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A LAND USE PROJECTION MODEL APPLIED TO EMMET COUNTY, MICHIGAN

Michigan State University PH.D. 1983

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A LAND USE PROJECTION MODEL
APPLIED TO EMMET COUNTY, MICHIGAN

By

Richard Dale Gustafson

A DISSERTATION

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ABSTRACT

A LAND USE PROJECTION MODEL
APPLIED TO EMMET COUNTY, MICHIGAN

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This study was part of a cooperative regional project concerned with developing guidelines for management of forest and recreation resources in the north central states. Anticipating problems due to increasing demands on scarce and often fragile resources, one component of this project was aimed at developing land use models for predicting and planning to alleviate such problems.

This study was to build upon a base of previously proposed models to develop and apply a land use projection model to a small region with considerable spatial resolution. Problems with a proposed mixed integer land use model are considered, and alternative formulations of land use linear programming models are presented. A model that incorporates a small, spatially aggregated input-output linear program to derive levels of output by sector and acreage requirements and rents by use and then allocates specific parcels to uses apart from the linear program is described and applied to Emmet County.

Development of an input-output model for Emmet County, using both primary survey and secondary data reduction techniques, is described. Steps in acquiring and compiling other data required for this model, much of which is geospecific (e.g. soil type, slope, travel times, current use), are also described.

Results of three demonstration runs of the model reflecting different rates of regional economic growth are presented in the form of maps of changing land use. Problems with this model and this application and with land use modeling in general that limit current usefulness are discussed along with implications for future research.

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INTRODUCTION

The Problem

The regional research project "Guidelines For More Effective Regional Development of Forest and Recreation Resources in the North Central United States" was formed to investigate major forces affecting the use of forest and recreation resources and to evaluate alternative means for influencing these forces and managing these resources to satisfy demands, while maintaining the attractiveness and productivity of the resources (Countryman, et al., 1982).

The motivation for such an investigation was the recognition of and concern over problems arising from increasing demands by competing uses for various scarce resources. Problems such as environmental degradation due to intensive use of unsuitable lands, close proximity of incompatible uses to the detriment of one or both users, and declining regional economies due to degradation or depletion of some resource were identified and were of primary concern in this regional project.

Several conditions existing in the North Central Region, which contribute to these types of problems, were identified. These include a high concentration of population (approximately 30 percent of the national total) relative to available recreactional land (12 percent of the national acreage primarily useful for outdoor recreation). This relative imbalance coupled with increasing population and increasing rates of participation in outdoor recreation add up to greatly intensifying demands on available forest and recreation resources.

Fuel shortages and anticipation of fuel shortages may also tend to increase the demands on forest lands within the region. It has been suggested that increasing cost and decreasing or uncertain availability of fuel will encourage shorter trips rather than eliminate recreational trips altogether. For the North Central Region this may mean more intensive use of recreational resources, as residents tend to travel more within the region, instead of driving to recreation sites in other parts of the country.

Aggravating the problems posed by the current imbalance and intensifying demands is the continuing pressure to convert forest land to nonforest uses. Residential sprawl, recreational residential development, mineral extraction, and conversion to crop or pasture land all continue to erode the forest land base. This land becomes unavailable not only for public outdoor recreation but for other forest uses as well, thereby intensifying the competition among forest users for the remaining forest resource.

Compounding the problem is the fact that those areas within the region that may be most susceptible to dramatic, negative effects of use conflicts and conversion are often the areas which are least prepared to recognize the potential for such effects or to control or influence further development to reduce undesirable impacts (Ragatz, 1970).

Study Objectives

Given the context and concerns of this regional project, the usefulness of, in fact the necessity for, some capability for predicting future land use patterns in space and time and for predicting the consequences of alternative policies intended to influence those land use patterns is readily apparent. Indeed, a major component of the overall project was devoted to developing or at least progressing toward just such a capability.

A computerized land use projection simulation model was envisioned as the vehicle for providing this capability. If such a model could be perfected, it would be very useful for decision making, policy analysis and planning to alleviate the kinds of problems of major concern in this regional project. Specific parcels within a region that might be subject to pressure for development for which they are not suited could be identified. Specific resources that may limit future economic growth of certain industrial sectors within the region could be identified with implications for the industries in which local officials might encourage or expect expansion. What seem to be efficient or at least reasonable land allocation decisions at the current time, might be seen to be serious restrictions to desired future development through such a projection model. The effects over time and space of public facilities development or public land ownership decisions in stimulating or limiting future private development could be examined, leading to better public decisions. These are a few of the potential uses for a "perfected" land use model and illustrate the underlying motivation for the model development goals of this study and of this component of the regional project. The extent to which the state-of-the-art in land use modeling, both at the outset and at the completion of this study, falls short of such a "perfected" model is acknowledged and is considered in some detail in subsequent chapters of this thesis.

A previous dissertation (Miley, 1977) completed under the land use modeling component of the regional project provided the underlying concept for the land use model that was pursued in this study. A linear programming formulation of an input-output model with land use and resource constraints was used to reflect the interactions among different sectors in a regional economy and the dependence of those sectors on the land and resource base. It was suggested that shadow prices from the solution of such a model could be used in evaluating the likelihood of conversion from one use to another on specific parcels of land in the region.

The primary purpose of this study was to build upon these basic concepts to formulate and program a land use projection simulation model. It was intended from the outset that this study include a reasonably serious attempt at applying the model to a region with a much finer spatial resolution than was employed in Miley's work. It was felt that only through such an attempt could the problems, costs, and benefits of employing such a model be realistically assessed.

The Study Region

Several factors led to the selection of Emmet County, Michigan as the study area to which to apply the model. Emmet County, occupying the northwest tip of the lower peninsula of Michigan, see Figure 1, was part of a larger study area, 18 counties of northern lower Michigan, previously identified for the overall regional project. As such, Emmet County had been designated for study by other components of the project, e.g. the legal component of the regional project had profiled laws and institutions pertinent to the land use and development question, providing potential contributions to this study. Emmet County was also somewhat unique among the counties of the larger study area because of its relatively rapid growth in recent years. The population of Emmet County increased by 45 percent between 1960 and 1980 (U.S. Dept. of Commerce, 1982). Growth rate was considered important so that the

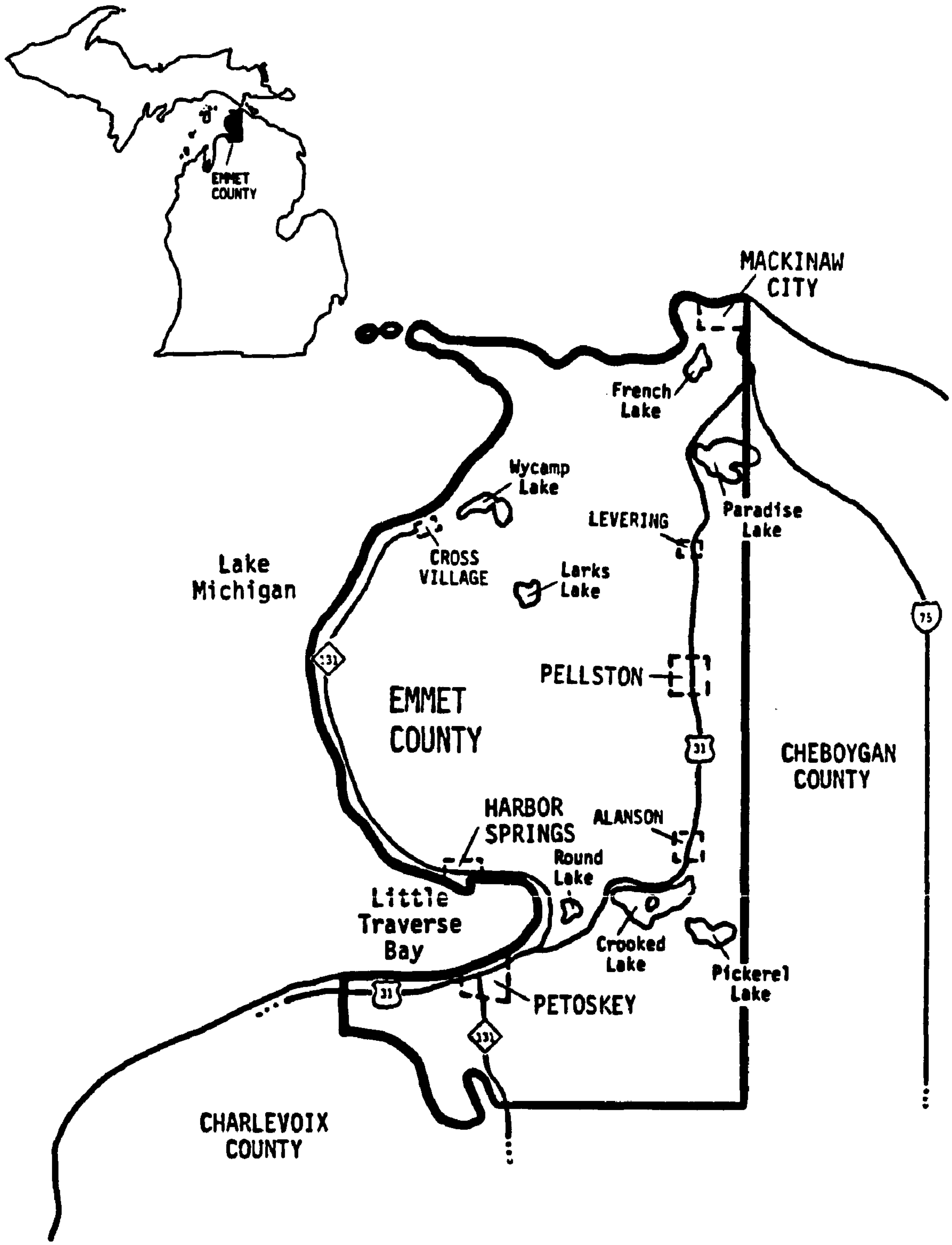


Figure 1. Location and Important Features of Emmet County

model would have some reasonable change in land use to project and also so that use conflicts or scarcity of land suitable for certain uses, which the model was supposed to identify, would have some likelihood of occurring in the near future. Emmet County was also of interest because questions about public land ownership had been raised locally, and an intended refinement for this model was the capability to explicitly recognize different ownership classes and their effects on future land use patterns. Finally, Emmet County seemed an appropriate study area because of its endowment of varied natural resources, some persistent economic disparities, and the potential for those resources to contribute to alleviating those disparities.

Through most of this century Emmet County, like much of the Upper Great Lakes region, has experienced a declining economy characterized by relatively high unemployment, low per capita income, and decreasing population. This decline followed the depletion of the region's timber resource in the late 1800's and early 1900's and the consequent contraction of the wood products industry. During the last two decades these trends have been reversed for Emmet County but, although the county economy has recently experienced rapid growth, there remains a gap between the general level of prosperity of this county and that of the Michigan and the United States in general.

A simple location quotient analysis of employment data suggests that construction, wood products, cement manufacturing, electrical equipment manufacturing, transportation equipment manufacturing, lodging and amusement services, and medical and health services are significant exporting industries for the county.

After the depletion of the original forest, the associated decline of the wood products industry, and the subsequent failure of agriculture on much of the cut-over land early in this century, a new hardwood forest was established over much of the region. According to the Michigan Department of Natural Resources there are over 180,000 acres of commercial forest land in Emmet County, mostly in hardwood types. Much of this forest is now or soon will be suitable for sawtimber and pulpwood production, but it is estimated that presently only 20 percent of the sustainable annual harvest is being utilized (Pfeifer and Spencer).

While this renewal of the forest in Emmet County suggests a potential for expansion of the wood products industry, perhaps of even greater importance to the county economy is the possibility for the continued growth of the recreation related industries because of this forest resource and other physical assets of the county. Recent studies have indicated high potentials for several categories of recreational use and/or development including second homes, campgrounds, picnic areas, hunting, natural and scenic areas, and winter sports areas. Much of this potential is due to the forest land base, over 68,000 acres of which is publicly owned. There is another 8,500 acres of publicly owned recreation land in the county, most of which is forested.

Other features of Emmet County important to this potential for recreational development include the topography, the abundance of surface water and shoreline, and the accessibility of the county to the large population of southern Michigan. The relatively significant variation in elevation over much of the county provides scenic values uncharacterisitic to much of the state as well as valuable downhill skiing sites. Two ski areas have already been developed in the central part of the county. Emmet County has over 60 miles of Lake Michigan shoreline (see Figure 2) and over 10,500 acres of inland surface water. Availability of quality surface water is considered a prime attraction for second home developments as it is for other types of outdoor recreation. Three major highways provide year-around access to Emmet County from southern Michigan. U.S. 31 runs from the southwest corner south of Little Traverse Bay then north along the eastern edge of the county. Michigan 131 enters the county at the south then runs north and northwest along the western shoreline of the county. Interstate 75 parallels the eastern border of the county just a few miles to the east in Cheboygan County.

This combination of year-around attractions and year-around accessibility to the market and the potential for expanding recreational development coupled with the likelihood of continued increasing demand for all of these types of recreation suggest an opportunity for the solution of some the past problems of the county economy.

Petoskey is the largest city in the county with a population of over 6,000 (U.S. Dept. of Commerce,1982) and is the major commercial center for the county. Both Petoskey and Harbor Springs are located in the southern portion of the county on Little Traverse Bay (see Figure 2) and are important resort communities. It has been estimated that with the influx of tourists and seasonal home occupants the population of the Petoskey area triples during the summer months. Mackinaw City at the north end of the county, and at the very northern tip of the lower peninsula of Michigan, is the southern terminus for the Mackinaw Bridge that joins upper and lower Michigan. Other towns and prominent features that will be referred to throughout the following discussion are also identified on the map of Figure 1.

CHAPTER I. RELATED LITERATURE

This chapter is not intended to be an exhaustive review of the literature related to land use modeling but attempts to describe briefly the breadth of that literature and to distinguish and describe in more detail those elements that are particularly relevant to the Emmet County study.

A general class of models, referred to here as land use models, is distinguished from other kinds of planning models simply by the primary purpose of projecting land use over space and time. Implicitly, the complexity of these models, due, if nothing else, to the degree of economic, land use, spatial, and temporal disaggregation, necessitates solution by digital computer.

Beyond this simple delineation of the general class of models of interest, several attributes that can vary widely from model to model and are useful for further classification can be identified. Such attributes include, but are not limited to, the theroretical basis for the model, its empirical basis, the type of region to which it is applied, land uses that are emphasized, degree of disaggregation of a number of factors (e.g. space, time, economic sectors, land use), and mathematical techniques used in modeling.

Urban Land Use Modeling

For this discussion one of the most important attributes mentioned above is the type of region to which the model applies. Since the late 1950's a great deal of effort has been devoted to the development of land use models, but the vast majority of these would be considered urban models, i.e. focussed on developed uses in and around major urban areas.

Although these urban models may not be particularly useful for the purposes of this study, e.g. in developing a land use model for a rural area such as Emmet County, there is a great deal to be learned from the overall urban land use modeling experience of the last two decades. Fortunately, in recent years there have been a number of attempts to criticize, evaluate, synthesize, and even quantify this experience, and these examinations are very pertinent to this study.

Probably the two most well known of the urban land use models are EMPIRIC (Hill, 1965) and PLUM (Goldner, et al, 1971). Both of these models have had wide application to areas beyond those for which they were originally developed.

EMPIRIC was originally developed in the mid-sixties for the Boston area. The model allocates exogenous population and employment forecasts among zones in the region through a system of equations. There are a number of residential and employment categories (activities) each represented by an equation with transportation, utilities and current activities levels as independent variables which vary between zones. These initial allocations are adjusted to meet policy constraints on activity levels by zones and then are translated into area by land use by zone according to available land and allowable densities (Brand, et al, 1967). EMPIRIC has subsequently been applied in Atlanta, Philadelphia, and several other areas (Pack, 1978, p. 33).

Originally developed for the San Francisco Bay Area in the sixties, PLUM (Planning and Land Use Model) has also subsequently been applied to a number of regions. Similar to but distinct from EMPRIC, PLUM allocates exogenously forecasted basic employment to residential zones based on travel times from those zones to exogenously located places of work. This basic employment by zone is then used to derive nonbasic employment and corresponding land use.

Both EMIPRIC and PLUM are simulation models rather than optimization models, so past statements about their finding efficient or optimal land use patterns have been appropriately criticized (Pack, p. 31). The Southeast Wisconsin Region Planning Commission (SEWRPC) Land Use Plan Design model (Schlager, 1965) was a well known urban region land use modeling effort that did employ optimization techniques, i.e. linear programs, and so warrants some consideration here. This model is described as a comprehensive urban plan design model, whose output is a land use plan that meets development constraints for area by land use (again totals are derived exogenously) while minimizing development, operating, and maintenance costs. This model development effort was viewed as research by the SEWRPC and was considered to have achieved very limited success in real world application. Yet, the general concept is still considered valid and promising and continues to be researched. For example Hopkins and Los (1979), Los (1978), and Hopkins (1977) have proposed even more complex and realistic formulations of the land use plan design problem and also present algorithms for solving it that avoid some of the major problems encountered in the SEWRPC effort.

Evaluations of Urban Land use Modeling

Perhaps more important to the purpose of the Emmet County study than the history, classification, or details of the various land use models that have been developed is a growing body of literature that attempts to evaluate the land use modeling experience. In response to the flurry of activity in land use modeling in the 1960's, by the early 1970's independent assessments of that activity had begun to emerge. The apparent similarity among almost all of these evaluations is that they are much more negative (realistic?) about the capabilities and state-of-the-art of land use modeling than were the proposals for and progress reports on those modeling efforts. There is, however, a range in degree of negativism and a variety of reasons for those negative assessments that are worth examining.

One of the most well known and perhaps the most negative of the available evaluations of land use modeling is

Douglas B. Lee's "Requiem for Large-Scale Models" (1973). Lee paints a picture of essentially total failure of the urban modeling efforts. According to Lee the modeling movement had virtually died by the end of the 1960's, but his requiem was necessary as a warning to those who, having not learned the lesson of the sixties, were trying to raise it from the dead. Lee's stated purpose was to

> "...evaluate in some detail the fundamental flaws in attempts to construct and use large models and to examine the planning context in which the models, like dinosaurs, collapsed rather than evolved. The conclusions can be summarized... 1. In general, none of the goals held out for large-scale models have been achieved, and there is little reason to expect anything different in the future. 2. For each objective offered as a reason for building a model, there is either a better way of achieving the objective (more information at less cost) or a better objective..."(Lee, p. 163)

Actually, Lee makes a number of valid, pertinent criticisms of land use modeling and modeling in general, but his arguments would probably have been more effective if his tone had been less cynical. For example he dismisses positive prospects due to increasing computational efficiency with "There is no basis for this belief; bigger computers simply permit bigger mistakes" (Lee, p. 169). One has the feeling that no matter what may have been accomplished in any of these efforts they would have been pronounced rightfully dead simply because in Lee's view big models are inherently bad.

A second important critique of urban modeling is Garry Brewer's Politicians, Bureaucrats, and the Consultant - A

Critique of Urban Problem Solving (1973). Brewer uses the San Francisco and Pittsburgh Community Renewal Program modeling experiences as case studies around which he centers his discussion of the problems of and possibilities for land use simulations. He considers many of the problems that Lee mentions, but for Brewer, rather than cause for despair, it is at least an open question, if not a necessity, that these problems be overcome so that this "...promising technique for meeting the challenge of complexity..." can be effectively employed. In Brewer's view "Policy-makers must integrate their intuitive hunches with the practical theories, models, and descriptive insights of specialists in such a way that the setting and theories about the setting are made understandable to practitioner and specialist alike. Computer simulation models have that integrative capacity...." (Brewer, p. 3).

Perhaps the most comprehensive evaluation of urban land use modeling to date is Urban Models: Diffusion and Policy Application by Janet Rothenberg Pack (1978). Pack's stated purpose was to "...investigate (1) the extent of model use by planning agencies; (2) the ways in which the models are being used and the influences they have; and finally (3) why some agencies adopted and used the models and others did not" (Pack, p. 11). The investigation included two approaches: extensive mail surveys of planning agencies and intensive case studies of several of the regional planning agencies that responded to the mail survey. The mail survey allowed wide coverage, while the subsequent case studies permitted careful consideration and clarification of specific questions, aiding in the interpretation of the mail survey results.

In presenting the results of these investigations Pack also includes a helpful historical overview of land use modeling, including a discussion of federal legislation and the associated political and institutional atmosphere that encouraged interest in and development of land use models.

Although problems with the modeling efforts of the early 1960's and a reevaluation period in the late 1960's are acknowledged, Pack does not see the extreme cycle of death and threatened rebirth that Lee described:

> "The picture presented is one of widespread failure in model development itself, or where model development succeeded, of very limited application.... As a result of these failures model development has been alleged to have 'died' in the mid-to-late 1960's... Even as these assertions were being made in the early 1970's there was a substantial amount of model development in planning agencies, particularly regional planning agencies." (Pack, p. 1,2)

Also included is a discussion of potential uses of land use models. A recurring theme in these evaluations of modeling is the divergence between current capability and expected or claimed uses and benefits of models. Pack reviews this ongoing discussion in preparation for presenting the results of the surveys with respect to actual versus expected uses and usefulness and implications of these for model adoption. Pack is realistic about present and past shortcomings:

> "...it is not difficult to show that models have often been oversold, little understood, and the difficulties of their development underestimated, with the result that many persons believe...that they can be applied to the planning process in ways which were and still remain well beyond the state-of-the-art. It is not surprising that the reaction was harsh when unrealistic expectations were measured against subsequent performance." (Pack, p. 17)

The results of the mail survey were somewhat surprising given the bleak picture of failure and disillusionment presented by some critics. Of the planning agencies that responded, 25 percent were either currently using or developing planning models and another 12 percent were at the time considering the use of such models. Planning models in this context include several different types of models, e.g. land use, transportation, population, and many model using agencies used more than one type of model, but two-thirds of these using agencies indicated that land use models were among those in use. Of those agencies currently using models, 53 percent indicated the models were "very useful," while only one percent said they were "not useful." To a related question 51 percent responded that their models were "more useful than available alternatives" while only two percent said they were not as useful as alternatives. Pack presents responses to a number of other questions and, of course, considers all of these results in much more detail than is appropriate to include here. Many interesting correlations between responses to different questions are identified, e.g. in-house model development with assessed usefulness, and some tentative explantations of what all these numbers really mean are offered (Pack, pp. 55-89).

The subsequent case studies of several of the larger regional planning agencies that responded to the mail survey largely confirmed, clarified and extended the results of that survey. Pack concludes "our case studies of model use are striking for their indication that land use models are being successfully developed and incorporated into the anlaytical work of regional planning agencies...," but by no means considers this entirely positive since "still there are substantial problems with the models themselves and with their suitability for the types of analyses in which they are employed." (Pack, p. 118)

Rural Regional Land Use Models

A class of rural land use models can be distinguished from the urban regional models considered above. These models may still be largely concerned with developed uses, e.g. residential, commerical, and industrial, but with emphasis on how these uses interact with less intensive uses in and around communities within predominantly rural regions. Characteristically, these models explicitly recognize inherent capabilities or resources of parcels of land and major natural features of the region as independent variables impacting land use decisions in addition to the usual independent variables of the urban models, i.e. transportation networks and current uses. Some models that can be included in this category focus exclusively on these natural resources and capabilities and their associated nonintensive uses. In contrast to the urban land use models, the rural regional models should be more directly applicable to the model development goals of the Emmet County study. Fortunately, as with the urban models, there is some recent literature that examines some of these rural regional modeling efforts, from which there is much to be learned.

The regional project of which this study was a part and the regional land use modeling work of Miley (1977) and its relationship to this study were mentioned in the previous chapter and will be discussed in more detail in the following chapter and so will not be considered here.

The Land use Model for Planning (LUMP), formulated and applied to 1100 square miles of Ontario by Nautiyal (1975), is of interest because of its use of mathematical programming. According to the author "Given the capability of each section or parcel of land, the concentration of population, the communication patterns, prices for products, transportation costs, economies of scale, etc., the model develops an optimal allocation of land parcels to various uses by maximizing net benefit." Nautiyal goes on to describe the LUMP mixed integer formulation which considers each parcel homogenous in its attributes and explicitly considers capability, cost, and value for each use for each parcel. Integer variables are used to implement linearized nonlinear cost and value functions. This formulation yielded an extremely large mathematical programming problem (190571 variables initially) for this 635 parcel region. A subsequent version of LUMP eliminated the integer variables and greatly reduced the size of the problem and time and cost for solving it.

The most significant effort in regional land use modeling during the 1970's was the Regional Environmental Systems Analysis Program (RESA) sponsored by the National Science Foundation at the Oak Ridge National Laboratory (ORNL) from 1971 to 1975. This program has been well documented in numerous ORNL publications that reveal its comprehensive scope. The program dealt in depth not only with land use modeling but with related areas of study such as computerized geographic information systems, political interactions in regional systems, regional socioeconomic analysis, and ecological impacts of land use:

> "The purpose of the program has been to develop and communicate to the planning and management community an improved basis for forecasting the environmental impacts of public and private decisions (such as land use).... The research strategy was to develop and validate a hierarchy

> of computer models to assist in the analysis of relevant economic, physical, ecological, and social processes..." (Craven, 1977, p. v)

The land use model developed under the RESA program is described in _A Cell-Based Land-Use Model_ by A. H. Voelker (1976). It was a simulation model for projecting future land use for a rural region of Eastern Tennessee. The model allocated land uses to 40 acre cells stochastically on the basis of relative attractiveness of a cell for a use. Attractiveness of a parcel for a use was based on a combination of indices reflecting the attributes of that parcel that were considered important to the site selection decision for that use. The stochastic allocation mechanism allowed for the realistic possibility of some sites with lower attractiveness being selected prior to sites with higher attractiveness. Total areas by use to be distributed among the parcels within the region were based on exogenous forecasts of economic and population growth.

Voelker acknowledged that a large part of the model development effort centered around the construction of indices to describe individual attributes of parcels and subsequent attractiveness indices based on composites of the indices for individual attributes. A separate publication by Voelker, _Indices, A Technique for Using Large Spatial Data Bases_ (1976), considers in detail this index building process. The challenge of converting raw data, often nominal data, to ratio scale indices with a common scale or one that can be used in composite equations or in the final model is discussed. Voelker frankly admits that

> "In the best situation, an accepted theory exists which describes the process well enough to allow it to be quantified. Short of this, it may be necessary to hypothesize relationships in order to complete an analysis. Indices in this case must arise from the mind of the index developer, conforming to his intuition and tacit understanding of the process being modeled." (Voelker, Indices..., p. 3)

Numerous examples of index development and associated problems for a number of specific attributes are presented.

As with the urban land use models, there is perhaps more to be learned from the critical evaluations of rural land use modeling efforts than from the models themselves. Several publications from the RESA program provide such evaluations of that particular effort. Some of the points made in these critiques echo those of the urban land use modeling efforts.

In Some Pitfalls of Land Use Model Building Voelker (1975) claims that there had been a lack of documentation of and openness about the real problems of land use modeling within the modeling community. Through this paper and comments in other ORNL publications Voelker attempts to avoid this deficiency for the RESA experience. Voelker distinguishes two types of problems, technical and perceptual, encountered in the RESA modeling effort that limited the utility of the models. Major technical problems included gaps in land use theory, failures in quantifying important variables and relationships, and underestimating time and costs of data acquisition. Perceptual problems refer to barriers to model use by planners and decision makers. There are many aspects to this problem, including the modelers' lack of understanding of the real world of planning and subsequent unrealistic expectations for model adoption by planners, differing goals for models between planners and modelers, reluctance of planners to adopt or try new tools, and unrealistic expectations of model capabilities by decision makers.

CHAPTER II. THE MODEL

The primary purpose of this study was to build upon the model suggested by Miley to develop a land use projection simulation model. The basic concept proposed by Miley was retained, that is, the model employs a linear programming input-output model to estimate sectoral total outputs in response to projected levels of final demand, subject to resource constraints, and to arrive at rents for various uses of various parcels of land. This chapter discusses some alternative large scale linear programming land use models based on this concept. The discussion then turns to a land use projection simulation model centered around an allocation mechanism which was largely inspired by these large scale linear programming formulations but which relies directly on a small, aggregated linear programming model. Reasons for diverging from Miley's original proposal are also discussed.

Input-Output and Linear Programming

Before discussing the land use model itself, it is appropriate to briefly review the two general economic models, input-output analysis and linear programming, which have already been mentioned as essential components of the land use model.

Consider momentarily a simplified overview of the Emmet County economy. The economy is comprised of individuals, firms, and institutions interacting within the county and with similar entities outside of the county through exchange of goods, services, and money. Money enters the economy primarily through sale of goods and services produced within the county to sources outside the county. However, all money entering the county economy does not remain in the county, because goods and services produced outside the county are purchased by sources in the county. For any period of time income to or net production by the county economy depends on the amount and mix of products produced and consumed within the county, the amount and mix of products produced in the county but purchased by outside sources, and the amount and mix of products imported to the county. The level of income to the county can change over time because of changes in any of these factors, and obviously these categories are not independent. A change in exports will likely lead to changes in the amount and mix of products exchanged within the county and to changes in imports. A change in the structure of interactions within the economy, for example the establishment of a new industry, can lead to changes in the amount and mix of imports and exports.

Input-output accounts provide a means for describing the relationships between sectors (groups of individuals, firms, and institutions) within the regional economy and the relationships between the regional economy and the economies of other regions through exports and imports.

Over the last twenty-five years input-output analysis has become an important tool of regional economics, and there is a vast literature describing input-output theory and its countless applications. It is unnecessary here to consider in detail the history or theory of input-output analysis, but the reader is referred to Richardson (1972) for a concise, comprehensive, objective overview of input-output analysis and associated issues in regional economics.

Having divided the economy into a number of sectors, some of which are designated endogenous while the rest are considered exogenous, an input-output model depicts the economy as interactions among those sectors through linear production functions. The total output of a sector is expressed as the sum of its sales to all endogenous and exogenous sectors in the economy, conversely total outlay for a sector is the sum of its purchases from all sectors in the economy. Usually, by convention total output equals total outlay for a sector, requiring balancing by capital accounts included as exogenous demand and payment sectors. These exchanges between sectors for a specified period of time are typically expressed in common terms, such as dollars, in the transactions table. Let t_{ij} be the purchases by sector j from sector i and x_j be total outlay which is equal to total output for sector j. (Throughout this discussion nonsubscripted lower case letters will represent vectors, nonsubscripted upper case letters will represent matrices, lower case letters with double subscripts indicate elements of matrices.) Assume the economy is divided into an endogenous or processing sectors, m exogenous or final demand sectors, and k exogenous or final payments sectors, then:

$$x_i = \sum_{j=1}^{n+m} t_{ij}$$

and

$$x_j = \sum_{i=1}^{n+k} t_{ij}$$

When used in forecasting or impact analysis a matrix of direct effects or technical coefficients, typically designated the A matrix, is computed from these transactions and total outlays for the endogenous sectors. The element a_{ij} of A is the ratio of purchases by sector j from sector i to total outlay of sector j

$$a_{ij} = t_{ij}/x_j$$

The intermediate product, p_i, for sector i, i.e. the output that is used in production by endogenous sectors rather than going to final demand, is defined by:

$$p_i = \sum_{j=1}^{n} t_{ij}$$

but may also be found by:

$$p = Ax$$

If f is the vector of total final demand, i.e.

$$f_i = \sum_{j=n+1}^{n+m} t_{ij}$$

then:

$$x = p+f = Ax + f$$

$$f = x - Ax$$

$$f = (I-A)x$$

where I is, of course, an n x n identity matrix.

Since A reflects the portion of total output which is required as inputs to the endogenous sectors, (I-A) can conversely be thought of as indicating portions of total output from the various sectors which are not required as inputs by endogenous sectors and are therefore available for final demand.

For impact analysis using input-output it is noted that multiplying both sides of the above equation by $(I-A)^{-1}$ yields:

$$x = (I-A)^{-1}f$$

With this equation a projected level of or change in final demand can be translated into an expected level of or change in total output.

There are several fundamental assumptions on which input-output analysis is based and which are necessary for solution of the system of equations and for practical implementation of the technique. These include such tenets as the linearity and additivity of the production functions. One important assumption which is made in conventional static input-output analysis but which is unacceptable for the purpose of land use modeling is the assumption of unlimited or perfectly elastic supply of resources required as inputs by the various sectors.

Every sector in the regional economy is to some degree directly dependent on the land and resources of the region, if for nothing other than space for facilities. Of course, economic activities vary widely with respect to their degree of dependence on natural resources. One of the great attractions of input-output analysis for land use modeling is that its flexibility with respect to sectorization allows distinction of activities according to their dependence on various resources. Conventional input-output analysis with its assumption of nonconstraining resources ignores this dependence of sectors on the resources, but by expanding an input-output model into a linear programming model by adding an objective function and resource constraints, both the relationships between the sectors in the economy and the relationship between the sectors and regional resources as well as the limits to the availability of these resources can be accounted for.

The general linear programming problem with n constraints and m activities can be depicted as follows:

$$\text{maximize } z = cx$$

$$\text{subject to:}$$

$$Bx \leq b$$

$$x \geq 0$$

where z is the scalar value resulting from multiplying the 1xm vector of objective coefficients c, by the mx1 solution vector, x. B is the nxm matrix of constraint coefficients with each row expressing the relationship between the activities and a limiting resource, the availability of which is indicated by the corresponding element of the nx1 right-hand-side vector b. Stated verbally, the problem is to find the vector x which maximizes the linear objective function, cx, while satisfying the linear equations $Bx \geq b$. By letting:

$$B = \begin{bmatrix} (I-A) \\ -R \end{bmatrix}$$

and

$$b = \begin{bmatrix} f \\ -r \end{bmatrix}$$

where (I-A) is the nxm Leontief matrix from an input-output analysis, and R is an nxm matrix of coefficients which relate sectoral resources use to sectoral gross outputs for m sectors and n resources. Then the linear programming problem,

$$\text{maximize:} \quad z = cx$$

$$\text{subject to:}$$

$$Bx \geq b$$

$$x \geq 0$$

where cx is some regional objective function, incorporates both intersectoral production relationships and the requirements of economic sectors for regional resources.

An important result of linear programming theory is that corresponding to the above problem, called the primal, there is a dual problem of the form:

$$\text{minimize:} \quad w = b'p$$

$$\text{subject to:}$$

$$B'p \leq c'$$

$$p \geq 0$$

The elements of p, the solution vector for the dual problem, are shadow prices for the primal. That is, the ith element of p is the marginal contribution to the value of the objective function of one additional unit of the ith element of b. Given the appropriate context and objective function these shadow prices may be viewed as economic rents accruing to the corresponding resource or input in the primal problem. Only if a resource is completely exhausted in the solution to the primal, i.e. the corresponding constraint is binding, will a positive shadow price or rent be associated with it.

Linear programming theory and the algorithms to solve such problems emerged during the 1940's. Today all but the
such problems emerged during the 1940's. Today all but the
most trivial problems are solved using digital computers. Modern linear programming software packages allow the solution of problems with thousands of contraints and tens of thousands of variables. It is this great capacity which makes possible the consideration of geospecific land use linear programming models. Rather than having merely one constraint for each category of resource required by the economy, as has been done with input-output linear programming models for many years, a separate constraint can be used for each of hundreds of specific parcels of land in the region to be modeled. Recognition of this possibility was the basis for the mixed integer programming land use model considered by Miley.

A Mixed Integer Programming Land Use Model

The model suggested by Miley (1977) was based on the contrained input-output model presented above, but with an additional constraint for each parcel in the region so that the model allocates different uses (use being the economic sector in this model) to spatially referenced parcels. Additional constraints and solution with a mixed integer programming algorithm assured the assignment of each parcel to one and only one use.

For an economy with m endogenous sectors and n parcels such a model would have m+nm variables and m+m+n constraints. As in the above constrained input-output model, m constraints relate gross output through the (I-A) matrix to final demands, and the next m contraints equate acreage allocated to acreage required for each use for given levels of gross output. These m contraints have the form:

$$q_i x_i - b_{i1} p_{i1} r_{i1} \cdots - b_{ij} p_{ij} r_{ij} \cdots - b_{in} p_{in} r_{in} \leq 0$$

Where q_i is a coefficient expressing the acreage requirements in acres per dollar. The coefficient b_{ij} can be thought of as the acreage in parcel j and is multiplied by a coefficient, p_{ij}, which reflects productivity of parcel j for use by sector i relative to some standard productivity on which q_i is based. An additional n constraints of the form:

$$\sum_{i=1}^{m} r_{ij} \leq 1 \text{ for } j=1, \ldots.,n$$

assure that total acreage allocated from each parcel does not exceed the acreage available from the parcel.

The solution vector is comprised of m gross output, x_i, elements and mn r_{ij} elements. Given the above constraints this r_{ij} is the proportion of the area of parcel j which is allocated to use i. In a standard linear programming problem this r_{ij} could range from 0 to 1, but the mixed integer algorithm allows specifying all

r_{ij} as binary, i.e. equal to either zero or one. Under this condition, to satisfy the above constraints no more than one of a sequence of m elements with j constant may be nonzero. This means that any one parcel is allocated entirely to one and only one use, although that "one" use might actually reflect a fixed mix of uses.

The motivation for using integer programming was the resulting availability of a shadow price or rent for the sector to which the parcel was allocated and the availability of opportunity costs associated with the parcel for all other sectors. These values are standard outputs from modern linear programming packages. With the shadow price and opportunity costs the potential marginal contribution to the objective function for any use of a given parcel is known. Without the integer stipulation a parcel could be allocated to several uses so that the resulting shadow price would not apply to any individual use but only to the combination of uses associated with the parcel in a particular solution.

It was suggested that the rents implied by these shadow prices and opportunity costs enter an equation of the form:

$$g = \left(\sum_{t=1}^{n} \frac{v_i - v_j}{(1+d)^t} \right) - c_{ij}$$

In this equation v_i is the periodic rent to use i, t is the number of periods from the present, d is the discount rate, c_{ij} is the cost of converting from use j to use i on the given parcel. The equation yields g, the discounted net value over n periods obtainable by shifting from use j to use i on the parcel under consideration. It is hypothesized that the probabilities that such use shifts will occur are positively correlated with these potential accumulated discounted rent differentials. Given these rent differentials and their relationship to shift probabilities, a matrix of probabilities of shifts from all uses to all other uses for each parcel can be obtained. Employing Monte Carlo methods in conjunction with these shift probability matrices, various possible future regional land use patterns can be generated.

Problems With the Integer Programming Model

Several problems with the suggested mixed integer programming land use model have been recognized. Some of these problems derive from the requirement that each parcel be allocated entirely to one use or a fixed mix of uses, while others are related to certain details in formulation and interpretation. These types of problems can be alleviated to some extent by some alternative formulations of the linear programming problem. Still there are certain inadequacies inherent in any linear programming model for detailed land use projections. Recognition of these inadequacies led to the suggestion for using the linear program only indirectly to derive rent differentials and shift probabilities. These inadequacies are acknowledged, but the particular remedy that has been suggested also presents a number of problems.

Unless very small parcels are used, the requirement that one parcel be devoted entirely to one use can result in distorted, unreasonable land use patterns associated with the solution to the linear programs. At first glance it would seem that this would not be a serious problem as long as the desired outputs from the linear program were only the rents and not the actual allocation of parcels to uses. The problem is seen as more serious, however, when it is recognized that such distorted allocations of land may be accompanied by unreasonable gross outputs in the solution and a distorted total objective function value, resulting in inappropriate rents.

Another serious problem with the proposed formulation stems from the desire to obtain a rent for each use for each parcel, which necessitates greater than or equal to final demand inequalities. A positive shadow price is obtained only for those constraints that are binding on the solution. Since a positive objective function coefficient is generally associated with each gross output variable and output available for final demand is positively correlated with gross output, the greater than or equal to final demand constraints assure that every parcel will be totally allocated to a use and will therefore have associated positive rents. Of course the gross outputs, final demands and allocation of parcels to uses resulting from such a model may bear little resemblance to reality, since in most regions where such a model would be applied the levels of gross outputs and final demands for most sectors at the present time are constrained more by available markets than by exhaustion of suitable land and resources. One must realize then that the rents resulting from such a model are no more valid for the near future than are the levels of gross outputs and final demands.

Further questions regarding the applicability of these rents arise from the nature of the objective function and with regard to suggestions for determining values for its coefficients. This problem applies to the standard linear programming land use model as well as to the mixed integer formulation. The question regarding the objective functions has two aspects which cannot be totally separated. First, there is the question of what to maximize or minimize. It has been suggested that various regional objectives, for example maximizing regional output, employment, or income, would be appropriate for such a model. While there is a role for these types of objectives, e.g. in policy analysis, they are probably not the appropriate objectives for projection of likely future land use under a capitalistic economy. If the model is to be used in a normative mode, then these regional objectives are entirely appropriate and the resulting rents will reflect societal values rather than surplus value to the individual land owner, but if the model is used in a predictive mode for a decentralized economy, then the objective function should be some reflection of surplus value to the land owner, e.g. excess profits, conforming to the concept of land rent (Barlowe, 1972, pp. 157-159).

It is doubtful that individuals or firms in their decisions to buy, sell, or convert use on specific parcels are primarily motivated by the contribution of such decisions to such regional objectives. Rather, it is assumed that such decisions are largely motivated by the desire of the individual or firm to maximize its own net returns. This brings up the second aspect of the objective function problem, for even if sectoral profit rate coefficients were used in the objective function, the rents derived from such a function would be averages over the sector, and the resulting rent differentials would not necessarily apply to any one owner or parcel. The optimal solution for the linear program is optimal for the system as a whole but is not necessarily optimal from the perspective of any one sector or any one entity within a sector.

A final problem with the proposed model deserves attention before considering some alternative formulations intended to alleviate some of these problems. Again this problem applies to the standard linear program as well as to the mixed integer formulation. The problem concerns the incapacity of the proposed formulation to generate rents which adequately reflect certain differences between parcels in profit potential.

The vehicle for distinguishing relative profitability between parcels is a productivity coefficient which can be employed directly as a coefficient in the linear program, or, as in the preceding description, may be multiplied by acres in the parcel to yield the coefficient. The productivity coefficient ranges from 0 to 1, and indicates a parcel's productivity for each use relative to some standard or ideal parcel for that use.

This approach is quite adequate for some types of relative productivity or profitability effects, but for others it is totally inadequate. The difference can probably best be explained by example. Consider the case of the effect of soil fertility on the production of some crop. For a given input mix the output or profit from a parcel that is less fertile than the ideal parcel could be approximated as a proportion of the ideal input or profit. An inherent property of the parcel, irrespective of location or demand, results in lower output and profit per acre relative to the standard. The effect of lower fertility can be offset by bringing more acres into production.

Consider on the other hand the case of the retail establishment located on an isolated back road. The per acre output and profit for land allocated to this use on this parcel would likely be substantially less than for the same use in an ideal location, say a city center. The reduced output and profit, however, is due to market limitations associated with location rather than to supply effects from inherent properties of the parcel. In this case increasing the acreage devoted to this use at this location would not increase total output or profit.

A zero to one productivity coefficient employed as a constraint coefficient in the land use linear programming model would account for the first case. It would not adequately account for the second situation, because not distinguishing between supply effects and demand limitations, the model would attempt to offset reduced producitivity in the isolated parcel by simply allocating more land to the use.

The two cases can be considered in terms of the differences in theories of rent as developed by Ricardo and von Thnen. Zero to one productivity coefficients as constraints coefficients adequately reflect the Ricardian rents but may result in distorted allocations and levels of output if used in an attempt to account for Thünien rents. A solution to this problem will be considered in the following sections.

Alternative Large Scale Linear Programming Models

Minor modifications to the proposed mixed integer programming land use model can alleviate several of the limitations mentioned above. Such a revised model is presented in Figure 2, where a large scale linear programming problem is depicted in explicit matrix notation as comprised of a number of matrix and vector components.

In Figure 2 m is the number of endogenous economic sectors, k is the number of land use categories and n is the number of parcels. OBJ is the objective function vector and the I-A matrix is from the input-output analysis, as discussed above. GO is the gross output component of the solution vector and multiplying OBJ yields the value of the objective function, scalar z. The ACPIUJ solution vector represents the acres of each parcel i allocated to each use j. The PARSUM matrix simply assures that the acres allocated to various uses from a given parcel do not exceed the total acres of that parcel as indicated in the ACRES right-hand-side vector.

This formulation features final demands constrained from above and below (FDN and FDO in Figure 2). This feature, coupled with abandonment of the integer requirement, results in reasonable levels of gross outputs and resource requirements. The upper constraint on final demands is intended to reflect the constraints imposed on all sectors by limited exogenous markets, while the lower constraint on final demand reflects some expected degree of stability in the distribution of sectoral outputs to historical markets.

Relaxing the integer stipulation that a parcel be devoted entirely to one and only one use can result in

$$
\begin{array}{cccccc}
\begin{bmatrix} OBJ \end{bmatrix}_{1xm} & & \begin{bmatrix} 0 \end{bmatrix}_{1x(k*n)} & & & = z \\
\begin{bmatrix} I - A \end{bmatrix}_{mxm} & & \begin{bmatrix} 0 \end{bmatrix}_{mx(k*n)} & & & \leq \begin{bmatrix} FDN \end{bmatrix}_{mx1} \\
\begin{bmatrix} I - A \end{bmatrix}_{mxm} & & \begin{bmatrix} 0 \end{bmatrix}_{mx(k*n)} & * & \begin{bmatrix} GO_{mx1} \\ \\ ACPIUJ_{(k*n)x1} \end{bmatrix} & \geq \begin{bmatrix} FDO \end{bmatrix}_{mx1} \\
\begin{bmatrix} ALURQ \end{bmatrix}_{kxm} & - & \begin{bmatrix} p_{11} & & & \cdot & p_{21} & & & \cdot & & PROCO \\ & p_{12} & & & \cdot & p_{22} & & & \cdot & \\ & & p_{13} & & 0 & & p_{23} & & \cdots p_{ij} \cdots & \\ & & & \ddots & & & & \ddots & & \end{bmatrix}_{kx(k*n)} & & & = \begin{bmatrix} 0 \end{bmatrix}_{kx1} \\
\begin{bmatrix} 0 \end{bmatrix}_{nxm} & & \begin{bmatrix} 1 & 1 & 1 & \cdot & \cdot & \cdot & 0 & & & \\ & & 0 & & 1 & 1 & 1 & \cdot & \cdot & \cdot \\ & & \vdots & & & & 0 & & PARSUM & \\ & & & & & & \vdots & & & \end{bmatrix}_{nx(k*n)} & & & \leq \begin{bmatrix} ACRES \end{bmatrix}_{nx1}
\end{array}
$$

Figure 2. An Alternative Land Use Linear Program Formulation

different portions of a single parcel being allocated to different uses. The result is more reasonable distributions of uses over space and avoidance of irregularities in total allocations of land to uses.

Another feature of this formulation is the allocation of land to use categories rather than to specific economic sectors. The requirements of each sector for land in each use category are expressed by the ALURQ matrix in Figure 2. A single economic sector may employ land in several different use categories, and conversely land in any one use category may be required by several different sectors.

A major advantage of this approach is that land use categories can be defined to closely conform to the categories that are typically used by planners and in land use regulations, while retaining a sectorization scheme which conforms to convention and to available information sources.

This feature also recognizes the fact that a single sector or entity within a sector may require two or more substantially different types of locations, resources, or facilities. For example a large resource based manufacturing operation may require vast acreage to supply its basic raw material while requiring land of substantially different attributes for its processing plant, and perhaps even another location with still other properties for the company headquarters.

Finally, this feature enables the model to realistically reflect the various land requirements of the various sectors, while minimizing the total number of land use categories that must be distinguished. As will become apparent, this is an important factor in keeping the model to a size that is practical and feasible to solve.

The coefficients in the PROCO matrix of Figure 2 indicate the relative productivity of respective parcels as inputs in the production process of respective uses. For use categories such as agriculture or forestry where factors such as soil fertility relate directly to yield this coefficient can range from zero to one, reflecting productivity relative to some ideally productive acre. For other use categories where gross output does not relate directly through the production process to some characteristic of the land the coefficient would assume a value of either zero or one, simply indicating whether the parcel is or is not suitable for the use. This distinction avoids the problem of the model trying to offset demand limitations with additional resource allocation, as was discussed in the preceding section. This treatment, however, does not adequately reflect the reduced rents due to reduced demand relative to the ideal location or similar influences.

Reference was made above to the role and selection of the objective function and associated problems. This solution does not avoid those problems. If the model is to be used either directly or indirectly, i.e. using the shadow prices apart from the resource allocation in the solution, to project future land use patterns due to market activity in a decentralized economy, then the coefficients of the objective function should be some reflection of profits or investment return in order to result in meaningful shadow prices for this purpose.

Ideally the objective function coefficient would be a proportion, which when multiplied by gross output would yield the contribution of the land to profit for the respective sector. There is a problem of course in arriving at such coefficients since contribution to profit is not an observable entity. The problem is compounded in this particular formulation by the association of several land use categories with a single economic sector and therefore a single objective function coefficient. Such a condition may dictate erroneous relationships between the imputed contributions of the different land use categories. A slight modification to the I-A and ALURQ matrices of Figure 2 can elminate this particular aspect of the objective function problem. Revised rows and columns for I-A and ALURQ, as indicated in Figure 3, allow distinct objective coefficients, c_{ij}, for each use j associated with each sector i. Another matrix component, SOEQ, is required simply to equate output across uses for each sector. This formulation makes more practical the use of empirically based coefficients, e.g. coefficients based on

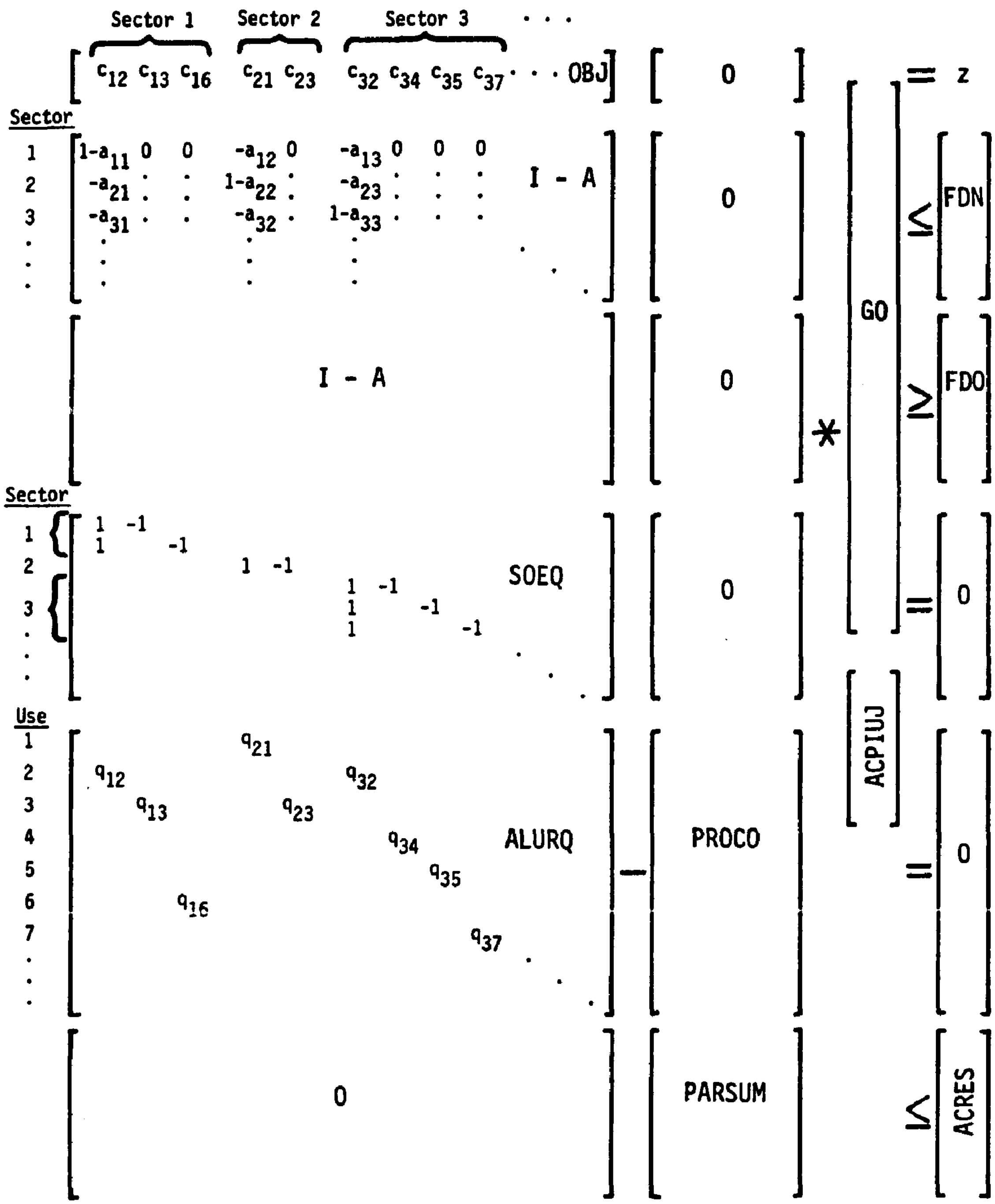


Figure 3. Use Specific Objective Coefficients Land Use Linear Program Formulation

assessed values or market prices of land, capitalized and translated into annual rates.

Miley recognized that the large scale linear programming land use model itself could not serve adequately as a projection device and so suggested a stochastic model whose probabilities derive from the shadow prices from the linear program. The linear program solution is inadequate because it cannot take into account the existing distribution of uses and the costs of converting from those uses. The alternative linear program formulations suggested above certainly do not eliminate this problem, in fact in the preceding discussion additional inadequacies are revealed, e.g. the model cannot adequately account for Thünien rents.

The need for a mechanism beyond the large scale linear program is acknowledged, but the appropriateness of a stochastic shift model in that role is questionable for several reasons.

Since Miley (1977) did not expand on the suggestion for a probabilistic shift process the following comments on possible limitations of such a process rely on speculation as to its exact form.

One potentially serious problem with such a process is that if the probabilities of certain shifts on certain parcels are considered to be independent probabilities, then the land use allocations from any one run of the model would not necessarily be, in fact would more than likely not be, consistent with the acreage requirement results from the economic model from which the rents and therefore the probabilities were derived. Spatial disaggregation with a relatively large number of relatively small parcels could reduce the seriousness of but not eliminate this problem.

As with any stochastic model, the use of such a shift process would entail a large number of repetitions of any one problem in order to begin to establish patterns of expected future conditions and events. With many of the outputs of the model, for example levels of aggregate economic variables and identification of likely limiting resources, this averaging over a number of runs would probably be a reasonable, straightforward process. For one very important output, however, namely patterns of land use over space, the task may not be so straightforward. The question that must be faced is how one averages, over multiple runs, the different uses that occur on a parcel, to arrive at expected patterns of use.

The most obvious problem with the stochastic shift process is the derivation of shift probability distributions as functions of rent differentials for the various uses.

Given these doubts about the practicality of a stochastic allocation device, it was decided to attempt to develop and employ a deterministic shift process. The resulting model is described in the following section.

The Land Use Projection Model

The land use projection model developed and employed in this study derives from the linear programming model depicted in Figure 2 and from the same contention that led to the contemplation of a stochastic shift process. That contention is that the probability of a shift from one use to another is directly related to a rent differential between the two uses on a given parcel. This model goes a step further in using the consequent relationship that a use shift is expected, i.e. probability of the shift is greater than fifty percent, if the rent differential exceeds a certain threshold. This model treats the process as deterministic, in that if a use shift is expected and if a need for such a shift is dictated by the requirements of the economic model then the shift will occur. Futhermore, within the model such shifts are designated in order of the magnitude of the rent differential. The model treats the process as deterministic not because it is denied that there are relevant influences other than rent differential, but primarily because it is felt that running of and interpreting the output from the deterministic version is considerably more practical. If a planner is to use such a model routinely, e.g. to answer "what if" questions, then the numerous solutions that might be necessary to establish patterns with a stochastic model would not be practical.

The overall structure of the model is depicted in the flow chart of Figure 4. An unconstrained input-output model is solved for gross outputs given projected maximum final demands for a period. These gross outputs, the land use requirements coefficients, and the objective function coefficients can be used to compute area required in each land use and standard rents for each use in the case where availability of suitable land is not constraining.

The model then enters a shift possibilities phase in which a file is created which lists all shifts from existing uses on parcels to other uses which would result in positive rent differentials. In computing rent differentials, for constructing this file the relative productivity and suitability for each use on each parcel is taken into consideration. Each parcel is assigned a suitability factor for each use which reflects various attributes of the parcel on which attractiveness for the particular use is dependent. The combination of these factors for a use on a parcel is used to adjust the standard rent for that use to obtain the rent for that use on the specific parcel. Only a limited number of values are allowed for the suitability factor for any use. The fact that there is a limited number of factors, a limited number of uses, and a finite number of parcels means that there is a finite number of possible use shifts. The output from this shift possibilities phase is a file in which each record indicates a rent differential for a shift between two uses and

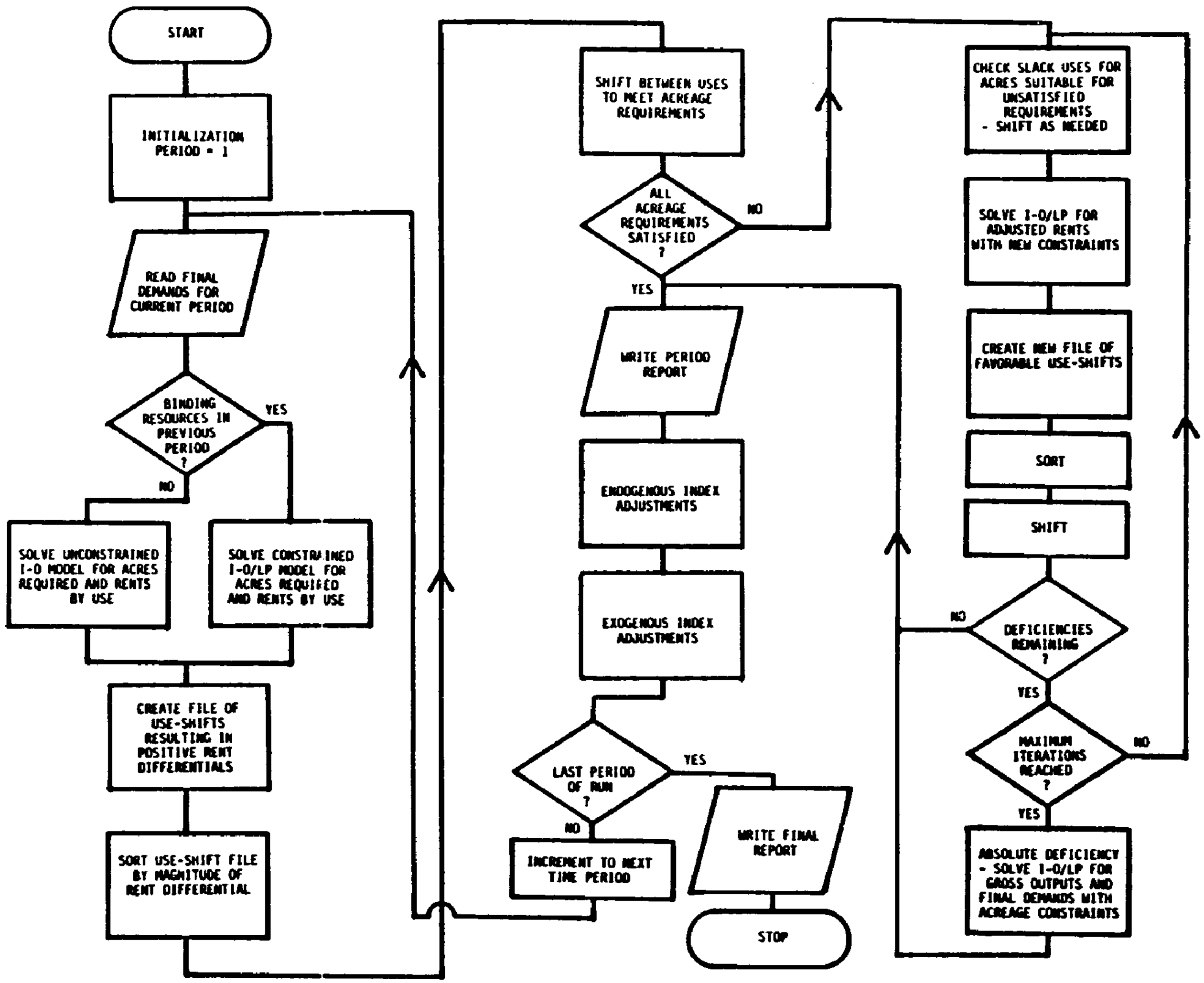


Figure 4. Land Use Projection Model Flow Chart

also indicates all parcels which would yield that particular differential for that shift.

The file produced by the shift possibilities phase is then sorted according to rent differentials in descending order. This ordered file and the acreage requirements by uses from the solution of the input-output model become the primary inputs to a shift phase. In this phase the ordered file of possible shifts is searched to find use shifts to eliminate any differences between acreage requirements and current acreage allocations for all uses. The search through the file is repeated until all such deficiencies are eliminated or until a specified maximum number of iterations is reached. If all acreage requirements can be satisfied during this phase then the model proceeds to the reporting function for the current period, after which the entire process is repeated for subsequent periods. If acreage deficiencies for some uses remain then a rent adjustment phase is entered.

Unsatisfied acreage requirements from the initial pass through the shift phase indicate that availability of suitable land for a particular use is constraining and suggests that the gross ouputs and standard rents from the unconstrained input-output model are inappropriate. It is in this situation that a small spatially aggregated input-output linear programming model is employed to yield adjusted gross outputs, acreage requirements, and rents. This aggregated linear program has an activity for each sector and current acreage allocations for the land use constraints. The fact that these current acreages are constraining for one or more uses will result in positive shadow prices which may be greater than the standard direct contribution to the objective for those uses.

These shadow prices for the constraining uses are then used in computing rents for construction of another ordered file of rent differentials for possible shifts from non-binding uses to binding uses. The process is repeated until sufficient acreage is allocated to satisfy requirements for each use or until a specified maximum number of iterations is reached. If the maximum number of iterations is reached without satisfying acreage requirements, an unresolvable deficiency for the use in the current period is assumed and the outputs of economic sectors directly and indirectly dependent on the use are adjusted correspondingly by solving the linear program with the final acreage allocations as the right-hand side. Reports for the current period are then written before repeating the process for subsequent periods.

It is not claimed that this process arrives at the optimal solution for the nonlinear problem, but it does approach this optimal and in so doing yields rents which surpass those from the large scale linear program in reflecting the true nature of the problem. The shifts search and rent adjustment procedure can be considered a case of "heuristic programming" (see for example Dykstra, 1976 or Khumawala, 1971). The allocation process is reasonable and understandable and may even approximate the appropriate real world allocation process. While an optimal solution is not guaranteed, the allocation that is obtained is expected to be considerably closer to that optimum than would be obtained by inspection or intuition.

CHAPTER III. DATA AND METHODS

The previous chapter describes a comprehensive land use projection model. The regional economy is modeled with some sectoral detail, while the regional resource base and land use are addressed with considerable spatial detail. The economy is linked to the resource base through productivity, suitability, and land requirements relationships. Obviously, such a model encompasses a wide range of variables, and a wide variety of data and techniques for employing them are required. This chapter considers data sources and steps involved in compiling those data for submission to the land use model.

The model can be thought of as consisting of two major components, the economic component and the land use and resources component. The economic component includes the I-A matrix of an input-output model, a total final demand vector used as the right-hand-side for the linear program, and the objective function, all of which focus on sectors of the regional economy. The land use requirements matrix, which is the link between the two major components, distinguishes land use categories as well as economic sectors. The major variables for the land use and resources component are land use and resources by spatially referenced parcels of lands. Within this component there are submodels for any number of explicitly recognized resources or parcel characteristics. This chapter is organized around these major components and submodels. This is appropriate since the different components required different types and sources of data and different methods for manipulating them.

The Input-Output Model

As has been thoroughly discussed elsewhere (Isard and Langford, 1971, Richardson 1972), many decisions must be made before embarking on the actual data collection and analysis phases of an input-output study. Primary among these decisions is that of regionalization. Will more than one region be considered in detail or will the analysis focus on one region with its linkages to all other regions represented grossly by an import row and export column? In either case what are the boundaries of the region or regions to be considered? That Emmet County would be the region of focus for this project was specified in the original project proposals for the reasons discussed in the Introduction. That it would be the sole region explicitly considered was dictated by the anticipations (later seen to be well founded) that time, costs, and computer capacity limitations would be strained even with just the single region.

Another important decision regarding the input-output analysis, which could not, however, be dispensed with so easily, was that of sectorization. As described in Chapter II an input-output model represents a regional economy as a matrix of linear relationships between different groups or sectors of households, firms, or institutions. Again the question of how many sectors as well as that of the exact definition of each sector must be addressed. Much has been written about both of these questions. One of the attractive features of input-output analysis is, of course, its capability for recognition of many different sectors, but in this case the value of fine sectoral resolution is questionable since the effects within the model are funneled into the land use categories the number of which by necessity is limited. Of course the number of sectors also directly affects the size of the linear programming problem and therefore should be no larger than necessary. When direct surveys are used to obtain data for the input-output model, two other factors dictate a limited number of sectors. One would expect that total sample size to achieve a desired level of precision in each sector would increase as the number of sectors increase thereby increasing data collection costs. Secondly, and particularly important when dealing with a small region, high sectoral disaggregation can result in very few firms in certain important sectors with resulting disclosure problems.

Based on these considerations and the relative importance of certain activities to the Emmet County economy, as indicated in published data, the sectors indicated in Table 1 were delineated. Where applicable, two digit S.I.C. codes corresponding to these sectors for firms in Emmet

County are also shown in Table 1. The row and column numbers in Table 1 refer to the various input-output tables included below.

A final major design question concerned the sources of data and methods of obtaining the input-output coefficients. The preferred approach to constructing such models has been to use direct survey for all sectors, but the costs of this approach have long been recognized as a major impediment to the development of input-output models. In recent years a great deal of effort has gone into developing and evaluating various techniques for estimating input-output coefficients for a particular region while avoiding or at least reducing primary data collection.

These techniques generally involve modifying an existing survey based input-output model from some other region, referred to as the base table, to more closely resemble the economy of the region in question than would the unadjusted base table. Often for regional studies in the United States the national input-output model is used as the base model. Typically, some effort is given to delineating the sectors from the base table that correspond most closely to the sectors of the region. Published data can often be used to estimate regional total outputs and some final demand and/or payment vectors. The transactions or technical coefficients for the appropriate sectors are then adjusted to reflect known differences within sectors or in the structure of the economy between the region and

Table 1. Emmet County Input-Output Analysis Sectorization

Sector	S.I.C. Code	I-O Table Row No.	I-O Table Column No.
Agriculture & Forestry	01,07,08,09	1	1
Construction	15,17	2	2
Wood Products & Furniture Manufacturing	24,25	3	3
Mining & Cement & Concrete Products Manufacturing	14,32	4	4
Electrical & Transportation Equipment Manufacturing	36,37	5	5
Primary Metal & Metal Fabrication Manufacturing	33,34	6	6
Nondurables Manufacturing	20,22,27,30	7	7
Transportation, Communication & Utilities	41,42,44,45 48,49	8	8
Wholesale & Retail Trade	50,52,53,54 55,56,57,58,59	9	9
Finance, Insurance & Real Estate	60,61,64,65	10	10
Lodging & Amusement Services	70,79	11	11
Medical Services	80	12	12
Other Services	72,73,75,81, 82,89	13	13
Government Enterprises		14	14
Households		15	15
Imports, Taxes & Other Payments		16	
Total Payments		17	
Seasonal Residents			16
Tourists			18
Other Export			19
Investment			20
Exogenous Government			21
Total Gross Output			22

the base region, and the model is balanced to accomodate the estimates of total or intermediate outputs. For a thorough review of the many variations on this theme see Stipe (1975), Richardson (1972), McMenamin and Haring (1974), and Morrison and Smith (1974).

A third approach to developing input-output models employs both direct survey and the secondary data reduction techniques. Typically direct survey would be used for the most important or unique sectors of the regional economy and for those final demands or payments for which it is very difficult if not impossible to obtain reliable estimates from published sources, e.g. imports and exports, while coefficients adjusted from a base table would be used to complete the model. There seems to be a growing concensus that such a hybrid model will often be an appropriate compromise between the higher accuracy of the pure survey model and the low cost of the secondary data reduction approach.

A combined direct survey and data reduction approach was adopted for this study. Some unique aspects of the Emmet County economy as well as improved accuracy in general suggested the need for some primary data collection, while the limited resources for the project prohibited and the objectives of the project cast doubt on the need for a full survey model.

The construction, manufacturing, medical, and hotel, motel, and resort sectors were surveyed. Sample sizes were determined based on the variance in establishment size from published data in order to be able to estimate sector employment totals within plus or minus ten percent with 95 percent confidence. For the manufacturing sectors the sample was stratified over the individual sectors being recognized in the input-output model. For the medical sector only the major hospital and clinic were contacted with secondary techniques used to account for the smaller establishments.

Preparation of questionnaires and initial contacts with the selected establishments occured in the winter and spring of 1977. Interviews, during which the questionnaires were explained in detail, followed in the summer and follow-up contacts continued into the fall. Despite these efforts response was poor and the usefulness of the results was limited, so the input-output model became even more dependent on secondary data than was originally intended.

Estimates of gross outputs were obtained by multiplying 1976 employment for a sector by the ratio of output to employment for the most recent year for which census data on output were available for that particular sector. Employment data were obtained from several sources, including County Business Patterns of the U.S. Department of Commerce, the Michigan State Employment Security Commission, and the 1976 Michigan Directory of Manufacturers.

Some useable data on final demands and payments was obtained from the survey. Where such data were lacking for imports and exports, location quotient techniques were used to derive reasonable estimates. In some cases, for example personal consumption expenditures, national averages from published sources were used to fill in missing elements in the final demands and/or payments sectors.

An iterative balancing technique for deriving an input-output transactions matrix given a base table and final demands and payments described by McMenamin (1973) was used.

The 1967 U.S. input-output model was the most recent available national model at the outset of this study and was used as the base table. Considerable effort went into delineating those sectors from the highly disaggregated national table that most closely corresponded to the various industries as they existed in Emmet County.

A FORTRAN program was written to apply the iterative balancing of the base table transactions to the estimated regional control totals. This program allowed specification of certain regional transactions for which direct data were available and then balanced the rest of the model around these fixed regional transactions as well as the total intermediate outputs by sectors.

The standard input-output tables and matrices resulting from this process are included below. The transactions shown in Table 2 are the estimated dollars paid by purchasing or final demand sectors to producing or final payment

Table 2. Emmet County Input-Output Analysis Transactions (dollars)

PRODUCING OR PAYMENT SECTOR	PURCHASING OR FINAL DEMAND SECTOR 1	2	3	4	5	6	7	8	9	10	11
1	1089250.	56511.	40000.	0.	0.	0.	8189.	5870.	34101.	262002.	120990.
2	41060.	6342.	6376.	162902.	38458.	11795.	21034.	388535.	120709.	929552.	242910.
3	3600.	460570.	575060.	250000.	6000.	2500.	9000.	605.	45000.	8440.	2000.
4	465.	1021049.	3383.	2469566.	96568.	248.	5324.	3942.	24447.	3451.	7647.
5	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
6	2200.	50300.	100000.	73400.	225000.	110000.	14800.	7300.	11600.	3450.	0.
7	4000.	53220.	0.	100910.	119400.	10700.	74650.	20600.	212170.	53060.	34550.
8	73409.	386432.	36840.	931207.	217383.	43163.	151759.	1154092.	732209.	237292.	557554.
9	184890.	1577980.	119895.	417770.	318820.	72840.	166490.	229180.	685500.	244260.	228180.
10	69134.	93660.	6776.	199219.	49001.	31634.	47531.	134719.	852769.	718497.	565057.
11	0.	0.	0.	0.	0.	0.	0.	35327.	12397.	26110.	651281.
12	9141.	0.	0.	0.	0.	0.	0.	0.	0.	32384.	1500.
13	49864.	534120.	13352.	263976.	218516.	36734.	102612.	193500.	1156646.	460448.	497527.
14	591.	2745.	1059.	21959.	17728.	3569.	43948.	581781.	268686.	176079.	51532.
15	2125000.	6992000.	1416500.	2229700.	2354600.	1545850.	2122050.	3959300.	17787000.	2510800.	3420000.
16	1044396.	11835071.	1707759.	9582391.	5652526.	2401967.	2708613.	6085249.	12454766.	10444175.	3159272.
17	4697000.	23070000.	4027000.	16703000.	9314000.	4271000.	5476000.	12800000.	34318000.	16110000.	9540000.

Table 2. (Continued)

PRODUCING OR PAYMENT SECTOR	PURCHASING OR FINAL DEMAND SECTOR 12	13	14	15	16	17	18	19	20	21
1	27275.	15.	575.	1150000.	80500.	170000.	1641722.	0.	10000.	4697000.
2	226810.	137432.	265312.	500000.	35000.	0.	1070772.	13365000.	5500000.	23070000.
3	0.	1000.	0.	56500.	5000.	0.	2601725.	0.	0.	4027000.
4	4765.	24338.	361.	25000.	2000.	0.	13010446.	0.	0.	16703000.
5	0.	0.	0.	0.	0.	0.	9301000.	0.	13000.	9314000.
6	0.	42000.	0.	0.	0.	0.	3630950.	0.	0.	4271000.
7	50640.	1057300.	5050.	382200.	30000.	57300.	3210250.	0.	0.	5476000.
8	675738.	614566.	204856.	5886500.	432000.	165000.	0.	0.	300000.	12000000.
9	660590.	467560.	15520.	17888300.	1313000.	2700000.	767225.	1360000.	4900000.	34310000.
10	677404.	347353.	17244.	11300000.	750000.	0.	0.	0.	250000.	16110000.
11	0.	10715.	12.	1555000.	114000.	7000000.	135158.	0.	0.	9540000.
12	809875.	0.	743.	4520000.	450000.	450000.	16200358.	0.	9000000.	31474000.
13	440777.	404738.	31193.	6712000.	493000.	1010000.	0.	0.	1500000.	14119000.
14	164726.	151137.	2659.	425800.	31000.	60000.	0.	0.	250000.	2255000.
15	17465000.	3931500.	1452000.	750000.	52500.	0.	4220600.	0.	32388000.	106642400.
16	10270400.	6929346.	259475.	34135700.	1749500.	3052700.	1.	0.	289000.	123762307.
17	31474000.	14119000.	2255000.	85287000.	5537500.	14665000.	55790207.	14725000.	54400000.	418578707.

sectors. Table 3 shows the direct requirements or technical coefficients, which are the proportions of the purchasing sectors total payments paid to each producing sector. Table 4 is the I-A matrix which, as discussed in Chapter II, is included in the constraint matrix of the linear programming model. The inverse I-A matrices, also called the direct and indirect requirements, without and with households, respectively, are shown in Table 5 and Table 6. The two different inverses are needed, along with the direct requirements of Table 3 to derive the output and income multipliers shown in Table 7.

Spatially Referenced Data

Spatially indexed land use and resources data had to be collected and prepared for input to the projection model. Again certain design decisions had to be made regarding spatial resolution, number and definition of land use categories, and the number and nature of other land resources characteristics to be explicitly recognized.

Spatial Resolution

As was discussed in the Introduction a goal of this study was to substantially improve the spatial resolution over Miley's previous work. Miley had used counties as parcels in his application. An Emmet County planner at one point stated that a one-eighth acre city lot was the appropriate parcel for projections useful for his planning.

Table 3. Input-Output Analysis Direct Requirements

PRODUCING SECTOR	PURCHASING SECTOR 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0.23190	0.00245	0.00993	0.0	0.0	0.0	0.00150	0.00046	0.00099	0.01626	0.01268	0.00087	0.00000	0.00025	0.01348
2	0.00874	0.00027	0.00158	0.00975	0.00413	0.00276	0.00384	0.03035	0.00352	0.05770	0.02546	0.00721	0.00973	0.11765	0.00586
3	0.00077	0.01996	0.14280	0.01497	0.00064	0.00059	0.00164	0.00005	0.00131	0.00052	0.00021	0.0	0.00007	0.0	0.00066
4	0.00010	0.04426	0.00084	0.14785	0.01037	0.00006	0.00097	0.00031	0.00071	0.00021	0.00080	0.00015	0.00172	0.00016	0.00029
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	0.00047	0.00218	0.02483	0.00439	0.02416	0.02576	0.00270	0.00057	0.00034	0.00021	0.0	0.0	0.00297	0.0	0.0
7	0.00085	0.00231	0.0	0.00604	0.01282	0.00251	0.01363	0.00161	0.00618	0.00329	0.00362	0.00161	0.07488	0.00224	0.00448
8	0.01563	0.01675	0.00915	0.05575	0.02334	0.01011	0.02771	0.09016	0.02134	0.01473	0.05844	0.02147	0.04353	0.09085	0.06902
9	0.03936	0.06840	0.02977	0.02501	0.03423	0.01705	0.03040	0.01790	0.01997	0.01516	0.02392	0.02099	0.03312	0.00688	0.20974
10	0.01472	0.00406	0.00168	0.01193	0.00526	0.00741	0.00868	0.01052	0.02485	0.04460	0.05923	0.02152	0.02460	0.00765	0.13249
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00276	0.00036	0.00162	0.06827	0.0	0.00076	0.00001	0.01823
12	0.00195	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00201	0.00016	0.02573	0.0	0.00033	0.05300
13	0.01062	0.02315	0.00332	0.01580	0.02346	0.00860	0.01874	0.01512	0.03370	0.02858	0.05215	0.01400	0.02867	0.01383	0.07870
14	0.00013	0.00012	0.00026	0.00131	0.00190	0.00084	0.00803	0.04545	0.00783	0.01093	0.00540	0.00523	0.01070	0.00118	0.00499
15	0.45242	0.30308	0.35175	0.13349	0.25280	0.36194	0.38752	0.30932	0.51597	0.15585	0.35849	0.55490	0.27845	0.64390	0.00879

Table 4. Input-Output Analysis I - A Matrix

PRODUCING SECTOR	PURCHASING SECTOR 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0.7681	-0.0024	-0.0099	0.0	0.0	0.0	-0.0015	-0.0005	-0.0010	-0.0163	-0.0127	-0.0009	-0.0000	-0.0003	-0.0135
2	-0.0087	0.9997	-0.0016	-0.0098	-0.0041	-0.0028	-0.0038	-0.0304	-0.0035	-0.0577	-0.0255	-0.0072	-0.0097	-0.1177	-0.0059
3	-0.0008	-0.0200	0.8572	-0.0150	-0.0006	-0.0006	-0.0016	-0.0000	-0.0013	-0.0005	-0.0002	0.0	-0.0001	0.0	-0.0007
4	-0.0001	-0.0443	-0.0008	0.8521	-0.0104	-0.0001	-0.0010	-0.0003	-0.0007	-0.0002	-0.0008	-0.0002	-0.0017	-0.0002	-0.0003
5	0.0	0.0	0.0	0.0	1.0000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	-0.0005	-0.0022	-0.0248	-0.0044	-0.0242	0.9742	-0.0027	-0.0006	-0.0003	-0.0002	0.0	0.0	-0.0030	0.0	0.0
7	-0.0009	-0.0023	0.0	-0.0060	-0.0128	-0.0025	0.9864	-0.0016	-0.0062	-0.0033	-0.0036	-0.0016	-0.0749	-0.0022	-0.0045
8	-0.0156	-0.0168	-0.0091	-0.0558	-0.0233	-0.0101	-0.0277	0.9098	-0.0213	-0.0147	-0.0584	-0.0215	-0.0435	-0.0908	-0.0690
9	-0.0394	-0.0684	-0.0298	-0.0250	-0.0342	-0.0171	-0.0304	-0.0179	0.9800	-0.0152	-0.0239	-0.0210	-0.0331	-0.0069	-0.2097
10	-0.0147	-0.0041	-0.0017	-0.0119	-0.0053	-0.0074	-0.0087	-0.0105	-0.0248	0.9554	-0.0592	-0.0215	-0.0246	-0.0076	-0.1325
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.0028	-0.0004	-0.0016	0.9317	0.0	-0.0008	-0.0000	-0.0182
12	-0.0019	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.0020	-0.0002	0.9743	0.0	-0.0003	-0.0530
13	-0.0106	-0.0232	-0.0033	-0.0158	-0.0235	-0.0086	-0.0187	-0.0151	-0.0337	-0.0286	-0.0522	-0.0140	0.9713	-0.0138	-0.0787
14	-0.0001	-0.0001	-0.0003	-0.0013	-0.0019	-0.0008	-0.0080	-0.0455	-0.0078	-0.0109	-0.0054	-0.0052	-0.0107	0.9988	-0.0050
15	-0.4524	-0.3031	-0.3518	-0.1335	-0.2528	-0.3619	-0.3875	-0.3093	-0.5160	-0.1559	-0.3585	-0.5549	-0.2786	-0.6439	0.9912

Table 5. Direct and Indirect Requirements

PRODUCING SECTOR	PURCHASING SECTOR 1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	1.3026	0.0038	0.0152	0.0008	0.0003	0.0003	0.0023	0.0012	0.0020	0.0225	0.0195	0.0018	0.0009	0.0011
2	0.0141	1.0029	0.0031	0.0159	0.0067	0.0042	0.0072	0.0409	0.0077	0.0636	0.0360	0.0108	0.0157	0.1226
3	0.0016	0.0244	1.1668	0.0210	0.0012	0.0006	0.0022	0.0011	0.0018	0.0023	0.0013	0.0003	0.0007	0.0030
4	0.0010	0.0523	0.0014	1.1745	0.0126	0.0003	0.0016	0.0026	0.0014	0.0037	0.0031	0.0008	0.0031	0.0067
5	0.0	0.0	0.0	0.0	1.0000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0008	0.0032	0.0298	0.0060	0.0251	1.0265	0.0030	0.0009	0.0006	0.0006	0.0004	0.0001	0.0035	0.0005
7	0.0030	0.0054	0.0008	0.0094	0.0155	0.0036	1.0159	0.0038	0.0094	0.0065	0.0095	0.0033	0.0791	0.0045
8	0.0256	0.0256	0.0139	0.0756	0.0301	0.0129	0.0343	1.1073	0.0279	0.0227	0.0766	0.0271	0.0554	0.1050
9	0.0550	0.0740	0.0374	0.0346	0.0383	0.0191	0.0339	0.0247	1.0237	0.0237	0.0346	0.0245	0.0403	0.0189
10	0.0224	0.0061	0.0039	0.0173	0.0081	0.0069	0.0113	0.0143	0.0282	1.0494	0.0706	0.0247	0.0294	0.0109
11	0.0002	0.0001	0.0001	0.0003	0.0001	0.0001	0.0002	0.0033	0.0006	0.0019	1.0737	0.0001	0.0011	0.0004
12	0.0026	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0022	0.0004	1.0265	0.0001	0.0084
13	0.0177	0.0283	0.0062	0.0228	0.0271	0.0104	0.0221	0.0205	0.0374	0.0343	0.0636	0.0173	1.0349	0.0201
14	0.0022	0.0024	0.0014	0.0058	0.0041	0.0018	0.0104	0.0510	0.0101	0.0132	0.0111	0.0073	0.0149	1.0065

Table 6. Direct and Indirect Requirements, With Households

PRODUCING SECTOR	PURCHASING SECTOR 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1.3218	0.0152	0.0289	0.0076	0.0096	0.0120	0.0155	0.0135	0.0189	0.0296	0.0340	0.0200	0.0122	0.0232	0.0298
2	0.0337	1.0146	0.0170	0.0229	0.0162	0.0161	0.0206	0.0534	0.0249	0.0707	0.0509	0.0293	0.0272	0.1451	0.0304
3	0.0032	0.0254	1.1679	0.0215	0.0020	0.0018	0.0033	0.0022	0.0032	0.0029	0.0025	0.0019	0.0017	0.0049	0.0025
4	0.0028	0.0533	0.0026	1.1751	0.0135	0.0014	0.0028	0.0037	0.0029	0.0043	0.0044	0.0025	0.0041	0.0087	0.0028
5	0.0	0.0	0.0	0.0	1.0000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0014	0.0036	0.0302	0.0062	0.0253	1.0269	0.0034	0.0012	0.0011	0.0008	0.0008	0.0007	0.0038	0.0012	0.0009
7	0.0157	0.0129	0.0099	0.0139	0.0217	0.0114	1.0246	0.0120	0.0206	0.0112	0.0191	0.0154	0.0866	0.0191	0.0198
8	0.1088	0.0749	0.0729	0.1053	0.0705	0.0638	0.0914	1.1606	0.1011	0.0532	0.1395	0.1059	0.1044	0.2006	0.1293
9	0.2557	0.1930	0.1798	0.1062	0.1359	0.1420	0.1717	0.1535	1.2004	0.0974	0.1866	0.2147	0.1584	0.2496	0.3120
10	0.1568	0.0877	0.0991	0.0652	0.0734	0.0912	0.1035	0.1004	0.1464	1.0988	0.1723	0.1520	0.1084	0.1653	0.2088
11	0.0182	0.0108	0.0128	0.0067	0.0089	0.0111	0.0125	0.0149	0.0164	0.0085	1.0873	0.0172	0.0117	0.0210	0.0280
12	0.0513	0.0288	0.0345	0.0174	0.0237	0.0298	0.0334	0.0312	0.0429	0.0201	0.0372	1.0725	0.0287	0.0562	0.0756
13	0.1047	0.0798	0.0679	0.0538	0.0694	0.0637	0.0818	0.0763	0.1139	0.0663	0.1294	0.0997	1.0861	0.1200	0.1351
14	0.0149	0.0099	0.0104	0.0103	0.0103	0.0096	0.0191	0.0591	0.0212	0.0178	0.0207	0.0193	0.0224	1.0211	0.0197
15	0.8878	0.5262	0.6297	0.3164	0.4316	0.5436	0.6095	0.5695	0.7814	0.3260	0.6720	0.8412	0.5223	1.0204	1.3799

Table 7. Emmet County Input-Output Analysis Multipliers

Sector	Output	Income Type I	Income Type II
Agriculture & Forestry	1.45	1.42	1.96
Construction	1.23	1.26	1.74
Wood Products & Furniture Manufacturing	1.28	1.30	1.79
Mining & Cement & Concrete Products Manufacturing	1.38	1.72	2.37
Electrical & Transportation Equipment Manufacturing	1.17	1.24	1.71
Primary Metal & Metal Fabrication Manufacturing	1.09	1.09	1.50
Nondurables Manufacturing	1.14	1.14	1.57
Transportation, Communication & Utilities	1.27	1.33	1.84
Wholesale & Retail Trade	1.15	1.10	1.51
Finance, Insurance & Real Estate	1.25	1.52	2.09
Lodging & Amusement Services	1.40	1.36	1.87
Medical Services	1.14	1.10	1.52
Other Services	1.28	1.15	1.58
Government Enterprises	1.30	1.15	1.58

As a compromise between these extremes, it was decided to use a section as the basic unit of land for this application of the model to Emmet County. Recall from Chapter II that any size parcel could be used and in fact size can vary from parcel to parcel in a given analysis, but as the number of parcels increases the problem to be solved either by linear programming or by sorting, searching, and shifting increases exponentially. The section as the basic spatial unit resulted in approximately 500 parcels in Emmet County which with a reasonable number of land use categories would yield a problem that could be handled by either approach with the computational capacity then available. The section as the basic parcel resulted in a degree of spatial resolution which seemed appropriate for the development and demonstrative purpose of the project.

Use of a fixed grid of square mile cells was considered, but it was felt that use of actual sections would better facilitate data collection and compilation. Land characteristic and resources data were taken from many different maps which typically had section lines designated. Section areas, both total and land surface, were determined from the photo based maps of the Emmet County Soil Survey using the DATATIZER digitizer at the Michigan State University Computer Center.

It was anticipated that many of the displays of inputs to and results from the model would be in the form of simple printer cell maps. The use of sections as parcels facilitated this type of display since they approximate a grid of equal size cells. Conceivably, if more sophisticated mapping hardware and software were available for displaying inputs and results one would not need either a grid or equal parcel size. Definition of parcels could be based on more appropriate considerations such as homogeneity of resources, zoning, or ownership. Much of the spatially indexed land characteristic and resource data considered below was collected and compiled by or in cooperation with the information systems component of the regional project. See McRae and Shelton (1982) for a description of the information systems component of the regional project.

Land Use

There were two main sources of current land use data for Emmet County. During the summer of 1978, an extensive ground survey of all types of developments in the county was conducted. This survey was a cooperative effort between the Emmet County Department of Planning and Zoning and this project. Every mile of rural road in the county was traveled and every building, mineral development and farm was plotted on a map and identified according to land use category, e.g. residential, commercial, industrial, by a local planner who was familiar with most of the county.

The second source of land use data for the county was a series of aerial photographs flown in the summer of 1978.

These photos were supplied by the Michigan Department of Natural Resources and interpreted by the Michigan State University Remote Sensing Project in conjunction with the information systems component of the regional project. A grid of ten acre cells was overlaid on each section of the county and the dominant cover or use recorded for each cell.

While each of these sources had its own deficiencies, the two proved to be quite complementary. For example, the ground survey did not record vegetative cover or recognize associated extensive uses such as agriculture and forestry, but vegetative cover by several different categories was obtained from the aerial photos allowing estimates of area in agricultural use. Conversely the approach of recording dominant use in the ten-acre cell could not possibly distinguish the numerous rural residences scattered throughout the county, but every one of these was identified by the ground survey. Considerable time and effort was spent in reconciling and combining data from these two sources to yield final estimates of current area devoted to each of eight land use categories for every section in the county. The effect of number of land use categories on the size of the linear programming problem or on the number of shift possibilities in the heuristic programming approach necessitates restraint in the number of such categories, so although the land use data was originally collected with some additional distinctions the following eight land use categories were finally designated for explicit consideration in the model: agriculture, commercial, industrial, mineral extraction, recreation, residential, recreation residential, and forest and open.

Soils

Soil type and slope were considered key parcel characteristics for determining productivity and suitability for the various uses. Soil type and slope were recorded from the photo based maps in the Soil Survey of Emmet County, Michigan (USDA SCS, 1973) by overlaying a grid of ten-acre cells on each section. The dominant type and slope in each ten-acre cell was recorded. The data were then keypunched and the computer was used to tally the number of cells by each type and slope for each parcel.

Factors indicating productivity of each soil type/ slope combination for the mix of crops produced in Emmet County (as indicated in the 1974 Census of Agriculture) were derived from a table of predicted average yields for crops in the soil survey. The maximum predicted production for each crop over all soils was used as the standard for that crop (i.e. productivity equals 1.0) and for lower levels of production proportional productivity was assumed. For each soil type average productivity was then computed from those proportions and weights reflecting crop mix. An average productivity factor for each parcel was then derived from soil type productivity factors weighted by the number of cells of each soil type in each parcel. Figure 5 displays the resulting agricultural productivity indexes by parcels for Emmet County. Compare Figure 5 to Figure 6 which indicates current agricultural use.

A similar procedure was used to derive woodland productivity factors by soil type and parcel based on a table of "potential productivity ratings per acre per year for woodland types" in the Emmet County soil survey (USDA SCS, 1973, p. 50). Resulting woodland productivity classes for Emmet County are displayed in Figure 7. As would be expected, there is a noticeable correlation between agricultural and woodland productivity.

Travel Times

The importance of distance to some key location in determining the value of a parcel of land in a given use is one of the fundamentals of land economics. Indeed, the roots of the concept of land rent can be traced to von Thunen's simple isolated state model where concentric zones of land use around a market center were determined by the nature of the product and distance to that market (see Barlowe, 1972, p. 35-37).

Just as the relative remoteness of Emmet County and Northern Lower Michigan in general to existing major regional markets and production centers affects the kinds of establishments that can locate in the county, allocation of land to uses within the county is affected by location

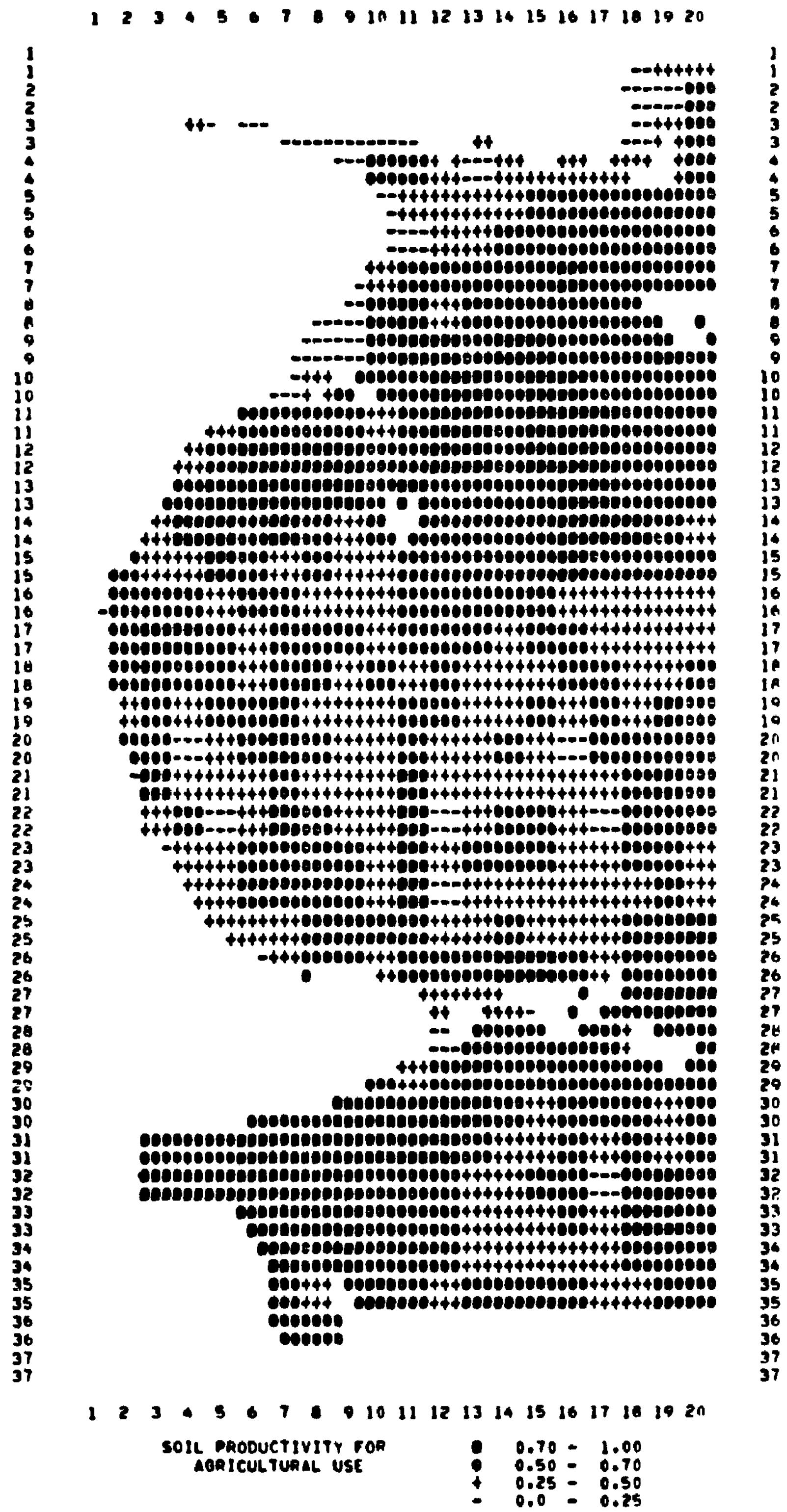


Figure 5. Soil Productivity for Agricultural Use

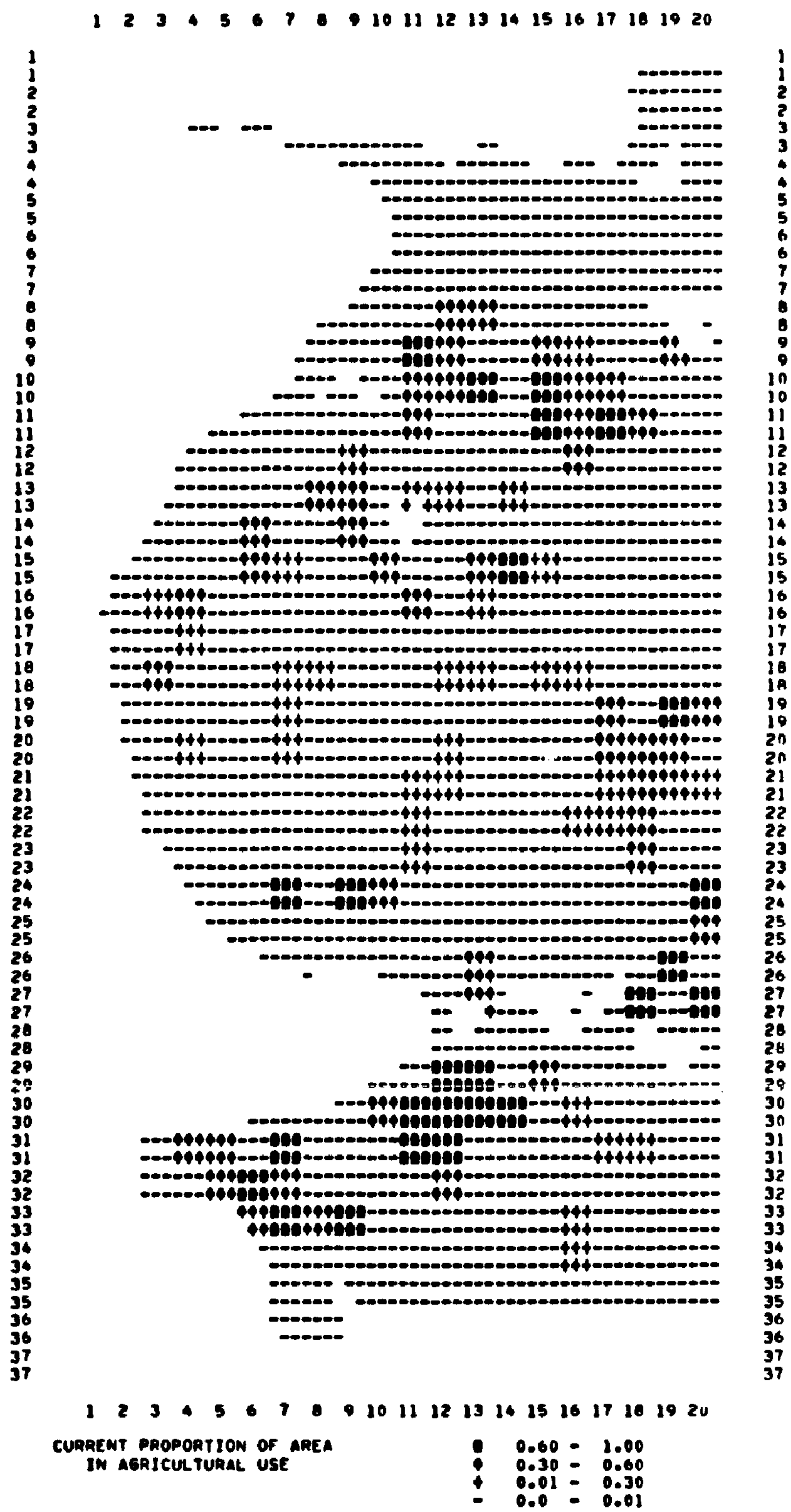


Figure 6. Current Proportion of Area in Agricultural Use

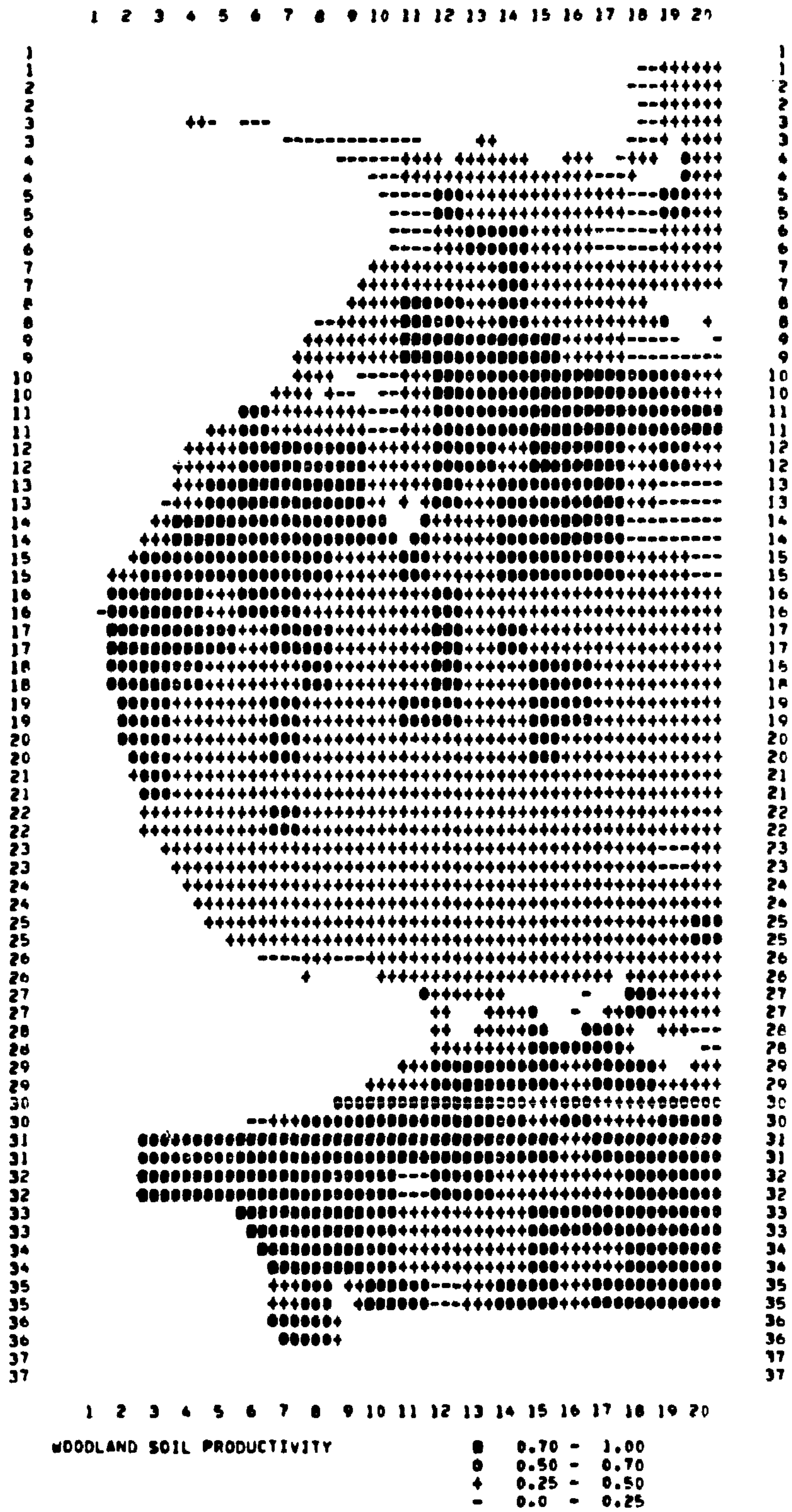


Figure 7. Woodland Soil Productivity

with respect to existing establishments, infrastructure, and resources. To reflect these kinds of influences travel times from every parcel in the county to the major commercial center, Petoskey, and to lesser commercial centers, Harbor Springs, Mackinaw City, Pellston, Alanson, and Cross Village were derived. Maps indicating travel times along major roads my segments were provided by the State of Michigan Department of Transportation. By interpolating and extrapolating from these maps travel times for every section of the county were estimated. Travel times to commercial centers are displayed in Figure 8.

While obtaining travel times by parcel was not a problem, knowing how to use them in deriving suitability factors, e.g. assessing for a given use the impact on expected rents of being two minutes from the commercial center versus ten minutes, was a substantial problem. It must be admitted that the limitations in scope and resources for this project did not permit rigorous development of this kind of relationship. Rather, for each use for which it was felt that travel time was an important factor an assumption was made as to the maximum impact this factor would have on rent for that use and at what point, i.e. travel time, this maximum impact would be reached. Interpolation between this maximum impact point and a zero impact point at some minimal distance to the center was used to derive factors for adjusting rents for intermediate categories of travel times. Figure 9 shows these assumed

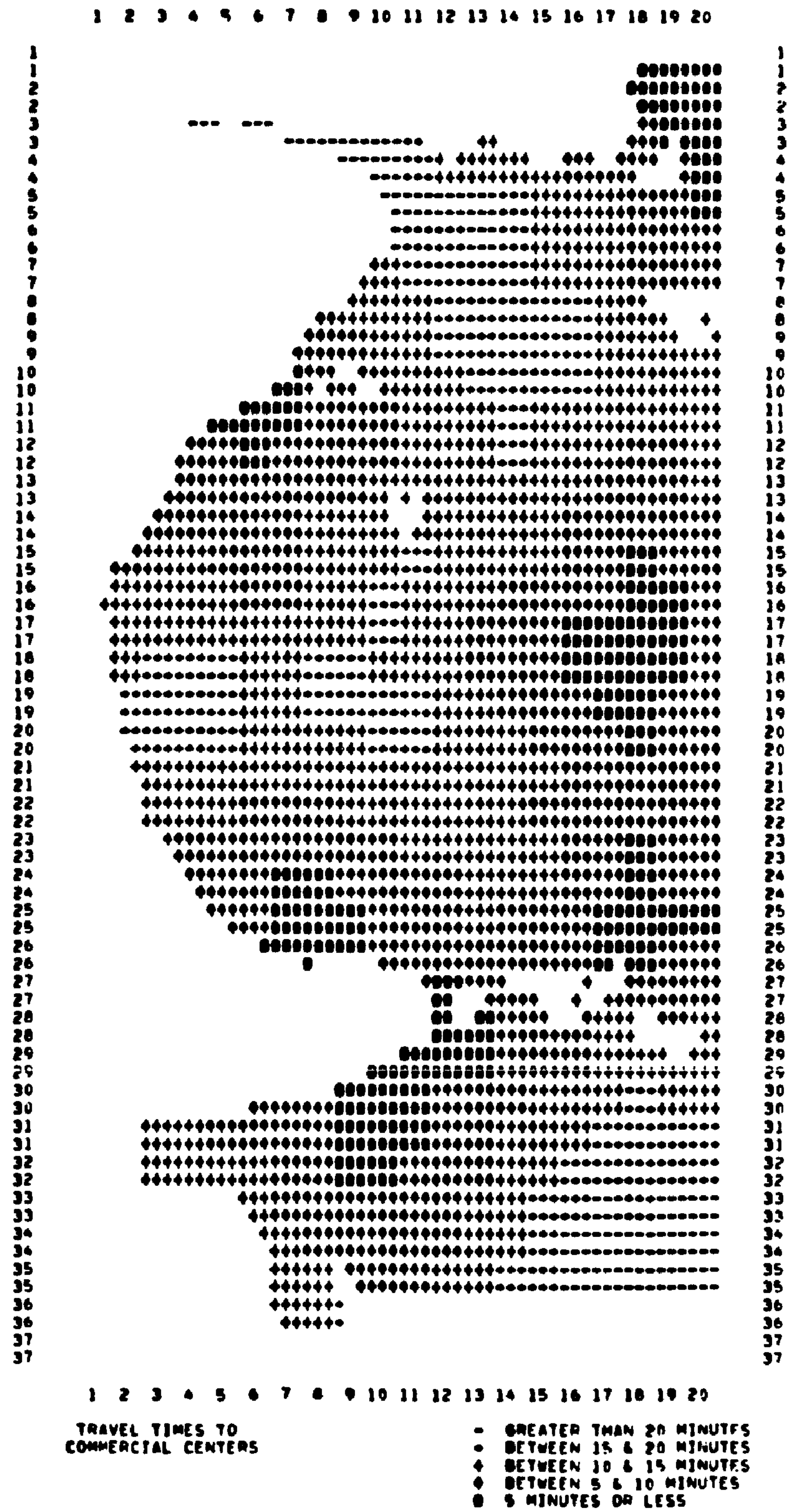


Figure 8. Travel Times to Commercial Centers

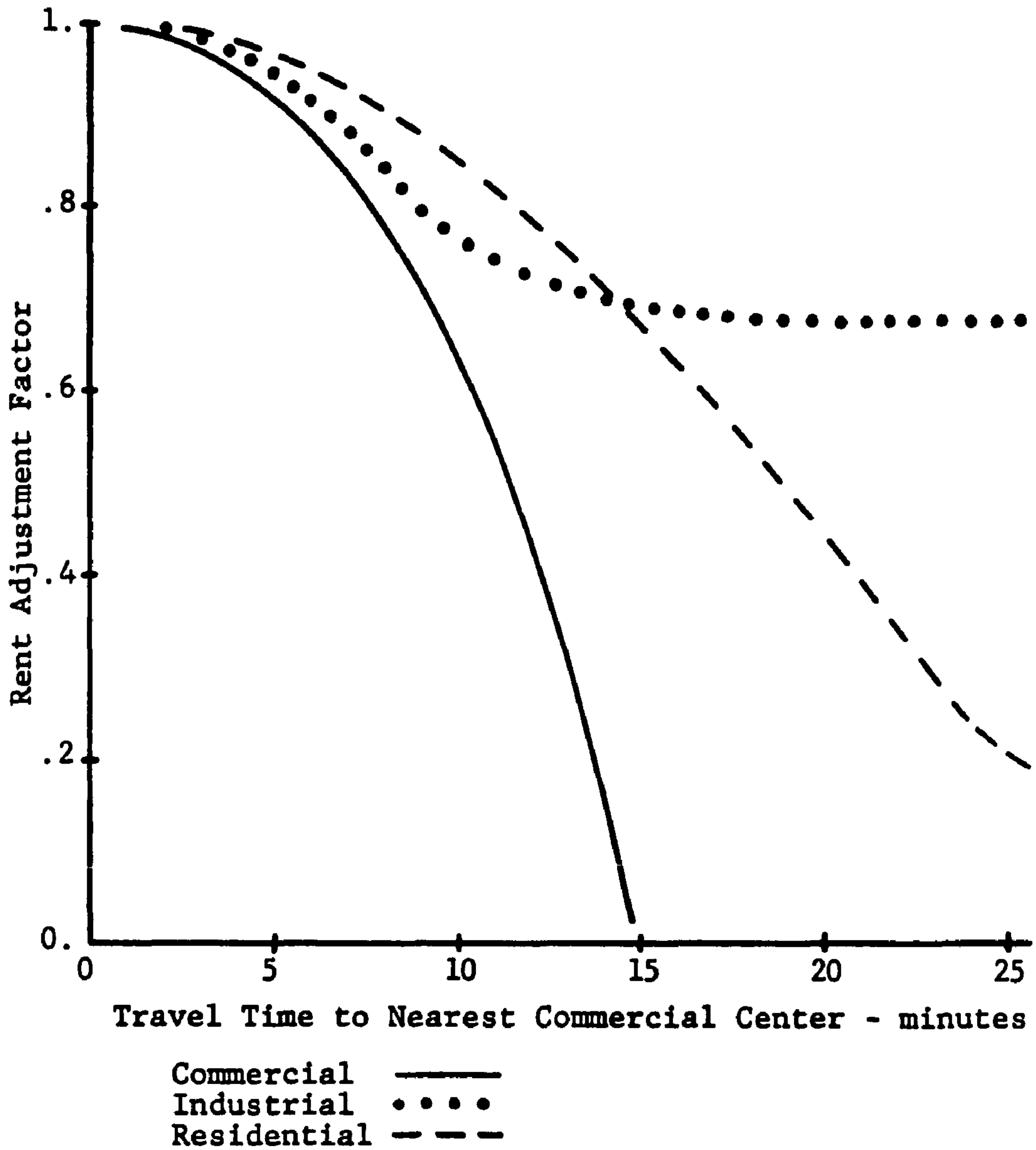


Figure 9. Assumed Impact of Travel Time on Rent

relationships between impact on rent and travel times to commercial centers for commercial, industrial and residential uses. For example Figure 9 indicates that, all other things being equal, the rent for commercial use for a parcel with a ten minute travel time to the nearest existing commercial center could be obtained by multiplying by a factor of .6 the rent for a parcel at the commercial center.

Zoning

Zoning is obviously an important variable for explicit consideration in the model, not only because it reflects existing legal limitations on productivity and/or suitability of a parcel for a use, but also because it is the most obvious tool available to planners and decision makers for attempting to control future land use patterns.

Emmet County has a county wide zoning ordinance which in some cases is superseded by township or city ordinances. Maps indicating zones and the descriptions of those zones for all of these ordinances were obtained from the Emmet County Department of Planning and Zoning (Emmet County Zoning Ordinance, 1977).

Zones were recorded from these maps by overlaying a grid of ten-acre cells on each section of the county. Areas by zones for each section were then used in conjunction with minimum lot sizes and allowable types of dwelling units by zone to yield productivity factors for residential use for each section of the county.

Zoning could also be used through a feature of the model which allows specifying maximum areas that can shift from or to a given use in a given parcel. These constraints on maximum area shifting to a use could be based on limited appropriate zoning for that use in a parcel.

Ownership

As with zoning, ownership has important implications for the availability of a parcel for a given use. Ownership data were collected from the 1975 Emmet County plat book by overlaying a grid of ten-acre cells on each section of the county. The following ownership categories were recognized: private, private-subdivided, state forest, state park, University of Michigan, village-city, other public, and quasi-public.

Again the constraints on maximum area allowed to shift from or to a given use in a given parcel were used to reflect expected limitations imposed by ownership. For example in a parcel well suited to residential development but with all underdeveloped land in the state forest ownership category, no area would be allowed to shift from forest use to residential use unless the constraint was relaxed during the course of the run to reflect a sale or land exchange by the Department of Natural Resources.

Many other land characteristics were or could be considered for explicit recognition in the land use model, indeed, some data for other characteristics than these mentioned above were actually collected, e.g. scenic viewpoints, present and planned sewer service and forest type. That these other characteristics were not ultimately used in the analysis reported here is more a reflection of the limitations of this study (purpose, funds, and time) than an assessment of the importance of these characteristics in influencing land use shifts. Of course the most serious limitation in actually using many of these other factors, and indeed for some of the factors mentioned above that were used, is the lack of documented empirical or quantifiable theorectical relationships indicating the effect of these factors on suitability of land for a given use.

CHAPTER IV. RESULTS AND CONCLUSIONS

This chapter has three distinguishable but interdependent purposes. First, the results of some runs of the model described in Chapter II, employing the data and derivations from those data as described in Chapter III, are presented. But these runs and results are considered, at best, demonstrations of the model rather than serious predictions of future land use in Emmet County. Such a disclaimer leads to the second purpose of this chapter, which is to acknowledge and consider in some detail many shortcomings of the model and its application in this study to Emmet County. Finally, recognition of the continuing problems with this model, or more generally this approach, relates closely to other recent attempts at and literature on land use modeling, as discussed in Chapter I, and leads to some reflections on land use modeling in general and on how experiences in the Emmet County study coincide with those reported from other land use modeling efforts.

Emmet County Analyses and Results

Originally, a number of different runs of the model were contemplated. Once the major model components are initially constructed then a number of variables can be changed with relative ease to yield different projections. Likely candidates for alteration from run to run can be grouped for convenience as policy control variables and variables for which input information is relatively uncertain.

Policy control variables are those which reflect the tools available to regional decision makers for actively influencing economic and land use development. Included in this class might be zoning regulations that are incorporated into the model through the geospecific indexes or constraints. Also included in this class could be public land ownership and public facilities location decisions, again implemented in the model through indexes and constraints, as well as initial land uses. Although not strictly a policy tool, the objective function could be included here as a likely candidate for analysis because of its implications for policy.

There is a great deal of uncertain information, economic and geographic, comprising the data base for this model. A common practice in modeling is sensitivity analysis, which involves selecting variables for which there is considerable uncertainty and varying those values to assess the impacts on important output variables. Given the number and levels of uncertainties in this model countless analyses of this type could be envisioned, but perhaps no variable, or more precisely vector of variables, is more uncertain and at the same time more important to the model than final demands. As explained previously, final demand is the exogenous driver of the economic model, which in turn drives the land requirements and allocation component.

Obviously then, final demand is a prime candidate for alteration from run to run.

It was initially intended to make a series of runs, varying several of the variables mentioned above, i.e. zoning, ownership, objective function, and final demand. The first few runs of the model with the full data base, however, cast doubt on the value of making many of the other runs. These first runs involved different levels of final demand, and perhaps the most notable result of these runs is that even with very optimistic projections of the future rate of economic growth in Emmet County, suitable land and resources to support that growth is not revealed to be constraining.

Following the reasoning presented in Chapter II, the objective function for these analyses was a reflection of after tax profit by sector derived from Internal Revenue Service data (U.S. Treasury Dept., 1979 and U.S. Treasury Dept., 1981).

The first run, which can be considered a base run, was intended to reflect a conservative "business as usual" scenario over the next fifteen years for Emmet County. That is, the model was run with all of the major variables and the structure of the economy held constant over the time horizon, simulating current zoning regulations, current public ownership patterns, and current and planned public facilities and utilities. The major input change from period to period in this run was a modest across the board increase in final demands of five percent per five year period. This rate of growth was based on the most recent available Bureau of the Census projections for population growth in Michigan, reasoning that much of these final demands, e.g. export of intermediate products, would be largely dependent on overall growth in the state.

The final demands and resulting gross outputs by sector over time for this run are displayed in Table 8. A general impression of changing land use over the projection period can be seen in the printer maps of Figure 10, Figure 11, Figure 12, and Figure 13. In these maps proportion of parcel area in developed uses (i.e. commercial, industrial, and residential) is used as an index to provide an overall impression of the trends in land use over time. The divisions between intensity levels displayed on the maps are somewhat arbitrary and are simply intended to provide some contrast between totally developed, less developed, and virtually undeveloped areas. At this rate of economic growth not much change is detected in this index over this series of maps. As would be expected, those that do show movement from one category to the next are in the southern portion of the county, near current commercial and industrial centers and along major transport routes.

The maps in Figure 14, Figure 15, Figure 16, Figure 17, and Figure 18 reveal changes in land allocated to specific uses not revealed in the preceeding series of

Table 8. Initial and Projected Final Demand and Gross Outputs for the First Run (Thousands of Dollars)

Sector	Current Final Demand	Current Gross Output	Period 1 Final Demand	Period 1 Gross Output	Period 2 Final Demand	Period 2 Gross Output	Period 3 Final Demand	Period 3 Gross Output
Agriculture	1929	5495	2028	5784	2134	6087	2232	6366
Construction	20251	24215	21292	25490	22412	26831	23434	20055
Wood Products Furniture Manufacture	2643	4105	2779	4321	2925	4548	3059	4756
Cement & Concrete Products Manufacture	10551	13893	11093	14624	11676	15393	12209	16095
Electrical & Transportation Equipment Manufacture	9441	9434	9930	9930	10452	10452	10929	10929
Primary Metal & Metal Fabrication	3682	4331	3871	4559	4075	4799	4261	5019
Nondurable Manufacture	3344	5979	3516	6294	3701	6625	3870	6928
Transportation, Utilities, Communication	910	15670	956	16495	1007	17363	1053	18155
Wholesale & Retail Trade	11195	41610	11771	43800	12390	46104	12955	48207
Finance, Insurance & Real Estate	4491	24487	4722	25776	4970	27132	5197	28369
Lodging & Amusement Services	7350	10279	7728	10820	8135	11389	8506	11909
Medical Services	26465	33538	27826	35303	29289	37159	30625	38854
Other Services	3045	17320	3202	18232	3370	19190	3524	20066
Endogenous Government	346	2743	364	2887	383	3039	400	3177
Households	37174	116570	39085	122706	41141	129159	43017	135051

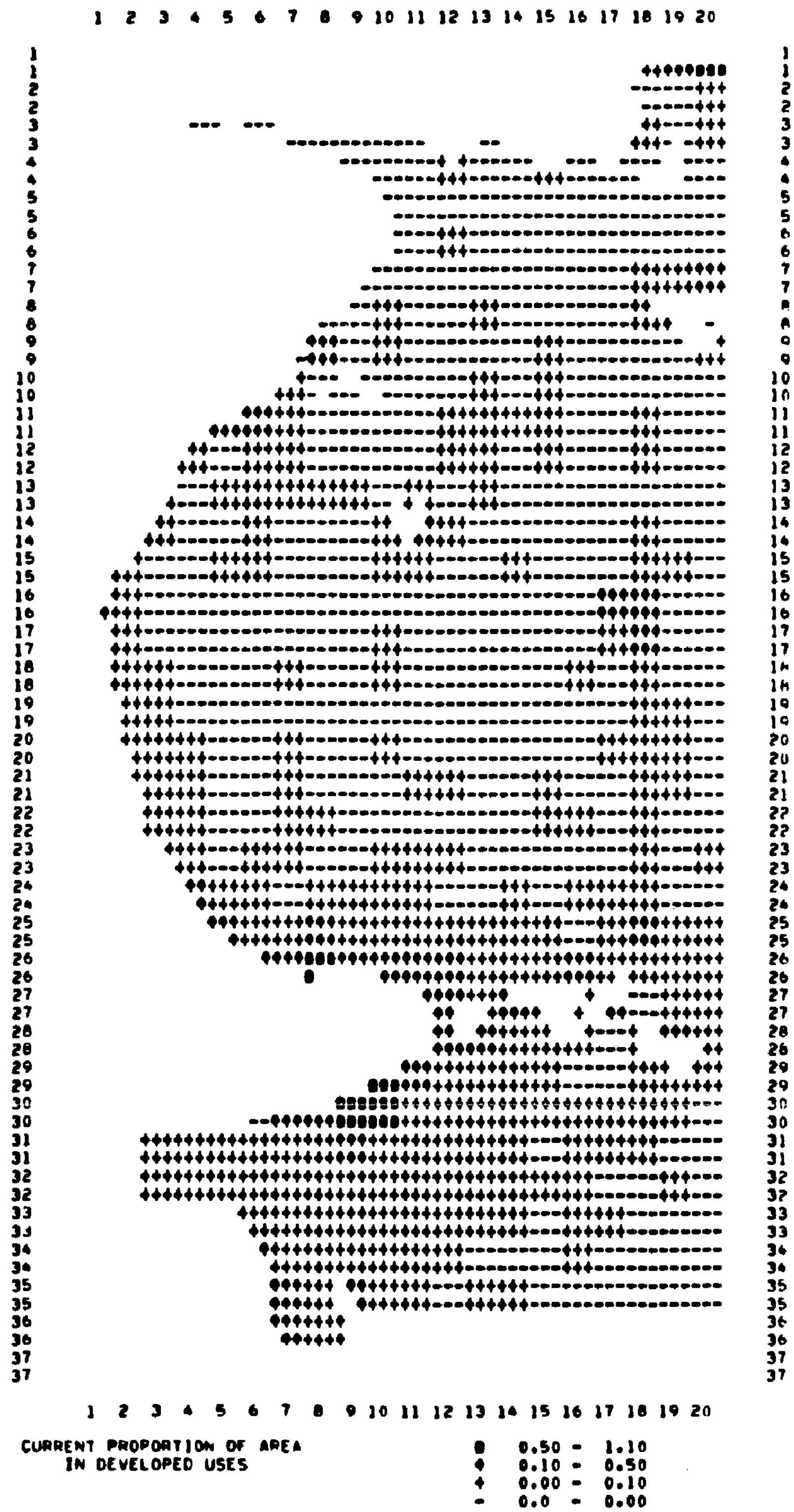
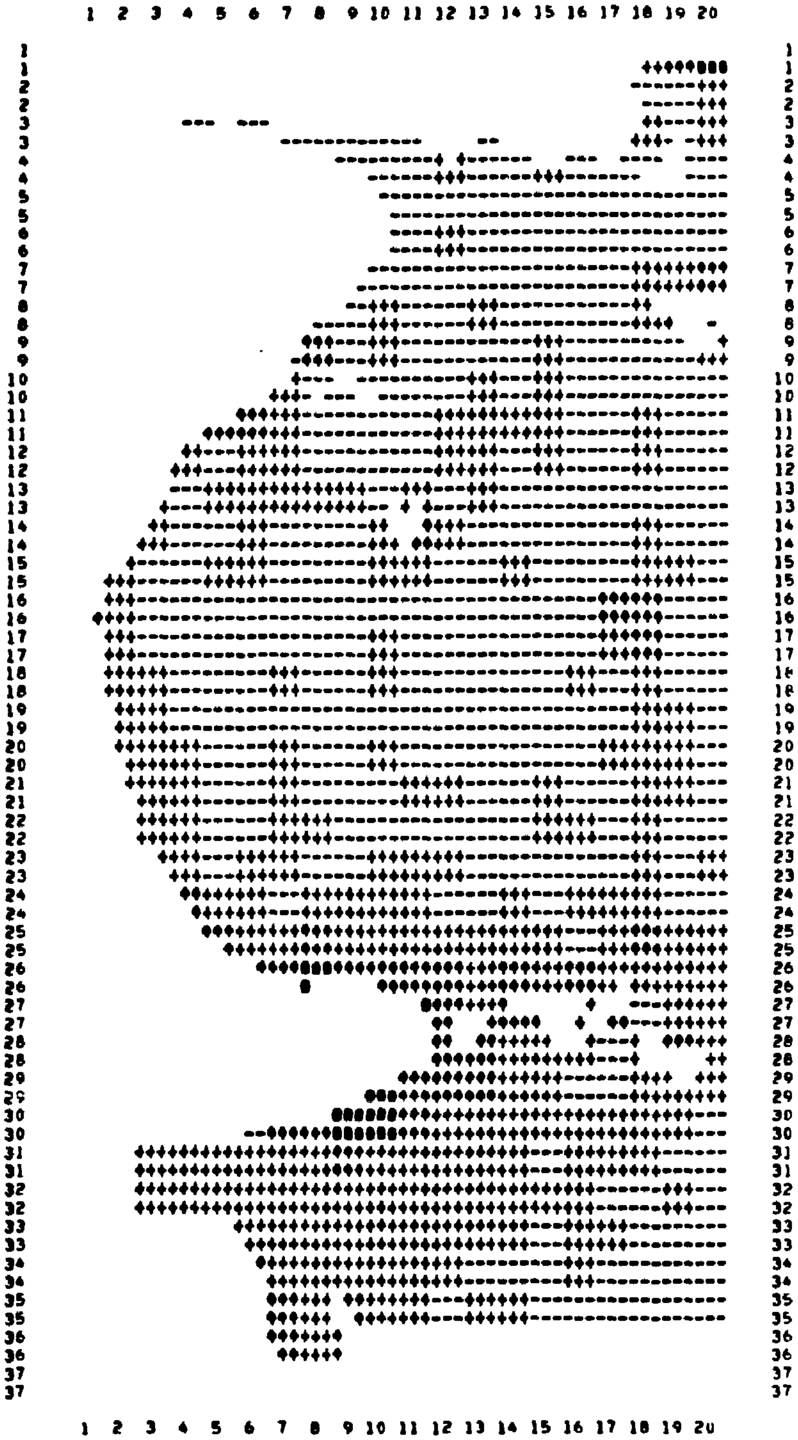


Figure 10. Current Proportion of Area in Developed Uses



PROJECTED PROPORTION OF AREA
IN DEVELOPED USES
RUN #1 - PERIOD 1

● 0.50 - 1.10
♦ 0.10 - 0.50
+ 0.00 - 0.10
- 0.0 - 0.00

Figure 11. Projected Proportion of Area in Developed Uses, Run 1, Period 1

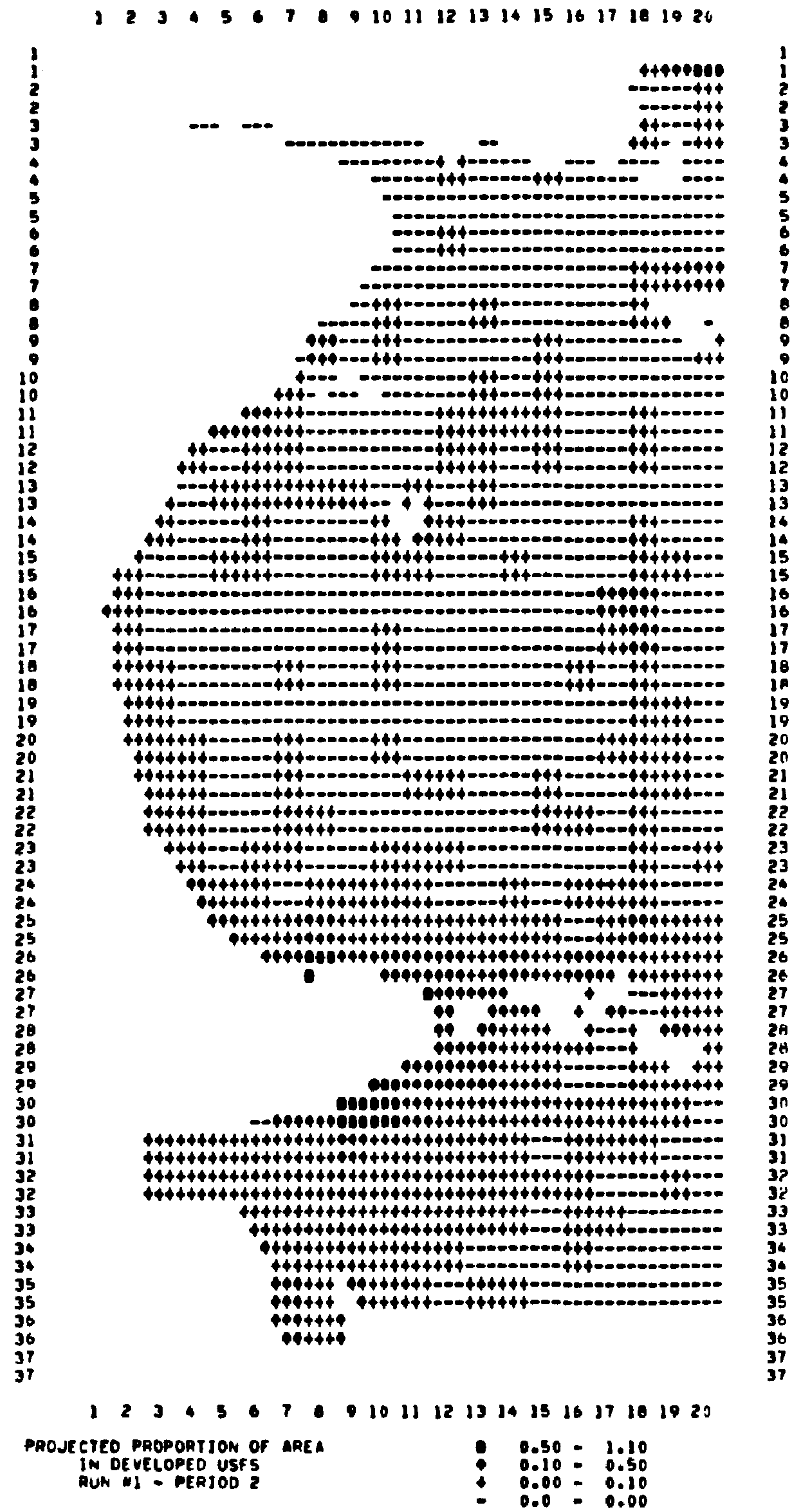


Figure 12. Projected Proportion of Area in Developed Uses, Run 1, Period 2

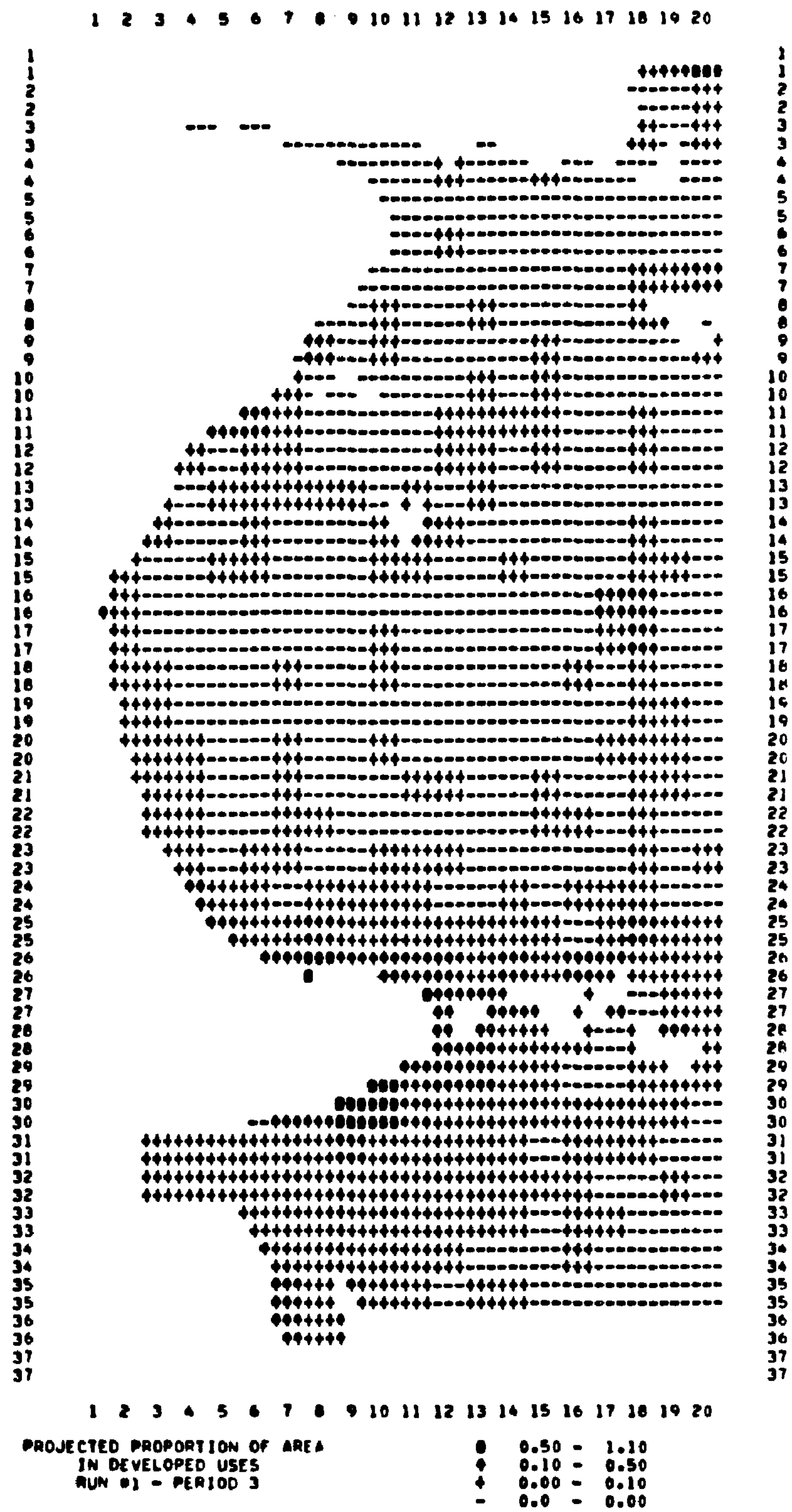


Figure 13. Projected Proportion of Area in Developed Uses, Run 1, Period 3

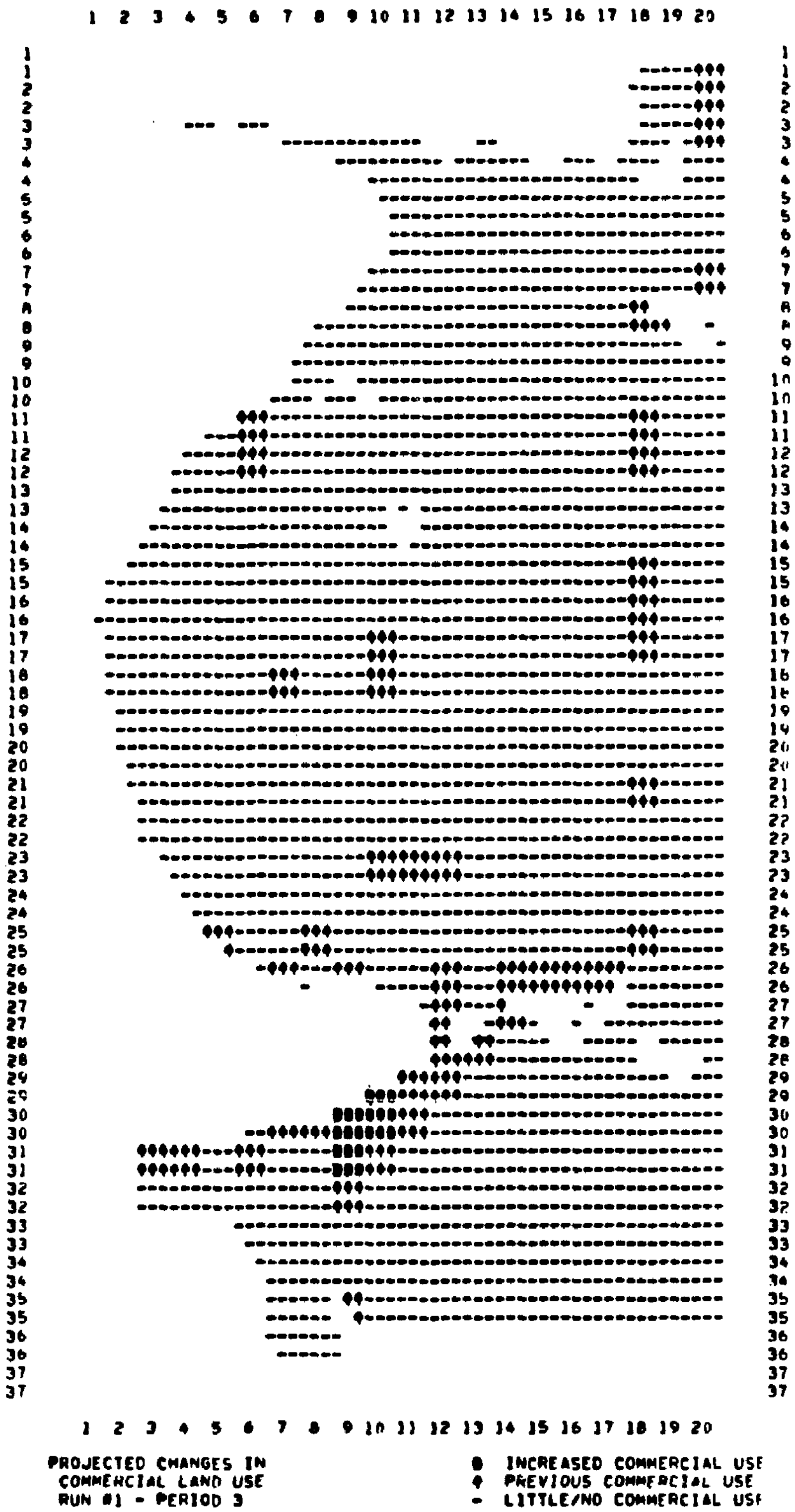


Figure 14. Projected Changes in Commercial Use, Run 1, Period 3

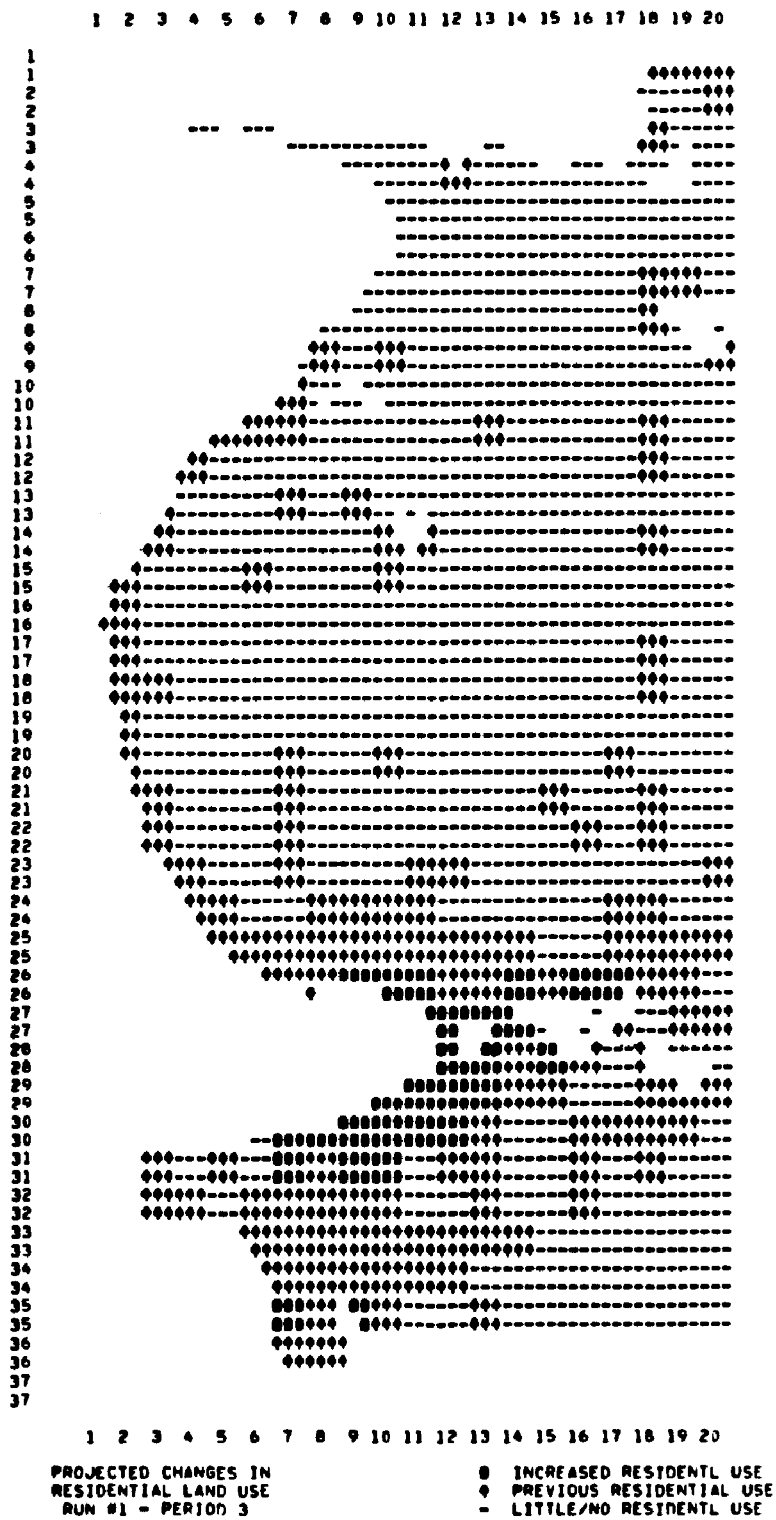


Figure 15. Projected Changes in Residential Use, Run 1, Period 3

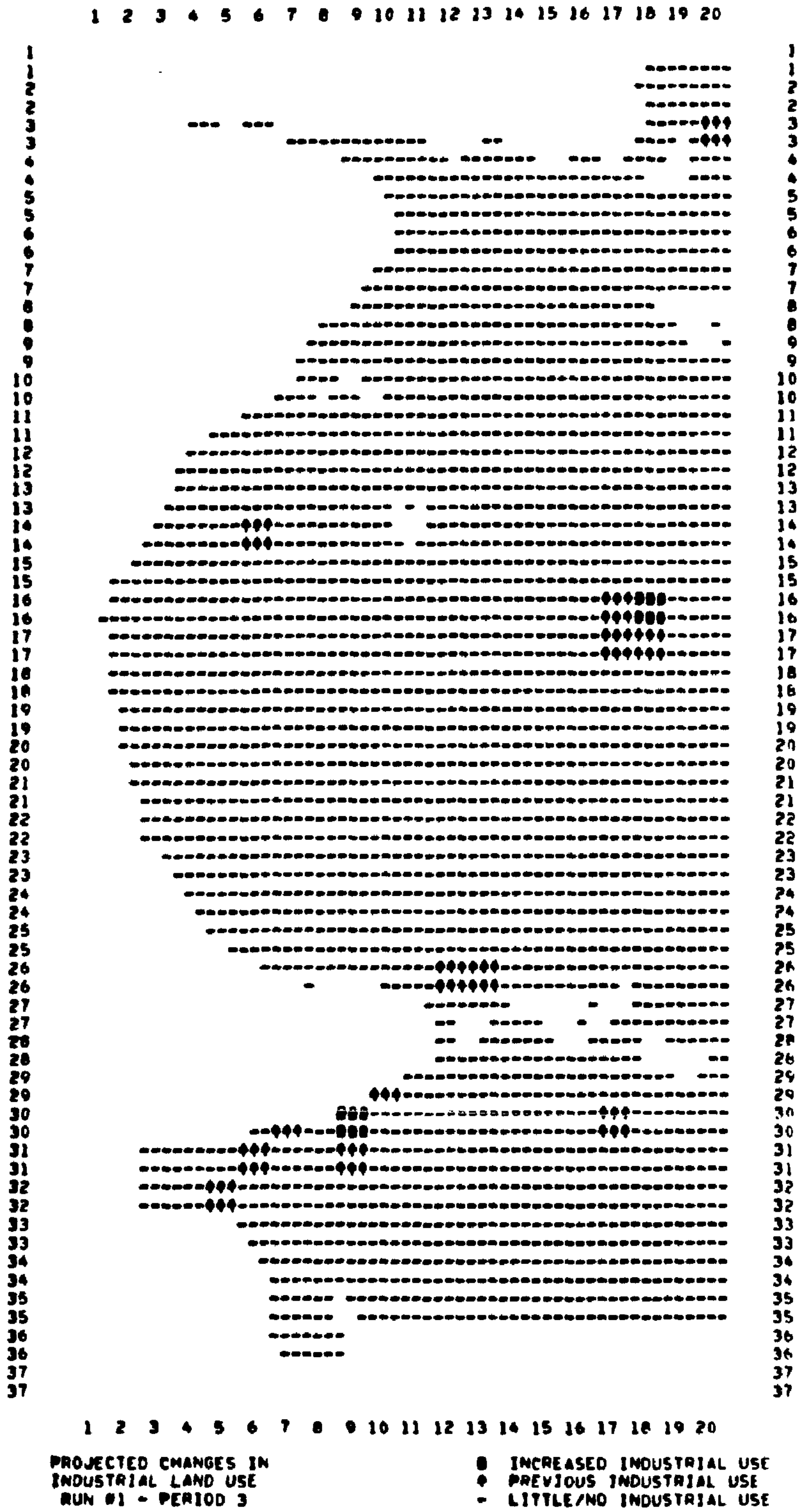


Figure 16. Projected Changes in Industrial Use, Run 1, Period 3

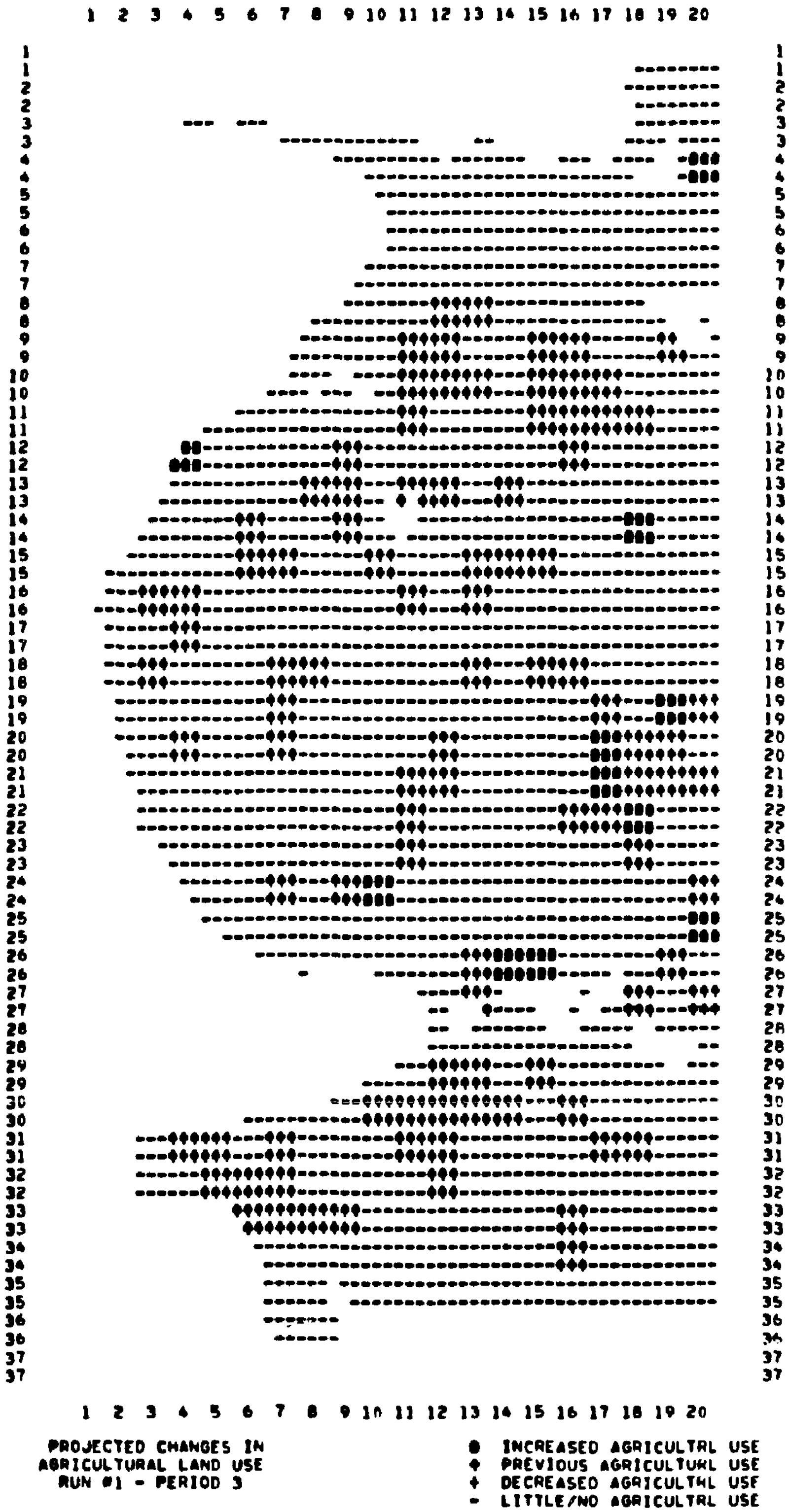


Figure 17. Projected Changes in Agricultural Use, Run 1, Period 3

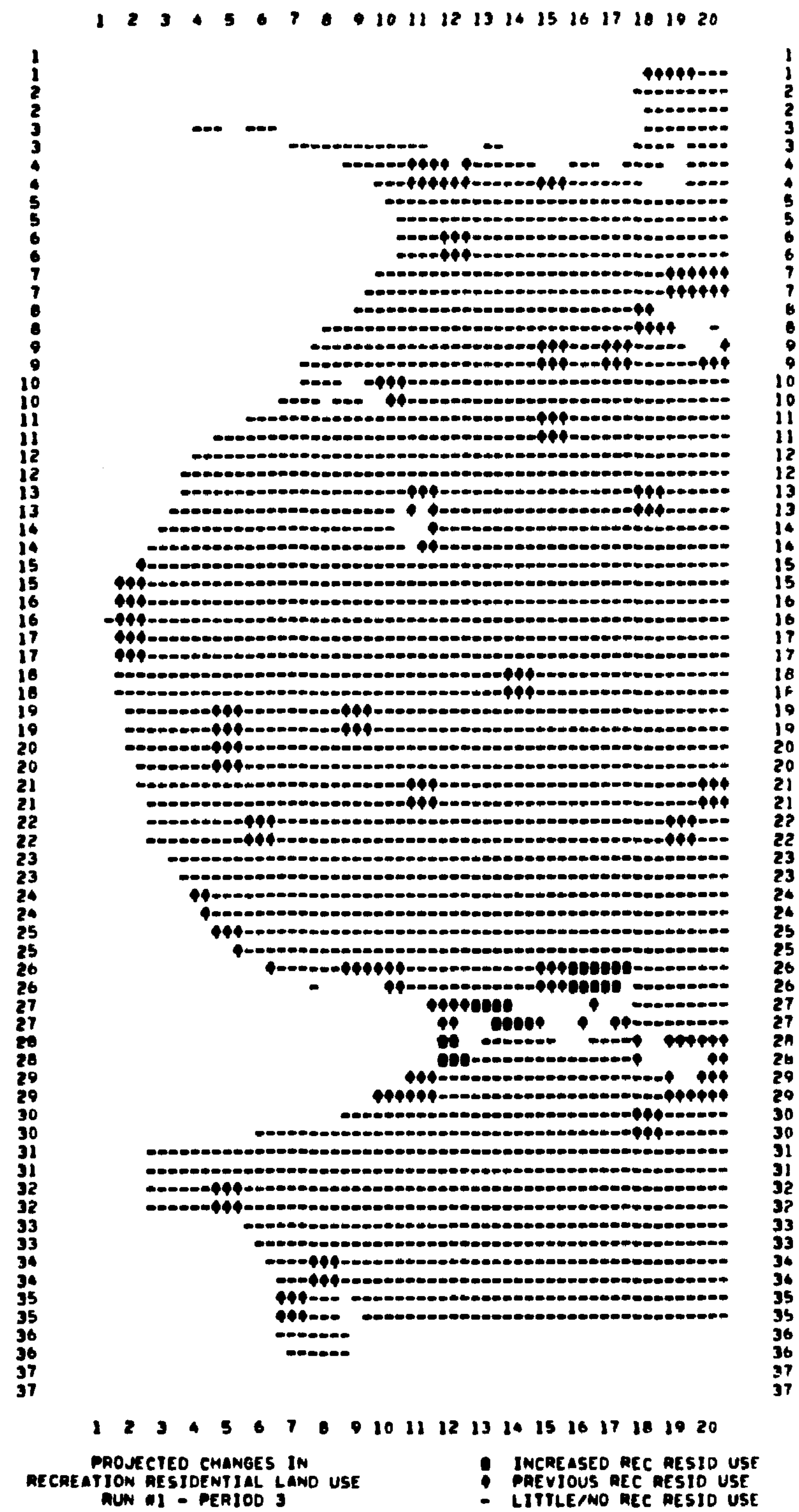


Figure 18. Projected Changes in Recreation Residential Use, Run 1, Period 3

maps. Again intensification of commercial use in or near those parcels already containing significant commercial use and increasing residential use in several parcels, predominantly east and northeast of Petoskey and in the Harbor Springs area are indicated and would be expected. A somewhat striking absence of further development in other parts of the county is suggested by this series of maps. More will be said about this result in the next section.

Independent of the question of distribution of future development, an important result from this run is that the total level of future development is such as to not strain the supply of suitable land for any of the various uses, at least to an extent that is detectable by this model in conjunction with this data base. This leads to some serious questions about the effectiveness of the model for its intended purpose, and these also will be considered in the following section. It also leads to the question of whether such a result holds true for substantially higher rates of economic growth.

It is not difficult to justify consideration of higher rates of economic growth for Emmet County. First of all, in the last two decades Emmet County has had a higher population growth rate than Michigan in general. Secondly, but more importantly, historic real economic growth in the United States has been much higher than population growth rates. Following this reasoning, a second run was executed with final demands established in order to result in gross output growth rates that approximate the costant dollar growth in contribution to gross domestic product by sector during the 1970's. The real economic growth rate had been about 3.4 percent per year or about 18 percent per five year period (based on data from the U.S. Dept. of Commerce, Bureau of Economic Analysis reported in the Economic Report of the President, 1981, p. 245) as opposed to the five percent per five year period used for the first run. So economic growth and corresponding land use requirements are substantially higher for this second run.

The final demands and resulting gross outputs by sector from this second run are shown in Table 9. Again proportion of parcel area in developed uses is used as an index to indicate overall land use trends in the printer maps of Figure 19, Figure 20, and Figure 21 for this run. Again, increased developed use east and northeast of Petoskey is indicated, but is even more pronounced, and contrary to the previous run, by the third period (Figure 21) noticeable development also occurs south and west of Petoskey, in Harbor Springs, and north along Highway 31 at Pellston, Levering, Paradise Lake, and Mackinaw City.

Projected changes in commercial use are displayed in Figure 22. The pattern observed reflects the overall development trends seen in the preceeding series of figures, with most of the increase occurring in and around Petoskey but with some also in Harbor Springs, north along Highway 31, and even some, perhaps questionably, in Cross

Table 9. Projected Final Demands and Gross Outputs for the Second Run (Thousands of Dollars)

Sector	Period 1 Final Demand	Period 1 Gross Output	Period 2 Final Demand	Period 2 Gross Output	Period 3 Final Demand	Period 3 Gross Output
Agriculture	1929	5953	1929	6515	1929	7213
Construction	20251	25060	20251	26088	20251	27376
Wood Products Furniture Manufacture	2935	4530	3238	4980	3567	5480
Cement & Concrete Products Manufacture	11677	15330	12919	16911	14279	18622
Electrical & Transportation Equipment Manufacture	11783	11783	14717	14717	18382	18382
Primary Metal & Metal Fabrication	4041	4804	4433	5326	4857	5909
Nondurable Manufacture	3920	7071	4590	8375	5366	9938
Transportation, Utilities, Communication	2549	19639	4742	24699	7634	31135
Wholesale & Retail Trade	15257	49681	20210	59532	26258	71617
Finance, Insurance & Real Estate	7597	30499	11666	38133	16946	47816
Lodging & Amusement Services	9120	12504	11301	15233	13974	18582
Medical Services	32696	40778	40361	49643	49736	60495
Other Services	4804	21212	7058	26075	9099	32153
Endogenous Government	346	3234	346	3846	346	4613
Households	37174	131280	37174	149295	37174	171494

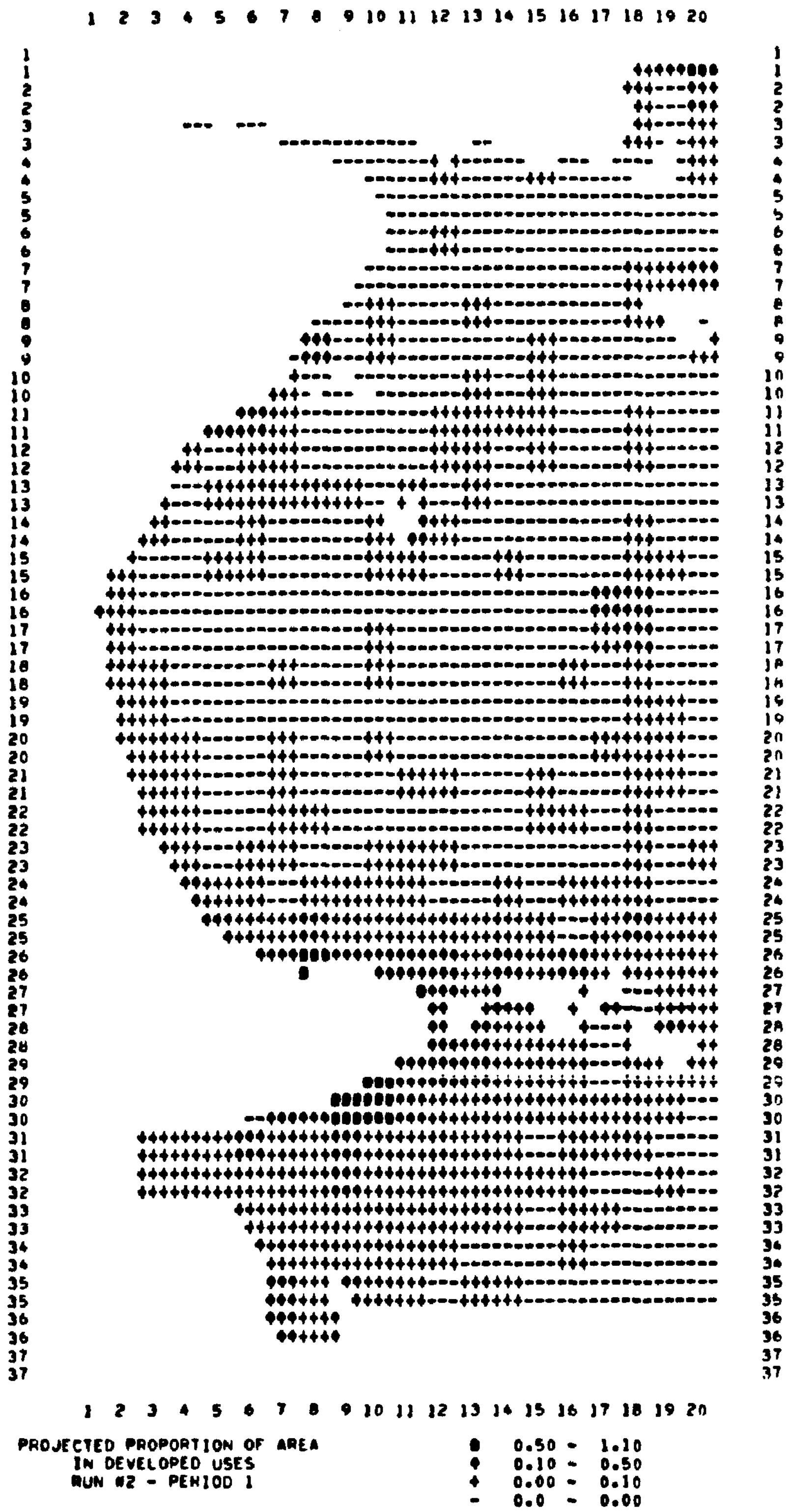


Figure 19. Projected Proportion of Area in Developed Uses, Run 2, Period 1

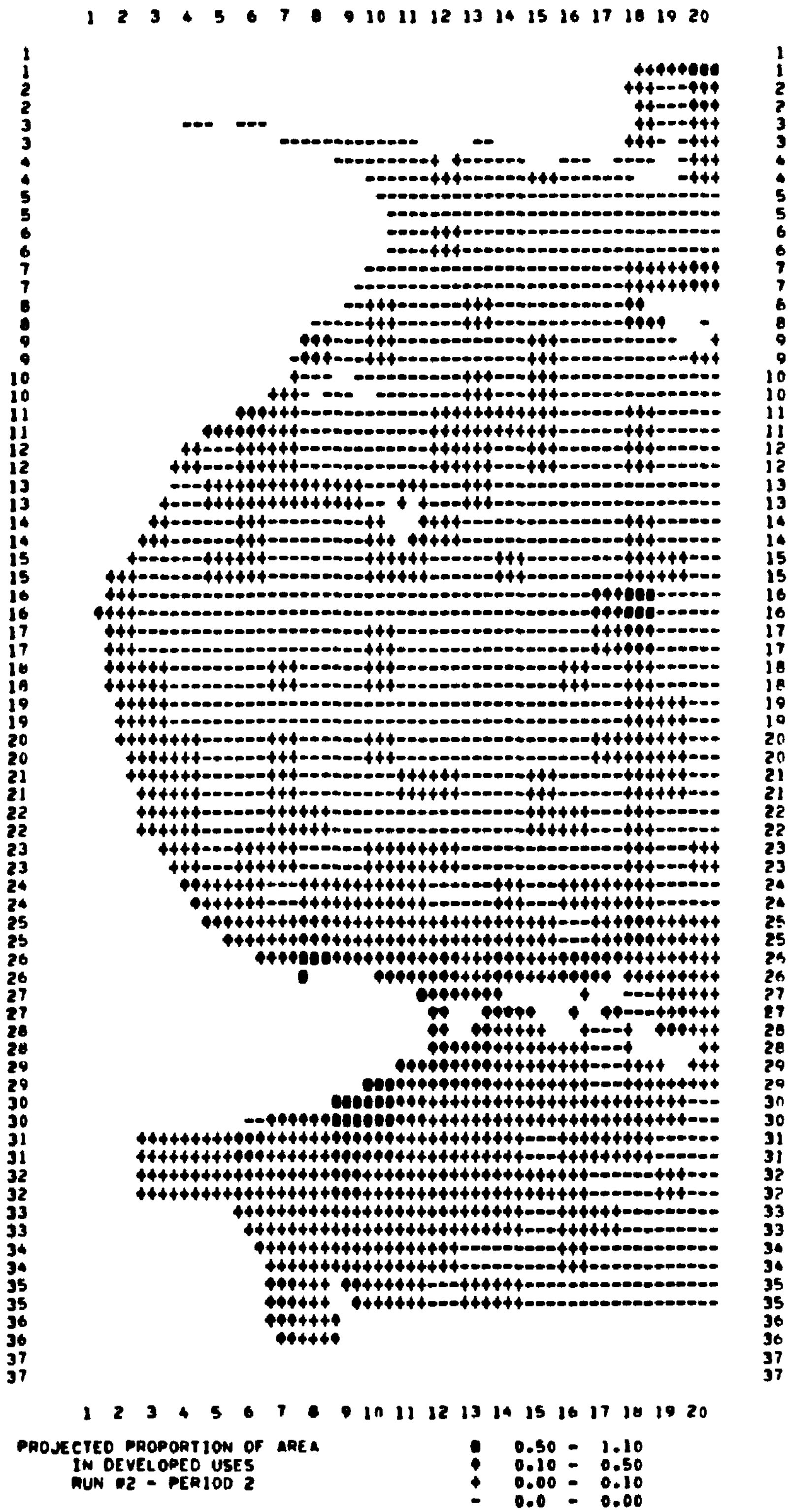


Figure 20. Projected Proportion of Area in Developed Uses, Run 2 Period 2

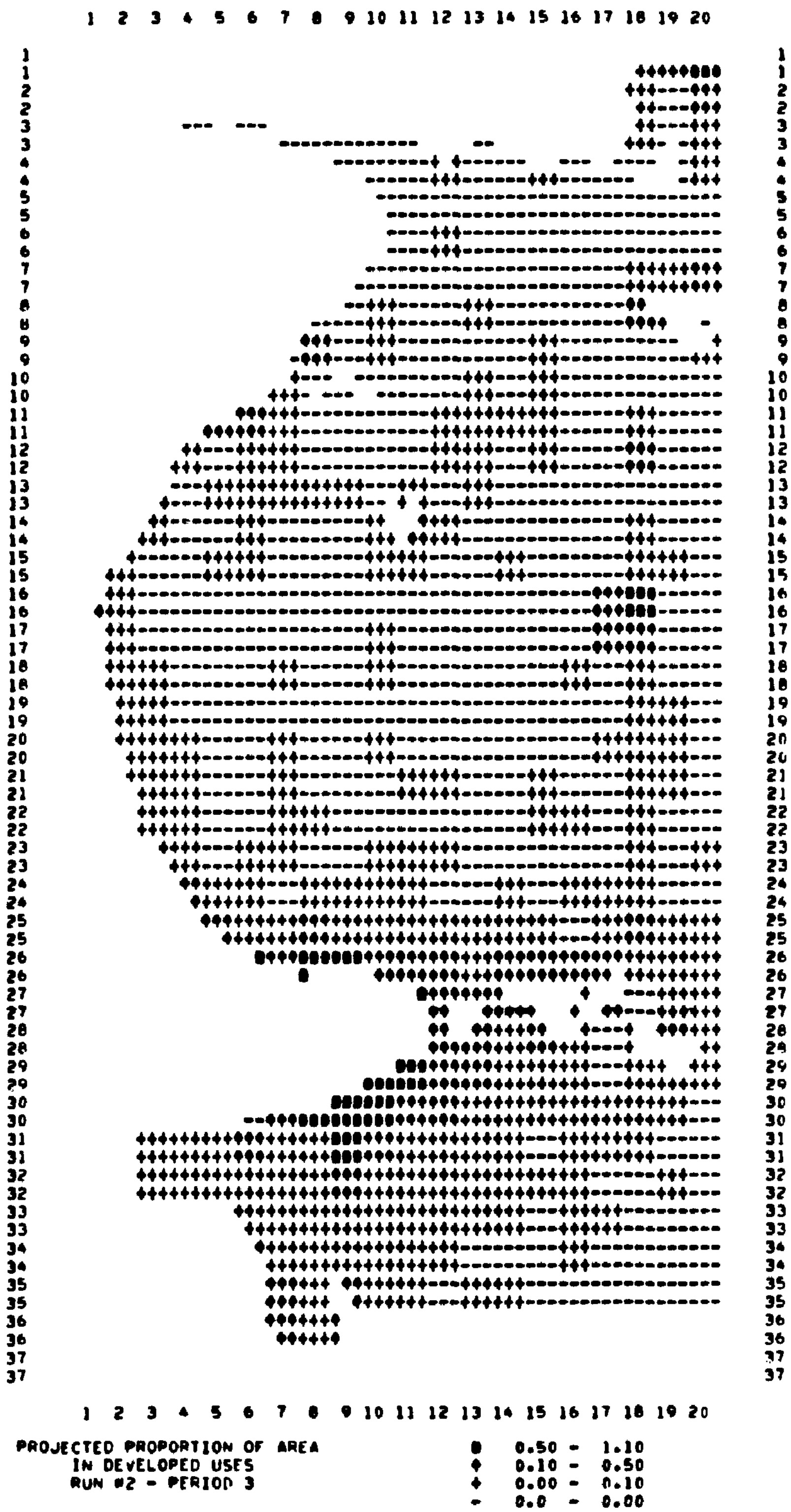


Figure 21. Projected Proportion of Area in Developed Uses, Run 2, Period 3

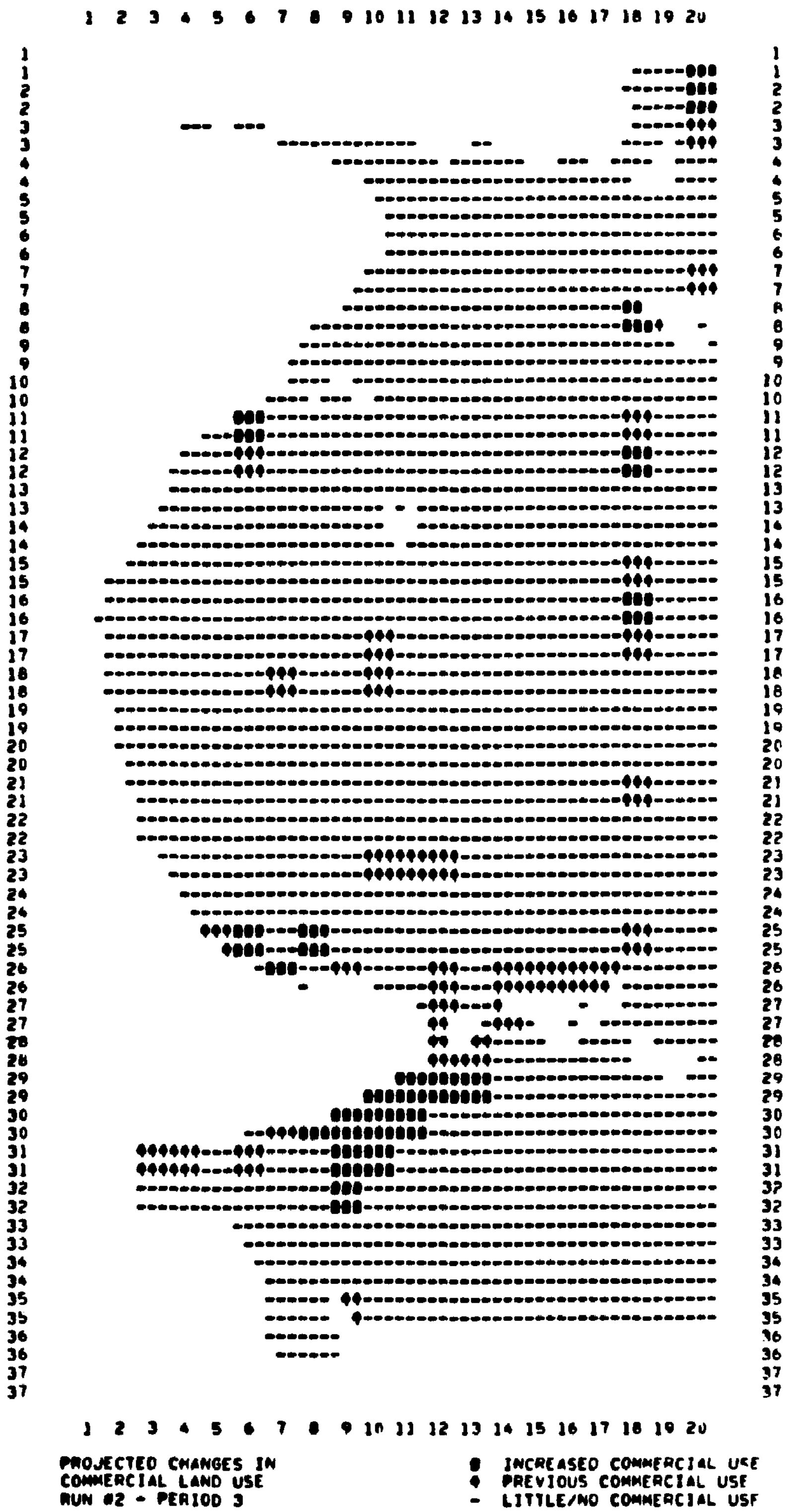


Figure 22. Projected Changes in Commercial Use, Run 2, Period 3

Village. Figure 23 displays projected changes in residential use, indicating increases west and south of Petoskey, as well within the town itself, east and north to Harbor Springs, and northeast along the highway. Given the industrial park at Pellston and current locations of industrial use, the projected increases in industrial use shown in Figure 24 seem reasonable, except perhaps for that at Levering. Projected increases in agricultural use are are shown in Figure 25 and should be compared to the map of soil productivity for agricultural use of Figure 6 in Chapter III. Notice in Figure 25 that no shifts out of agricultural use occur, indicating that additional area needed for other uses over time through this run is coming out of the forest and open category. Figure 26 shows projected changes in seasonal home land use for this run.

Again, even with these very optimistic assumptions about economic growth, suitable land is not revealed to be constraining for any use. However, potential for intensification of what might be conflicting uses within close proximity is suggested by the individual use maps of Figure 22, Figure 23, and Figure 24. Central and south central Petoskey (column 9, rows 30, 31, and 32) is indicated as an area that is likely to experience intensified commercial, residential, and industrial use.

Since neither of these first two runs encountered constraints due to insufficient suitable area, a final run was

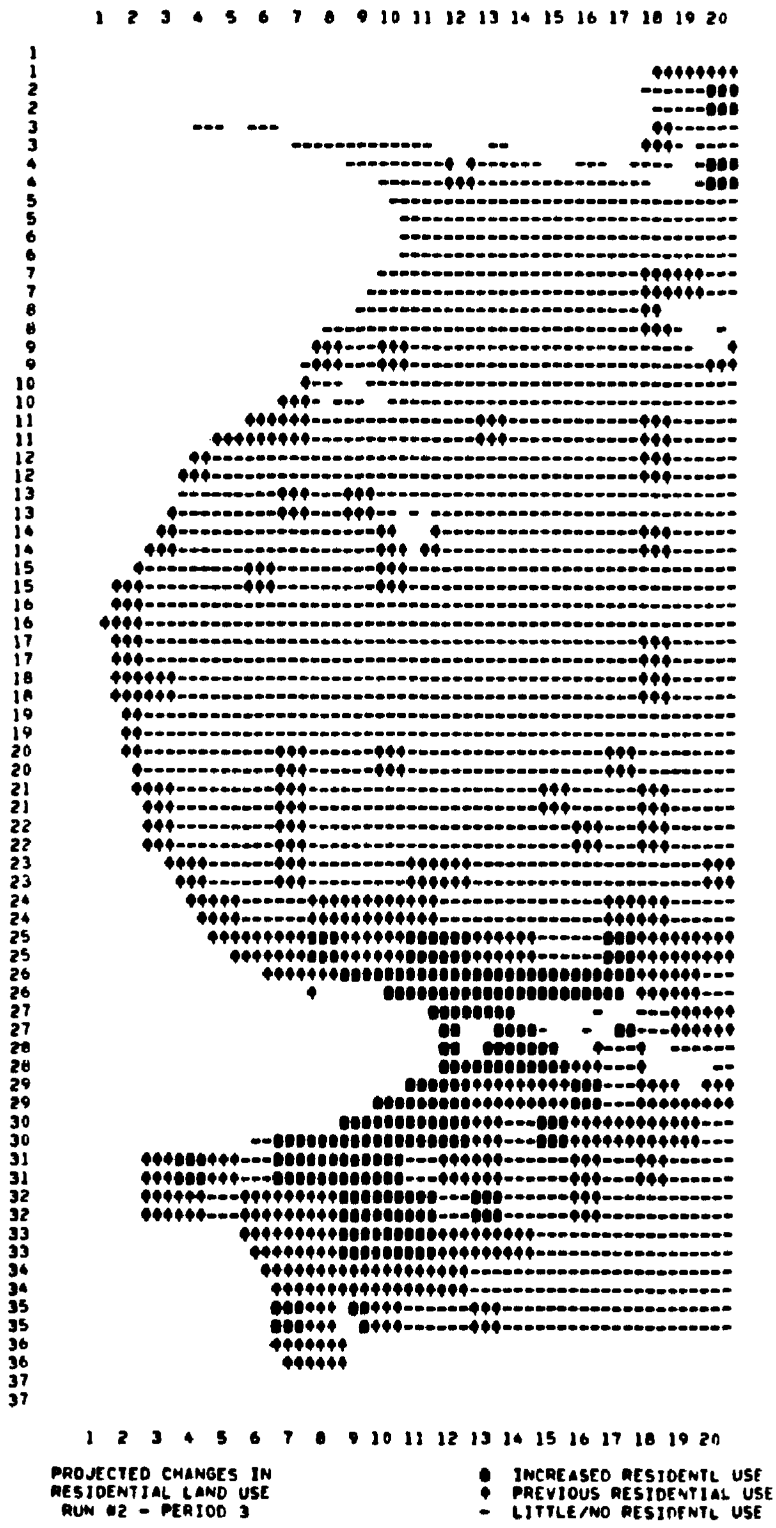


Figure 23. Projected Changes in Residential Use, Run 2, Period 3

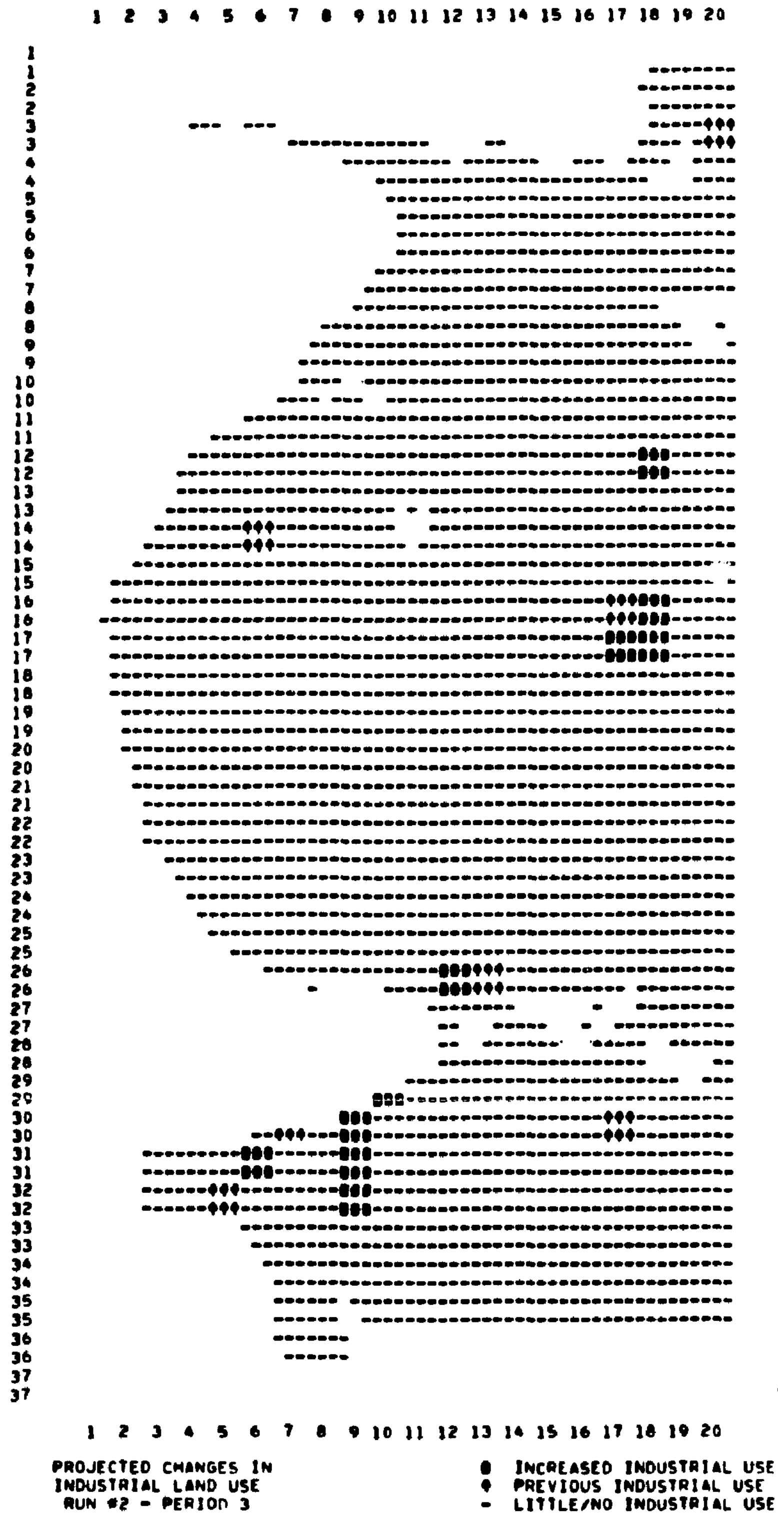


Figure 24. Projected Changes in Industrial Use, Run 2, Period 3

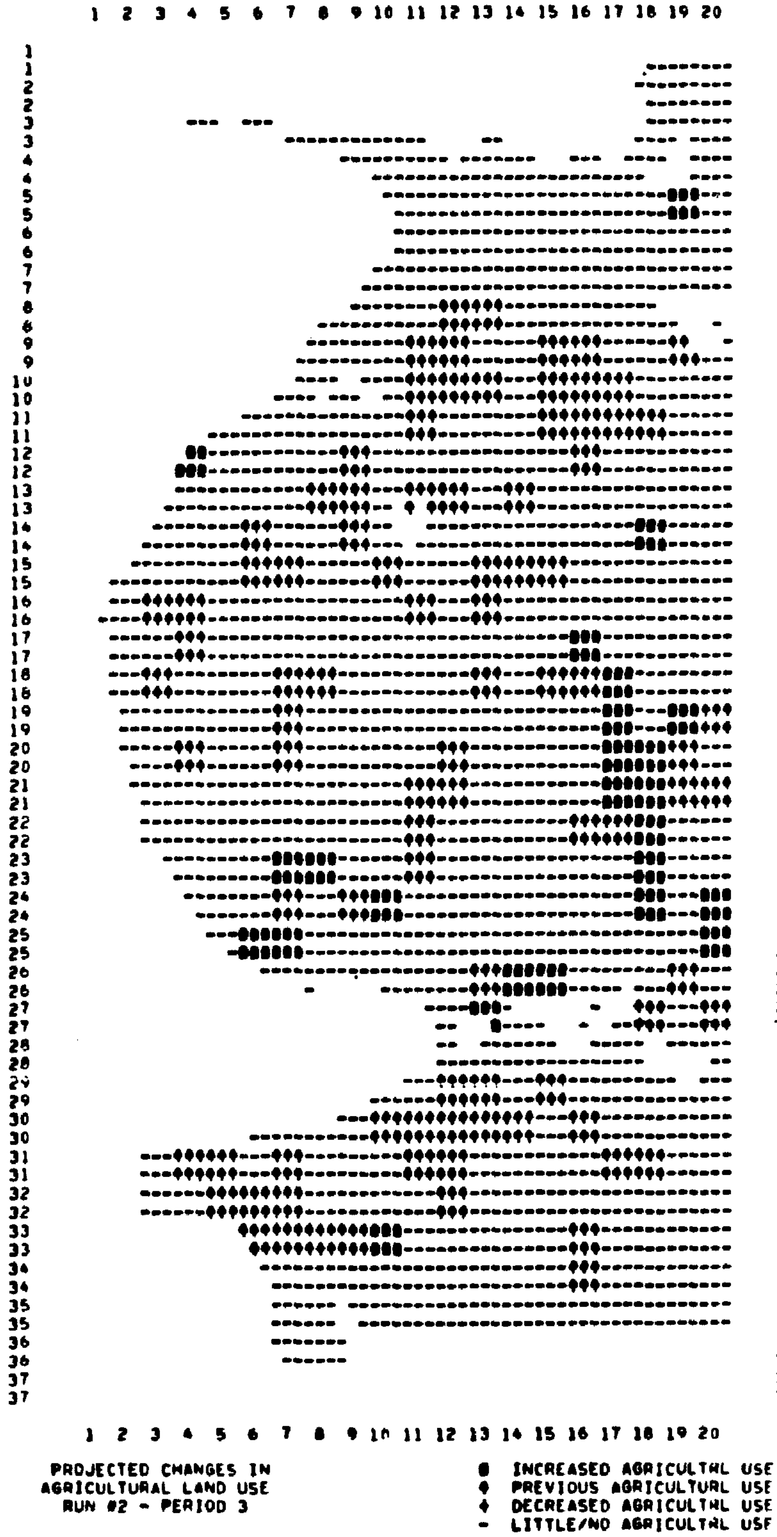


Figure 25. Projected Changes in Agricultural Use, Run 2, Period 3

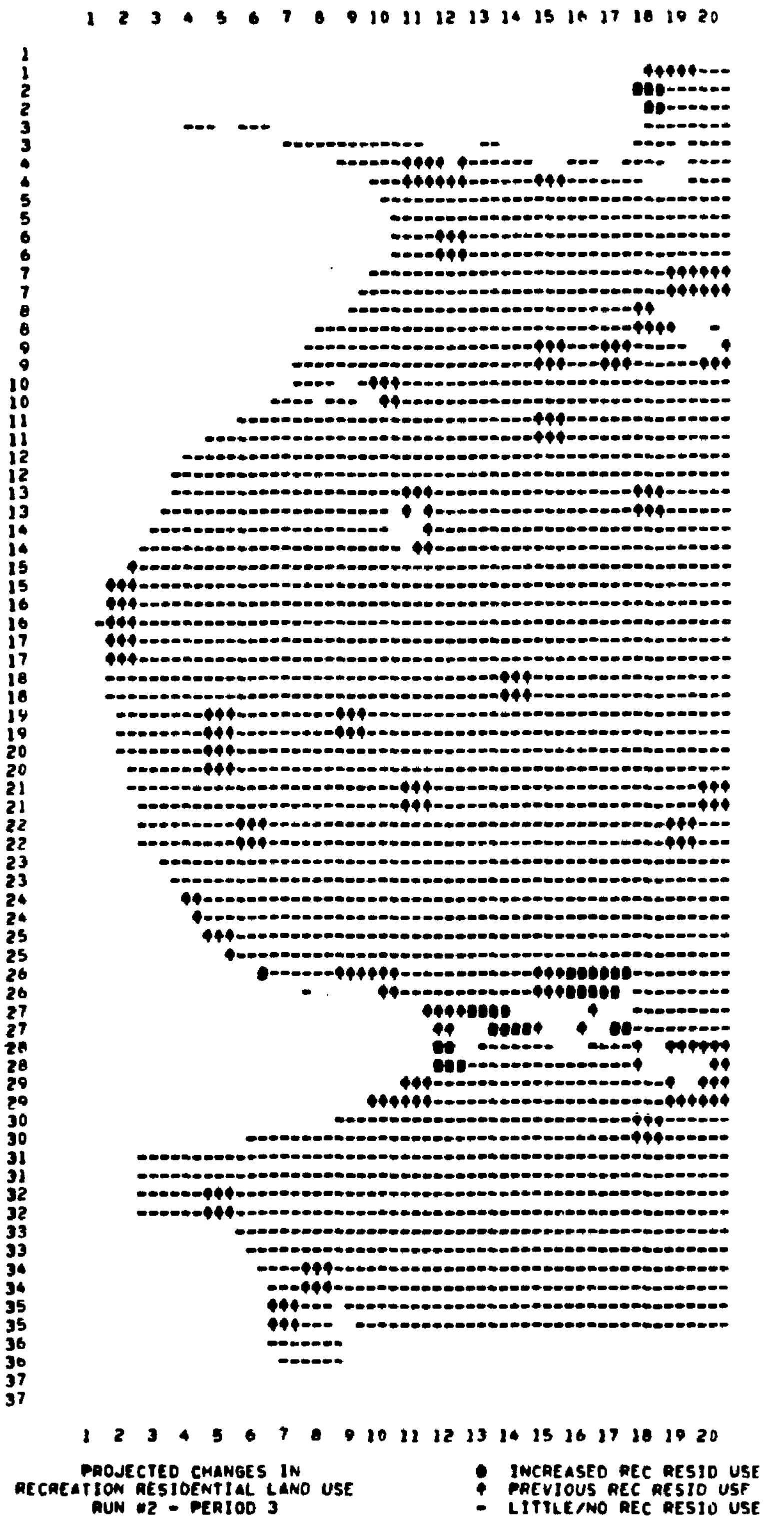


Figure 26. Projected Changes in Recreation Residential Use, Run 2, Period 3

set up largely as a demonstration of how the model reacts when suitable land does become constraining.

When this study began, it was suggested that Emmet County's rich resource base had potential for alleviating some persistent economic disparities. Timber is one resource in the county that is substantially underutilized according to a Michigan Department of Natural Resources study (Pfeifer and Spencer). The scenario for this third run involved increasing the wood products industry to the point of full utilization of the timber producing potential of the current 182,700 acres of commercial forest land in the county. The DNR study also provided an estimate of the sustainable annual harvest from that commercial forest land.

Final demands for this run were the same as for the second run, except for the wood products sector whose final demands were increased so that by the third period gross output for that sector would be such that requirements for timber producing forest land would exceed availability of suitable land. A crude assumption about the current use by the wood products sector of timber from within versus timber from outside of Emmet County was made based on ratios of forest based employment and timber harvests for the county and for the United States (USDA Forest Service, 1980). An assumption was made that future increases in the wood products sector would be entirely dependent on increased timber production within the county. This assumption implies a changing ratio of wood products sector gross output dollars to acres required for timber production within the county, and so was simulated by increasing the appropriate land use requirements coefficient each period through the run. That coefficient was calculated on the basis of sufficient acreage to provide on a sustained yield basis the annual harvests implied by the level of wood products sector gross output.

Figure 27 shows a map of the index of developed use for the third period of this run. When compared to the corresponding map for the second run (Figure 21) the only noticeable difference is lower levels of developed use in some of the parcels south of Petoskey. The maps of Figure 28 , Figure 29, Figure 30, and Figure 31 reflect the expanding and intensifying use of forest land for timber production through time in this run in terms of proportion of parcel area devoted to timber production.

Table 10 shows the final demands and implied gross outputs for the wood products sector by period that were inputs for this run. Table 11 shows final demand inputs and implied (unconstrained) gross outputs versus the constrained final demands and outputs by sector for the third period of this run. Notice that only the wood products sector is constrained by resources from meeting the projected maximum final demand, but gross output for

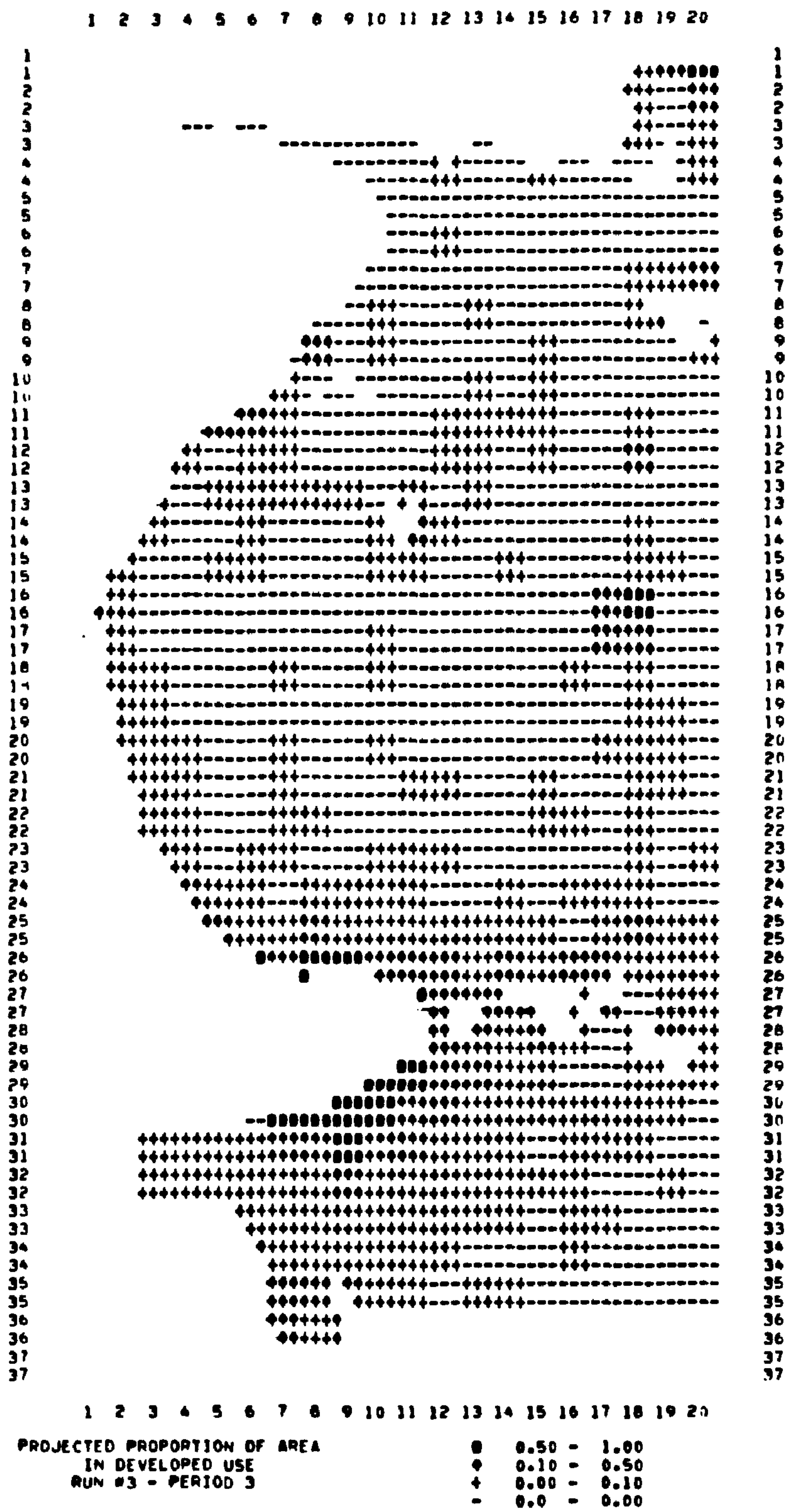


Figure 27. Projected Proportion of Area in Developed Uses, Run 3, Period 3

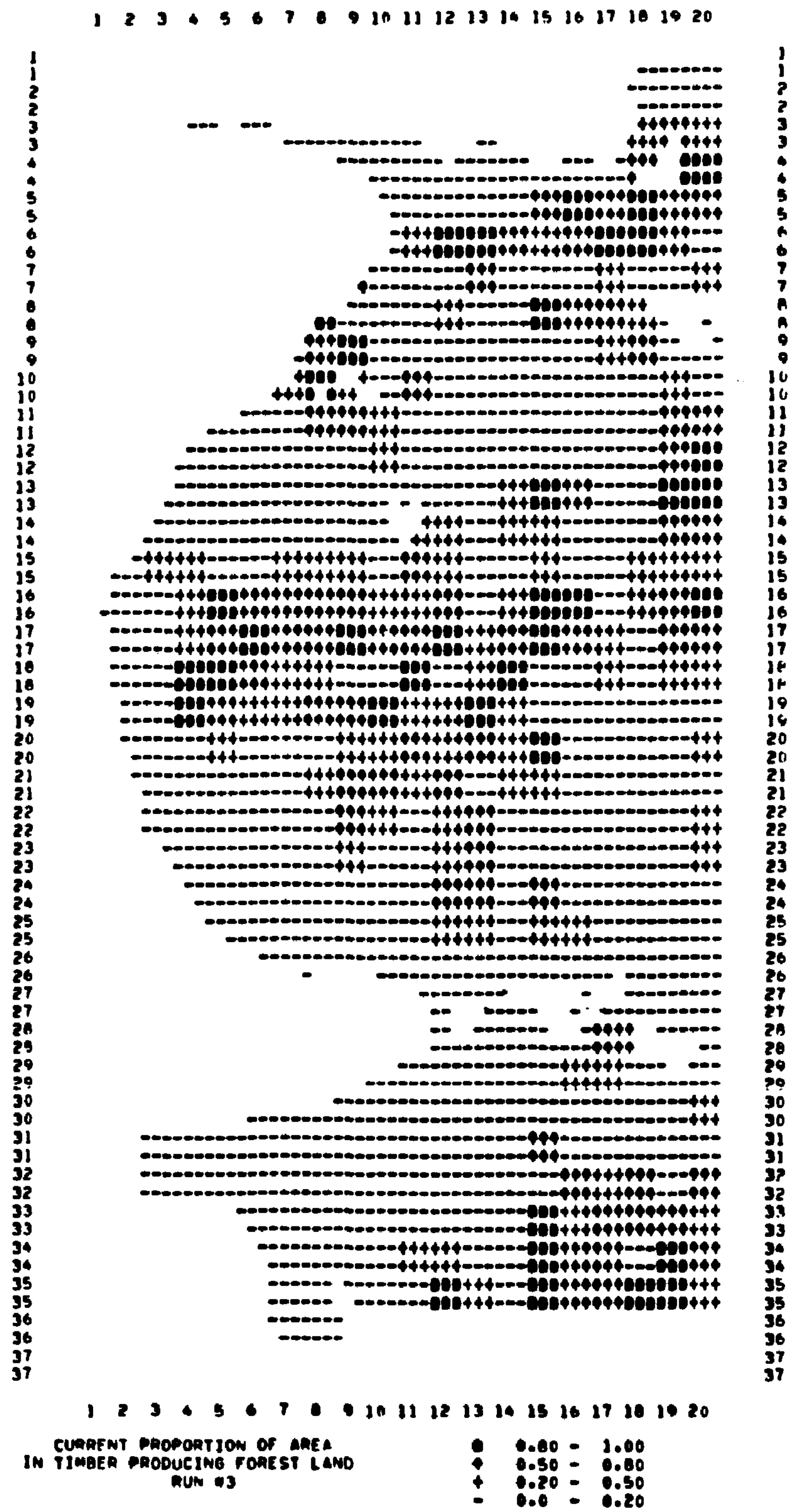


Figure 28. Assumed Current Proportion of Area in Timber Prodaution, Run 3

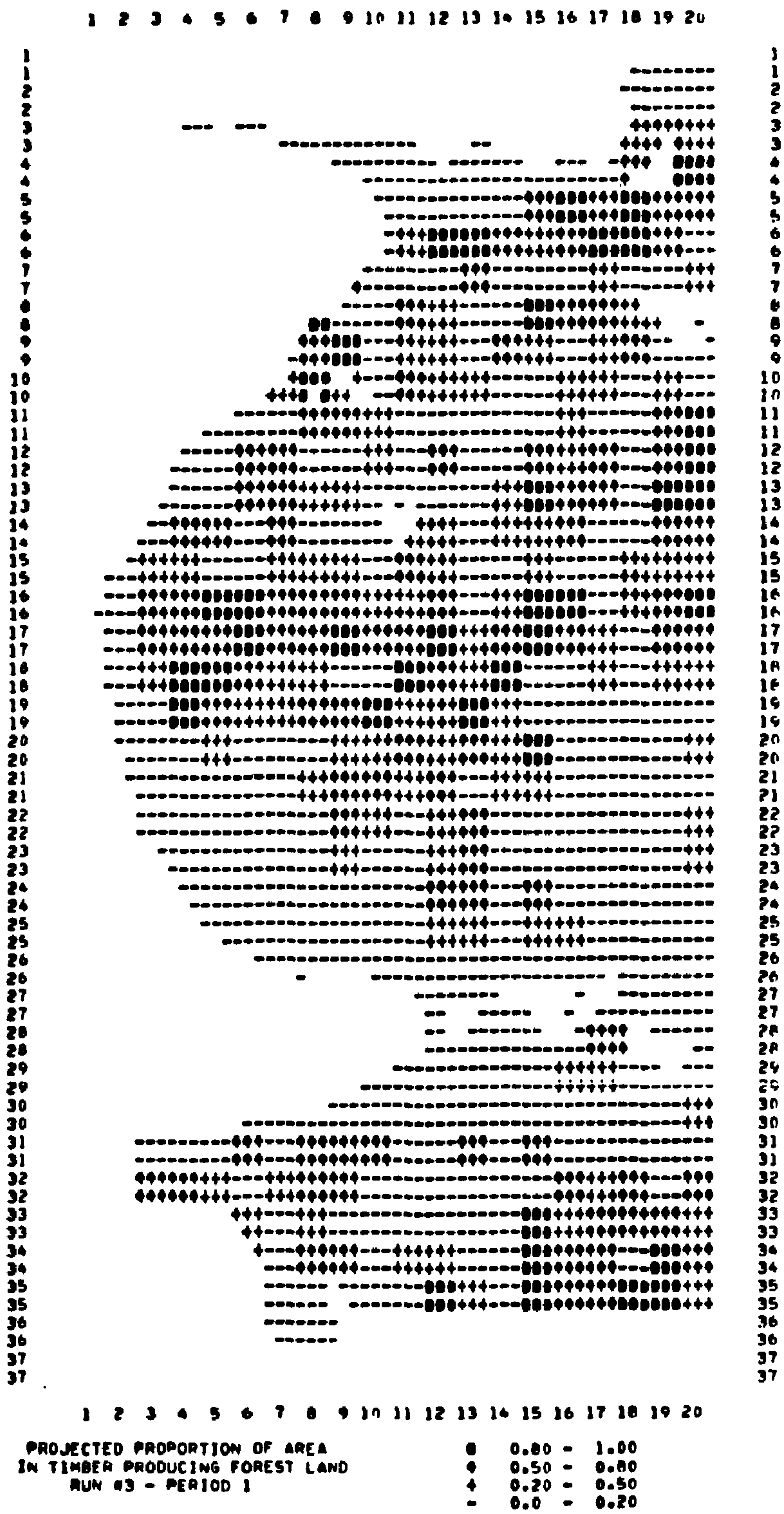


Figure 29. Projected Proportion of Area in Timber Production, Run 3, Period 1

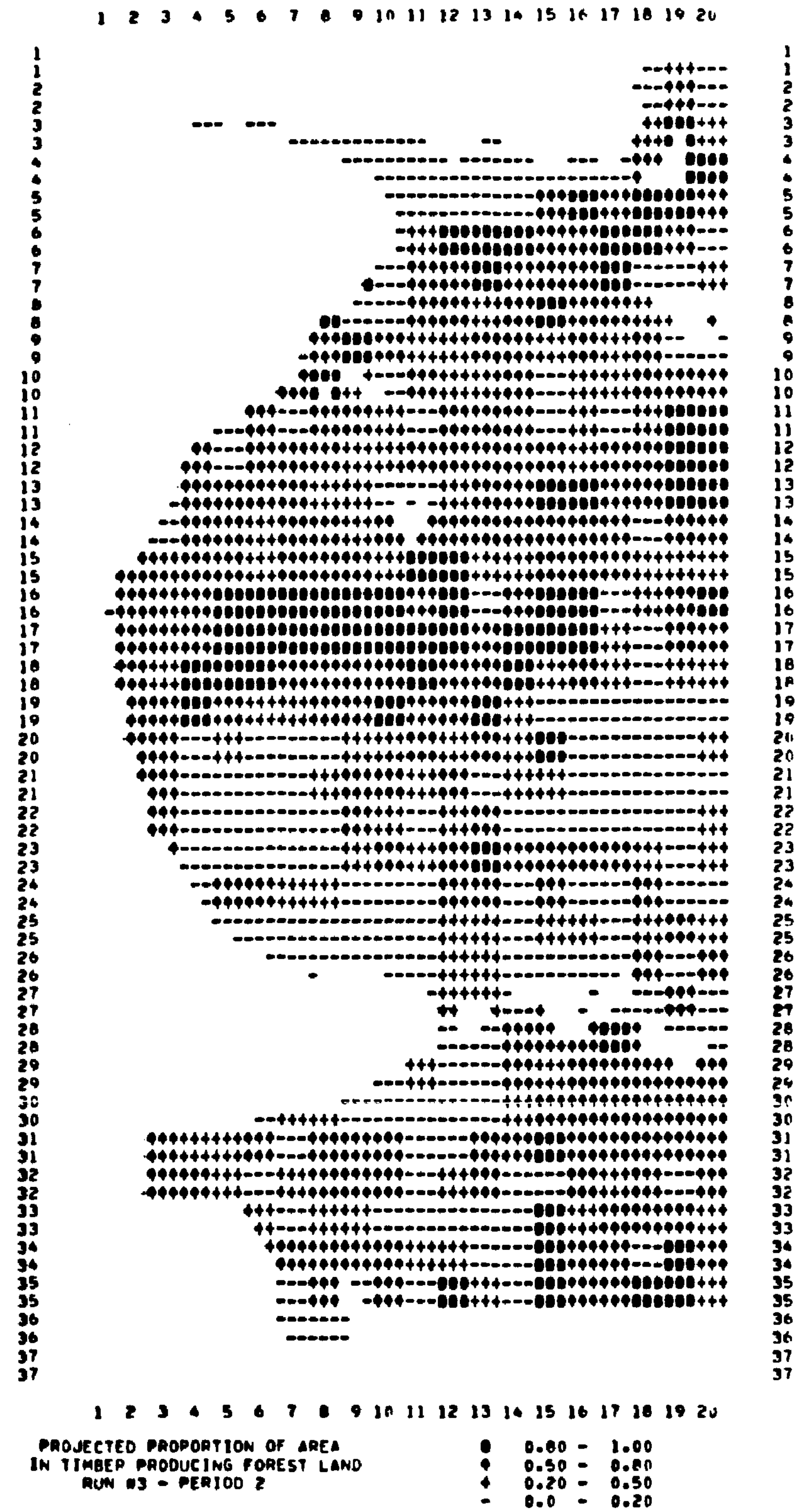


Figure 30. Projected Proportion of Area in Timber Production, Run 3, Period 2

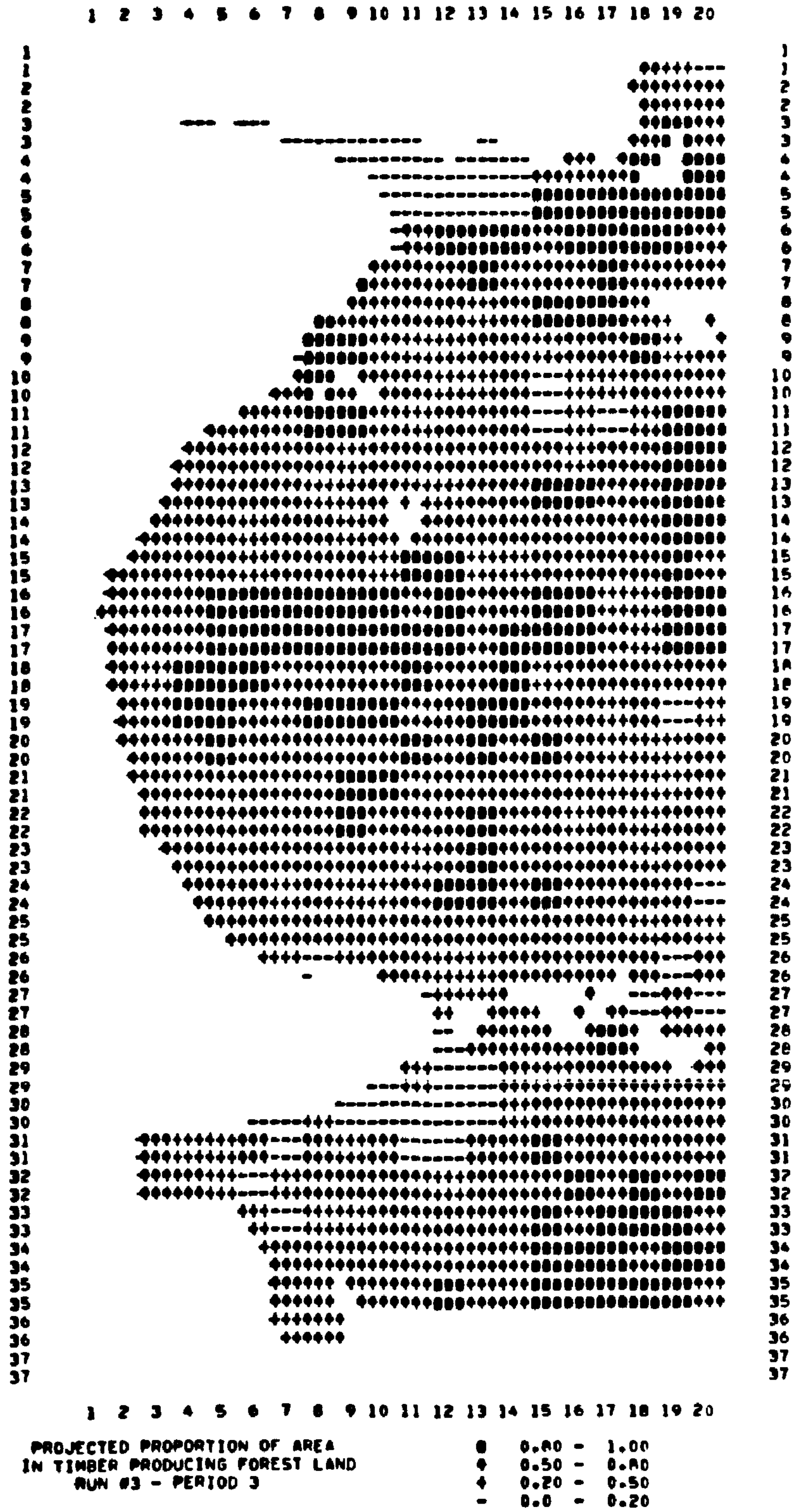


Figure 31. Projected Proportion of Area in Timber Production, Run 3, Period 3

Table 10. Final Demand Inputs and Implied Gross Outputs for the Wood Products Sector in the Third Run (Thousands of Dollars)

Period	Final Demand	Gross Output
1	3383	5053
2	4330	6255
3	5542	7786

Table 11. Unconstrained and Constrained Final Demands and Gross Outputs for Period 3, Run 3 (Thousands of Dollars)

Sector	Unconstrained Final Demand	Unconstrained Gross Output	Constrained Final Demand	Constrained Gross Output
Agriculture	1929	7270	1929	7249
Construction	20251	27409	20251	27397
Wood Products Furniture Manufacture	5542	7786	4805	6926
Cement & Concrete Products Manufacture	14279	18667	14279	18665
Electrical & Transportation Equipment Manufacture	18382	18382	18382	18382
Primary Metal & Metal Fabrication	4857	5969	4857	5947
Nondurable Manufacture	5366	9958	5366	9950
Transportation, Utilities, Communication	7634	31279	7634	31225
Wholesale & Retail Trade	26258	71973	26258	71840
Finance, Insurance & Real Estate	16946	48012	16946	47939
Lodging & Amusement Services	13974	18608	13974	18598
Medical Services	49736	60563	49736	60538
Other Services	9909	32287	9909	32237
Endogenous Government	346	4633	364	4626
Households	37174	172738	37174	172274

several sectors is reduced due to the interaction of those sectors with the wood products sector.

Problems With the Model and Application

Examining the overall land use trends as reflected in the series of maps of levels of total developed use, e.g. compare Figure 10 to Figure 21, one might be satisfied that projected land use patterns from the model are somewhat reasonable. One does not have to look too closely, however, before certain problems with these projections become apparent. Compare the projected changes in commercial use from the second run in Figure 22 to the projected changes in residential use in Figure 23. Expanded residential use is largely concentrated in and around Petoskey and Harbor Springs with some at Mackinaw City. Increased commercial use also occurs predominantly in the Petoskey and Harbor Springs areas, but with noticeable changes in several towns along Highway 31 and even in Cross Village on Highway 131 in the northwest portion of the county. It is reasonable to be suspicious of the projected intensifying commercial use where there is little or no projected increase in residential use.

This is just one example of an inconsistency in the results from the model, but it relates to several known deficiencies in the model in its current form, and many other inconsistencies could no doubt be found under close examination of these runs or in other types of runs. It is appropriate to consider these deficiencies, not only to acknowledge the current limitations of the model and these results but also to identify those areas in which further study is needed.

The dilemma of the simultaneous importance and uncertainty of final demand projections has already been mentioned. This, of course, is not exclusive to this model, in fact it pervades not only land use modeling in general but much of economic planning and modeling. Of importance is not just total final demand but how demand from a number of different exogenous categories is allocated among various endogenous categories over time, which compounds the uncertainties. When this study began it was intended that a serious attempt be made to lessen this problem, but this was one of several goals that was pared as study resources became limiting and as the scope of the task became appreciated. A more analytical basis, if no more credibility, could have been added by employing shift-share analysis to arrive at final demand projections. Shift-share analysis relies on time trends in national production by sector, as was used in the second run reported here, but also considers the recent trend in share of those sectoral totals for the region in question. This has for some time been a commonly applied technique for exogenous demand forecasts, but its validity has long been questioned. It is argued that the observed changes in regional share are somewhat volatile and therefore unsuitable for this purpose and perhaps less reliable than simply using the national trends alone (Kuehn, 1974). Also the regional share is essentially a residual which includes all of the error. So for this analysis, sets of final demands with minimal rationale behind them were used, being considered suitable for demonstration purposes though not serious forecasts, and all that can be claimed is that a wide range of economic growth was considered.

As mentioned previously, a surprising result of the first two runs, given this range of final demands and given the original impetus for the regional project, i.e. concern over the possibility of critical land use conflicts, was that lack of suitable area for any use in either run was not detected. Either the original premise of scarcity of suitable land to satisfy all competing uses or the ability of this model with this data base to detect relevant scarcity and conflict must be questioned. In fact, for Emmet County, there is probably basis for both of the doubts expressed above, i.e. for Emmet County there may not be the major impending conflicts that loom for other areas in the region or nation where initial use intensity and prospects for future growth are higher, but also there are definitely deficiencies in the current model that may prevent the detection of some of the problems that are in the future for Emmet County.

A major problem with this model, or more precisely this application, may be referred to as the resolution problem. A resolution problem is not inherent in the model, but for any given application, as discussed in Chapter III, levels of spatial, sectoral, temporal, and land use resolution or aggregation must be chosen, usually to a large degree before data collection is begun. The degree of resolution in all of these areas can affect the ability of the resulting model to identify use conflicts and constraints arising from lack of suitable land. Problems related to resolution often stem from the effects of averaging differing traits or levels of some variable over a defined class or unit to come up with a single value to represent that unit. That single average value for the unit (e.g. one coefficient to relate to broad sectors in an input-output model, an average soil suitability for a large parcel, or one coefficient to reflect land use requirements of a sector for a broadly defined land use category) often does not adequately reflect the impact of the variablility of that factor within the unit.

The rationale for the spatial resolution used in this study, i.e. one section parcels, was presented in Chapter III, and though the rationale is still valid, the choice was not without adverse effects. Ideally, the chosen spatial resolution allows defining parcels based on homogeneity of important traits, but from a practical standpoint the number of different traits considered and the limitations on total number of parcels may result in parcels that are not homogeneous for even one of those traits.

Soil, terrain, and water frontage are but a few examples of factors which may not be homogeneous over a parcel but whose implications for suitability for certain land uses can not be adequately reflected by an average value for the parcel. For example a parcel could be rated suitable for some recreational use or seasonal homes because of the presence of undeveloped water front, but without additional constraints the entire area of the parcel would be treated as though it were suitable even though only a portion of the area is actually adjacent to the water. A parcel homogenous with respect to this trait could be defined by a narrow corridor along the water front, and as mentioned previously such an irregular parcel could be handled by the model.

Water front recreation also provides an example of the resolution problem with respect to land use classification in the Emmet County application. As explained in Chapter III, for this study eight land use categories were used, one of which was a "recreational lands" category. This one category includes everything from the water front oriented parks near Petoskey to the ski areas to the wild lands of Wilderness State Park. At this point the model does not distinguish between these substantially different recreation resources, and so does not address a likely future, if not current, land use problem in Emmet

County, i.e. available, suitable waterfront for public recreation.

The spatial resolution problem is closely related to another serious problem with the current model, which may be referred to as the intraregional allocation or distribution problem. One aspect of this problem is seen in the tendency of the model to allocate all of the increase in area for a use in a period to a single parcel, subject of course to the availability of suitable land in that parcel. This is a natural result of the algorithm which deterministically allocates increased use requirements to the parcel with the highest rent differential for a shift to that use.

Again because of large parcel size and the implicit assumption of homogeneity within any one use category within that parcel, a relatively large portion of a given parcel would be treated as though all of it yielded the same rent differential from a certain shift, while over that portion of the parcel a range of suitabilities, productivities, and conversion costs actually exist resulting in a wide range of rent differentials. More reasonable projected patterns of land use would result if part of any increase in a use requirement were spread over a number of parcels, taking advantage of the high end of that range of differentials, rather than all being concentrated in a single parcel. To reduce the effects of this problem, but certainly not solving it, constraints on the maximum area in any parcel that can shift to any use in any one period were employed. More theoretically appealing solutions to this problem can be envisioned, for example an "interregional" approach to the economic component could be used to yield land use requirements by subregions in the county, thus spreading at least to some degree projected increases in different uses without increasing the number of parcels. The practicality of such an approach is, however, certainly questionable. Of course the problem could be alleviated with smaller parcels but with the resulting costs of many more parcels.

Another problem with the current application that relates directly to the inability of the model to detect deficiencies of suitable land is the exclusion of conversion costs in these runs. In Chapter II cost of converting land from one use to another is acknowledged as an important component of the rent differential equation for identifying and ranking possible land use shifts, and the model can account for conversion costs, but as with a number of variables, as resources for the study became limiting and as the difficulty of determining such costs on a parcel by parcel basis was realized, it was decided to exclude conversion costs from these initial analyses (except as noted for the third run).

Even had conversion costs been explicitly included, with the current spatial resolution it is doubtful that their effects could have been adequately modeled. The average conversion cost for a shift from one use to another would apply to all of the area in the current use in a given parcel, but again because of the heterogeneity of other factors (e.g. terrain, access, vegetation) that average cost would understate true costs for part of the area while overstating costs for other parts. The shift would appear to be either profitable or unprofitable for the entire area. The real effects of conversion costs could only be reflected if the spatial resolution allowed delineation of these kinds of differences.

While it was suggested that several of the problems mentioned above could account for the model's failure to detect suitable land deficiencies, other problems with the current model would tend to have the opposite effect by overstating land use requirements. As mentioned in Chapter IV, the land use requirements coefficients were based on current area by land use, current gross outputs by sector, and some specific land use information from the input-output survey. In other words existing average ratios of acres by use to dollars of gross output by sector were used. These ratios were used with awareness of the dangers in their use, i.e. that these average ratios may not closely approximate current or future marginal ratios and their use implicitly assumes current utilization at full capacity. That this is a serious problem can probably be appreciated by considering the historic increases in output relative to land input as observed in agriculture.

The land use requirements coefficients could be made to vary from period to period through a run, but a better basis for determining initial marginal ratios and how they would be likely to change over time is needed.

A similar, but perhaps even more serious problem, is the static nature of the input-output technical coefficients. Instability in technical coefficients and especially in interregional trade coefficients has long been considered in the input-output modeling literature, but little in the way of practical remedies have been offered. Again, there would be no particular mechanical problem in varying these coefficients from period to period if it was possible to project how they should change. The importance of this problem to the analyses discussed above can be understood by considering the record of increasing labor efficiency over the years. For the second run the average rate of real economic growth during the 1970's was used as the basis for future levels of final demands, and it was noted that real economic growth had been much higher than population growth. This disparity in growth rates is evidence of the fallacy of stable coefficients for the households sector and suggests that the residential land use requirements projections are overstated. The relevance of concerns about unstable trade coefficients for this kind of analysis was seen in the third run, where one of the major assumptions was changing relative dependence of the wood products sector on timber from within versus timber from outside of Emmet County. The model does not currently explicitly recognize or constrain interregional trade, so this changing relationship had to be approximated by some ad hoc changes in a land use requirements coefficient through the run. More explicit recognition of interregional trade could be added and would represent a substantial improvement, and again, the coefficients could vary between periods where there was a basis for such projections, but interregional trade data are very difficult to obtain.

The current nondynamic nature of another set of coefficients may seem to be an even more serious deficiency. Late in the study a conscious decision was made to employ static rather than dynamic suitability and productivity indexes. Although this may seem to seriously violate the intent of the simulation, there was a rationale for the decision. It was realized that the real limitation in the indexing process was not the mechanics or software for updating the indexes from period to period through the run, but in the index submodels and composites themselves, i.e. in defining the relationship between the various parcel attributes and parcel suitability and productivity for a use. While it would have taken considerable effort to program for dynamic indexing, little would have been gained given the admittedly crude state of the suitability and productivity submodels. In most cases, given the simple submodels currently being employed, dynamic indexing would simply have reinforced the effects of the current approach. Dynamic indexing should definitely be added to the model if serious projections are to be made, but improving the indexing submodels is an even more fundamental need at this point. This indexing process is really a key to the model and the current deficiencies contribute to the intraregional allocation problem mentioned above, since through their contribution to rents the indexes are the basis for allocation over space. Although it would be a step backward with respect to incorporating a behavioral basis in the model, there could conceivably be a geo-specific land use model without the economic component of this model, simply relying on exogenous statements of areas required by use over time, but without the indexing process, or something similar, there could not be a geo-specific land use model.

Reflections on Land Use Modeling

The preceding section dealt with a number of specific problems with the current model and its application to Emmet County, but there are a number of more general impressions from this experience that should be considered. These impressions are worth considering as cautions or guidance for subsequent research, but they are also of interest because they corroborate conclusions from previous land use modeling efforts.

The preceding section gave considerable attention to the resolution problem, especially the problem associated with relatively gross spatial resolution, but there is an opposing perspective on the issue of resolution that must not be neglected. This study involved a constant struggle between an urge to increase detail in order to adequately handle the micro-level effects of importance and the need to limit scope and resolution so that any progress could be made toward the macro-level goals of the study. At times the data gathering, processing, and error checking requirements seemed overwhelming, and finer spatial resolution would have compounded the problem. Of course the Emmet County study was not the first land use modeling effort to encounter this problem. Underestimating time and cost of data collection and manipulation was one of the serious technical problems identified by Voelker (1975) in the Oak Ridge National Laboratory's Regional Environmental Systems Analysis (RESA) program, as mentioned in Chapter I of this thesis. This experience suggests the need for and should help provide understanding of the enormity of the data compilation task for this kind of research but also has implications for the practicality of routine, operational use of this kind of system by a planning agency. Development, modification, and use of such a system may not be infeasible, but it is costly, and these costs should be appreciated before the fact.

Despite the above remarks, the data compilation task was not a negative experience. The exposure to such a variety of data variables and sources was extremely valuable. Several data handling methods and programs (e.g. routines for aggregating, mapping, and debugging) were developed and should be of at least limited usefulness beyond this study.

A pervasive theme in the literature evaluating land use modeling is that model developers more often than not have unrealistic expectations for their models. There are often unrealistic expectations and corresponding claims for the capabilities of the models, and there are unrealistic expectations for the acceptance of models by planners. Certainly this observation applied to the Emmet County effort, especially in the initial stages. These types of unrealistic expectations are addressed by both Voelker (1975) and Pack (1979).

Associated with the unrealistic expectations with respect to model capability is the often cited problem of lack of land use theory or at least lack of explanatory power in the theory that does exist. Again this problem was experienced first hand in this study and relates to the discussion in the preceding section of the crude state of the indexing submodels. This study did at least attempt to incorporate some theory into the model with its concern for rents and its inclusion of the input-output linear programming model. This would seem to be a step forward from what Pack identifies as the mechanical models of the past that lacked a behavioral basis for location decisions.

Even if the first type of unrealistic expectation, i.e. resulting from limited predictive capability, was not as common as it is, the second type of unrealistic expectation would still occur frequently, i.e. planners in general or a "client" planning agency in particular would still be much more reluctant to embrace a model than the modeler would expect. Pack's survey results indicate that model adoption does not seem to depend on model quality but on personal factors such as the presence or absence of model or quantitatively oriented people in the planning agency. As it is, given the very real limits of model capabilites and the notoriety that past overly optimistic claims have achieved, the reluctance on the part of planners to accept models is understandable. Again this study provided first hand experience with these kinds of attitudes.

A corollary to identifying the lack of explanatory power in current land use theory as perhaps the main factor limiting the capability of these models for reliable and reasonable land use projections, is the conclusion that model software is not the most pressing need. This is another common conclusion in the land use modeling evaluations and again was independently realized in the Emmet County study. This is not to suggest that the software development in this study was not necessary for the purposes of this study, but it must be acknowledged, as it was in the preceeding section, that theoretical and empirical model development and the data on which to base that development are more pressing needs than computer code to implement existing conceptual models.

A lengthy, but certainly not exhaustive, compilation of problems with the current model and application has been provided. The intent is not, however, to present a predominantly negative picture of this experience. Some of the very things that made the experience somewhat frustrating and less than totally successful, e.g. the comprehensiveness of data requirements, have also made it extremely valuable educationally. Also, suggestions for future research in this area can be distilled from this experience, a few of which are summarized below.

Probably the greatest weakness in the current model and application is in the area of the indexing submodels for adjusting rents based on attributes of the specific parcel. Empirically estimated, theoretically based multivariate models that relate value in use to observable attributes of parcels are needed. The requirement of a theoretical basis is meant to imply that the submodels can to some extent (at least in identification of relevant variables and perhaps equation forms and rough orders of magnitude for coefficients) be transferred with calibration to other regions.

Despite a fairly careful rationale for the resolution decisions made in this study, resolution problems are pervasive in explaining limitations of this effort. The levels of land use, economic, and spatial aggregation all presented certain difficulties. The restrictions on resolution were felt necessary because of what turned out to be somewhat artificial restrictions on computer capacity. If a similar analysis is to be undertaken in the future greater disaggregation of land use categories and of land parcels (either through irregularly shaped, variable sized parcels or many more smaller parcels) should be employed to alleviate some of the problems mentioned above.

Related to the discussion of the preceding paragraph, rather artifical computing limitations were also largely responsible for the early abandonment of the large scale, spatially disaggregated linear programming approach to land use models. This approach is now perceived to be more of a promising avenue than it was previously. The linear program formulations of Chapter II or variations on them could be applied to a region, and because proven solution techniques and software could be used, proportionately more time could be spent on data collection, submodel development and analysis than was possible in this study.

It is strongly recommended that future research of this kind be done in close conjunction with a client planning agency in the study region that is truly interested in the entire concept, i.e. application of the land use model, rather than merely in isolated parts or products of the study.

The importance of final demand projections in driving the land use model has been mentioned several times, and current limitations in arriving at reliable final demand predictions have been acknowledged. While the importance of and current weakness in this area should not be minimized, the need for and scope of such research certainly goes far beyond the context of land use modeling. If progress in land use modeling had to wait for a definitive, concensus answer to the exogenous demand problem it would be waiting a long time. The implication is a need for being resolved to the fact that the product of land use modeling is and will continue to be projections rather than predictions or forecasts. The consolation being that land use models can reflect whatever projections or forecasts of exogenous variables are available and provide the only means for a comprehensive, detailed analysis of their impacts.

This attempt at understanding and modeling this whole has identified or at least emphasized many holes in the process, perhaps more vividly than any alternative approach could have. The filling of these holes with better information and models through additional research would take time but could eventually lead to a practical, useful, and needed tool.

APPENDIX

APPENDIX

LAND USE MODEL FORTRAN SOURCE LISTING


```
               C      PROGRAM LUPRO
 0001                 COMMON/UNVRSL/ CUSE(525,10),ACAL(15),ACRQ(15),DFCT(15),RNTS(20),
                     1 ACU(15),TACRS(525),DMXSFT(15),NLUC,NPAR,NLINE,ITMXS,XGO(57),
                     2 FDN(20),FDO(20),NSEC,DSCR1,IER1,IER2,IECHO1,IECHO2,NPRD,
                     3 IPRD,IPDLGT,INVFLG,IFLG,IACU,IOPTU,NLUCX,ACRQMN(15),
                     4 NUSE(15),LFLG,NCOUNT,ICOUNT,ISFLG,NLUCZ,MUSE(15),DFCTMX(15),
                     5 RNTX(15)
 0002                 DIMENSION IO13(33)
               C
               C  THIS CODE IMPLEMENTS THE LAND USE PROJECTION MODEL.  THE PROGRAM
               C  IS STILL VERY MUCH IN A RESEARCH MODE, RATHER THAN A THOROUGHLY
               C  TESTED "USER FRIENDLY" TOOL.
               C
               C  THESE ROUTINES RELY ON SEVERAL SYSTEM DEPENDENT ROUTINES, IN THIS
               C  CASE:  IBM SORT/MERGE, UNIVERSITY OF VICTORIA, B.C. FORCE FORTRAN
               C  SORT/MERGE INTERFACE, THE INTERNATIONAL MATHEMATICS AND STATISTICS
               C  LIBRARY (IMSL) LEQT1F LINEAR EQUATION SYSTEM SOLUTION ROUTINE, AND
               C  IMSL ZX3LP LINEAR PROGRAMMING SOLUTION ROUTINE.
               C
               C
               C  THIS PROGRAM WAS ORIGINALLY WRITTEN FOR A SYSTEM ON WHICH MEMORY
               C  WAS EXTREMELY LIMITED SO OVERLAYS AND SUBSTANTIAL INPUT/OUTPUT
               C  WERE USED THAT ARE NOT NECESSARY BUT ARE STILL REFLECTED IN
               C  THE STRUCTURE OF THIS VERSION.
               C
               C
               C  MAJOR VARIABLE DEFINITION:
               C     NPRD = NUMBER OF PERIODS IN THE RUN
               C     NSEC = NUMBER OF ECONOMIC SECTORS
               C     NLUC = NUMBER OF LAND USE CATEGORIES
               C     NPAR = NUMBER OF PARCELS
               C     CUSE(I,J) = CURRENT LAND USE - ACRES OF PARCEL I ALLOCATED TO USE J
               C     ACAL(J) = TOTAL ACRES ALLOCATED TO USE J
               C     ACRQ(J) = TOTAL "IDEAL" ACRES REQUIRED IN USE J (BY CURRENT
               C               SOLUTION OF ECONOMIC MODEL)
               C     ACU(J) = TOTAL ACTUAL ACRES ALLOCATED TO EACH USE J
               C     DMXSFT(J) = DEFAULT MAXIMUM ACRES THAT CAN SHIFT INTO USE J IN
               C                 A SINGLE PERIOD
               C     AMXSFT(I,J) = CONSTRAINT ON MAXIMUM ACRES IN PARCEL I THAT CAN
               C                   SHIFT INTO USE J IN A SINGLE PERIOD
               C     XGO(K) = TOTAL GROSS OUTPUT FOR EACH SECTOR K FROM SOLVING THE
               C              INPUT-OUTPUT MODEL
               C     FDN(K) = FINAL DEMAND FOR EACH SECTOR K FOR CURRENT PERIOD
               C     FDO(K) = FINAL DEMAND FOR PREVIOUS PERIOD
               C     AIO(K,K) = INPUT-OUTPUT TECHNICAL COEFFICIENTS MATRIX
               C     AIMA(K,K) = INPUT-OUTPUT I - A MATRIX
               C     ALURQ(J,K) = MATRIX OF LAND USE REQUIREMENTS COEFFICIENTS -
               C                  ACRES/DOLLAR OF GROSS OUTPUT FOR K SECTORS & J USES
               C     OBJ(K) = OBJECTIVE COEFFICIENT
               C     OBJ(K) = OBJECTIVE FUNCTION FOR LINEAR PROGRAM
               C     IPRIX(I,J) = PRODUCTIVITY INDEX FOR USE J ON PARCEL I
               C     ISUIX(I,J) = SUITABILITY INDEX FOR USE J ON PARCEL I
               C     ICVIX(I,J) = CONVERSION COST INDEX FOR USE J ON PARCEL I
               C     CVNCST(J,JJ) = STANDARD CONVERSION COSTS FOR CONVERTING FROM USE J
               C                    TO USE JJ
```

```
C     PFCTR(N) = PRODUCTIVITY FACTORS THAT CORRESPOND TO PRODUCTIVITY INDEXES
C     SFCTR(N) = SUITABILITY FACTORS THAT CORRESPOND TO SUITABILITY INNDEXES
C     CFCTR(N) = CONVERSION COST ADJUSTMENT FACTORS THAT CORRESPOND TO
C                CONVERSION COST INDEXES
C
C
C  FILE DEFINITIONS:
C    I/O UNIT
C        2   -   RUN CONTROL AND FINAL DEMANDS INPUT
C        6   -   STANDARD OUTPUT DEVICE FOR PRINTED REPORTS & TRACKING
C        8   -   FILE OF MAXIMUM AREA SHIFT CONSTRAINTS(AMXSFT(I,J))
C       10   -   INPUT FILE FOR NUMBER OF INDEX CLASSES AND FOR REAL
C                FACTORS CORRESPONDING TO INDEXES
C       11   -   UNSORTED FILE OF POSITIVE RENT DIFFERENTIAL LAND USE
C                SHIFT POSSIBILITIES
C       12   -   INPUT FILE OF CURRENT LAND USE BY PARCEL AT BEGINNING
C                OF RUN
C       13   -   SORTED FILE OF USE SHIFT POSSIBILITIES
C       14   -   INPUT FILE FOR PRODCUTIVITY, SUITABILITY, & CONVERSION
C                COST INDEXES
C       16   -   FILE OF MINIMUM AREA CONSTRAINTS BY PARCEL AND LAND USE
C       17   -   FILE OF ACCUMULATED SHIFTS TO A USE IN A GIVEN PARCEL
C                WITHIN THE CURRENT PERIOD - OUTPUT & INPUT FROM SHIFT
C                ROUTINE
C       18   -   ECONOMIC MODEL COEFFICIENTS, I.E. I-O,ALURQ,OBJ,ETC.
C       20   -   OUTPUT FILE - AREA BY USE BY PARCEL FOR EACH PERIOD
C
C
      REWIND 2
      REWIND 21
      NLUCX=0
      IPRD=0
      CALL INITL
   10 IPRD=IPRD+1
      IFLG=0
      ICOUNT=0
      WRITE(6,1000) IPRD
        DO 20 I=1,NSEC
        FDO(I)=FDN(I)
   20   CONTINUE
      READ(2,2000) (FDN(I),I=1,NSEC)
      CALL IOSLV
      IF(NLUCX.EQ.0) GO TO 40
   30 CALL LPSLV
   40 CONTINUE
        DO 50 I=1,NLUC
        NUSE(I)=I
        MUSE(I)=I
   50   CONTINUE
      NLUCX=NLUC
      NLUCZ=NLUC
   60 ICOUNT=ICOUNT+1
      CALL INRN
      IF(NLINE.EQ.0) GO TO 65
      CALL RNTSRT
```

```
0030          65 CALL SHIFT
0031             IF(IFLG.EQ.0) GO TO 80
0032             IF(ICOUNT.EQ.NCOUNT) GO TO 70
0033             CALL LPRNT
0034             IF(NLUCZ.NE.0) GO TO 60
0035             DO 68 J=1,NLUC
0036             IF(DFCT(J).GT.0) WRITE(6,3000) J
0037          68 CONTINUE
0038          70 CALL LPSLV
0039          80 CONTINUE
           C     CALL INDX
0040             CALL PRPRTS
0041             IF(IPRD.LT.NPRD) GO TO 10
           C     CALL FRPRTS
           C     REWIND 13
           C  81 READ(13,4000,END=82) IO13
           C     WRITE(6,4500) IO13
           C     GO TO 81
           C  82 CONTINUE
0042        4000 FORMAT(33A4)
0043        4500 FORMAT(1X,33A4)
0044        1000 FORMAT(1H1,10X,'PERIOD ',I3)
0045        2000 FORMAT(10F8.0)
0046        3000 FORMAT(//' INSUFFICIENT SUITABLE AREA FOR USE',I4)
0047             STOP
0048             END
```



```
0001             SUBROUTINE INITL
0002             COMMON/UNVRSL/ CUSE(525,10),ACAL(15),ACHU(15),DFCT(15),RNTS(20),
                1 ACU(15),TACHS(525),DMXSFT(15),NLUC,NPAR,NLINE,ITMXS,XGO(57),
                2 FDN(20),FDU(20),NSEC,DSCNT,IER1,IER2,IECHO1,IECHO2,NPRD,
                3 IPRD,IPDLGT,INVFLG,IFLG,TACU,IOPTU,NLUCX,ACHUMN(15),
                4 NUSE(15),LFLG,NCOUNT,ICOUNT,ISFLG,NLUCZ,MUSE(15),DFCTMX(15),
                5 RNTX(15)
           C
           C  THIS ROUTINE INITIATES RUN CONTROL PARAMETERS, FINAL DEMAND
           C  VECTOR, AND CURRENT LAND USE ARRAY.
           C
0003             REWIND 2
0004             REWIND 12
0005             READ(2,1000) NPRD,IPDLGT,NSEC,NLUC,NPAR,IECHO1,IECHO2,IOPTU,
                1        ITMXS,NCOUNT,DSCNT,(FDN(I),I=1,NSEC)
0006               DO 10 I=1,NPAR
0007               READ(12,2000) (CUSE(I,J),J=1,NLUC)
0008          10   CONTINUE
0009        1000 FORMAT(10I5,F5.0/(10F8.0))
0010        2000 FORMAT(5X,8F6.0)
0011             RETURN
0012             END
```

```
FORTRAN IV G1  RELEASE 2.0          RNTSRT          DATE = 83041        19/51/07            PAGE 0001

0001                SUBROUTINE RNTSRT
0002                DIMENSION FLDS(7),RECD(7)
0003                EXTERNAL FSORT,SRTIN,SRTOUT
0004                DATA LS/26/,LR/26/,LCOR/100000/
0005                DATA FLDS/' SOR','T FI','ELDS','=(17',',10,','CH,D',') '/
0006                DATA RECD/' REC','ORD ','TYPE','=F,L','ENGT','H=13','2 '/
              C
              C  THIS ROUTINE CALLS THE IBM SORT/MERGE INTERFACE ROUTINES FROM THE
              C  UNIV. OF VICTORIA, B.C.  FORCE PACKAGE.
              C
0007                REWIND 11
0008                REWIND 13
0009                CALL SORTD(FLDS,LS,RECD,LR,LCOR,SRTIN,SRTOUT)
0010                ENDFILE 13
0011                REWIND 11
0012                REWIND 13
0013                RETURN
0014                END

FORTRAN IV G1  RELEASE 2.0          SRTIN           DATE = 83041        19/51/07            PAGE 0001

0001                SUBROUTINE SRTIN(IADDR,IRET)
0002                DIMENSION A(33)
              C
              C  INPUT FOR SORT/MERGE INTERFACE
              C
0003                NN=132
              C     CALL GET(11,A,NN)
              C     IF(NN) 20,10,10
0004                READ(11,1000,END=20) A
0005             10 CALL ADDR(A,IADDR)
0006                IRET=12
0007                RETURN
0008             20 IRET=8
0009           1000 FORMAT(33A4)
0010                RETURN
0011                END

FORTRAN IV G1  RELEASE 2.0          SRTOUT          DATE = 83041        19/51/07            PAGE 0001

0001                SUBROUTINE SRTOUT(A,IRET)
0002                DIMENSION A(33)
0003                DATA NN/132/
              C
              C  OUTPUT FOR SORT/MERGE INTERFACE
              C
0004                IF(IRET-4) 20,10,10
              C  10 CALL PUT(13,A,NN)
0005             10 WRITE(13,1000) A
0006           1000 FORMAT(33A4)
0007             20 RETURN
0008                END
```

```
0001              SUBROUTINE PRPRTS
0002              COMMON/UNVRSL/ CUSE(525,10),ACAL(15),ACRQ(15),DFCT(15),RNTS(20),
                 1 ACU(15),TACRS(525),DMXSFT(15),NLUC,NPAR,NLINE,ITMAS,XGO(57),
                 2 FDN(20),FDO(20),NSEC,DSCRT,IER1,IER2,IECHO1,IECHO2,NPRD,
                 3 IPRD,IPOLGT,INVFLG,IFLG,TACU,IOPTO,NLUCX,ACRQMN(15),
                 4 NUSE(15),LFLG,NCOUNT,ICOUNT,ISFLG,NLUCZ,MUSE(15),DFCTMX(15),
                 5 RNTX(15)
            C
            C  THIS ROUTINE WRITES REPORTS AT END OF EACH PERIOD - LIST OF ACRES
            C  BY USE BY PARCEL AND TOTALS
            C
0003              WRITE(20,4000) ((CUSE(I,J),J=1,NLUC),TACRS(I),I=1,NPAR)
0004         4000 FORMAT(8F6.1,F8.1)
0005              WRITE(IOPTO,1000) IPRD,(J,J=1,NLUC)
0006              WRITE(IOPTO,2000) (I,(CUSE(I,J),J=1,NLUC),TACRS(I),I=1,NPAR)
0007              WRITE(IOPTO,3000) (ACU(J),J=1,NLUC),TACU,(ACAL(J),J=1,NLUC),
                 1      (ACRQ(J),J=1,NLUC)
0008         1000 FORMAT(1H1///10X,'PERIOD',I3///42X,'ACTUAL ACRES ALLOCATED',
                 1        ' FROM PARCELS TO USES'//63X,'USES'//9X,'PARCELS',4X,
                 2        8I9,8X,'TOTAL'/)
0009         2000 FORMAT(9X,I5,8X,8F9.1,F12.1)
0010         3000 FORMAT(/' TOTAL ACTUAL ACRES'/' ALLOCATED TO USES',4X,
                 1      8F9.1,F12.1///' IDEAL ACRES ALLOCATED',8F9.1//
                 2      ' IDEAL ACRES REQUIRED ',8F9.1)
0011              RETURN
0012              END
```

```
0001        SUBROUTINE IOSLV
0002        COMMON/UNVRSL/ CUSE(525,10),ACAL(15),ACRQ(15),DFCT(15),RNTS(20),
           1 ACU(15),TACRS(525),DMXSFT(15),NLUC,NPAR,NLINE,ITMXS,XGO(57),
           2 FDN(20),FDO(20),NSEC,DSCRT,IER1,IER2,IECHO1,IECHO2,NPRD,
           3 IPRD,IPDLGT,INVFLG,IFLG,TACU,IOPTU,NLUCX,ACRQMN(15),
           4 NUSE(15),LFLG,NCOUNT,ICOUNT,ISFLG,NLUCZ,MUSE(15),DFCTMX(15),
           5 RNTX(15)
0003        REAL*8    AIO(20,20),AIMA(20,20),WKAREA(20),
           1 ALURQ(15,20),OBJ(20),FFCTR(20),B(20,2)
      C
      C  THIS ROUTINE SOLVES THE UNCONSTRAINED INPUT-OUTPUT MODEL FOR
      C  GROSS OUTPUTS TO SATISFY THE FINAL DEMAND PROJECTIONS FOR THE CURRENT
      C  PERIOD, THEN SOLVES FOR ACRES REQUIRED AND RENTS BY USE.
      C
0004        WRITE(6,5555) IPRD,NLUC,NSEC,NPAR
0005   5555 FORMAT('0IN IOSLV',4I5)
0006        REWIND 18
0007        READ(18,1000) ((AIO(I,J),J=1,NSEC),I=1,NSEC),((ALURQ(I,J),
           1 J=1,NSEC),I=1,NLUC),(OBJ(J),J=1,NSEC),(FFCTR(J),J=1,NSEC)
0008        IDGT=7
0009        IA=20
0010        MM=2
0011          DO 20 I=1,NSEC
0012            DO 10 J=1,NSEC
0013            AIMA(I,J)=-AIO(I,J)
0014            IF(I.EQ.J) AIMA(I,J)=1.-AIO(I,J)
0015     10     CONTINUE
0016          B(I,1)=FDN(I)
0017          B(I,2)=FDO(I)*FFCTR(I)
0018     20   CONTINUE
      C  CALL TO IMSL SIMULTANEOUS EQUATION SOLVING ROUTINE TO SOLVE I-O MODEL
      C
0019        CALL LEQT1F(AIMA,MM,NSEC,IA,B,IDGT,WKAREA,IER1)
0020        WRITE(6,2000) IER1
0021          DO 30 I=1,NSEC
0022          XGO(I)=B(I,1)
0023     30   CONTINUE
0024          DO 60 I=1,NLUC
0025          ACRQ(I)=0.
0026          ACRQMN(I)=0.
0027          SOX=0.
0028            DO 50 J=1,NSEC
0029            ACRQ(I)=XGO(J)*ALURQ(I,J)+ACRQ(I)
0030            ACRQMN(I)=B(J,2)*ALURQ(I,J)+ACRQMN(I)
0031            IF(ALURQ(I,J).GT.0.) SOX=SOX+OBJ(J)*XGO(J)
0032     50     CONTINUE
0033          IF(ACRQ(I)-0.) 55,55,52
0034     52   RNTX(I)=SOX/ACRQ(I)
0035          RNTS(I)=RNTX(I)
0036          GO TO 60
0037     55   RNTS(I)=0.
0038          RNTX(I)=0.
```

```
   60   CONTINUE
        WRITE(6,4000) (XGO(I),I=1,NSEC)
        WRITE(6,3000) (ACRQ(I),RNIS(I),I=1,NLUC)
 1000 FORMAT(17F5.0)
 2000 FORMAT(/10X,'IER1 = ',I3/)
 3000 FORMAT(//(10X,F12.2,F12.5))
 4000 FORMAT(//5X,17F7.0/)
      RETURN
      END
```

```
0001              SUBROUTINE LPSLV
0002              COMMON/UNVRSL/ CUSE(525,10),ACAL(15),ACRG(15),DFCT(15),RNTS(20),
                 1 ACU(15),TACRS(525),DMXSFT(15),NLUC,NPAR,NLINE,ITMXS,XGO(57),
                 2 FDN(20),FDO(20),NSEC,DSCRT,IER1,IER2,IECHO1,IECHO2,NPRD,
                 3 IPRD,IPDLGT,INVFLG,IFLG,TACU,IOPTU,NLUCX,ACRQMN(15),
                 4 NUSE(15),LFLG,NCOUNT,ICOUNT,ISFLG,NLUCZ,MUSE(15),DFCTMX(15),
                 5 RNTX(15)
0003              REAL*8    AIO(20,20),A(57,20),B(57),OBJ(20),BB(57),ALURQ(15,20),
                 1  DSOL(57),RW(2070),U(15),AFCTR(15),FFCTR(20),X(57)
            C
            C  THIS ROUTINE SOLVES THE I-O MODEL WITH LAND USE AREA CONSTRAINTS
            C  BINDING
            C
0004              DIMENSION IW(130)
0005              REWIND 18
0006              READ(18,1000)  ((AIO(I,J),J=1,NSEC),I=1,NSEC),((ALURQ(I,J),J=1,NSEC
                 1 ),I=1,NLUC),(OBJ(J),J=1,NSEC),(FFCTR(J),J=1,NSEC),
                 2 (AFCTR(I),I=1,NLUC)
0007              WRITE(6,5555) IPRD,NLUC,NSEC,NPAR
0008         5555 FORMAT('0IN LPSLV',4I5)
            C
            C  SET UP I-O AND AREA CONSTRAINTS
            C
0009                DO 15 I=1,NSEC
0010                  DO 10 J=1,NSEC
0011                   A(I,J)=-AIO(I,J)
0012                   IF(I.EQ.J) A(I,J)=1.-AIO(I,J)
0013                   A(I+NSEC,J)=-A(I,J)
0014           10     CONTINUE
0015                B(I)=FDN(I)
0016                B(NSEC+I)=-FDO(I)*FFCTR(I)
0017           15   CONTINUE
            C       DO 30 K=1,NLUCX
0018                DO 30 I=1,NLUC
0019                I1=NSEC+NSEC+I
            C       I=NUSE(K)
            C       I1=K+NSEC+NSEC
0020                  DO 20 J=1,NSEC
0021                  A(I1,J)=ALURQ(I,J)
0022           20     CONTINUE
0023                IF(IFLG-0) 22,22,24
0024           22   B(I1)=ACAL(I)*AFCTR(I)
0025                GO TO 30
0026           24   B(I1)=ACAL(I)
0027           30   CONTINUE
0028              IER1=0
            C     M1=NSEC+NSEC+NLUCX
0029              M1=NSEC+NSEC+NLUC
0030              M2=0
0031              IA=57
            C
            C  SOLVE I-O/LP WITH IMSL LP ROUTINE
            C
0032              CALL ZX3LP(A,IA,B,OBJ,NSEC,M1,M2,OBJV,X,DSOL,RW,IW,IER1)
0033                DO 40 I=1,NSEC
```

```
          XGO(I)=X(I)
   40     CONTINUE
        WRITE(6,2000) IER1,OBJV
          DO 60 I=1,NLUC
          ACHQ(I)=0.
          SOX=0.
            DO 50 J=1,NSEC
            ACHQ(I)=XGO(J)*ALURQ(I,J)+ACHQ(I)
            IF(ALURQ(I,J).GT.0.) SOX=SOX+OHJ(J)*XGO(J)
   50       CONTINUE
          IF(ACHQ(I)-0.) 55,55,52
   52     RNTS(I)=SOX/ACHQ(I)
          GO TO 60
   55     RNTS(I)=0.
   60     CONTINUE
          IF(IFLG.GT.0) GO TO 91
            DO 70 I=1,M1
            BB(I)=B(I)
   70       CONTINUE
            DO 80 K=1,NLUCX
            I=NUSE(K)
            II=NSEC+NSEC+I
            BB(II)=ACHQ(I)-1.
            CALL ZX3LP(A,IA,BB,OBJ,NSEC,M1,M2,OBJV,X,DSOL,RW,IW,IER1)
            BB(II)=B(I)
            IF(DSOL(II).GT.RNTS(I).AND.IER1.LE.70) RNTS(I)=DSOL(II)
            WRITE(6,2000) IER1,OBJV
   80       CONTINUE
            DO 90 I=1,NLUC
            RNTX(I)=RNTS(I)
   90       CONTINUE
   91   CONTINUE
        WRITE(6,3000) (XGO(I),I=1,NSEC),(I,ACHQ(I),RNTS(I),I=1,NLUC)
 1000   FORMAT(17F5.0)
 2000   FORMAT(/5X,'IER1 = ',I5//5X,'OBJ VALUE = ',F12.2)
 3000   FORMAT(//,5X,17F7.0//(5X,I5,F8.1,F12.4))
        RETURN
        END
```

```
0001              SUBROUTINE LPRNT
0002              COMMON/UNVRSL/ CUSE(525,10),ACAL(15),ACHQ(15),DFCT(15),RNTS(20),
                 1 ACU(15),TACRS(525),DMXSFT(15),NLUC,NPAR,NLINE,ITMXS,XGO(57),
                 2 FDN(20),FDO(20),NSEC,DSCRT,IER1,IER2,IECHO1,IECHO2,NPRD,
                 3 IPRD,IPOLGT,INVFLG,IFLG,TACU,IOPTO,NLUCX,ACHQMN(15),
                 4 NUSE(15),LFLG,NCOUNT,ICOUNT,ISFLG,NLUCZ,MUSE(15),DFCTMX(15),
                 5 RNTX(15)
0003              REAL*8    X(57),A(57,20),B(57),OBJ(20),BB(57),RW(2070),
                 1 DSOL(57),ALURQ(15,20),AIO(20,20),U(15),FFCTR(20)
            C
            C  THIS ROUTINE SOLVES I-O/LP FOR RENTS WHEN AREAS FOR SOME USES ARE
            C  CONSTRAINING.
            C
0004              DIMENSION IW(150)
0005              WRITE(6,5555) IPRD,NLUC,NSEC,NPAR
0006         5555 FORMAT('0IN LPRNT',4I5)
0007              REWIND 18
0008              READ(18,1000) ((AIO(I,J),J=1,NSEC),I=1,NSEC),((ALURQ(I,J),
                 1 J=1,NSEC),I=1,NLUC),(OBJ(J),J=1,NSEC),(FFCTR(J),J=1,NSEC)
            C
            C  SET UP I-O AND AREA CONSTRAINTS
            C
0009                DO 15 I=1,NSEC
0010                  DO 10 J=1,NSEC
0011                  A(I,J)=-AIO(I,J)
0012                  IF(I.EQ.J) A(I,J)=1.-AIO(I,J)
0013                 A(I+NSEC,J)=-A(I,J)
0014           10     CONTINUE
0015                B(I)=FDN(I)
0016                B(I+NSEC)=-FDO(I)*FFCTR(I)
0017           15   CONTINUE
0018              M1=NSEC+NSEC+NLUC
0019              M2=0
0020              IA=57
0021                DO 25 I=1,NLUC
0022                II=NSEC+NSEC+I
0023                B(II)=ACAL(I)
0024                  DO 20 J=1,NSEC
0025                  A(II,J)=ALURQ(I,J)
0026           20     CONTINUE
0027           25   CONTINUE
0028              IER1=0
0029              WRITE(22,4000) ((A(I,J),J=1,NSEC),B(I),I=1,II)
0030              WRITE(22,6000) (XGO(I),I=1,NSEC)
0031         6000 FORMAT(17F7.0)
            C
            C  SOLVE I-O/LP WITH IMSL ROUTINE
            C
0032              CALL ZX3LP(A,IA,B,OBJ,NSEC,M1,M2,OBJV,X,DSOL,RW,IW,IER1)
0033              WRITE(6,5000) X
0034         5000 FORMAT(1X,10F10.0)
0035         4000 FORMAT(1X,17F7.4,F7.0)
            C
            C  COMPUTE ACRES ALLOCATED TO USES IMPLIED INN LP SOLUTION
            C
```

```
          DO 35 I=1,NLUC
          U(I)=0.
            DO 30 J=1,NSEC
            II=NSEC+NSEC+I
            U(I)=U(I)+A(II,J)*X(J)
   30       CONTINUE
   35     CONTINUE
C
C  IDENTIFY SLACK AND DEFECIT USES - SET FLAGS AND ASSIGN RENTS ACCORDINGLY
C
C  SET UP CONSTRAINTS ON MAXIMUM AREA DEFICIENCIES ALLOWED BY USE
C  FOR NEXT ROUND OF SHIFTS
C
        NLUCX=0
        NLUCZ=0
          DO 50 I=1,NLUC
          IF(ACAL(I).GT.ACRQ(I)) GO TO 48
          NLUCX=NLUCX+1
          NUSE(NLUCX)=I
          IF(ACAL(I).GT.U(I)) GO TO 45
          IF(U(I).EQ.ACRQMN(I)) GO TO 43
          NLUCZ=NLUCZ+1
          MUSE(NLUCZ)=I
   43     II=NSEC+NSEC+I
          RNTS(I)=USOL(II)
          IF(RNTS(I).LT.RNTX(I)) RNTS(I)=RNTX(I)
          DFCTMX(I)=ACRQ(I)-ACRQMN(I)
          GO TO 50
   45     NLUCZ=NLUCZ+1
          MUSE(NLUCZ)=I
          DFCTMX(I)=ACRQ(I)-U(I)
          RNTS(I)=RNTX(I)
          GO TO 50
   48     NLUCZ=NLUCZ+1
          MUSE(NLUCZ)=I
          RNTS(I)=.000001
          DFCTMX(I)=0.
          IF(U(I).GT.ACRQ(I)) DFCTMX(I)=ACRQ(I)-U(I)
   50     CONTINUE
        WRITE(6,3000) RNTS
 3000 FORMAT(8F9.5)
 1000 FORMAT(17F5.0)
 2000 FORMAT(//10X,I5,3X,F10.1,3X,F12.4,3X,F12.2,5X,I5)
        RETURN
        END
```

```
      SUBROUTINE INRN
      REWIND 10
      REWIND 14
      CALL INITS
      CALL RNTCMB
      ENDFILE 11
      RETURN
      END
```

```
0001            SUBROUTINE INITS
0002            COMMON/UNVRSL/ CUSE(525,10),ACAL(15),ACRQ(15),DFCT(15),RNTS(20),
               1 ACU(15),TACRS(525),DMXSFT(15),NLUC,NPAR,NLINE,ITMXS,XGO(57),
               2 FDR(20),FDD(20),NSEC,DSCRT,IER1,IER2,IECHO1,IECHO2,NPRD,
               3 IPRD,IPDLG1,INVFLG,IFLG,TACU,IOPTU,NLUCA,ACRQMN(15),
               4 NUSE(15),LFLG,NCOUNT,ICOUNT,ISFLG,NLUCZ,MUSE(15),DFCTMX(15),
               5 RNTX(15)
0003            COMMON/INTRNT/ IPRIX(525,10),ISUIX(525,10),ICVIX(525,10),
               1 PFCTR(50),SFCTR(75),CFCTR(50),NCLS(15,6),CVNCST(15,15)
          C
          C  THIS ROUTINE INITIALIZES PRODUCTIVITY, SUITABILITY, AND CONVERSION
          C  COST INDICES AND FACTORS FOR CREATION OF SHIFTS POSSIBILITIES
          C  FILE.
          C
0004            WRITE(6,5555) IPRD,NLUC,NSEC,NPAR
0005       5555 FORMAT('0IN INITS',4I5)
0006            READ(10,1020) ((NCLS(I,J),I=1,NLUC),J=1,3)
0007            READ(10,1030) (DMXSFT(I),I=1,NLUC)
0008            READ(14,1050) ((IPRIX(I,J),J=1,NLUC),(ISUIX(I,J),J=1,NLUC),
               1         (ICVIX(I,J),J=1,NLUC),I=1,NPAR)
0009            READ(10,1060) ((CVNCST(I,J),J=1,NLUC),I=1,NLUC)
          C     WRITE(6,5555) IPRD,NLUC,NSEC,NPAR
          C       DO 5 I=1,NLUC
          C         DO 5 J=1,NLUC
          C         CVNCST(I,J)=0.
          C   5   CONTINUE
0010            NCLS(1,4)=1
0011            NCLS(1,5)=1
0012            NCLS(1,6)=1
0013            NN=NLUC-1
          C     WRITE(6,5555) IPRD,NLUC,NSEC,NPAR
          C
          C
          C  SET UP FACTOR ARRAY KEYS ACCORDING TO THE NUMBER OF PRODUCTIVITY,
          C  SUITABILITY, OR CONVERSION COST CATEGORIES FOR EACH USE
          C
0014              DO 10 I=1,NN
0015              NCLS(I+1,4)=NCLS(I,4)+NCLS(I,1)
0016              NCLS(I+1,5)=NCLS(I,5)+NCLS(I,2)
0017              NCLS(I+1,6)=NCLS(I,6)+NCLS(I,3)
0018         10   CONTINUE
          C     WRITE(6,5555) IPRD,NLUC,NSEC,NPAR
0019            NN1=NCLS(NLUC,4)+NCLS(NLUC,1)-1
0020            READ(10,1070) (PFCTR(I),I=1,NN1)
0021            NN2=NCLS(NLUC,5)+NCLS(NLUC,2)-1
0022            READ(10,1070) (SFCTR(I),I=1,NN2)
0023            NN3=NCLS(NLUC,6)+NCLS(NLUC,3)-1
0024            READ(10,1070) (CFCTR(I),I=1,NN3)
          C     WRITE(6,5555) IPRD,NLUC,NSEC,NPAR
0025              DO 30 I=1,NPAR
0026              TACRS(I)=0.
0027                DO 20 J=1,NLUC
0028                TACRS(I)=TACRS(I)+CUSE(I,J)
0029         20     CONTINUE
0030         30   CONTINUE
```

```
                C
                C  SUM IDEAL ACRES ALLOCATED TO USES BY MULTIPLYING ACTUAL ACRES BY THE
                C  PRODUCTIVITY FACTOR FOR THE USE OVER ALL PARCELS
                C
0031                   DO 50 J=1,NLUC
0032                   ACAL(J)=0.
0033                     DO 40 I=1,NPAR
0034                     IPN=NCLS(J,4)+IPRIX(I,J)-1
0035                     ACAL(J)=ACAL(J)+CUSE(I,J)*PFCTR(IPN)
0036              40     CONTINUE
0037              50   CONTINUE
                C      WRITE(6,5555) IPRD,NLUC,NSEC,NPAR
0038             1020 FORMAT(24I2)
0039             1030 FORMAT(10F8.0)
0040             1050 FORMAT(10X,24I2)
0041             1060 FORMAT(8F10.0)
0042             1070 FORMAT(10F8.0)
0043                  RETURN
0044                  END
```

```
              SUBROUTINE RNTCMB
              COMMON/UNVRSL/ CUSE(525,10),ACAL(15),ACRQ(15),UFCT(15),RNTS(20),
             1 ACU(15),TACRS(525),DMXSFT(15),NLUC,NPAR,NLINE,ITMXS,XGO(57),
             2 FDN(20),FDU(20),NSEC,DSCRT,IER1,IER2,IECHO1,IECHO2,NPRD,
             3 IPRD,IPDLGT,INVFLG,IFLG,TACU,IOPTU,NLUCX,ACRQMN(15),
             4 NUSE(15),LFLG,NCOUNT,ICOUNT,ISFLG,NLUCZ,MUSE(15),UFCTMX(15),
             5 RNTX(15)
              COMMON/INTRNT/ IPRIX(525,10),ISUIX(525,10),ICVIX(525,10),
             1 PFCTR(50),SFCTR(75),CFCTR(50),NCLS(15,6),CVNCST(15,15)
              DIMENSION IPRCL(525),ICMBF(34)
C
C  THIS ROUTINE CREATES A FILE OF POSSIBLE USE SHIFTS FROM USE J TO
C  USE JJ WHICH RESULT IN POSSITIVE RENT DIFFERENTIALS.  SHIFTS ARE
C  CONSIDERED FOR ALL USES JJ FOR WHICH THERE IS CURRENTLY INSUFFICIENT
C  AREA ALLOCATED AND FROM USES J FROM WHICH SHIFTS ARE ALLOWED.  EACH
C  RECORD OF THIS FILE INDICATES THOSE PARCELS WHICH FOR A GIVEN SHIFT
C  (J TO JJ) HAVE IDENTICAL PRODUCTIVITY, SUITABILITY, AND CONVERSION
C  COST INDEXES FOR THE USES INVOLVED AND SO RESULT IN THE SAME
C  RENT DIFFERENTIAL.
C
      WRITE(6,5555) IPRD,NLUC,NSEC,NPAR
 5555 FORMAT('0IN RNTCMB',4I5)
      REWIND 11
      NNC=34
      NLINE=0
        DO 100 JO=1,NLUCZ
        J=MUSE(JO)
        NS=NCLS(J,2)
        NP=NCLS(J,1)
          DO 95 IS=1,NS
          IS1=NCLS(J,5)+IS-1
            DO 90 IP=1,NP
            IP1=NCLS(J,4)+IP-1
            RNTS1=RNTS(J)*SFCTR(IS1)*PFCTR(IP1)
              DO 20 I=1,500
              IPRCL(I)=0
   20         CONTINUE
            NPRC=0
              DO 30 I=1,NPAR
              IF(CUSE(I,J).EQ.0.) GO TO 30
            IF(ISUIX(I,J).NE.IS) GO TO 30
              IF(IPRIX(I,J).NE.IP) GO TO 30
              NPRC=NPRC+1
              IPRCL(NPRC)=I
   30         CONTINUE
            IF(NPRC.EQ.0) GO TO 90
              DO 80 KJ=1,NLUCX
              JJ=NUSE(KJ)
              IF(JJ.EQ.J) GO TO 80
              NNS=NCLS(JJ,2)
              NNP=NCLS(JJ,1)
                DO 75 IIS=1,NNS
                IS2=NCLS(JJ,5)+IIS-1
                  DO 70 IIP=1,NNP
                    IP2=NCLS(JJ,4)+IIP-1
```

```
                  RNTS2=RNTS(JJ)*SFCTR(IS2)*PFCTR(IP2)
                  RNTDF=(RNTS2-RNTS1)/DSCRT - CVNCST(J,JJ)
                  IF(RNTDF.LE.0.) GO TO 70
                  DO 65 II=1,34
                  ICMBF(II)=0
   65             CONTINUE
                NC=0
                  DO 60 II=1,NPRC
                  IPRC=IPRCL(II)
                  IF(ISUIX(IPRC,JJ).NE.IIS) GO TO 60
                  IF(IPRIX(IPRC,JJ).NE.IIP) GO TO 60
   54             NC=NC+1
                  IF(NC.GT.34) GO TO 55
                  ICMBF(NC)=IPRC
                  GO TO 60
   55             WRITE(11,1000) JJ,J,PFCTR(IP2),PFCTR(IP1),RNTDF,NNC,
     1            (ICMBF(LK),LK=1,NNC)
                  NC=0
                  NLINE=NLINE+1
                  DO 59 IL=1,34
                  ICMBF(IL)=0
   59             CONTINUE
                  GO TO 54
   60             CONTINUE
                IF(NC.EQ.0) GO TO 70
                WRITE(11,1000) JJ,J,PFCTR(IP2),PFCTR(IP1),RNTDF,NC,
     1          (ICMBF(LK),LK=1,NC)
                NLINE=NLINE+1
   70           CONTINUE
   75           CONTINUE
   80         CONTINUE
   90       CONTINUE
   95     CONTINUE
  100     CONTINUE
      WRITE(6,2000) NLINE
 1000 FORMAT(2I3,2F5.3,F10.3,I3,34I3)
 2000 FORMAT(10X,'NLINE = ',I6)
      RETURN
      END
```

```
      SUBROUTINE SHIFT
      COMMON/UNVRSL/ CUSE(525,10),ACAL(15),ACRQ(15),DFCT(15),RNTS(20),
     1 ACU(15),TACRS(525),DMXSFT(15),NLUC,NPAR,NLINE,ITMXS,XGO(57),
     2 FUN(20),FDU(20),NSEC,DSCNT,IER1,IER2,IECHO1,IECHO2,NPRD,
     3 IPRD,IPDLGT,INVFLG,IFLG,TACU,IOPTO,NLUCX,ACRQMN(15),
     4 NUSE(15),LFLG,NCOUNT,ICOUNT,ISFLG,NLUCZ,MUSE(15),DFCTMX(15),
     5 MNTX(15)
      COMMON/SHFIT/ ACMIN(525,10),AMXSFT(525,10),ASHFT(525,10)
      DIMENSION ICMBF(34),IO13(33)
      DATA IBGF/0/
C
C  THIS ROUTINE SEARCHES THE SORTED SHIFTS POSSIBILITIES FILE AND SHIFTS
C  ACRES TO USES THAT HAVE UNMET REQUIREMENTS.  CONSTRAINTS ON MINIMUM
C  AREA BY USE BY PARCEL AND CONSTRAINTS ON THE MAXIMUM AREA TO SHIFT
C  TO A USE IN A GIVEN PARCEL IN A SINGLE PERIOD.ARE RECOGNIZED.
C
      WRITE(6,5555) IPRD,NLUC,NSEC,NPAR
 5555 FORMAT('0IN SHIFT',4I5)
      REWIND 16
      REWIND 8
      REWIND 13
C     IF(IBGF.EQ.0) GO TO 550
C 500 READ(13,6000,END=550) IO13
C      WRITE(6,6001) IO13
C     GO TO 500
C 550 IBUG=1
C     IF(IRPD.EQ.3) WRITE(6,5000) IBUG
      IF(NLINE.EQ.0) GO TO 75
        DO 3 J=1,NLUC
          DO 2 I=1,NPAR
          ASHFT(I,J)=0.
    2     CONTINUE
    3   CONTINUE
      IF(IFLG.EQ.0) GO TO 12
      REWIND 17
C     IBUG=2
C     IF(IRPD.EQ.3) WRITE(6,5000) IBUG
   11 READ(17,800,END=12) I,J,ASHFT(I,J)
      GO TO 11
   12 CONTINUE
        DO 4 J=1,NLUC
        DFCT(J)=ACRQ(J)-ACAL(J)
        IF(DFCT(J).GT.0.) IFLG=1
    4   CONTINUE
C     IBUG=3
C     IF(IRPD.EQ.3) WRITE(6,5000) IBUG
      IF(IFLG.NE.1) GO TO 76
        DO 6 I=1,NPAR
          DO 5 J=1,NLUC
          ACMIN(I,J)=0.
          AMXSFT(I,J)=DMXSFT(J)
    5     CONTINUE
    6   CONTINUE
C     IBUG=4
C     IF(IRPD.EQ.3) WRITE(6,5000) IBUG
```

154

```
0033            7 READ(8,900,END=8) I,J,AMXSFT(I,J)
0034              GO TO 7
0035            8 READ(16,900,END=9) I,J,ACMIN(I,J)
0036              GO TO 8
0037            9 IT=0
          C       IBUG=5
          C       IF(IRPD.EQ.3) WRITE(6,5000) IBUG
0038           10 IT=IT+1
0039              REWIND 13
0040              L=0
          C       IBUG=6
          C       IF(IRPD.EQ.3) WRITE(6,5000) IBUG
0041           15 L=L+1
          C       IBUG=20
          C       IF(IBGF.EQ.1) WRITE(6,5000) IBUG
0042              READ(13,1000) IUN,IUO,PFN,PFO,RNTDF,NE,(ICMBF(I),I=1,NE)
0043              IF(DFCT(IUN)-0.) 16,16,20
0044           16 IF(L.LT.NLINE) GO TO 15
0045              GO TO 50
0046           20 IF(DFCT(IUO).GE.DFCTMX(IUO)) GO TO 16
0047              K=0
0048           25 K=K+1
0049              IPRC=ICMBF(K)
0050              AVAC=CUSE(IPRC,IUO)-ACMIN(IPRC,IUO)
0051              IF(AVAC) 45,45,26
0052           26 ASFTD=AMXSFT(IPRC,IUN)-ASHFT(IPRC,IUN)
          C       IBUG=11
          C       IF(IBGF.EQ.1) WRITE(6,5000) IBUG
0053              IF(AVAC.GT.ASFTD) AVAC=ASFTD
0054              DDX=DFCTMX(IUO)-DFCT(IUO)
0055              AVACP=AVAC*PFO
0056              IF(AVACP.GT.DDX) AVAC=DDX/PFO
0057              ADF=DFCT(IUN)-AVAC*PFN
          C       IF(IPRD.EQ.2) WRITE(6,9000) IT,IUN,IUO,DFCT(IUN),DFCT(IUO),
          C      & IPRC,CUSE(IPRC,IUN),CUSE(IPRC,IUO),ACMIN(IPRC,IUO),AVAC,
          C      & DDX,AVACP,PFO,PFN
          C9000 FORMAT(1X,3I2,2F8.1,I5,6F8.1,2F6.3)
0058              IF(ADF-0.) 30,30,40
0059           30 DFCT(IUN)=DFCT(IUN)/PFN
          C       IBUG=12
          C       IF(IBGF.EQ.1) WRITE(6,5000) IBUG
0060              CUSE(IPRC,IUN)=CUSE(IPRC,IUN)+DFCT(IUN)
0061              ASHFT(IPRC,IUN)=ASHFT(IPRC,IUN)+DFCT(IUN)
0062              ASHFT(IPRC,IUO)=ASHFT(IPRC,IUO)-DFCT(IUN)
0063              CUSE(IPRC,IUO)=CUSE(IPRC,IUO)-DFCT(IUN)
0064              DFCT(IUO)=DFCT(IUO)+DFCT(IUN)*PFO
0065              DFCT(IUN)=0.
0066              GO TO 50
0067           40 CUSE(IPRC,IUN)=CUSE(IPRC,IUN)+AVAC
          C       IBUG=13
          C       IF(IBGF.EQ.1) WRITE(6,5000) IBUG
0068              ASHFT(IPRC,IUN)=ASHFT(IPRC,IUN)+AVAC
0069              ASHFT(IPRC,IUO)=ASHFT(IPRC,IUO)-AVAC
0070              CUSE(IPRC,IUO)=CUSE(IPRC,IUO)-AVAC
0071              DFCT(IUN)=ADF
```

```
0001                 SUBROUTINE CNSTRC
0002                 COMMON/UNVRSL/ CUSE(525,10),ACAL(15),ACRU(15),DFCT(15),RNTS(20),
                    1 ACU(15),TACRS(525),DMXSFT(15),NLUC,NPAR,NLINE,IIMAS,XGO(57),
                    2 FUN(20),FUU(20),NSEC,DSCRT,IER1,IER2,IECHO1,IECHO2,NPRD,
                    3 IPRD,IPDLGT,INVFLG,IFLG,TACU,IOPTU,NLUCX,ACRQMN(15),
                    4 NUSE(15),LFLG,NCOUNT,ICOUNT,ISFLG,NLUCZ,MUSE(15),DFCTMX(15),
                    5 RNTX(15)
0003                 WRITE(6,5555) IPRD,NLUC,NSEC,NPAR
0004            5555 FORMAT('0IN CNSTRC',4I5)
0005                 DO 10 I=1,NLUC
0006                 IF(DFCT(I).GT.0.) WRITE(6,1000) I
0007              10 CONTINUE
0008            1000 FORMAT(///5X,'INSUFFICIENT SUITABLE AREA FOR USE ',I2)
0009                 RETURN
0010                 END
```

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