agencies to help develop land use plans on which to base recommendations concerning land management to private landowners given the agency's objectives. 3) It can be used to predict how land will be managed given demands for products and constraints on land use such as qualities and quantities of land resources and land use regulations. The third use of the model assumes that the model will simulate how landowners will behave under certain conditions.

In the Kalamazoo River basin, the federal government owns no land. The only problems to which this system can be applied in the basin are types 2 and 3. Since the federal government does not have ownership, the police power, condemnation powers, or property taxation powers, it cannot require that land management plans be implemented. The only powers that the federal government has to guide land use is the spending power and the power to make information available and to educate. These land management plans could become useful to extension efforts and federal assistance programs to landowners.

A Review of the Problems of the Current USDA Approach

Throughout this report, problems with the current USDA approach have been discussed. These problems will be reviewed. Space is brought in only by considering the spatial differentiation of land resources. The location of demands for products produced on the land and what impacts this might have on land management decisions are not considered. As a result, transportation costs, the costs of overcoming the barriers of space, are not considered in the objective function. These costs can potentially influence the decisions of landowners and ought to be considered in the model when the location of land management strategies is being evaluated. Closely related to this point is the fact that the current USDA approach does not consider the openness of the river basin economy. The river basin undoubtedly exports some products and imports others. The region is not self-sufficient and goods flow in and out of the region. The location of suppliers and demanders outside of the river basin can also influence the decisions of landowners.

The current approach assumes that land is the only limiting factor. Other resources, such as labor and capital, are neglected. It appears that the model assumes that these resources are not fully employed and therefore do not limit production.

The current USDA approach is not well suited to problems in which time is an important component. Time is important to consider when dealing with forest resources. A large number of years can pass between an investment in a forest stand such as planting, thinning, or fertilization and a yield of merchantable timber. Growth of a stand occurs over a large number of years. The current Economic Research Service approach deals only with certain individual years. This approach seems perfectly acceptable for most agricultural problems where planting and harvesting occur in a single year. The approach is not so well suited to problems which consider a large number of years.

The objective function used in the current approach is a cost minimizing approach to meet certain demands. People probably think in terms of maximizing returns given constraints. However, there are problems with estimating prices for certain intangibles such as recreation or scenery. Neither approach will account for any degree of indifference to costs. People may not always be maximizers or minimizers but, rather, may be satisfied with "adequate" levels of performance in some cases. This satisficing approach could result in a different allocation of resources than an optimizing approach. Both optimizing approaches must beware of distributional effects in specifying the objective function. The determination of requirements for a cost minimizing solution also has distributional implications.

Both determining the products to be considered and the quantities required can favor some groups over others in planning. Distributional effects such as these must always be considered in model construction.

Closely related to the problem of distributional effects is the problem of what management options to consider. The optimal solution is affected by the management strategies, which represent land management options, included in the linear programming problem. The management options considered will have distributional effects since each option can favor different interests. The Forest Service has proposed management options for forest lands. They include intensive timber management, environmental emphasis, multiple use, and current use. Other possible options seem to be neglected. Management strategies could be developed to emphasize the production of different species of wildlife, hunterdays, or other recreation activities. Other timber management strategies could also be considered. In particular, short rotation forestry management for various species should be developed. Once new management options are developed, new products flowing from these options would require consideration by the model.

Problems discussed above indicate conceptual deficiencies of the current approach. There are other data problems encountered in river basin planning studies that will make any approach difficult. There is a lack of data at the sub-county level in the Kalamazoo River Basin. Most data used in this study was obtained from the U.S. Forest Service. Many of these data are published by county or substate region. Remote sensing data were obtained from the Michigan State University remote sensing project concerning land cover. Information for sub-county units could be obtained from maps based on remote sensing data. However, data were not specific enough for Forest Service land management purposes. The data base limits the definition of spatial differentiation of the resource. A grid framework can be no finer than the data base will allow it to be. In this study, useful forest resource data could be defined in no area smaller than a river sub-basin. It is the data base, rather than computer technology, which limits the spatial specificity of this river basin study.

Problems were also encountered with data obtained from the Forest Service for use in this study. For example, data prepared for the Kalamazoo River Basin planning study were not documented. Sources of data, operations performed on data, and assumptions behind calculated coefficients and acreages were not provided, thereby making it difficult to know what the data meant and how they could be used. It is difficult for independent researchers and citizens to use data in their present form.

Criticism of the Ideal Model

Assumptions of the Model

There are a variety of assumptions behind the ideal model which will affect the usefulness of the model for river basin planning. First of all, there are the assumptions of linear programming. The first assumption of linear programming is linearity which means all proportions remain constant in an activity, regardless of the level of the activity. Diminishing returns could be handled by including several activities with constraints on the levels of the activities. However, diminishing returns are not included in this model. The second assumption is complete divisibility of input and output units.

Fractional parts of any activity are possible. Integers could be required through the use of mixed integer linear programming, however. The third assumption is additivity and independence which means that there are no interactions between activities. When there are interactions, they must be combined into a single activity. The fourth assumption is that inputs and outputs are homogeneous. There is no variation of the characteristics of each input or output. Fifth, the number of activities that can be considered must be finite. Sixth, limiting factors are required. The seventh assumption is that costs and prices are constant. This restriction can be overcome through the use of quadratic programming. Eighth, the model must either maximize or minimize an objective function. This model minimizes costs. The ninth assumption is that all activity levels must be non-negative.

Since pseudodynamic linear programming is recommended in the ideal model and used in the application, additional assumptions must be listed. Pseudodynamic linear programming minimizes an expected stream of dollars, or other units of value, over a given time period. The time period of consideration must be the same for all activities included in the model. Time is an implicit variable in this model because the objective function values are discounted dollar values. Time enters through the use of an interest rate. A time period of analysis must also be defined.

There are also some special assumptions for the ideal model. First, the river basin is viewed as a single entrepreneur who desires to use scarce land resources in an economically efficient way. The region's economy is assumed to be an open system. Goods can flow in and out of the system. Goods can also flow between river sub-basins. Transfer costs and the location of markets are assumed to affect the allocation of land management strategies. The model also assumes that requirements for various goods produced by management strategies can be projected. It is also assumed that transport routes and supply and demand areas can be defined.

Implications of the Assumptions

These assumptions have implications for the economic system, technological possibilities, and behavior of the environment. The assumptions of linearity, additivity, and independence have very important ramifications. Economies of scale in the management and harvesting of timber are neglected. The impact of the size of a contiguous area of a given management strategy is not considered. Management and harvesting costs of a single tract of 1000 acres of land in the intensive timber management strategy are the same as those on 1000 isolated, single-acre tracts. Minimum size tracts for a given management strategy cannot be included in the linear program. Interactions between two different classes of land such as agricultural or forest land are not included. For example, edge effects on wildlife populations are not considered. The only way these kinds of effects can be included is by developing an activity which will include these interactions. Also, effects of different patterns of land use cannot be considered.

Not including diminishing returns affects the realism of the model since varying proportions of inputs are not considered. This problem is compounded since only the factor of land is limiting. Other possible units are not included and thus must be considered non-limiting.

The assumption that land owners act as a single entrepreneur desiring to use resources in an economically efficient way limits the results. This assumption could be valid only under the following conditions: 1) There is only one land owner, or 2) There is central planning of individual efforts and the power to enforce the plan, or 3) Land owners have the same goals and work in such a way as to efficiently use resources without conflict. In the description of the study area in the first chapter, it was shown that land ownership is largely private and highly parcelized, so that the first possibility is eliminated.

The second possibility conflicts with the American political system. Planning in this country generally tries to avoid serious conflicts rather than plan for the optimum use of land. Neither the states nor the federal government have the power, at this time, to compel large numbers of private land owners to manage land in a certain way. The police power is used to avoid conflicts. In special cases, eminent domain is used to force a certain parcel of land into a given use. Central planning and implementation likely would take place during a national emergency. But for the time being, land owners are free to make a large number of decisions without government intervention. The third possibility seems unrealistic. Private land owners appear to have a variety of goals in managing the land that they own. Economic efficiency may not be the most important motivation. The U.S. Forest Service has discussed the problem of private, non-industrial ownership of forest lands. These forest lands were classified according to the goal of ownership as follows (U.S. Forest Service, 1973):

a) Perhaps 5% of this land is intensively managed on a continuing basis.

b) About a third of the owners have some interest in forestry and manage their lands under extensive forestry practices that are usually unplanned or accomplished at random.

c) Nearly half of the landowners display no interest in intensified forestry practice. Timber on these lands may be sold from time to time.

d) Perhaps 15% of this land is held for non-timber purposes.

Most of these forest land owners appear to be more interested in obtaining periodic income from selling timber than investing in forest management to increase future growth and returns. The return to investment might be too small to merit much consideration. Perhaps the most important problem is the long planning period involved. Private land owners may be thinking in terms of 5 years while forest investments may take place over 50 or more years. This short planning period is a good reason for the Forest Service to investigate the possibility of encouraging short rotation forestry on privately-held, non-industrial, sub-marginal agricultural lands.

It would appear, then, that the model probably would not be a good predictor of what would happen given various land use plans and constraints on the system. Although, the structure of the economic system, particularly the distribution of land ownership rights, is not approximated very well by the assumptions of the system, the model might be used to generate guidelines to a forestry extension program. It might also be helpful in showing which management options should receive public assistance.

Some of the model's assumptions are intended to offer improvements over the current Economic Research Service approach. The economic system is assumed to be an open system. Goods can flow in and out of the system. Goods can also flow between sub-basins of the river basin. The reason for these assumptions is to overcome the concept of self-sufficiency. In reality, it seems unlikely that river basins would be self-sufficient in the production of many products. Importing and exporting is the rule rather than the exception. Accounting for the transfer of goods requires that the linear programming matrix be increased in size. Problems arise in defining where goods are demanded and the quantity demanded at each location. It becomes more difficult to project demands or requirements for a region as the area decreases since the amount of data available decreases. Specifying demand models would become more difficult since variables which vary over space would have to be included. A problem also arises in specifying transport routes. Not all routes can be included because the number of transfer activities would become too great. It is difficult to pick representative transport routes between demand points and supply areas.

Time is also included to overcome a shortcoming of the current approach. As discussed earlier, choosing among timber management options requires that time be considered. It is rather difficult to include time into a linear programming framework, but an attempt has been made to include it in this model.

Problems Encountered by Including Space

Including space into a linear programming matrix has great impact on the size of the matrix. A set of rows and columns must be defined for each region to maintain spatial differentiation. Essentially, each region has its own matrix. Figure 5-1 illustrates the form such a matrix might take. Each region has approximately the same number of non-zero coefficients. There is some variation in the

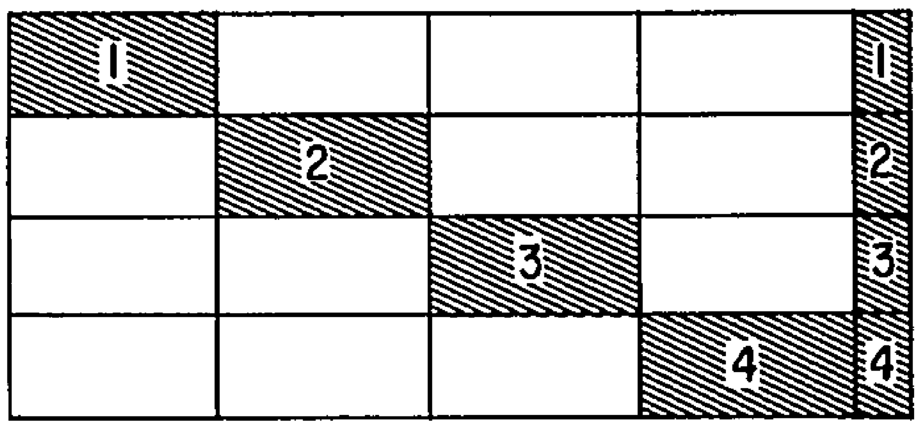


Figure 5-1.--Diagram of Linear Program Tableau. Shaded areas are non-zero coefficients. White areas are all zeros. The numbers 1, 2, 3, and 4 identify the regions.

number of non-zero coefficients in each region. For purposes of this discussion, however, they can be assumed constant. The total number of non-zero coefficients is a linear function of the number of regions as shown in the following equation:

non-zero coefficients = coefficients/region
x number of regions.

The number of rows is a linear function of the number of regions as shown in the following equation:

rows = rows/region x number of regions.

The number of columns can vary slightly between regions. However, for purposes of this discussion, it is assumed that the number of columns is the same for each region. The number of columns is a linear function of the number of regions as shown in the following equation:

columns = columns/region x number of regions.

To derive the total number of elements in the matrix, the number of rows is multiplied by the number of columns as shown in the following equation:

total elements = rows/region x columns/region
x $(\text{regions})^2$.

As a result the total number of elements increase by the square of the number of regions. The total number of zero coefficients increases at a rate much faster than the number of non-zero coefficients. When space is included by sub-dividing an area into regions, the density of the region decreases by adding large numbers of zeroes.

Problems Encountered by Including Time

Including time also increases the size of the matrix. Product coefficients must be included for each time period. Transportation activities must also be included for each time period. Resource constraints are included only once. Figure 5-2 illustrates the effects of time for that portion of the matrix allocated to one region. The number of non-zero coefficients increase linearly with time as shown by the following equation:

Non-zero coefficients = resource constraint coefficients
+ [(product and transfer coefficients)/time period] x number of time periods.

The number of rows increases linearly with the number of time periods as shown in the following equation:

rows = resource contraint rows + [(product and transfer rows)/ time period] x number of time periods.

The number of columns also increases linearly with the number of time periods:

columns = management strategies + [transport activities/time period x number of time periods.]

The total number of elements increases with the square of the time periods. However, only the transportation component increases this way. The number of elements in the production component increases linearly with the number of time periods.

total number of elements = resource constraint coefficients
+ [product coefficients/time period
+ transport coefficients/time period]

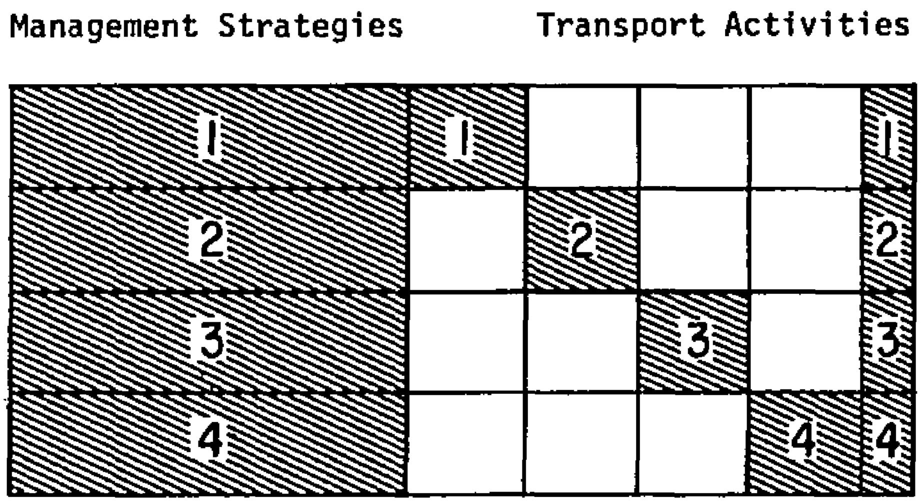


Figure 5-2.--Diagram of Linear Programming Tableau Showing the Effects of Adding Time Dimension. The shaded areas contain non-zero coefficients. The numbers 1, 2, 3, and 4 indicate the region in which the non-zero coefficients belong.

X (time periods)^2.

The number of zero coefficients increases much more praidly as the number of regions increases than as the number of time periods increases.

Including both time and space will increase the costs of a linear program. The increased number of coefficients will increase the costs of reaching a solution. It is possible that the size of the matrix could grow so large as to force a more expensive algorithm to be used or to make solution impossible.

Criticism of the Specific Application

There are also special problems and assumptions associated with the specific application of the model. These assumptions were made to make the problem easier to handle. There are assumptions dealing with both conceptual and data problems. These assumtions will affect how well the model is suited to the problem.

Conceptual Problems

There are a variety of assumptions concerning the conceptual basis of the application. Conversions between major classes of land use are not possible in the model. Forest land cannot be converted to agricultural land and vice-versa. This assumption is built into the Economic Research Service model. Impacts of converting forest land to urban land are handled outside of the model. Other conversions are assumed not to occur. Management strategies and resource classes were aggregated to reduce the number of activities in the linear programming model. Maximum wood production and multiple use management strategy coefficients were aggregated resulting in an information loss. Soil groups and stand condition classes were aggregated for the forest ecosystems. The number of columns was reduced by aggregation since conversions between management strategies were being considered.

There are other assumptions which were made concerning forest management strategies. Once a tract of land is managed intensively or under the environmental emphasis management strategy, no conversions can take place. Only land in the current use management can be converted. This assumes that once a decision is made to manage land for timber or to remove land from timber production, the decision will not be reversed. Decisions to convert land from one management strategy to another can occur only once during the time that a stand is in a certain stand size class. This assumption was made to limit the number of activities resulting from converting management strategies. A separate activity is required for each conversion at a different point in time. The decision to convert land from one management strategy to another can occur only before the first harvest after 1965. Once the first harvest after 1965 occurs, the land will remain in a given management strategy. Whenever forest land requiring timber stand improvement is in the current use strategy, an investment in management will be required to convert the land to intensive management. The land will then be in the adequate condition class.

There were also some important assumptions concerning time. Assumptions were made concerning the growth of the forest resource. A rotation length was established for each forest ecosystem and management strategy. A period of time was defined for each ecosystem during which a growing stand remains in a specific stand size class. Also growth rates were assigned to each stand size class of each ecosystem. These assumptions were needed to calculate merchantable timber coefficients and other product coefficients for each time period. A planning period of 60 years was defined and a discount rate of 5.88% was used. The planning period coincides with the period of analysis used by the Economic Research Service in the Kalamazoo River Basin (Economic Research Service, personal correspondence, 1974). The discount rate was determined by the Water Resources Council for land use planning studies (Water Resources Council, 1974).

These assumptions have several ramifications. Management options are simplified. Forest management conversions that might take place are eliminated. A bias might be built into the system by not allowing conversions from environmental emphasis to intensive management or current use and by not allowing conversions from intensive management to environmental emphasis or current use. Management options become more gross through aggregation of management strategies. Information is lost. Coefficients which are calculated may become less accurate.

The model also simplified landowner behavior. The bias in management options biases landowner behavior by restricting the courses of action a landowner may take. Landowner behavior is also simplified by restricting the points in time when a conversion can take place. The planning period chosen might not be representative of the planning period held by people living in the river basin. The discount rate may not reflect people's time preferences or opportunity costs of capital. These simplifications may reduce the suitability of the model for predicting producer behavior.

The natural system is also simplified. Resource classes are aggregated thus consolidating management strategies and causing losses in information in the calculation of product coefficients. Variations in the land resource are averaged out to simplify the problem. Variations in the land resource are not expressed in the production of products. Also environmental diffusion was not included in the model. The growth of timber stands and changes in forest ecosystems are also simplified. The time of timber harvest and maturity is greatly simplified by defining a uniform rotation age for each forest ecosystem and management strategy. The time period during which a growing stand remains in a stand size class is also uniform for each ecosystem and management strategy. Variations in growth of stands over space are greatly simplified in this manner.

The predictability of the model would seem to decrease as assumptions simplify human behavior and natural functions. Bias may also result from limitations on the management options considered. Therefore, it is difficult to estimate the accuracy of the model.

Data Problems

There were a variety of assumptions made because data problems were encountered. There were a number of assumptions concerning demands and supplies of roundwood. Pulpmills in the lower peninsula of Michigan were assumed to demand a constant proportion of the lower peninsula pulpwood production each year. The lower peninsula was assumed to be self-sufficient in pulpwood production. This assumption was made because of a confidentiality problem. The Michigan Department of Natural Resources would not release volume data for pulpwood purchased by pulpmills each year. Requirements for sawlogs and veneer logs for regions in the river basin were based on the data of a given year. Purchase data for sawlogs and veneer logs by county are extremely scarce. Purchase estimates were based on residual production by assuming that residuals were a constant proportion of roundwood purchases. Requirements for sawlogs and veneer logs were taken as an average of purchases for three different years. It is difficult to find out how much is consumed. Other factors that might affect demand are difficult to define and include in data collection efforts. Roundwood demands are assumed to increase according to Forest Service assumptions in the Timber Outlook Study. Each region is assumed to grow at the same rate as the nation. This assumption does not allow for regional differentiation from the nation. However, lack of data makes it difficult to specify models and predict supply and demand for each region.

Production of roundwood or regions outside of the study regions was based on state figures. Roundwood production was assumed to be constant during each time period for each region. Supplies of each type of roundwood were based on an average of only three data points. Not enough data are available to specify a supply function for timber. Factors which determine timber supply were not considered in the calculation. Hence, variations in supply resulting from changes in factors which determine supply are not considered.

Assumptions were also made concerning hunterdays. Requirements for hunterdays are directly related to population. The number of hunterdays per person is assumed constant. This introduces a degree of inflexibility into the system. There are not sufficient data to specify a demand model for each region for hunterdays. Increases in requirements, then, are assumed to increase directly with increases in population. Population growth, based on Economic Research Service projections, is assumed to increase at the same rate as the population of the state. Regional differentiation caused by migration is not considered. Hunter behavior in terms of travel was determined from national data. Hunters are assumed to behave according to the national average. There is a lack of data for local hunter behavior. There could be a bias in the number of hunters in a party and the number of days per trip.

Assumptions were made concerning transportation costs. Regions were assumed to be square with a single demand point in the center. A north-south, east-west transportation network is defined. Other roads are evenly distributed over the area. These assumptions were made to calculate distances travelled in a region. They are, however, unrealistic. Some regions do not even approach a square shape. Demand points often are not in the center of the region. Realistically, there is often more than one demand node for a commodity. Different commodities may have different demand nodes. Roads are not evenly distributed over the area of the region. Transport routes chosen were assumed to be representative of routes across which people and goods move. Representative routes were chosen to limit the number of transfer activities in the matrix. This approach assumes that the most important travel routes were always chosen. These assumptions simplify the transportation network of the region. However, it should be recognized that milages based on these assumptions could result in inaccurate transportation costs. Difficulties were encountered in classifying roads into classes for purposes of calculating transportation costs.

This may be another source of inaccuracy in calculating transportation costs. In calculating transport costs, it was also assumed that the proportion of each class of car ownership was the same in the region as it was in the nation. There was some difficulty in classifying automobiles and calculating the number of each class of automobile on the road. This may also be a source of inaccuracy.

This discussion points out that there are many problems involved in a study of this sort. Few data are available to help calculate supplies, demands, excess supplies, and transport costs. It is difficult to devise good projection models from the available data. Undoubtedly, there is great dispersion, and possibly bias, in the estimates made. Confidentiality might also be a problem in obtaining consumption data from large firms, as it was in this study. It would be difficult to obtain these data for a study which is to be made available to the general public.

Assumptions made to overcome these data problems have ramifications for the economic and natural systems. Behavior of the pulpwood market of the lower peninsula of Michigan is assumed to be highly inflexible. The lower peninsula of Michigan is assumed to be a closed market with pulpmills purchasing a fixed share. This is highly unrealistic. The impacts of price on regional demands for and supplies of timber are not recognized. No recognition of regional advantages and disadvantages in the wood markets is included. The price elasticity of demand for hunterdays is very inelastic. Per capita consumption of hunderdays is assumed constant regardless of the cost of hunting. Regional variations in population growth are not considered.

The natural system is also simplified. Variations in the quality and quantity of wildlife habitat over space in regions outside of the river basin are not included. Factors affecting growth and decline of wildlife populations are omitted in the projections of supply. Natural factors affecting the growth and supply of timber in regions outside of the river basin are also neglected.

In summary,assumptions behind the conceptual basis of the model introduce unrealities into the description of the river basin system. Most of these assumptions were required to overcome data deficiencies.

Usefulness of the Model to Policy Analysis

The purpose of the model is to allocate land management strategies among resource classes and regions, given goals and constraints. The model, then, can be used to assist policy-makers by generating guidelines for land management. Impacts of alternative guidelines for land management can be generated with this model. Impacts of variations of product requirements over time and space can be studied. Growth rates of reqquirements and spatial variations in growth rates can be studied by varying product requirements. By the same token, the impacts of favoring certain product users can be investigated by varying the levels and growth rates of product requirements relative to each other. Also, impacts of varying constraints on environmental impacts over space and time can be studied in a similar way.

Impacts on guidelines to land management from allocating land to various uses according to different criteria can also be studied. Land uses in certain areas can be determined based on criteria not in the model. These strategies can be used to constrain the model by use of a constraint generator. The model can then be run to optimize the objective function given these constraints on land use.

Impacts of changes in the transportation system, transportation technology, and fuel costs can also be studied. Such changes will ultimately change the transport costs. The costs of the transport activities can be varied in the model to study impacts on land management.

There are a variety of questions that are not easily handled by the model. For example, individual site problems, such as planning a park or other small scale problems, cannot be easily handled by this model. The model will not choose the best site of a given area from a set of alternative sites. Since the model is a land management model, it does not seem well suited to such problems as mining, manufacturing, wholesaling, and retailing. However, impacts on land use could be considered through activities in the model although they might be handled more easily outside of the model. The model does not deal well with problems of distributional effects on social groups within a given region. Also, the model does not seem well suited to problems of urban growth because of interdependencies involved in urban growth.

There is one policy question that can be handled by the model which might be more easily handled with a different type of model. All lands may be allocated to management strategies outside of the model. The model could then be used to produce spatial economic and environmental impacts. This problem might be handled more easily by using a simulation model to generate the goods produced by each of these management strategies. The spatial effects could then be generated by use of separate environmental diffusion and spatial economic models. No examples of simulation models linked to spatial economic and environmental diffusion models were found. The Honey Hill report describes a simulation model which generates the impacts of land uses for individual grid cells (Murray et. al., 1971). The movement of impacts through space are not considered in this model, however.

Final Assessment of the Suitability of the Model

The approach used in this study appears to be well suited to providing policy guidelines for managing publicly owned lands. The model could be employed by federal or state land management agencies. This is a situation where a normative model is desirable since it says what ought to be done to meet objectives given constraints. The model could also be used by state agencies to develop guidelines for the application of police powers, taxation powers, and spending powers to guide land use toward state land use goals. Finally, the model could also be used as a guideline for extension efforts of federal land agencies. The model could help to indicate what management options should be encouraged by education and public assistance programs, given the agency's land use goals and resource constraints. However, the model does not indicate how to implement such a program.

There are some important limitations of this approach. The neglect of economies of scale and interactions between land management strategies eliminate important aspects of land management options. Economies of scale can be included through separable programming, however. Interactions can be included only by developing special activities for the model. However, the minimum contiguous area for a land management strategy to be practiced cannot be specified. It is expensive to include the dimensions of time and space in the model. This model also has large data requirements which may be the most serious limitation. Both the spatial specificity and accuracy of results are dependant upon the quantity and quality of data available for spatial divisions of the resource base.

Many of the assumptions brought about by data problems in the application could be overcome by better data. Because of the data problems, there are serious doubts about the accuracy of the results of the model. In order for this approach to be implemented, better data sources need to be developed. Overcoming these data problems will probably be the most expensive barrier to implementing this approach.

No matter what is done, however, assumptions will be required. Models are abstractions of reality, not substitutes for reality. The purpose of models such as this one is to help policy-makers to understand the ramifications of their proposed actions or desires. Models cannot become a substitute for decisionmaking. Decision-makers must bear full responsibility for their decisions. However, the assumptions behind any model used should be made explicit so that the shortcomings of the model can be better understood.

There are some problems with linking this model of the forest sector to the current USDA model. This problem is based on time. This model solves for six time periods simultaneously. The USDA model solves for each time period individually. Either the current USDA model must be changed to a pseudodynamic linear programming format, or some other approach which considers time, or the forest sector must be handled separately with the results entered into the USDA model. Including many time periods would create problems for the agricultural sector since large numbers of conversions in crops could easily make the problem unmanageable. The transportation and environmental diffusion components could be easily added onto the current model used in river basin planning.

This study has made several improvements over the current USDA approach. Time has been included. More aspects of space have been included. The transportation network, transport costs, and spatial aspects of demand have been included in the application. Diffusion of environmental impacts through space were discussed in the ideal model but not included in the application. The river basin economy was modeled as an open system.

The model seems to be poorly suited to the problem of predicting what production "will" occur given a set of requirements, constraints, and restrictions on land use. The basic problem is the assumption that the community acts as a single entrepreneur. This assumption does not agree with the structure of the American political and economic system. People may be satisficers rather than optimizers. Also, there may be a degree of indifference to differences in costs or benefits in decisionmaking. People may not change land management if changes in costs and benefits are not large enough. For purposes of predicting landowner behavior in the river basin studies, it is highly recommended that the Forest Service or some other branch of the USDA study the possibility of developing a simulation model. The model should be designed to predict what behavior is likely to be, rather than what it ought to be. That is to say, it should be a non-optimizing model. In connection with such a study, more time should be spent analyzing the determinants of land owner behavior.

CHAPTER VI

SUMMARY AND CONCLUSIONS

Summary

The primary objective of this study is to examine the feasibility of building an integrated land inventory and evaluation system for river basin planning studies. This study is concerned with the locational aspects of planning forest resources. Planning by USDA must concern itself with national economic development, environmental quality, regional development, and social well-being.

The purpose of the model developed in this study is to locate land management strategies in space given requirements for products and resource strategies. Four stages were involved in developing this model: 1) literature search, 2) conceptualization of the model, 3) testing the model, and 4) criticism of the model. The emphasis of the study was on locational aspects and linking new concepts to existing Economic Research Service models. The summary will concentrate on the last three stages of the study.

Conceptualizing the Model

Preliminary work included determining what ought to be included in the model. Several issues were identified to be considered by the model: 1) space and time aspects of demand, production, and environmental impact, 2) transfer of goods through the economy, 3) openness of the economy, 4) regionalization, and 5) distributional effects. A set of components were identified for the system: 1) the land evaluation system which includes production and locational aspects, 2) land inventory system, 3) constraint generator, 4) land management strategy data, 5) goals, and 6) displays.

A set of alternative model categories were put forth which could be used in the land evaluation system: 1) input-output models, 2) linear programming models, 3) simulation models, 4) dynamic programming models, and 5) hybrid models. Specific applications and theories were discussed after a survey of the literature. Three general alternatives, then, were developed for the land evaluation system.

I. A regional linear programming model with spatial economic and environmental components which allocate strategies among regions. A multiple land use assignment is used to allocate management strategies among grid cell subdivisions of the regions.

II. A multiple land use assignment model allocates management strategies among grid cells. Spatial economic and environmental aspects are included through separate relationships but do not influence the allocation of management strategies.

III. A simulation model generates production of commodities for alternative land use plans developed outside of the model. These results become input to relationships which calculate spatial economic and environmental impacts.

A set of criteria were used to evaluate these three alternatives: 1) spatial economic impact, 2) spatial environmental impact, 3) quality of data needed, 4) provision of policy guidelines, 5) relevance of necessary assumptions, 6) capacity to deal with time, 7) compatibility with the present Economic Research Service model, and 8) operating cost. The first alternative was chosen as the alternative favored for further investigation.

The structure of the first alternative was more specifically determined. Criteria were used to choose among alternative structures: 1) transportation impact, 2) environmental diffusion impact, 3) spatial specificity, 4) construction cost, and 5) operating cost. The transportation and environmental diffusion components are incorporated directly into the production model in order to have impact on the allocation of management strategies among regions. Time is incorporated through the use of pseudo-dynamic programming and costs are discounted to the present. A cost-minimizing approach, the current approach of the Economic Research Service, is used. A multiple land use assignment model allocates management strategies among grid cells. Variables and equations were defined.

Land management strategy information consists of product coefficients for management strategies at different points in time. Relationships must be defined to calculate these coefficients. Variables in these relationships should be based on physical resource data, time, and land practices.

Goals for land management and output are alternative constraints and requirements for land use and land products. These must be determined for every river basin study.

The purpose of the land information system is to store information needed for calculating acreage constraints for management by resource class and location. Acreages of each resource class must be defined. Resource classes should be based on the multi-dimensional land type concept. Each dimension is a class of data important to decision-making.

There are two methods to define the acreages of these resource classes. First, each dimension could be mapped separately and the acreages of each resource class determined by overlays of the maps or through use of computer techniques based on a grid system. Second, each resource class could be mapped individually through an integrated inventory.

Grid cells store land information by location. The grid cell is chosen to store information in this system because of its widespread use and the availability of computer technology based on the grid cell. There are two general sizes of grid cells. One size is small enough to allow only one resource class or dimension to be assigned to it. The second size is large enough to allow more than one resource class or dimension to be assigned to it. Criteria selected to determine the size that should be used in the system include: 1) cost of classifying the resource, 2) ease of mapping resource data and classes, and 3) ease of mapping management strategies. The size chosen is a cell small enough for only one resource class or dimension to be assigned to it. The desired accuracy of land use information determines the threshhold at which a small cell becomes a large cell.

Geographic referencing is needed to determine the location of each grid cell. Alternative systems include latitude-longitude, Universe Transverse Mercator, state plane coordinates, and the rectangular survey. The Universe Transverse Mercator system was selected as the ideal because of many desirable characteristics. However, many existing secondary data sources will be referenced by other systems.

The means of data storage will vary according to the needs of the specific situation. There are alternative means of organizing data files: sequential organization, random organization, and list processing. Alternative storage media also exist, that is, cards, discs, and tapes.

The combination of file organization and storage media chosen depends on the amount of data stored and the frequency of access. The combination of random organization and disc storage seems to be well suited to a large amount of data that is accessed frequently. This combination is expensive, however. Records, which make up files, should contain location information, resource data for the grid cell, that is, each dimension, and the resource class of the grid cell. Blank fields could be in the record to allow new data to be added to each grid cell.

Alternative flow charts to generate resource constraints for the production model and the land use assignment model were illustrated. The algorithms are relatively simple. Use of a computer program would be particularly useful when there is a large number of grid cells.

The constraint generator develops constraints for the production model and the land use assignment model according to decisions on land management made outside of the system. Alternative flowcharts were illustrated. A computer program would be particularly useful with a large number of grid cells or with a large number of alternative sets of land management decisions made outside of the system.

Printer routines for mapping that can be used on the CDC 6500 were surveyed. The routines were GRIDS, SYMAP, and MIADS. GRIDS and MIADS are favored for mapping resource data. MIADS is favored for mapping resource classes and the output of the land assignment model. SYMAP is favored for any maps made of the sub-regions.

Testing of the Model

The model tested was a cost-minimizing, pseudo-dynamic linear programming model. Total production and transportation costs are minimized.

The transportation component is incorporated into the production model while the environmental diffusion model was not included in this test. The products included in this analysis were timber, big-game hunterdays, small-game hunterdays, and erosion. Resource classes were based on forest ecosystem, soil group, stand size class, and stand condition class. Six ten-year time periods from 1965 to 2025 were included. There are four sub-areas in the basin and eight demand regions outside of the basin.

The land use assignment model which would allocate management strategies among grid cells was not included. The reason for this is that the land resource data base for the Kalamazoo River Basin is not location specific enough to support a grid system. Soil management groups are not mapped. All forest inventory data was on a county basis. Remote sensing data, though specific enough in spatial terms, was not specific enough for management decisions. The result, then, is that management strategies can only be allocated among regions and not among grid cells.

Data were collected for the spatial and temporal economic aspects of the forest sector. Requirements for roundwood were calculated. Data sources include the U.S. Forest Service, the Michigan Department of Natural Resources, and Lockwood's Directory of the Paper and Allied Trades. Requirements were calculated for each county in the studyarea and allocated to regions on the basis of timber-using capacity. Projections into the future were based on medium-level projections of timber consumption in the Outlook for Timber in the United States. Roundwood production in regions outside of the river basin was estimated. Production was averaged for each county. This production was allocated among regions on the basis of area. Michigan Department of Natural Resources data were used. The production of timber was assumed constant over each 10-year period. Excess supplies of timber for regions outside of the river basin were calculated by subtracting requirements from production.

Consumption requirements for hunterdays for each region were calculated by multiplying the consumption of the region by hunterdays per person. Requirements were projected over time by using population projections calculated by the Economic Research Service. Supplies of hunterdays for regions outside of the river basin were also calculated by multiplying acres times kill per acre for each county times hunterdays per kill. Supplies were allocated to regions on the basis of area. Excess supplies over local consumption were calculated for regions outside of the river basin by subtracting requirements from supplies.

Transport costs were calculated. Transport routes were defined from the supply area to the demand point. Classes of roads were defined and the average number of miles travelled on each class of road to get to the final destination was calculated. Timber transport costs per mile were based on U.S. Forest Service figures. Hunterday transport costs per mile were based on U.S. Department of Transportation, U.S. Department of Interior and Motor Vehicle Manufacturers Association figures. Transport costs per cubic foot of timber or per hunterday were calculated for each year in a 10 year period and discounted to the present at 5.88%. The discounted annual cost per unit each year in the 10 year period was then summed.

Production costs and coefficients for production activities were calculated. Management strategies and resource classes were aggregated when feasible to reduce calculations and computer core requirements. A rotation was defined for each management strategy. A relation between stand size class and time was assumed. An age distribution based on forestry inventory data for the southern half of the lower peninsula was also assumed. The forest system was then conceptualized as a system of age cohorts moving through time. Harvesting and management were assumed to be even-aged in character with no merchantable cuts made except at rotation. Conversions between management strategies were limited to simplify the problem. Average annual timber costs per acre for each 10 year period were calculated given growth, rotation, and waste. Information was obtained from the U.S. Forest Service and the Michigan Department of Natural Resources. Average annual coefficients for hunterdays and erosion were averaged for each 10 year period and were based on the movement of age cohorts through time. Points in time were determined when expenditures were incurred. These expenditures were then discounted to the present at 5.88%.

A number of computer runs were made:

Run A: A baseline run with timber and hunterday requirements assumed constant over time.

Run B: Timber requirements in pulpwood-using regions grow at a rate assuming rising relative prices while all other requirements remain constant over time.

Run C: Timber requirements grow at a rate assuming rising relative prices while hunterday requirements grow at the same rate as population.

Run D: Timber requirements grow at a rate assuming 1970 relative prices while hunterday requirements grow at the same rate as population.

Run E: Timber requirements remain constant over time while hunterday requirements grow at the same rate as population.

There is no spatial variation in the pattern of managing timber producing lands. Two levels of production exist. In runs A and E, all timber producing lands are converted to intensive production as soon as possible, except for seedling-sapling classes of aspen-birch which are converted to environmental emphasis. In runs B, C, and D, all timber producing lands are converted to intensive management as soon as possible. The timber producing potential is fully utilized with these three runs.

On non-timber producing lands, all adequate class lands are converted to intensive management as soon as possible. Most classes not in adequate condition remain in current use with some exceptions. In run A, intensive management of some of these classes occurs in regions 2 and 3. In run B, fewer acres of these lands are converted to intensive management in regions 2 and 3 because of increased hunterday production on timber producing lands. In runs C and D, the number of acres converted to intensive management decreases in some ecosystems and increases in others relative to run A. Some acres are converted to intensive management in region 4. In run E, more of these acres are converted to intensive management in regions 2, 3, and 4 than in run A. This occurs because there were no increases in hunterday production on timber producing lands while requirements for hunterdays increased. The hunterday production potential of the river basin is not fully utilized in any of these runs.

There were a variety of factors affecting the location of management strategies and marginal lands. The levels of requirements and their distribution over time and space are the most important. Development costs, harvesting costs, transport costs, and importing costs are all important factors. There is an important trade-off between development costs and importing costs in determining whether lands are to be managed intensively. The time distribution of production is another important factor.

Surpluses in goods received over quantities required seldom occur. There are timber surpluses in time period 5 in regions 1 and 4 of run A. Small surpluses of small game hunterdays exist in time period 1 of runs B, C, and D in region 4. There were deficits of timber in time periods 2 through 6 in runs B, C, and D.

Production was ranked for each product, region, and time period. OBERS demands could not be met in time periods 1 and 3. Flows of goods between regions were discussed. Production, transport, and importing costs were discussed. Importing costs are ranked from lowest to highest as follows: A, E, B, C, and D.

These results have implications for growth in the timber industry. Small amounts of forest land, conversion of forest land to urban use, and the state of land tenure limit growth possibilities for timber-using industries. The Menasha Corporation appears to be at a competitive disadvantage compared to other Michigan pulpmills due to its distance from the pulpwood resource of the northern half of the lower peninsula. It might be able to overcome these disadvantages through the availability of labor and capital, economies of scale, and short rotation poplar culture on sub-marginal farmlands in the river basin. The growth of small, specialty mills could probably be accommodated. Intensive timber management could improve wood quality and improve the growth potential of these firms.

It is difficult to apply these results of this testing to other river basins. Each river basin will have its unique set of location factors, it own natural resources, and its own economic structure.

A linear programming model accounting for time and space in forest land planning is feasible to construct and run. The model allocates production requirements at demand points among supply regions and allocates management strategies over space. However, it is difficult to construct and costly to use.

Criticism of the Model

The model used in the land evaluation system can be applied to several types of situations: 1) management of publically-owned land by a public land agency, 2) making recommendations for private landowners, given the objectives of a public agency, and 3) predicting land use patterns. Only the second and third situations are relevant in the Kalamazoo River Basin. The first situation is not considered because there is so little publically-owned land in the Kalamazoo River Basin. Problems of the current USDA approach are reviewed. Spatial aspects of demand and the openness of the economy are not considered. Land is the only limiting factor. Time is poorly considered. The objective function is cost-minimizing. Important land management options are not considered. There are some important data problems. Data on a sub-county basis are lacking. The documentation of data provided by the Forest Service for this study was poor.

Assumptions of the ideal model have implications for the usefulness of the model. Linearity, additivity, and independence neglect economies of scale so that the size of the operation has no impact on unit costs. Non-additive interactions and variable proportions are not considered. The assumption that landowners act as a single entrepreneur is not valid. There are many landowners and there is no central planning. Landowners do not seem to have identical goals and do not appear to work together. The model seems likely to be a poor predictor of reality because of the assumptions. The model seems to be best suited for problems concerned with management of publically-owned land or making recommendations to privatelandowners given agency goals. Some of the assumptions were made to make the model more realistic. They include spatial distribution of requirements, flows of goods through space, openness of the economy, and inclusion of time.

Including space and time increases the size of the linear programming tableau. Computer core requirements increase as a result thereby increasing costs. It is possible that computer core requirements could be increased until they exceed the limits of the computer.

The assumptions used in the tested model also have implications. The assumptions simplify behavior and could introduce bias into the results. Conversions between classes of land, such as between forest and agriculture, are not allowed to occur. Soil groups, condition classes, and management strategies were aggregated. Conversions between management strategies are limited. Even-aged management of the timber resource is assumed. Impacts on the rotation, merchantable size, and cutting cycle are not considered. The planning period and discount rate might not be realistic. The environmental diffusion model and the multiple land use assignment model were not included.

Assumptions were made to overcome certain data problems, since data were scarce. The assumptions could introduce bias into the results. The lack of information results in estimates which are very imprecise. Increasing the amount of data will increase precision. Both problems decrease the accuracy of the results. There is a scarcity of production and purchase data for timber and hunterdays. Little data are available to calculate supplies, excess supplies, and transport costs. The lack of data makes it difficult to specify and use projection models. The assumptions simplify the economic and natural systems. Demand and supply do not interact to determine price. Regional advantages and disadvantages do not change.

The model is well suited to some problems. Production requirements and management strategies can be collected over space. Economic and ecological impacts of land management can be studied. The impacts of economic growth on land management and the impacts of land management on economic growth can be considered. Specific site problems and non-land management problems are not easily handled. It is difficult to link this model of the forest sector to the model now used by the Economic Research Service because of the way in which time is handled.

If alternative land management plans are proposed completely outside of the computer model by a planning group, a simulation model could be useful in studying impacts. A simulation model could be less costly, have less restrictive data requirements than linear programming, and can be tailored to the specific problem. More behavioral or empirical relationships could be included in such a model.

Needs for Further Research

Alternative space-time models for use in planning the management of forest land should be developed. Two major suggestions are made. First, a recursive linear programming model could be developed. Relationships concerning the changes in the forest resource over time resulting from land practices would have to be accounted for after the solution for each time period. Second, a simulation model could be developed. With this model, alternative land use plans could be formulated by a planning groups outside of the system. The production of goods by a grid or region over time would be calculated. The impact on economy and the environment could be accounted for through a set relationships included in the model. Empirically tested relationships should be used whenever possible.

Research should be directed to other components of the system. Research is needed for the land information system. A standardized set of resource classes should be developed. Alternative geographic referencing systems should be investigated more deeply. Relationships to estimate coefficients for more products should be developed. Errors in land information and in the estimation of product coefficients should be investigated. The desired accuracy of land data and its impact on the costs of data collection should be investigated. Also, impacts on grid cell size should be investigated. Research into the best software and storage methods to be used under different situations should be undertaken.

Further research is needed for the land evaluation system. Relationships for the environmental diffusion model need to be developed. More time should be devoted to determining relationships to calculate product coefficients. Relationships should be specified and tested for accuracy. These relationships could be compared with those currently used. Constraints for erosion need to be developed. More data are needed. More time should be devoted to the specification and testing of regional models which project demand and supply. The projection methods used in this study were necessarily very crude. Definition of relationships of stand development over time in this model needs to be improved. More management strategies should be developed. Some suggestions include: 1) hunterday emphasis for different game species, 2) short rotation forestry for different species, and 3) changes in rotation length and stand structure. More products should be included in this analysis. Criteria for developing objective function values for the land use assignment model should be developed. The use of an objective function which maximizes profit, benefits, or regional income in the production model should be investigated.

Further research is needed to develop the constraint generator. More time should be spent developing software for this component. Investigators should look into new techniques for measuring mapped areas such as digitizers.

More computer graphics and plotter routines should be surveyed, particularly those designed for computer systems other than the CDC 6500. Some time should be spent in investigating what information should be mapped with computer graphics.

Conclusions and Recommendations

System Structure

Conclusions:

1. A linear programming model including spatial and temporal economic and ecologic dimensions is feasible to construct and operate for purposes of planning the forest resource of river basins. However, the model is difficult to construct and expensive to operate.

2. Inclusion of time into a model of the forest resource makes it difficult for it to be linked to the Economic Research Service model. The management strategy concept is most compatible with pseudo-dynamic linear programming since impacts of management strategies over time can be included. Recursive linear programming is more compatible with the Economic Research Service model than pseudo-dynamic linear programming. However,it would be more difficult to include various time aspects of

management with recursive linear programming than with pseudo-dynamic linear programming. A model would be required outside of the linear programming model to generate impacts that occur in later time periods and input these to later stages of the recursive program. With pseudo-dynamic linear programming. These time impacts can be included in an activity column.

3. Transportation and environmental diffusion components could be linked to the existing Economic Research Service model.

4. The land evaluation system could be linked to an information system based on a system of grid cells.

5. Management strategies can, in turn, be allocated among a system of grid cells.

Recommendations:

1. Production Component:

   a. The production model should be based on pseudo-dynamic linear programming.

   b. The transportation and environmental diffusion models should be incorporated into the production model.

   c. A land assignment model should be used to allocate management strategies among grid cells.

   d. The use of a gain-maximizing objective function should be investigated.

2. An explicit set of relationships to calculate product coefficients based on resource data, management option, and time should be developed.

3. Land Inventory System:

   a. Resource classes should be based on the multi-dimensional land type concept. These resource classes should be standardized for use in all river basins. The dimensions of these resource classes are classes of land information important to making land management decisions.

b. The grid cell is recommeded as the basis of information storage because it is commonly used and much technology is available to use this type of information system.

c. The grid cell should be small enough to allow classification of only one resource.

d. Research is needed to determine the desired precision of land information which in turn will affect the size of the grid cell.

e. Geographic referencing should be standardized and based on the Universe Transverse Mercator system.

f. The amount of data to be stored and the frequency of accessing the data should determine the choice of data storage technology and media.

g. The individual data record for a grid cell should contain location information, basic resource data, resource classes, and blank fields for information added at later times.

4. Constraint Generator:

   a. If many alternative sets of land management strategies made outside of the system are to be considered, a component to read acreages and constrain the land evaluation system should be included.

   b. More work is needed to develop this software.

5. Mapping Routines:

a. Algorithms chosen must be operable on the computer system used.

b. More printer and plotter routines should be surveyed.

c. Printer routines on the CDC 6500:

1) GRIDS and MIADS are best suited to gridded information: resource data, resource classes, output from the land assignment model.

2) SYMAP is best suited to mapping large, irregularly shaped areas.

6. Time should be spent to specify and test relationships which will project requirements and production for regions.

Data

Conclusions:

1. The data system of the Kalamazoo River Basin is insufficient to support a gridded information system because of a lack of soil maps and sub-county forest inventory data, and a lack of precision in remote sensing data in terms of making management decisions.

2. There is a lack of data to be used for projecting requirements and supplies of timber and hunterdays. More economic and physical data should be collected to meet the needs of the relationships specified for projection.

3. Sources of data, definitions, assumptions, and relationships were not documented sufficiently by U.S. Forest Service personnel when calculating product coefficients thus making it difficult for private researchers and citizens to interpret the data provided.

4. Assumptions made in constructing the model simplify behavior and could introduce bias into the model.

5. Important management options were neglected in developing the model thus introducing possible bias into the model.

Recommendations:

1. If the data situation of the Kalamazoo River Basin is representative of other river basin studies, much effort in inventorying and mapping data will be required if a grid system is to be implemented.

2. A standardized time series of production and consumption data of various land products for different regions should be established if better projections of requirements and production are to be made. Collection of other data needed should also be standardized.

3. The U.S. Forest Service needs to improve documentation of data submitted in river basin studies.

4. More management strategies should be developed such as hunter-day emphasis and short rotation forestry.

Usefulness of the Model

Conclusions:

1. The ideal model is well suited to developing management plans on publically-owned land by a land management agency or for developing land management recommendations for private landowners given the goals of the public agency.

2. The ideal model is poorly suited for prediction of land use patterns.

Recommendations:

1. If a predictive model is desired, it is recommended that investigation of development of a simulation model based on observed behavorial patterns be undertaken. Alternative land management possibilities could be developed and allocated to grid cells outside of the model.

The production of commodities over time by grid cell could be calculated. These results could become input for spatial economic and environmental impact models. Investigation would be required to determine production and impact relationships. An information system would have to be developed to store data for determination of possible land management patterns and to provide inputs to the production and impact relationships.

Kalamazoo River Basin Land Use

Conclusions:

1. The following are important factors affecting allocation of management strategies among regions:

   a. The most important factor is the level of requirements for commodities produced on the land. When levels of requirements for a commodity are below a certain critical level, there is a spatial differentiation in the allocation among regions of management strategies which produce that commodity. When the levels of requirements for a commodity are above a certain critical level, any spatial differentiation in the allocation among regions of management strategies which produce that commodity ceases to exist. That is to say, all timber producing lands must be managed intensively for timber when the critical level is reached.

   b. There is an important trade-off between development costs and transportation and importing costs. Development costs in a region are incurred only when it is cheaper to invest in intensive management than to import.

   c. The time distribution of production will be an important factor.

d. The time period of analysis affects the definition of which lands are timber producing and which are not and thus will have an effect on the pattern of land management.

2. OBERS demands for sawtimber cannot be met in time periods 1 and 3 given the structure and assumptions of this model.

3. Small amounts of commercial forest land, conversions of forest land to urban use, and characteristics of land tenure limit the possibilities for growth in output in timber-using industries. As a result:

a. Growth in output from the Menasha Corporation appears to be limited by a comparative disadvantage relative to other pulpmills in Michigan. This pulpmill is relatively distant from the large pulpwood resource of the northern lower peninsula of Michigan when compared to other pulpmills, which are located in that area. However, other factors might make the distance from the pulpwood resource less limiting: availability of labor and capital, economies of scale, new technology, and short rotation poplar culture on sub-marginal farmland.

b. Growth in output of small mills which use hardwoods can be accommodated. Intensive management could improve the quality of timber and further improve the growth potential of these operations.

4. It is difficult to apply the results of this study to other river basins because of the unique location factors of each river basin.

Recommendations:

1. All lands capable of producing merchantable timber during the time period of analysis should be converted to intensive management as

soon as possible to meet requirements in an economically efficient manner.

2. The following recommendations are made for lands not capable of producing merchantable timber during the time period of analysis:

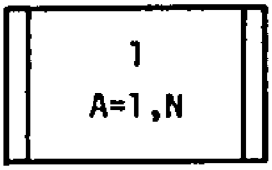
a. All adequate condition class lands should be converted to intensive management as soon as possible.

b. Forest land classes which are in the non-adequate condition class have the lowest priority for intensive management. Intensive management is concentrated on certain key land classes in regions 2, 3, and 4. Conversions to intensive management can occur later in time.

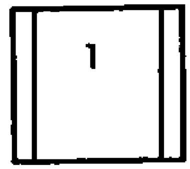
APPENDICES

APPENDIX A

FLOWCHART SYMBOLS

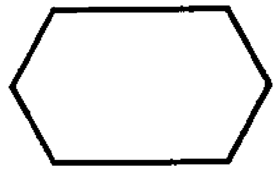


Begin Do Loop from 1 to N

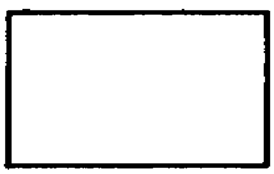


End Do Loop

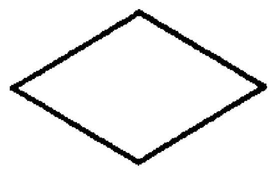
Input/Output



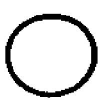
Initialize Elements of Array to Zero



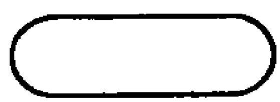
Assign Value to Variable



Decision



Connector



Start/End

Flow Arrow

X ← Y

Variable X is assigned the value of Y

APPENDIX B

PURCHASES OF SAWLOGS AND VENEER LOGS

Table B-1.--Purchases of Veneerlogs and Sawlogs by County (MCF)

County	1972	1969	1965
Allegan	709.4	585.2	363.1
Barry	2068.9	530.6	507.3
Berrien	235.9	196.7	1279.3
Branch	737.2	930.2	896.5
Calhoun	26.6	450.1	2669.0
Cass	111.9	924.7	combined with Berrien
Clinton	705.5	450.3	731.0
Eaton	1112.3	1206.6	1210.7
Gratiot	107.9	52.7	combined with Clinton
Hillsdale	426.0	91.2	398.6
Ingham	947.8	763.7	315.2
Ionia	1593.6	1023.5	758.5
Jackson	190.6	116.7	combined with Calhoun
Kalamazoo	187.1	112.7	183.2
Kent	1721.1	1522.8	1130.2
Lake	407.4	420.6	380.4
Mecosta	-	-	-
Montcalm	408.9	761.2	683.1
Muskegon	994.7	827.2	815.7
Newaygo	1184.6	1450.3	924.2
Osceola	824.8	463.4	265.6
Ottawa	81.7	50.0	combined with Muskegon
St. Joseph	10.7	8.3	combined with Berrien
Van Buren	152.0	53.3	120.5

APPENDIX C

PROPORTIONS OF COUNTY CONSUMPTION ALLOCATED TO REGIONS

Table C-1.--Proportions of County Consumption Allocated to Regions

County	Proportion	Region
Allegan	0.18	2
	0.82	4
Barry	0.07	2
	0.93	7
Berrien	0.5	3
	0.5	10
Branch	1.	9
Calhoun	0.86	1
	0.14	9
Cass	1.	8
Clinton	1.	7
Eaton	0.59	1
	0.41	7
Gratiot	1.	12
Hillsdale	1.	9
Ingham	1.	10
Ionia	1.	7
Jackson	1.	1
Kalamazoo	0.67	2
	0.33	9
Kent	1.	6
Lake	1.	11
Mecosta	1.	11
Montcalm	1.	11
Muskegon	1.	5
Newaygo	1.	11
Osceola	1.	12
Ottawa	1.	5
St. Joseph	1.	9
Van Buren	0.55	3
	0.45	4

APPENDIX D

DEMAND MULTIPLIERS USING TREND OF FIRST DERIVATIVE

Table D-1.--Demand Multipliers at 1970 Relative Prices

Product	1970	1980	1990	2000	2010	2020
Sawlogs	1.0	1.36	1.63	1.81	1.90	1.90
Veneer	1.0	1.22	1.44	1.67	1.90	2.13
Pulpwood	1.0	1.77	2.74	3.91	5.20	6.85
Total	1.0	1.39	1.83	2.32	2.86	3.45

Source: U.S. Forest Service, 1973.

Table D-2.--Demand Multipliers at Rising Relative Prices

Product	1970	1980	1990	2000	2010	2020
*Sawlogs	1.0	1.18	1.27	1.27	1.27	1.27
Veneer	1.0	1.00	1.05	1.33	1.77	2.38
Pulpwood	1.0	1.70	2.50	3.40	4.40	5.50
Total	1.0	1.30	1.60	1.90	2.20	2.50

Source: U.S. Forest Service, 1973

*Trend predicts a decrease in demand after the year 2000, this was assumed not to occur.

Table D-3.--Demand Multipliers at Relative Prices Above 1970

Product	1970	1980	1990	2000	2010	2020
Sawlogs	1.0	1.13	1.31	1.54	1.82	2.15
Veneer	1.0	1.22	1.44	1.67	1.90	2.13
Pulpwood	1.0	1.62	2.49	3.61	4.98	6.60
Total	1.0	1.28	1.66	2.14	2.72	3.40

Source: U.S. Forest Service, 1973

APPENDIX E

REQUIREMENTS FOR SAWLOGS, VENEER LOGS, AND PULPWOOD

Table E-1.--Requirements for Sawlogs and Veneer Logs with 1970 Relative Prices (Mcf)

Region	1970	1980	1990	2000	2010	2020
1	872	1177	1412	1569	1657	1666
2	828	1117	1341	1490	1573	1581
3	201	271	326	361	382	384
4	227	306	368	409	431	434
5	913	1233	1479	1643	1735	1744
6	1455	1964	2357	2619	2764	2799
7	3198	4317	5181	5756	6076	6108
8	542	732	878	976	1030	1035
9	1125	1519	1823	2025	2183	2149
10	859	1160	1392	1546	1632	1641
11	2103	2839	3407	3785	3996	4017
12	671	906	1087	1208	1275	1282

Table E-2.--Requirements for Sawlogs and Veneer Logs with Rising Relative Prices (Mcf)

Region	1970	1980	1990	2000	2010	2020
1	872	1020	1098	1107	1134	1160
2	828	969	1043	1052	1076	1101
3	201	235	253	255	261	267
4	227	266	286	288	295	302
5	913	1068	1150	1160	1187	1214
6	1455	1702	1833	1848	1892	1935
7	3198	3742	4030	4061	4157	4253
8	542	634	683	688	705	721
9	1125	1316	1418	1429	1463	1496
10	859	1005	1082	1091	1117	1143
11	2103	2461	2650	2671	2734	2797
12	671	785	845	852	872	892

Table E-3.--Pulpwood Requirements with 1970 Relative Prices (Ccf)

Region	1970	1980	1990	2000	2010	2020
2	41673	73761	114184	162941	216699	287515
5	119271	211109	326802	466349	620209	817006

Table E-4.--Pulpwood Requirements with Rising Relative Prices (Ccf)

Region	1970	1980	1990	2000	2010	2020
2	41673	70844	104183	141688	183361	229202
5	119271	202761	298177	405521	524792	655991

APPENDIX F

ROUNDWOOD REQUIREMENTS

Table F-1.--Roundwood Requirements with 1970 Relative Prices (Mcf)

Region	1970	1980	1990	2000	2010	2020
1	872	1177	1412	1569	1657	1666
2	4995	8493	12759	17884	23242	30332
3	201	271	326	361	382	384
4	227	306	368	409	431	434
5	12840	22343	34159	48278	63756	83445
6	1455	1964	2357	2619	2764	2799
7	3198	4317	5181	5756	6067	6108
8	542	732	878	976	1030	1035
9	1125	1519	1823	2025	2138	2149
10	859	1160	1392	1546	1632	1641
11	2103	2839	3407	3785	3996	4017
12	671	906	1087	1208	1275	1282

Table F-2.--Roundwood Requirements with Rising Relative Prices (Mcf)

Region	1970	1980	1990	2000	2010	2020
1	872	1020	1098	1107	1134	1160
2	4995	8053	11461	15221	19412	24021
3	201	235	253	255	261	267
4	227	266	286	288	295	302
5	12840	21344	30967	41712	53666	66813
6	1455	1702	1833	1848	1892	1935
7	3198	3742	4030	4061	4157	4253
8	542	634	683	688	705	721
9	1125	1316	1418	1429	1463	1496
10	859	1005	1082	1091	1117	1143
11	2103	2461	2650	2671	2734	2797
12	671	785	845	852	872	892

APPENDIX G

PROPORTIONS OF COUNTY TIMBER PRODUCTION ALLOCATED TO REGIONS

Table G-1.--Proportions of County Timber Production Allocated to Regions

County	Proportion	Region
Allegan	1.00	2, 4
Barry	0.36	2
	0.64	7
Berrien	0.20	3
	0.80	8
Branch	1.00	9
Calhoun	0.69	1
	0.31	9
Cass	1.00	8
Clinton	1.00	7
Eaton	0.24	1
	0.76	7
Gratiot	1.00	12
Hillsdale	0.12	1
	0.88	9
Ingham	1.00	10
Ionia	1.00	7
Jackson	0.24	1
	0.76	10
Kalamazoo	0.61	2
	0.39	9
Kent	1.00	6
Lake	1.00	11
Mecosta	1.00	11
Montcalm	1.00	11
Muskegon	1.00	5
Newaygo	1.00	11
Osceola	1.00	12
Ottawa	0.24	4
	0.76	5
St. Joseph	1.00	9
Van Buren	0.89	2, 3
	0.11	8

APPENDIX H

SAWLOG PRODUCTION IN OUTSIDE REGIONS

Table H-1.--Sawlog Production from Outside Regions by County (Mcf)

Region	County	1972	1969	1965
5	Muskegon	887	255	446
	Ottawa	197	242	153
6	Kent	1363	930	859
7	Ionia	1745	1131	827
	Barry	817	576	364
	Eaton	577	520	498
	Clinton	925	573	647
8	Berrien	168	161	259
	Cass	408	660	455
	Van Buren	30	220	36
9	St. Joseph	254	137	223
	Branch	277	460	403
	Kalamazoo	123	140	110
	Calhoun	76	172	170
	Hillsdale	314	238	218
10	Ingham	814	973	925
	Jackson	409	358	395
11	Lake	594	906	650
	Mecosta	46	149	317
	Newaygo	1219	1621	1206
	Osceola	914	651	292
12	Gratiot	636	1059	706
	Montcalm	717	706	772

APPENDIX I

VENEER LOG PRODUCTION IN OUTSIDE REGIONS

Table I-1.--Veneer Log Production by Region and County (Mcf)

Region	County	1972	1969
5	Muskegon	19	6
	Ottawa	5	0
6	Kent	32	3
7	Ionia	30	4
	Barry	46	8
	Eaton	12	33
	Clinton	0	0
8	Berrien	37	30
	Cass	43	43
	Van Buren	10	9
9	St. Joseph	6	26
	Branch	9	29
	Kalamazoo	6	12
	Calhoun	6	1
	Hillsdale	11	31
10	Ingham	4	30
	Jackson	13	18
11	Lake	25	0
	Mecosta	0	16
	Newaygo	25	0
	Osceola	0	24
12	Gratiot	0	3
	Montcalm	13.5	7

APPENDIX J

EXCESS SUPPLIES OF TIMBER

Table J-1.--Excess Supplies of Timber with 1970 Relative Prices (Mcf)

Region	1970	1980	1990	2000	2010	2020
5	-11853	-21356	-33172	-42290	-62770	-82457
6	-365	-874	-1267	-1529	-1674	-1709
7	-702	-1821	-2685	-3260	-3580	-3612
8	354	165	19	-79	-133	-138
9	22	-372	-676	-878	-991	-1002
10	464	150	-69	-233	-309	-318
11	3244	2508	1940	1562	1351	1330
12	875	640	459	338	271	264

Table J-2.--Excess Supplies of Timber with Rising Relative Prices (Mcf)

Region	1970	1980	1990	2000	2010	2020
5	-11853	-20357	-29980	-40725	-52679	-56261
6	-365	-612	-742	-758	-802	-845
7	-702	-1246	-1534	-1565	-1661	-1757
8	354	263	214	209	192	176
9	22	-169	-271	-282	-316	-349
10	464	318	241	232	206	180
11	3244	2886	2697	2676	2613	2550
12	875	761	701	694	674	654

Appendix K

REQUIREMENT FOR DEER HUNTERDAYS, 1970

Table K-1.--Requirements for Deer Hunterdays by County and Region, 1970

Region	County	DNR zone	Population	Requirements
1	Calhoun	17	128437	15926
	Eaton	14	15437	2161
	Hillsdale	17	2666	331
	Jackson	17	12419	1540
2	Allegan	18	49303	7691
	Barry	18	12458	1943
	Kalamazoo	18	172457	26903
3	Berrien	18	50518	7881
	Van Buren	18	24057	3753
4	Allegan	18	13115	2046
	Ottawa	13	52311	5859
	Van Buren	18	23200	3619
5	Muskegon	13	157426	17631
	Ottawa	13	73311	8211
6	Kent	13	411044	46037
7	Ionia	13	45848	5135
	Barry	18	25708	4010
	Eaton	14	53455	7484
	Clinton	14	48492	6789
8	Berrien	18	113357	17684
	Cass	18	43312	6757
	Van Buren	18	8916	1391
9	St. Joseph	18	47392	7392
	Branch	17	37906	4700
	Kalamazoo	18	29093	4538
	Calhoun	17	13526	1677
	Hillsdale	17	34505	4279
10	Ingham	14	261039	36545
	Jackson	17	130855	16226

Appendix L

REQUIREMENTS FOR HUNTERDAYS

Table L-1.--Requirements for Deer Hunterdays

Regions	1970	1980	1990	2000	2010	2020
1	19958	21953	23930	25307	26684	28061
2	36537	40191	43808	46329	48850	51371
3	11634	12797	13949	14752	15555	16357
4	11526	12676	13817	14612	15408	16203
5	25842	28426	30984	32768	34551	36334
6	46037	50641	55198	58375	61552	64728
7	23418	25760	28078	29694	31310	32926
8	25832	28415	30973	32755	34537	36320
9	22587	24846	27082	28640	30199	31757
10	52771	58048	63272	66914	70555	74196

Table L-2.--Requirements for Small Game Hunterdays

Regions	1970	1980	1990	2000	2010	2020
1	70735	77809	84811	89692	94573	99453
2	104227	114650	124968	132160	139352	146543
3	33186	36505	39790	42080	44370	46660
4	39438	43383	47287	50009	52730	55451
5	102678	112946	123111	130196	137281	144365
6	182915	201207	219315	231936	244557	257179
7	77209	84930	92574	97901	103228	108556
8	73685	81054	88348	93433	98517	103601
9	72278	79506	86661	91649	96636	101623
10	174393	191832	209097	221130	233163	245197

Appendix M

GAME KILLS IN REGIONS OUTSIDE OF THE RIVER BASIN

Table M-1.--Game Kills Per County in Regions Outside of the River Basin

Region	County	DNR Region	Deer	Squirrel	Cottontail
5	Muskegon	13	440	14283	22587
	Ottawa	13	369	11984	18952
6	Kent	13	736	23887	37775
7	Ionia	13	490	15907	25155
	Barry	18	238	10079	15939
	Eaton	14	283	11984	18952
	Clinton	14	372	15769	24937
8	Berrien	18	303	12823	20278
	Cass	18	328	13898	21978
	Van Buren	18	45	1926	3046
9	St. Joseph	18	337	14225	22543
	Branch	17	335	14228	22500
	Kalamazoo	18	147	6214	9826
	Calhoun	17	143	6076	2608
	Hillsdale	17	344	14594	23079
10	Ingham	14	364	15411	24371
	Jackson	17	356	15080	23847

Appendix N

HUNTERDAYS SUPPLIED IN REGIONS OUTSIDE OF THE RIVER BASIN, 1970

Table N-1.--Hunterdays Supplied by Counties in Regions Outside of the Basin, 1970

Region	County	Deer	Squirrel	Cottontail
5	Muskegon	16456	22139	40657
	Ottawa	13801	18576	34114
6	Kent	25095	37025	67995
7	Ionia	18326	24656	45279
	Barry	8901	15622	28690
	Eaton	10584	18575	34114
	Clinton	13921	24442	44887
8	Berrien	11332	19876	36500
	Cass	12267	21542	39560
	Van Buren	1683	2985	5483
9	St. Joseph	12604	22095	40577
	Branch	12579	22053	40500
	Kalamazoo	5498	9632	17687
	Calhoun	5348	9418	17294
	Hillsdale	12866	22621	41542
10	Ingham	13615	23887	43868
	Jackson	13315	23374	42925

Appendix O

EXCESS PRODUCTION OF HUNTERDAYS BY OUTSIDE REGION

Table O-1.--Excess Production of Deer Hunterdays

Region	1970	1980	1990	2000	2010	2020
5	4415	1831	-727	-2511	-4294	-6077
6	-20942	-25546	-30103	-33280	-36457	-39633
7	28314	25792	23654	22038	20422	18806
8	-550	-3133	-5691	-7473	-9255	-11038
9	26258	23999	21763	20205	18646	17088
10	-25841	-31118	-36342	-39984	-43625	-47266

Table O-2.--Excess Production of Small Game Hunterdays

Region	1970	1980	1990	2000	2010	2020
5	12507	2539	-7626	-14711	-21796	-28880
6	-77895	-96187	-114295	-126176	-139537	-152129
7	159056	151335	143691	138364	133037	217709
8	52261	44892	37708	32513	27429	22345
9	171141	163913	156758	151770	146780	141796
10	-40339	-57878	-75043	-87076	-94109	-111143

APPENDIX P

MILES TRAVELLED ON EACH CLASS OF ROAD IN EACH REGION

Table P-1.--Miles Travelled on Each Class of Road in Each Region

Class	1	2	3	4	5	6	7	8	9	10	11	12
Trunk	3.5	2.3	.6	.3	7.3	6.5	21.3	12.2	11.6	8.2	18.9	8.6
Non-Trunk	3.9	5.7	4.0	5.4	5.8	4.7	4.3	3.0	4.9	4.6	5.6	4.1
I	.6	.3	.2	.2	.4	.5	.1	.1	.4	.2	.2	.6
II	.1	.2	.0	.1	.1	.1	.3	.1	.2	.1	1.5	.4
III	.1	.2	.1	.3	.2	.1	.4	.0	.1	.1	.2	.6
IV	.0	.0	.0	.1	.0	.0	.1	.0	.0	.0	.1	.1
V	.5	.5	.4	.5	.4	.5	.5	.4	.4	.4	.6	.5

APPENDIX Q

MILEAGE TRAVELLED ON THE TRANSPORTATION NETWORK IN EACH REGION

Table Q-1.--Mileage Travelled on the Transportation Network in Each Region

Subarea	Longest Distance (Road Mileage/4)	Average Distance (Distance/$\sqrt{2}$)
1	16.7	11.81
2	23.7	16.76
3	21.0	14.85
4	19.5	13.79
5	16.8	11.88
6	17.8	12.59
7	17.94	12.69
8	16.38	11.58
9	28.45	20.12
10	20.55	14.53
11	24.13	17.06
12	19.5	13.79

APPENDIX R

TIMBER TRANSFER COSTS BETWEEN REGIONS, 1970

Table R-1.--Timber Transfer Costs Between Regions ($/Ccf), 1970

Route Number	Origin	Destination	Cost
1	1	2	9.65
2	2	1	8.63
3	1	3	9.50
4	3	1	10.79
5	1	4	11.86
6	4	1	13.03
7	2	3	7.43
8	3	2	8.39
9	2	4	7.34
10	4	2	9.09
11	3	4	8.53
12	4	3	7.84
13	1	5	18.26
14	5	1	18.26
15	1	6	15.29
16	6	1	14.84
17	1	7	9.89
18	7	1	10.90
19	1	8	12.53
20	8	1	13.76
21	1	9	7.38
22	9	1	8.97
23	1	10	9.23
24	10	1	9.12
25	2	5	11.42
26	5	2	11.43
27	2	6	9.76
28	6	2	8.64
29	2	7	13.54
30	7	2	15.34
31	2	8	10.25
32	8	2	8.40
33	2	9	9.78
34	9	2	13.17
35	2	10	14.66
36	10	2	15.07
37	3	5	13.28
38	5	3	12.86
39	3	6	14.03
40	6	3	12.29

Table R-1. (cont'd.)

Route Number	Origin	Destination	Cost
41	3	7	17.81
42	7	3	18.64
43	3	8	7.79
44	8	3	7.34
45	3	9	11.94
46	9	3	13.49
47	3	10	16.80
48	10	3	14.88
49	4	5	8.65
50	5	4	7.58
51	4	6	8.35
52	6	4	8.10
53	4	7	12.43
54	7	4	13.72
55	4	8	8.98
56	8	4	13.55
57	4	9	18.09
58	9	4	17.46
59	4	10	18.29
60	10	4	17.57
61	1	1	5.08
62	2	2	5.83
63	3	3	5.01
64	4	4	17.57
71	11	1	25.03
72	11	2	19.08
73	11	3	22.49
74	11	4	17.63
75	12	1	15.44
76	12	2	12.82
77	12	3	16.23
78	12	4	11.30

APPENDIX S

WEIGHTS ON EACH YEAR'S CAR CLASS

Table S-1.--Weights on Each Year's Car Class

Year	Attrition Weight	Production Weight	Total Weight
1974	1.0	1.0	1.0
1973	.945	1.29	1.22
1972	.89	1.24	1.10
1971	.84	1.16	.96
1970	.78	.93	.74
1969	.73	1.08	.78
1968	.67	1.09	.73
1967	.62	1.09	.67
1966	.56	1.09	.61
1965	.50	1.09	.54

Source: Motor Vehicle Manufacturers Association of the U.S., Inc., 1974.

APPENDIX T

PROPORTIONS OF EACH CAR CLASS PRODUCED

Table T-1.--Proportions of Each Car Class Produced

Year	Standard	Compact	Subcompact
1974	.509	.242	.248
1973	.573	.179	.248
1972	.619	.151	.230
1971	.617	.157	.226
1970	.631	.199	.170
1969	.720	.164	.116
1968	.746	.150	.104
1967	.746	.150	.104
1966	.746	.150	.104
1965	.746	.150	.104

Source: Motor Vehicle Manufacturers Association of the U.S., Inc., 1974.

Appendix U

TRANSFER COSTS FOR BIG AND SMALL GAME HUNTERDAYS, 1970

Table U-1.--Transfer Costs for Big and Small Game Hunterdays, 1970

Route number	Origin	Destination	Cost Big Game (Dollars)	Cost Small Game (Dollars)
1	1	2	2.85	4.06
2	2	1	3.60	5.14
3	1	3	4.19	5.97
4	3	1	3.52	5.02
5	1	4	5.41	7.72
6	4	1	4.84	6.94
7	2	3	2.84	4.05
8	3	2	2.18	3.11
9	2	4	3.21	4.57
10	4	2	2.12	3.03
11	3	4	2.51	3.58
12	4	3	2.92	4.17
13	1	5	2.17	3.10
14	5	1	2.61	3.71
15	1	6	6.49	9.25
16	6	1	6.76	9.64
17	1	7	3.68	5.24
18	7	1	4.18	5.96
19	1	8	5.96	8.50
20	8	1	5.22	7.44
21	1	9	3.01	4.30
22	9	1	2.33	3.33
23	1	10	3.26	4.64
24	10	1	2.74	3.91
25	2	5	4.61	6.57
26	5	2	4.41	6.29
27	2	6	3.15	4.50
28	6	2	3.48	4.96
29	2	7	6.16	8.79
30	7	2	5.66	8.08
31	2	8	2.96	4.22
32	8	2	4.09	5.84
33	2	9	5.37	7.65
34	9	2	3.70	5.28
35	2	10	6.59	9.39
36	10	2	6.22	8.86
37	3	5	5.41	7.72
38	5	3	5.59	7.96

Table U-1. (cont'd.)

Route number	Origin	Destination	Cost Big Game (Dollars)	Cost Small Game (Dollars)
39	3	6	5.06	7.22
40	6	3	6.00	8.56
41	3	7	8.02	11.43
42	7	3	8.57	12.22
43	3	8	2.37	3.38
44	8	3	2.51	3.57
45	3	9	5.54	7.90
46	9	3	4.76	6.79
47	3	10	6.48	9.24
48	10	3	7.55	10.77
49	4	5	2.47	3.51
50	5	4	2.97	4.23
51	4	6	2.72	3.87
52	6	4	2.79	3.98
53	4	7	5.26	7.49
54	7	4	5.51	7.86
55	4	8	5.84	8.33
56	8	4	3.15	4.48
57	4	9	7.77	11.07
58	9	4	8.25	11.76
59	4	10	7.99	11.39
60	10	4	8.36	11.92
61	1	1	1.37	2.13
62	2	2	1.75	2.49
63	3	3	1.36	1.95
64	4	4	1.38	1.99

Appendix V

RANGES OF FIBER PRODUCTION

Table V-1.--Ranges of Fiber Production by Resource Class, Management Strategy and Stand Size Class

Resource Class	Management Strategy[a]	Stand Size Class[b]	Average (cf/yr)	Low (cf/yr)	High (cf/yr)
1	CU	NS	8	8	8
		SS	32	27	37
		PT	64	63	76
		ST	40	37	46
	IM	SS	41	36	46
		PT	89	84	95
		ST	52	47	54
2	CU	NS	8	8	8
		SS	26	21	31
		PT	57	46	68
		ST	32	22	34
	IM	SS	33	28	39
		PT	73	61	85
		ST	41	30	54
3	CU	NS	2	2	2
		SS	13	11	15
		PT	49	42	56
		ST	28	22	34
	IM	SS	17	14	19
		PT	63	57	70
		ST	37	32	42
4	CU,IM	NS	0	0	0
		SS	0	0	0
		PT	0	0	0
		ST	0	0	0
5	CU	NS	3	2	4
		SS	13	7	22
		PT	49	37	58
		ST	31	19	30
	IM	SS	14	14	18
		PT	63	49	70
		ST	31	25	37
6	CU	NS	3	2	4
		SS	8	5	10
		PT	43	33	50
		ST	20	17	22
	IM	SS	10	7	12
		PT	55	44	62

Table V-1. (Cont'd)

Resource Class	Management Strategy[a]	Stand Size Class[b]	Average (cf/yr)	Low (cf/yr)	High (cf/yr)
		ST	25	23	28
7	CU,IM	NS	0	0	0
		SS	0	0	0
		PT	0	0	0
		ST	0	0	0
8	CU,IM	NS	0	0	0
		SS	0	0	0
		PT	0	0	0
		ST	0	0	0
9	CU	NS	3	2	4
		SS	23	17	31
		PT	86	57	103
		ST	42	31	59
	IM	SS	30	23	39
		PT	112	77	129
		ST	54	41	74
10	CU	NS	3	2	4
		SS	23	17	31
		PT	70	53	92
		ST	34	27	43
	IM	SS	23	19	26
		PT	90	71	115
		ST	44	36	54
11	CU,IM	NS	0	0	0
		SS	0	0	0
		PT	0	0	0
		ST	0	0	0
12	CU	NS	6	5	7
		SS	18	12	24
		PT	65	57	84
		ST	45	35	56
	IM	SS	23	11	30
		PT	84	75	105
		ST	55	47	70
13	CU	NS	4	4	4
		SS	12	10	16
		PT	43	33	53
		ST	31	24	37
	IM	SS	16	13	20
		PT	55	44	60
		ST	40	32	46

[a]Management Strategies
CU = Current Use Management Strategy
IM = Intensive Management Strategy

[b]Stand Size Class
NS = Non-Stocked
SS = Seedling-Sapling
PT = Poletimber
ST = Sawtimber

APPENDIX W

AGE DISTRIBUTION OF FOREST TYPES IN THE SOUTHERN LOWER PENINSULA

Table W-1.--Age Distribution of Forest Types in the Southern Lower Peninsula (1000 Acres)

Forest Type	All Ages	0-20	20-40	40-50	50-60	60-70	70-80	80-90	90-100	100-120	120-140
White-red-jack pine											
jack pine	12.1	10.7	1.6								
red pine	36.5	29.2	7.3								
white pine	24.0	11.6			.4	6.5				5.6	
scotch pine	36.2	31.9	4.3								
Spruce-Fir											
white spruce	16.1	16.1									
white cedar	10.1	5.5		4.6							
tamarack	20.5	6.1	8.5	5.9							
Oak	1016.5	347.3	133.4	71.9	81.9	75.7	86.9	32.8	14.8	130.2	41.6
Elm-Ash-Cottonwood	719.4	337.2	102.9	54.9	62.7	25.5	35.8	44.3	25.9	19.6	10.6
Maple-Beech-Birch	501.6	149.8	80.6	58.	23.9	23.4	21.	32.5	56.3	44.	12.1
Aspen-Birch	429.4	301.5	108.3	6.8	5.1	7.7					

APPENDIX X

ACRES OF COMMERCIAL FOREST LAND BY STAND SIZE CLASS IN THE SOUTHERN LOWER PENINSULA

Table X-1.--Acres of Commercial Forest Land by Stand Size Class in the Southern Lower Peninsula (1000 Acres)

Ecosystem	Total	Sawtimber	Poletimber	Seed-Sapling	Non-Stocked
Conifer	149.3	26.1	27.1	84.1	11.6
Oak	1016.5	432.3	237.1	259.4	87.7
Elm-Ash-Cottonwood	719.4	191.2	185.2	227.0	116.0
Maple-Beech-Birch	501.6	239.8	103.6	145.6	12.6
Aspen-Birch	429.4	14.5	126.8	253.9	34.2

APPENDIX Y

PRODUCTION ACTIVITIES

Activities to be included in resource classes where adequate and TSI condition classes are differentiated:

Stand Size Class	Activity[c]
Seedling-sapling	CU,EE IM,CU to IM at the present[a] CU to IM at SS-PT juncture[a] CU to IM at PT-ST juncture[a] CU-TSI to IM-AD at the present[b] CU-TSI to IM-AD at SS-PT juncture[b] CU-TSI to IM-AD at PT-ST juncture[b]
Poletimber	CU,EE IM - current[a] CU to IM at the present[a] CU to TSI to IM-AD at PT-ST[b]
Sawtimber	CU EE,CU to EE at the present IM - current[a] CU to IM before cut[a] CU to IM after cut[a] CU-TSI to IM-AD
Non-stocked	CU CU to IM at the present CU to IM at 2000

[a]not in TSI class

[b]not in adequate class

[c]CU = current use
EE = environmental emphasis
IM = intensive management

Activities to be included when TSI and Adequate condition classes are not differentiated:

Stand Size Class	Activity
Seed-sapling	CU,EE* IM-current CU to IM at the present CU to IM at the SS-PT juncture CU to IM at the PT-ST juncture
Poletimber	CU,EE* IM-current CU to IM at the PT-ST juncture
Sawtimber	CU EE,CU to EE - present IM-current CU to IM before cut CU to IM after cut
Non-stocked	CU CU to IM at the present CU to IM at the year 2000

*separated with aspen-birch

Activities to be included when no merchantable timber is produced:

Stand Size Class	Activity
Seed-sapling	CU,EE IM-current CU to IM at the present CU to IM at the SS-PT juncture CU to IM at the PT-ST juncture
Poletimber	CU,EE IM-current CU to IM at the PT-ST juncture
Sawtimber	CU,EE,CU to EE IM-current CU to IM
Non-stocked	CU CU to IM at the present CU to IM at the year 2000

APPENDIX Z

MULTIPLIERS FOR PRODUCT COEFFICIENTS

Table Z-1.--Conifer Ecosystem

Stand Size Class	Time Period	Multiplier[a]
Seed-sapling	1	.66SS + .34PT
	2	.17SS + .83PT
	3	.83PT + .17ST
	4	.34ST + .66PT
	5	1.0ST
	6	1.0ST
Poletimber	1	.89PT + .11ST
	2	.67PT + .33ST
	3	.28PT + .72ST
	4	1.0ST
	5	1.0ST
	6	1.0ST
Sawtimber	1	.89ST + .11SS
	2	.67ST + .27SS + .06PT
	3	.56ST + .22SS + .22PT
	4	.56ST + .39PT + .06SS
	5	.66ST + .34PT
	6	.89PT + .11PT
Timber Multiplier for sawtimber class	1	.22ST
	2	0
	3	0
	4	0
	5	0
	6	.25

[a]Stand Size Classes
SS = Seedling-sapling
PT = Poletimber
ST = Sawtimber

Table Z-2.--Oak Hickory Ecosystem

Stand Size Class	Time Period	Multiplier
Seed-sapling	1	.66SS + .34PT
	2	.17SS + .83PT
	3	.83PT + .17ST
	4	.66PT + .34ST
	5	1.0ST
	6	1.0ST
Poletimber	1	.88PT + .12ST
	2	.64PT + .36ST
	3	.41PT + .59ST
	4	.15PT + .85ST
	5	1.0ST
	6	1.0ST
Sawtimber, current use	1	.89ST + .11SS
	2	.70ST + .25SS + .05PT
	3	.61ST + .18SS + .21PT
	4	.56ST + .10SS + .34PT
	5	.42ST + .16SS + .42PT
	6	.46ST + .14SS + .40PT
Timber multipliers for sawtimber class, current use	1	.232ST
	2	.142ST
	3	.034ST
	4	.072ST
	5	.19ST
	6	.156ST
Sawtimber, intensive use	1	.98ST + .02SS
	2	.94ST + .05SS + .01PT
	3	.84ST + .12SS + .04PT
	4	.7ST + .19SS + .12PT
	5	.61ST + .16ST + .23PT
	6	.58ST + .10SS + .32PT
Timber Multipliers for sawtimber class, intensive use	1	.044ST
	2	.044ST
	3	.142ST
	4	.142ST
	5	.034ST
	6	.034ST

Table Z-3.--Elm-Ash-Cottonwood Ecosystem

Stand Size Class	Time Period	Multiplier
Seed-sapling	1	.66SS + .34PT
	2	.17SS + .83PT
	3	.83PT + .17SS
	4	.34ST + .66PT
	5	1.0ST
	6	1.0ST
Poletimber	1	.91PT + .09ST
	2	.74PT + .26ST
	3	.58PT + .42ST
	4	.25PT + .75ST
	5	1.0ST
	6	1.0ST
Sawtimber, current use	1	.95ST + .05SS
	2	.89ST + .09SS + .02PT
	3	.81ST + .11SS + .08PT
	4	.65ST + .2SS + .15PT
	5	.47ST + .25SS + .28PT
	6	.38ST + .23SS + .39PT
Sawtimber, intensive management	1	.99ST + .01SS
	2	.96ST + .03SS + .01PT
	3	.93ST + .05SS + .02PT
	4	.88ST + .06SS + .06PT
	5	.81ST + .1SS + .09PT
	6	.67ST + .2SS + .13PT

Table Z-4.--Maple-Beech-Birch Ecosystem

Stand Size Class	Time Period	Multiplier
Seed-sapling	1	.75SS + .25PT
	2	.25SS + .75PT
	3	.75PT + .25ST
	4	.25PT + .75PT
	5	1.0ST
	6	1.0ST
Poletimber	1	.91PT + .09ST
	2	.66PT + .34ST
	3	.34PT + .66ST
	4	.14PT + .86ST
	5	1.0ST
	6	1.0ST
Sawtimber	1	.98ST +.02SS
	2	.95ST + .05SS
	3	.87ST + .11SS + .02PT
	4	.75ST + .20SS + .05PT
	5	.54ST + .33SS + .13PT
	6	.32ST + .44SS + .24PT
Timber multipliers	1	.032ST
	2	.032ST
	3	.12ST
	4	.12ST
	5	.30ST
	6	.16ST

Table Z-5.--Aspen-Birch Ecosystem

Stand Size Class	Time Period	Multiplier
Seed-sapling, intensive use	1	.66SS + .34PT
	2	.17SS + .83PT
	3	.83PT + .17ST
	4	.33PT + .50ST + .17SS
	5	.33ST + .67SS
	6	.66SS + .34PT
Poletimber, intensive use	1	.9PT + .1ST
	2	.69PT + .21ST + .1SS
	3	.29PT + .4ST + .31SS
	4	.29ST + .51SS + .2PT
	5	.34ST + .66PT
	6	.9PT + .1ST
Sawtimber, intensive use	1	1.0ST
	2	1.0SS
	3	.5SS + .5PT
	4	1.0PT
	5	1.0PT
	6	1.0ST
Timber multipliers, intensive use	1	1.0ST
	2	.2PT
	3	.22PT
	4	.58PT for poletimber .33SS for seed-sapling
	5	.66SS
	6	1.0ST
Seed-sapling, current use	1	.66SS + .34PT
	2	.5SS + .5PT
	3	.83PT + .17ST
	4	.34PT + .64ST
	5	.83ST + .17SS
	6	.34ST + .66SS
Poletimber, current use	1	.9PT + .1ST
	2	.69PT + .31ST
	3	.29PT + .61ST + .1SS
	4	.69ST + .26SS + .05PT
	5	.29ST + .51SS + .2PT
	6	.34SS + .66PT
Sawtimber, current use	1	.66ST + .34SS
	2	.17ST + .67SS + .16PT
	3	.42SS + .58PT
	4	.09SS + .91PT
	5	.66PT + .33ST
	6	.17PT + .83ST
Timber multipliers, current use	1	.66ST
	2	.34ST
	3	.10PT

Table Z-5. (cont'd.)

Stand Size Class	Time Period	Multiplier
	4	.11PT
	5	.29PT for poletimber .33SS for seed-sapling
	6	.66SS

APPENDIX AA

AGE CLASS AS A PROPORTION OF STAND SIZE CLASS BY ECOSYSTEM

Table AA-1.--Age Class as a Proportion of Stand Size Class by Ecosystem

Ecosystem	Age Class	Proportion of Age Class		
		Seedling-Sapling	Poletimber	Sawtimber
Conifer	0-10	.67		
	10-15	.33		
	15-20		.56	
	20-30		.22	
	30-40		.22	
	40-50			.52
	50-60			.01
	60-70			.25
	70-80			
	80-90			
	90-100			
	100-110			
	110-120			.22
Oak	0-10	.67		
	10-15	.33		
	15-20		.21	
	20-30		.23	
	30-40		.22	
	40-50		.34	
	50-60			.18
	60-70			.16
	70-80			.19
	80-90			.07
	90-100			.03
	100-110			.14
	110-120			.14
	120-130			.03
	130-140			.01
Elm-Ash-Cottonwood	0-10	.67		
	10-15	.33		
	15-20		.50	
	20-30		.16	
	30-40		.16	
	40-50		.18	
	50-60			.28
	60-70			.11
	70-80			.16
	80-90			.19
	90-100			.12

Table AA-1. (cont'd.)

Ecosystem	Age Class	Proportion of Age Class		
		Seedling-Sapling	Poletimber	Sawtimber
	100-110			.04
	110-120			.04
	120-130			.02
	130-140			.02
Maple-Beech-Birch	0-10	.5		
	10-20	.5		
	20-30		.24	
	30-40		.24	
	40-50		.36	
	50-60		.15	
	60-70			.13
	70-80			.11
	80-90			.16
	90-100			.29
	100-110			.12
	110-120			.12
	120-130			.03
	130-140			.03
Aspen-Birch	0-10	.67		
	10-15	.33		
	15-20		.41	
	20-30		.30	
	30-40		.29	
	40-50			.35
	50-60			.26
	60-70			
	70-80			.39

APPENDIX BB

COSTS OF PRODUCTION ACTIVITIES, 1970

Table BB-1.--Conifer Ecosystem, Soil Group 1

Stand Size Class	Activity[a]	Cost Condition Class Adequate (Dollars)	TSI (Dollars)
Seedling-sapling	CU,EE	0	0
	IM,CU to IM, present	0	*
	CU to IM at SS-PT	0	*
	CU to IM at PT-ST	0	*
	CU-TSI to IM-Ad at present	*	50
	CU-TSI to IM-Ad at SS-PT	*	32.60
	CU-TSI to IM-Ad at PT-ST	*	12.93
Poletimber	CU,EE	0	0
	IM	0	*
	CU to IM, present	0	*
	CU-TSI to IM-Ad at PT-ST	*	2.45
Sawtimber	CU	5089.31	4116.29
	EE,CU to EE, present	0	0
	IM	16843.42	*
	CU to IM, before cut	13353.14	*
	CU to IM, after cut	5089.31	*
	CU-TSI to IM-Ad, after cut		10528.26
Non-stocked	CU	*	0
	CU to IM, present	*	64.50
	CU to IM, 2000	*	11.62

[a]Activity
- CU = Current Use Management Strategy
- EE = Environmental Emphasis
- IM = Intensive Management Strategy
- CU to IM, present = Convert from Current Use to Intensive Management at the Present
- CU to IM at SS-PT = Convert from Current Use to Intensive Management at the juncture between seedling-sapling and poletimber
- CU to IM at PT-ST = Convert from Current Use to Intensive Management at the juncture between poletimber and sawtimber
- CU to IM, 2000 = Convert from Current Use to Intensive Management in the year 2000

CU to IM, before cut = Convert from Current Use to Intensive Management before harvest
CU to IM, after cut = Convert from Current Use to Intensive Management after the harvest
CU-TSI to IM-Ad at present = Convert from Current Use requiring timber stand imporovement to Intensive Management in adequate condition at the present
CU-TSI to IM-Ad at SS-PT = Convert from Current Use requiring timber stand improvement to Intensive Management in adequate condition at the juncture between seedling-sapling and sawtimber
CU-TSI to IM-Ad at PT-ST = Convert from current use requiring timber stand improvement to intensive management in adequate condition at the juncture between poletimber and sawtimber
CU-EE, present = Convert from Current Use to Environmental Emphasis at the present

Table BB-2.--Conifer Ecosystem, Soil Group 2

Stand Size Class	Activity	Cost ($)
Seed-sapling	CU,EE	0
	IM	0
	CU to IM, present	50
	CU to IM at SS-PT	32.60
	CU to IM at PT-ST	12.93
Poletimber	CU	0
	EE,CU to EE, present	0
	IM	0
	CU to IM at PT-ST	2.45
Sawtimber	CU	3419.38
	EE,CU to EE, present	0
	IM	13857.71
	CU to IM, before cut	9868.87
	CU to IM, after cut	4045.66
Non-stocked	CU	0
	CU to IM, present	64.50
	CU to IM, 2000	11.62

Table BB-3.--Conifer Ecosystem, Soil Group 3

Stand Size Class	Activity	Cost ($)
Seed-sapling	CU,EE	0
	IM	0
	CU to IM, present	50
	CU to IM at SS-PT	32.60
	CU to IM at PT-ST	12.93
Poletimber	CU,EE	0
	IM	0
	CU to IM,	8.67
Non-stocked	CU	0
	CU to IM, present	64.50
	CU to IM, 2000	11.62

Table BB-4.--Oak Ecosystem, Soil Group 1

Stand Size Class	Activity	Cost Condition Class Adequate (Dollars)	TSI (Dollars)
Seed-sapling	CU,EE	0	0
	IM,CU to IM, present	0	*
	CU to IM at SS-PT	0	*
	CU to IM at PT-ST	0	*
	CU-TSI to IM-Ad, present	*	30
	CU-TSI to IM-Ad at SS-PT	*	33.98
	CU-TSI to IM-Ad at PT-ST	*	1.07
Poletimber	CU,EE	0	0
	IM	0	*
	CU to IM at PT-ST	0	*
	CU-TSI to IM-Ad at PT-ST	*	4.73
Sawtimber	CU	3856	3416.35
	EE,CU to EE, present	0	0
	IM	16719.36	*
	CU to IM, before cut	14231.04	*
	CU to IM, after cut	3856	*
	CU-TSI to IM-Ad	*	11428.75
Non-stocked	CU	*	0
	CU to IM, present	*	61
	CU to IM, 2000	*	8.13

Table BB-5.--Oak Ecosystem, Soil Group 2

Stand Size Class	Activity	Cost ($)
Seed-sapling	CU,EE	0
	IM	0
	CU to IM, present	30
	CU to IM at SS-PT	33.98
	CU to IM at PT-ST	1.07
Poletimber	CU,EE	0
	IM	0
	CU to IM at PT-ST	4.73
Sawtimber	CU,EE	0
	IM	0
	CU to IM	13.08
Non-stocked	CU	0
	CU to IM, present	61
	CU to IM, 2000	8.13

Table BB-6.--Elm-Ash-Cottonwood Ecosystem

Stand Size Class	Acitvity	Cost ($)
Seed-sapling	CU,EE	0
	IM	0
	CU to IM, present	28
	CU to IM at SS-PT	19.50
	CU to IM at PT-ST	3.24
Poletimber	CU,EE	0
	IM	0
	CU to IM at PT-ST	7.73
Sawtimber	CU,EE	0
	IM	0
	CU to IM	0
Non-stocked	CU	0
	CU to IM, present	61
	CU to IM, 2000	8.13

Table BB-7.--Maple-Beech-Birch Ecosystem, Soil Group 1

Stand Size Class	Activity	Cost Condition Class Adequate (Dollars)	Cost Condition Class TSI (Dollars)
Seed-sapling	CU,EE	0	0
	IM,CU to IM, present	0	*
	CU to IM at SS-PT	0	*
	CU to IM at PT-ST	0	*
	CU-TSI to IM-Ad	*	30
	CU-TSI to IM-Ad	*	16.04
	CU-TSI to IM-Ad	*	3.24
Poletimber	CU,EE	0	0
	IM	0	*
	CU to IM at PT-ST	0	*
	CU-TSI to IM-Ad at PT-ST	*	3.91
Sawtimber	CU	7076.18	5738.79
	EE,CU to EE, present	0	0
	IM	14739.68	*
	CU to IM, before cut	10965.74	*
	CU to IM, after cut	7076.18	*
	CU-TSI to IM-Ad, before cut	*	9417.25
Non-stocked	CU	*	0
	CU to IM, present	*	61
	CU to IM, 2000	*	8.13

Table BB-8.--Maple-Beech-Birch Ecosystem, Soil Group 2

Stand Size Class	Activity	Cost ($)
Seed-sapling	CU,EE	0
	IM	0
	CU to IM, present	30
	CU to IM at SS-PT	16.04
	CU to IM at PT-ST	3.24
Poletimber	CU,EE	0
	IM	0
	CU to IM at PT-ST	3.91
Sawtimber	CU,EE	0
	IM	0
	CU to IM	3.24
Non-stocked	CU	0
	CU to IM, present	61
	CU to IM, 2000	8.13

Table BB-9.--Aspen-Birch Ecosystem, Soil Group 1

Stand Size Class	Activity	Cost ($)
Seed-sapling	CU	1278.5
	EE	0
	IM	3918.47
	CU to IM, present	3924.95
	CU to IM at SS-PT	3819.01
	CU to IM at PT-ST	3200.23
Poletimber	CU	1454.83
	EE	0
	IM	8584.65
	CU to IM at PT-ST	7280
Sawtimber	CU	15243.49
	EE,CU to EE, present	0
	IM	32732.61
	CU to IM, before cut	25942.12
	CU to IM, after cut	15250.95
Non-stocked	CU	0
	CU to IM, present	0
	CU to IM, 2000	0

Table BB-10.--Aspen-Birch Ecosystem, Soil Group 2

Stand Size Class	Activity	Cost ($)
Seed-sapling	CU	863.23
	EE	0
	IM	2677.64
	CU to IM, present	2585.34
	CU to IM at SS-PT	2188.56
	CU to IM at PT-ST	2684.12
Poletimber	CU	980.25
	EE	0
	IM	6035.67
	CU to IM at PT-ST	4927.18
Sawtimber	CU	10279.44
	EE,CU to EE	0
	IM	22193.52
	CU to IM, before cut	17439.50
	CU to IM, after cut	10287.27
Non-stocked	CU	0
	CU to IM, present	0
	CU to IM, 2000	0

APPENDIX CC

QUANTITIES OF GOODS PRODUCED OUTSIDE OF THE MODEL

Table CC-1.--Quantities of Outputs Produced on Forest Land Converted to Urban Use

Time Period	Product	Region 1	2	3	4
1	Timber (CF)	3261	18654	7468	18669
	Big Game Hunterdays	176	854	434	739
	Small Game Hunterdays	549	2495	1305	2493
	Erosion (Tons/acre/yr)	500	2108	1142	2034
2	Timber (CF)	4236	13459	4073	12257
	Big Game Hunterdays	170	601	269	587
	Small Game Hunterdays	632	2339	1102	2176
	Erosion (Tons/acre/yr)	470	1532	761	1700
3	Timber (CF)	8898	27084	10915	26682
	Big Game Hunterdays	148	365	190	391
	Small Game Hunterdays	602	1498	711	1449
	Erosion (Tons/acre/yr)	411	1071	628	1927
4	Timber (CF)	6907	13244	5385	13254
	Big Game Hunterdays	111	173	82	562
	Small Game Hunterdays	485	766	353	790
	Erosion (Tons/acre/yr)	308	519	240	536
5	Timber	8543	9209	3989	16787
	Big Game Hunterdays	79	98	46	103
	Small Game Hunterdays	285	455	206	486
	Erosion (Tons/acre/yr)	193	304	138	339
6	Timber	2300	3809	2188	4191
	Big Game Hunterdays	25	32	14	36
	Small Game Hunterdays	100	153	66	164
	Erosion (Tons/acre/yr)	66	96	45	110

Table CC-2.--Quantities of Outputs Produced on Lands Currently in Intensive Management and Environmental Emphasis

Time Period	Product	Region 1	2	3	4
1	Timber (CF)	167050	266481	214710	177470
	Big Game Hunterdays	3572	5048	2790	3701
	Small Game Hunterdays	7449	10627	5702	7683
	Erosion (Tons/acre/yr)	5246	7620	3647	5017
2	Timber (CF)	44260	200930	156780	120370
	Big Game Hunterdays	3561	5285	2641	3599
	Small Game Hunterdays	6999	12116	5841	7610
	Erosion (Tons/acre/yr)	4891	10673	3521	4709
3	Timber (CF)	109460	253960	204450	180830
	Big Game Hunterdays	3494	5210	2680	3574
	Small Game Hunterdays	7923	11024	5733	8555
	Erosion (Tons/acre/yr)	4898	7133	7009	4314
4	Timber (CF)	189160	293580	196628	251260
	Big Game Hunterdays	3707	5304	2693	4511
	Small Game Hunterdays	8274	11109	5966	8386
	Erosion (Tons/acre/yr)	4670	7202	2656	4953
5	Timber (CF)	392660	674240	573610	499882
	Big Game Hunterdays	4467	6778	3559	3833
	Small Game Hunterdays	8813	14531	6184	8690
	Erosion (Tons/acre/yr)	8273	7126	3117	4996
6	Timber (CF)	340140	426762	310030	289129
	Big Game Hunterdays	4454	7505	3548	3836
	Small Game Hunterdays	8778	14426	6123	9295
	Erosion (Tons/acre/yr)	8273	7027	3180	4998

APPENDIX DD

ACREAGES ALLOCATED TO MANAGEMENT STRATEGIES IN LINEAR PROGRAMMING SOLUTIONS

Table DD-1.--Run A

Stand Size Class[b]	Management Strategy[a]	Region 1	2	3	4
Ecosystem: Conifer	Soil Group: 1	Condition Class: Adequate			
SS	CU-IM, present	375	51	-	-
PT	CU-IM, present	-	-	-	169
ST	CU-IM, before cut	319	451	-	369
Ecosystem: Conifer	Soil Group: 1	Condition Class: Needs TSI			
SS	CU	519	2005	568	1900
PT	CU	691	573	285	664
ST	CU-IM, before cut	-	96	-	-
	CU-IM, after cut	-	-	-	95
NS	CU	159	191	-	95
Ecosystem: Conifer	Soil Group: 2				
SS	CU	291	-	275	1275
	CU-IM, at PT-ST	-	1423	-	-
PT	CU	95	182	-	643
	CU-IM, at PT-ST	-	-	87	-
ST	CU-IM, before cut	-	473	87	270
NS	CU	97	191	94	97
Ecosystem: Conifer	Soil Group: 3				
SS	CU	483	569	189	176
PT	CU	95	192	-	92
	CU-IM, present	-	-	96	-
ST	CU	-	92	-	-
NS	CU	97	-	-	-
Ecosystem: Oak	Soil Group: 1	Condition Class: Adequate			
SS	CU-IM, present	-	1312	502	4657
	CU-IM at PT-ST	2568	-	-	-
PT	CU-IM, present	472	2474	2254	2485
ST	CU-IM, before cut	6101	13405	3600	7614

Table DD-1. (cont'd.)

Stand Size Class[b]	Management Strategy[a]	Region 1	2	3	4
Ecosystem: Oak	Soil Group: 1	Condition Class: Needs TSI			
SS	CU	1833	14237	2926	6136
PT	CU	3773	7322	-	3072
	CU-IM, present	-	-	1502	-
ST	CU-IM, before cut	1143	2165	2842	1289
NS	CU	1440	6390	1328	3819
Ecosystem: Oak	Soil Group: 2				
SS	CU	1466	2002	564	259
PT	CU	1951	1332	-	76
	CU-IM, present	-	-	564	-
ST	CU	2894	2378	1028	359
NS	CU	587	1143	189	76
Ecosystem: Elm-Ash-Cottonwood	Soil Group: 1				
SS	CU	5520	-	-	6553
	CU-IM at PT-ST	-	10832	4794	-
PT	CU	5335	-	3450	5621
	CU-IM, at present	-	9490	-	-
ST	CU-IM	5335	8097	4536	4956
NS	CU	3694	4746	2344	3278
Ecosystem: Maple-Beech-Birch	Soil Group: 1	Condition Class: Adequate			
SS	CU-IM, present	553	711	625	1846
PT	CU-IM, present	668	311	-	373
ST	CU-IM, before cut	2802	6041	3329	5167
Ecosystem: Maple-Beech-Birch	Soil Group: 1	Condition Class: Needs TSI			
SS	CU	877	6296	1412	3420
PT	CU	1169	2375	947	1190
ST	CU-IM, before cut	975	3230	369	1205
NS	CU	195	765	283	371
Ecosystem: Maple-Beech-Birch	Soil Group 2				
SS	CU	875	1045	475	176
PT	CU	873	373	193	90
ST	CU	1460	1233	850	169
NS	CU	94	191	-	-

Table DD-1. (cont'd.)

Stand Size Class[b]	Management Strategy[a]	Region 1	Region 2	Region 3	Region 4
Ecosystem: Aspen-Birch Soil Group: 1					
SS	CU-EE	3222	6468	2496	3407
PT	CU-IM at PT-ST	758	2561	648	1195
ST	CU-IM, before cut	185	387	93	279
NS	CU	194	1233	467	35
Ecosystem: Aspen-Birch Soil Group: 2					
SS	CU-EE	3322	4955	2429	2796
PT	CU-IM at PT-ST	775	2193	745	1084
ST	CU-IM, before cut	192	187	188	183
NS	CU	192	756	282	537

[a]Refer to Appendix BB, Table BB-1 on page 308 for the definition of symbols in the management strategy column.

[b]Stand Size Classes

NS = Non-Stocked
SS = Seedling-Sapling
PT = Poletimber
ST = Sawtimber

Table DD-2.--Run B, Changes in Acreages Allocated to Management Strategies as Compared to Run A

Stand Size Class	Management Strategy	Region 1	2	3	4
Ecosystem: Conifer	Soil Group: 2				
PT	CU	95	182	2.98	643
	CU-IM, present	-	-	84.02	-
Ecosystem: Oak	Soil Group: 1	Condition Class: Adequate			
SS	CU-IM, present	-	-	502	-
	CU-IM at SS-PT	2586	1312	-	4657
Ecosystem: Elm	Soil Group: 2				
SS	CU	5520	10832	-	6553
	CU-IM at PT-ST	-	-	4794	-
Ecosystem: Maple	Soil Group: 1	Condition Class: Adequate			
SS	CU-IM, present	-	711	625	1846
	CU-IM at PT-ST	553	-	-	-
Ecosystem: Aspen-Birch	Soil Group: 1				
SS	CU-IM, present	3222	6468	2494	3407
Ecosystem: Aspen-Birch	Soil Group: 2				
SS	CU-IM, present	3322	4955	2429	2796

Table DD-3.--Run C, Changes in Acreages Allocated to Management Strategies as Compared to Run A

Stand Size	Management Strategy	Region 1	Region 2	Region 3	Region 4
Ecosystem: Conifer Soil Group: 3					
PT	CU	95	-	-	-
	CU-IM at PT-ST	-	192	96	92
Ecosystem: Oak Soil Group: 1 Condition Class: Adequate					
SS	CU-IM, present	-	-	502	-
	CU-IM at SS-PT	2586	1312	-	4657
Ecosystem: Oak Soil Group: 1 Condition Class: Needs TSI					
PT	CU	3773	7322	-	3072
	CU-IM, present	-	-	1502	-
Ecosystem: Oak Soil Group: 2					
SS	CU	1466	2002	-	259
	CU-IM at PT-ST	-	-	564	-
PT	CU	1951	-	-	-
	CU-IM, present	-	1332	564	76
Ecosystem: Elm Soil Group: 1					
SS	CU	5520	10832	-	6553
	CU-IM at PT-ST	-	-	4794	-
Ecosystem: Maple Soil Group: 1 Condition Class: Adequate					
SS	CU-IM, present	-	711	625	1846
	CU-IM at PT-ST	553	-	-	-
Ecosystem: Aspen-Birch Soil Group: 1					
SS	CU-IM, present	3222	6468	2494	3407
Ecosystem: Aspen-Birch Soil Group: 2					
SS	CU-IM, present	3322	4955	2429	2790

Table DD-4.--Run D, Changes in Acreages Allocated to Management Strategies as Compared to Run A

Stand Size Class	Management Strategy	Region 1	2	3	4
Ecosystem: Conifer	Soil Group: 3				
PT	CU	95	-	-	-
	CU-IM, present	-	192	96	92
Ecosystem: Oak	Soil Group: 1	Condition Class: Adequate			
SS	CU-IM, present	-	-	502	-
	CU-IM at PT-ST	2586	1312	-	4657
Ecosystem: Oak	Soil Group: 1	Condition Class: Needs TSI			
PT	CU	3773	1083.9	-	3072
	CU-IM, present	-	6238.1	1502	-
Ecosystem: Oak	Soil Group: 2				
SS	CU	1466	2002	-	259
	CU-IM at PT-ST	-	-	564	-
PT	CU	1951	-	-	-
	CU-IM, present	-	1332	564	76
Ecosystem: Elm	Soil Group: 1				
SS	CU	5520	10832	-	6553
	CU-IM at PT-ST	-	-	4794	-
Ecosystem: Maple	Soil Group: 1	Condition Class: Adequate			
SS	CU-IM, present	-	711	625	1846
	CU-IM at PT-ST	553	-	-	-
Ecosystem: Aspen-Birch	Soil Group: 1				
SS	CU-IM, present	3222	6468	2494	3407
Ecosystem: Aspen-Birch	Soil Group: 2				
SS	CU-IM, present	3322	4955	2429	2790

Table DD-5.--Run E, Changes in Acreages Allocated to Management Strategies as Compared to Run A

Stand Size Class	Management Strategy	Region 1	2	3	4
Ecosystem: Oak	Soil Group: 2				
SS	CU	1466	2002	-	259
	CU-IM at PT-ST	-	-	564	-
PT	CU	1951	-	-	-
	CU-IM at PT-ST	-	1332	564	76
Ecosystem: Elm	Soil Group: 1				
SS	CU	5520	-	-	618.3
	CU-IM at PT-ST	-	10832	4794	5934.7

APPENDIX EE

SURPLUSES AND DEFICITS

Table EE-1.--Surpluses and Deficits in Receipts Derived in Linear Programming Solutions

Run	Product	Units	Region	Time	Surplus	Deficit
A	Timber	CF	1	5	662,217.8	-
			4	5	1,784,606.8	-
B	Timber	CF	2	2	-	1,374,269.7
				3	-	4,458,152.5
				4	-	4,693,107.4
				5	-	2,524,877.6
				6	-	14,239,313.4
C	Timber	CF	1	3	-	31,444.1
			2	2	-	2,304,569.7
				3	-	5,565,010.0
				4	-	6,169,407.4
				5	-	4,693,177.6
				6	-	16,045,013.4
D	Timber	CF	1	3	-	869,411.6
				4	-	264,169.3
				6	-	475,157.3
			2	2	-	3,145,569.7
				3	-	8,212,110.9
				4	-	11,168,238.1
				5	-	10,840,677.6
				6	-	24,602,456.1
B	Small Game Hunterdays	Days	4	1	353	-
C	Small Game Hunterdays	Days	4	1	357	-
D	Small Game Hunterdays	Days	4	1	354	-

APPENDIX FF

RIVER BASIN PRODUCTION

Table FF-1.--River Basin Production

Output[a]	1	2	3	4	5	6
Run A						
TIM	4545602	3042430	3366448	4421147	8969125	6145187
BHD	63333	61262	58487	61582	66799	68632
SHD	179076	185868	186403	195080	200568	201052
ERO	127636	128540	127686	120470	123374	122367
Run B						
TIM	4545602	3042430	3366448	6663993	13477522	6145187
BHD	62083	60561	59808	61843	66232	68016
SHD	182705	189691	188308	198888	214723	226270
ERO	127677	128261	126940	119744	122699	121734
Run C						
TIM	4545602	3042430	3366448	6663993	13477522	6145187
BHD	62420	50361	60366	63917	68679	70371
SHD	182779	189242	188557	199383	215324	209581
ERO	127671	128387	127148	120296	123046	122081
Run D						
TIM	4545602	3042430	3366448	6663993	13477522	6145187
BHD	62380	61239	60117	63906	71459	70021
SHD	184768	194229	196130	199302	204660	209489
ERO	122714	128367	127115	120251	122992	122027
Run E						
TIM	4545602	3042430	3366448	6663993	13477522	6145187
BHD	64185	62143	46860	62312	68272	72021
SHD	176163	186215	186434	195263	192422	201492
ERO	127289	128274	127651	120631	123098	122120

[a]Outputs

TIM = cubic feet of timber
BHD = big game hunterdays
SHD = small game hunterdays
ERO = tons per year of erosion

APPENDIX GG

DEFINITION OF TERMS

Agricultural land: Agricultural land includes that land used for the raising of livestock and crops.

Conversion of Land Use: A change in man's activity on the land from one category, such as agriculture, to another, such as urban.

Forest land: Forest land includes that land which is at least 10 percent stocked by forest trees of any size. It excludes land currently developed for non-forest use such as urban or thickly settled residential or resort areas, city parks, orchards, improved roads or improved pasture land. Unproductive forest land incapable of yielding crops of industrial wood because of adverse site conditions are excluded. Productive forest land withdrawn from commercial timber use through statute or administrative regulation.

Growing-stock trees: All live trees of any size except rough and rotten trees.

Hunterday: One person hunting a game animal for a portion of one day.

Inland water: Inland water includes the surface area of all water bodies within the state boundaries, excluding the Great Lakes. Land areas underlying lakes, streams and ponds are included.

Intensive management: Intension management involves investment in forest stands through the application of cultural practices to increase wood yields and economic returns.

Recreation land: Publically owned land used primarily for recreation purposes. Includes national and state forest campgrounds, national parks, state parks, game areas, recreational areas, public fishing sites, public water access, and county and township recreation areas.

Roundwood: Logs removed from the stump and limbed.

Stand size clases:

Sawtimber trees: Live trees of commercial species containing at least a 12-foot saw log. Softwoods must be at least 9.0 inches in diameter at breast height and hardwood at least 11.0 inches.

Poletimber trees: Live trees of commercial species at least 5.0 inches in diameter at breast height but smaller than sawtimber size, and of good form and vigor.

Seedling-Sapling trees: Live trees of commercial species less than 5.0 inches in diameter at breast height.

Stocking: The degree of utilization of land by trees as measured in terms of basal area and/or the number of trees required to utilize fully the growth potential of the land.

Stocking Classes:

Well-stocked stands: Stands 70 percent or more stocked with growing-stock trees

Medium-stocked stands: Stands 40 to 69 percent stocked with growing-stock trees

Lightly stocked stands: Stands 10 to 39 percent stocked with growing-stock trees

Non-stocked areas: Forest land less than 10 percent stocked with growing-stock trees

Transportation land: Transportation land includes land devoted to public highways, roads, railroads, and airports. City and village street are considered to be urban land.

Urban land: Land in the following categories:

a. All incorporated cities and villages over 2,500 inhabitants

b. Incorporated cities and villages between 1,000 and 2,500 inhabitants, providing their density was generally greater than 1,000 inhabitants per square mile.

c. Unincorporated places over 1,000 inhabitants as identified by the U.S. Census Bureau, providing their density is over 1,000 inhabitants per square mile.

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