SENSITIVITY ANALYSIS OF SELECTED LINEAR PROGRAMMING ASSUMPTIONS: A STUDY OF THE STABILITY OF AGRICULTURAL PROJECTIONS IN RIVER BASIN RESEARCH

Thesis for the Degree of Ph. D.
MICHIGAN STATE UNIVERSITY
JOHN EDWARD HOSTETLER
1970

This is to certify that the

thesis entitled

Sensitivity Analysis of Selected Linear Programming Assumptions
A Study of the Stability of Agricultural Projections
in River Basin Research

presented by

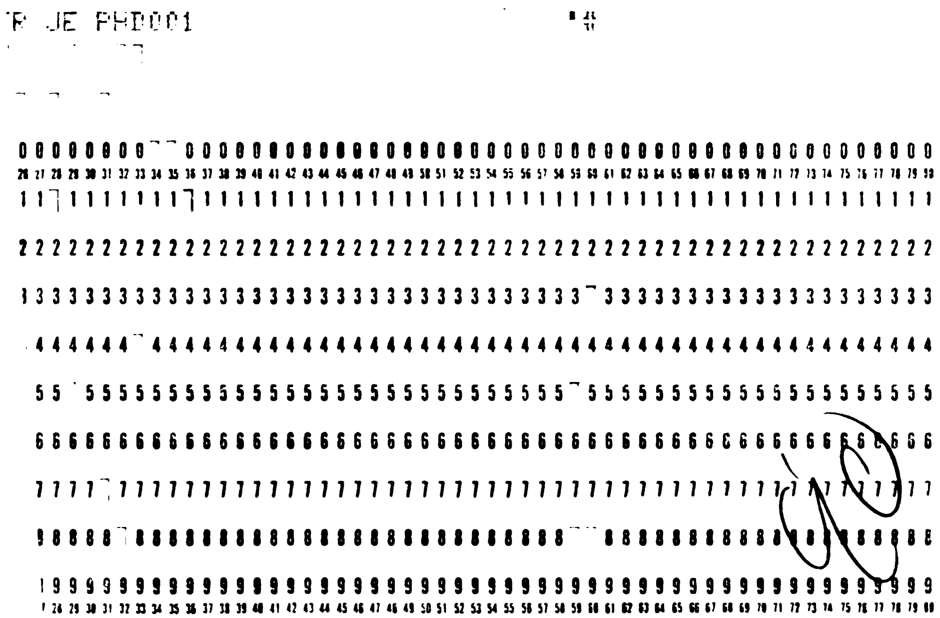
John Edward Hostetler

has been accepted towards fulfillment
of the requirements for

Ph.D. degree in Agricultural Economics

John R. Brake
Major professor

Date November 17, 1970



R JE PHD001

ABSTRACT

SENSITIVITY ANALYSIS OF SELECTED LINEAR PROGRAMMING ASSUMPTIONS: A STUDY OF THE STABILITY OF AGRICULTURAL PROJECTIONS IN RIVER BASIN RESEARCH

By

John Edward Hostetler

Assumptions built into river basin linear programming projection models are subject to errors because of limiting timetables, funds, data or techniques, and these errors have an impact on the resulting estimation of economic potential for water resource development. This study was undertaken to evaluate the extent and direction of such errors associated with certain assumptions used in river basin projection models.

Analysis centered on the sensitivity of 1980 Benchmark Model results to deviations in assumptions relating to: (1) livestock feeding relationships, (2) projected demands, (3) soil management practices, (4) minimum production considerations, and (5) the adopted level of crop producing technology. To test these five classes of assumptions required ninety-three different linear programming solutions reflecting three distinct

levels for each assumption class. Infeasibilities were encountered on eighteen of the solutions. When irrigation opportunities were added to the Basic Model, production possibilities were expanded sufficiently to remove all but one of the previous infeasibilities.

Two procedures for analyzing sensitivity of Benchmark projections were developed. The first relied on total production costs as a broad and readily available general indicator. In the first analysis of sensitivity it was found that certain alternative assumptions were more critical than others in causing variation in the Benchmark cost projections. These cost projections, serving as indicators of sensitivity, identified assumptions concerning livestock feeding relationships, projected demands and technology adoption levels as much more sensitive than assumptions about soil management practices or minimum acreage constraints.

In a similar analysis, where irrigation was included in the 1980 Benchmark Model, almost identical results were produced. The essential difference was that irrigation reduced the general level of total production costs, by $2.5 to $3.2 million, by reducing the number of acres required to meet production objectives.

The second procedure for analyzing sensitivity of Benchmark projections was concerned with "shift points" in the projected economic potential for irrigation. It identified sensitivities of the Model to changes in assumptions as they influence the total projected level of irrigated acreage and its distribution among subareas. Primary concern centered on stability of irrigated acreage projections, both in magnitude and location.

It was observed that the only crop with an economic potential for irrigation was potatoes at Benchmark demand levels. Variations in the assumptions had little or no effect upon irrigated acreage until demands were raised to medium and high levels. Livestock feeding efficiencies at low levels along with low concentrate rations caused substantial increases in irrigated acreage and shifts among subareas. The influence from increasing demand from Benchmark to high levels was seen as irrigated acreage climbed from 20,000 acres to over 2 million acres and a range of crops entered the solution.

Minimum acreage requirements were very effective in controlling irrigated acreage shifts among subareas. Sensitivity of the location of irrigated acreage among subareas was directly related to levels of assumed acreage minimums.

Variations in technology caused moderate sensitivity in total irrigated acreage. Only one subarea was affected by these variations.

The results of both analyses of sensitivity imply that assumptions about soil management practice levels

should be dropped from river basin models unless unusual conditions exist. Such conditions would be a large proportion of sloping soils or a predominance of row crop production.

SENSITIVITY ANALYSIS OF SELECTED LINEAR PROGRAMMING ASSUMPTIONS: A STUDY OF THE STABILITY OF AGRICULTURAL PROJECTIONS IN RIVER BASIN RESEARCH

By

John Edward Hostetler

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Agricultural Economics

1970

ACKNOWLEDGMENTS

The author wishes to express sincere appreciation to Dr. A. Allan Schmid as chairman of the guidance committee and to Dr. John Brake who served as thesis advisor. Their suggestions and constructive criticisms, as well as those of the entire thesis committee, have improved the manuscript significantly.

The assistance of Dr. Myron Wirth of Washington State University, who served as a sounding board for ideas and a strong critic of the manuscript, is greatly appreciated. The review of earlier drafts of the manuscript by Dr. Neil Cook, William Heneberry, and Carmen Sandretto, co-workers in the Natural Resource Economics Division, ERS, is also appreciated.

A debt of gratitude is due Dr. Melvin Cotner, Director of NRE, and Max Tharp, Assistant Director for Field Operations, who provided administrative and technical support as well as financial arrangements for the work.

The author thanks Miss Florence Wright, Mrs. Joan Roby, and Mrs. Ludonna Anderson for their untiring assistance in typing earlier drafts of the manuscript.

Finally, the encouragement and understanding by my wife Beverly, and children Kim, Carrie, and Scott is deeply appreciated. Without their sacrifice this undertaking would not have been completed.

TABLE OF CONTENTS

APPENDICES

Appendix

LIST OF TABLES

Table Page

LIST OF FIGURES

CHAPTER I

INTRODUCTION

The Problem

One of the major recommendations of the Senate Select Committee on Water Resources was that all major river systems in the United States should be thoroughly studied by 1970, and a comprehensive plan of development made for each.[1] The responsibility for initiating and conducting these river basin planning efforts has been assigned primarily to the resource oriented agencies of the Federal Government with the further directive that they work closely with the state and local interests in the study area.[2]

---

[1] In 1959, Senator Robert S. Kerr, as Chairman of the Senate Select Committee on Water Resources, launched a two-year national survey on the nature and extent of existing and future water problems in the country. Probably greatest attention centered on the growing problem of water pollution. All interests and problem areas were covered by the voluminous hearings and reports, however. Of primary interest to anyone seeking information in this area would be the <u>Report of the Senate Select Committee on National Water Resources</u>, Senate Report No. 29, 87th Congress, January 30, 1961, and the thirty-two separate Committee Prints on specific issues.

[2] The four Secretaries most concerned with river basin planning, namely Agriculture, Army, Health, Education

The United States Department of Agriculture, as one of the four departments primarily involved in river basin planning, has assigned certain aspects of each basin study to several of its component agencies. The Economic Research Service is assigned primary responsibility for conducting agricultural economic base studies and analyses of the economic potential for water resource development. Within ERS, the Natural Resource Economics Division (NRED) fulfills this responsibility.

Studies are currently under way in all major river basins of the United States. The first such study (the Ohio) has just recently been completed.[3] Linear programming techniques were used in the Ohio study and they continue to be the main tool of analysis in the other studies.[4] Each new basin survey benefits from experience gained in the advanced stages of earlier surveys.

---

and Welfare, and Interior, were requested by the President to form a Water Resources Council to coordinate the overall progress of the planning effort. They served in an Ad Hoc capacity until the passage of the Water Resources Planning Act, Public Law 89-80, July 22, 1965.

[3] See, U.S. Army Engineer Division, Ohio River-Cincinnati, Ohio, "Main Report of the Ohio River Basin Comprehensive Survey," August, 1969.

[4] Three-quarters of a million dollars have been spent in developing an input-output model at the University of Colorado which is being adapted for use in the Upper and Lower Colorado River Basin studies. Also, Battelle Memorial Institute, under USDA contract, has investigated the feasibility of computer simulation techniques for projecting future economic activity in the agricultural sector of a river basin. Estimated costs of developing a workable model were $500,000 along with a 2-3 year effort

New techniques of analysis are continually being tried and evaluated by staff members of NRED in an effort to improve current procedures. Emphasis has been placed on either cost reduction through respecification of the analytical model, or on improved explanatory ability, through added realism, without greatly increasing the data development costs. Where additional assumptions or refinements in assumptions improve the realism of results, they are incorporated into the projection model. Certain assumptions are made, of necessity, where data do not exist or would be too costly in time or funds to develop and evaluate. But one of the main purposes of assumptions is to make the analytical problem more manageable by cutting down on the number of variables that must be evaluated.

Assumptions built into river basin projection models are subject to errors because of limiting timetables, funds, data or techniques, and these errors have an impact on the resulting estimation of economic potential for water resource development. At this time the extent and direction of these sources of error is not known. Water resource development projects to alleviate various local and basin-wide problems are justified on the basis of

---

by a team of scientists. The currently operational NRED linear programming model will continue to be the most realistic alternative as a tool of analysis for some time in view of budgetary constraints, study time limitations, and immediate need. Therefore, every effort should be made to understand and improve the current procedures.

estimated economic potentials derived in part from these assumptions. If and when these projects receive Congressional authorization for construction, they are undertaken largely through the expenditure of public funds. Therefore, interest in the improvement of projection methodology is of public as well as professional concern. This study examines a selection of some of the most common assumptions currently in use. An attempt is made to determine the effects of these assumptions on the resulting projections.

Objectives and Scope of the Study

Objectives

The central concern of this study is an analysis of typical assumptions underlying the NRED river basin projections, an assessment of the sensitivity of these projections to atlernative assumptions, and an analysis of the effects of these assumptions on the projected economic development potentials for irrigation.

Specifically, the study objectives are:

1. To evaluate selected assumptions made in developing the basic ERS model used in projecting agricultural activity in comprehensive river basin surveys.
2. Analyze the sensitivity of model projections of total costs of production to changes in these assumptions.

3. Evaluate the sensitivity of model projections of locations and acreages of potentially irrigable crops to changes in these assumptions.

Realization of these objectives will provide a basis for general evaluation of some of the typical assumptions river basin investigators are required to make in carrying out their studies. It will also identify which model specifications and assumptions are most critical in river basin projection work, which assumptions require more intensive background research, and which are relatively insensitive to large variation with respect to their impacts on analysis results.

Scope

The "NRED 1980 Agricultural Projection Model for Southern Michigan" was chosen as the subject for analysis in this study. The model is a relatively small minimum-cost linear programming construct, readily manipulated and relatively inexpensive to operate in terms of research time and funds.[5] It was designed to analyze a 42-county study area in the lower half of Southern Michigan containing five subareas delineated on a type-of-farming basis. Each

---

[5] The Southern Michigan model has a matrix that is 212 rows by 554 vectors while, in comparison, the Upper Mississippi model is about 850 by 10,000 and the Wabash model is 2,000 by 15,000. With one of the other models, this study would have been prohibitive.

subarea contained severn major soil groupings among which the model allocated twelve overall field crop requirements subject to such constraints as limitations on the full use of certain resources, minimum subarea production requirements, and limited potential physical development of resources. Most of the characteristics of the larger NRED models are contained in the Southern Michigan model. Thus, the relationships which develop from an analysis of this small model will have general application to the larger models currently being used and to others that may be developed which also contain the same characteristics.

With the beginning of the Ohio River Basin Comprehensive Survey in 1963, a decision was made to utilize the least-cost linear programming model.[6] Considerable time and effort at the NRE Division level have gone into evaluating alternative projection techniques for use in river basin analysis.[7] There continues to be interest and

---

[6] An operational linear programming model, oriented to the identification of water resource development potential and likely future cropping patterns in a river basin context, was first developed by NRED for use in the Texas study. For a discussion of the methodology behind this model, see, A Methodological Supplement to "Resource Requirements for Meeting Projected Needs for Agricultural Production, Texas River Basins," prepared for United States Study Commission--Texas, by Farm Economics Division, ERS, USDA, 1962. Since the model and experience in its operation had already been developed in the Division, it was logical to turn to this source for analytical tools in 1963 rather than try to develop new techniques in view of the time constraints imposed by various phases of the Ohio study.

[7] See, for example: Stanley F. Miller and Albert N. Halter, "Simulation Systems in Making Water Resource

effort directed toward adapting other techniques, such as input-output analysis or simulation, for use in river basin analysis. But, it appears that the current analytical tool of the Division will be in use for some time. This study focuses on potential improvements in that technique.

The Research Format

The overall research format of the study consists of an analysis of the results of a cost-minimizing linear programming model used in river basin planning, and the impact that variations in selected model assumptions have on those results. Projected 1980 agricultural activity in a 42-county subregion of Southern Michigan serves as a benchmark against which alternative formulations of model assumptions are examined. The Benchmark solution reflects an absence of irrigation, drainage or flood protection beyond the current level. The sensitivity to changes in Benchmark Model assumptions are evaluated in terms of the

---

Decisions," Proceedings, Committee on Economics of Water Resource Development, Western Agricultural Economic Research Council, San Francisco, California, December, 1965; Albert N. Halter and Stanley F. Miller, "River Basin Planning: A Simulation Approach," Oregon Agricultural Experiment Station Special Report 224, November, 1966; Stanley F. Miller and Albert N. Halter, "Computer Simulation of the Substitution Between Project Size and Management," *American Journal of Agricultural Economics*, LI, No. 5 (December, 1969), 1119-1123; Neil E. Harl, "Research Methods Adaptable to Legal-Economic Inquiry: Linear Programming and Simulation," in *Methods for Legal-Economic Research into Agricultural Problems*, Agricultural Law Center Monograph No. 8, University of Iowa, 1966; Battelle Memorial Institute, "The Usefulness of Computer Simulation for River Basin Analysis," Research Report to NRED, ERS, USDA, March, 1967.

impact upon total costs of meeting production objectives. Later, an irrigation development alternative is introduced into the Benchmark Model as a matrix extension and similar comparisons are made of deviations arising from model assumption variations. Additional sensitivity analysis examines the identification of economic potential for irrigation, its location and extent. In that analysis the deviations from Benchmark assumptions that cause shifts in irrigated acreage among subareas are evaluated. Because of the limited scope of this study, only agricultural irrigation is included as a water resource development alternative. Agricultural drainage and flood protection are also important considerations and would be included in a more comprehensive analysis.

CHAPTER II

ANALYTICAL APPROACH AND FRAMEWORK OF THE STUDY

Analytical Approach

The future agricultural use of land and water resources in a particular river basin will reflect the kinds of food and fiber products that consumers demand and the competitiveness of basin farmers in meeting such demands. Basin farmers produce for both national and foreign markets and must compete with other basins and regions in the production of agricultural commodities. In so doing, the future productivity of the agricultural land base will have a major impact upon the amount and kind of agricultural production forthcoming from a river basin. Several non-agricultural uses of land, such as urban-related, recreation, and transportation development also have a bearing on land availability for agricultural production.

The general analytical approach used in this study is similar to that employed by NRED in their standard river basin studies. It represents an attempt to project the output of an area by assessment of the following three components that affect output:

1. The determination of demand for agricultural products from the basin.
2. The determination of the quantity and productive capacity of the land resource (supply).
3. The estimation of the amount, kind and location of agricultural production in the basin, reflecting current and potential water resource developments (given demand and supply conditions).

Demand for Agricultural Products

The estimated demand for agricultural products is based upon national population projections and the expected per capita consumption rates of agricultural products. Trends in per capita meat, cereal, and dairy product consumption were developed from commodity studies made by the USDA. Estimated per capita consumption multiplied by projected population in addition to net export requirements provided estimated national demand.[8]

A portion of the national demand was allocated to the study area, a 42-county subregion in Southern Michigan.

---

[8] Demand estimates used in this study were developed by ERS. These data are reported in unpublished memoranda dated March 29, 1965, developed by the Economic Framework Section, River Basin and Watershed Branch, Resource Development Economics Division, ERS, USDA, cooperatively with the Economic and Statistical Analysis Division, ERS. Current estimates are made by the Resource Data Systems Group, Natural Resources Economics Division, ERS.

The allocation was thought to be consistent with productive efficiency in other parts of the country, being founded upon existing trends in regional production. Commodity specialists in the Marketing Economics Division, ERS, USDA made estimates of regional shifts in production based on relative efficiencies of production in the various regions. Given the Subregional share of national food and fiber requirements the problem was one of determining where the production would likely locate within the Subregion based on comparative advantage and resource potentials.

Productive Capacity of Land Resources

The soil resource provides the physical basis for the Benchmark Model. Over the length of the projection period, land in its various forms was assumed to be the only limiting resource at the Subregional level. Land resources were divided into seven soil groupings on the basis of similarities in yield response to like management practices, soil texture, fertility, and land treatment requirements (Appendix Table C-1).

The Inventory of Soil and Water Conservation Needs was used in determining the productive potential of the resource base.[9] This source identified the kind and

---

[9] Michigan Conservation Needs Committee, "An Inventory of Michigan Soil and Water Conservation Needs," Michigan State University, Agricultural Experiment Station, October, 1962.

acreage of soils within the Subregion and provided the base for projecting cropland available for agricultural production in future time periods.

Certain reductions were made in the agricultural resource base. They reflect the impact of such nonfarm uses as urban-residential, industrial, commercial, recreational, and transportation needs for the land. Further reductions were made to account for land requirements of minor and specialty crops. The remaining acreage of cropland and pasture was assumed to be available to farm operators for agricultural production.

Crop enterprises were developed for each soil grouping with the help of crop and soils specialists. Projections were made of the yield potential of all major crop and pasture uses of each soil grouping. These estimates were derived in cooperation with Michigan Agricultural Experiment Station and Soil Conservation Service specialists, and represent expected average yields that reflect the normal climatic, disease, and insect hazards expected to affect future yields. The projected yields take into account the improvements in technology applied to crop production, but do not include the gains obtainable through water resource development programs such as irrigation, drainage, and flood protection. The irrigation development aspects are discussed at length in a later section. Other water resource development alternatives are not considered in this study, but they may be equally as important.

In addition to projected yield information, production costs were developed for each crop grown on a particular soil grouping. These costs reflect all fixed and variable costs incurred in land preparation, cultivation, and harvesting and account for such materials as seed, fertilizer, lime, twine, pesticides, etc. However, they do not account for land charges, transportation, or storage costs. They represent only the on-farm costs of production.

Location of Agricultural Production

Estimation of the amount, kind, and location of agricultural production was accomplished through the use of minimum-cost linear programming techniques. The demand side provided estimates of the future agricultural products required from the Subregion while the supply side indicated future crop and pasture productive capacity of the soils available for agricultural production. Given the demand and supply potential, the Benchmark Model selected appropriate acreages of each soil that most efficiently met production requirements within the constraints placed on the model.[10]

---

[10] A much more detailed discussion of the procedures used in this methodology is available in Appendix 0--Economic Base Study-Part IV, Comprehensive Water Resources

The Basic Linear Programming Model

The Linear Programming Format

The theoretical basis of the projection model has its grounding in the Iowa State interregional analysis work pioneered by the Egbert-Heady team and more recent modifications.[11] However, the model used in river basin analysis is regional in construction while the Iowa models are national in scope.[12]

The basic model used for the Subregion in this study is concerned with 5 subareas, 12 crops, and 7 soil groupings. The objective of the basic model is to minimize

---

Study, Grand River Basin, Michigan, January, 1966. See also Melvin L. Cotner, "The Potential Role of Agricultural Land Drainage in Economic Growth," unpublished Ph.D. thesis, Michigan State University, 1967.

[11] See for example: A. C. Egbert and E. C. Heady, Regional Adjustments in Grain Production, A Linear Programming Analysis, U.S. Department of Agriculture, Bulletin No. 1241 and Supplement, June, 1961; Egbert and Heady, Regional Analysis of Production Adjustments in the Major Field Crops: Historical and Prospective, USDA Technical Bulletin No. 1294, 1963; Egbert, Heady and Brokken, Regional Changes in Grain Production, An Application of Spatial Linear Programming, Agricultural and Home Economics Experiment Station, Iowa State University, Research Bulletin 521, January, 1964; and recently, Whittlesey and Heady, Aggregate Economic Effects of Alternative Land Retirement Programs: A Linear Programming Analysis, ERS, USDA, in cooperation with the CAED, Agricultural and Home Economics Experiment Station, Iowa State University, Technical Bulletin No. 1351.

[12] The Resource Data Systems Group, NRED, ERS, is currently developing a national river basin model that also encompasses the entire United States and has the seventeen major river systems as its subregions.

subregional on farm costs of production. The objective function is:

Minimize:

$$Z = \sum_{i=1}^{7} \sum_{j=1}^{12} \sum_{k=1}^{5} C_{ijk} X_{ijk}$$

Subject to the following constraints:

$$\sum_{i=1}^{7} \sum_{k=1}^{5} a_{ijk} X_{ijk} \geq b_j \qquad \text{for } j - 1, 2, \ldots, 12$$

$$\sum_{ij}^{7} a_{ij} X_{ijk} \geq g_{j,k} \qquad \text{for } j = 1, \ldots, 12 \text{ and } k = 1, \ldots, 5$$

and

$$\sum_{j=1}^{12} d_{i,j} X_{ijk} \leq S_{i,k} \qquad \text{for } i = 1, 2, \ldots, 7 \quad k = 1, 2, \ldots, 5$$

and

$$X_{ijk} \geq 0 \qquad \text{for all } i, j, \text{ and } k$$

Where:

Z: total cost of production

C_{ijk}: cost of producing an acre of crop j on soil i in subarea k

X_{ijk}: the number of acres of the activity producing crop j on soil i in subarea k

a_{ijk}: a coefficient expressing output of j in terms of an acre of soil i in subarea k

b_j: subregional production requirements of crop j

g_{jk}: minimum production requirement of crop j for subarea k

d_{ij}: quantity of land resource i used in producing an effective acre of activity j

$r_{i,k}$: quantity of soil group i available in subarea k

$S_{ik} = r_{ik} - P_{i,k}$

$P_{i,k}$ = restriction placed on the full use of soil group i in subarea k to reduce soil loss

The optimal solution to the linear programming problem is a summation of the least costly means of producing specified quantities of twelve crops on seven soils within the Subregion's five subareas ignoring public resource development costs. The first set of constraints (b_j) establish minimum Subregion production requirements for each of the twelve crops considered by the model. The model is further constrained (g_{jk}) to ensure a minimum level of production of each crop within all subareas. Constraints of the form (S_{ik}) establish upper bounds on the availability of soil resources within subareas. Certain crops are not allowed full use of soil resources (P_{ik}) as a means of reducing erosion. The final constraint ($X_{ijk} \geq 0$) ensures that the solution will have positive values.

Typical Linear Programming Assumptions and Constraints

In any linear programming problem, it is necessary to make several simplifying assumptions that reduce the problems of data collection and machine computation to a manageable size. It has been the opinion of most model builders that these assumptions do not detract greatly from the realism of an investigation, but allow the development of sufficiently detailed models to meet research objectives.

The basic assumptions which have been established for most least-cost linear programming river basin models are:

1. The special distinguishing characteristics of the area under study can be represented by spatially separated and independent producing regions, each of which is internally homogeneous, whether it be major river basins in a national model, sub-basins of large basin studies or the five types of farming subareas used in this study.
2. Land within a soil management grouping within a subarea is a homogeneous factor and all crops may compete for it.
3. Cropland area is the limiting factor of production for each subarea.

4. Potential cropping activities for a subarea are determined by cropping history, climatic factors, and soil limitations.
5. Constant returns per acre of a given soil management grouping are assumed regardless of the output level.
6. Farm operators will minimize costs in their choice of the crops to be grown on particular soils.
7. Subregional demands for food, feed, and fiber, including domestic and foreign export requirements, are exogenously determined and known.
8. Resources can be used and products produced in quantities which are fractional units.
9. Resource supplies, input-output coefficients, and prices are assumed to be known.

Partial Matrix Example--The Southern Michigan 1980 Benchmark Model

While the presentation of model specifications in equation form is a very efficient descriptive means from the viewpoint of the mathematically inclined reader, this method presents certain difficulties for others. Not only is a tabular representation more readily understood by non-mathematicians, it may also present a clearer understanding of the relationships to mathematicians as well.

Thus, a sample segment of the matrix from the Benchmark Model is included and discussed briefly to provide a clearer understanding of its use in the study.

A partial matrix of the Southern Michigan 1980 model was selected to show how two subareas, three soils, and three commodity demands would appear when constrained by production mimima and faced with an irrigation development alternative for one of the subareas (Table 1). The projection year of 1980 is a nationally established target date for river basin studies and provides a time frame within which to assess early action programs.

All of the characteristics of the complete model are represented in partial form by the example except for the constraints (actual right-hand side values of the table). This discussion may help those who are not familiar with linear programming to visualize some of the internal workings of the model and how a particular program is "set up."

Beginning with the left-hand side of Table 1, each row in the matrix is identified with a specific name that must only appear once if the logic of the system is to be maintained. The center and major part of the matrix contains all activities which compete among themselves in deriving the least-cost solution to the particular problem. Each of these activities is developed on a per-acre basis.

TABLE 1.--Sample partial matrix of the Southern Michigan 1980 Model with right-hand side

Row Identification	Activities												
	Subarea 1 Soil 1			Subarea 1 Soil 2			Subarea 1 Soil 3			Subarsa 2 Soil 1			Sub-
	WHT	CRN	SBS	WHT	CRN	SBS	WHT	CRN	SBS	WHT	CRN	SBS	WHT
Cost	42.32	54.24	33.60	42.30	48.37	33.60	41.71	45.75	33.56	42.30	54.24	38.21	42.30
(Demands)													
TDWHT	48.00			49.00			47.00			49.00			50.00
TDCRN		106.00			99.00			89.00			107.00		
TDSBS			31.00			30.00			30.00			32.00	
(Subarea 1 Resources)													
ACMG1	1.02	1.04	1.04										
ACMG2				1.02	1.04	1.04							
ACMG3							1.02	1.04	1.04				
RLMG1		1.04	1.04										
RLMG2					1.04	1.04							
RLMG3								1.04	1.04				
(Production Minimum)													
PWHT1	1.00			1.00			1.00						
PCRN1		1.00			1.00			1.00					
PSBS1			1.00			1.00			1.00				
(Subarea 2 Resources)													
ACMG1										1.02	1.04	1.04	
ACMG2													1.02
ACMG3													
RLMG1											1.04	1.04	
RLMG2													
RLMG3													
(Production Minimum)													
PWHT2										1.00			1.00
PCRN2											1.00		
PSBS2												1.00	
(Subarea 1 Irrigation)													
IACG1													
IACG2													
IRLG1													
IRLG2													

Activities												
area 2 Soil 2		Subarea 2 Soil 3			Subarea 1 Soil 1			Subarea 1 Soil 2				Constraints
CRN	SBS	WHT	CRN	SBS	IWHAT	ICRN	ISBS	IWHT	ICRN	ISBS	Sign	
54.14	38.21	41.71	48.68	33.56	82.60	110.70	81.11	88.37	114.26	81.11		Minimize
		46.00			68.00			80.00			≥	27,668,470 bu.
103.00			91.00			161.00			172.00		≥	109,882,282 bu.
	31.00			30.00			45.00			46.00	≥	11,194,720 bu.
					1.02	1.04	1.04				≤	11,854 ac.
								1.02	1.04	1.04	≤	180,718 ac.
											≤	150,301 ac.
						1.04	1.04				≤	8,891 ac.
									1.04	1.04	≤	143,996 ac.
											≤	136,746 ac.
					1.00			1.00			≥	18,988 ac.
						1.00			1.00		≥	48,321 ac.
							1.00			1.00	≥	43,057 ac.
1.04	1.04										≤	56,572 ac.
		1.02	1.04	1.04							≤	593,511 ac.
											≤	245,888 ac.
1.04	1.04										≤	41,818 ac.
			1.04	1.04							≤	511,310 ac.
											≤	213,431 ac.
		1.00									≥	66,187 ac.
1.00			1.00								≥	86,495 ac.
	1.00			1.00							≥	8,742 ac.
					1.02	1.04	1.04				≤	8,254 ac.
								1.02	1.04	1.04	≤	148,818 ac.
						1.04	1.04				≤	5,291 ac.
									1.04	1.04	≤	112,096 ac.

On the right-hand side of the example are the constraints within which the problem must be solved. Each value on the right-hand side corresponds to a particular row name on the left-hand side and the sign indicates the type of constraint being imposed on the model. The objective is to minimize total cost of production for the two-area Subregion subject to the limitations imposed by the constraints listed for each row.

The first row in the matrix is reserved for per-acre production costs. Each crop capable of being grown on a particular soil in each subarea is represented in the cost row by a production cost. Following the cost row is a section of total demands facing the Subregion, represented in this example by wheat (TDWHT), corn and soybeans. Next listed are the resources available for production in Subarea 1, available cropland in management group 1 (ACMG1) 2, and 3 soils, and the row crop limitation on the same soils (RLMG1). The right-hand side (constraints column) indicates the values corresponding to each row of the matrix, such as the number of acres of each soil that are available for production.

Each subarea has a commitment to produce a minimum acreage of each crop. This is expressed by minimum production rows, for example to produce wheat in Subarea 1 (PWHT1). The process repeats itself for each subarea and is expanded to cover all twelve crops and seven soil groupings.

Introduction of the irrigation development activity takes place at the end of the matrix as a simple extension to the existing activities. Irrigated available cropland (IACG1) and the irrigation row crop limits (IRLG1) are more restrictive than those imposed on the total resources since not all land can be effectively irrigated.

It may be instructive to trace one or two activities through the matrix to see what effect each coefficient has on the model. For instance, in Subarea 1 (soil management grouping 2) the activity producing wheat costs $42.30 per acre and contributes 49 bushels toward the total Subregion wheat requirement of 27,668,470 bushels. For each acre of wheat produced, 1.02 acres of the 180,718 acre total soil resource are planted so that one acre of wheat may be harvested. This activity also contributes, on a one for one basis, an acre of wheat toward the minimum acreage required of the Subarea.

The same process is followed for an irrigated activity except that there are additional resources which are drawn upon if one of these activities enters the solution. For instance, in the production of irrigated soybeans on Soil 2, $81.11 is spent to produce 46 bushels; but 1.04 acres of cropland are used of that available for general production, row crops, and irrigation. Also, the production of an acre of soybeans on this soil contributes to both the total production and subarea minimum requirements.

Given the inputs to the model as illustrated by the partial matrix (Table 1), the least-cost linear programming technique is an iterative process (typically done by computer) for finding that combination of resources and activities that will produce the required output at the lowest cost subject to the conditions set forth in the matrix. The selection criterion for choosing among soil resources and subareas are unit production costs. It must be made clear that the particular ordering of activities and rows chosen for this model does not represent the only possible arrangement. Only the cost row is inflexible, it must be the first row in the matrix. The remainder may be in any sequence as long as the logical order is followed consistently throughout.

CHAPTER III

CHARACTERISTICS OF THE STUDY AREA AND BENCHMARK RESULTS

General Characteristics of the Subregion

Description of Study Area

The Southern Michigan Subregion consists of a 42-county area in Lower Michigan (Figure 1). This Subregion had been divided into five subareas on a type of farming basis for the Lake States Dairy Study.[13] The same breakdown was adopted for this study to draw upon data available from that study. Subarea 1 comprises five intensively farmed counties surrounding metropolitan Detroit. Subarea 2 consists of five cash crop counties in the "Thumb." Subareas 3 and 4 include twenty-three general farming and livestock producing counties in the center of the Subregion, while Subarea 5 includes nine counties near Lake Michigan producing poultry, fruit, and vegetables.

---

[13] D. E. McKee, et al., "Equilibrum Analysis of Income Improving Adjustments on Farms in the Lake States Dairy Region, 1965," University of Minnesota Technical Bulletin 246, October 1963.

Fig. 1.--Map of Michigan, 42 county Subregion and five Subareas

Soil Resource Availability

In developing the Benchmark Model, the location and productivity of soils were important factors in estimating productive potentials of the subareas. All cropland and pasture soils were converted to soil management groupings which combined soil series and capability units on the basis of soil texture and natural drainage profiles.[14]

Acreages of cropland and pasture were reduced by nearly 11 percent to account for non-farm uses and the growing of minor crops (Appendix Tables C-2, C-3, and C-4). The remainder was considered as available for production of major field crops and pasture to meet projected demands under the model assumptions.

Cropland distribution indicates that Subarea 5 predominates in coarse textured soils, Subarea 4 in finest texture, while Subarea 2 clearly exceeds all others in loams--the most productive soil grouping. Subarea 1, because of its highly urbanized nature, has only a small quantity of mainly fine to medium textured soils. Pasture

---

[14] These large groups were based on the cooperative work at Michigan State University between the U.S. Soil Conservation Service and the Michigan Agricultural Experiment Station. Both organizations use the soil management groups as a basis for recommending conservation and production practices that have general applicability to the combined soils of a particular management group. Appendix Table 1 lists in greater detail the general characteristics of the soil management groups in each large grouping.

acreage is concentrated in Subareas 3 and 4 (Appendix Table C-5.

Crop and Livestock Production Trends

In general, only four of the eleven major field crops considered in the study increased acreage from 1959 to 1964; corn silage, soybeans, dry beans, and alfalfa hay (Appendix Table C-6). Potato acreage held nearly constant while the remaining crops declined substantially. Changes in production of livestock and livestock products during the same period varied with cattle, dairy, and poultry products other than chickens increasing while hogs and pigs, sheep and lambs, and chickens declined (Appendix Table C-7).

Results of the 1980 Benchmark Model

The Benchmark Model (least cost programming model) was developed for the Southern Michigan Subregion to identify what the pattern of cropland use would likely be in projected time periods under the assumption of no additional water resource developments and continued emphasis on efficiency in resource use. The Benchmark Model represents the probable cropping pattern that would result from the most efficient use of land resources once certain restrictions are met. These restrictions include provisions that: (1) one-half of the acreage necessary to produce each crop be distributed within the subareas on the basis of historical production patterns, (2) the use of cropland for row crops be restricted to something less than continuous use depending upon the slope, texture, and drainage characteristics of the particular soil.

Projected Production of Major Crops

Availability and Use of Cropland

Benchmark projections of soil resource use indicate considerable variability among subareas. Those areas that were predominantly agricultural are projected to remain so while the urbanizing areas are expected to experience decline in agricultural activity (Table 2). Of the projected 7.2 million acres of cropland available for use in 1980, only slightly more than 4 million were projected for production of major field crops. But such use of cropland depends upon the qualifying assumption that all permanent pasture acreage would be utilized in partially meeting overall pasture requirements.

Within the Subregion, approximately 55 percent of the available cropland is expected to be utilized to produce major field crops in 1980. Major field crops can be separated into row crops and close growing crops. Row crops require spacing for purposes of cultivation and include corn, soybeans, potatoes, and dry beans. Close growing crops require no cultivation and include the hays, pasture, and small grains like wheat and oats.

TABLE 2.--Availability of cropland and Benchmark projection of use for major crops in 1980, by subarea, Southern Michigan Subregion

Resource Availability and Use	Subarea					Total Subregion
	1	2	3	4	5	
			1,000 acres			
Total available cropland	511.7	1,631.2	2,081.8	1,656.9	1,367.5	7,249.1
Actually utilized[a]	223.2	1,510.0	937.1	1,043.0	305.2	4,018.5
Available for row crops	449.1	1,473.6	1,597.4	1,324.8	1,052.9	5,897.8
Actually utilized	101.8	637.5	275.6	808.2	129.9	1,953.0
Minimum production required	150.7	422.0	599.8	477.2	196.2	1,845.9
Actually produced[a]	218.6	1,475.1	921.0	1,009.1	299.0	3,922.8
Permanent pasture available	56.4	148.4	328.8	371.1	129.7	1,034.4
Actually utilized	56.4	148.4	328.8	371.1	129.7	1,034.4

[a] The difference between the acreage utilized and produced represents planted but not harvested acreage which varies by type of crop.

Only one-third of the cropland available for row crop production would be expected to be utilized for that purpose. It is projected that Subarea 1, long an area of decline in agricultural importance, will continue the downward trend with only 44 percent of the cropland required and only half that percentage for row crops. Southwestern Subarea 5 would be relatively under-utilized because larger quantities of the lower producing soils are not required to meet the level of production specified by the Benchmark. Close growing crops would predominate in Subarea 3, which lies between 1 and 5 both physically and in terms of production; row crops would occupy 17 percent and all crops 45 percent of cropland available for these uses. Three-fifths of all acreage available for row crop production in Subarea 4 would be utilized for that purpose, significantly larger than the next most important subarea. The proportion of all production devoted to row crops would also be large--about 80 percent in Subarea 4. Close growing crops would predominate in Subarea 2 where nearly 93 percent of all cropland is expected to be in production with intertilled crops accounting for 43 percent.

Subregional Demand Requirements and Production

Projections indicate that corn will continue to be the dominant field crop in the Southern Michigan Subregion in 1980 as it was in 1964 (Table 3). More than a

TABLE 3.--Benchmark projections of demand requirements for 1980 compared with 1964 production levels, Southern Michigan Subregion

Crop	Units	1964	Benchmark 1980	Percentage Change
Wheat	bu.	32,890,100	27,668,500	-15.8
Corn	bu.	72,780,000	109,882,300	50.9
Oats	bu.	26,379,500	20,233,000	-23.3
Barley	bu.	1,065,700	2,697,700	153.1
Soybeans	bu.	5,181,600	11,194,700	116.0
Dry Beans	cwt.	7,645,400	8,202,200	7.2
Potatoes	cwt.	5,470,200	11,960,000	118.6
Corn Silage	ton	3,069,500	2,672,300	-12.9
Alfalfa	ton	2,279,100	1,563,600	-31.3
Other Hay	ton	289,100	337,200	16.6
Cropland Pasture	AUD[a]	87,028,500	116,228,500	33.5

Source: Census of Agriculture 1964, and working data for the report, "Agricultural Activity in the Grand River Basin: A Projective Study, NRED, ERS, USDA, January, 1966.

[a] One animal unit day (AUD) is equivalent in feeding value to fifteen pounds of corn. No attempt is made to identify permanent pasture production in 1964, although 90 million AUD's are projected for 1980 in the Benchmark.

50 percent increase in production is expected to occur during that time period. Declines from 1964 levels are expected in the production of wheat, oats, corn silage (as an increasing proportion of all corn is produced as corn for grain), and alfalfa hay, while sizeable increases are expected for soybean and potato production. The projections for barley production indicate a significant increase from 1964 to 1980; the extent of the increase is exaggerated by the fact that 1964 production was abnormally low.

On a subarea basis, the acreage required to meet projected needs declined in all but Subarea 2 (Table 4). Acreage required per crop increased for soybeans and potatoes and declined for all others. Subarea 1 indicates an increase in acreage of cropland pasture and also the relative share of acreage in alfalfa. Potato acreage projections show gains both relatively and absolutely in Subarea 5 with a general decline occurring in the harvested acreage of all other major field crops. Although the harvested acreage in Subarea 4 is projected to decline somewhat, the relative share overall shows a 2 percent gain because of the nearly 180 percent increase in corn acreage. Projections for barley, soybeans, and pasture acreage show increases in Subarea 3, but the relative share for these crops of total major crop acreage declines about 5 percent. Subarea 2 is expected to increase its

TABLE 4.--Benchmark projection of harvested acreage for 1980 compared with 1964, by subarea, Southern Michigan Subregion[a]

Crop	Subarea 1		Subarea 2		Subarea 3		Subarea 4		Subarea 5		Total	
	1964	1980	1964	1980	1964	1980	1964	1980	1964	1980	1964	1980
					1,000 acres							
Wheat	79	19	183	335	239	83	174	65	135	38	810	540
Corn	121	48	193	86	420	164	221	615	284	87	1,239	1,002
Oats	41	11	137	107	147	76	80	32	81	16	486	242
Barley	1	1	7	7	6	29	2	2	6	6	22	45
Soybeans	87	43	5	200	59	62	51	49	34	24	236	378
Dry Beans	6	1	238	237	73	17	270	90	2	0	589	344
Potatoes	3	2	2	15	4	2	17	10	3	4	29	33
Corn Silage	20	4	73	76	85	21	58	13	46	9	282	123
Alfalfa	67	15	220	265	300	73	233	49	168	38	988	439
Other Hay	13	4	49	71	45	15	40	12	41	13	188	116
Crop Pasture	45	71	175	76	211	378	192	72	146	64	769	662
Total Use	484	218	1,282	1,475	1,589	921	1,339	1,009	947	299	5,638	3,922

Source: Census of Agriculture 1964, and Benchmark solution.

[a] Projections assume full utilization of permanent pastureland. See Appendix Table C-8 for comparisons where this assumption was removed.

relative share by 15 percent as the harvested acreage of all but feed grains and pasture show significant gains.

Benchmark projections show that acreages required to produce many of the major field crops in 1980 decreased in some subareas and even in the Subregion. However, the production from those acres, in many instances, increases sufficiently to more than compensate for the acreage decline (Table 5). For instance, although the harvested acreage of soybeans is projected to decline by 11,000 in Subareas 4 and 5, the production in those two areas increases by about 365,000 bushels. Corn production gains by 50 percent in the face of a 19 percent acreage decline and the production of potatoes more than doubles with only a 13 percent acreage increase.

Projected yield increases of substantial magnitude in all subareas are responsible for these production improvements (Table 6). In general, the largest increases occur in corn, corn silage, and potato yields. The projected 1980 yields represent the use of the most productive soils available which are generally more efficient than the less productive soils on a per unit cost of production basis. If all soils were used in 1980, the resulting yield levels would undoubtedly be much lower.

TABLE 5.--Benchmark projection of major field crop production in 1980 compared with 1964, by subarea, Southern Michigan Subregion[a]

Crop	Units	Subarea 1		Subarea 2		Subarea 3		Subarea 4		Subarea 5		Total	
		1964	1980	1964	1980	1964	1980	1964	1980	1964	1980	1964	1980
						1,000 units							
Wheat	bu.	3,008	930	7,994	16,745	9,602	4,981	7,542	3,177	4,745	1,836	32,890	27,669
Corn	bu.	7,720	4,784	12,260	9,070	24,624	16,690	15,014	70,938	12,162	8,402	72,780	109,884
Oats	bu.	2,492	828	8,142	9,005	8,548	6,715	3,689	2,497	3,508	1,187	26,380	20,233
Barley	bu.	40	41	374	449	289	1,719	91	138	272	351	1,066	2,698
Soybeans	bu.	2,001	1,300	100	5,992	1,339	1,790	1,159	1,375	582	736	5,182	11,195
Dry Beans	cwt.	64	21	3,001	5,768	731	400	3,831	2,005	19	8	7,645	8,202
Potatoes	cwt.	636	603	299	5,734	778	815	3,230	3,295	527	1,512	5,470	11,958
Corn Silage	ton	232	86	769	1,663	974	434	638	290	457	200	3,070	2,672
Alfalfa	ton	156	63	475	882	763	278	501	191	384	149	2,279	1,564
Other Hay	ton	21	12	72	207	73	44	62	36	62	38	289	337
Crop Pasture	AUD	5,110	14,145	19,731	13,183	23,873	65,441	21,756	12,452	16,558	11,004	87,028	116,226

Source: Census of Agriculture 1964, and Benchmark solution.

[a] Projections assume full utilization of permanent pasture land. See Appendix Table C-9 for comparisons where this assumption was removed.

TABLE 6.--Benchmark projected yields of major crops in 1980 compared with 1964, by subarea, Southern Michigan Subregion[a]

Crop	Unit	Subarea 1		Subarea 2		Subarea 3		Subarea 4		Subarea 5		Total	
		1964	1980	1964	1980	1964	1980	1964	1980	1964	1980	1964	1980
Wheat	bu.	38.3	50.0	43.7	50.0	40.2	60.0	43.4	49.4	35.2	48.0	40.7	51.2
Corn	bu.	64.0	99.0	63.5	104.9	58.6	101.6	67.9	115.3	46.3	96.6	58.7	109.7
Oats	bu.	60.4	77.0	59.4	84.0	58.2	88.0	46.1	79.0	43.4	75.0	54.3	83.7
Barley	bu.	42.5	56.9	51.7	65.0	45.4	59.0	45.9	64.0	42.2	60.0	46.4	60.3
Soybeans	bu.	23.0	30.2	19.2	30.0	22.6	29.0	22.7	28.0	17.2	30.0	21.9	29.6
Dry Beans	cwt	10.0	24.6	12.6	24.4	10.0	24.0	14.2	22.4	8.3	24.1	13.0	23.8
Potatoes	cwt	185.0	327.8	142.9	383.0	199.4	359.0	194.7	342.5	185.6	367.0	189.5	364.4
Corn Silage	ton	11.3	21.4	10.5	21.9	11.5	21.0	10.9	21.9	9.8	21.4	10.8	21.7
Alfalfa	ton	2.3	4.3	2.2	3.3	2.5	3.8	2.1	3.9	2.3	4.0	2.3	3.6
Other Hay	ton	1.6	3.0	1.5	2.9	1.6	2.9	1.5	2.9	1.5	3.0	1.5	2.9
Crop Pasture	AUD	113.0	198.6	113.0	173.0	113.0	173.0	113.0	172.4	113.0	173.0	113.0	175.7

Source: Census of Agriculture 1964, and Benchmark solution.

[a] The 1980 yields are weighted averages, as are those for 1964, derived by dividing total subarea production by solution acreage. Since yields vary by soil management grouping the variation observed in the table is a result of the relative mix of soils among the subareas.

Cost of Production

Basis for Development

Current input price levels and relationships provided the basis for developing production cost data. Consequently, all costs used and reported by this study are in terms of constant 1964 dollars. Cost budgets were developed with the assistance of specialists at the Ohio and Michigan Agricultural Experiment Stations. All items of on-farm costs were included with the exception of land charges and charges for on-farm storage. Off-farm development costs were ignored. The per acre production costs for each crop and soil were aggregates of four major types of costs: preharvest costs, harvesting costs, cost of materials and overhead charges. These costs were developed by applying an hourly charge against the time required to perform each operation. Tillage operations, equipment size, and performance rates represent better than current average production methods.[15] These production costs and the associated productivities of subarea soils served as the basis for allocation within the Benchmark Model and all additional models developed to analyze the effects of alternative assumptions.

---

[15] For a detailed account of equipment and labor costs used in these budgets, see: Melvin L. Cotner, "The Potential Role of Agricultural Land Drainage in Economic Growth" (unpublished Ph.D. Thesis, Michigan State University, 1967).

Benchmark Model Production Costs

The projected total cost of producing the major field crops specified in the Benchmark was approximately $191.0 million in 1964 constant dollars, including an estimated charge of $14.5 million for permanent pasture (Table 7). Only the on-farm production costs of these crops are represented by this figure. Off-farm transportation and marketing charges are not included nor are the production costs of livestock and minor crops a part.

Nearly 38 percent of the total cost of projected production in the Subregion is incurred in Subarea 2 where about 93 percent of the resources are expected to be committed to major crop production in 1980. Other important agricultural subareas are Subareas 3 and 4 where proportionate shares of 19 percent and 30 percent of the Subregion's costs would be incurred, respectively. Only about 5 percent of all costs would be accounted for in Subarea 1, where 44 percent of available resources are utilized. Eight percent of the costs would be incurred in Subarea 5, although only 22 percent of those resources are used.

The projected distribution of production costs among major crops is generally similar to the projected distribution of acreage used in the production of these crops. There are a few exceptions to this distribution however. Notable among them is the production of potatoes and

TABLE 7.--Benchmark projected total cost of producing major field crops in 1980, by subarea, Southern Michigan Subregion[a]

Crop	Subarea 1	Subarea 2	Subarea 3	Subarea 4	Subarea 5	Subregion
			1,000 dollars			
Wheat	803	14,166	3,894	2,757	1,618	23,238
Corn	2,337	4,687	7,996	32,535	4,254	51,809
Oats	423	4,309	3,068	1,244	609	9,653
Barley	25	262	768	81	213	1,349
Soybeans	1,447	6,703	2,019	1,572	825	12,566
Dry Beans	41	11,324	776	4,152	16	16,309
Potatoes	805	7,254	1,063	4,369	1,945	15,436
Corn Silage	428	8,089	2,129	1,411	995	13,052
Alfalfa	720	8,678	3,296	2,235	1,741	16,670
Other Hay	157	2,778	471	484	488	4,378
Cropland Pasture	1,319	1,388	6,888	1,280	1,158	12,033
Permanent Pasture	790	2,078	4,603	5,195	1,816	14,482[b]
Total Cost	9,295	71,716	36,971	57,315	15,678	190,975

[a] Projections assume full utilization of permanent pasture land. See Appendix Table C-10 for comparisons where this assumption was removed. All values are in terms of 1964 constant dollars.

[b] The total cost of $14.5 million for permanent pasture was an estimate based on average costs for these activities, later added to the model. These costs were added to the solution and were not an integral part of original Branchmark runs.

cropland pasture where potatoes occupy less than 1 percent of the acreage but account for 8 percent of the production costs. Conversely, cropland pasture acreage represents 17 percent of the total but contributes only 6 percent to overall production costs (Tables 4 and 7).

The expected output of corn requires the greatest amount of land--about 26 percent of the acreage--and accounts for nearly 30 percent of all production costs while potatoes occupy the smallest acreage. On a cost per acre basis, potatoes are by far the most expensive crop produced in the Subregion. Potatoes, at $470 per acre, are at one extreme of the spectrum while cropland pasture, averaging just over $18 per acre, is at the other (Table 8). One other crop, corn silage, has a cost of $106 per acre which greatly differs from the typical cost range of $30 to $50 for most crops in the model.

Comparing acreage projections (Table 4) with associated per acre costs (Table 8), causes an apparent inconsistency between the location of production and the lowest per acre costs. But, when the minimum acreage requirements are considered in light of the relative productivities of available soils, it is clear that the per unit production costs are really the important allocators of production among subareas (Table 9). Generally, less than fifteen cents per unit of product separates the highest cost producing area from the lowest for a

TABLE 8.--Benchmark projected cost per acre of producing major field crops in 1980, by subarea, Southern Michigan Subregion[a]

Crop	Subarea 1	Subarea 2	Subarea 3	Subarea 4	Subarea 5	Subregion
			Dollars			
Wheat	42.30	42.30	46.91	42.52	42.30	43.04
Corn	48.37	54.19	48.67	52.86	48.91	51.73
Oats	39.35	40.20	40.20	39.35	38.49	39.94
Barley	34.33	37.87	26.37	37.53	36.34	30.12
Soybeans	33.60	33.56	32.70	32.01	33.60	33.22
Dry Beans	48.02	47.82	46.54	46.39	46.54	47.39
Potatoes	437.50	484.58	468.43	454.13	472.03	470.32
Corn Silage	106.55	106.55	103.04	106.55	106.55	105.96
Alfalfa	48.82	32.79	44.99	45.68	46.39	37.96
Other Hay	38.69	38.95	30.56	38.88	38.88	37.81
Crop Pasture	18.52	18.21	18.21	17.73	18.21	18.19
Average	38.91	47.21	35.14	51.65	46.37	44.99

[a] Represents the average costs of producing a particular crop weighted by the soil management groups entering the solution for a particular subarea. All values are in terms of 1964 constant dollars.

TABLE 9.--Benchmark projected unit costs of producing major field crops in 1980, by subarea, Southern Michigan Subregion[a]

Crop	Unit	Subarea 1	Subarea 2	Subarea 3	Subarea 4	Subarea 5	Subregion
				Dollars			
Wheat	bu.	.863	.846	.782	.868	.881	.846
Corn	bu.	.488	.526	.504	.481	.513	.488
Oats	bu.	.511	.478	.457	.498	.513	.508
Barley	bu.	.603	.582	.447	.588	.606	.447
Soybeans	bu.	1.120	1.119	1.128	1.143	1.120	1.119
Dry Beans	cwt.	1.953	2.053	1.939	2.071	1.930	2.053
Potatoes	cwt.	1.372	1.265	1.305	1.418	1.286	1.310
Corn Silage	ton	4.980	4.865	4.906	4.864	4.978	4.973
Alfalfa	ton	11.350	11.016	11.839	11.712	12.237	11.539
Other Hay	ton	12.907	13.433	13.886	13.398	12.953	13.431
Crop Pasture	10 AUD's	1.029	1.052	1.052	1.035	1.052	1.052

[a] 1964 constant dollars.

particular crop. The least difference in per unit cost of production projections among subareas occurs in crop pasture, while the greatest occurs in alfalfa. This difference is mainly due to the choice of units (1 ton vs. 10 AUD's). Moreover, it should be made clear that the unit cost of production of these major crops may vary significantly with different alternative assumptions, especially those that bring pressure to bear on the resource base and force larger quantities of the less efficient soils into the solution.

Utilization of Permanent Pasture

Dropping the assumption that permanent pasture will be fully utilized, before requiring cropland pasture, to meet pasture objectives, caused several adjustments in the Benchmark solution. The total cost of production decreased by $4.8 million from $191.0 million to $186.2 million. Although pasture costs declined by over $5 million, the reorganization of soil resource use among the other crops in the model caused the costs of these crops to rise or fall slightly from their earlier values. Distribution of harvested acreage by crop shifted among the subareas in response to the increase in cropland pasture production. And most significantly, no permanent pasture acreage entered the solution.

What is the basis for such a response? Farm operators in general have historically devoted less effort to improving the yields of permanent pasture than other crops. Usually, the land devoted to permanent pasture has had some problem, such as extreme wetness, stoniness, or steepness which has precluded its conversion to productive cropland. Farmers have thus treated such land as a necessary evil and the yields of permanent pasture have reflected this. The permanent pasture activities incorporated into the Benchmark Model also reflect the history of depressed yields. But, improved management was considered to be applied to permanent pasture as well as the other crops.

It is therefore obvious that when permanent pasture had to compete with cropland pasture the response from cropland was more efficient and that source prevailed. This is not to say that farm operators with permanent pasture should idle that land in favor of cropland pasture. Operators who produce roughage consuming livestock will undoubtedly continue to utilize permanent pasture to some degree. But, with the concentration of livestock production into fewer and larger herds the relative use of permanent pasture must decrease of necessity. And, cropland pasture provides considerably more flexibility.

As a result of the foregoing analysis it appeared unrealistic to continue to assume full permanent pasture usage. Consequently, permanent pasture activities were added to the Benchmark Model as well as all other models with which it is compared. Companion Tables to 4, 5, and 7 are found in Appendix Tables C-8, C-9 and C-10 and reflect the extent of changes brought about by the inclusion of permanent pasture in the model.

CHAPTER IV

ALTERNATIVE ASSUMPTIONS AND MODEL SPECIFICATIONS: THEIR IDENTIFICATION AND PURPOSE

The Role of Assumptions

The necessity of "getting on with the job" causes researchers to adopt certain simplifying assumptions relating to their work. River basin studies and those who are responsible for their undertaking are no exception. Assumptions make the problem of explaining relationships more manageable than is possible without the assumptions. Moreover, they provide the opportunity to reduce the number of variables under consideration so they may be brought into sharper focus. Often the researcher is not completely satisfied with the assumptions he has to make and wonders how important or critical they may be to his study results.

In this section, some of the assumptions that were made in the Southern Michigan Study are discussed in detail. These assumptions are either the same as, or similar to, those being made in other river basin studies. Variations in assumptions from those used in the Benchmark Model are developed for further analysis and used as a means of answering questions about the model's sensitivity.

The variations in assumptions that will be examined represent most situations found in river basin analyses ranging from the surplus resource situation to the limiting case. Additional questions about other aspects of the Benchmark Model are formulated and alternative models specified to test them. Variations in assumptions are allowed to interact with each other to provide a broad range of answers to the questions of relative sensitivities. Thus, the results of these tests will have applicability to other river basin studies in which linear programming is being, or will be, utilized. Any insights into the sensitivity of certain types of assumptions, gained for this study, will have value for other researchers.

The assumptions of the basic model that are subjected to sensitivity analysis have been grouped into the following classes:

<u>Class 1</u>--Assumptions relating to livestock feeding relationships.

<u>Class 2</u>--Assumptions relating to projected demands.

<u>Class 3</u>--Assumptions relating to soil management practices.

<u>Class 4</u>--Assumptions relating to minimum production considerations.

<u>Class 5</u>--Assumptions relating to adopted level of crop producing technology.

These five classes of assumptions include ninety-three linear programming solutions which reflect three distinct levels for each of the five classes of assumptions.

Class 1--Assumptions Relating to Livestock Feeding Relationships

Subregional shares of the United States and export demand for livestock and livestock products are translated into requirements for feed and forage. In typical river basin studies, these requirements are incorporated into the basic model as demands for feed grains and roughages under the assumption that resulting cropping patterns will be associated with the location of livestock production. Feeding efficiencies and hypothetical rations for each class of livestock serve as the basis for converting livestock demands into feed and forage demands. In deriving demands for feed and forage through this process, the final output of the model is subject to a major source of error.

Insufficient published information on feeding efficiencies by state, for each class of livestock or livestock products, forces the researcher to rely on national data for the detail necessary in river basin studies. The procedure used requires a determination of average feeding efficiencies per unit of output at the national level. This is adjusted to represent estimated conditions in the region under study. Total feed requirements, in feed unit terms, are subdivided into components such as feed grains and high protein, hay, other forage, and pasture based on average rations by class of livestock. While there is some basis at the national level for an average ration that represents the total feed input of a livestock class, this is generally not true at the state level. Results from various feeding trails are available, but are inadequate for accurate measurement of the total intake of all types of feed by all associated animals to produce a unit of livestock or livestock product.

Average feed requirements in terms of pounds of feed units per 100 pounds of product for 1959-1961 at the national level, served as the base level for the study (Table 10). These data are derived by allocating annual feed disappearance to the various types of livestock production. In this way, the maintenance of breeding animals and young stock and the feed consumed by those animals which die during the year are accounted for. The figures are not intended as a guide to the quantity of feed needed to increase the weight of a particular unit of livestock by 100 pounds. Their purpose is as a planning tool for estimating the total amount of feed needed to meet the requirements of projected quantities of livestock and livestock products.

For the purposes of this study, average feed requirements were converted to feeding efficiencies at the national level and adjusted to approximate the livestock

TABLE 10.--Average feed requirements, including pasture, consumed per unit of production, by each class of livestock, United States, 1959-1961[a]

Year Beginning October 1	Dairy Cattle	Beef Cattle			Sheep & Lambs	Hogs	Hens & Pullets	Broilers	Turkeys
	Milk	Grain Fattened	Other Cattle	All Cattle & Calves	Combined	All Fed During Year	100 Eggs	Meat	Meat
	Per 100 pounds of product (live weight basis)								
1959	109	741	1141	1053	1502	553	53	300	515
1960	107	755	1121	1033	1485	574	52	289	526
1961	107	864	1172	1034	1466	595	53	301	541

Source: Adapted from working materials for *Changes in Farm Production and Efficiency: A Summary Report 1965*, USDA Statistical Bulletin No. 233, Revised July, 1965; and *Livestock-Feed Relationships 1909-1963*, USDA Statistical Bulletin No. 337, November 1963 and subsequent.

[a] Expressed in feed units. A feed unit is equivalent to one pound of corn in feeding value.

mix and feeding relationships of the Lake States (Table 11).[16] The 1980 projected feeding efficiencies reflect expected advances in nutrition, breeding, and livestock management that continue the long-term trend.[17] Feeding efficiencies for most classes of livestock in Michigan differ from the national average. Beef and veal feeding levels reflect a higher proportion of fattened dairy cattle and dairy calves than the national level. The proportion of livestock on grain fattening rations is also higher in Michigan than the national average. Milk production is a little more efficient in the State due to a higher average production level per cow which lowers the maintenance requirements per unit of production.

Estimated rations, which are consistent with livestock production and feed disappearance at the national level, were used to determine feed consumption by various

---

[16] These adjustments to reflect local conditions were made in Washington by FPED, ERS, USDA production specialists based on their knowledge of regional feeding relationships.

[17] See Appendix O--Economic Base Study-Part IV, Comprehensive Water Resources Study, Grand River Basin, Michigan, January, 1966, for a detailed discussion of the assumed advances in technology and management practices used in this study. They are similar to those discussed in Project '80: Rural Michigan Now and in 1980, Highlights and Summary, Michigan Agricultural Experiment Station Research Report, February, 1966, and in earlier Phase I individual livestock reports.

TABLE 11.--Feeding efficiencies for livestock and livestock production, United States and State of Michigan, 1959-61 and projected to 1980

Year		Milk	Beef and Veal	Lamb and Mutton	Pork	Eggs	Broilers	Turkeys
		Feed units per pound of product (live weight)						
1959-61	U.S.	1.10	10.6	14.8	5.8	4.1	3.0	5.3
1959-61	Mich.	1.00	11.5	13.0	4.6	3.6	3.0	3.7
1980	Mich.	.85	10.5	12.0	4.0	3.1	2.5	3.2

Source: Unpublished data from the Economic Framework Investigation Section, River Basin and Watershed Branch, RDED, ERS, USDA, and working data for the interagency report *Agricultural Activity in the Grand River Basin, A Projective Study*, Natural Resources Economics Division, ERS, USDA, January, 1966.

classes of livestock and feed components (Table 12.)[18] These rations are highly aggregated; the components are in terms of feed units as a percentage of the total ration by livestock class. For this study, national relationships were adjusted for use in Southern Michigan, with the same consideration being given as with feeding efficiencies, and were applied to 1980 Benchmark projections without further adjustment.

Pasture requirements were divided between cropland pasture and permanent pasture. Initially all available acreage of permanent pasture was assumed to be used in partially meeting the total pasture requirement. The unsatisfied portion then became a demand for cropland pasture in the Benchmark Model. High protein feed needs were assumed to be met by shipment into the study area and, therefore, did not enter the Model. Hay and related roughages were divided between alfalfa mixtures and clover mixtures at the rate of 82.4 percent for alfalfa and 17.6 percent for clover mixtures. This roughage component contains such items as all hays and haylage. Other forage consists of corn silage, stover, and crops which are temporarily pastured. Green chop and grass silage are included in the pasture category. Feed grains in the ration are distributed among corn, oats, and barley at

---

[18] Adapted from, Livestock-Feed Relationships 1909-1963, USDA Statistical Bulletin No. 337, November, 1963, Table 28, and annual supplements thereto.

TABLE 12.--Distribution of average ration components among concentrates and roughages in terms of feed units, by class of livestock, United States 1960-1963

Livestock Class	Concen-trates	Feed Grains	High Protein	Roughages	Hay & Related	Other Forage	Pasture	Total
				Percent				
Milk	32.0	23.0	9.0	68.0	30.0	12.2	25.8	100.0
Beef and Veal	21.1	15.3	5.8	78.9	13.2	5.8	59.9	100.0
Lamb and Mutton	10.0	5.8	4.2	90.0	5.4	3.6	81.0	100.0
Pork	96.0	80.6	15.4	4.0	. .	. .	4.0	100.0
Chickens	96.0	65.3	30.7	4.0	. .	. .	4.0	100.0
Broilers	100.0	54.9	45.1	. .	. .	. .	. .	100.0
Turkeys	95.0	57.9	37.1	5.0	. .	. .	5.0	100.0
Eggs	98.5	64.0	34.5	1.5	. .	. .	1.5	100.0

Source: Adapted from, *Livestock-Feed Relationships 1909-1963*, USDA, Statistical Bulletin No. 337, November 1963, Table 28 and annual supplements thereto.

82.3 percent, 16.1 percent and 1.6 percent respectively. Michigan has been a surplus producer and net exporter of feed grains and hay for some time.[19] Total demands for feed grains and hay were, therefore, increased to reflect and maintain this relationship in the model.[20]

Several important factors must be evaluated in estimating what levels feeding efficiencies will likely attain at any point in the future. There are two major opposing forces that are always prevalent and the resulting feeding efficiency level is a reflection of the relative strengths of these forces.

The first of these forces is toward less efficient production in the short-run. It reflects major production expansion efforts, requiring proportionately more breeding animals, or changes in consumer preferences toward higher quality. This force implies shifts to confinement feeding, shifts to higher levels of finish, and so on; and is encouraged by lower feed grain and concentrate prices and/or

---

[19] See Supplement for 1965 to Livestock-Feed Relationships 1909-1964, Statistical Bulletin No. 337, ERS, USDA, September, 1965; and Hay in the United States, Quantities Grown in a Normal Year, Surplus and Deficit Areas, Statistical Bulletin No. 349, ERS, USDA.

[20] It is recognized that this relationship may change over time due to expanding relative population, foreign exports, comparative advantage, etc. However, in view of the surplus magnitudes which have been as large as 45 percent in excess of feed requirements (1964-65), a modest 20 percent excess in feed grains and 10 percent in roughages are maintained.

higher livestock product prices. This force can be expected to continue at least in the short-run until adjustments can be made in breeding herds, management techniques, and feeding practices.

In contrast to the first, the second force is longer run in nature and is toward greater efficiency in feeding. It includes improved technical abilities for converting feed into livestock products, genetic improvements in livestock, potential shifts in demand for different qualities of livestock products, and substitution of low cost roughages in some livestock rations.

While aggregate statistics are adequate in reflecting overall major changes, they do not measure relative strengths of these two forces. There may be considerable adjustment taking place that is masked by the aggregate data, and such adjustments would be of major concern to planners if they were aware of them. Currently, projections are based on arbitrary estimates of likely adjustments between the relative strengths of these two forces. Because these projections may also serve as the basis for public resource development decisions, their sensitivity to alternative forms of the livestock feeding relationship assumptions is important.

> Question: What effect would a small change in the nature of assumptions concerning relative feeding efficiencies and livestock rations used in river

basin linear programming studies, have on the model projections?

Alternative specifications of the basin model needed to answer this question take the form of two additional levels of feeding efficiency and two variations in the composition of the livestock ration.

It is believed that the projected feeding efficiencies for 1980 in the Benchmark Model (Table 11) are the best estimates on the basis of current knowledge. Two alternative levels of feeding efficiency, that represent a 10 percent increase (High Efficiency) and a like decrease (Low Efficiency) from the Benchmark level are specified to represent likely deviations from this level (Table 13). Two variations were also specified in the basic ration for each class of livestock. The high concentrate ration reflects higher levels of concentrate feeding for high production, rapid gain, proportionately more animals with a high degree of finish and greater concentration of lambs and steers than the level assumed by the Benchmark Model. The low concentrate ration reflects more extended feeding, feeding to a lower degree of finish, proportionately more breeding animals and a greater use of low cost roughages at lower levels of production. It represents a deviation toward a ration with a lower proportion of concentrates than the Benchmark Model ration (Table 14).

TABLE 13.--Feeding efficiencies for livestock and livestock production, Benchmark and alternatives, 1980

Level of Feeding Efficiency	Milk	Beef and Veal	Lamb and Mutton	Pork	Eggs	Broilers	Turkeys
	Feed units per pound of product (live weight)						
Medium Efficiency-- Benchmark Level	.85	10.50	12.00	4.00	3.10	2.50	3.20
High Efficiency-- 10 Percent Less Requirement	.76	9.45	10.80	3.60	2.79	2.25	2.88
Low Efficiency-- 10 Percent More Requirement	.94	11.55	13.20	4.40	3.41	2.75	3.52

Source: Unpublished working material developed for the report, "Agricultural Activity in the Grand River Basin: A Projective Study," Natural Resource Economics Division, ERS, USDA, January, 1966.

TABLE 14.--Distribution of average ration components among concentrates and roughages by class of livestock, in feed units, Benchmark and alternatives, 1980

Ration and Livestock Class	Concentrates	Feed Grains	High Protein	Roughages	Hay and Related	Other Forage	Pasture	Total
				Percent				
Medium Concentrate Benchmark Level								
Milk	40.0	25.0	15.0	60.0	25.0	14.0	21.1	100.0
Beef and veal	35.0	28.0	7.0	65.0	20.0	10.0	35.0	100.0
Lamb and mutton	25.0	15.0	10.0	75.0	11.0	4.0	60.0	100.0
Pork	96.0	80.0	16.0	4.0	. .	. .	4.0	100.0
Chickens	98.0	68.0	30.0	2.0	. .	. .	2.0	100.0
Broilers	100.0	55.0	45.0	. .	. .	. .	. .	100.0
Turkeys	95.0	58.0	37.0	5.0	. .	. .	5.0	100.0
Eggs	98.5	64.0	34.5	1.5	. .	. .	1.5	100.0
High Concentrate								
Milk	55.0	32.0	23.0	45.0	20.0	20.0	5.0	100.0
Beef and veal	50.0	40.0	10.0	50.0	10.0	20.0	20.0	100.0
Lamb and mutton	40.0	25.0	15.0	60.0	15.0	5.0	40.0	100.0
Low Concentrate								
Milk	25.0	17.0	8.0	75.0	30.0	10.0	35.0	100.0
Beef and veal	20.0	15.0	5.0	80.0	20.0	15.0	45.0	100.0
Lamb and mutton	10.0	6.0	4.0	90.0	6.0	3.0	81.0	100.0

Source: Adapted from unpublished working material developed for the report, "Agricultural Activity in the Grand River Basin: A Projective Study," Natural Resource Economics Division, ERS, USDA, January, 1966.

Poultry and hog rations are already heavily weighted toward concentrate feeding and likely future adjustments would be toward more concentrates. Considerable variation may occur in the rations of roughage consuming animals within a fairly wide range. Therefore, the alternative rations under consideration affect only feed requirements for milk, beef and veal, and lamb and mutton. The basic ration assumed in the Benchmark Model was increased by 15 percent in concentrates to represent the "High Concentrate" ration and increased by 15 percent in roughages to represent the "Low Concentrate" ration.

Class 2--Assumptions Relating to Projected Demands

In the Benchmark Model projected demands for food and fiber are extrapolations of past trends in crop and livestock production. Adjustments were made to reflect the thinking of commodity specialists as to the probable shifts by 1980 in production among regions. The shares of United States production requirements coming from the Southern Michigan Subregion generally declined for all livestock and livestock product items between 1959-61 and 1980. The only commodities showing slightly increased shares were soybeans, drybeans, potatoes and non-citrus fruit. Projections were not made for feed grains and roughages specifically since the conversion of livestock products into feed requirements, plus an allowance for export, provide these data.

It was, therefore, assumed that past production trends were good indicators of the location of future production; and that the only cause for deviation through 1980 from this pattern of production would be known changes taking place among regions. There are very real problems with this procedure of projecting regional requirements. One of the objectives of river basin surveys is to evaluate the capability of a region to meet projected requirements with and without the further development of the region's water resources. Since the extrapolation of production trends assumes that the factors affecting production in the past will also be acting in the future, certain biases are inherent in this process. Historically these biases have led to an understatement of requirements produced by the Great Lake States.

NRED is currently working to evaluate the potential for further water resource development, but the possible biases in estimating regional demands may invalidate these efforts. In the absence of a national model that would allocate the total demand regionally, those areas that have experienced considerable water resource development in the recent past might be projected to receive a disproportionate share of the national demand. This situation could force the impression that further development in such a region would be required when production requirements might be met more efficiently in other regions.

Question: What effect will varying an area's projected share of United States requirements have on the projected water resource development potential for that area?

To answer this question, results from the Benchmark Model were compared with two alternative models that reflect increases of 50 percent ("Medium" demand level) and 100 percent ("High" demand level) in the Benchmark ("Low" demand level) 1980 requirements (Table 15.)[21] These two alternatives to the Benchmark level may also be viewed as providing some insights into the problems that might arise from expanded exports or programs of food aid. In only one instance does a doubling of the 1980 projected requirements create an unrealistic situation, that of nearly 70 percent of the expected national requirements of dry beans. However, the export levels are not large for this commodity, and any sizeable increases could conceivably have such an effect on the Subregion.

Class 3--Assumptions Relating to Soil Management Practices

In the Benchmark Model certain constraints were imposed on the resource base to account for crop rotations and improved management practices encouraged through

---

[21] The alternatives are both increases since the regional share of national requirements have recently been adjusted upward and the Benchmark Model represents a known understatement in view of current shares.

TABLE 15.--Current and projected demands for production from the Southern Michigan Subregion (SMS) with alternative specifications for 1980

Commodities Required	Units	Actual Demand		Projected Demand in 1980			
				Benchmark Model "Low" Demand Level		"Medium" Level of Demand (50% Above Benchmark)	"High" Level of Demand (100% Above Benchmark)
		SMS 1959-61	SMS as a Percentage of U.S. Total	SMS	SMS as a Percentage of U.S. Total		
		1000	Percent	1000	Percent	1000	1000
Livestock Products							
Farm Chickens	pounds	8,400	.671	5,195	.356	7,792	10,390
Eggs	numbers	1,299,860	2.086	1,245,280	1.648	1,867,920	2,490,560
Turkeys	pounds	18,170	1.134	28,000	.786	42,000	56,000
Broilers	pounds	29,460	.474	18,205	.170	27,308	36,510
Lamb & Mutton	pounds	17,240	1.024	15,750	.926	23,625	31,500
Pork	pounds	213,760	1.057	261,270	.965	391.905	522,540
Beef & Veal	pounds	372,190	1.287	477,260	1.005	715,890	954,520
Milk	pounds	3,998,410	3.238	4,707,840	3,244	7,061,760	9,415,680
Food Crops							
Wheat	bushels	27,268	2.203	27,668	1.464	41,502	55,336
Soybeans	bushels	4,183	.709	11,195	.857	16,792	22,390
Dry Beans	cwt.	6,586	34.575	8,202	34.976	12,303	16,404
Potatoes	cwt.	5,681	2.138	10,368	3.152	15,552	20,736
Fruits and Vegetables							
Non-citrus Fruit	cwt.	7,612	3.824	13,774	5.248	20,661	27,548
Vegetables	cwt.	11,666	2.888	17,896	2.786	26,844	35,792

Source: Unpublished material developed for the report, "Agricultural Activity in the Grand River Basin: A Projective Study," Natural Resource Economics Division, ERS, USDA, January, 1966.

research and extension efforts. Not all of the available cropland is suited to continuous growing of certain crops. Cultivation of row crops over the growing season has a tendency to destroy soil structure and encourage soil loss on certain soils through both wind and water erosion. Consequently, restrictions were placed on the full use of these soils by certain crops in the Benchmark Model. In general, these restrictions were based upon standard recommendations of the Soil Conservation Service to keep erosion losses within three tons per acre. This restriction implies that the percentage of soils that may be continuously row-cropped ranges from 32 to 90 percent among the different soil management groupings.[22]

These restrictions on soil resources were imposed as a means of creating a more realistic pattern of crop production in the program output. While the restrictions quite accurately represent how farm operators manage their soils, the benefits that may be derived by building these provisions into models may not be worth the expense necessary to develop them.

<u>Question</u>: How are the projections of resource use and development potential affected by restrictions

---

[22] No re-cropping restrictions are recommended for organic soils. See "Instructions for Determining Cropping Systems for Sloping Land," <u>Technical Guide</u>, Sec. III-B, March 6, 1964, Soil Conservation Service, Michigan. R. H. Drullinger of SCS provided assistance in the interpretation of the guide and its application to Subregion soils.

placed on the full use of soil resources for the production of row crops?

To answer this question, 1980 Benchmark Model results were compared with the results of two alternative levels of soil management practices. The Benchmark level designated as "Medium," reflects improved soil management practices that the average farm operator is expected to employ in 1980 to retard soil loss under more intensive cropping practices (Table 16). The alternative designated as "Low" represents how farm operators currently are using their soil resources in the production of row crops. The other, designated as "High," represents the other extreme; no restriction to the full use of all soil resources for the production of row crops. While this second alternative represents a very unrealistic assumption, it is important to test its effect upon the models.

Class 4--Assumptions Relating to Minimum Acreage Constraints

During the early stages of this study, a test was made of the Benchmark Model's predictive power with respect to crop acreage. An attempt was made to reproduce the 1959 Census of Agriculture crop acreage and production data within the five subareas. The total 1959 production of each major crop grown in the 42-county area served as demand requirements for these crops. Not only did the model fail to recognize significant production patterns,

TABLE 16.--Percentage of cropland available for the production of row crops under varying soil management practices, Southern Michigan Subregion, 1980

Soil Management Practices	Area	Soil Management Groupings						
		1abc	2ab	2c	3abc	4abc	5abc	Mc
				Percent				
"Low" (Current Level, 1964)	1	60.00	61.83	90.00	61.68	45.96	45.00	100.00
	2	58.56	69.04	90.00	57.91	49.12	44.70	100.00
	3	43.33	49.95	86.16	50.47	45.17	31.98	100.00
	4	46.37	63.65	90.00	40.93	42.05	36.66	100.00
	5	54.48	42.79	87.44	48.47	48.16	44.65	100.00
"Medium" (Benchmark Level, 1980)	1	75.00	79.68	100.00	90.68	84.43	90.00	100.00
	2	73.92	86.15	100.00	86.80	88.72	89.88	100.00
	3	62.50	70.29	97.12	74.95	81.32	68.32	100.00
	4	64.76	81.31	100.00	66.74	76.80	75.34	100.00
	5	63.77	62.78	98.54	73.38	86.42	89.33	100.00
"High" (Unrestricted Level, 1980)	1	100.00	100.00	100.00	100.00	100.00	100.00	100.00
	2	100.00	100.00	100.00	100.00	100.00	100.00	100.00
	3	100.00	100.00	100.00	100.00	100.00	100.00	100.00
	4	100.00	100.00	100.00	100.00	100.00	100.00	100.00
	5	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Source: Soil Conservation Service, Michigan "Instructions for Determining Cropping Systems for Sloping Land," Technical Guide, Sec. III-B, March 6, 1964. R. H. Drullinger of SCS provided assistance in the interpretation of the guide and its application to subregion soils.

like the concentration of dry bean production that had developed over time, but it was extremely inaccurate in reflecting the relative distribution of output among subareas.

Recognizing that the model was inadequate in its original form, certain adjustements were made and the model was re-tested. Tree and bush fruits, that had become concentrated in Subarea 5 because of particularly favorable climate were removed from the model along with sugar beets, which were highly oriented to the location of processing facilities in Subarea 2. Other crops were added to this list either because of small acreage or special characteristics which precluded wide distribution. It was also recognized that the influence of government programs, especially with respect to wheat, would not necessarily be identified by a model designed to minimize production costs over the 42-county area.

With these considerations in mind, a 50 percent constraint on production in each subarea was chosen. This meant that a minimum of one-half of the 1959 acreage of each crop in the model was required to be produced in the same subarea. Thus, habit patterns and other non-market influences were given substantial weight in determining the location of production within the Subregion. When the 1959 Census model was tested with this minimum constraint, the results were sufficiently satisfactory that the same procedure was used in the 1980 Benchmark Model projections.

To implement the procedure, the relative distribution of crop acreage among the five subareas was used to distribute one-half of the 1980 Benchmark projected demand by crop to each of the subareas as minimums required in the solution. This production was converted to acreage through the use of average yields.

While this procedure was logical, straight-forward, and easily understood, it is recognized that it had little scientific or statistical basis. It had produced "reasonable" results when tested against one point in time but how representative was that one point?

> Question: Will changes in assumptions that represent minimum acreage constraints have a major or minor effect upon projected resource use and development potential?

Two alternatives to the Benchmark 50 percent ("Medium") constraint were utilized in answering this question. The first alternative designated "Low," was less restrictive requiring only approximately 25 percent of the total acreage of each crop to be distributed among the subareas. The second alternative designated "High," was much more restrictive than the Benchmark level. It required a distribution among subareas of 75 percent of all production before efficiency was allowed to allocate the remainder.

Class 5--Assumptions Relating to Adopted Level of Crop Producing Technology

To develop the agricultural production potential for the Subregion in 1980, crop and pasture yields were projected on the basis of past trends and implications of current research work. Soils and crops specialists at the Michigan Agricultural Experiment Station were given a point of departure for yield projections based on ERS analysis of Statistical Reporting Service time series data. The projected yields represent the specialists' evaluation of how rapidly new varieties will be made available to farmers and a judgment of the rate of new practice adoption by average farmers.[23]

Average farm management capabilities and average weather conditions, assumed for the Benchmark Model, resulted in projected crop yield levels for 1980 approximately 50 percent above the 1959-61 average levels. The 1980 yield estimates represent increased levels of all management inputs such as improved seed, use of insecticides, timeliness of operations, and approximately a 30 percent increase in per acre use of fertilizer nutrients. The costs associated with these additional inputs and added harvesting charges have also been incorporated into the Model.

---

[23] See "Agricultural Activity in the Grand River Basin: A Projective Study," Natural Resources Economics Division, ERS, USDA, January, 1966, for a detailed discussion of this procedure.

Previous attempts at projecting the productive potential of a region's resources have often underestimated the rate at which new practices were developed and adopted by farm operators. The rapid increase in use of fertilizer in recent years is a case in point. Since yields on experimental plots and some farms are currently far in excess of the average levels projected for 1980, it is conceivable that the average production levels assumed may also be seriously underestimated.

> Question: What effect will the underestimation of an area's production potential have on projected resource requirements or projected potential for resource development?

There is a companion assumption implicit in this question--that additional research and extension efforts are not perfectly substitutable for land resources or land-increasing technology (i.e., agricultural irrigation). To answer this question, the technology level designated as "Low," which was assumed for the Benchmark Model was compared with two alternatives. These alternatives reflect technology increases of approximately 20 percent designated "Medium," and 40 percent designated "High," respectively over the Benchmark basic level.[24]

---

[24] For a detailed presentation of the comparable yields by soil management grouping for these various levels of technology see Melvin L. Cotner, "The Potential Role of Agricultural Land Drainage in Economic Growth" (unpublished Ph.D. thesis, Michigan State University, 1967).

All crops have not shared equally in the response to technology in the past and are not expected to in the foreseeable future. The 1980 projected yield index for all crops is 148, with the greatest increases in yields of wheat and dry beans and the smallest gains in alfalfa and soybeans (Table 17). The two technology alternatives are based primarily upon assumptions of equal increments of research and extension toward improving management and encouraging more wide-spread application of improved strains and varieties and near optimum use of fertilizers. The assumptions of technology adoption at the "High" level reflect yield and fertilizer use levels consistent with those obtained currently by top farm managers and from experimental plots.

TABLE 17.--Projected index of selected crop yields under 1980 Benchmark level ("Low") of adopted crop producing technology, Southern Michigan Subregion

Crop	Indexes 1959-61 Yield Levels = 100
Wheat	165
Dry Beans	163
Potatoes	156
Corn for Silage	153
Corn for Grain	152
Barley	152
Soybeans	130
Oats	141
Alfalfa	137
Other Hay	144
Cropland Pasture	138
Permanent Pasture	140

Source: Unpublished material developed for the report entitled, "Agricultural Activity in the Grand River Basin: A Projective Study," Natural Resource Economics Division, ERS, USDA, January, 1966.

CHAPTER V

SENSITIVITY OF THE BENCHMARK MODEL TO CHANGES IN ASSUMPTIONS

Procedures

The objective function of an optimal solution to a cost-minimizing linear programming problem reflects the least costly method of attaining production objectives. Its relative size under alternative model formulations can serve as a criterion of analysis. Comparison of the change in objective function provides a basis for evaluating the sensitivity of production costs to changes in model assumptions. Relative differences in the empirical results under alternative sets of assumptions serve to determine whether a particular alternative model formulation is measurably different from the specification of the Benchmark projection model. In testing for sensitivity, the relationship of change in the objective function to change in model assumptions constitutes a relevant measure. Put differently, the method is one of assessing the relative change in output to known changes in input.

To provide the basis from which to test sensitivity, thirty-one different models at three levels of technology adoption were evaluated. The structure of all ninety-three models and their resulting objective functions represent the full range of analysis undertaken by this study (Table 18). No attempt is made to go into depth on each model variation. The results are presented in this form for those who may wish to explore particular variations. A similar set of comparisons which include agricultural irrigation are presented and analyzed in the latter part of this Chapter.

Within the body of Table 18 the five classes of assumptions are identified by the letters L, M, and H. These letters stand for the three levels, low, medium, and high which each class of assumption is allowed to take. They are presented in this way to facilitate understanding of the comparisons made in the table. Detailed discussion of the magnitudes represented by the three levels was provided in Chapter IV and is briefly summarized in the discussions that follow.

Part I--Sensitivity Analysis Without Irrigation

Because of the complexity associated with an evaluation of all ninety-three models, both in presentation and understanding, fifteen models have been selected for sensitivity analysis (Table 19). These models incorporate changes in the five classes of assumptions discussed in Chapter IV. In the sensitivity tests that follow, the

TABLE 18.--Structure of alternative model formulations with respect to assumptions, and projected total costs of subregion production, Southern Michigan Subregion, 1980[a]

Assumptions of the Models							
Class - 1 Livestock Feeding		Class 2	Class 3	Class 4	Projected[b] Total cost of producion given assumptions 1-4, and under the following technology assumption (Class-5):		
Feeding Efficiency	Proportion of Concen. in ration	Demand Level	Soil Management Practices	Minimum Acreage Constraints	Low	Med.	High
					Mil $	Mil $	Mil $
M	M	L	M	M	186.2	178.6	171.2
H	M	L	M	M	174.6	167.5	160.5
H	H	L	M	M	175.0	167.2	160.2
H	L	L	M	M	175.9	168.8	161.6
L	M	L	M	M	198.1	189.8	182.0
L	H	L	M	M	198.1	189.5	181.6
L	L	L	M	M	200.0	191.4	183.4
M	M	M	M	M	282.6	266.7	255.0
H	M	M	M	M	262.6	249.3	238.4
H	H	M	M	M	262.0	248.6	237.6
H	L	M	M	M	266.3	251.6	240.5
L	M	M	M	M	304.3	284.2	271.8
L	H	M	M	M	298.7	282.7	270.3
L	L	M	M	M	*	287.7	275.0
M	M	H	M	M	*	*	343.2
H	M	H	M	M	*	337.2	319.6
H	H	H	M	M	*	332.1	317.3
H	L	H	M	M	*	344.2	323.3
L	M	H	M	M	*	*	369.9
L	H	H	M	M	*	384.5	363.0
L	L	H	M	M	*	*	*
M	M	L	L	M	186.5	178.9	171.3
M	M	L	H	M	186.2	178.4	171.2
M	M	M	L	M	284.0	267.0	255.2
M	M	M	H	M	282.4	266.5	255.0
M	M	H	L	M	*	*	344.2
M	M	H	H	M	*	*	343.0
M	M	L	M	L	185.2	178.1	170.3
M	M	M	M	L	281.1	265.6	253.9
M	M	M	M	H	284.4	268.2	258.3
M	M	H	M	H	*	*	346.0

*Linear programming solution not feasible under the assumptions given. given.

[a] The designation L, M, and H mean respectively Low, Medium, and High. The precise meaning differs among the five classes of assumptions. Detailed definitions are given in the narrative discussions of each class of assumptions.

[b] 1964 constant dollars.

TABLE 19.--Definitions of alternative models with respect to variations in assumptions from the Benchmark Model, and projected total costs of subregion production, Southern Michigan Subregion, 1980.

Model Number and Designation	Assumptions[a]						Projected Total Cost of Production Under Assumptions as Given[c]
	Class 1 - Livestock Feeding		Class 2	Class 3	Class 4	Class 5	
	Feeding Efficiency	Proportion of Concentrate in Ration	Demand Level	Soil Management Practices	Minimum Acreage Constraints	Level of Technology	
							Mil. Dol.
1. Benchmark	M	M	L	M	M	L	186.2
	Changes from Benchmark Model Assumptions						
2. Feeding Efficiency	H						174.6
3. Feeding Efficiency	L						198.1
4. Ration	H	H					175.0
5. Ration	H	L					175.9
6. Ration	L	H					198.1
7. Ration	L	L					200.0
8. Demand			M				282.6
9. Demand			H[b]			H	343.2
10. Soil Management				L			186.5
11. Soil Management				H			186.2
12. Acreage Constraints					L		185.2
13. Acreage Constraints			H		H[b]	H	346.0
14. Technology						M	178.6
15. Technology						H	171.2

[a] The designation L, M, and H mean respectively Low, Medium, and High. The precise meaning differs among the five classes of assumptions. Detailed definitions are given in the narrative discussions of each class of assumptions.

[b] Linear programming solution not feasible under this assumption unless the "High" level of technology assumption is used.

[c] 1964 constant dollars.

Benchmark Model is compared against alternative models under each class of assumption. Differences from the Benchmark solution, arising from alternative assumptions, are described and their implications discussed.

Class 1--Assumptions Relating to Livestock Feeding Relationships

The assumptions centering on livestock and livestock products can be separated into two categories: those affecting the average efficiency of feed conversion and those relating to the composition of the average feed ration. Both components vary by class of livestock and undoubtedly among subareas of a particular river basin not to mention regions of the nation. Ration composition also affects the feed conversion efficiency but it was felt that this problem would average out across the subregion.

Feeding Efficiency

Two alternative levels of average feeding efficiency were examined. The "High" level was 10 percent more efficient than the Benchmark level ("Medium") and the "Low" level 10 percent less efficient. Evaluation of past trends suggests that errors in excess of 10 percent in projecting to 1980 would be unlikely barring unforeseen circumstances.

Deviations from Benchmark Projections

In testing the sensitivity of variations in the feeding efficiency assumption, deviations from the Benchmark total production costs were nearly identical in both directions (Table 20). An increase of 10 percent in feeding efficiency to the "High" level resulted in a saving of $11.6 million in production costs or 6.2 percent below the Benchmark level. Total costs increased by nearly $12.0 million when the "Low" level of feeding efficiency was assumed.

TABLE 20.--Projected 1980 total cost of production for models testing the sensitivity of the _feeding efficiency assumptions_, Southern Michigan Subregion[a]

Model Number	Level of Feeding Efficiency	Total Cost of production (Objective Function)	Differences in total cost of production from Benchmark level	
		Mil. Dol.	Mil. Dol.	Percentage
1 (Benchmark)	Medium	186.2		
2	High	174.6	-11.6	-6.2
3	Low	198.1	11.9	6.4

[a] 1964 constant dollars.

Models that compare changes in the feeding efficiency assumption at the Benchmark demand level ("Low") are presented in Table 20. When demands are raised the effects of "High" and "Low" levels of feeding efficiency are of greater magnitude. For instance, at the "Medium" demand level (50 percent above Benchmark) the effect of "low" feeding efficiency is to raise the total cost of production above the Benchmark by more than 63 percent. High feeding efficiency, on the other hand, limits the increase to 41 percent.

Implications

Variations in the feeding efficiency assumption caused substantial changes in the Benchmark total cost of production. The model is sensitive to these changes, more so as the soil resource becomes a limiting factor. Why is this so? The assumptions about feeding efficiency affect the quantities of all feed components required to produce a given level of livestock and livestock products. As feeding efficiency rises less feed is required to meet production objectives and vice versa. At higher demand levels the effects are more pronounced, especially for the "Low" efficiency assumption. In this case, the production requirements are increased because of larger demands, and the addition of lowered efficiency of feeding only means that more feed is required.

As would be expected, cost increases were larger as the production problem became more difficult to solve. Additional soil resources were required which forced the model to select less efficient soils after the more efficient were fully utilized.

For those involved in river basin planning or other agricultural projection work, care should be exercised in the establishment of feeding efficiency levels. More time is normally given to this task is warranted. Errors in the direction of overstating feeding efficiency are less critical than errors toward understatement. The Benchmark Model should be considered highly sensitive to variations in the feeding efficiency assumption.

Livestock Rations

Livestock producers are influenced in the type of feed they use in the ration by such factors as weather, prices, the kinds of roughage handling equipment they have and what becomes available. They are influenced by new technology, educational efforts, and fads. Consequently, the composition of livestock rations is generally considered to be more variable than feeding efficiencies. Thus, a range of plus or minus 15 percent was selected as a reasonable range to represent possible errors in estimating livestock rations.

The national data that reflect highly generalized livestock rations by class of livestock were adjusted to derive a best estimate of the types of rations currently in use in Southern Michigan. An estimate of the likely rations to be used and a mix of feeding conditions in the future were also established with assistance from Michigan Agricultural Experiment Station personnel.

Deviations from Benchmark Projections

In evaluating the sensitivity of livestock ration assumptions, the effect of varying ration composition with high feeding efficiencies was analyzed and compared with low efficiencies. Also, effects of maintaining high concentrate levels when efficiency varied were compared with low concentrate levels and varied efficiency. These comparisons are somewhat more complicated than those for the feeding efficiency assumption alone.

"High" feeding efficiency assumptions when coupled with rations both "High" and "Low" in concentrates yield surprisingly similar results (Table 21). Deviations from the Benchmark ("Medium") are both negative and nearly the same magnitude. The "High" concentrate ration is only slightly more efficient. Holding feeding efficiency 10 percent below the Benchmark and allowing concentrates to vary by 15 percent around the original assumption raised the cost of production by $12 million or 6.4 percent for "High" concentrates and nearly $14 million or 7.4 percent for "Low" concentrates. These deviations imply sensitivities of the Benchmark which are no greater than those induced by variations in the feeding efficiency assumption alone.

TABLE 21.--Projected 1980 total cost of production for models testing the sensitivity of the livestock ration assumptions under high and low feeding efficiency, Southern Michigan Subregion[a]

Model Number	Level of Feeding Efficiency	Proportion of Concentrate in Ration	Total Cost of Production (Objective Function)	Differences in Total Cost of Production From Benchmark Level	
			Mil. Dol.	Mil. Dol.	Percent
1 (Benchmark)	Medium	Medium	186.2		
4	High	High	175.0	-11.2	-6.0
5	High	Low	175.9	-10.3	-5.5
6	Low	High	198.1	11.9	6.4
7	Low	Low	200.0	13.8	7.4

[a] 1964 constant dollars.

The effects of changing both feeding assumptions at once was neutralized by comparisons where the only variation was that of concentrate level. In each case holding feeding efficiency constant and either raising or lowering concentrate levels caused nearly imperceptable changes in the objective functions.

When the impact of ration composition is controlled at either "High" or "Low" concentrate levels and feeding efficiency is allowed to move from "Low" to "High," nearly the same reduction in production cost occurs. At "High" concentrate levels the cost saving from a 20 percent increase in feeding efficiency is $23 million. Similarly, at "Low" concentrate levels the reduction is $24 million--slightly larger but still approximately a 12 percent change in objective function.

Implications

Once the effect of feeding efficiency is accounted for, variations in concentrate content of the assumed rations has little influence on the total costs of meeting production objectives. There appears to be no interaction between feeding efficiency and ration composition with the exception that combinations of "Low" feeding efficiency and "Low" concentrate ration assumptions yield slightly larger variations. This follows since "Low" concentrate assumptions imply high roughage requirements which are less efficient in the use of soil resources than are the feed grains that make up concentrate rations.[25]

In this analysis errors of 15 percent in concentrate levels caused variations of about 1 per cent or less in production costs. This suggests that river basin analysis should place more emphasis on establishing reliable coefficients to represent livestock feeding efficiencies than would be the case for ration composition. The livestock feed components of total demands in the model are so strongly influenced by the total feed needs established by feeding efficiency coefficients that even large variations in the source of nutrients (roughages or concentrates) has minimal influence on the total production cost.

Class 2--Assumptions Relating to Projected Demand

Projected regional or subregional demands for food, feed, and fiber are based upon allocations of national demand. As discussed in Chapter IV, estimated future demands at the national level represent a logical and

---

[25] In this regard, infeasible solutions were only encountered under the following conditions: (1) Low feeding efficiency, concentrate, technology and medium demand, (2) Technology medium, demand high, and (a) medium feeding efficiency and concentrate, (b) low feeding efficiency and concentrate, and (c) low feeding efficiency but medium concentrate, and (3) Technology and demand high but feeding efficiency and concentrate low.

consistent determination. However, in the absence of a national model to assess relative productivities and comparative advantages, these demands are broken down into regional shares by USDA marketing specialists, and these serve as the basis for regional demands. At the regional level, these estimates are still consistent with the national demands, but as further disaggregation takes place, the possibility of errors increases.

The forty-two county Southern Michigan Subregion represents slightly more than 22 percent of the Great Lakes Region production. Great Lakes regional demands served as the basis for the allocation to the Subregion. These allocations took into consideration a number of known and estimated factors that might influence the location of production.[26]

Since these factors are subject to substantial errors in estimation, assessment of the effects of understating Subregional shares of national requirements is important. Regional shares of national demands have been influenced most strongly by the effects of irrigation development in the west. Resulting allocation of 1980

---

[26] Research on these factors included discussions with Michigan Agricultural Experiment Station personnel and evaluations of the many Michigan State University "Project-80" reports published during the period of this study. In review of those decisions there is no additional evidence yet to refute the original choices made. By the same token, the confidence in those same choices has increased.

demands to the Subregion are relatively less than was experienced in the 1959-1961 period (Table 15). Raising Subregion demands in this analysis by 50 percent (demand assumption "Medium") resulted in approximately the same relative level of production with respect to the nation as would have existed had the 1959-1961 level been maintained. There were some variations; production of milk and eggs increased slightly while output of other livestock and livestock products remained unchanged or were slightly lower. With the exception of dry beans, soybeans, and potatoes which registered gains, crop production generally was unchanged. Dry bean production was influenced by Michigan's dominant position in the national market while soybeans are projected to continue the strong upward trend in which the State has not shared. The national projections were made prior to the establishment of new potato processing facilities in Subarea 4 which have stimulated increased potato production.

Demand assumption "High" (100 percent above Benchmark) is used in two ways in this analysis. First, it provides a contrasting level to "Low," assuming historic shares of production are maintained. It also assures that the least efficient soil resources will be forced into projected production. This latter property was introduced to test its influence on the behavior of the other assumptions.

Deviations from Benchmark Projections

Comparisons between demand levels "Low" and "Medium" are possible for all three technology levels but only at the "High" level of assumed technology adoption is it possible to evaluate "High" demand (Table 22). The "High" demand level is unattainable at the two lower levels of technology. A 50 percent increase in demand ("Medium") from the Benchmark level ("Low") brings forth nearly a 52 percent increase over the Benchmark cost of production. At the "Medium" level of technology adoption, where there is less pressure on the resource base, "Medium" demand causes slightly more than a 43 percent increase in Benchmark costs, a saving of 9 percent. But in terms of the "Medium" demand levels a shift from "Low" to "Medium" technology results in cost savings of not quite 6 percent.

At the "High" level of assumed technology adoption, it is possible to compare all levels of demand. In the comparison with "Medium" and "High" demand the effect is to raise "Low" demand production costs by 49 percent and 100 percent respectively. Had it been possible to make the same comparisons on the "High" demand level throughout, the induced changes in production costs would undoubtedly have commenced above 100 percent and declined as pressure was removed from the resource base. This influence is observed in Table 22 where "High" demand and technology

TABLE 22.--Projected 1980 total cost of production for models testing the sensitivity of demand level assumptions, Southern Michigan Subregion[a]

Model Number	Level of Demand	Level of Technology	Total Cost of Production (Objective Function)	Difference in Total Cost of Production from Benchmark Level	
			Mil. Dol.	Mil. Dol.	Percent
1 (Benchmark)	Low	Low	186.2		
8	Medium	Low	282.6	96.4	51.8
9	High	High	343.2	157.0	84.3

[a] 1964 constant dollars.

levels are responsible for only an 84 percent increase in production costs above the Benchmark level.

Implications

The implication of an error in the specification of demand level is that projected production costs will also be in error by approximately the same degree and in the same direction. This error in costs increases as the deviation from the Benchmark increases. It is possible that the small number of soil groups used in this model obscure some of the diseconomies associated with forcing less efficient soils into production at higher demand levels. In that respect a model containing a more comprehensive classification of soil resources would be far more sensitive to errors in demand specification. Decreasing the numbers of soils may be a means of correcting for such sensitivity; but that is an empirical question that must be tested. The conclusion to be drawn from this analysis is that the Benchmark Model is very sensitive to variations in the demand assumption.

Class 3--Assumptions Relating to Soil Management Practices

The long standing problems of erosion and sedimentation have been the basis for extensive efforts on the part of Federal and state governments and educational institutions to solve these problems. The establishment of the Soil Conservation Service and much of its overall program is such a response. Land grant universities, much of the early extension effort, and vocational agriculture courses concentrated on the benefits to be derived from maintaining soil conserving crops on steeply sloping land. Sod crops were also encouraged in the rotation to cut down on soil loss. These problems were also recognized as critical in the projections work being done by NRED.

After a lengthy process of evaluating the degree of slope, length of slope, soil texture, and erodibility factors of the soils making up the soil management groups, a weighting procedure was devised.[27] This procedure was

---

[27] This process required considerable assistance from SCS soils men and Agronomists who helped interpret

applied to each of the soil resource groups by subarea. The end result was the table depicting restricted cropland availability for the production of row crops (Table 16) discussed in Chapter IV. Cropland was restricted to growing no more than a specified percentage of crops requiring cultivation which increase the susceptibility of the soil to erosion. This upper limit on row crop production for each soil in the Benchmark Model was consistent with expected soil management practices in 1980, and was designated the "Medium" soil management assumption.

Because of the substantial effort devoted to this aspect of the study, it was possible to test two alternative soil management practice levels to determine how sensitive the model was to variations in this assumption. These alternatives were designated "Low" which implied no change in soil management practices from current levels and, "High," which placed no restriction on growing row crops. An assessment of the difference between these two alternatives and the Benchmark level presents difficulties. The constraints representing current practices ("Low") are more restrictive than those for the projected 1980 Benchmark ("Medium") level. But the no-constraint ("High") level is closer to "Medium" than "Medium" is to the "Low" level. What is most important about this test is the

---

their Technical Guides in light of estimates of what practices would be employed by average farmers in 1980.

determination of whether soil management assumptions have substantial impacts on the magnitudes of projections.

Deviations from Benchmark Projections

Comparison of the Benchmark level ("Medium") and the "Low" alternative indicate increased production costs of only $300,000, about 0.2 percent (Table 23). The "High" management alternative resulted in no deviation from Benchmark level production costs. When all three demand levels were considered, a shift to "High" technology was necessary for the "High" demand level. Again very little total variation existed between the "Medium" and "High" management alternatives. Greater variation in total production costs resulted between "Medium" and "Low" management levels as had been anticipated; but the variation was less then 1 percent.

Implications

Assumptions which restrict the full use of soil resources may cause some variation in projected total costs of production. But the data from this study indicate it to be so slight it can be disregarded. In view of the information required to derive the data to implement such assumptions these efforts do not seem warranted. While this position appears sound for the general case, it may not be warranted for studies where a large percentage of the soil resources is relatively steeply sloping. In the

TABLE 23.--Projected 1980 total cost of production for models testing the sensitivity of the soil management practices assumptions, Southern Michigan Subregion[a]

Model Number	Soil Management Practices	Total Cost of Production (Objective Function)	Difference in Total Cost of Production from Benchmark Level	
		Mil. Dol.	Mil. Dol.	Percent
1 (Benchmark)	Medium	186.2		
10	Low	186.5	0.3	0.2
11	High	186.2	0	0

[a] 1964 constant dollars.

Subregion only a small proportion of sloping land exists and the programming coefficients necessarily reflect this fact. Consequently, measurable changes in production costs, even though minor, were not encountered until soil management considerations were tested at higher demand levels. Typically each soil in the programming solutions was projected for production of a variety of crops. Had a larger number of soil groups been used, the tendency for a particular crop to dominate a soil would increase and the usefulness of this assumption might be enhanced.

Class 4--Assumptions Relating to Minimum Acreage Constraints

Farm operators' long-run production decisions are influenced by many different factors, some of which are not readily measurable. In addition to the operator's image of supply and demand conditions are such factors as personal preference, local custom, government programs, and administrative regulations. The latter influences are, in many cases, more important in evaluating past production trends and locational advantages than economic conditions. Thus, in projecting agricultural activity for river basin planning purposes, it is necessary that consideration be given to such influences.

In the Benchmark Model a constraint was made to the full economic efficiency of the linear programming system. This constraint arose from experience with a test of the model with the 1959 Census of Agriculture which was discussed earlier. As was pointed out, the unconstrained model produced such unrealistic results that a partial production restriction was required for each crop. This modification enabled the model to produce a satisfactory representation of the 1959 Census. As a result, for each of the five subareas, approximately one-half of each area's historic share of Subregional crop acreage was made a production requirement of the subarea. Subregional production requirements were converted to acreage through

1980 average yields and one-half of the acreage distributed among the subareas according to their share of 1959 acreage. These adjustments formed the basis for the minimum acreage constraints built into the 1980 Benchmark Model projections.

Deviations from Benchmark Projections

Levels choosen for comparison with the Benchmark were believed to reflect a sufficient range of possibilities to be meaningful. They range from consideration of the least restrictive to the most restrictive situations. The Benchmark ("Medium") acreage constraint is compared with the "Low" level acreage constraint at the "Low" demand level. And the Benchmark ("Medium") and "High" acreage constraints are compared at the "High" demand level.

The results indicate little change in Benchmark production costs from a shift to the "Low" level minimum acreage constraint (Table 24). Total costs declined by only $1 million, or less than 1 percent from the Benchmark level.

It appears that the Benchmark Model is more sensitive to increased levels of constraint than to reductions of a similar nature. The extreme situation of "High" levels of acreage constraint and demand required "High" technology for a feasible solution. This combination of assumptions raised production costs by 86 percent above

TABLE 24.--Projected 1980 total cost of production for models testing the sensitivity of the minimum acreage constraints assumptions, Southern Michigan Subregion[a]

Model Number	Minimum Acreage Constraint	Level of Demand	Level of Technology	Total Cost of Production (Objective Function)	Differences in Total Cost of Production From Benchmark Level	
				Mil. Dol.	Mil. Dol.	Percent
1 (Benchmark)	Medium	Low	Low	186.2		
12	Low	Low	Low	185.2	-1.0	-0.5
13	High	High	High	346.0	159.8	85.8

[a] 1964 constant dollars.

the Benchmark. It is an example of the extreme situation on the high side to contrast with the earlier comparison which is the extreme on the low side.

To give perspective to the high extreme it was compared with a similar model differing only in that acreage constraints were "Medium." The 25 percent increase in acreage constraint caused production costs to rise $2.8 million, less than 1 percent.

Only at "Medium" demand is it possible to compare all three acreage constraint assumptions. Although variations due to "High" constraints are larger than "Low" constraints they are still less than 1 percent. Even the 50 percent range in constraints from "Low" to "High" produced a cost variation of only 1.2 percent.

Implications

It is difficult to imagine that minimum acreage constraints of 75 percent on each subarea are only slightly more restrictive than 25 percent constraints; but with respect to total costs of production that is so. The only explanation possible is that the 25 percent constraint is sufficiently restrictive over the unconstrained model to have the major influence on whatever cost adjustments take place. Here, resources are quite efficiently organized and little additional change that affects total costs takes place. At high levels of constraint a reordering of production occurs among the soils of a subarea without much relative influence on costs. This is not to say that total costs remain unchanged; they change by upwards of a million dollars. Had there been a larger number of soils among which to redistribute production is it possible that production costs may have varied to a greater extent.

It must be kept in mind that the primary purpose of the acreage constraint assumption was to assure that shifts in the location of production occur at a rate that was reasonable in light of historical trends. Although costs did not vary greatly as a result of changing acreage constraint assumptions, soil resource use within and among the five subareas shifted substantially. However, within the criteria of the sensitivity test, the Benchmark Model was not sensitive to changes in minimum acreage assumptions.

Class 5--Assumptions Relating to Adopted Level of Crop Producing Technology

Assumptions about the rate at which new technology will be adopted have historically suffered from underestimation. This is particularly true of the most recent past as a base from which to project, whether it be looking back five to ten years from today, 1965, or even 1955. Technology appears to be growing at an increasing rate. As its base becomes larger, it serves as a springboard for new ideas which in turn swell the base. These developments have induced some to conclude that technology will undoubtedly solve our future problems because of its past performance. And, this may be partially or entirely true if it is all channeled into problem solving pursuits. However, researchers and planners are a somewhat conserative group, preferring to have a contingency plan to cover the possibility that new technology might not live up to expectations.

In this regard initial crop yield projections were based on continuous data, where available, for twenty years or more. And, where data covering the smaller area became unavailable companion State data were developed and extended to appraise the longer trends in crop yields. The longer the time series, usually the more conservative are the projected estimates of crop yield in the future. In this study the initial projections were discussed thoroughly with Michigan Agricultural Experiment Station soil scientists and crop specialists and also with personnel of the Soil Conservation Service. The purpose in this step was to incorporate the knowledge of plant breeders and others working in soil productivity, who were aware of research on new technology, with the knowledge of extension men in similar areas of work who also knew how rapidly farmers had adopted available technology in the past. This blend of intelligence served as the basis for projections of crop yields used in this study.

The Benchmark ("Low") level of technology represents the matrix of crop yields and associated production costs arising from the above process. Two additional levels of technology, "Medium" (20 percent higher) and "High" (40 percent higher), were chosen to evaluate the sensitivity of the Benchmark Model to higher crop yields that might have been estimated had a shorter historical perspective been taken or had the yields currently being attained by top managers been adopted directly as Benchmark (average 1980) yields.

Deviations from Benchmark Projections

Evaluation of the technology assumption was somewhat restricted, as were other tests of sensitivity, by the infeasibility of models at the "High" demand level. However, the effects of technology at the "Low" and "Medium" demand levels can be evaluated.

The influence of technology adoption assumption changes at "Low" demand were compared against Benchmark ("Low") technology (Table 25). An increase of 20 percent from "Low" to "Medium" technology adoption decreased Benchmark production costs by 4 percent. At the "High" level of technology costs were reduced by $15 million or 8 percent below the Benchmark. But higher levels of crop producing technology have more influence as demand rises.

TABLE 25.--Projected 1980 total cost of production for models testing the sensitivity of the <u>level of technology assumptions</u>, Southern Michigan Subregion[a]

Model Number	Level of Technology	Total Cost of Production (Objective Function)	Differences in Total Cost of Production from Benchmark Level	
		Mil. Dol.	Mil. Dol.	Percent
1 (Benchmark)	Low	186.2		
14	Medium	178.6	-7.6	-4.1
15	High	171.2	-15.0	-8.1

[a] 1964 constant dollars.

Comparisons at "Medium" demand show production cost savings of 5.6 and 9.8 percent respectively.

The most restrictive situation in which to test the sensitivity of all variations in the technology adoption assumption also occurred at "Medium" demand. However, a shift to "Low" feeding efficiency was an additional variation from the Benchmark Model. At "Low" technology this restrictive formulation exceeded Benchmark costs by $118 million. Cost savings of 6.6 and 10.6 percent were induced by shifts to technology levels "Medium" and "High" respectively.

Implications

Increasing levels of technology adoption caused responsive reductions in Benchmark production costs at the "Low" demand level. As levels of demand are raised the cost reductions associated with increased technology grow both absolutely and relatively. However, it also became evident that sensitivity to the first increment of technology was relatively greater than to the second.

At a given demand level an increase in technology from "Low" to "Medium" had a greater affect on cost reductions because it allowed sufficient increases in crop yields to shift production from less productive soils to more efficient soils. The second increment, to "High" technology, also contributed to cost reductions by increasing crop yields; but the better soils already were producing the majority of crops and the savings due to shifts from low producing soils were substantially reduced. This is why the level of cost sensitivity to changing technology rises relatively more as the level of demand rises. More of the less productive soils are forced into production and their removal from the solution through increased technology becomes more obvious in the level of total costs.

The effect of the first increment of technology is relatively greater than the second. An error in estimating the future level of technology adoption is more likely to be made at the first increment level than the second.

Planners should, therefore, consider the Benchmark Model as sensitive to variations in the technology adoption assumption.

Alternative Criteria of Analysis

In the foregoing analysis of sensitivity the total cost of meeting production objectives was chosen as the criterion of sensitivity. Other criteria could just have easily been chosen as a measure of sensitivity. It is highly probable that variations in each of these criteria would differ from those of the objective function as alternative levels of the assumptions under study are tested.

As an example of the type of variation one could expect from other criteria of analysis, the sensitivity of technology assumptions were tested using three alternative criteria. These are only three of many criteria which could have been chosen and are: (1) total acreage of cropland required to meet production objectives, (2) total production of wheat, and (3) total production of a major row crop--corn. From the preceding analysis of the technology assumptions it was observed that variations in the assumption caused only moderate sensitivity.

When resource use serves as the criteria of analysis, total Subregional acreage declines by about 18 percent and 28 percent as technology is increased by 20 and 40 percent respectively (Table 26). Variations in the

TABLE 26.--Projected 1980 soil resource use by subarea for models testing the sensitivity of the level of technology assumptions, Southern Michigan Subregion

Model Number	Level of Technology	Subarea 1	Subarea 2	Subarea 3	Subarea 4	Subarea 5	Subregion
				1,000 Acres			
1 (Benchmark)	Low	282.6	1,517.1	1,153.9	1,086.2	409.9	4,449.7
14	Medium	299.8	788.5	1,126.2	1,021.1	423.4	3,659.0
15	High	305.6	905.1	802.6	888.0	308.0	3,209.3

technology assumption cause far more sensitivity in Benchmark projections of resource use than in projected total production costs. Also of interest is the relative use of soil resources among subareas as the technology level is raised. Although total resource use declines, this is not true for all subareas. Subarea 1 increases acreage in crops by 23,000 acres and only Subareas 3 and 4 decline with both increases in technology.

In the case of wheat as the criterion of sensitivity, raising technology to "Medium" and "High" levels cause marked shifts among subareas as the total production remains constant for the Subregion (Table 27). Subareas 1 and 5 increase wheat production by about a quarter while Subarea 3 experiences a rise of about two and one-half times. Production drops then rises in Subarea 2 but the reverse is true for Subarea 4.

Of all the crops in the Benchmark Model corn has the largest demand and as such might serve as a likely criterion of analysis. Testing the sensitivity of corn production to increased yield levels reveals that as technology levels are raised for all crops it induces higher and higher levels of corn production in Subareas 3 and 5 (Table 28). Raising yield levels causes a substantial shift of production primarily from Subarea 4 to the other subareas.

These types of sensitivity are not detected by an analysis using the broad criterion of production costs as

TABLE 27.--Projected 1980 total production of wheat by subarea for models testing the sensitivity of the level of technology assumptions, Southern Michigan Subregion

Model Number	Level of Technology	Subarea 1	Subarea 2	Subarea 3	Subarea 4	Subarea 5	Subregion
				Million Bushels			
1 (Bench-mark)	Low	0.9	13.6	4.5	6.9	1.8	27.7
14	Medium	1.1	4.6	9.9	10.0	2.1	27.7
15	High	1.3	5.2	13.4	5.3	2.5	27.7

TABLE 28. Projected 1980 total production of corn by subarea for models testing the sensitivity of the level of technology assumptions, Southern Michigan Subregion

Model Number	Level of Technology	Subarea 1	Subarea 2	Subarea 3	Subarea 4	Subarea 5	Subregion
				Million Bushels			
1 (Bench-mark)	Low	4.8	9.0	16.7	70.6	8.8	109.9
14	Medium	9.7	11.8	19.7	58.7	10.0	109.9
15	High	6.2	11.7	21.5	59.6	10.9	109.9

a measure. By the same token that criterion may be more sensitive than some others that could have been chosen. It is more important to realize that the choice of criteria may influence the degree of sensitivity than to believe that a given criterion is an adequate measuring stick.

Part II--Sensitivity Analysis With Irrigation

Part I of this chapter was concerned with an analysis of the sensitivity of Benchmark costs of production to changes in the specification of five classes of assumptions. In that analysis, no irrigation activities were included in the Benchmark Model, and thus, no evaluation of the economic potential for irrigation development was made. The remainder of this chapter is devoted to a sensitivity analysis of the Benchmark Model which was modified to include irrigation activities. These activities were added to the Benchmark Model through a substantial expansion of the programming matrix. Irrigation activities were created for all major crops and they could only enter the programming solution in an irrigated state if they were economically justified in meeting production objectives.

In the analysis of sensitivity in Part I of this chapter, it was found that certain alternative assumptions were more critical than others in causing variation in the

Benchmark cost projections. These cost projections, serving as indicators of sensitivity, identified assumptions concerning livestock feeding relationships, projected demands and technology adoption levels as much more sensitive than assumptions about soil management practices or minimum acreage constraints.

In a similar analysis for Part II, where irrigation was included in the 1980 Benchmark Model, almost identical results were produced. Projected production costs for the Benchmark Model with irrigation were less than the model without irrigation by $2.5, $3.2, and $2.5 million at the "Low," "Medium," and "High" levels of technology respectively.[28] At demand levels above Benchmark demand ("Low"), savings also increased and by about the same magnitude.

The results of this second sensitivity analysis were, on the whole, very similar to the analysis in Part I. The essential difference was that irrigation reduced the general level of total production costs by reducing the number of acres needed to produce a given output of product.

---

[28] See Table 18 and Appendix Table C-11 for comparisons used in this analysis.

Of all the crops in the Model the only crop entering the Benchmark solution with irrigation was potatoes.[29] Potato production in the 1980 Benchmark Model without irrigation required 32,800 acres, a 13 percent increase over 1964 production levels (Table 29). When irrigation was added to the Benchmark Model, the same production was possible on 19,800 acres, nearly 32 percent less than were required in 1964 and about 40 percent below potato acreage projections for the 1980 Benchmark without irrigation. In 1964, the Census of Agriculture reported that approximately 7,300 acres of potatoes were irrigated, about one-quarter of the total potato acreage. But the entire crop was irrigated when the irrigation option was made available in the Benchmark Model.

Comparison of potato acreage distribution among the five subareas in 1980 with that in 1964, indicates that the Model is capable of identifying the most likely areas where irrigation would take place. Moreover, it is consistent with what farmers are already doing with respect to the limited amount of potato production now under irrigation.

---

[29] Specialty crops like fruit, vegetables, and sod crops were recognized as having high irrigation potential. They, however, were removed from the basic model and are not a part of this analysis.

TABLE 29.--Comparison of harvested acreage of potatoes with and without irrigation, 1964, and 1980 Benchmark projections, by subarea, Southern Michigan Subregion

Subarea	1964 Census of Agriculture		1980 Benchmark Projections	
	Total Potatoes	Total Irrigated Potatoes	Total Potatoes[a]	Total Irrigated Potatoes[b]
	1,000 Acres			
1	3.4	0.9	1.8	1.8
2	2.1	0.2	15.0	0.9
3	3.9	0.5	2.3	2.3
4	16.6	4.9	9.6	13.4
5	2.8	0.8	4.1	1.4
Total Subregion	28.8	7.3	32.8	19.8

Source: Census of Agriculture 1964 and Benchmark solutions.

[a] Benchmark solution without irrigation.

[b] Benchmark solution with irrigation--all potato acreage was projected for irrigation.

Shift-Point Analysis

In Part I of this chapter, it was found that certain alternative assumptions were more critical than others in causing change in Benchmark Model projections. With changes from the Benchmark projections of total production costs as indicators of sensitivity, assumptions concerning livestock feeding relationships (Class-1), projected demands (Class-2), and technology adoption (Class-5) were found to be much more sensitive than the other classes of assumptions. In Part II when irrigation activities were introduced into the Benchmark Model similar sensitivities were observed. However, in comparing the two Benchmark solutions (with and without irrigation) it is clear that the introduction of irrigation caused certain shifts in the projected location of potato production among subareas. All subareas except 1 and 3 were projected to lose potato acreage while Subarea 4 indicated gains. Further shifts to Subarea 4 were precluded by the minimum acreage constraint assumption in the Benchmark Model.

An important question then concerns what changes might occur in the projected economic potential for irrigation as deviations from Benchmark assumptions are introduced. Since river basin development plans are based in part upon projections of economic potential for development, the stability of those projections is most important. Therefore, a procedure was devised for evaluating the sensitivity of Benchmark irrigation projections to changes in the five classes of assumptions analyzed in Part I. This procedure is essentially an analysis of "shift-points" in the projected economic potential for irrigation. More specifically, it identifies sensitivites of the Model to changes in assumptions as they influence projections for irrigated acreage and its distribution among subareas.

In the analysis to follow, primary concern centers on the stability of projected irrigated acreage magnitude and location among subareas as affected by variations from Benchmark Model assumptions. Of major interest will be points at which shifts occur either in total irrigated acreage or location. The same selection of basic comparisons among models as used in Part I was made for this analysis (Table 30). Also the same designation of the letters L, M, and H has been retained.

Class 1--Assumptions Relating to Livestock Feeding Relationships

In view of their effects upon resource use the assumptions that would appear to have the greatest influence on irrigated requirements are "Low" feeding efficiency and "Low" concentrate rations. Both of these would require added resources to meet production objectives and might induce higher levels of irrigation.

TABLE 30.--Structure of alternative model formulations incorporating irrigation with respect to model assumptions, projected 1980 irrigated acreage and total cost of production, Southern Michigan Subregion

Model Number and Designation	Assumptions[a]						Projected Irrigated Acreage Under Assumptions Given	Projected Total Cost[b] of Production Under Assumption Given
	Class 1-Livestock Feeding		Class-2	Class-3	Class-4	Class-5		
	Feeding Efficiency	Proportion of Concentrate in Ration	Demand Level	Soil Management Practices	Minimum Acreage Constraints	Level of Technology		
							1,000 Acres	Mil. Dol.
1 Benchmark-Irrigation	M	M	L	M	M	L	19.8	183.8
			Changes from Benchmark Model Assumptions					
2 Feeding Efficiency	H						19.8	172.2
3 Feeding Efficiency	L						19.8	195.6
4 Ration	H	H					19.8	172.6
5 Ration	H	L					19.8	173.4
6 Ration	L	H					19.8	195.6
7 Ration	L	L					19.8	197.5
8 Demand			M				29.6	278.5
9 Demand			H				2,247.3	411.9
10 Soil Management				L			19.8	184.0
11 Soil Management				H			19.8	183.7
12 Acreage Constraints					L		19.6	182.9
13 Acreage Constraints			H		H		2,249.3	417.8
14 Technology						M	56.4	175.3
15 Technology						H	42.3	168.7

[a] The designation L, M, and H mean respectively Low, Medium, and High. The precise meaning differs among the five classes of assumptions. Detailed definitions appear in the narrative.

[b] 1964 constant dollars.

Feeding Efficiency

The Benchmark Model assumes "Medium" feeding efficiency and concentrate ration levels. All other assumptions are at "Low" levels. Feeding efficiency assumptions tested deviate by 10 percent above ("High) and below ("Low") Benchmark levels.

Deviation from Benchmark Projections.--When comparison of alternative feeding efficiency assumptions were made with the Benchmark level no shifts in irrigated acreage took place (Table 31). Total irrigated acreage remained the same at both "High" and "Low" feeding efficiency. The only crop entering the solution was potatoes at 19,000 acres (Appendix B, Table B-1). At the next higher demand level ("Medium") feeding efficiency assumptions "Medium" and "High" again produced identical results; but at a higher level. A change of 10 percent to "Low" feeding efficiency caused total irrigated acreage to increase 47 percent and locational shifts affecting Subareas 2 and 4 to occur. In addition to potatoes 14,000 acres of corn silage entered the projected irrigation solution.

Implications.--At Benchmark levels of demand ("Low") the alternative feeding efficiency assumptions have no influence on projected irrigated acreage. However, as demand rises, shifts do occur in total acres irrigated and among subareas. These shifts are affected most by the

TABLE 31.--Projected 1980 irrigated acreage for models testing the sensitivity of the feeding efficiency assumptions, by subareas, Southern Michigan Subregion

Model Number	Feeding Efficiency	Subarea 1	Subarea 2	Subarea 3	Subarea 4	Subarea 5	Total Subregion
				1,000 Acres			
1 (Benchmark-Irrigated)	Medium	1.8	0.9	2.3	13.4	1.4	19.8
2	High	1.8	0.9	2.3	13.4	1.4	19.8
3	Low	1.8	0.9	2.3	13.4	1.4	19.8

"Low" feeding efficiency assumption. The change from Benchmark ("Low") demand to "Medium" demand is too large to identify at what point in the range shifts due to "Low" efficiency occur. It is known, however, that the potato crop, in its entirety, is irrigated at all demand levels. The irrigation of corn silage was induced by the greater feed requirements of "Low" feeding efficiency which in turn meant more acres were needed in production. Therefore, it is probable that shifts to corn silage irrigation would take place slightly before reaching demand "Medium" if other assumptions remained unchanged. Errors in specifying the feeding efficiency coefficients cause greater variation in projections of irrigated acreage if they understate efficiency than if they overstate it, particularly at high demand levels.

Livestock Rations

"Medium" concentrate levels are assumed by the Benchmark Model. Variations under study are 15 percent more concentrate ("High") and 15 percent less ("Low").

Deviation from Benchmark Projections.--When alternative ration formulations are considered it is instructive to do so with feeding efficiency either above ("High") or below ("Low") the Benchmark ("Medium") level. First, comparisons are made at "High" feeding efficiency and, second, at "Low" efficiency. Finally the effects of higher demand levels upon feeding relationships are assessed.

Holding feeding efficiency constant at the "High" level while varying concentrate composition of the livestock ration caused absolutely no variation in Benchmark projections of irrigated acreage (Table 32). The same was true of similar comparisons where feeding efficiency was held constant at the "Low" level. As the demand level was increased the first incidence of sensitivity was encountered with "Low" feeding efficiency and demand "Medium." Here variations in concentrate rations caused substantial shifts in total irrigated acreage and among subareas as reported.

It will be remembered that, in the analysis of feeding efficiency sensitivities, "Low" efficiency and demand "Medium" caused irrigated acreage to increase

TABLE 32.--Projected 1980 irrigated acreage for models testing the sensitivity of the livestock ration assumptions, by subareas, Southern Michigan Subregion

Model Number	Proporation of Concentrate in Ration	Feeding Efficiency	Subareas					Total Sub-region
			1	2	3	4	5	
					1,000 Acres			
1 (Benchmark-Irrigated	Medium	Medium	1.8	0.9	2.3	13.4	1.4	19.8
4	High	High	1.8	0.9	2.3	13.4	1.4	19.8
5	Low	High	1.8	0.9	2.3	13.4	1.4	19.8
6	High	Low	1.8	0.9	2.3	13.4	1.4	19.8
7	Low	Low	1.8	0.9	2.3	13.4	1.4	19.8

14,000 acres.[30] This also represented the Benchmark "Medium" concentrate assumption. When that concentrate assumption was increased 15 percent ("High") the 14,000 acres of irrigated corn silage left the solution. The "High" concentrate ration effectively removed the influence of "Low" feeding efficiency on projected irrigated acreage. On the other hand, lowering concentrate in the ration by 15 percent ("Low") caused irrigated acreage to rise by nearly 600,000 acres while the relative distribution among subareas was considerably altered. With respect to maintaining "High" feeding efficiency as concentrate ration relationships varied, no shift-points were in evidence until "High" demand levels were reached where results were completely unrealistic. At this level, variations in the ration caused projected acreage of irrigation to range from 476,000 acres to over 2 million acres.

Implications.--Contrary to observations made in Part I, there does appear to be interaction between feeding efficiency and ration composition. This is especially true in the direction of "Low" efficiency and "Low" levels of concentrate in the ration. At "High" concentrate levels the effects of "Low" efficiency are dampened. Similar but slightly less sensitive results were encountered when

---

[30] See Appendix B, Table B-1 for an indication of which crops were irrigated under each of the alternative model formulations.

feeding efficiency was held at the "High" level. Acreage shifts were not encountered at "Low" demand but increased precipitously as demand climbed.

In view of these results river basin planners should consider projections of economic potential for irrigation as highly sensitive to changes in assumptions concerning ration composition. This is especially true if demands may be overstated or soil resources are in short supply. At high demand levels an error in overstating the concentrate ration component will result in an understatement of irrigated acreage because the comparative advantage of feed grain production reduces the acreage needed for production. The reverse error of understating concentrate will have a greater effect on overstating irrigation projections, particularly if accompanied by an understatement in feeding efficiency because of the increased soil resources brought into production to meet the expanded requirements.

Class 2--Assumptions Relating to Projected Demand

Some of the discussion relevant to this analysis can be found in the preceding section. However, the concern there was to identify sensitivity of irrigated acreage projections to changes in livestock feeding relationships. The influence of demand was secondary. This section is concerned with shift-points between the

Benchmark Model demand ("Low") and models where changes occur in demand assumptions by 50 percent ("Medium") and 100 percent ("High").

Deviations from Benchmark Projections

Increasing Benchmark demands ("Low") by 50 percent ("Medium") resulted in nearly a 50 percent rise in irrigated acreage that generally followed the Benchmark subarea distribution (Table 33). But the next 50 percent increment in demand ("High") brought forth more than a 100 fold increase in irrigated acreage that was not shared equally or proportionately by the subareas. Whereas in the previous two situations Subarea 4 contributed two-thirds of the irrigated acreage, with "High" demand that share was reduced to one-quarter. One-third of the irrigation took place in previously insignificant Subarea 3, nearly a fourth was in Subarea 2, while Subarea 5 increased to 17 percent of the total, and Subarea 1 alone had a small relative decline. The "High" demand level caused lower producing soils to be forced into production which in turn gave crops other than potatoes a comparative advantage when irrigated and these crops entered the solution in all subareas.

The increase in irrigated acreage from Benchmark demand ("Low") to "Medium" demand was due solely to increased potato requirements. At the "High" demand

TABLE 33.--Projected 1980 irrigated acreage for models testing the sensitivity of the demand level assumptions, by subareas, Southern Michigan Subregion

Model Number	Demand Level	Subareas 1	2	3	4	5	Total Sub-region
		1,000 Acres					
1 (Benchmark-Irrigated)	Low	1.8	0.9	2.3	13.4	1.4	19.8
8	Medium	2.8	1.3	3.4	20.0	2.1	29.6
9	High	13.4	536.5	725.9	578.1	393.4	2,247.3

assumption variation, however, over 2 million acres of irrigated crops were forced into the solution. Over 1 million acres of that total were in corn and the remainder was made up of wheat, dry beans, hay crops, and potatoes in that order.[31]

Implications

The Benchmark model projection of irrigated acreage is very sensitive with respect to changes in demand assumptions in a positive direction. Also sensitivity increases exponentially as demands are raised. At low levels of demand the only crop with economic potential for irrigation is potatoes. Thus, errors in specifying demand

---

[31] See Appendix B, Tables B-1, B-2, and B-3 for acreages of irrigated crops under alternative assumption formulations.

at low levels will cause variation in irrigated acreage in the same direction and magnitude as variations occur in potato demand. However, as the assumed level of demands are raised potatoes cease to be the only crop irrigated and sensitivity of the irrigation projections becomes a function of the relative availability of soil resources.

River basin planners should, therefore, have less faith in the stability of their development potential projections in limited resource situations. In this regard, errors in disaggregation of regional demands are more likely to be made for smaller areas than for large. If funds permit additional model runs, the projected development potential should be tested for sensitivity to variations in demand assumptions, particularly on the high side.

Class 3--Assumptions Relating to Soil Management Practices

In the analysis of sensitivity in Part I of this chapter, the assumptions relating to soil management practices created slightly different restrictions on the model than those to be analyzed in this section. There the Benchmark level ("Medium") of projected soil management practices was closer to the "High" level (no restriction) than to the "Low" level (current management practices). In the analysis to follow the variations are approximately the same because soils with slow permeability, very high water holding capacity, or steep slopes were removed from consideration. These are the same soils that caused unequal differentials to exist in the earlier analysis.

Assumptions relating to soil management practices were incorporated into the Benchmark Model so it could account for crop rotations to reduce soil erosion. The Benchmark assumption ("Medium") provided 4.3 million acres as an upper bound for irrigated row crops. The "Low" assumption variation was 3.1 million acres while 5.6 million acres were possible under the no restriction "High" level. Relative availability of irrigable soils ranked by subarea is as follows: Subarea 3, 4, 5, 2, and 1.

Deviations from Benchmark Projections

Shift-point analysis of the deviations in soil management practice assumptions show no sensitivity with respect to the Benchmark at "Low" demand levels (Table 34.) Projected irrigation is identical for each alternative and limited to potatoes which is the only crop with a comparative advantage in irrigation at this demand level. At demand "Medium" a slight variation occurs in Subarea 4 with the "Low" level of soil management. Irrigated acreage increased by about 2,000 acres of corn silage.

More substantial shifts occur among subareas at "High" demand, however. Total irrigated acreage increased by 4 percent as the Benchmark management practice

TABLE 34.--Projected 1980 irrigated acreage for models testing the sensitivity of the soil management practices assumptions, by subareas, Southern Michigan Subregion

Model Number	Soil Management Practices	Subareas 1	2	3	4	5	Total Subregion
				1,000 Acres			
1 (Benchmark-Irrigated)	Medium	1.8	0.9	2.3	13.4	1.4	19.8
10	Low	1.8	0.9	2.3	13.4	1.4	19.8
11	High	1.8	0.9	2.3	13.4	1.4	19.8

assumption ("Medium") was compared with the "Low" level. But Subareas 1, 3, and 4 increased in irrigated acreage while Subarea 2 and 5 declined. The change from Benchmark ("Medium") soil management practices to no constraints on soil resource use ("High") caused a slight drop in irrigated acreage. More variation occurred between Subareas 2 and 3 than in total irrigated acreage.

Implications

Projections of total irrigated acreage were generally insensitive to variations in assumptions about soil management practice levels. However, when influenced by assumed demand increases above Benchmark levels ("Low") some sensitivity in the form of shifts among subareas occurred. This was more evident at the "Low" (current practice) level than at "High" (no restrictions) levels.

The relative magnitude of these shifts were only substantial under the limiting resource situation of "High" demand.

An apparent inconsistancy developed in comparisons involving the "Low" soil management practice assumption. This assumption was the most restrictive in the acreage available for irrigated row crops, yet at higher demand levels more acreage was irrigated under this assumption than the other variations of it. The reason for this was the partial displacement of row crops under the more restrictive situation. In the process of readjustment soils with higher unit production costs were selected which made certain irrigation alternatives more efficient alternatives.

As a result of the analysis in Part I and in this section also the continued use of this assumption does not appear warranted. It should be removed from use in most river basin models. Possible exceptions would be areas with a large proportion of sloping soils or a predominance of row crop production.

Class 4--Assumptions Relating to Minimum Acreage Constraints

Minimum acreage constraints were developed for the Benchmark Model to insure that such extra-market considerations as personal preference, asset fixity, and administrative regulation would be accounted for in 1980 projections. Deviations from the Benchmark assumption of 50 percent ("Medium") were chosen as 25 percent ("Low") and 75 percent ("High"). These proportions of projected demand were required to be produced in the same subareas as had been the case historically.

Deviations from Benchmark Projections

At the "Low" demand level only 200 acres of irrigated crops separated the Benchmark minimum acreage requirement ("Medium") from the "Low" level (Table 35). However, considerable variation exists in irrigated acreage among subareas. The only crop irrigated in both solutions was potatoes. And in the Benchmark solution ("Medium") they entered at the minimum acreage requirement in all but Subarea 4. It was concluded that a reduction in minimum acreage requirements would cause shifts in the location of production. The "Low" requirement alternative verified the conclusion as the four subareas that had formerly entered the solution at the minimum potato acreage again entered at the minimum even though the constraint had been halved. Subarea 4 received the shifted acreage of irrigated potatoes and accounted for nearly 85 percent of Subregion production. With respect to irrigated potatoes the Model seems to verify farmers actions in Southern Michigan. Subarea 4 contains both Bay and Montcalm Counties where most of the states' irrigated potato acreage is currently located.

TABLE 35.--Projected 1980 irrigated acreage for models testing the sensitivity of the minimum acreage constraints assumptions, by subarea, Southern Michigan Subregion

Model Number	Minimum Acreage Constraints	Demand Level	Subareas 1	2	3	4	5	Total Subregion
					1,000 Acres			
1 (Benchmark-Irrigated)	Medium	Low	1.8	0.9	2.3	13.4	1.4	19.8
12	Low	Low	0.9	0.4	1.1	16.5	0.7	19.6
13	High	High	12.1	396.7	922.1	557.1	361.3	2,249.3

At demand "Medium," identical results occurred in the comparison between "Medium" and "Low" minimum acreage assumptions. As minimums were reduced potato acreage shifted to Subarea 4. However, when the minimum constraints were raised to "High" (75 percent), Subareas 1 and 5 no longer produced irrigated crops and the total irrigated acreage declined 18 percent as potato production was removed from Subarea 4 and forced into the less productive subareas by the minimum acreage constraint.

At the "High" demand extreme, a comparison was made between Benchmark minimum acreage ("Medium") and "High." Almost 2.3 million acres were irrigated under each alternative. There were, however, considerable shifts in irrigated acres between Subareas 2 and 3 caused by the "High" acreage constraints.

Implications

Very little sensitivity exists in the projected total irrigated acres under variations in the minimum acreage constraint assumption except at "High" demand. However, sensitivity of the location of that irrigated acreage among subareas does exist and is directly related to the assumed level of acreage minimums.

If a particular crop demonstrates irrigation potential, as in this analysis, it is highly probable that the location of that projected potential will be completely controlled by the level of minimum acreage assumed for the model. The lower the assumed minimums the less likely a small error will cause sensitivity in the location or projected economic potential for irrigation. The effect of "High" minimums is to preclude efficient location of crops among subareas but not within. This relocation within a subarea often removes the potential for irrigating a single crop by requiring the resource for efficient production of other crops not having an irrigation potential but forced into the subarea.

It is possible that greater sensitivity would have been observed had more than one crop exhibited economic potential for irrigation, or whatever development alternative might be considered. River basin planners should evaluate, or at least be aware of, this possibility where a variety of crops display similar potentials.

Class 5--Assumptions Relating to Adopted Level of Crop Producing Technology

In this analysis, as in Part I, assumptions about Benchmark yield levels ("Low") are compared with projected yields that are higher by 20 percent ("Medium"), and 40 percent ("High"). Of concern in this analysis is whether variations in assumed yield levels will affect the level and location of irrigated acreage.

Deviations from Benchmark Projections

The Benchmark Model with "Low" crop yield technology projected 19,800 acres of irrigated potatoes. At "Medium" technology total irrigated acreage increased nearly three times to 56,400 acres, only 16,000 of which were in potatoes and the remaining acres were in irrigated hay crops (Table 36). The "High" technology assumption also produced increases from Benchmark levels but not as large as the first ("Medium") alternative. With higher yields under the second alternative less acres were required for the same production.

TABLE 36.--Projected 1980 irrigated acreage for models testing the sensitivity of the <u>level of technology assumptions,</u> by subareas, Southern Michigan Subregion

Model Number	Level of Technology	Subareas 1	2	3	4	5	Total Subregion
		1,000 Acres					
1 (Benchmark-Irrigated)	Low	1.8	0.9	2.3	13.4	1.4	19.8
14	Medium	1.8	0.9	2.3	50.0	1.4	56.4
15	High	1.8	0.9	2.3	37.3	0	42.3

All of the sensitivity observed in total irrigated acreage generally occurred in Subarea 4, with one exception; at "High" technology levels. The first increment of technology ("Medium") raised yields enough to reduce potatoes by 3,700 acres. But in the process hay crops became economically feasible to irrigate and 40,400 acres entered the solution in Subarea 4. At "High" technology the same two crops continued in the solution; although, due to the higher yields, acreage declined to 13,000 for potatoes and 29,400 for hay crops.

Because the Benchmark minimum acreage constraint ("Medium") was controlling potatoes, the same level of irrigation continued in all subareas but 4 which lost potato acreage with rising technology levels to offset the forced production elsewhere. At "High" yield technology the economic potential for irrigated potatoes in Subarea 5 no longer existed; but 1,400 unirrigated acres were still forced into the solution by acreage minimums.

When similar comparisons were made at demand level "Medium" similar results were observed. Although Subarea 5 continued to produce potatoes at the "High" technology level because of higher general requirements. Somewhat different results occurred at the "High" demand level. With Benchmark technology ("Low") nearly 2,300,000 acres were irrigated including wheat, corn, dry beans, potatoes, and hay crops. When the "Medium" technology level was compared the projected total dropped to 215,000 acres of irrigated hay and potatoes. This was also the case at "High" technology where only 94,000 acres were required.

Essentially all of the change in these last two comparisons occurred in Subarea 4 as before.

Implications

The only shift-points observed in this analysis of sensitivity due to deviations in technology assumptions center on total Subregion irrigated acreage. At "Low" and "Medium" demand levels the effect of changes in technology was to shift irrigated acreage into or out of Subarea 4 in the same amount as total acreage changed. At "High" demand, the first increment in technology above Benchmark ("Low") produced substantial irrigated acreage reductions. But at "High" technology the yields were large enough that results were similar to those observed at lower demand levels.

In this analysis minimum acreage requirements tended to control shifting of irrigated acreage among subareas. If acreage minimums were changed to minimum production requirements the model might be more responsive to changes in technology or to the initial efficiency conditions in the Benchmark solution. If this were true the acreage observed unchanged in this analysis would have decreased in response to rising technology levels and Subarea 4 would have had a larger irrigated acreage.

Sensitivities observed at "Low" and "Medium" demand may have been spurious due to the unique situation that developed in relative crop yields giving hay crops an irrigation advantage at technology "Medium" and "High." However, this same peculiarity might be associated with any error in technology estimation. River basin planners should be aware that such a relationship could develop for most any crop with a development potential.

It must be concluded from this analysis that deviations from the Benchmark assumptions of crop producing technology cause moderate sensitivity in total projected irrigated acreage. Variations in technology that apply equally to all subareas cause imperceptable locational sensitivity, even at high levels of demand.

CHAPTER VI

SUMMARY AND IMPLICATIONS

Summary

The Natural Resource Economics Division carries out a national and regional program of research, planning assistance, and related policy assistance on natural resource problems. A major area of concern of this work relates to development of plans to improve river basins and sub-basins, including investigations to identify and evaluate economic needs for development in rural areas. Most of the investigations are applied economic research which contributes to inter-agency-interdepartment comprehensive studies. Survey data and analyses for this area of work are prepared for use mainly by participating agencies.

In carrying out this planning function, researchers and planners must rely to a certain extent on informed judgment and assumptions concerning certain factors of the total analysis. Such assumptions and judgments play an important role in developing the input data for the NRED least cost linear programming model used in river basin analysis. Considerable concern has developed over the possible effects that errors in judgment or assumptions might have upon the solution of linear programming problems.

This study was undertaken to: (1) evaluate selected assumptions made in developing the NRED model used in projecting agricultural activity on a range of soil resources in river basin studies, (2) analyze the sensitivity of model projections of total production costs to changes in these assumptions, and (3) evaluate the sensitivity of model projections of locations and acreages of potentially irrigable crops to changes in these assumptions. The 42-county Southern Michigan model was chosen for this study because it was representative of other larger models and its relatively small size enhanced the simplicity of incorporating adjustments.

Five classes of assumptions were tested for sensitivity. They were assumptions relating to: (1) livestock feeding relationships, (2) projected demand levels, (3) soil management practices, (4) minimum acreage constraints, and (5) level of crop producing technology adoption. The Benchmark Model consists of a specific level of each of the five assumption classes. Sensitivity of the Benchmark Model to changes in these assumptions was first tested using changes in the total costs of production as the principal criterion. After incorporating irrigation into the Benchmark Model a second sensitivity analysis was made of shifts in the location or total irrigated acreage projected because of changes in these same assumptions.

Feeding efficiency assumptions that varied by 10 percent on either side of the Benchmark level caused a similar directional response in total cost of production but the magnitude was on the order of 6 to 7 percent. The model was quite sensitive to these changes, more so as the soil resource became limiting because assumptions about feeding efficiency affect livestock feed demands. At low efficiency more feed is required and less productive-higher cost soil resources are required to meet demands. The reverse is true for high efficiency but to a lesser degree. Thus, planners should take care in estimating feeding efficiency levels as errors that understate efficiency are more critical than those that overstate it.

Livestock ration assumptions were changed by 15 percent in concentrate composition on either side of the Benchmark ration because of short run influences like weather, price, fad, or harvesting equipment. Once the effect of feeding efficiency was accounted for, variations in concentrate content of assumed rations had little influence on total production costs. Combinations of low feeding efficiency and low concentrate rations caused slightly more sensitivity since roughages were less efficiently produced than feed grains. Errors of 15 percent in concentrate levels caused variations of 1 percent or less in production costs. These results suggest that basin planners should place more emphasis on establishing reliable coefficients for feeding efficiency than for ration composition.

Three demand level models were tested for sensitivity; they included: (1) Benchmark 1980 projected level of demand, (2) Benchmark level increased by 50 percent, which approximated constant relative production levels with respect to the nation, and (3) Benchmark level increased by 100 percent. Results of these tests indicated that errors in demand specification would cause production costs to be in error in the same direction by approximately the same degree. The small number of soils in this analysis may have obscured the diseconomies of forcing less efficient soils into production at higher demand levels. Thus, a model containing a more comprehensive classification of soils may be far more sensitive to errors in demand specification than this model--which was very sensitive.

Soil management practice assumptions reflecting estimated 1980 levels in the Benchmark Model were compared with alternative assumptions that reflected, (1) current levels of soil management practices as constraints, and (2) no constraints to the full use of soil resources for growing row crops. Variation in the total costs of production occurred from assumptions that restricted the full use of soil resources, but it was so slight that it can be ignored. This study indicates that efforts required to derive data to implement such assumptions are not warranted. While this appears to be a sound conclusion for the general case, it may not be true for studies where a large percentage of the soil resources are steeply sloping or a high proportion of all crops grown are row crops.

Analysis of the class of assumptions dealing with minimum acreage constraints measured variations in production costs due to three levels of contraint, 25 percent, 50 percent (Benchmark), and 75 percent. These constraints required a certain percentage of 1980 Subregion demand to be produced as a minimum among the subareas according to the historical distribution. Considerable variation occurred among subareas and within subareas as a result of reorganizing resource use in response to changes in the assumptions. But only small changes occurred in total production costs. With respect to that criterion this class of assumptions caused little model sensitivity.

The class of assumptions relating to adopted levels of crop producing technology reflected crop yields expected to exist in 1980 under average conditions of farm management and weather. This Benchmark level, believed to be conservative, was increased by 20 percent and 40 percent. Since the effect of increased technology is to raise yield levels it also allows cost savings by removing less productive soils from the solution. At low demand levels 4 to 8 percent cost savings were obtained from the two additional increments of technology. These savings increased with rising demand and equalled nearly 7 to 11 percent at the highest demand level. Sensitivity was relatively greater to the first additional level of technology than to the second because it induced a larger shift away from the less productive soils. Underestimating future crop yields will cause an over-statement of production costs and vice versa. However, the error in yields will be far larger than in the costs. If the situation is one of resource scarcity, the errors and the model sensitivity would be increased.

When irrigation was included as an activity in the Benchmark Model, a similar analysis of sensitivities measured by changes in total production costs revealed almost identical results. Because the irrigation alternative was responsible for reducing the magnitude of the objective function, through lower unit production costs, it resulted in slight proportionate increases in sensitivity, but did not change any of the preceding conclusions based on that analysis.

The introduction of irrigation into the Benchmark Model caused certain shifts in the projected location of potato production, the only crop demonstrating irrigation potential at low demand levels. It then became important to learn what shifts might occur in the projected economic potential for irrigation as variations from Benchmark assumptions were introduced. In this approach, the focus was on shift-points in the solutions, on a subarea basis, and the assumptions that triggered such shifts.

It was observed that the feeding efficiency assumptions had no influence on projected irrigated acreage at Benchmark demand. However, the reduced feeding efficiency assumption became extremely sensitive at higher demand levels. Shifts occurred between Subareas 2 and 4. Increased feeding efficiency caused no changes until the highest demand level was reached. There a 10 percent increase in efficiency reduced irrigated acreage by 35 percent but no subarea sensitivity occurred. Errors in specifying feeding efficiency coefficients are more critical if understated than overstated, particularly at high demand levels.

Although Benchmark total production costs were insensitive to variations in ration composition, that was not true for projected irrigated acreage. No sensitivity was observed at Benchmark demand but at the medium demand level and low feeding efficiency an increase of 15 percent in concentrate caused a 32 percent decline in irrigated acres, selectively from two subareas. Fifteen percent lower concentrate in the assumed rations caused irrigated acreage to rise from 44,000 acres to 630,000 acres. More variation occurred at higher demand levels. River basin planners should consider projections of economic potential for irrigation as highly sensitive to changes in ration composition, especially at high demand levels or where soil resources are in short supply.

Shift-point analysis of the demand assumptions indicated that raising Benchmark demand 50 percent resulted in a 50 percent rise in irrigated potatoes, the only crop with an economic potential. Since the minimum acreage constraint was controlling, the increase was proportional for all subareas. However, the next 50 percent increment in demand caused a 7,000 percent increase in total irrigated acreage and disrupted the subarea distribution. Over 1 million acres were in corn and the remainder consisted of wheat, dry beans, hay crops and potatoes in that order. This analysis indicates that planners should question the stability of projected development potentials where demands may be overstated, particularly in limited soil resource situations. If funds permit, alternative runs at different demand levels are advisable.

Shift-point analysis of soil management practice assumptions revealed no sensitivity at Benchmark demand and only a slight variation in Subarea 4 when demands were increased by 50 percent. At the high demand level, where more than 2 million irrigated acres were forced into the solution, a change from Benchmark soil management practices to current management was restrictive enough to increase irrigation by 4 percent. But removing all restrictions from growing row crops only reduced irrigated acreage 0.6 percent. The results of both analyses of sensitivity imply that assumptions about soil management practice levels should be dropped from river basin models unless special conditions exist.

The analysis of assumptions concerned with minimum acreage constraints revealed that changing acreage constraints from the Benchmark (50 percent) to the 25 percent level reduced the irrigated acreage slightly but caused shifts from all subareas to Subarea 4. The only crop irrigated was potatoes which would have shifted completely into Subarea 4 had not minimum acreage constraints been set. This was generally true at all demand levels. When minimum acreage constraints were raised to 75 percent it placed severe limits on Subareas 1 and 2. The effect was to preclude efficient location among subareas but not within. Realocation within these subareas, to provide efficient production of other crops, removed the potential for irrigating potatoes and total irrigated acreage decreased. More sensitivity might have occurred had other crops exhibited an economic potential for irrigation at other than forced conditions.

The final analysis of shift-point sensitivity concerned variations in the assumed level of adopted crop producing technology. Essentially all the sensitivity occurred in total projected acreage of irrigation due to increased levels of technology. Shifts of irrigated acreage did take place in Subarea 4 but only reflected the changes taking place in the Subregion total. A 20 percent increase in technology from Benchmark levels raised irrigated acreage about 180 percent simply because 40,000 acres of hay crops became economically feasible to irrigate. A 40 percent increase in technology above the Benchmark induced the same two crops (potatoes and hay) into the solution; although the relative increase was only about 110 percent as acreage requirements dropped substantially with the yield increases. Throughout the analysis minimum acreage requirements precluded any shifting among subareas as yields increased. Had minimum acreage requirements been changed to production minimums the model may have been much more sensitive to technology changes.

Implications

This study has shown that sensitivity analysis, using aggregate criteria such as objective functions, can identify the relative importance of certain alternative model assumptions and the implications of errors or variance in these assumptions. This information is extremely useful in establishing model specifications. Yet, it is clear from the results of the shift-point analysis that aggregate criteria, such as the objective function, for the most part, fail to adequately identify important changes in model subareas that may be masked by the more aggregative approach.

Results from the sensitivity and shift-point analyses suggest that in future river basin models attempts should be made to more adequately account for projected livestock and livestock products. The current procedure of converting demands for livestock into demands for livestock feed creates an artificial situation in which the researcher must not only assume the livestock mix within class and appropriate feeding efficiency but the unique ration as well.

If additional activities were added to the model to produce the livestock product requirements, several problems would be solved concurrently. The problem of locating livestock production is currently associated with the two-step process of converting livestock feed needs to crop demands and reconverting the projected cropping patterns back to livestock. This process requires additional assumptions about the mix of livestock in a particular subarea; partly tied to historical production mix and partly to the dominant ration components of the livestock class. For a feed crop exporting area the problem is further complicated; which Subarea or subareas should be considered as the exporters, and on what basis should the livestock be distributed among surplus crop producing subareas? There is also the compound problem of obtaining realistic cropping patterns among subareas.

Currently this process is handled through constraints to full efficiency in resource use. Minimum production requirements are placed on subareas and row-crop limitations are placed on certain soil resources. This process is supposed to provide sufficient quantities of the appropriate feed stuffs to accommodate a realistic distribution of livestock production throughout the basin. Introducing livestock activities that draw upon the crops produced for their feed requirements would tend to eliminate this problem. In the process of simultaneously meeting both the overall crop demands and livestock feed requirements, the livestock would be located in subareas that also produce the appropriate feed crops. Additionally, any excess feed grains, for export purposes, would be identified by Subarea.

Conceptually, within each subarea an activity would be specified for the production of each type of livestock and livestock product required of the whole basin. Each activity would have the capability of meeting part of the overall demand for the particular livestock item. In so doing, certain quantities of feed grains and roughages would be utilized per unit of livestock product produced. Upper and lower bounds, within fairly narrow ranges, could be placed on feed categories to allow some substitution of feed stuffs within the ration for any class of livestock. This would preclude the problems of set rations and absolute crop requirements since overall demands could be set at minimum levels and determined, in the final analysis, by efficient ration selection endogenous to the model.

Placing minimum and maximum bounds by subareas on total livestock product demands through an alternative specification of the model, would produce results quite similar to the current procedure. Since the type and location of feed production is related to livestock production, there would be added realism in the model. The projection of agricultural labor requirements would be facilitated by this process and would more nearly represent the likely future situation due to the greater correspondence among farm enterprises. There may also be greater reliability in the projected development potential with respect to feed crop-livestock combinations than with current procedures which identify potentials related to crop production alone. Moreover, further improvements would be expected from incorporation of transportation costs into the model if the difficult data problems associated with these costs could be resolved.

The results of this analysis indicate that, of the five classes of assumptions tested, the assumption concerning soil management practices should be dropped from future river basin models. Practically no variation in Benchmark results was induced by deviations in this assumption. The considerable effort in developing coefficients to implement the assumption is, therefore, not warranted.

In this study the analysis of economic potential for irrigation has identified certain crops and subareas that appear to have a comparative advantage. This work needs to be extended by tracing the variability in model solutions through to their implications for agricultural population, employment, and income on a subarea basis. While the analysis of this study reflects only what is economically potential in the way of irrigation when the source of water and public development costs are not considered, it is true that there are locations in the State with much greater ground water resources than others. There is also considerable variability in the volumes of stream flow throughout the area. Thus, it is important to find answers to such questions as: What are the distributional consequences of a policy to expand supplemental irrigation? What are the implications of irrigation development for the large number of local communities that are dependent upon agricultural activity? If stream use is restricted by law, what are the implications if ground water is the sole source for irrigation?

Limitations

This study looked at the sensitivity of the Benchmark Model projections of total production costs and irrigated acreage as affected by alternative levels of five classes of assumptions. These assumptions are commonly used in NRED models to project agricultural activity for analysis in river basin studies.

The brief example of variation in sensitivity due to the choice of alternative criteria for measuring sensitivity indicates that a variety of variables could have been chosen. Each choice may give somewhat different results and this must be kept in mind when evaluating relative sensitivities among the assumptions under study. One measure of sensitivity may indicate a low overall level of sensitivity for the entire study area while another measure may reveal substantial variation among subareas.

While the assumptions and Model studied are similar if not identical to many of the NRED river basin models using linear programming techniques, the results of this study may not be directly applicable. It must be remembered that the Benchmark Model was specified for an area in Southern Michigan. Application can readily be made, therefore, to studies in the North Central region where production functions, type of farming practices, costs, and crops grown are quite similar. In other areas of the country these variables may be sufficiently different to negate the direct application of these results. However, the general knowledge derived from this study will be useful in indicating the type of sensitivity that planners should remain aware of in evaluating results of projection models.

Application of Results

Each river basin study undertaken or participated in by USDA member agencies has, as part of the study guidelines, the requirement that data be developed to assist in updating study results periodically. Such updating may be called for in several instances, for example, where particular projects within the study area are authorized for construction feasibility analysis, or where changes occur in the data upon which the study results are based.

The latter situation is one that most often occurs either late in the study or several years following study completion. Usually, there is not sufficient time or funding for more than a partial analysis of the impacts associated with the changes. Sensitivity analysis, such as was carried out in this study, can readily provide the basis for rule of thumb estimates of the direction and extent of change in criterion variables due to either recognized errors in assumed levels of input coefficients or revised estimates of such controlling variables as population or regional demands.

Results of sensitivity analyses would make the user much more responsive to other agencies needs to analyze the effects of changes in study projections. The implications could be interpreted by NRED personnel for all users of study projections. In turn, the influence of other study participants determinations could also be traced back through the model if they happen to influence the underlying assumptions tested for sensitivity.

Another direct use of the sensitivity analysis relates to the evaluation of economic potential for resource development (in this case the potential for irrigation). Since the economic potential is expressed in terms of acres of particular soils, it is related to a particular location in addition to representing a specific level of development potential. With a soils map of the river basin under study the location of soils demonstrating an economic potential for irrigation could be identified under various assumptions. Cooperating agencies such as the Corps of Engineers, Soil Conservation Service, Bureau of Recreation, Federal Water Quality Administration, and Bureau of Sport Fisheries and Wildlife could then observe the location and type of cropping pattern associated with on-farm economic development potential.

Such information would be useful to the construction agencies who would be able to divert planning resources from areas without a demonstrated economic potential for development to those areas that have potential. Recreation and fish and wildlife interests could evaluate possible effects of changes in agricultural activity or reservoir development on their aspects of the planning process. And, possible changes in water quality due to different cropping patterns and more intensive management could be identified and planned for.

Once development potentials were identified generally on a soils map and potential structure sites located, the area serviced by a particular site could be determined. By ranging upward on the on-farm costs of implementing the development activity in the linear programming model, that point where it is no longer profitable to undertake the development from the farmers viewpoint would be determined. The change in cost necessary to reach that point could then be compared against the costs associated with getting water to the land, in the case of irrigation. The cut-off point for economic feasibility from a particular source would then be related to topography and the length of transmission possible in view of the assumptions made concerning who was to bear the costs.

BIBLIOGRAPHY

BIBLIOGRAPHY

Battelle Memorial Institute. *The Usefulness of Computer Simulation in River Basin Analysis*. Research Report to Natural Resources Economics Division, ERS, USDA, March 1967.

Blaney, Harry F., and Criddle, Wayne D. *Determining Water Requirements in Irrigated Areas from Climatological and Irrigation Data*. SCS-TP-96 Bulletin, 1950.

Cotner, Melvin L. "The Potential Role of Agricultural Land Drainage in Economic Growth." Unpublished Ph.D. thesis, Michigan State University, 1967.

Dale, Robert F., and Shaw, Lawrence H. "The Climatology of Soil Moisture, Atmospheric Evaporative Demand, and Resulting Moisture Stress Days for Corn at Ames, Iowa." *Journal of Applied Meteorology*, IV, No. 6 (December 1965), 661-69.

DeWolfe, Mildred R. *Hay in the United States, Quantities Grown in a Normal Year, Surplus and Deficit Areas*. USDA Statistical Bulletin 349, August, 1964.

Dorfman, Robert; Samuelson, Paul A.; and Solow, Robert M. *Linear Programming and Economic Analysis*. New York: McGraw-Hill Book Company, Inc., 1958.

Egbert, Alvin C., and Heady, Earl O. *Regional Adjustments in Grain Production, A Linear Programming Analysis*. USDA Technical Bulletin 1241 and Supplement, June, 1961.

________. *Regional Analysis of Production Adjustments in the Major Field Crops: Historical and Perspective*. USDA Technical Bulletin 1294, November, 1963.

________, and Brokken, Ray F. *Regional Changes in Grain Production, An Application of Spatial Linear Programming*. Iowa Agricultural Experiment Station, Research Bulletin 521, Ames, January, 1964.

Fritschen, John F., and Atherton, James C. Resource Requirements for Meeting Projected Needs for Agricultural Production, Texas River Basins: A Methodological Supplement. Prepared by Farm Economics Division, ERS, USDA, for U.S. Study Commission, Texas, 1962.

Grand River Basin Coordinating Committee. Comprehensive Water Resource Study, Grand River Basin, Michigan: Appendix O-Economic Base Study. Vol. X, January, 1966.

Hadley, G. Linear Programming. Reading, Mass.: Addison-Wesley Publishing Company, Inc., 1962.

Halter, Albert N., and Miller, Stanley F. River Basin Planning: A Simulation Approach. Eugene: Oregon State University, Special Report 224, November, 1966.

Harl, Neil E. "Research Methods Adaptable to Legal-Economic Inquiry: Linear Programming and Simulation." Methods for Legal-Economic Research into Agricultural Problems. Iowa City: University of Iowa, Agricultural Law Center Monograph No. 8, 1966.

Hill, Elton B., and Mawby, Russell G. Types of Farming in Michigan. East Lansing: Michigan Agricultural Experiment Station, Special Bulletin 206, September, 1954.

Hodges, Earl F. Livestock-Feed Relationships 1909-1964. USDA Statistical Bulletin 337 and annual supplements, September, 1965.

Hostetler, John E., and Cotner, Melvin L. Agricultural Activity in the Grand River Basin: A Projective Study. Natural Resources Economics Division, ERS, USDA, January, 1966.

McKee, D. E.; Sundquist, W. B.; Bonnen, J. T.; Baker, C. B.; and Day, L. M. Equilibrium Analysis of Income Improving Adjustments on Farms in the Lake States Dairy Region, 1965. St. Paul: University of Minnesota, Technical Bulletin 246, October, 1963.

Michigan Conservation Needs Committee. An Inventory of Michigan Soil and Water Conservation Needs. East Lansing: Michigan Agricultural Experiment Station, October, 1962.

Michigan State University. *Project '80: Rural Michigan Now and in 1980, Highlights and Summary*. East Lansing: Michigan Agricultural Experiment Station, Research Report 37, February, 1966.

Miller, Stanley F., and Halter, Albert N. "Simulation Systems in Making Water Resource Decision." *Proceedings*. Committee on Economics of Water Resource Development, Western Agricultural Economics Research Council, San Francisco, Calif., December, 1965.

________. "Computer Simulation of the Substitution Between Project Size and Management." *American Journal of Agricultural Economics*, LI, No. 5 (December, 1969), 1119-23.

Ohio River Basin Survey Coordinating Committee. *Main Report-Ohio River Basin Comprehensive Survey*. Cincinnati: Ohio River Division, Corps of Engineers, August, 1969.

Palmer, Wayne C. *Meteorological Drought*. Research Paper 45, Weather Bureau, USDC, February, 1965.

U.S. Congress. House. Committee on Interior and Insular Affairs. "Water in Relation to Plant Growth." *The Physical and Economic Foundation of Natural Resources I: Photosynthesis--Basic Features of the Process*, by Paul J. Kramer. Washington, D.C.: Government Printing Office, 1952, pp. 34-39.

________. "Evaporation in the Hydrologic Cycle." *The Physical and Economic Foundation of Natural Resources I: Photosynthesis--Basic Features of the Process*, by C. W. Thornthwaite. Washington, D.C.: Government Printing Office, 1952, pp. 28-33.

U.S. Congress. Senate. *Report of the Senate Select Committee on National Water Resources*. Sen. Report 29, 87th Cong. 1st. sess., 1961.

U.S. Soil Conservation Service. Michigan. "Instructions for Determining Cropping Systems for Sloping Land." *Technical Guide*, Section III-B, March, 1964.

VanBavel, C. H. M., and Verlinden, F. S. *Agricultural Drought in North Carolina*. Raleigh: North Carolina Agricultural Experiment Station, Technical Bulletin 122, June, 1956.

Whiteside, E. P.; Schneider, I. P.; and Cook, Ray. Soils of Michigan. East Lansing: Michigan Agricultural Experiment Station, Special Bulletin 402, December, 1959.

Whittlesey, Norman K., and Heady, Earl O. Aggregate Economic Effects of Alternative Land Retirement Programs: A Linear Programming Analysis. ERS, USDA, in cooperation with Iowa Agricultural Experiment Station, USDA Technical Bulletin 1351, Ames, 1966.

APPENDICES

APPENDIX A

IRRIGATION IN SOUTHERN MICHIGAN--DATA AND ESTIMATING PROCEDURES

APPENDIX A

IRRIGATION IN SOUTHERN MICHIGAN--DATA AND ESTIMATING PROCEDURES

Available Survey Data

Specialized USDA Data

One of the first tasks in any river basin study is the collection of basic data relating to the soils of each sub-study area. This is usually rather specialized data that must be tailored to the needs of the particular study. For instance, where there are tight limits on either the time or funds available for the study, wide use is made of the more general secondary data available. However, where warranted, more specific primary data is collected from the field. This frequently is the only source of such specialized information and is useful as a check against assumptions based on the more general data.

Early in the planning stages of the Great Lakes Basin Survey, conducted in 1968, the Economic Research Service initiated a common soil classification system for the study area with the assistance of soil scientists of the Soil Conservation Service in each of the eight states participating in the study. Several hundred soil series were eventually grouped into twenty-three soil resource groups (SRG's) for use in planning for the future development needs of the Basin.

Each SRG represented soils with similar texture, slope, and hazard, such as wetness, erodibility, droughtiness, or flooding. These soils were also grouped to respond similarly to management with relatively homogeneous crop yields and costs of production. Such groupings were intended to provide a basis to evaluate the relative productive capabilities of the soil resource in the study area.

Subsequently, a Soil Conservation Service-Economic Research Service team undertook an extensive data collection effort. Land use data for each of the 190 counties in the Great Lakes Study area were initially determined from the 1967-1968 Conservation Needs Inventory data. Meetings were held in central locations and in addition to District Conservationists from each county, the Area Conservationists and Regional Soil Scientiests were on hand to ensure continuity of the estimates over the broad area and to interpret particular soils groupings where required.

At that point, major attention centered on cropland use. With the Conservation Needs Inventory as a point of departure, District Conservationists were asked to make whatever adjustments in reported acreages they felt were necessary to accurately represent the current situation. The adjusted cropland acreage in each SRG category was then distributed among an array of crops normally grown in each county. For each crop, the SRG acreage was further subdivided into the five following groups: (1) adequately drained or flood protected, (2) untreated drainage problems, (3) partially treated drainage problems, (4) flooding problems, and (5) combined flooding and drainage problems.

For the major field crops and pasture types, estimates were made of normal yields under prevailing hazards. In the case of specialty crops, such as some fruits and vegetables, nursery crops, and sod, no attempt was made to derive a yield estimate. Instead, only the acreage grown on an SRG according to hazard was documented. In addition, estimates of the extent of irrigation in each county by crop by SRG were requested. As in the case of non-irrigated crops, no attempt was made to establish yields for specialty crops.

Table A-1 is a complete picture of the estimated extent of irrigation in the Southern Michigan Subregion by crop and subarea. These data reflect the best estimates of District Conservationists when asked to consider the crop being irrigated and the soils upon which those crops are normally grown. Under these conditions irrigation estimates for the 42-county subregion reached slightly more than 119,900 acres in 1968, about 2 percent of available cropland. The primary crop being irrigated at that time was potatoes followed in order by sod, corn for grain, field beans, sweet corn, and strawberries. These

TABLE A-1.--Estimated acreage being irrigated by crop and by subarea, 1968, Southern Michigan Subregion, Great Lakes Basin Data Survey

Crop	Subareas					Sub-region Total
	1	2	3	4	5	
			Acres			
Corn, grain			730	4,007	8,000	12,807
Corn, silage					600	600
Apples					1,900	1,900
Peaches					1,200	1,200
Cherries					300	300
Other tree fruit					1,390	1,390
Strawberries			90	100	5,731	5,921
Blueberries					2,650	2,650
Raspberries					1,495	1,495
Hay					500	500
Sweet Corn	4,210		110	200	2,242	6,762
Green Peas	30		20		502	552
Tomatoes	15				4,389	4,404
Snap Beans	20		80	2,000	2,500	4,600
Asparagus			50	700	1,743	2,493
Cauliflower					200	200
Cucumbers			600		4,327	4,927
Carrots					100	100
Onions			100		1,700	1,800
Lettuce			100			100
Celery					2,050	2,050
Other vegetables	1,000	1,500		100	500	3,100
Cantaloupe, Melons					500	500
Mint			200			200
Nursery stock	800					800
Field Beans			350	10,123		10,473
Sugar Beets				800		800
Potatoes	6,300	1,000	595	19,000	3,450	30,345
Sod	6,307	4,000	4,829		1,300	16,436
Wormwood					200	200
Popcorn					300	300
Total	18,682	6,500	7,854	37,100	49,769	119,905

six crops accounted for nearly 70 percent of all irrigation in the study area.

Subarea 5 was by far the most significant both in acreage and variety of crops irrigated. Subarea 4 was second, due to its dominent position in the irrigation of field beans and potatoes. Surprisingly, Subarea 1, the five-county metropolitan area, was third entirely on the basis of specialty crops. The remaining two subareas had similar acreages of irrigation but a somewhat different array of crops grown.

Michigan Water Resources Commission Data

At approximately the same time as the USDA survey of Great Lakes Basin, the Michigan Water Resources Commission (MWRC) was completing the second phase of an irrigation study begun in 1958. This two-part study of irrigation by MWRC was an attempt to get a complete survey of all irrigators in the State for agricultural or other purposes. It was directed at the user, while the USDA survey was a poll of county and regional officials of the Soil Conservation Service. It also sought to identify the source of irrigation water used and the quantities applied both by county and river basin.

Data from these two MWRC surveys, 1958 and 1968, help to indicate the shifts taking place in irrigation among crops and subareas of the Southern Michigan Subregion. There has been a general increase in irrigation over the ten-year period of the two surveys (Table A-2). However, certain crops have not shared in that increase, namely pasture and hay crops, tomatoes, strawberries, raspberries, and tree fruit. The downward trend in the total acreage of most of these crops grown in the study area helps to explain such declines in the face of a general increase of nearly 60 percent in irrigation acreage.

The one single crop that stands out in both periods is potatoes which was also the dominant irrigated crop in the USDA survey. Here the comparisons become a little more difficult due to the differences in reporting results of surveys (Table A-3). It is obvious that sod is also an important acreage in each survey, although it was unreported in the 1958 MWRC survey, either because it was not irrigated at all or was insignificant and combined with some other category.

Agricultural Census Data

Both the USDA survey and the MWRC surveys were particularly interested in an accurate picture of the extent and location of irrigation in the State. The Census of Agriculture, on the other hand, is much more general and only recently has asked questions about irrigation from its respondents. In the 1959 Census only the total acreage irrigated is available (Table A-4). One would assume that this should coincide fairly closely with the 1958 MWRC survey. However, the Census data falls short

TABLE A-2.--Irrigation of agricultural and miscellaneous crops by crop and subarea, 1958 and 1968, Southern Michigan Subregion, Michigan Water Resources Commission

Crop	Subareas					Sub-region Total
	1	2	3	4	5	
			1968 Acres			
Field Crops	258	395	1,121	1,783	6,543	10,100
Hay and Pasture	70	105	47	25	299	546
Total Vegetables	1,417	1,389	4,267	16,080	12,320	35,473
Melons, pickles	(-)	(310)	(270)	(1,160)	(2,369)	(4,109)
Truck Crops	(1,177)	(934)	(3,277)	(381)	(6,407)	(12,176)
Tomatoes	(-)	(-)	(-)	(284)	(1,430)	(1,714)
Potatoes	(240)	(145)	(720)	(14,255)	(2,114)	(17,474)
Total Fruit	247	378	948	292	10,101	11,966
Strawberries	(77)	(65)	(86)	(162)	(3,912)	(4,302)
Raspberries	(-)	(16)	(36)	(5)	(690)	(747)
Blueberries	(-)	(-)	(8)	(15)	(2,276)	(2,299)
Tree Fruit	(170)	(297)	(809)	(110)	(2,963)	(4,349)
Small Fruit	(-)	(-)	(9)	(-)	(260)	(269)
Sod	1,615	2,187	2,569	205	1,298	7,874
Nursery Stock	381	165	722	27	2,723	4,018
Total	3,988	4,619	9,674	18,412	33,284	69,977
			1958 Acres			
Field Crops	203	101	510	1,395	1,637	3,846
Hay and Pasture	46	92	376	143	969	1,626
Total Vegetables	2,982	951	2,650	4,198	11,094	21,875
Melons, pickles	(65)	(20)	(694)	(1,001)	(1,702)	(3,482)
Truck Crops	(1,798)	(656)	(1,122)	(247)	(6,457)	(10,280)
Tomatoes	(153)	(3)	(51)	(52)	(1,878)	(2,137)
Potatoes	(966)	(272)	(783)	(2,898)	(1,057)	(5,976)
Total Fruit	421	113	496	241	11,456	12,727
Strawberries	(111)	(56)	(205)	(184)	(4,536)	(5,092)
Raspberries	(2)	(27)	(66)	(13)	(1,294)	(1,357)
Blueberries	(35)	(10)	(8)	(26)	(1,651)	(1,730)
Tree Fruit	(268)	(20)	(202)	(18)	(4,010)	(4,518)
Small Fruit	(5)	(-)	(15)	(-)	(10)	(30)
Sod	-	-	-	-	-	-
Nursery Stock	1,195	125	426	30	2,117	3,893
Total	4,847	1,382	4,458	7,006	27,273	43,967

Source: Working data provided by the Staff of the Michigan Water Resources Commission.

TABLE A-3.--Summary of irrigated acreage of agricultural crops, 1958 and 1968, Southern Michigan Subregion, as estimated by the Michigan Water Resource Commission surveys and the Great Lakes Basin Data survey of 1968

Crop	Subareas, 1968 MWRC Survey					Sub-region Total	Subareas, 1958 MWRC Survey					Sub-region Total
	1	2	3	4	5		1	2	3	4	5	
			Acres						Acres			
Field Crops	258	395	1,121	1,783	6,543	10,100	203	101	510	1,395	1,637	3,846
Hay and Pasture	70	105	47	25	299	546	46	92	376	143	969	1,626
Total Vegetables	1,417	1,389	4,267	16,080	12,320	35,473	2,982	951	2,650	4,198	11,094	21,875
Total Fruit	247	378	948	292	10,101	11,966	421	113	496	241	11,456	12,727
Sod	1,615	2,187	2,569	205	1,298	7,874	-	-	-	-	-	-
Nursery Stock	381	165	722	27	2,723	4,018	1,195	125	426	30	2,117	3,893
Total	3,988	4,619	9,674	18,412	33,284	69,977	4,847	1,382	4,458	6,007	27,273	43,967

	Subareas, 1968 USDA Survey					Sub-region Total
	1	2	3	4	5	
			Acres			
Field Crops	-	-	1,080	15,000	8,600	24,680
Hay and Pasture	-	-	-	-	500	500
Total Vegetables	11,575	2,500	1,855	22,000	24,703	62,633
Total Fruit	-	-	90	100	14,666	14,856
Sod	6,307	4,000	4,829	-	1,300	16,436
Nursery Stock	800	-	-	-	-	800
Total	18,682	6,500	7,854	37,100	49,769	119,905

Source: Working data from the Michigan Water Resources Commission 1958 and 1968 surveys and USDA Great Lakes data survey.

TABLE A-4.--Irrigated acreage of harvested agricultural crops, 1959 and 1964, by subarea, Southern Michigan Subregion

Subarea	Irrigated Crops 1964									Total 1964	Total 1959
	Corn	Field Beans	Potatoes	Vegetables	Straw-berries	Rasp-berries	Blue-berries	Orchard	Nursery Stock		
					Acres						
1	36	-	869	1,982	45	2	16	275	326	3,988	3,984
2	226	-	227	553	26	6	4	77	53	1,721	1,154
3	96	92	518	1,875	98	39	2	297	313	3,501	3,016
4	78	1,146	4,899	707	98	26	61	80	54	7,219	5,854
5	1,481	15	816	9,782	2,957	1,412	2,041	3,274	891	25,630	20,450
Total Sub-region	1,917	1,253	7,329	14,899	3,224	1,485	2,124	4,003	1,637	42,059	34,458
Total State	2,077	1,263	8,943	16,900	4,269	1,573	2,131	4,665	1,778	48,991	40,178

Source: Census of Agriculture 1959 and 1964.

by 35 percent, partly due to under-reporting and partly due to what constitutes a farm for Census purposes. Further comparisons between Census and MWRC data indicate that while most Census subareas are substantially below acreages reported in MWRC, Subarea 4 is nearly the same. In both the 1959 Census and 1958 MWRC survey, subareas are ranked 5, 4, 1, 3, and 2 in order of importance.

In the 1964 Census the relative ranking of subareas remained the same (5, 4, 1, 3, 2) while some shifts had taken place in the 1968 MWRC survey (5, 4, 3, 2, 1). In both census years the Subregion counties represented nearly 86 percent of the State's irrigated acreage while a general increase of 23 percent took place. By this time the 1964 Census and 1958 MWRC survey nearly agreed on total irrigated acreage in the Subregion. Also, in 1964 the Census provides a partial breakdown of crops irrigated. In total, the 1964 Census seems to be fairly consistent with the MWRC survey in acreage of field crops and tree fruit irrigated, but only close among subareas on field crops. The same can be said for total vegetable acreage, including potatoes, however when the potato crop is removed so is comparability. The relative importance of potatoes and other vegetables is reversed between the two surveys.

Since the USDA survey in 1968 identified a greater acreage irrigated than either the 1968 MWRC survey or the 1964 Census, it is useful to compare only the relative distribution of crops between it and the Census. It is interesting to note, however, that the relative importance of subareas between the USDA and 1964 Census surveys is identical--5, 4, 1, 3, 2.

Projected Potential and Comparisons

How can one use such conflicting data sources to gain some insight into the future use of irrigation in Michigan? At the very best there are only two points in time from which to project. Following the Census, an estimated increase of approximately 1,500 acres a year would be indicated, while the MWRC data would suggest that the figure should be more like 2,600 acres a year. Since it is fairly evident that irrigation is practiced extensively on high value crops, such as sod, nursery crops, and other specialty crops, it seems most important to evaluate its potential among the general field crops, such as corn, wheat, beans, and potatoes. It is evident from the numerous surveys that potatoes are profitably irrigated and should be expected to continue in the future, but what about the other more general crops? A check of the ten-year trend for these crops in MWRC data (the only source for this comparison) indicates that an average increase of 1,700 acres a year for these crops might be a useful approximation.

If one were to carry out such an effort of approximating what irrigated agriculture might resemble in 1980 within the Southern Michigan Subregion, he would estimate that 48,500 acres of general field crops and potatoes would be involved. They would be distributed with approximately 1,000 acres in hay crops, 17,500 acres in general field crops, and 30,000 acres of potatoes. Since this exercise simply extends a trend established by two points and does not take economics into consideration few would have much faith in its accuracy.

The Palmer procedure for estimating irrigation water demands and future potentials for agricultural irrigation appears superior to any of the methods discussed above. Details concerning this procedure are discussed in the remainder of this Appendix.

The Problem of Estimating Irrigation Potential

Review of census data and other sources such as experiment station bulletins and various journal articles reveals a growing interest by farm operators and researchers in the use of supplemental irrigation in humid areas. Unfortunately, the census data are aggregates or averages and do not indicate the types of crops irrigated, size of equipment, source of water, and amounts applied. Also unaccounted for are relative differences among irrigated and nonirrigated soils and yields of the same crop, and other pertinent variables that are of importance in projections of future use. Research results, while a much improved source for this type of information, do not provide, as yet, a sufficient base for making generalized projections. There is a definite lack of consistency among experimental data both from various experiment stations, and even between years on the same experiment. Differences exist between management practices, soils, timing and quantity of irrigation relative to soil moisture levels, rate of fertilizer applied, and volume of water applied per irrigation to mention but a few of the variations.

Irrigation studies have generally been undertaken on medium to coarse textured soils. This provides considerable range over which to apply the results, but without more specific identification of the soils, it is not suitable for the purposes of this study. Another disadvantage of this practice is the lack of experimental data at each side of the coarse-texture spectrum. Also, interest has centered on only a few general crops, such as corn and potatoes and such specialty crops as small fruits and certain vegetables. Little or no experimental data exist for the irrigation potential of other major field crops. The necessity of developing some sort of synthetic statistical approach to the evaluation of yield response to irrigation is thus essential.

An Improved Estimating Procedure

The approach chosen for this study relates certain weather variables with the yields of most major field crops over time. Blaney and Criddle have developed a weather index based on effective rainfall that produces reasonable results in explaining variations in crop yields as fluctuations occur in key weather variables.[1] This work is primarily confined to the less humid western states and does not give similar results when applied to weather conditions in humid areas. VanBavel's work suggests a very accurate approach to the problem but the data requirements are too demanding for the purpose of this or most river basin studies.[2]

The work of Palmer, using the Thornthwaite formula, was adapted to the needs of this study and relationships were developed that related moisture deficiencies with known variations in crop yields.[3] The procedures in developing stress-yield relationships are similar to the

---

[1] Harry F. Blaney and Wayne D. Criddle, "Determining Water Requirements in Irrigated Areas from Climatological and Irrigation Data," SCS-TP-96 Bulletin, 1950.

[2] C. H. M. VanBavel and F. S. Verlinden, "Agricultural Drought in North Carolina," Technical Bulletin No. 122 (Raleigh, N.C.: North Carolina Agricultural Experiment Station, June, 1956).

[3] The author is indebted to James E. Horsfield, Jr., Agricultural Economist, NCRG, for his pioneering work in this area and his assistance in making certain improvements in the procedure for use in this study.

refinements introduced by Dale in his work at Iowa on experimental plots.[4]

Palmer was primarily interested in developing a methodology that would enable him to identify the beginning, severity, and extent of agricultural drought in any particular area. The procedure followed was a complex moisture budgeting process using numerous climatological variables which allowed the measurement of the deviation between the atmospheric demand for and supply of potential soil moisture. Monthly weather data were utilized as they were more readily available, less costly to analyze and manipulate, and provided surprisingly similar results when compared with analyses of shorter periods.[5]

Incorporation of Irrigation Development Into the Basic Model

The Palmer procedure was adapted for use in this study to provide a means of estimating irrigation water demands and the future potential for agricultural irrigation. This procedure requires that the soil root zone be separated into two distinct areas. The surface layer

---

[4] Robert F. Dale and Lawrence H. Shaw, "The Climatology of Soil Moisture, Atmospheric Evaporation Demand, and Resulting Moisture Stress Days for Corn at Ames, Iowa," Journal of Applied Meteorology, IV, No. 6 (December, 1965), 661-69.

[5] Wayne C. Palmer, Meteorological Drought, Research Paper No. 45 (Washington, D.C.: U.S. Department of Commerce, Weather Bureau, February, 1965), p. 54.

is assumed to hold one inch of available moisture, while the underlying layer holds the remainder. The budgeting process requires that soil moisture leave by evapotranspiration or be returned through recharge to the surface layer before any change is allowed to take place in the underlying area. These relationships are expressed by the following two equations:

1. $Ls = S's$ or $(PE - P)$, whichever is smaller, and

2. $Lu = (PE - P - Ls)\,\frac{S'u}{AWC}$, $Lu \leq S'u$

Where Ls = moisture loss from the surface layer,

$S's$ = available moisture stored in the surface layer at the start of the month,

PE = potential evapotranspiration for the month,

P = precipitation for the month,

Lu = loss from the underlying levels,

$S'u$ = available moisture stored in underlying levels at the start of the month, and

AWC = combined available water holding capacity of both levels

Potential evapotranspiration reflects the optimum transfer of moisture to the atmosphere under ideal conditions of soil moisture and vegetative cover.[6] Actual evapotranspiration (ET) is usually somewhat less than this value since soil moisture conditions, primarily during the growing season, are at less than field capacity. Field capacity is reached when the soil no longer is capable of retaining additional moisture for any length of time. Additional moisture is naturally removed through either deep percolation or surface runoff. As the soil moisture content decreases below field capacity, the strength of the bond between the soil particles and soil moisture increases and makes it more difficult for the plant to utilize the available moisture. This moisture stress on the plant becomes greater as soil moisture declines, and results in reduced growth and yields.[7] An index of this moisture stress relationship was constructed and used as the primary climatological variable in the irrigation analysis in this study.

Weather data have been tabulated and used in a generalized moisture budget for nearly all weather districts

---

[6] C. W. Thornthwaite, "Evaporation in the Hydrologic Cycle," The Physical and Economic Foundation of Natural Resources I: Photosynthesis--Basic Features of the Process, Interior and Insular Affairs Committee, House of Representatives, U.S. Congress, 1952, pp. 28-33.

[7] Paul J. Kramer, "Water in Relation to Plant Growth," The Physical and Economic Foundation of Natural Resources I: Photosynthesis--Basic Features of the Process, Interior and Insular Affairs Committee, House of Representatives, U.S. Congress, 1952, pp. 34-39.

in the eastern half of the United States. These data provide a 36-year series by month, based upon an average water holding capacity for a particular weather district. Since Palmer's intent was different from that of this study, his data had to be adjusted somewhat. Thornthwaite's formula for estimating potential evapotranspiration (PE) requires temperature and effective day length evaluated at the midpoint of the month. To establish day length, the weather districts latitude and solar declination must be determined from meteorologic tables.

Following the Thornwaite formula, 36 years of PE data were generated by month for each of the weather districts in the Subregion. These data then became one of the major inputs to the moisture budget. The available water holding capacity (AWC) chosen to represent the soil of a particular weather district sets the limits for loss and recharge in the budget. Evapotranspiration (ET), the other primary variable in the stress relationship, is calculated from the budget by adding the moisture loss from both soil layers to the precipitation for the month. The soil moisture budget was also programmed to develop, in addition to the thirty-six years of monthly data, twelve months of average weather and a yearly moisture stress index for the growing season.

Potential evapotranspiration represents the atmospheric demand for water under ideal moisture conditions. It may be met through precipitation or depletion of soil moisture reserves. Actual evapotranspiration is the amount of moisture supplied through precipitation or soil moisture loss. If precipitation is insufficient to meet the plant's demand for moisture, soil moisture is lost at the potential rate corrected for the increasing strength of the bond between soil and water as the moisture in the soil decreases. Thus, demand for moisture by potential evapotranspiration may exceed the supply of moisture as provided by actual evapotranspiration.

The difference between potential (PE) and actual (ET) evapotranspiration represents a lack of sufficient moisture in the form of precipitation. This difference identifies the amount of stress placed on growing plants due to moisture deficiency. It is this stress, the sum of PE-ET over the growing season for a particular crop, that is used in a least-squares regression analysis with average crop yield to determine yield reduction associated with one unit of moisture deficiency (stress).

For the moisture-stress index to be meaningful, it must truly represent the available moisture conditions in a particular weather district. Therefore, general estimates for differences in soil moisture holding capacities were developed for each soil management group in each weather district. These AWC's were weighted by the cropland acreage of each soil management group to arrive at a representative AWC for each selected root zone depth within the weather district. Since crops do not have the same effective root zone, they draw their moisture from different soil depths. In turn, varying the soil depth also influences the effective AWC of a particular soil for analysis purposes. Thus, a separate series was developed for each of four different root zone depths. They represented the root zones of major crops from which the majority of moisture is withdrawn.

Crop Response Estimate

In determining preliminary estimates of yield response to irrigation least-squares regression analysis of several functional forms was used. In all cases, the independent variable or variables were some form of the sum of PE-ET over the growing season. However, the dependent variable represented either the actual crop yield or some variation of the yield residuals once the variation due to time had been removed. The purpose in this phase of the analysis was to evaluate the moisture stress-plant yield relationship. Regression analysis utilizing various time trends provided the basis for removing management and technologic factors from crop yields. The residual was thus attributed to the effects of weather variation on soil moisture.

In evaluating yield loss relationships and response to irrigation, a two-step procedure was followed. Regression analysis, of the form Yield = f $(a + bx_1 + bx_1^2 =$

log bx_1) where x = time, was conducted using the time series 1929-1964 to determine the residuals in each weather district to be used in the next step. In the second step, the actual residuals, as well as the residuals as a percent of trend, were run independently with the moisture stress variable. The resulting regression coefficients from each of the final regressions were almost identical when converted to the same basis. The coefficients for the moisture stress variable were thus assumed to represent a relative reduction in crop yield due to one unit of stress. The average moisture deficiency is multiplied by the relative yield reduction due to one unit of moisture stress to determine the percentage increase in yield in any future year that can be expected from removing the average deficiency through supplemental irrigation.

In this manner, the response to irrigation was determined for wheat, corn, corn silage, soybeans, dry beans, potatoes and hay. The assumed growing season for use in determining soil moisture deficiency was June, July, August and September for all crops except wheat. For wheat, the previous September and October and the current May and June weather factors were used in the calculation. Together, this information provided the basis for adjusting the model coefficients to reflect irrigation activities.

Management Response Estimate

In addition to the yield response due to irrigation alone, an increment was added for the increase in yield assumed to be associated with increased management inputs made possible by the removal of weather uncertainty through supplemental irrigation. This would include greater applications of seed in closer row spacing, increased use of fertilizer, labor, and equipment. These additional inputs also enter into the calculation of costs associated with the increased yield levels from irrigation. The percentage increases ranged from 21 percent to 25 percent depending upon the average weather uncertainty relationships of the different weather districts. Irrigated experimental plot data indicated a range of yield response to management inputs from 20 to 45 percent. The conservative choice of 25 percent was felt to more accurately reflect normal farm conditions and was set as the top level. Each of the five weather districts was differentiated from the others by one percentage point. The district with the greatest average moisture stress received a 25 percent response to additional management while the district with the lowest stress received 21 percent. It was assumed that the lower the moisture stress, the less uncertainty would be a factor and more of the management inputs would already be incorporated in the non-irrigated yield levels. These management coefficients were estimated from the combined experiment station data on irrigation results in the midwest. Data were used which separated the response from water and additional management. The response from management for the limited crops, soils, and years studied was used as an upper bound or optimum. Since superior management is not assumed, the results were adjusted downward to add reality to the coefficients used in the irrigation activities incorporated into the models for this study.

APPENDIX B

SOUTHERN MICHIGAN IRRIGATION POTENTIAL

APPENDIX B

SOUTHERN MICHIGAN IRRIGATION POTENTIAL

General Field Crops Demonstrating Irrigation Potential

The full range of crops that demonstrated an irrigation potential in the Southern Michigan Subregion under all assumptions tested are reviewed in this Appendix. Irrigated acreage at each of the three technology levels is arrayed by crop and by computer run as discussed in Chapter V.

Relatively conservative yield levels of Technology 1 are, as discussed earlier, insufficient to preclude abnormally large increases in irrigated acreage under the more demanding runs (Table B-1). In those instances nearly all crops considered for irrigation entered the solution at very high levels. Model 21 was infeasible but in all other cases, potatoes were irrigated. Corn silage entered twelve of the thirty solutions and dry beans, corn grain, and wheat were about equally well represented. Hay crops were only represented at the highest requirement level and then only under the more severe constraints. At no time did it appear profitable to irrigate soybeans although dry beans frequently entered the solution.

TABLE B-1.--Alternative model projections of general field crops with an irrigation potential in 1980, Southern Michigan Subregion, Technology 1

Alternative Model	Crop						Total
	Wheat	Corn Grain	Dry Beans	Potatoes	Corn Silage	Hay Crops	
				1,000 Acres			
1				19.7			19.7
2				19.7			19.7
3				19.7			19.7
4				19.7			19.7
5				19.7			19.7
6				19.7			19.7
7				19.7			19.7
8				29.6			29.6
9				29.6			29.6
10				29.6			29.6
11				29.6			29.6
12				29.6	14.1		43.7
13				29.6			29.6
14	143.5	24.4	298.1	29.5	137.4		632.9
15	649.6	847.2	459.4	39.4	168.8	82.9	2,247.3
16	423.4	395.6	463.1	39.5	138.0		1,459.6
17	92.0		212.9	39.4	131.6		475.9
18	649.4	743.1	459.4	39.4	164.2	80.3	2,135.8
19	743.4	1,172.0	459.7	39.8	186.2	516.4	3,117.5
20	370.2	649.5	453.6	39.5	285.6		1,798.4
21	Infeasible						
22				19.7			19.7
23				19.7			19.7
24				29.6	1.9		31.5
25				29.6			29.6
26	682.0	894.8	463.1	39.8	168.8	83.9	2,332.4
27	608.7	877.5	459.3	39.4	168.8	80.8	2,234.5
28				19.7			19.7
29				29.5			29.5
30				24.6			24.6
31	619.5	857.1	371.7	36.8	141.8	222.5	2,249.4

Source: Alternative irrigation model solutions.

Shifting to Technology 2 removed the one infeasibility and also much of the irrigation potential of most crops. Corn silage again occurred in nine of the thirty-one solutions (Table B-2). The most significant happening was the enhancement of irrigation potential of hay crops. They, like potatoes, were represented in all thirty-one solutions.

Another rise of 20 percent in technology to level 3 removed all but potatoes and hay crops from consideration as potentially irrigable except under extreme conditions when corn silage and dry beans entered the solution (Table B-3). As with Technology levels 1 and 2, the entire output of potatoes was produced under irrigated conditions. Although hay crops entered the solutions under all three technology levels the total requirement for hay was only partially met by irrigation even under the most severe demands upon the resource base.

Ground and Surface Water Availability

The efforts of this study were directed at identifying the irrigation potential of particular general field crops and soil groupings. In doing that, an assumption was made that irrigation water of sufficient quality and quantity was available at the field where it would be applied. It was felt that this approach would provide an upper bound on the indicated irrigation potential in the absence of specific knowledge about water availability at

TABLE B-2.--Alternative model projections of general field crops with an irrigation potential in 1980, Southern Michigan Subregion, Technology 2

Alternative Model	Crop						Total
	Wheat	Corn Grain	Dry Beans	Potatoes	Corn Silage	Hay Crops	
			1,000 Acres				
1				16.0		40.4	56.4
2				16.0		36.2	52.2
3				16.0		23.7	39.7
4				16.0		39.6	55.6
5				16.0		44.5	60.5
6				16.0		29.2	45.2
7				16.0		48.8	64.8
8				23.9		66.8	90.7
9				23.9		58.8	82.7
10				23.9		35.7	59.6
11				23.9		70.0	93.9
12				23.9		78.8	102.7
13				23.9		47.5	71.4
14				23.9		87.6	111.5
15				32.0	89.7	93.8	215.5
16				32.0	32.7	93.8	158.5
17				32.0		57.0	89.0
18				32.0	36.1	93.8	161.9
19	92.3	95.3	290.8	32.0	159.2	167.8	837.4
20				32.0	84.4	80.9	197.3
21	168.9	497.0	368.9	32.0	172.2	202.4	1,441.4
22				16.0		40.3	56.3
23				16.0		41.3	57.3
24				23.9		70.8	94.7
25				23.9		66.9	90.8
26			45.8	31.9	105.3	93.8	276.8
27				32.0	89.7	93.8	215.5
28				15.8		57.6	73.4
29				23.6		88.9	112.5
30				14.8		40.0	54.8
31			30.9	19.6	59.8	91.6	201.9

Source: Alternative irrigation model solutions.

TABLE B-3.--Alternative model projections of general field crops with an irrigation potential in 1980, Southern Michigan Subregion, Technology 3

Alternative Model	Crop						Total
	Wheat	Corn Grain	Dry Beans	Potatoes	Corn Silage	Hay Crops	
			1,000 Acres				
1				13.0		29.4	42.4
2				13.0		26.2	39.2
3				13.0		16.9	29.9
4				13.0		28.8	41.8
5				13.0		29.9	42.9
6				13.0		21.0	34.0
7				13.0		32.8	45.8
8				19.4		45.0	64.4
9				19.4		40.3	59.7
10				19.4		26.1	45.5
11				19.4		44.2	63.6
12				19.4		49.8	69.2
13				19.4		32.4	51.8
14				19.4		60.6	80.0
15				26.2		67.6	93.8
16				26.2		60.0	86.2
17				25.8		36.2	62.0
18				25.8		65.6	91.4
19				26.2	114.9	86.8	227.9
20				26.2		49.2	75.4
21			72.4	26.2	124.3	93.8	316.7
22				13.0		28.8	41.8
23				13.0		30.5	43.5
24				19.4		47.8	67.2
25				19.4		46.1	65.5
26				26.2		73.9	100.1
27				26.2		70.2	96.4
28				14.3		41.8	56.1
29				21.4		64.5	85.9
30				9.5		28.0	37.5
31				12.7		38.2	50.9

Source: Alternative irrigation model solutions.

any particular location. In addition, this approach did not influence the yields obtainable through irrigation by favoring those areas known to have abundant surface or ground water supplies.

Groundwater Availability

Under the Urban Planning Assistance Program authorized by Section 701 of the Housing Act of 1954, the State of Michigan received a grant to study the groundwaters of the State. This work was undertaken by the U.S. Geological Survey in cooperation with the Michigan Water Resources Commission and Resources Planning Division and culminated recently in generalized maps of groundwater availability in the glacial deposits and bedrock underlying the State. Figure 2 is an approximation of that work and relates the general location of groundwater to the five subareas of the Southern Michigan Subregion under study.

Throughout most of the areas marked with dots, wells in glacial deposits will yield less than 10 GPM. Locally, wells six inches or more in diameter may yield several tens of gallons per minute and in places, especially where sand and gravel deposits occur along streams, will yield several hundreds of gallons per minute.

In most of the areas identified by horizontal lines, wells six inches or more in diameter in glacial deposits will yield from ten to one hundred gallons per minute. Locally, wells may yield less than 10 GPM; and in places,

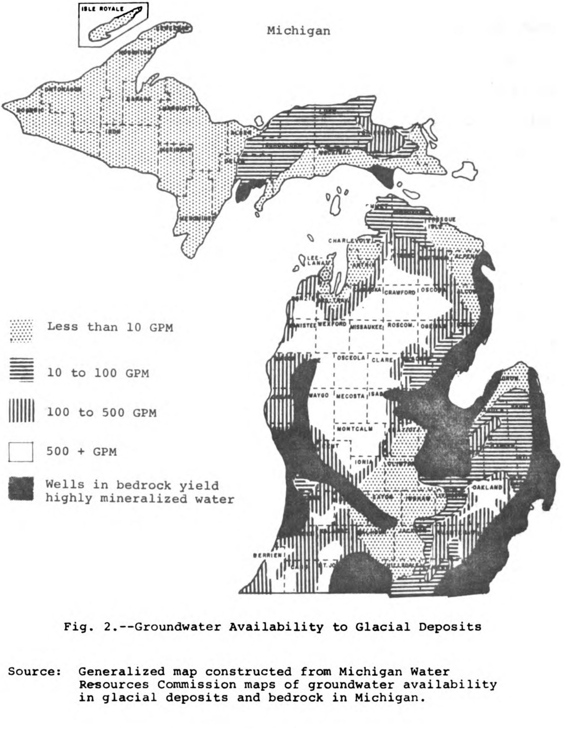


Fig. 2.--Groundwater Availability to Glacial Deposits

Source: Generalized map constructed from Michigan Water Resources Commission maps of groundwater availability in glacial deposits and bedrock in Michigan.

especially where sand and gravel deposits occur along streams, will yield several hundreds of gallons per minute.

Throughout most of the areas designated with vertical lines, irrigation wells eight inches or more in diameter in glacial deposits will yield from 100 to 500 GPM. Locally, wells will yield less than one hundred gallons per minute and in places, especially where sand and gravel deposits occur along streams, will yield more than 500 GPM.

The areas with the greatest groundwater availability are identified by no shading. Throughout most of these areas, irrigation wells of ten inches or greater in diameter and located in glacial deposits, will yield more than 500 gallons per minute.

In general, most water in the glacial deposits is of good chemical quality although it may be hard. However, in some local areas the water may be of very poor quality, especially in those areas where the glacial deposits are directly underlain by bedrock containing highly mineralized water. These area generally include the eastern third to half of all counties south of Presque Isle, with the band getting wider as it proceeds completely covering Wayne and Monroe. It is also a slender crescent running from the southeastern corner of Manistee County broadening to include Muskegon County and ending in south central Eaton County. A small pocket also exists in Branch and St. Joseph Counties.

Surface Water Availability

With respect to the availability of surface water, Michigan is blessed with an abundance of streams and lakes of all sizes. However, their use is limited to riparian owners as they may be regulated in their withdrawals by the Michigan Water Resources Commission. Because of the relatively high rainfall in southern Michigan, there is usually sufficient runoff during most years to fill a pond for irrigation, domestic, livestock, or recreational purposes. The construction of farm ponds for irrigation purposes is a very good alternative to drilling a large irrigation well in those areas where a high volume well is needed, especially where the probabilities of achieving high volume are not great.

APPENDIX C

SUPPLEMENTAL DATA TABLES

TABLE C-1.--Significant characteristics of large soil management groupings, Southern Michigan Subregion[a]

Soil Management Groups	Relief and Drainage	Parent Materials and Management Problems	Native Vegetation	Land Use and Major Crops
0a, b, c 1a, b, c	Nearly level to rolling with moderate to poor drainage characteristics.	Developed in clay loam or silty clay parent materials. Problems of soil structure and drainage exist.	Relatively wet and swampy, heavily timbered with elm, ash and soft maple.	Suitable to general cropping when adequately drained if soil structure is maintained.
2a, b,	Level to hilly, well to imperfectly drained, poor drainge in depressional areas and natural drainways.	Deep and durable soils developed in loam, clay loam, and silty clay loam drift. Associated wet areas influence size and shape of fields. Slope, erosion and drainage are problems.	Generally hardwood forest consisting of sugar maple, oak, ash hickory, elm and soft maple.	Dairy and livestock with associated general crops and some cash cropping.
2c	Nearly level to depressional areas which are naturally poorly drained.	Relatively high in organic matter, nitrogen and lime, moisture retentive. Developed in loams, silt loams and clay loams; have high natural fertility but problems of drainage.	Heavily timbered primarily with elm, ash and soft maple.	Generally used for high-value crops such as corn, field beans and sugar beets but suitable for general cropping.
3a, b, c	Level to hilly with slow to rapid surface drainage.	Surface and subsoils slight to strongly acid, sandy loams with moderate waterholding capacity underlain with sand and gravel in places, water erosion a serious problem in some areas, drainage needed in others.	Largely hardwood forest of oak, hickory, elm, ash and soft maple.	Moderate natural fertility adapted to a wide range of crops, especially potatoes and all types of livestock production. Gravel and sand sources, hilly areas suitable for recreation and forestry.

TABLE C-1.--(cont'd).

Soil Management Groups	Relief and Drainage	Parent Materials and Management Problems	Native Vegetation	Land Use and Major Crops
4a, b, c	Level to hilly and rolling to extremely rough with lakes, swamps and marshes in the basin-like associated areas, surface drainage good to rapid.	Open and loose loamy sands with a finer testured subsoil. In some cases there is loam to silty clay at depths of 18 to 42 inches. Some with seasonally high water tables require drainage. Droughtiness, low produtivity and erosion on steep slopes are problems on others.	Hardwood forest of oak, hickory, elm ash, marsh and short grasses.	Diversity of soils and unfavorable topography result in a wide range of field crops, fruits and special crops. Many hilly areas are unsuitable for farming and are used for Forestry, recreation and sand or gravel enterprises.
5a, b, c	Level to extremely hilly uplands, with sand dunes along Lake Michigan, generally well drained, but some poorly drained areas included.	Mainly deep sands to more than 66 inches, strongly acid, low water-holding capacity and low fertility. Level areas respond to irrigation and fertilization, wind erosion is a problem where the soil is tilled.	Hardwood forest of oak, hickory, elm and ash, sedges and short grasses.	Some general cropping, pasture, truck crops, small fruits, second growth forest, public recreation areas and rural residences.
Mc	Level to depressional with poor to extremely poor natural drainage.	Mucks and peats of variable thickness developed from the partial decomposition of plant remains, with water level management, fertility, frost and wind erosion problems.	Marsh and bog vegetation, short grasses, scrubby trees, elm, ash, soft maple, brush and shrubs.	Production of onions, mint, celery, potatoes, and truck crops, small acreages of pasture and blueberries where the soil is very acid.

Source: Whiteside, Schneider and Cook, Soils of Michigan, Michigan Agricultural Experiment Station, Special Bulletin 402, December 1959, and Hill and Mawby, Types of Farming in Michigan, Michigan Agricultural Experiment Station, Special Bulletin 206, September, 1954.

[a] Clarence A. Engberg, State Soil Scientist, Michigan SCS, USDA, and Dr. Eugene P. Whiteside, Professor of Soil Science, Michigan State University, assisted in developing this table.

TABLE C-2.- 1958 land use distribution by subarea, Southern Michigan Subregion

Subarea	Inventory Acreage							Noninventory Acreage				Total Land Area
			Forest & Woodland		Other Land							
	Crop-land	Pasture	In Farms	Other	In Farms	Not in Farms	Total	Federal Land	Urban & Built-up	Water Areas	Total	
						1,000 Acres						
1	758	60	158	30	109	245	1,360	5	656	8	669	2,028
2	1,705	149	323	2	173	92	2,444	0	110	4	114	2,558
3	2,205	364	478	9	321	198	3,575	2	280	24	306	3,881
4	1,766	395	1,714	6	200	282	4,363	128	185	19	332	4,695
5	1,673	154	653	8	252	437	3,177	30	299	22	351	3,528
Total	8,107	1,112	3,326	55	1,055	1,254	14,919	165	1,530	77	1,772	16,691

Source: An Inventory of Michigan Soil and Water Conservation Needs, 1962.

TABLE C-3.--Estimated cropland available in 1980, adjusted for minor crops and nonfarm uses by soil groups and subareas, Southern Michigan Subregion

Soil Group	Subarea 1	2	3	4	5	Total
			Acres			
1	11,854	56,572	12,909	123,651	72,081	277,067
2	180,718	593,511	824,585	493,472	251,051	2,343,337
2c	92,000	464,530	202,199	298,862	44,569	1,102,160
3	150,301	245,888	690,330	241,724	507,323	1,835,566
4	31,105	206,084	210,529	355,360	273,059	1,076,137
5	45,047	49,401	52,201	136,063	208,469	491,181
M	701	15,272	89,070	7,813	10,933	123,789
Total	511,726	1,631,258	2,081,823	1,656,945	1,367,485	7,249,237

Source: Working data for the report, "Agricultural Activity in the Grand River Basin: A Projective Study," NRED, ERS, USDA, January, 1966.

TABLE C-4.--Estimated pastureland available in 1980, adjusted for nonfarm uses by soil groups and subareas, Southern Michigan Subregion

Soil Group	Subarea 1	2	3	4	5	Total
			1,000 Acres			
1	0.0	3.9	0.0	24.6	8.0	36.5
2	28.3	41.5	90.2	74.4	17.2	251.6
2c	2.4	20.4	20.8	24.3	5.4	73.3
3	14.0	35.4	116.8	51.9	50.3	268.4
4	4.1	24.2	29.9	109.2	23.5	190.9
5	4.8	12.6	12.7	66.4	17.4	113.9
M	2.8	10.4	58.4	20.3	7.9	99.8
Total	56.4	148.4	328.8	371.1	129.7	1,034.4

Source: Working data for the report, "Agricultural Activity in the Grand River Basin: A Projective Study," NRED, ERS, USDA, January, 1966.

TABLE C-5.--Estimated percentage distributions of cropland and pastureland available in 1980, by soil groups within subareas and by subarea within soil groups, Southern Michigan Subregion

Soil Group	Distribution of Cropland Within Subareas					Soil Group	Distribution of Cropland Among Subarea					Total
	Subarea 1	2	3	4	5		Subarea 1	2	3	4	5	
1	2.3	3.5	.6	7.5	5.3	1	4.3	20.4	4.7	44.6	26.0	100.0
2	35.3	36.4	39.6	29.8	18.4	2	7.7	25.3	35.2	21.1	10.7	100.0
2c	18.0	28.5	9.7	18.0	3.2	2c	8.4	42.1	18.4	27.1	4.0	100.0
3	29.4	15.1	33.2	14.6	37.1	3	8.2	13.4	37.6	13.2	27.6	100.0
4	6.1	12.6	10.1	21.4	20.0	4	2.9	19.1	19.6	33.0	25.4	100.0
5	8.8	3.0	2.5	8.2	15.2	5	9.2	10.1	10.6	27.7	42.4	100.0
M	.1	.9	4.3	.5	.8	M	.6	12.3	72.0	6.3	8.8	100.0
Total	100.0	100.0	100.0	100.0	100.0							

Soil Group	Distribution of Pastureland Within Subarea					Soil Group	Distribution of Pastureland Among Subareas					Total
	Subarea 1	2	3	4	5		Subarea 1	2	3	4	5	
1	.0	2.6	.0	6.6	6.2	1	.0	10.7	.0	67.4	21.9	100.0
2	50.2	28.0	27.4	20.0	13.3	2	11.2	16.5	35.9	29.6	6.8	100.0
2c	4.2	13.8	6.3	6.6	4.1	2c	3.3	27.8	28.4	33.1	7.4	100.0
3	24.8	23.8	35.5	14.0	38.8	3	5.2	13.2	43.5	19.4	18.7	100.0
4	7.3	16.3	9.1	29.4	18.1	4	2.1	12.7	15.7	57.2	12.3	100.0
5	8.5	8.5	3.9	17.9	13.4	5	4.2	11.0	11.2	58.3	15.3	100.0
M	5.0	7.0	17.8	5.5	6.1	M	2.8	10.4	58.5	20.4	7.9	100.0
Total	100.0	100.0	100.0	100.0	100.0							

Source: Working data for the report, "Agricultural Activity in the Grand River Basin: A Projective Study," NRED, ERS, USDA, January, 1966.

TABLE C-6.--Major cropland acreage use, by crop and subarea, Southern Michigan Subregion, 1959 and 1964

Crop	Subarea 1		Subarea 2		Subarea 3		Subarea 4		Subarea 5		Total	
	1959	1964	1959	1964	1959	1964	1959	1964	1959	1964	1959	1964
					1,000 Acres							
Corn Grain	161	121	157	193	468	420	231	221	335	284	1,352	1,239
Corn Silage	17	20	56	73	62	85	45	58	34	46	214	282
Wheat	86	79	222	183	277	239	207	174	160	135	952	810
Oats	57	41	157	137	191	147	131	80	115	81	651	486
Barley	5	1	10	7	28	6	7	2	20	6	70	22
Soybeans	77	87	2	5	32	59	29	51	24	34	164	236
Alfalfa	68	67	207	220	269	300	251	233	149	168	944	988
Other Hay	20	13	64	49	84	45	58	40	67	41	293	188
Irish Potatoes	4	3	3	2	4	4	16	17	4	3	31	29
Dry Beans	9	6	236	238	49	73	196	270	2	2	492	589
Crop Pasture	67	45	212	175	286	211	234	192	183	146	982	769
Total Use	571	483	1,326	1,282	1,750	1,589	1,405	1,338	1,093	946	6,145	5,638

Source: Census of Agriculture, 1959 and 1964.

TABLE C-7.--Production of livestock and livestock products, by type and subarea, Southern Michigan Subregion, 1959 and 1964

Livestock and Livestock Products	Units	Subarea 1		Subarea 2		Subarea 3		Subarea 4		Subarea 5		Total	
		1959	1964	1959	1964	1959	1964	1959	1964	1959	1964	1959	1964
Cattle & Calves	thousands	90	86	270	305	371	404	266	296	218	227	1,215	1,318
Hogs & Pigs	thousands	60	37	54	43	303	204	116	82	247	218	780	584
Sheep & Lambs	thousands	26	20	20	14	224	166	55	33	44	32	369	265
Chickens	thousands	398	311	709	663	1,269	623	624	544	3,123	2,384	6,123	4,525
Milk	mil. lbs.	238	246	904	1,045	1,092	1,254	687	779	600	686	3,521	4,010
Eggs	millions	5	6	9	8	14	14	8	12	25	30	61	70
Turkeys	thousands	43	46	21	14	174	144	191	119	503	889	932	1,212

Source: Census of Agriculture, 1959 and 1964.

TABLE C-8.--Benchmark projection of harvested acreage for 1980 with permanent pasture assumption removed compared with 1964, by subarea, Southern Michigan Subregion[a]

Crop	Subarea 1		Subarea 2		Subarea 3		Subarea 4		Subarea 5		Total	
	1964	1980	1964	1980	1964	1980	1964	1980	1964	1980	1964	1980
						1,000 Acres						
Wheat	79	19	183	270	239	83	174	141	135	38	810	551
Corn	121	48	193	86	420	164	221	612	284	87	1,239	997
Oats	41	11	137	77	147	118	80	18	81	16	486	240
Barley	1	1	7	7	6	29	2	2	6	6	22	45
Soybeans	87	43	5	200	59	62	51	49	34	24	236	378
Dry Beans	6	1	238	234	73	17	270	90	2	0	589	342
Potatoes	3	2	2	15	4	2	17	10	3	4	29	33
Corn Silage	20	4	73	76	85	21	58	13	46	9	282	123
Alfalfa	67	15	220	269	300	73	233	49	168	38	988	444
Other Hay	13	4	49	71	45	15	40	12	41	13	188	115
Crop Pasture	45	135	175	212	211	570	192	90	146	175	769	1,182
Total Use	484	282	1,282	1,517	1,589	1,154	1,338	1,086	946	410	5,638	4,449

Source: Census of Agriculture 1964, and Benchmark solutions.

[a] Companion Table to Table 4.

TABLE C-9.--Benchmark projection of major field crop production in 1980 with permanent pasture assumption removed compared with 1964, by subarea, Southern Michigan Subregion[a]

Crop	Units	Subarea 1		Subarea 2		Subarea 3		Subarea 4		Subarea 5		Total	
		1964	1980	1964	1980	1964	1980	1964	1980	1964	1980	1964	1980
							1,000 Units						
Wheat	bu.	3,008	931	7,994	13,503	9,602	4,476	7,542	6,923	4,745	1,836	32,890	27,669
Corn	bu.	7,720	4,784	12,260	9,005	24,624	16,690	15,014	70,586	12,162	8,820	72,780	109,884
Oats	bu.	2,492	829	8,142	6,453	8,548	10,342	3,689	1,423	3,508	1,187	26,380	20,233
Barley	bu.	40	41	374	449	289	1,719	91	138	272	351	1,066	2,698
Soybeans	bu.	2,001	1,300	100	5,992	1,339	1,790	1,159	1,375	582	736	5,182	11,195
Dry Beans	cwt.	64	21	3,001	5,768	731	400	3,831	2,005	19	8	7,645	8,202
Potatoes	cwt.	636	603	299	5,734	778	815	3,230	3,295	527	1,512	5,470	11,958
Corn Silage	ton	232	86	769	1,663	974	434	638	290	457	200	3,070	2,672
Alfalfa	ton	156	63	475	900	763	278	501	191	384	131	2,279	1,564
Other Hay	ton	21	12	72	207	73	44	62	36	62	38	289	337
Crop Pasture	AUD	5,110	25,221	19,731	36,638	23,873	98,596	21,756	15,573	16,558	30,199	87,028	206,226

Source: Census of Agriculture 1964, and Benchmark solution.

[a] Companion Table to Table 5.

TABLE C-10.--Benchmark projected total cost of producing major field crops in 1980 with permanent pasture assumption removed, by subarea, Southern Michigan Subregion[a, b]

Crop	Subarea 1	Subarea 2	Subarea 3	Subarea 4	Subarea 5	Subregion
			1,000 Dollars			
Wheat	803	11,424	3,675	6,007	1,618	23,527
Corn	2,337	4,657	7,996	32,366	4,399	51,755
Oats	423	3,088	4,724	709	609	9,553
Barley	25	262	768	81	213	1,349
Soybeans	1,447	6,703	2,019	1,572	825	12,566
Dry Beans	41	11,259	776	4,152	16	16,244
Potatoes	805	7,254	1,063	4,369	1,945	15,436
Corn Silage	428	8,089	2,129	1,411	995	13,052
Alfalfa	720	8,874	3,296	2,235	1,607	16,732
Other Hay	157	2,778	600	484	488	4,507
Cropland Pasture	2,485	3,857	10,378	1,600	3,179	21,499
Permanent Pasture	-0-	-0-	-0-	-0-	-0-	-0-
Total Cost	9,671	68,245	37,424	54,986	15,894	186,220

Source: Benchmark solution.

[a] Companion Table to Table 7.

[b] 1964 constant dollars.

TABLE C-11.--Objective functions of alternative Benchmark Model formulations with irrigation allowed, Southern Michigan Subregion, 1980[a]

Model	Technology Level		
	1	2	3
	Dollars	Dollars	Dollars
1	183,774,370	175,325,090	168,675,550
2	172,200,420	164,358,270	158,015,490
3	172,620,540	164,336,190	157,922,990
4	173,450,025	165,559,780	159,131,510
5	195,637,590	186,459,150	179,420,970
6	195,642,280	186,435,830	179,269,680
7	197,533,790	187,897,370	180,798,630
8	278,549,160	261,365,860	250,965,930
9	258,674,110	244,222,510	234,490,090
10	258,063,980	244,040,730	234,092,590
11	262,246,860	246,332,730	236,462,810
12	300,112,370	278,672,690	267,592,330
13	294,706,780	277,796,340	266,609,740
14	309,387,160	281,859,270	270,463,820
15	411,863,890	356,782,890	337,090,270
16	371,295,140	328,711,540	313,959,280
17	355,136,240	325,499,200	312,295,480
18	388,992,690	335,391,190	317,426,420
19	459,600,070	387,581,240	362,465,050
20	424,557,550	376,319,419	357,574,380
21	*	401,494,530	369,848,440
22	184,014,030	175,590,440	168,772,420
23	183,718,718	175,190,460	168,628,530
24	279,832,610	261,482,950	251,079,530
25	278,345,990	261,243,090	250,912,890
26	414,316,430	357,822,500	337,844,310
27	411,511,400	356,524,340	336,851,390
28	182,896,540	174,422,640	167,242,010
29	277,220,320	260,024,470	249,013,170
30	281,123,000	265,399,100	257,035,850
31	417,821,620	362,291,700	343,511,690

Source: Alternative model solutions.

[a] 1964 constant dollars.

*Infeasible.