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INPUT-OUTPUT ANALYSIS AS A TOOL IN ASSESSING THE IMPACTS OF CLIMATIC VARIATIONS ON REGIONAL ECONOMIES: WITH PROTOTYPE APPLICATIONS TO THE OKLAHOMA ECONOMY

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INPUT-OUTPUT ANALYSIS AS A TOOL IN ASSESSING THE IMPACTS OF CLIMATIC VARIATIONS ON REGIONAL ECONOMIES: WITH PROTOTYPE APPLICATIONS TO THE OKLAHOMA ECONOMY

A DISSERTATION

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To Ellen

again

with love

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ABSTRACT

Input-output analysis techniques are developed to relate climate impacts affecting specific economic sectors to overall economic impacts in a regional economy. The types of applied problems covered include:

1) Estimates of impacts from "natural" (or historical) climatic variability on the agricultural crop sector and residential consumption
2) Estimates of likely impacts from an operational weather modification program
3) Estimates of likely impacts from the implementation of climate-conscious irrigation scheduling strategies
4) Estimates of likely impacts resulting from climate-conscious residential retrofitting
5) The feasibility of instituting a statewide water transfer program, including consideration of the impact of scenarios involving climate-conscious irrigation scheduling
6) A general consideration of using input-output techniques as an "optimal" decision-making tool for regional planners faced with coping with climate-related water shortages.

The potentials of input-output analysis for dealing with such problem contexts are explored. Provisional estimates are made of the magnitude of the dollar impacts on the Oklahoma economy. Suggestions are made as how such information can be used to tailor programmatic expenditures to match expected economic gains. Finally, suggestions are made as to promising avenues for future study.

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CHAPTER I

INTRODUCTION

The goal of this dissertation is to suggest a modeling framework that relates patterns of regional climate variability to their impacts on levels of overall regional economic activity. Most existing work in climate impact assessment has focused on showing how fluctuations in pertinent climate variables directly affect components of a regional economy. For instance, changes in crop yields can be related to changes in temperatures, soil moisture, and precipitation during critical phases of crop development. Similarly, changes in such climatological variables as heating or cooling degree days can be shown to affect significantly the levels of seasonal consumer demand for electricity or natural gas. Such impact assessments focus on specific economic sectors, e.g., agriculture, or on the spending behaviors of constituent groups within the economy, as in the example cited above for consumer energy demand. To assess the overall economic consequences of these specific, direct impacts, a modeling framework is required that explicates the interlinkages among all pertinent regional production and consumption components. Even though only a handful of components may display significant direct responses to climate variations, the structure of regional economic interdependencies assures that the direct impacts will induce rounds of indirect changes throughout the rest of the system. Through these indirect ramifications, the production levels for all sectors in the regional economy, the levels of demand for the output of these sectors, and the levels of income and employment generated by the sectors may show appreciable changes.

An ability to estimate such overall economic impacts is of apparent interest. The capacity simply to gauge the magnitude of the effect on, say, regional income, of a severe winter or a major drought in and of itself could provide valuable information for decision makers at both the regional and national levels. Knowledge of this sort can form the basis for purposeful responses to ameliorate the climate impacts through appropriate changes in production processes, consumer behavior patterns, or governmental policy.

Input-output analysis is a valuable tool in assessing the overall consequences of sets of triggering, direct impacts; and input-output techniques will form the central focus for several types of climate impact assessment approaches to be discussed below. In general, these approaches will embody the logical and causal structure outlined in figure I-1. Techniques centering on input-output techniques will be proposed that, when supplied with pertinent information on regional climate patterns and the associated direct impacts, can yield estimates of an entire range of direct and indirect economic consequences. The under-

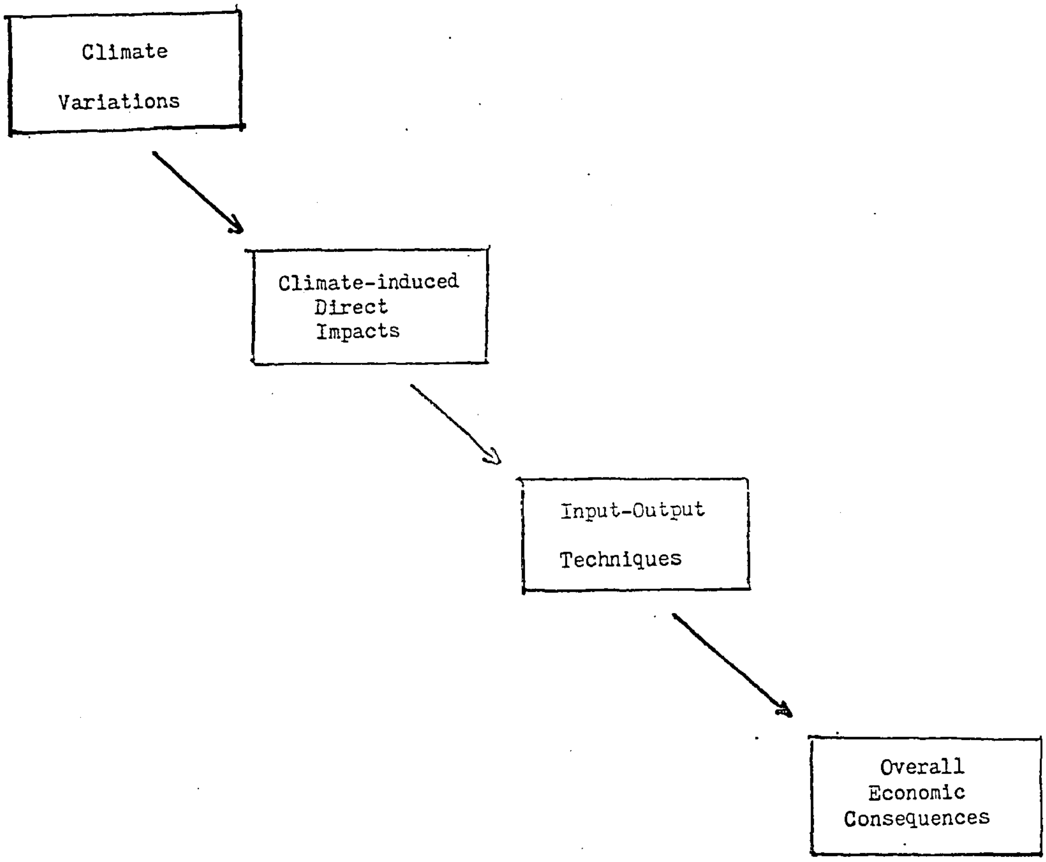

Figure I-1. Structure of a Framework for Assessing Overall Economic Responses to Climatic Variations lying approach is modular; the input-output techniques are designed to be adaptable to a variety of direct impact assessment techniques that are either in existence or in the process of development. Examples will be given of entire operational systems where climate patterns are used to drive direct impact functions and these in turn to drive the input-output models. Examples will also be presented where the information needed to drive the input-output analysis is of a simulated or hypothetical nature. In such instances, the information needed to yield actual estimates or predictions has not been readily available. In many cases, the task of implementing the overall models would properly be a team project, drawing on the pooled contributions of many researchers. Still, even exploratory analyses can provide insights as to the scope, magnitude, or importance of overall economic responses to different climate perturbations. Throughout, the aim will be toward practical and attainable applied models. In some cases, the overall structure is at present skeletal, but the overall structures could eventually be fully implemented using existing state-of-the-art capabilities.

The regional focus of the modeling frameworks to be discussed involves states or subdivisions of states like climate districts or planning regions. A concentration on geographical units of this sort allows the potential utilization of a veritable wealth of direct impact models, especially for the agricultural sector, that either already exist or will soon become available. While solid empirical data will be marshalled only for Oklahoma, the modeling approaches are readily transferable to other states.

Two major types of substantive modeling approaches will be explored. First, a climate impacts assessment model will be developed for the state of Oklahoma which relates climate-induced direct and stemming-from impacts to indirect effects for the whole economy. Second, a multiregional water resource constraints model will be developed for Oklahoma to address a range of possible responses to dwindling groundwater supplies in the western part of the state.

In the next chapter, background information will be presented on the techniques of input-output analysis and instances in the literature cited of approaches either germane to the field of climate and water resource impacts-analysis or suggestive of modeling slants readily transferable to such analysis. Chapters III and IV will set out the basic input-output modeling frameworks, giving their mathematical rationales and supplying the information needed to implement them for the Oklahoma economy. Chapter V develops a set of crop yield and production models and uses these in conjunction with the input-output materials to analyze the economic impacts of historical climatic variability. Chapter VI uses the same crop models to study the potential impacts of an operational weather modification program. Chapter VII extends the analysis to the potential impacts of crop irrigation scheduling strategies. Chapter VIII introduces direct impact models for the impact of climate variability to residential natural gas consumption and for the estimation of likely energy savings from residential retrofitting programs. Input-output techniques then assess the overall economic impacts. Chapter XI shows how input-output techniques can be used to explore economic responses to regional water resource bottlenecks. Finally, the general potential of the techniques explored will be summarized and suggestions made for future research efforts.

CHAPTER II

INPUT-OUTPUT ANALYSIS: BACKGROUND AND BASIC PRINCIPLES

The basic tool to be used to assess the direct and indirect ramifications of regional climate impacts is input-output analysis and, specifically, a form of this analysis based on the so-called static input-output model. A convenient point of departure is to introduce the basic structure of the static model, first somewhat informally, then cast into matrix algebra form. This basic mathematical framework will then be expanded and adapted in constructing the actual modeling frameworks for Oklahoma.

Consider an idealized example where a region's economy has been broken down into two sectors: agriculture and manufacturing. At some point in time, annual data were collected on the levels of sales and purchases to form a table of transactions as in Figure II-1. If one examines a column of this transactions table, say, for agriculture, one finds that agriculture purchased a total of \$10 billion of inputs. It purchased \$2 billion of these inputs from itself and \$3 billion from the regional manufacturing sector. In addition, there were \$5 billion worth of "primary inputs." These primary inputs could include outlays for items like wages, taxes, items imported from outside the region, and, of course, would include the farmers' own income. Turning to a

	Agriculture	Manufacturing	Final Demand	Total Output
Agriculture	2	3	5	10
Manufacturing	3	3	4	10
Primary Inputs	5	4		
Total Inputs	10	10		

Figure II-1. Baseline Conditions (Transactions in Billions of Dollars) row in the same model, one sees that for agriculture, out of the \$10 billion worth of total production, \$2 billion worth was sold to itself, \$3 billion to manufacturing, and \$5 billion worth as final demand. Final demand would include sales for final consumption, e.g., purchases by households along with export sales outside the region.

In one of its most common and straightforward applications, input-output analysis could be applied to answer the question: what would happen if the final demand sales by agriculture and manufacturing increased to, say, \$7.5 billion for agriculture and \$6 billion for manufacturing? If one assumes that the underlying structure of the region's economy does not change radically (exactly what assumptions this entails will be addressed when the model is put in mathematical form), then a new table of transactions can be estimated as in Figure II-2. The input-output projections are for the output of both sectors to increase to \$15 billion, with corresponding increases in purchases and sales between the two sectors and increases in the levels of primary inputs.

Given a set of direct impact estimates, therefore, that peg the levels of a set of exogenous driving variables (in this case, the levels of sectoral final demands), input-output analysis can project the whole structure of sales and purchases needed to underwrite the estimated final demand changes. The mathematical reasoning allowing such projections will now be briefly outlined.

The basic assumption underlying input-output analysis is that from a baseline transactions table (as in Figure II-1 above), a set of linear production recipes can be derived for each of the economic sectors showing the value of inputs needed to yield a dollar's worth of

	Agriculture	Manufacturing	Final Demand	Total Output
Agriculture	3	4.5	7.5	15
Manufacturing	4.5	4.5	6	15
Primary Inputs	7.5	6		
Total Inputs	15	15		

Figure II-2. New Conditions (Transactions in Billions of Dollars) output. The first step would be to recast the information in the first two rows of Figure II-1 in the following algebraic form:

$$\begin{aligned} x_{11} + x_{12} + y_1 &= x_1 \\ x_{21} + x_{22} + y_2 &= x_2 \end{aligned} \tag{1}$$

The x_{ij}'s stand for transactions between sectors, e.g., referring to Figure II-1, x_{11} equals \$2 billion and so forth. The y_i's stand for final demands, e.g., y_1 equals \$5 billion. The x_j's stand for total outputs, which are also equal to the values of total inputs, e.g., x_1 equals \$10 billion. Even in this simple two sector example, examination of equation system (1) reveals that there are more unknowns than equations. To reduce the number of unknowns, the x_{ij}'s are assumed to be simple linear functions of the sectoral input levels. The desired transformation is given in equation system (2):

$$\begin{aligned} (x_{11}/x_1)x_1 + (x_{12}/x_2)x_2 + y_1 &= x_1 \\ (x_{21}/x_1)x_1 + (x_{22}/x_2)x_2 + y_2 &= x_2 \end{aligned} \tag{2}$$

The assumed constant ratios, x_{ij}/x_j, may be replaced by scalars, a_{ij}, as follows:

$$\begin{aligned} a_{11}x_1 + a_{12}x_2 + y_1 &= x_1 \\ a_{21}x_1 + a_{22}x_2 + y_2 &= x_2 \end{aligned} \tag{3}$$

It will be noted that the 8 unknowns of equation system (1) have been reduced to only 6 unknowns in equation system (3). If values are given for the final demands (the y_i's), then equation system (3) can be solved for the x_j's. From this information, the entire transactions table can be recovered.

The solution technique is vastly simplified by introducing matrix notation. For the two sector example, let:

$$A = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} ; \quad Y = \begin{bmatrix} y_1 \\ y_2 \end{bmatrix} ; \quad \text{and } X = \begin{bmatrix} x_1 \\ x_2 \end{bmatrix}$$

Equation system 3 can then be expressed compactly as:

$$AX + Y = X \tag{4}$$

If I is an identity matrix of the same dimensions as A, one can also say:

$$AX + Y = IX \tag{5}$$

Solving for X, one has:

$$X = (I - A)^{-1}Y \tag{6}$$

It can be shown (e.g., see Hawkins and Simon, 1949) that a matrix of the form (I - A) in an input-output system is always nonsingular. The desired inverse in equation system (6) therefore exists, and a unique solution for X is possible.

Once the information from a baseline transactions table (as in Figure II-2) is cast into the form of matrix equation (6), by specifying a set of values for Y, the baseline levels of X can be recovered. Input-output analysis becomes a predictive tool if one specifies a different set of values for the entries in Y. Then a new set of output levels will be generated, and a new transactions table can be produced.

In the idealized two sector example, the underlying production recipes would be described in the matrix A of technical coefficients where

$$A = \begin{bmatrix} 0.2 & 0.3 \\ 0.3 & 0.3 \end{bmatrix}$$

In the baseline case in Figure II-2, $Y^t = (5, 4)$. Using the form of matrix equation (6), one finds that

$$X = \begin{bmatrix} 10 \\ 10 \end{bmatrix} = (I - A)^{-1} \begin{bmatrix} 5 \\ 4 \end{bmatrix} \tag{7}$$

In figure II-3, one has a new set of conditions where $Y^t = (7.5, 6)$. Using the form of matrix equation (6), it can be predicted that now

$$X = \begin{bmatrix} 15 \\ 15 \end{bmatrix} = (I - A)^{-1} \begin{bmatrix} 7.5 \\ 6 \end{bmatrix} \tag{8}$$

From this information, and assuming that the production recipes embodied in matrix A have remained constant, the entire transactions table of Figure II-2 can be estimated.

In a real input-output model, tens to hundreds of sectors may be represented. The basic matrix form of equation (6) can then be used to estimate an enormous quantity of information concerning intersectoral transactions and primary input requirements. For detailed expositions of this basic input-output model, one can turn to the classic presentation by W. W. Leontief (1936), the technique's originator, or to discussions in such authors as Richardson (1972) or Miernyk (1965). Such a formulation is called a "static" model since an implicit configuration of capital arrangements is assumed in place for each sector. These fixed capital arrangements are then assumed to absorb inputs according to the fixed production recipes described by the matrix A of technical coefficients so as to meet the levels of specified demands embodied in the vector Y. Obviously, changes over time in capital formation could change the basic technology of sectoral production. Input substitution into existing capital structures could also be expected to change the basic production recipes. Nonproportional changes in commodity prices, even given a fixed underlying technology, could also alter the values of the technical coefficients over time. Various sorts of dynamic input-output model formulations have been proposed to accomodate such phenomena, examples including Leontief (1972), Hudson and Jorgenson (1974), or Finan and Schink (1979). By and large, these more sophisticated dynamic techniques are more applicable to national-level models, especially since it is often only at the national level where data can be acquired for the needed capital stock information. For state and regional applications, the predominant approach (see Liew and Liew, 1979 for exceptions) is to update periodically a static model, usually every five years or so (Polenske, 1980).

Lags in updating state and regional input-output materials will introduce errors into predictions. Considerable debate has raged as to the magnitude of such errors as well as possible errors stemming from the manner in which baseline transactions tables are developed (see Polenske, 1980 or Richardson, 1972). While the possibility for unavoidable prediction errors using static models should be borne in mind, the fact remains that for nearly all regional applications, and even for many national applications, input-output analysis is the only practical tool available for making any sort of detailed and comprehensive projections for impacts on an overall economic system. Input-output projections are unamenable to the types of confidence tests possible using statistical econometric models. Still, at the national level, econometric models can seldom provide the sectoral detail possible from input-output techniques, and at the state or regional levels, it is usually impossible, given the fragmentary nature of available regional economic accounting (see Polenske, 1978 and 1980 and Bendavid, 1974) to provide either the desired sectoral detail or the comprehensive, overall consistency of input-output methods. Input-output analysis allows one to take account of the complete web of simultaneous interindustry linkages. If one seeks to capture a picture of changes in the levels of economic activity for an entire regional economy, input-output analysis is, fundamentally, unrivaled. In many cases it is not only the best tool available; it is the only tool available.

Errors in input-output projections can be minimized by lavishing care in the estimation of the direct impact information used to drive the model. In the simple two sector example discussed above, this would mean that the estimates of final demands should be as accurate as possible. Estimation of such direct impacts can be obtained using statistical techniques like regression analysis. Crop yield and production functions for the agricultural sector are an obvious application and will be used or referred to extensively in the projected study. Values for driving variables can also be drawn from analyses based on engineering criteria as, for example, in estimates of the impact of retrofitting or climate-conscious dwelling design on final demand for energy in space heating and cooling (Reiter, 1980 or E. Cooter, 1980). Decision theory tools like linear programming can also be employed to advantage, both in estimating driving variable values and in estimating changes in sectoral production recipes (see Lamphear and Supalla, 1981 for sophisticated applications to agricultural problems). By using the best available techniques in estimating the crucial driving variable values, errors in overall projections may be minimized, and input-output analysis can be expected to yield meaningful quantitative predictions.

Input-output analysis was pioneered by W. W. Leontief in the period before World War II (see Richardson, 1972 or Dorfman, Samuelson and Solow, 1958 for background). Its first major applications came during the war as a planning tool for estimating the country's capacity to achieve mobilization goals. Through the early 1950's, the technique was similarly employed to gauge the impacts resulting from decreased governmental outlays associated with demobilization. The 1950's saw the rapid proliferation of state and regional applications, usually with an eye to assessing the impacts of large scale government public works expenditures or major industrial openings, expansions, or shutdowns. As a consequence of this longstanding interest in input-output applications, the basic modeling materials, e.g., sets of baseline transactions and technical coefficients, are available for a wide assortment of regional frameworks. Input-output materials are available at the national level, for most states (e.g., see Bourque and Cox, 1970 or Giarratani, Maddy and Socher, 1976), and for such smaller regions as planning districts (e.g., Doeksen and Little, 1969), SMSA's (e.g., Oklahoma City Planning Department, 1977), or even counties (e.g., Goldman, 1974).

There exists, therefore, a convenient arsenal of available input-output models and a copious literature centering on the sorts of traditional applications outlined above. Many of these convenient approaches are suggestive of applications to the areas of climatic or hydro-climatological impact modeling. The number of applications specifically geared to climate-related analysis is, relatively speaking, slender. A set of pioneering studies directed by H. Grubb of the Texas Water Development Board is especially noteworthy (see Allaway, _et al._, 1975; Lippke, 1978; and Kengla, Morey, and Grubb, 1979). Dr. Grubb's research group sought to assess the potential benefits from a proposed weather modification program in Texas. A set of regression crop response models was developed. Assumed levels of crop response from augmented rainfall were then used in an input-output analysis of the derivative benefits for the entire regional economy. This basic methodology has been applied by the present author to an assessment of operational weather modification activities in North Dakota (Eddy, Cooter, and Cooter, 1979; and Cooter, 1980). With modifications, this basic methodology will be elaborated on in the present discussion, with applications not only to weather modification but to natural climatic variations.

The basic methodology developed by Dr. Grubb has also found applications in feasibility studies of weather modification programs in Kansas (Bark, 1978), South Dakota (South Dakota State University Special Study Team, 1973), and North Dakota (Added Rainfall Effects Research Team, 1974). The Texas research also made innovative use of techniques developed by Charles Lamphear (see Roesler, Lamphear, and Beveridge,

1968) in estimating so-called stemming from effects. Direct benefits to the agricultural crop sector can be expected to stimulate production in the local livestock or crop processing sectors. Variations on this approach will figure prominently in the subsequent treatment of the Oklahoma input-output modeling approaches.

In these approaches, techniques will also be incorporated for modeling overall economic changes stemming from changes in demand for energy for space heating and cooling. The author is indebted here to work undertaken by E. Reiter (1980) and E. Cooter (1980) in applying physical, engineering models to assess changes in residential demand associated with such measures as retrofitting.

Another source of insights has come from studies that relate levels of sectoral output to water consumption through sets of water use coefficients. Perhaps the most ambitious work along these lines was conducted at the University of California at Berkeley. These studies (see especially Lofting and McGauhey, 1968) used projections of final demand growth over time in the California economy to estimate the growth in sectoral outputs and the associated demand for water resources. A major goal was to ascertain the pressures that economic growth, especially in Southern California, would place on California's allotment of water from the Colorado River basin. Little attention was paid in this work to possible variations in the yearly yield of the Colorado River stemming from climatological variations. Still, the underlying approach is suggestive of ways that hydro-climatological perturbations, say, from drought episodes, could potentially be incorporated.

An ambitious attempt to include such hydro-climatological variations in an input-output modeling framework is found in a study by Millan (1972). Millan analyzed a small region in Colorado on the upper main stem of the Colorado River. Using a projected time series of final demands, a time series of unconstrained output levels and water use requirements was estimated. Using simulation techniques, various types of possible drought episode patterns were then formulated, which would constrain the annual water availabilities. For each simulated drought pattern, the unconstrained projections were checked to see if water bottlenecks developed. Where these occurred, a linear programming algorithm was employed to allocate optimally water supplies so as to maximize a welfare function involving regional income. The regional economic performances over time in the drought simulations could then be compared to the unconstrained growth scenarios. From such comparisons, information was generated that could be related to planning strategies for the region in question.

The approaches of Lofting (Lofting and McGauhey, 1968) and Millan (1972) form the basis for a multi-region water resource constraints model for Oklahoma to be developed in the present dissertation. Water availability poses a crucial problem for the future economic well-being of Oklahoma. Dwindling groundwater supplies in the western part of the state have long been a source of concern. The recent severe drought of 1980 also showed how depletion of surface water storage could create problems, even for the relatively water rich eastern part of the state. Various patterns of final demand growth for the state will be explored with an eye to their compatibility with water availability constraints.

Included will be consideration of the possible impacts of a proposed water transfer system (Oklahoma Water Resources Board, 1980) designed to bring "excess" surface water from the eastern to the western parts of the state. Also discussed will be ways of adapting linear programming techniques along the lines of Millan's to overcoming water availability bottlenecks engendered by phenomena like drought episodes.

The present chapter has introduced the reader to the basics of input-output modeling techniques. Background information has been presented on the conventional uses of input-output modeling, and literature has been noted with a particular bearing on the climate-sensitive applications central to the proposed dissertation. The next chapter will explore the technical and methodological principles underlying the major modeling approaches to be considered.

CHAPTER III.

STRUCTURE OF THE MAJOR MODELING FRAMEWORKS

A. Extensions of the Basic Input-Output Model

In the preceding chapter, the basic mathematical formulation for the static regional input-output model was outlined. The present section will explore some modifications of the basic model that will find use in various of the subsequent modeling approaches. Consider, then, the idealized 3-sector transactions table in Figure III-1 below.

	1	2	3	final demand	total output
sector 1	x_{11}	x_{12}	x_{13}	y_1	x_1
sector 2	x_{21}	x_{22}	x_{23}	y_2	x_2
sector 3	x_{31}	x_{32}	x_{33}	y_3	x_3
income	r_1	r_2	r_3		
imports	im_1	im_2	im_3		
other inputs	p_1	p_2	p_3		
total inputs	x_1	x_2	x_3		

Figure III-1. Baseline Transactions Table.

Assume that from the information in the baseline transactions table, one could define the set of direct requirements coefficients given in Figure III-2.

$$\begin{array}{cccc} a_{11} & a_{12} & a_{13} & h_1 \\ a_{21} & a_{22} & a_{23} & h_2 \\ a_{31} & a_{32} & a_{33} & h_3 \\ v_1 & v_2 & v_3 & \\ m_1 & m_2 & m_3 & \end{array}$$

Figure III-2. Augmented Matrix of Direct Requirement Coefficients.

In the augmented matrix of Figure III-2, one finds the familiar matrix $A = [a_{ij}]$ of technical coefficients. One also finds $HC = [h_i]$, a vector of household spending coefficients describing the share of each dollar's worth of total household spending going to each economic sector; and one finds $HR = [v_j]^t$, a vector of household income coefficients describing the share of income generated by each dollar's worth of output by each economic sector. A vector $M = [m_j]^t$ of import coefficients is also indicated. Coefficients for the "other inputs" are not given since these could easily be recovered by subtraction given the other direct requirement coefficients.

In the conventional input-output formulation, one uses a model of the following sort:

$$(I - A)^{-1} \begin{bmatrix} y_1 \\ y_2 \\ y_3 \end{bmatrix} = \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} \qquad (1)$$

In the model of equation system (1) above, the levels of final demand are made exogenous to the system. The model then estimates how the outputs of the economic sectors will accommodate themselves to meet this specific set of final demands.

One can make other sectors exogenous. Consider a case where the first sector in Figure II-1 is crop agriculture and where an appropriate crop model or set of crop models estimated that a given climate pattern resulted in an output response of Δx_1^*. Associated with this output response, assume one also estimated input changes for the agriculture sector of Δx_{11}^*, Δx_{21}^*, Δx_{31}^*, Δr_1^*, Δim_1^*, and Δp_1^*. Two types of impacts on the rest of the economy could be anticipated. First, the changes Δx_{21}^* and Δx_{31}^* would represent sectoral demand changes for the outputs of sectors 2 and 3. Second, the change in farmer income, Δr_1^*, would be translated into changes in household final demand for the output of all the economic sectors (sectors 1, 2, and 3). Assume that one could estimate these spending changes as $\Delta\bar{y}_1$, $\Delta\bar{y}_2$, and $\Delta\bar{y}_3$.

One can create the following sets of identities for sectors 2 and 3:

$$\begin{aligned} \Delta x_{21}^* + \Delta x_{22}^* + \Delta x_{23}^* + \Delta\bar{y}_2 &= \Delta x_2^* \\ \Delta x_{31}^* + \Delta x_{32}^* + \Delta x_{33}^* + \Delta\bar{y}_3 &= \Delta x_3^* \end{aligned} \tag{2}$$

These identities can be rewritten as follows:

$$\begin{aligned} \Delta x_2^* - (\Delta x_{22}^* + \Delta x_{23}^*) &= (\Delta x_{21}^* + \Delta\bar{y}_2) \\ \Delta x_3^* - (\Delta x_{32}^* + \Delta x_{33}^*) &= (\Delta x_{31}^* + \Delta y_3) \end{aligned} \tag{3}$$

The relations in equation system (3) define an input-output system. Using the technical coefficients, one can write:

$$\left[I - \begin{pmatrix} a_{22} & a_{23} \\ a_{32} & a_{33} \end{pmatrix} \right] \begin{bmatrix} \Delta x_2^* \\ \Delta x_3^* \end{bmatrix} = \begin{bmatrix} (\Delta x_{21}^* + \Delta\bar{y}_2) \\ (\Delta x_{31}^* + \Delta\bar{y}_3) \end{bmatrix} \tag{4}$$

Solving for x_2^* and x_3^*, one has:

$$\begin{bmatrix} \Delta x_2^* \\ \Delta x_3^* \end{bmatrix} = \left[I - \begin{pmatrix} a_{22} & a_{23} \\ a_{33} & a_{33} \end{pmatrix} \right]^{-1} \begin{bmatrix} (\Delta x_{21}^* + \Delta \bar{y}_2) \\ (\Delta x_{31}^* + \Delta \bar{y}_3) \end{bmatrix} \qquad (5)$$

Since it is assumed that Δx_{21}^*, Δx_{31}^*, $\Delta \bar{y}_2$, and $\Delta \bar{y}_3$ are known, one can solve equation system (5) for Δx_2^* and Δx_3^*. Since one now has estimates for Δx_2^* and Δx_3^*, one can use the direct requirement coefficients from Figure III-2 above to solve for the body of the partial transactions table given in Figure III-2 below.

	1	2	3
sector 1	Δx_{11}^*	Δx_{12}^*	Δx_{13}^*
sector 2	Δx_{21}^*	Δx_{22}^*	Δx_{23}^*
sector 3	Δx_{31}^*	Δx_{32}^*	Δx_{33}^*
income	Δr_1^*	Δr_2^*	Δr_3^*
imports	Δim_1^*	Δim_2^*	Δim_3^*
other inputs	Δp_1^*	Δp_2^*	Δp_3^*
total inputs	Δx_1^*	Δx_2^*	Δx_3^*

Figure III-3. Partial Table of Transactions Changes.

One also knows that for sectors 2 and 3 the final demand changes are $\Delta \bar{y}_2$ and $\Delta \bar{y}_3$. For sector 1, there is an analogous final demand change of $\Delta \bar{y}_1$. The row of transactions changes for sector 1, however, will probably need to be balanced. Following Ekholm _et_ _al._ (1976), a reasonable assumption is that export final demand, $\Delta \hat{y}_1$, will adjust itself to the demands of the local economy. If one assumes that local transactions changes will take priority, then one has:

$$\Delta\hat{y}_1 = \Delta x_1^* - (\Delta x_{11}^* + \Delta x_{12}^* + \Delta x_{13}^* + \Delta\bar{y}_1) \qquad (6)$$

Letting $\Delta y_1^* = \Delta\bar{y}_1 + \Delta\hat{y}_1$, $\Delta y_2^* = \Delta\bar{y}_2$, and $\Delta y_3^* = \Delta\bar{y}_3$, one can construct the following complete table of transactions changes (see Figure III-4).

	1	2	3	final demand	total output
sector 1	Δx_{11}^*	Δx_{12}^*	Δx_{13}^*	Δy_1^*	Δx_1^*
sector 2	Δx_{21}^*	Δx_{22}^*	Δx_{23}^*	Δy_2^*	Δx_2^*
sector 3	Δx_{31}^*	Δx_{32}^*	Δx_{33}^*	Δy_3^*	Δx_3^*
income	Δr_1^*	Δr_2^*	Δr_3^*		
imports	Δim_1^*	Δim_2^*	Δim_3^*		
other inputs	Δp_1^*	Δp_2^*	Δp_3^*		
total inputs	Δx_1^*	Δx_2^*	Δx_3^*		

Figure III-4. Complete Table of Transactions Changes for Model I.

This set of <u>direct and indirect</u> changes would be estimated as the overall impacts of <u>direct</u> changes in the agricultural sector (sector 1). The steps involved in deriving such a set of transactions changes will be referred to as <u>Model I</u>.

Now consider that sector 1 is crop agriculture, as above, and that sector 2 is a sector like livestock or crop processing, whose output may change in response to changes in the output of the local agricultural crop sector. Such effects are often referred to as stemming from effects. Assume that one could predict that the agricultural crop direct impact of Δx_1^* entailed an output change for sector 2 of $\Delta\bar{\bar{x}}_2$. This output change could have an impact on the remaining sectors. In this idealized example, the only sector whose output change has not been specified is sector 3. The task, then, is to estimate the impact, $\Delta\bar{\bar{x}}_3$, on sector 3. From the estimate of $\Delta\bar{\bar{x}}_2$ and using that sector's direct requirement coefficients, one could predict changes of $\Delta\bar{\bar{x}}_{12}$, $\Delta\bar{\bar{x}}_{22}$, $\Delta\bar{\bar{x}}_{32}$, $\Delta\bar{\bar{r}}_2$, $\Delta\overline{\overline{im}}_2$, and $\Delta\bar{\bar{p}}_2$ for the input requirements for sector 2. Since no changes are entailed from the processes discussed here for the agricultural crop sector, one would have $\Delta\bar{\bar{x}}_{11} = 0$; $\Delta\bar{\bar{x}}_{21} = 0$; $\Delta\bar{\bar{x}}_{31} = 0$; $\Delta\bar{\bar{r}}_1 = 0$; $\Delta\overline{\overline{im}}_1 = 0$; $\Delta\bar{\bar{p}}_1 = 0$; and $\Delta\bar{\bar{x}}_1 = 0$.

As before, assume that the income change for sector 2, $\Delta\bar{\bar{r}}_2$, can be translated into a set of household final demand changes, $\Delta\bar{y}_1'$, $\Delta\bar{y}_2'$, and $\Delta\bar{y}_3'$. The balance equation (for a model with more than the three sectors considered here, a system of equations would result) of interest is now:

$$\Delta\bar{\bar{x}}_{32} + \Delta\bar{\bar{x}}_{33} + \Delta\bar{y}_3' = \Delta\bar{\bar{x}}_3 \tag{7}$$

System (7) defines an input-output system, so that one could derive:

$$(I - (a_{33}))^{-1}(\Delta\bar{\bar{x}}_{32} + \Delta\bar{y}_3') = \Delta\bar{\bar{x}}_3 \tag{8}$$

From $\Delta\bar{\bar{x}}_3$ and sector 3's direct requirement coefficients, one could estimate $\Delta\bar{\bar{x}}_{13}$, $\Delta\bar{\bar{x}}_{23}$, $\Delta\bar{\bar{x}}_{33}$, $\Delta\bar{\bar{r}}_3$, $\Delta\overline{\overline{im}}_3$, and $\Delta\bar{\bar{p}}_3$. Since both sector 1 and sector 2 are exogenous in this formulation, one needs to adjust the final demand changes so that

$$\begin{aligned} \Delta\bar{\bar{y}}_1 &= \Delta\bar{y}_1' + \Delta\hat{y}_1' \\ \Delta\bar{\bar{y}}_2 &= \Delta\bar{y}_2' + \Delta\hat{y}_2' \end{aligned} \tag{9}$$

where

$$\begin{aligned} \Delta\hat{y}_1' &= \Delta\bar{\bar{x}}_1 - (\Delta\bar{\bar{x}}_{12} + \Delta\bar{\bar{x}}_{13} + \Delta\bar{y}_1') \\ \Delta\hat{y}_2' &= \Delta\bar{\bar{x}}_2 - (\Delta\bar{\bar{x}}_{22} + \Delta\bar{\bar{x}}_{23} + \Delta\bar{y}_2') \end{aligned} \qquad (10)$$

Finally let

$$\Delta\bar{\bar{y}}_3 = \Delta\bar{y}_3' \qquad (11)$$

One therefore has the information needed to complete the table of stemming from transactions changes given in Figure III-5.

	1	2	3	final demand	total output
sector 1	$\Delta\bar{\bar{x}}_{11}$	$\Delta\bar{\bar{x}}_{12}$	$\Delta\bar{\bar{x}}_{13}$	$\Delta\bar{\bar{y}}_1$	$\Delta\bar{\bar{x}}_1$
sector 2	$\Delta\bar{\bar{x}}_{21}$	$\Delta\bar{\bar{x}}_{22}$	$\Delta\bar{\bar{x}}_{23}$	$\Delta\bar{\bar{y}}_2$	$\Delta\bar{\bar{x}}_2$
sector 3	$\Delta\bar{\bar{x}}_{31}$	$\Delta\bar{\bar{x}}_{32}$	$\Delta\bar{\bar{x}}_{33}$	$\Delta\bar{\bar{y}}_3$	$\Delta\bar{\bar{x}}_3$
income	$\Delta\bar{\bar{r}}_1$	$\Delta\bar{\bar{r}}_2$	$\Delta\bar{\bar{r}}_3$		
imports	$\Delta\bar{\bar{im}}_1$	$\Delta\bar{\bar{im}}_2$	$\Delta\bar{\bar{im}}_3$		
other inputs	$\Delta\bar{\bar{p}}_1$	$\Delta\bar{\bar{p}}_2$	$\Delta\bar{\bar{p}}_3$		
total inputs	$\Delta\bar{\bar{x}}_1$	$\Delta\bar{\bar{x}}_2$	$\Delta\bar{\bar{x}}_3$		

Figure III-5. Transactions Changes for Model II.

The steps involved in deriving the set of transactions changes summarized in Figure III-5 will be referred to as Model II.

The last model to be considered involves a case where sector 3 could be interpreted as an utility (energy) sector. Assume that models existed capable of relating a specific pattern of climate to a change in household spending of value ΔU. This change in demand for sector 3's output would likely be counter-balanced by corresponding changes for the demand of all the other sectors of value $(-\Delta U)$. Assume that one could estimate a set of such final demand changes as $\Delta\tilde{y}_1'$, $\Delta\tilde{y}_2'$, and $\Delta\tilde{y}_3'$, where $\Delta\tilde{y}_3' = \Delta U$ and $(\Delta\tilde{y}_1' + \Delta\tilde{y}_2') = (-\Delta U)$. Since the transactions change pattern for sector 1 will have already been determined in Model I, these final demand changes would be reflected in output changes by sectors 2 and 3. One would form a system of the following type:

$$\left[I - \begin{pmatrix} a_{22} & a_{23} \\ a_{32} & a_{33} \end{pmatrix} \right]^{-1} \begin{bmatrix} \Delta\tilde{y}_2' \\ \Delta\tilde{y}_3' \end{bmatrix} = \begin{bmatrix} \Delta\tilde{x}_2 \\ \Delta\tilde{x}_3 \end{bmatrix} \tag{12}$$

One could then estimate overall input requirement changes for sectors 2 and 3. One would also need to balance the transactions for sector 1 so that:

$$\Delta\tilde{y}_1 = \Delta\tilde{y}_1' + \Delta\tilde{y}_1^{*} \tag{13}$$

where

$$\Delta\tilde{y}_1^{*} = \Delta\tilde{x}_1 - (\Delta\tilde{x}_{11} + \Delta\tilde{x}_{12} + \Delta\tilde{x}_{13} + \Delta\tilde{y}_1') \tag{13}$$

Since the input changes for sector 1 have already been determined in Model I and no further changes are assumed through the present processes, one would have:

$$\Delta\tilde{x}_{11} = \Delta\tilde{x}_{21} = \Delta\tilde{x}_{31} = \Delta\tilde{r}_1 = \Delta\tilde{im}_1 = \Delta\tilde{p}_1 = \Delta\tilde{x}_1 = 0 \tag{14}$$

Letting $y_2 = y_2'$ and $y_3 = y_3'$, one has the following set of overall transactions changes (see Figure III-6).

	1	2	3	final demand	total output
sector 1	$\Delta\tilde{x}_{11}$	$\Delta\tilde{x}_{12}$	$\Delta\tilde{x}_{13}$	$\Delta\tilde{y}_1$	$\Delta\tilde{x}_1$
sector 2	$\Delta\tilde{x}_{21}$	$\Delta\tilde{x}_{22}$	$\Delta\tilde{x}_{23}$	$\Delta\tilde{y}_2$	$\Delta\tilde{x}_2$
sector 3	$\Delta\tilde{x}_{31}$	$\Delta\tilde{x}_{32}$	$\Delta\tilde{x}_{33}$	$\Delta\tilde{y}_3$	$\Delta\tilde{x}_3$
income	$\Delta\tilde{r}_1$	$\Delta\tilde{r}_2$	$\Delta\tilde{r}_3$		
imports	$\Delta\widetilde{im}_1$	$\Delta\widetilde{im}_2$	$\Delta\widetilde{im}_3$		
other inputs	$\Delta\tilde{p}_1$	$\Delta\tilde{p}_2$	$\Delta\tilde{p}_3$		
total inputs	$\Delta\tilde{x}_1$	$\Delta\tilde{x}_2$	$\Delta\tilde{x}_3$		

Figure III-6. Transactions Changes for Model III.

The steps involved in this estimation procedure will be referred to as *Model III*.

These three types of effects, from Models I, II, and III, can be combined to yield an overall set of transactions change estimates by letting:

$$\Delta x_{ij} = \Delta x_{ij}^{*} + \Delta\bar{\bar{x}}_{ij} + \Delta\tilde{x}_{ij} \qquad \text{for } i = 1,3;\ j = 1,3 \qquad (15a)$$

$$\Delta y_i = \Delta y_i^{*} + \Delta\bar{\bar{y}}_i + \Delta\tilde{y}_i \qquad \text{for } i = 1,3 \qquad (15b)$$

$$\Delta r_j = \Delta r_j^{*} + \Delta\bar{\bar{r}}_j + \Delta\tilde{r}_j \qquad \text{for } j = 1,3 \qquad (15c)$$

$$\Delta im_j = \Delta im_j^{*} + \Delta\overline{\overline{im}}_j + \Delta\widetilde{im}_j \qquad \text{for } j = 1,3 \qquad (15d)$$

$$\Delta p_j = \Delta p_j^{*} + \Delta\bar{\bar{p}}_j + \Delta\tilde{p}_j \qquad \text{for } j = 1,3 \qquad (15e)$$

$$\Delta x_i = \Delta x_i^{*} + \Delta\bar{\bar{x}}_i + \Delta\tilde{x}_i \qquad \text{for } i = 1,3 \qquad (15f)$$

$$\Delta x_j = \Delta x_j^{*} + \Delta\bar{\bar{x}}_j + \Delta\tilde{x}_j \qquad \text{for } j = 1,3 \qquad (15g)$$

Such an overall set of transactions changes is summarized in Figure III-7.

	1	2	3	final demand	total output
sector 1	Δx_{11}	Δx_{12}	Δx_{13}	Δy_1	Δx_1
sector 2	Δx_{21}	Δx_{22}	Δx_{23}	Δy_2	Δx_2
sector 3	Δx_{31}	Δx_{32}	Δx_{33}	Δy_3	Δx_3
income	Δr_1	Δr_2	Δr_3		
imports	Δim_1	Δim_2	Δim_3		
other inputs	Δp_1	Δp_2	Δp_3		
total inputs	Δx_1	Δx_2	Δx_3		

Figure III-7. Combined Transactions Changes from Models I, II, and III.

A number of the modeling applications in the present dissertation will draw on features from Model I, Model II, Model III, a combination of two or more of these models, or the conventional input-output framework driven solely by final demand. The next sections will outline how these various modeling approaches can be implemented in the study of specific problems or contexts.

B. Supplying Information on Exogenous Driving Variables

Given the necessary input-output baseline transactions tables and direct requirement coefficients, an input-output analysis proceeds by specifying a set of exogenous demands on the system. In the conventional input-output model, a set of final demands or final demand changes are used to drive the model. In Models I, II, and III discussed above, the demands involve information on production impacts for one or more sectors and information on shifts in household consumption patterns.

For the agricultural sector, crop yield and production models derived, say, using regression techniques, can be used to estimate changes in the value of crop output associated with climate variations. Given this information, one then needs to decide how this output change will be reflected in farmer income and outlays for inputs from other sectors. The simplest approach is to view the climate impact as a free gift (or liability) against farmer income over and beyond the economic inputs going into that year's crops. The farmer invests in the planted crop and then waits to see what that year's climate patterns will add to or subtract from his harvests. Such an approach has been advocated by such scholars as Dr. H. Grubb (e.g., in Lipke, 1978). In an input-output context, such an approach is very attractive. The only input change involved is a change in income corresponding to the change in the value of agricultural crop production. The change in all other input levels is set at zero. The only exogenous demand placed on the system would come as the income change is translated into changes in household spending. Under these assumptions, an estimate of these household spending changes would suffice to drive Model I.

Such a formulation is especially appropriate for dryland farming, where the major economic outlays have been made by planting time. For irrigated agriculture, inputs may continue through the growing season, mainly in the form of pumping costs. Climate variations may lead to changes in these costs as more or less water is used. Models developed by researchers at the University of Nebraska (Lamphear and Supalla, 1981) drawing on linear programming techniques are currently being developed to estimate such within-season economic responses to climate variations. Simulation techniques developed by researchers at Oklahoma State University (e.g., Mapp, et al., 1975) could also be used to address this issue. Much less sophisticated, but perhaps more feasibly implemented approaches have been advanced (Dr. H. Grubb and his research colleagues)(see Kengla, Morey, and Grugg, 1979). In the present dissertation, the potentials for incorporating such information on climate-associated input shifts for irrigation agriculture will be explored.

In Model II, a stemming from response by the livestock or crop processing sector is involved. If time series information was available, regression techniques might be employed to relate output changes in the processing or livestock sectors to output changes in the agricultural sector. A simpler approach is to use information already embodied in the baseline input-output transactions table. The method described below draws on suggestions in work by C. Lamphear (in Roesler, Lamphear and Beveridge, 1968) and Giarratani (1978). In brief, the rows of a baseline transactions table can be used to estimate the distributional pattern of sectoral sales, i.e., the fraction per dollar of total sales going to each sector. Giarratani (1978) has used such a method to develop a whole modeling system centered around distributional coefficients instead of the production-oriented technical coefficients of the conventional input-output formulation. For present purposes, all that is needed would be the distributional coefficients for the crop sector to obtain the coefficients for sales to sectors like livestock or crop processing assumed to experience stemming from effects.

From Model I, one will have estimates of the crop sector production change. Using the appropriate distributional coefficients, estimates can be made of the changes in purchases by the processing sector from the crop sector. The livestock sector would similarly be expected to change its purchases of hay, silage, or other feedstuffs. Using the ordinary input-output direct requirement coefficients, these input changes by the livestock and agricultural processing sectors can be related to overall output changes and, in turn, to changes in all other input levels for the livestock and crop processing sectors. These changes would include income changes. These income changes would then be translated into household spending changes. These sectoral input changes and the household spending changes could then provide the exogenous information needed to drive Model II.

In both Models I and II, climate-induced income changes need to be translated into household spending changes. Similarly, Model III focuses entirely on the redistribution of spending associated with climate induced changes in household final demand for utility (energy) sector output. Potentially, elaborate econometric models could be developed to estimate these spending changes. To the author's knowledge, no such models currently exist applicable to the state or regional levels. Information from a baseline input-output transactions table, however, can be used to supply models of household consumption.

If the baseline transactions table contains information on household final demand expenditures by economic sector as a separate category, then one can define a set of household spending coefficients in the same manner that technical coefficients are derived for the economic sectors. In Figure III-2 in the previous section, such a set of coefficients was indicated as the vector HC = $\left[h_i\right]$. In Models I and II, assume that income changes C_I and C_{II} were to be translated into spending changes. For a given sector, i, these spending changes would be estimated as $C_I{*}h_i$ and $C_{II}{*}h_i$. In general, the summation of the coefficients in HC will be less than unity. Households will purchase items from outside the region, and, hence, there will be some leakage. Taxes paid to the government will also detract from the spending on the economic sectors. In the present formulation, all spending of this sort will be considered as leakage. In short, something less than the combined income change of $\left(C_I + C_{II}\right)$ will be transformed into household spending for the output of the regional economic sectors.

To the author's knowledge, the procedure outlined above has not been used explicitly in input-output analyses. Such an approach does figure implicitly in the so-called closed input-output model (see Miernyk, 1965). In the conventional, or open, input-output model, one has a system of the form:

$$(I - A)^{-1}Y = X \tag{16}$$

where Y is a vector of final demands (that includes final demand spending by households for the output of the economic sectors). A is a matrix of technical coefficients, and X is the estimated vector of sectoral output responses. In a closed model, the household spending and income coefficients are augmented to the technical coefficients to create a matrix of the following type:

$$AA = \left[\begin{array}{c|c} A & HC \\ \hline HR & HH \end{array}\right] \tag{17}$$

where HH is a 1x1 "matrix" representing transactions among households. The closed model then becomes:

$$(I - AA)^{-1}F = \bar{X} \tag{18}$$

where F is a vector of final demand changes (now excluding household final demand) and where $\bar{X}$ is a vector that comprises output responses by the economic sectors and an income effect for households. Such closed models are often used to gauge the impacts of changes associated with government spending programs or changes in regional exports. By making household spending and income endogenous to the system, household spending and income changes are automatically estimated. In deriving these estimates, the vector HC is used as a model of household consumption. The use of these household spending coefficients in the present study is simply an extension of the type of approach outlined for the closed model. Using such an estimation procedure, all the information is provided needed to drive Models I and II.

In Model III, a variant of this approach is used. From engineering-oriented building design models or from regression models, it is possible to estimate climate-induced changes in household spending for space heating or cooling. Let this spending change be ΔU. It is assumed that compensatory spending changes of total amount $(-\Delta U)$ will result in household spending for all the other economic sectors. The household spending coefficients, HC, may be used to estimate the sectoral distribution of these compensatory changes. This can be accomplished by allocating $(-\Delta U)$ over the non-utility sectors, using the household spending coefficients as weights. By iteratively allocating any remaining residual, the whole of the amount $(-\Delta U)$ may be allocated down to some arbitrarily small remainder. In this allocation procedure, one can draw on outside knowledge in deciding how many of the non-utility sectors to include. For instance, households might not be expected to change significantly their purchases for agricultural products or foodstuffs, the adjustment coming in purchases of retail merchandise and services. Once the range of sectors is specified wherein compensatory spending adjustments are to be expected, the method outlined above provides a means for generating the information needed to drive Model III.

C. Climate-Economic Impact Assessment Frameworks for Oklahoma

Combinations of Models I, II, or III outlined above can be applied to the analysis of a variety of state-level climate-economic problems. A good illustration of these techniques can be drawn from work completed by the author for North Dakota. This has involved the estimation of changes in precipitation within crop reporting districts (CRD's) over a 36 day critical period (approximately June 5 to July 10) associated with weather modification activities. Previous work has also led to the development of a set of CRD yield response models for the following crops: oats, barley, durum wheat, other spring wheat, soybeans, sugarbeets, sunflowers, flaxseed, potatoes, corn grain, tame hay, wild hay, native pasture, and corn silage. Using levels of mean harvested acreages for these crops and the yield change information, estimates for production responses are obtained. This information and commodity price figures allows estimation of production responses in dollar terms. Using such direct impact information and a set of available input-output materials for North Dakota, techniques analogous to Models I and II were implemented (Cooter, 1980) to assess economy-wide ramifications. These total impact measures, along with the direct production impacts on the agricultural crop sector constitute a variety of benefit measures which, when compared with the costs of the weather modification program, allow estimation of benefit/cost ratios. In the case of North Dakota, previous work suggests that the direct benefits to the agricultural crop sector probably more than cover the costs of the program.

The techniques applied to the North Dakota materials are directly transferable to Oklahoma. Available state-level input-output materials will be used to create frameworks applying Models I, II, and III. The resulting frameworks will be able to capture economy-wide responses to shifts in final demand spending patterns associated with variations in consumer utility (energy) demand, which were not considered in the North Dakota framework. The goal is to pinpoint explicitly the contributions of climate variations to overall economic variability. Such a framework could be used to access the impacts of particular climate patterns, e.g., drought conditions. Such a framework could also be used to relate a whole distribution of probable climate patterns to an associated pattern of economic responses. Such a framework allows one to address a myriad of "what if" questions, allowing decision makers to anticipate a range of climate impacts, both in terms of their magnitude and their probability of occurrence. Distributional assessments in terms of changes in total output, total final demand, total income, tax revenues, employment, and Gross State Product (GSP) are possible.

The applications outlined above aim merely at describing patterns of overall economic responses to climate-induced direct impacts.

Frameworks identical or similar to these can also be used to estimate responses to climate-conscious strategies designed to augment sectoral production or economize on household expenditures. Three types of such purposeful strategies will be explored for Oklahoma. First, the responses likely from weather modification activities will be considered. The approach will be patterned after the North Dakota example. Available crop models will be employed in conjunction with estimates of the likely precipitation enhancement potentials of an operational weather modification program. Techniques drawing on Models I and II can then estimate state-wide economic impacts. Second, available household energy demand models can be used to estimate changes in household demand for utility (energy) output possible from such strategies as retrofitting or climate-conscious housing design. Using the techniques of Model III, overall economic responses may then be estimated. Finally, available models or background information on climate-conscious irrigation scheduling can be employed to gauge overall economic responses to increased crop production or shifts in agricultural input requirements associated with the scheduling activities. Where the scheduling efforts simply augment production for the same level to input requirements, straightforward application of techniques from Models I and II is possible. Situations are also likely where production levels may stay the same, or even decrease slightly, but where appreciable economies in pumping costs are attainable from climate-conscious applications of irrigation water (see Kengla, Morey, and Grubb, 1979). The decreased pumping costs would lead to reduced purchases of electricity, diesel fuel, or natural or liquified petroleum gas to power the pumps. This situation would require information on these input changes in order to implement Model I. The ways such information could be obtained and fit into the input-output framework will be explored.

D. A Multiregion Water Resource Constraints Model for Oklahoma

As has been seen in the previous discussion, many types of coefficients can be constructed relating sectoral output levels to input use. To this point, technical coefficients, import coefficients, income coefficients, and so forth have figured in the modeling frameworks. All these coefficients relate sectoral output to demands for products from other economic sectors within the region (as with the technical coefficients), goods and services from outside the region (as with import coefficients), or demands for entrepreneurial and wage labor (as with the income coefficients). It is also possible to relate output levels to the use of actual physical units of natural resources. An example is water use coefficients, that describe the amount of water (an annual requirement in physical units like acre-feet) needed by each sector to produce a dollar's worth of output. Using input-output analysis to estimate a set of sectoral output levels, the water use coefficients can then be used to estimate water requirements for each sector and, by summation, the total water use for the entire region.

Given estimates for the levels of economic activity in a region, one can determine the associated required water availability. From knowledge of the hydro-climatological features of the region, one can then check to see whether such an amount of water is actually available. If the economy is living beyond its means, hydrologically speaking, then a water bottleneck to economic activity has been pinpointed.

Recent decades have seen a growing concern over regional water availabilities as posing threats to continued economic growth or even to the maintenance of current levels of economic activity. Many regions are already beginning to experience such natural resource bottlenecks, and the number of affected regions will increase in the decades to come. The problems are most pronounced in the western and plains states (see Federal Reserve Bank of Kansas City, 1979) although many regions in the eastern states will likely share in this dilemma (e.g., see General Accounting Office, 1979a). In the western and plains states, water availability pure and simple is the basic problem. A classic example is the High Plains-Ogallala area, where surface water supplies are extremely limited and groundwater levels are steadily declining (see Banks, 1979). In the eastern United States, problems of water availability are compounded by pollution of both surface and ground water supplies. Unrestrained economic and population growth could eventually create water supply bottlenecks for nearly every region in the country. As such resource constraint thresholds are approached, climatological variations will obviously become of mounting concern. Drought episodes can deplete surface water supplies and increase drawdowns on aquifers. Some type of modeling framework for pinpointing the conditions under which these water availability bottlenecks can be expected is highly desirable. Such a framework would be a powerful policy tool both in anticipating the timing and severity of the problems and as a springboard towards ameliorating them through appropriate programs and actions. Input-output analysis can be brought to bear to help address many of these critical issues.

To place these problems in an empirical perspective, a prototype model will be developed for Oklahoma. Oklahoma can be divided into a "dry" western portion, depending mainly on groundwater, and a "wet" eastern portion, which shows a much higher dependence on surface water. In the prototype formulation, the assumption is made that the dry region is totally dependent on groundwater stocks while the wet region is totally dependent on surface water. Estimates from Oklahoma Water Resources Board materials (especially Oklahoma Water Resources Board, 1980) will be used to estimate the average annual surface water yields for the eastern region and the groundwater stocks for the western region for a baseline period of around 1980. Drawing on materials presented in Doeksen and Little (1969), sets of input-output coefficients for the two regions are created along with a set of baseline final demand estimates. Drawing on a variety of sources (especially Texas Water Development Board, 1977), sets of sectoral water use coefficients are estimated for both regions.

Beginning from the baseline period, a set of economic growth scenarios are created. Such studies as Millan (1972) and Lofting and McGauhey (1968) use changes in sectoral final demand to define economic growth trends, and this practice is followed by the present author. The growth trends include: a continuation of present final demands (i.e., no growth); a growth rate of 5% per year for all sectors (growth levels of this sort are often considered a sign of a healthy, expansive economy); growth rates of 5% per year for all sectors except irrigation agriculture, whose growth rate is allowed to decrease logistically to near zero after approximately 10 years; and a similar logistic pattern imposed on all sectors. To these basic economic growth patterns, other features can be added. Estimates of attainable water conservation in the irrigated crop sector (see, e.g., Stewart, 1977; Ferry, 1977; General Accounting Office, 1979b; General Accounting Office, 1980; or Baumann, *et al.*, 1979) can be used to adjust the associated sectoral water use coefficients. The economic growth scenarios can then be repeated incorporating the effects of such conservation measures. The Oklahoma Water Resources Board (OWRB, 1980) has also assembled background information on a proposed state water transfer plan. The estimated extra water made available to the western part of the state (and likewise, the decrease in supplies to the east) can be used to conduct simulations assuming such a water transfer plan were operational. The effects of different delays in the start up period for the operational program can be simulated. The impacts on conservation measures can similarly be explored. From this large array of possible alternative futures, one can estimate which ones are more sustainable. Some scenarios would be expected to encounter water resource bottlenecks within a very few decades; others might allow sustained economic performance well into the next century.

Whether considering interactions of economic processes and hydro-climatological patterns over time or for a given year, water availability bottlenecks are possible. The preceding modeling approaches are to be set up primarily to detect when such bottlenecks occur. Deciding how an economic system will or could react to such bottlenecks is a problem of a different nature. In the past, most regions have coped with such bottlenecks through emergency rationing programs and the formulation of schemes to enlarge their water supply or delivery systems to prevent episodic emergencies in the future. As water resources become fully developed and exploited, the option of tapping new supplies will become less and less feasible. Emergencies may then become the norm, and some way of adjusting economic performance to regional water constraints will become a pressing need.

Input-output analysis can be adapted to provide guidelines for coping with water availability bottlenecks. One possibility is to use linear programming techniques along the lines discussed in Millan (1972). In this dissertation, the author will provide a general discussion of the potentials for such approaches. A linear programming framework would provide economic solutions that are in some sense "optimal." The nature of the solution, however, is largely a function of how the programming problem is formulated. Should one seek to optimize some linear combination of sectoral final demands, or incomes, or output? Should the sectoral decision variables be weighted equally, or should some sectors be weighted more highly than others? These regional welfare considerations will also be a problem in setting up the constraints. These issues go beyond mere technical matters. Normative and even ethical considerations come into play, involving economic, social, and political ramifications. These issues will be explored in their bearing on what sort of programming formulation or formulations are most appropriate.

CHAPTER IV

IMPLEMENTING A CLIMATE IMPACTS ASSESSMENT FRAMEWORK USING INPUT-OUTPUT ANALYSIS FOR OKLAHOMA

The operational input-output materials needed to explore specific problem contexts introduced in Chapters V-VIII will now be specified. Detailed attention will be given to the development of sets of input-output multipliers bearing on applications having to do with economic responses triggered by climate-related direct impacts in the crop and livestock sectors.

For the Oklahoma model, the goal is to integrate the types of effects captured by Models I, II, and III introduced in Chapter III above. The first step in implementing the desired framework is to introduce the basic empirical input-output materials together with a rationale for their selection. In scrutinizing available input-output materials, two types of considerations had to be balanced. One would like to use models that are as current as possible; however, the models should also possess, as nearly as possible, a disaggregation scheme suitable for the applications envisioned. In the light of the discussion in earlier chapters, one would ideally want sectoral delineation on each sector for which there was a major direct impact. If at all possible, this would entail the presence of a crop agriculture sector, a livestock sector, an agricultural processing sector, and a utilities sector. Ideally, one would like even further resolution in the crop sector down to commodity type: e.g., sectors for wheat, cotton, sorghum, and so forth. Ideally, the livestock sector would be broken down into a beef sector, a dairy sector, and so forth. Gas and electric utilities should similarly be distinguished. For states like Texas (Texas Water Development Board, 1977) and Kansas (Emerson, 1969), such an extensive degree of disaggregation is in fact obtainable. The most current Oklahoma materials fall far short of this level of resolution. To obtain as close an approximation as possible to the needed levels of disaggregation, it was decided to use materials for Oklahoma presented by Little and Doeksen (1968). A key to the sectors distinguished in these input-output materials is given in Table IV-1.

Sector Number	Sector Description
1	Crop Agriculture
2	Livestock
3	Agricultural Processing
4	Manufacturing
5	Transportation, Communication, and Utilities
6	Real Estate, Finance, and Insurance
7	Services
8	Wholesale and Retail Trade
9	Mining
10	Construction

Table IV-1: Key to Sectors Used in Oklahoma Input-Output Model (adapted from Little and Doeksen (1968)).

The materials from Little and Doeksen (1968) were deemed adequate as far as their resolution vis-a-vis agriculturally associated impacts are concerned; i.e., a crop sector, a livestock sector, and an agriculture processing sector are distinguished. The sector that includes utilities, however, also includes transportation and communications. The lumping together of these sectors seems common to a large number of state-level models. While hardly ideal, it is felt that this feature does not unduly affect the usefulness of the analysis. The moral seems to be that few state-level models have ever been assembled with an eye to climate-sensitive applications. It is to be hoped that the desired disaggregation scheme will be communicated to regional economists and that the present study, and related research, will act as a stimulus to this end.

Having selected the basic input-output transactions and technical coefficients table from Little and Doeksen (1968), computer models were then constructed combining pertinent features of Models I, II, and III. Several major types of impacts can then be simulated depending on the type of direct impacts input to the models. For Oklahoma, the following major types of situations were incorporated:

Type I): Estimates of impacts on the value of changes in agricultural crop production are supplied for crops (e.g., wheat) that are either sold outside the region or to the local agricultural processing sector. Sets of indirect impacts are estimated combining Models I and II.

Type II): Estimates of impacts on the value of agricultural crop production are supplied for crops (e.g., hay) that are either sold outside the region or will stimulate the local livestock industry. Changes in local livestock production will in turn produce a stemming from effect via the agricultural processing sector. Sets of indirect impacts are estimated using Models I and II.

Type III): Estimates of impacts on the value of livestock production are supplied. This production change will also lead to a stemming from effect via the local agricultural processing sector. Indirect effects are estimated using features of Models I and II.

Type IV): Estimates are supplied on changes in input purchases and total value of production by the crop agriculture sector associated with climate-conscious irrigation scheduling. Indirect changes in economic activity are then estimated using Model I techniques.

Type V): Estimates are supplied on changes on consumer final demand spending associated with climate-sensitive changes in utility final demand. Estimates of economy-wide impacts are made using the techniques of Model III.

Deriving empirical results for any of the situations above depends, in the last analysis, on the availability of pertinent direct impact information for the crop, livestock, and utility sectors. Given this information, estimates are forthcoming for sets of exogenous demands on the remaining endogenous sectors of the economy. The exogenous demands are of two varieties: changes in production or sectoral input patterns for the crop, livestock, and agricultural processing sectors; and changes in household final demand spending associated either with income changes in the crop, livestock, and processing sectors or redistributions of consumer final demand spending associated with changes in household utility demand.

Some of these exogenous variable values depend on independent, modular, direct impact functions. Other exogenous variable values will build on these primary input data. Before turning to applications based on specific, independent direct impact models, one can block out the general implications of the input-output analysis by assuming hypothetical levels of the primary direct impacts. The steps needed to set out these general input-output implications will now be explored.

One will note that in the techniques of Model II, one tries to estimate stemming from effects on the livestock and agricultural processing sectors where this is called for in situations of Types I-III. If one assumes a $1 increase in crop production for crops (e.g., wheat) either exported from the region or sold in part to the local agricultural processing sector, one would like to estimate the value of extra production by the processing sector. Similarly, for a $1 increase in crop production for crops (e.g., hay) that may stimulate the local livestock sector, one would like to estimate the value of the extra livestock production. Finally, for a $1 increase in livestock production, one would like to estimate the value of extra output stimulated in the local agricultural processing sector. Estimates for such direct stemming from effects can be derived from the set of input-output technical coefficients and from the baseline transactions table.

Consider the following general notation:

a_{C-P}: technical coefficient showing fraction of crop sector inputs needed for each $1 of processing sector output.

a_{C-L}: technical coefficient showing fraction of crop sector inputs needed per $1 of livestock output.

a_{L-P}: technical coefficient showing fraction of livestock inputs needed per $1 of processing sector output.

X_{C-P}: sales of crop sector output to local processing sector from baseline transactions table.

X_{C-L}: sales of crop sector output to local livestock sector from baseline transactions table.

X_{L-P}: sales of livestock sector output to the local processing sector from baseline transactions table.

X_C : total value of crop sector output.

X_L : total value of livestock sector output.

From this information, one can formulate the following three types of constants, one for each type of stemming from effect:

Stimulation to crop processing sector per dollar change in crop output

$$K_1 = (X_{C-P}/X_C)/a_{C-P} \tag{1}$$

Stimulation to livestock sector per dollar change in output of pertinent crop (e.g., hay) output

$$K_2 = (X_{C-L}/X_C)/a_{C-L} \tag{2}$$

Stimulation to crop processing sector per dollar change in livestock output

$$K_3 = (X_{L-P}/X_L)/a_{L-P} \tag{3}$$

Using the technical coefficients and baseline transactions information from Little and Doeksen (1968), constants of this sort were estimated for Oklahoma. For comparative purposes, similar coefficients were estimated for North Dakota using materials presented in Senechal (1971). The results are summarized in Table IV-2.

These constants reveal certain important contrasts in the economies of the two states. For each dollar of extra crop sector output

	Oklahoma	North Dakota
K_1	1.264	0.510
K_2	1.086	1.070
K_3	1.164	0.476

Table IV-2: Stemming from Constants for Oklahoma and North Dakota.

for crops that are locally processed (e.g., wheat processed to flour), there is approximately a $1.26 change in the processing sector output in Oklahoma but only about a $0.51 change in North Dakota. This reflects the greater development of agricultural processing industries in Oklahoma. For each dollar of extra crop sector output for crops that can be used by the livestock sector (e.g., hay), the Oklahoma livestock sector shows about a $1.09 change in output while the North Dakota livestock sector shows about a $1.07 change. This implies a great similarity in economic structure. For each dollar of extra livestock production, the processing sector (which would turn, e.g., cattle into sales of dressed beef) in Oklahoma shows an output change of about $1.16 while in North Dakota the change is only about $0.48. This shows the much greater capacity of the livestock processing industries in Oklahoma to absorb extra local livestock production.

The constants given above provide virtually all the information needed to implement the Model II stemming from effects for Oklahoma assuming in addition that one has independent models for gaging production impacts on the crop and livestock sectors. Assuming such models are in hand (this will be done in subsequent chapters for the crop sector), the procedures for estimating other types of exogenous variable information will now be summarized as these bear on implementing Models

I or II for situations of Types I-III. (Implementation of situations of Types IV-V will be examined later.)

Situation of Type I: The value of an independently supplied crop production impact is taken to correspond exactly to a crop sector income change. Direct stemming from impacts on the local crop processing sector are then estimated using a K_1-type constant. Income changes to the crop and processing sector are then distributed over the final demand spending categories using the household spending coefficients. This supplies all the exogenous information needed to drive the model.

Situation of Type II: The value of an independently supplied crop production impact is taken to correspond exactly to a crop sector income change. Direct stemming from impacts on the local livestock sector are estimated and, in turn, stemming from impacts on the local livestock processing sector using the K_2 and K_3 constants. Income changes from the crop, livestock, and processing sectors are then converted to household final demand spending changes using the household spending coefficients. This supplies all the exogenous information needed to drive the models.

Situation of Type III: The value of an independently supplied livestock production impact is taken to correspond exactly to a livestock sector income change. Direct stemming from impacts on the local livestock processing sector are then estimated using a K_2 type constant. Income changes to the livestock and processing sectors are then converted to household final demand spending changes. This supplies all the exogenous information needed to drive the models.

The computer models can take specific estimates of crop or livestock sector production changes and generate detailed transactions tables. For the types of applications of interest in the present study, however, such highly detailed information is of less interest than measures of impacts on such aggregates as total output, final demand, income, and Gross State Product (GSP). These can be derived from appropriate aggregations of the sectoral impacts. Since interest will focus on these aggregate measures, the general input-output implications can be concisely summarized through the development of a set of multipliers for situations of Types I, II, or III (multipliers for situations of Types IV and V will be developed in subsequent chapters). In addition to the aggregate measures mentioned above, provisional estimates were made of employment impacts.

To estimate employment impacts, a set of employment coefficients are required, relating the number of jobs associated with a change in sectoral output. A partial set of such coefficients was obtained from Little and Doeksen (1968). A complete set of coefficients was obtained by borrowing the missing coefficients from information available for Texas (Texas Water Development Board, 1977). The resulting sectoral employment coefficients are given in Table IV-3. These coefficients are probably fairly adequate for labor intensive sectors such as numbers 6 (Real Estate, Finance, and Insurance), 7 (Services), 8 (Wholesale and Retail Trade), and 10 (Construction). For other sectors, e.g., agriculture, utilities, and mining, the changes in employment in relation to changes in output may be highly non-linear, an artifact of the greater use of capital versus labor and the degree of governmental regulation in these enterpriese.

In general, one can see that for an output change of around $1,000,000, employment will change by some 20-70 jobs, depending on the sector. For any set of sectoral employment changes generated from situations of Type I-V, overall employment impacts are determined through a straightforward summation.

Sector	Number Jobs/$1000 Change in Output
1. Crop Agriculture	0.047027
2. Livestock	0.028810
3. Agricultural Processing	0.033124
4. Manufacturing	0.033124
5. Transportation, Communication, and Utilities	0.036943
6. Real Estate, Finance, and Insurance	0.024166
7. Services	0.069929
8. Wholesale and Retail Trade	0.049780
9. Mining	0.027834
10. Construction	0.034655

Table IV-3: Provisional Employment Coefficients for Oklahoma.

Multipliers will now be presented (see Table IV-4) for situations of Type I-III assuming an initial $1 change in the driving production variable. Once again, it should be emphasized that the overall employment multipliers are highly provisional, since the employment coefficients on which they are based are simply estimates. These multipliers vastly simplify the computational process for estimating aggregate measure impacts. Given the linearity assumptions implicit in input-

Type I: Impacts for a $1 change in crop production for crops that may be processed by the local crop processing sector.

Aggregate Measure	Impacts	
Output	$	3.68
Final Demand	$	1.99
Income	$	1.28
Taxation	$	0.23
G.S.P.*	$	1.93
Employment	jobs	0.00015

Type II: Impacts for a $1 change in crop production for crops that may be sold to the livestock sector; this extra livestock production in turn being processed in part by the local processing sector.

Aggregate Measure	Impacts	
Output	$	5.04
Final Demand	$	2.47
Income	$	1.32
Taxation	$	0.59
G.S.P.*	$	2.37
Employment	jobs	0.0002

Type III: Impacts for a $1 change in livestock production that in turn stimulates local livestock processing activity.

Aggregate Measure	Impacts	
Output	$	3.44
Final Demand	$	1.92
Income	$	1.27
Taxation	$	0.22
G.S.P.*	$	1.86
Employment	jobs	0.00012

Table IV-4: Input-output Multipliers for Situations of Types I-III.

*Gross State Product (G.S.P.) ≡ Final Demand - Imports output analysis, simple scalar multiplications are all that is needed to calculate impacts initiated by production changes (positive or negative) in the crop and livestock sectors. The next chapter will explore ways in which the modeling structure presented above can be applied as a climate-economic impacts assessment tool for Oklahoma. Such applications hinge on the introduction of serviceable direct impact functions for agricultural production. The development of such a set of production models will be the first order of business.

CHAPTER V

DEVELOPMENT OF CLIMATE SENSITIVE CROP MODELS AND INPUT-OUTPUT APPLICATIONS

The present chapter will summarize the steps in the development of climate sensitive crop models for winter wheat, sorghum, cotton, and hay. These models will then be used to estimate the impacts on the Oklahoma economy based on historical climatic variations over the period of record (1950-1980) for which the crop models were developed. In the next chapter, these same crop models will be used to estimate the likely economic impacts of an operational weather modification program.

The crop models are of a simple type patterned after those used in Allaway, Riggio and Tuck (1975) and used by the present author in Eddy, Cooter and Cooter (1979) and W. Cooter (1980). First, statistical multilinear regression models are developed for each crop relating changes in detrended yields to climate variables. Five year average harvested acreages over the period 1976-1980 were used to convert the yield changes into production changes. Five year average commodity prices were then used to derive a cash value for the production changes. These estimates of direct dollar impacts on production were then used to drive the input-output economic assessments.

Information on crop yields, harvested acreages, and prices were obtained from an Oklahoma Climatological Survey tape copied from crop statistic information initially digitized at the Agricultural Economics Department of Oklahoma State University. OCS staff performed a check of this data set against hard copy information obtained from the Oklahoma City office of the Crop and Livestock Reporting Service. State level time series of yields for the crops in question were then selected over the period of record 1950-1981. While the period of record could have been extended for crops like winter wheat, a cut off point of 1950 was selected in light of the availability of climatological information.

Climate data were taken from a set of tapes developed at the Oklahoma Climatological Survey (McDonald, et al., 1983). The variables selected were weekly cumulative precipitation, weekly average temperature, and weekly soil moisture. These variables were available at the station level. Within any given year, the number of available stations may be different. At least 150 stations were available during any given year.

The goal was to derive state-level crop models. This leaves open a number of possibilities for relating state-level yields to the available climate information. Since the crops selected are often grown in different parts of the state, it is desirable to somehow weight the climate variable accordingly. The approach adopted was to isolate, for each crop, a crop area consisting of those counties accounting for 95% of the average production over the period of 1976-1980. These crop areas are displayed in Figures V-1 through V-4.

The criteria used to establish these crop areas, it should be noted, were part of a collective decision affecting several graduate students, including the present author. For some crops, in particular

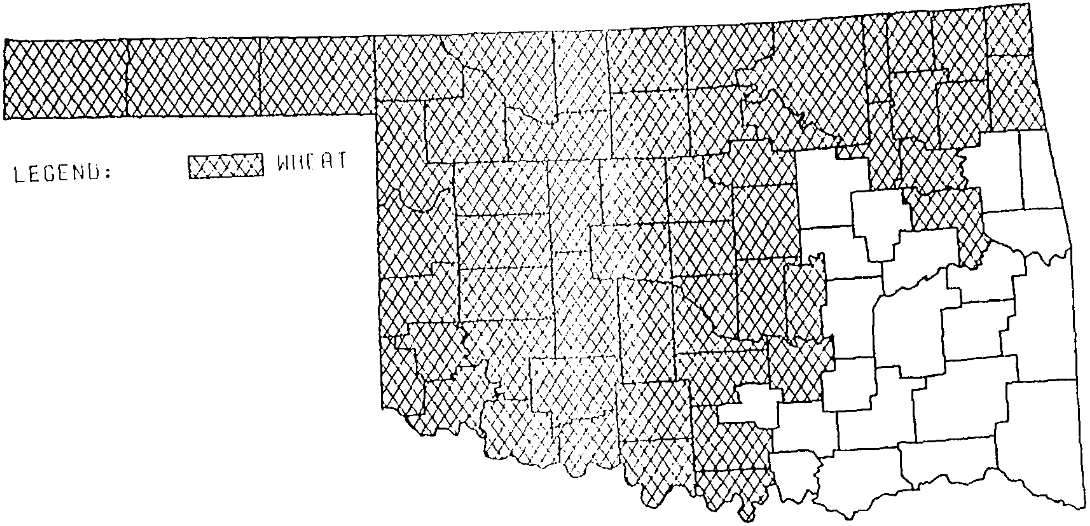

Figure V-1: Wheat Crop Area

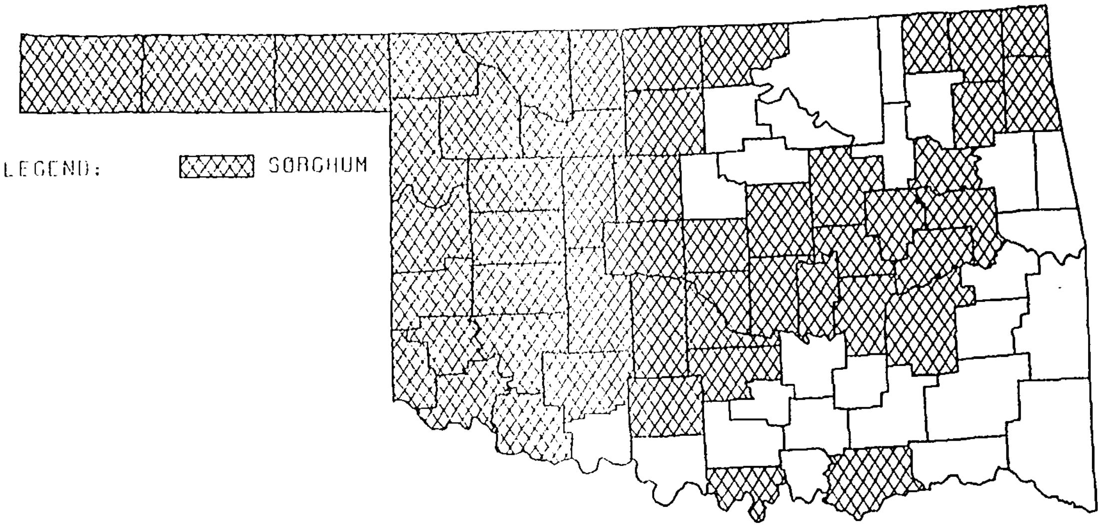

Figure V-2: Sorghum Crop Area

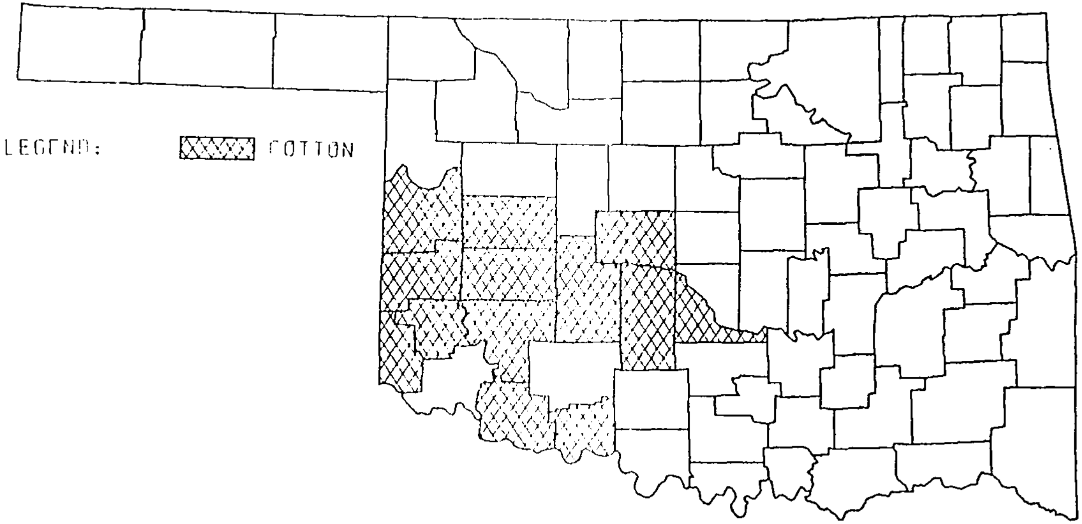

Figure V-3: Cotton Crop Area

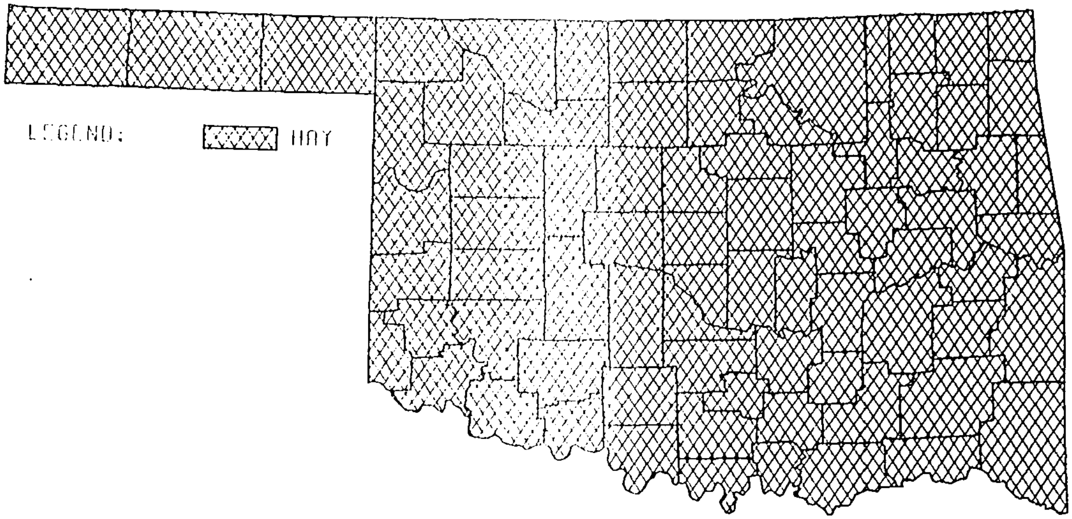

Figure V-4: Hay Crop Area

winter wheat, the 95% level is probably too broad. Future work at the Oklahoma Climatological Survey can be expected to get a firmer handle on the best ways to define cropping areas. At the time, the approach used here seemed a logical screening tool to cull out expecially significant weather variables.

In developing weather variables for each crop, only stations within a crop area were selected. For each year, the appropriate station variable values were averaged to produce a time series over the crop years 1950-1981. For sorghum, cotton, and hay there is no ambiguity whether one talks in terms of crop year, or calendar years. For winter wheat, the crop year (say for a harvest in the summer of 1950) may show the impacts of the weather for part of the preceding calendar year (e.g., the months through December, 1949 during which time the 1950 crop year crop was planted and became established). The climate variable data set for winter wheat, then, included some variables over the calendrical period of 1949-1979, suitably synchronized to correlate with the crops harvested over the time period 1950-1980.

In selecting climate variable candidates for the regression analysis, only variables were chosen that had some important phenological significance. Phenological periods were selected based on information contained in the series Oklahoma Crop Calendar (1959-1975) and supplemented with suggestions on winter wheat supplied by E. Cooter (personal communications). For each phenological period, a central average date was selected based on at least 80% of the crop in the state having reached that stage. This Julian date was then associated with a specific week number. This week number and the week immediately preceding and immediately following it were then used to select climate variables used for further analysis. The periods considered are summarized in Table V-1.

The first step in the regression analysis was to detrend the yield series. Simple ordinary least squares models were developed for each crop of the form

$$\hat{Y} = a_0 + a_1 * \mathrm{TIME} \qquad (1)$$

where $\hat{Y} \equiv$ estimated yield
$Y \equiv$ actual yield
a_0 and $a_1 \equiv$ regression coefficients
TIME $\equiv$ last two digits of year (50-80)

For each crop, the detrended residuals would be:

$$DY = Y - \hat{Y} \qquad (2)$$

Regression models were then set up of the general form:

$$\hat{DY} = b_0 + b_1 \, WX_1 + \dots b_n \, WX_n \qquad (3)$$

where $\hat{DY} \equiv$ residual estimate
$b_0, b_1, \dots b_n \equiv$ regression coefficients
$WX_1, \dots WX_n \equiv$ climate variables

Multiple linear regression analyses were performed using Statistical Analysis System software implemented on the O.U. computer system. First, Pearson correlation coefficients were determined. For a sample size of 31, the lower margin of significance at the 95% confidence level was about ±0.3. The potential set of predictors was screened according to the following criteria:

1) a predictor climate variable must show a correlation coefficient with DY of absolute value ≥ 0.3

2) this set of predictors for a given crop should show correlations with each other of absolute value <0.3.

The first criterion aimed to consider only the strongest predictors.

Table V-1: Phenological periods investigated for winter wheat, sorghum, cotton, and hay.

WINTER WHEAT

Phenological Conditions	Date When Crop 80% at this Stage Statewide	Three Weeks Bracketing this Central Date		
Seedbed prepared	Sept. 27	36	37	38
Seeding/planting	Nov. 8	42	43	44
Post-emergence (=acceptable stand)	Nov. 22	45	46	47
Joint to boot	March 22	11	12	13
Booting	April 26	16	17	18
Heading	May 14	18	19	20
Dough	May 31	20	21	22
Harvesting	June 28	25	26	27

SORGHUM

Planting	June 10	22	23	24
Heading	Aug. 16	32	33	34
Dough	Aug. 30	34	35	36
Mature/ripening	Oct. 8	39	40	41

COTTON

Planting	June 14	27	28	29
Squaring	Aug. 2	30	31	32
Boll setting	Aug. 30	34	35	36
Boll opening	Nov. 8	43	44	45
Harvesting	Dec. 20	49	50	51

HAY

First cutting	May 24	11	12	13
Second cutting	July 10	26	27	28
Third cutting	Aug. 18	32	33	34
Fourth cutting	Sept. 20	37	38	39

The trend expressions are presented in Table V-2 with accompanying t, F and R^2 statistics.

Table V-2: Trend line expression for winter wheat, sorghum, cotton, and hay. (TIME ranges from 50 to 80 for 1950 to 1981)

Winter Wheat Trend

$$\hat{Y} = -16.41330645 + 0.5875 * \text{TIME}$$

$t = 6.76$

$F = 45.68$ $R^2 = 0.611673$

($\hat{Y}$ in bushels/acre)

Sorghum Trend

$$\hat{Y} = -36.99596774 + 1.02822581 * \text{TIME}$$

$t = 8.03$

$F = 64.43$ $R^2 = 0.689596$

($\hat{Y}$ in bushels/acre)

Cotton Trend

$$\hat{Y} = -29.25604839 + 4.50120968 * \text{TIME}$$

$t = 3.27$

$F = 10.69$ $R^2 = 0.269013$

($\hat{Y}$ in lbs./acre)

Hay Trend

$$\hat{Y} = -0.36342742 + 0.0301758 * \text{TIME}$$

. $t = 7.37$

$F = 54.32$ $R^2 = 0.65167$

($\hat{Y}$ in tons/acre)

Table V-3: Statistical summary for detrended winter wheat yield model.

Winter Wheat Model

$$\hat{DY} = 6.99076355 - 0.17982153 * TEMP11$$

$$|t| = 2.07123$$

$$+ 4.10600584 * PPT43$$

$$t = 3.86523$$

$$F = 10.26 \qquad R^2 = 0.42299977$$

Correlation Coefficients

	PPT43
TEMP11	-0.074

	DY
TEMP11	-0.339
PPT43	0.578

where

DY ≡ estimated detrended yield (BU/AC)

DY ≡ detrended yield (BU/AC)

TEMP11 ≡ average weekly temperature in week 11 (joint to boot stage)

PPT43 ≡ weekly precipitation in week 43 (planting)

Table V-4: Statistical summary for detrended sorghum yield model.

Sorghum Model

$$\hat{DY} = 29.81941605 + 3.82027473 * PPT24$$

$$t = 3.15278$$

$$+ 5.54220555 * PPT34$$

$$t = 3.937$$

$$- 0.50420693 * TEMP35$$

$$|t| = 2.88964$$

$$+ 4.7380069 * PPT36$$

$$t = 4.7927$$

$F = 17.33$ $R^2 = 0.7273$

Correlation Coefficients

	PPT24	PPT34	TEMP35	PPT36
PPT24	-	0.2	0.48	0.123
PPT34	-	-	-0.196	-0.295
TEMP35	-	-	-	-0.075
PPT36	-	-	-	-

	DY
PPT24	0.48
PPT34	0.42
TEMP35	-0.42
PPT36	0.46

where: $\hat{DY}$ = estimated detrended yield (BU/AC)

DY = detrended yield (BU/AC)

PPT24 = weekly precipitation for week 24 (planting)

PPT34 = weekly precipitation for week 34 (heading to dough)

TEMP35 = weekly average temperature for week 35 (dough)

PPT36 = weekly precipitation for week 36 (dough)

Table V-5: Statistical summary for detrended cotton yield model.

Cotton Model

$$\hat{DY} = -73.74076897 + 36.70458257 * SM28$$

$t = 3.09$

$$- 50.06306484 * PPT45$$

$|t| = 1.50$

$F = 7.40$ $R^2 = 0.345909$

Correlation Coefficients

	PPT45
SM28	-0.23

	DY
SM28	0.54
PPT45	-0.35

where:

$\hat{DY}$ = estimated detrended yield (lbs/ac)

DY = detrended yield (lbs/ac)

SM28 = soil moisture for week 28 (planting)

PPT45 = weekly precipitation for week 45 (boll opening)

Table V-6: Statistical summary for detrended hay yield model.

Hay Model

$$\hat{DY} = -0.18252041 + 0.1503732 * PPT27$$

$t = 2.55$

$$+ 0.11609198 * PPT33$$

$t = 2.28$

$F = 5.72$ $R^2 = 0.290023$

Correlation Coefficients

	PPT33
PPT27	-0.023

	DY
PPT27	0.397
PPT33	0.354

where: $\hat{DY}$ = estimated detrended yield (tons/ac)

DY = detrended yield (tons/ac)

PPT27 = weekly precipitation for week 27 (2nd cutting)

PPT33 = weekly precipitation for week 33 (3rd cutting)

The second criteria aimed to reduce the potential for multicolinearity. A <u>final criterion</u> was that the final models should contain at least one precipitation variable. This feature is vital for the weather modification analysis in the next chapter.

Models were set up using the SAS stepwise regression option. Details of this procedure are given in Draper and Smith (1966). Resultant models were then evaluated judgmentally to take account of criterion 3, i.e., the inclusion of at least one precipitation variable. Where the stepwise procedure failed to produce models satisfying criterion 3, precipitation variables for time periods selected by the stepwise procedure were substituted and new models estimated using the SAS General Linear Models procedure. Models were also considered using only the precipitation variables with the highest simple Pearson correlations with detrended yields and the "best" non-precipitation variables produced through the stepwise procedure. The aim was to come up with models that met the three criteria outlined above, that looked statistically sound, and that could be rationalized by bio-climatic considerations. Models suitable for the applications envisioned were required; not just models that were the "best" in some abstract, purely mathematical, statistical sense. A certain measure of professional judgment was often required, but, in the author's opinion, this is probably the only way to do applied statistics. Over-reliance on the mathematics pure and simple of some canned algorithm can often be self-defeating.

The models finally selected are described below. The parameter estimates are given along with t, F, and R^2 statistics. Pertinent correlation coefficients are also included.

It should be emphasized that these are not the last word in Oklahoma crop yield models. They are merely prototype efforts that should, in time, be replaced by more sophisticated materials. More skillfull delineation of crop areas, a more sophisticated way of weighting the weather variables, or simply consideration of different types of climate predictor variables should eventually produce better models. These efforts are continuing at the Oklahoma Climatological Survey. Still, these models are a promising beginning. The sorghum model is a very good one indeed. The winter wheat and hay models are at least adequate. The cotton model is somewhat disappointing. For instance, the precipitation variable (PPT45) is only significant at about the 85% confidence level according to the t-test. This was the only instance of a variable being included significant at less than the 95% confidence level. A major factor here may be the effects of irrigation. The data simply do not exist to distinguish between dryland and irrigated cotton. Another factor is that Oklahoma is at the northern limit for cotton production in this country. Cotton is harvested very late in the calendar year. Episodic fronts, coupled with extreme soil moisture conditions can have a considerable impact on the harvest. These episodic factors may be poorly represented in the set of climate predictors utilized. Whatever the reason, a weather sensitive cotton model deserves someone's detailed scrutiny.

Allowing for the proto-type nature of the models, the weather variables included seem to make reasonable bio-climatic sense. Statistical models, in the strictest terms, are not really supposed to be causally explanatory. It is always reassuring, however, to be able to relate the variables in the models to agronomic considerations of the general causal mechanisms at play. A summary of this type of rationale will now be presented along with references to pertinent literature that explore the bioclimatic factors in more detail.

The wheat model suggests that increased precipitation around planting time has a positive impact on yield while increased temperatures during the joint to boot period of the crop's development have negative impact on yield. The first phenomenon is fairly self-explanatory, a good illustration being the planting season for the 1983 Oklahoma wheat crop. Very dry conditions at planting and immediately thereafter led to an extremely poor emergent stand of wheat across much of the state. If inadequate moisture is available around planting, the root system is stunted, and the crop's chances of over wintering in good shape are reduced. Adequate moisture aids in root establishment and a better start for the crop after the winter dormant period. Detailed discussion may be found in Feyerherm (1977a and 1977b), E. Cooter (1977) and Greene (1977). The study by E. Cooter also notes a deleterious impact on yield from low soil moisture during the joint to boot stages for Kansas winter wheat. One factor that can contribute to lowered soil moisture is increased temperature. Stress during this period has a deleterious impact on the forming grain heads. The results of the model would seem in keeping with these considerations.

The sorghum model indicates that extra precipitation is beneficial around planting time at the heading to dough stage and during the dough stage. An increase in temperature at the dough stage, however, has an adverse impact on yield. A good source of information on sorghum is the USDA Grain Sorghum Handbook (U.S.D.A., 1978). This publication stresses the importance of good soil moisture conditions around planting time. Adequate precipitation from the early booting through the dough stages is also stressed as contributing to good yields. Similar considerations would apply to soil moisture. Since higher temperatures can drive down soil moisture, this probably accounts for the negative correlation between dough stage temperature and yields. There would seem to be a reasonable bio-climatic basis, then, for the variables and coefficients in the sorghum model.

The cotton model suggests a beneficial input for extra soil moisture around planting and a deleterious impact on yield for increased precipitation around the boll opening stage. Research by Wanjura (1973) found that cotton needs soil moisture levels near field capacity at and prior to emergence for good germination. This conclusion is consistent with the model results. In the discussion on cotton in Doyle (1941) and Thorp (1960), the importance of good weather conditions around the boll opening stage is stressed. Excess moisture may contribute to boll rot or other pest and pathogen infestations. This would seem to provide a good rationale for the model results.

The hay model suggests that extra precipitation around the period of the 2nd and 3rd cuttings helps increase yield. This seems in keeping with the observations of Spedding (1971). Hay tends to show an early season peak in productivity. If a managed hay crop is to be mowed or grazed into the summer, adequate moisture is essential or the crop will cease growing. These observations are in keeping with the model results. It can be concluded, therefore, that all of the models make good bio-climatic sense.

The next step is to use the models to derive some economic implications for Oklahoma. To do this, the detrended yield models must be related to production and to the cash value of the production. As outlined earlier in this chapter, this is most easily done by multiplying a given yield change by an average harvested acreage figure and then an average commodity prices. The acreage and price values needed for this conversion process are given in Table V-7.

Table V-7: Average harvested acres and prices for wheat, sorghum, cotton and hay.

Crop	Average Harvest Acres (1976-80)	Average Price (1976-80)
Winter wheat	6,100,000	$3.39/bushel
Sorghum	514,000	$2.32/bushel
Cotton	73,000	$2.78/lb of lint
Hay	1,731,000	$60.50/ton

From the information in hand, one could derive dollars estimates of production changes for the crops winter wheat, sorghum, cotton, and hay. Overall economic impacts can be estimated from the input-output multipliers developed in the last chapter. Winter wheat, sorghum, and cotton would, in general, require additional processing before being used by other sectors. The Type I multipliers should be used for these crops. Hay would be feed to livestock, so that Type II multipliers would be used for this crop. For convenience, these multipliers are listed in Tables V-8 and V-9.

Table V-8: Changes in aggregate measures per $1 production change for winter wheat, sorghum, or cotton.

Type I Multipliers

Aggregate Measure	Impacts	
Output	$	3.68
Final demand	$	1.99
Income	$	1.28
Taxation	$	0.23
G.S.P.	$	1.93
Employment	jobs	0.00015

Table V-9: Changes in aggregate measures per $1 production change for hay.

Type II Multipliers

Aggregate Measure	Impacts	
Output	$	5.04
Final demand	$	2.47
Income	$	1.32
Taxation	$	0.59
G.S.P.	$	2.37
Employment	jobs	0.0002

There are many possible ways to present information on economic impacts associated with climate variations over the historical period 1950-1980. Two ways will be presented. The first approach is to give changes associated for each unit change (i.e., an extra inch of precipitation, an extra inch of soil moisture, an extra degree Fahrenheit of temperature) in the weather variables appearing in the crop models. This information is summarized in Tables V-10 through V-13.

While the type of presentation given in Tables V-10 to V-13 can be very useful if one wants to estimate the economic response to a given magnitude of change in crop-related climate variable, one gets no true feel for how often a given type of change can be expected. To get at this type of information, another sort of summary presentation is needed. Based on the historic record from 1950-1980, one can estimate such measures of central tendency for each climate variable as means and medians. This gives a notion of the climate conditions one would expect over the long term or on the average. One can then define certain types of deviations from these "normal" conditions with which probabilities of occurrence can be defined. A first step is to summarize pertinent descriptive statistics for each climate variable. This information is given in Table V-14 (computations were performed using the SAS univariate procedure).

These summary climate variable statistics can be related to economic impacts in the following fashion. In a normal distribution, about 68.27% of the sample will be within one standard deviation of the mean. For those variables that are reasonably normally distributed, then, a summary of the economic impacts for variable values one standard deviation above the mean provides a considerable amount of probabilistic information. Several of the climate variables, however, have extremely skewed, non-normal distributions. These are marked with an asterisk in Table V-14. This determination was based on the author's judgment from the higher order moments and scatter plots generated from the SAS uni-

TABLE V-10: WINTER WHEAT

Aggregate Responses to a Unit Increase in Climate Variable

Climate Variable and Associated Production Changes	Output	Final Demand	Income	Taxation	G.S.P.	Employment
Week 43 Precipitation (planting)	$312,461,775	$168,967,109	$108,682,359	$19,528,861	$163,872,618	12,609 jobs
Production change for a 1 inch increase in ppt: 25,046,635 bushels						
Dollar value of this production change: $84,908,095						
Week 11 Temperature (joint to boot stage)	$(-)13,684,200	$(-)7,399,870	$(-)4,759,720	$(-)855,262	$(-)7,176,760	(-)552 jobs
Production change for a 1°F increase in temperature: (-)1,096,911 bushels						
Dollar value of this production change: $(-)3,718,530						

TABLE V-11: SORGHUM

Climate Variable and Associated Production Changes	Aggregate Responses to a Unit Increase in Climate Variable					
	Output	Final Demand	Income	Taxation	G.S.P.	Employment
Week 24 Precipitation (planting) Production change for a 1 inch increase in ppt: 1,963,621 bushels Dollar value of this production change: $4,555,600	$16,764,600	$9,065,640	$5,831,170	$1,047,790	$8,792,310	677 Jobs
Week 34 Precipitation (heading to dough stage) Production change for a 1 inch increase in ppt: 2,848,694 bushels Dollar value of this production change: $6,608,970	$24,321,000	$13,151,900	$8,459,480	$1,520,060	$12,755,300	981 Jobs
Week 35 Temperature (dough stage) Production change for a 1°F increase in temperature: (-)259,162 bushels Dollar value of this production change: $(-)601,256	$(-)2,212,620	$(-)1,196,500	$(-)769,608	$(-)138,289	$(-)1,160,420	(-)89 Jobs
Week 36 Precipitation (dough stage) Production change for a 1 inch increase in ppt: 2,435,336 bushels Dollar value of this production change: $5,649,980	$20,791,900	$11,243,500	$7,231,970	$1,299,500	$10,904,500	839 Jobs

TABLE V-12: COTTON

Climate Variable and Associated Production Changes	Aggregate Responses to a Unit Increase in Climate Variable					
	Output	Final Demand	Income	Taxation	G.S.P.	Employment
Week 28 Soil Moisture (planting)	$27,411,700	$14,823,200	$9,534,500	$1,713,230	$14,376,200	1,106 jobs
Production change for a 1 inch increase in S.M.: 2,679,435 lbs.						
Dollar value of this production change: $7,448,830						
Week 45 Precipitation (boll opening stage)	$(-)37,388,062	$(-)20,218,002	$(-)13,004,543	$(-)2,336,753	$(-)19,608,413	(-)1,509 jobs
Production change for a 1 inch increase in ppt: (-)3,654,603 lbs.						
Dollar value of this production change: $(-)10,159,800						

TABLE V-13: HAY

Aggregate Responses to a Unit Increase in Climate Variable

Climate Variable and Associated Production Changes	Output	Final Demand	Income	Taxation	G.S.P.	Employment
Week 27 Precipitation (2nd cutting)	$79,369,415	$38,897,313	$20,787,226	$9,291,261	$37,322,524	2,992 jobs
Production change for a 1 inch increase in ppt: 260,296 tons						
Dollar value of this production change: $15,747,900						
Week 33 Precipitation (3rd cutting)	$61,275,311	$30,029,766	$16,048,295	$7,173,102	$28,813,987	2,310 jobs
Production change for a 1 inch increase in ppt: 200,955 tons						
Dollar value of this production change: $12,157,800						

TABLE V-14: Composite Weather Variables and their Summary Statistics.

Crop	Variable	Mean	Standard Deviation	Median	25th Percentile	75th Percentile
Wheat	TEMP11	47.5161	7.0563	50.0	42.0	53.0
	*PPT43	0.378387	0.576652	0.06	0.0	0.56
Sorghum	PPT24	0.77871	0.556044	0.81	0.25	1.12
	PPT34	0.608387	0.509844	0.41	0.17	0.93
	TEMP35	78.2581	3.82071	79.0	76.0	81.0
	*PPT36	0.694839	0.702865	0.49	0.13	0.96
COTTON	SM28	2.25806	0.892989	2.22	1.44	2.99
	*PPT45	0.182581	0.318716	0.03	0.0	0.33
HAY	PPT27	0.614839	0.541226	0.42	0.18	1.04
	PPT33	0.775806	0.628287	0.68	0.23	1.14

*Variable distribution is highly skewed

variate procedure. Economic computations will be performed for these at one standard deviation from the means of the driving climate variables, but the following type of probabilistic interpretation is recommended for these skewed variables.

The calculation of means and standard deviations does not change the underlying shape of the sample distribution. If the sample is not reasonably normal, it will always remain so. Where this is the case, percentiles may give a much better handle on generating probabilistic conclusions. In Table V-14 the mean, first quartile, and third quartile are given. If one takes the variable increment from the third quartile to the median, then only 25% of the sample would lie above this increment (Q3-Q2). Similarly, only 25% of the sample would be below the increment Q2-Q1. The increments defined by these two breakpoints can be used to define a range of "good" and "bad" impacts in a

WHEAT

		Breakpoints or Increments	
	1 S.D.	Q3-Q2	Q2-Q1
1) TEMP11 (°F)	7.0563	3.0	8.0
Production Impact (Bu)	(-)7,740,136	(-)3,290,734	8,775,291
Production Impact ($)	(-)26,239,100	(-)11,155,600	29,748,200
Output ($)	(-)96,559,883	(-)41,052,606	109,473,371
Final Demand ($)	(-)52,215,809	(-)22,199,644	59,198,918
Income ($)	(-)33,586,047	(-)14,279,167	38,077,695
Taxation ($)	(-)6,034,993	(-)2,565,788	6,842,086
G.S.P. ($)	(-)50,641,462	(-)21,530,307	57,414,024
Employment (jobs)	(-)3,897	(-)1,657	4,418
2) PPT43 (Inches)	0.576652	0.50	0.06
Production Impact (Bu)	14,443,377	12,523,318	(-)1,502,798
Production Impact ($)	48,963,050	42,454,049	(-)5,094,490
Output ($)	180,184,016	156,230,893	(-)18,747,700
Final Demand ($)	97,436,470	84,483,558	(-)10,138,000
Income ($)	62,672,703	54,341,182	(-)6,520,950
Taxation ($)	11,261,501	9,764,431	(-)1,171,730
G.S.P. ($)	94,498,684	81,936,312	(-)9,832,370
Employment (jobs)	7,271	6,305	(-)757

TABLE V-15: Economic impacts for breakpoint or increment values of winter wheat driving climate variables with probabilistic implications.

fashion similar to the way the standard deviation can be used to demarcate upper and lower tails of a distribution. Economic computations will be performed for the increments (Q3-Q2) and (Q2-Q1) defined by the distributions of the driving climate variables. These computations are given in Tables V-15 through V-18.

A few examples will now be given on how to use the information in Tables V-15 to V-18. For instance, consider Table V-18 for hay. For the variable PPT27, one finds the figure of $5,028,680 in the standard deviation column. Around 68% of the time, the input on taxation would fall somewhere between $5 million of extra taxes and $5 million less in

SORGHUM

			Breakpoints or Increments	
		1 S.D.	Q3-Q2	Q2-Q1
1)	PPT24 (In. of ppt)	0.556044	0.31	0.56
	Production Impact (Bu)	1,091,860	608,723	(-)1,099,628
	Production Impact ($)	2,533,120	1,412,240	(-)2,551,140
	Output ($)	9,321,880	5,197,040	(-)9,388,200
	Final Demand ($)	5,040,910	2,810,360	(-)5,076,770
	Income ($)	3,242,390	1,807,670	(-)3,265,460
	Taxation ($)	582,618	324,815	(-)586,762
	G.S.P. ($)	4,888,920	2,725,620	(-)4,923,700
	Employment (jobs)	376	210	(-)379
2)	PPT34 (In. of ppt)	0.509844	0.52	0.24
	Production Impact (Bu)	1,452,389	1,481,320	(-)683,687
	Production Impact ($)	3,369,540	3,436,660	(-)1,586,150
	Output ($)	12,399,900	12,646,907	(-)5,837,040
	Final Demand ($)	6,705,380	6,838,950	(-)3,156,440
	Income ($)	4,313,010	4,398,930	(-)2,030,280
	Taxation ($)	774,994	790,432	(-)364,815
	G.S.P. ($)	6,503,210	6,632,750	(-)3,661,270
	Employment (jobs)	500	510	(-)235
3)	TEMP35 (°F)	3.82071	2.0	3.0
	Production Impact (Bu)	(-)990,184	(-)518,325	777,488
	Production Impact ($)	(-)2,297,230	(-)1,202,510	1,803,770
	Output ($)	(-)8,453,810	(-)4,425,260	6,637,890
	Final Demand ($)	(-)4,571,490	(-)2,393,010	3,589,520
	Income ($)	(-)2,940,450	(-)1,539,220	808,830
	Taxation ($)	(-)528,363	(-)276,579	414,869
	G.S.P. ($)	(-)4,433,650	(-)2,320,850	3,481,280
	Employment (jobs)	(-)341	(-)179	269
4)	PPT36 (In. of ppt)	0.702865	0.47	0.36
	Production Impact (Bu)	1,711,712	1,144,610	(-)876,723
	Production Impact ($)	3,971,170	2,655,490	(-)2,033,990
	Output ($)	14,613,900	9,772,198	(-)7,485,090
	Final Demand ($)	7,902,630	5,284,430	(-)4,047,650
	Income ($)	5,083,100	3,399,030	(-)2,603,570
	Taxation ($)	913,369	610,763	(-)467,819
	G.S.P. ($)	7,664,360	5,125,100	(-)3,925,610
	Employment (jobs)	590	395	(-)303

TABLE V-16: Economic impacts for breakpoint or increment values of sorghum driving climate variables with probabilistic implications.

COTTON

		Breakpoints or Increments	
	1 S.D.	Q3-Q2	Q2-Q1
1) SM28 (In. of S.M.)	0.892989	0.77	0.78
Production Impact (lbs)	2,392,706	2,063,170	(-)2,089,970
Production Impact ($)	6,651,720	5,735,600	(-)6,326,310
Output ($)	24,478,300	21,106,975	(-)21,375,077
Final Demand ($)	13,236,900	11,413,820	(-)11,562,085
Income ($)	8,514,200	7,341,560	(-)7,436,930
Taxation ($)	1,529,900	1,319,190	(-)1,336,330
G.S.P. ($)	12,837,800	11,069,687	(-)11,213,482
Employment (jobs)	988	852	(-)863
2) PPT45 (In. of ppt)	0.318716	0.30	0.03
Production Impact (lbs)	(-)1,164,781	(-)1,096,380	109,638
Production Impact ($)	(-)3,238,090	(-)3,047,940	304,794
Output ($)	(-)11,916,200	(-)11,216,445	1,121,645
Final Demand ($)	(-)6,443,800	(-)6,065,400	606,540
Income ($)	(-)4,144,760	(-)3,901,370	390,137
Taxation ($)	(-)744,761	(-)701,026	70,103
G.S.P. ($)	(-)6,249,510	(-)5,882,520	588,252
Employment (jobs)	(-)481	(-)453	45

Table V-17: Economic impacts for breakpoint or increment values of cotton driving climate variables with probabilistic implications.

taxes. About 16% of the time, the impact on taxation would be greater than this in the direction of greater tax revenue; about 16% of the time, one could expect a greater negative impact. From commonly available tables of standard normal deviates, one could find the multiple of a standard deviation needed to find any desired probabilistic threshold or range. Since the models involved are completely linear, estimates of the economic impacts are forthcoming simply by scaling the figures in the standard deviation column up or down.

If one is dubious as to the normality of the distributions involved, or simply wants greater accuracy, one can use the percentile based information. For instance, the (Q3-Q2) column for hay for variable PPT27 indicates that 25% of the time a beneficial impact on tax-

HAY

			Breakpoints or Increments	
		1 S.D.	Q3-Q2	Q2-Q1
1)	PPT27 (In. of ppt)	0.541226	0.62	0.24
	Production Impact (tons)	140,879	161,384	(-)62,471
	Production Impact ($)	8,523,180	9,763,730	(-)3,779,510
	Output ($)	42,956,800	49,209,163	(-)19,048,718
	Final Demand ($)	21,052,300	24,116,463	(-)9,335,410
	Income ($)	11,250,600	12,888,125	(-)4,988,954
	Taxation ($)	5,028,680	5,760,600	(-)2,229,910
	G.S.P. ($)	20,199,900	23,139,996	(-)8,957,422
	Employment (jobs)	1,620	1,856	(-)718
2)	PPT33 (In. of ppt)	0.628287	0.56	0.45
	Production Impact (tons)	126,258	112,535	(-)90,430
	Production Impact ($)	7,638,610	6,808,390	(-)5,471,030
	Output ($)	38,498,600	34,314,301	(-)27,573,979
	Final Demand ($)	18,867,400	16,816,758	(-)13,513,460
	Income ($)	10,083,000	8,987,109	(-)7,221,780
	Taxation ($)	4,506,780	4,016,950	(-)3,227,900
	G.S.P. ($)	18,103,500	16,135,884	(-)12,966,329
	Employment (jobs)	1,451	1,293	(-)1,639

Table V-18: Economic impacts for breakpoint or increment values of hay driving climate variables with probabilistic implications.

ation of greater than $5,760,600 could be expected. The (Q2-Q1) figure of $2,229,910 shows the loss in taxation relative to median climate conditions one would expect 25% of the time. For more flexibility, one would probably need to construct an ogive for the cumulative distribution function of a particular climate variable to get economic impact estimates in terms of particular percentile breakpoints. Since one is talking about a specific distribution, standard tables will be lacking as are available for standard normal deviates. One gains in accuracy, but has to go to extra computational expense.

The types of information assembled in this chapter could be of great benefit to decision makers at various levels. The information on direct production impacts could be helpful to farmers attempting to choose an optimal match of crops to climate conditions. The overall economic impact assessments could be helpful to a variety of governmental planners at the state and federal levels. Through price support or loan programs, the federal government in particular can influence what sorts of crops are grown. Depending on the general economic climate, it may want to encourage farmers to avoid extremely risky crops. The type of analysis outlined above gives a basis for giving this sort of advice. Finally, this modeling approach provides a tool for anticipating the consequences of particular climate scenarios. If there is good reason to believe, for instance, that a drought episode is likely, planners can get estimates of the probable impacts on tax revenues, incomes, and employment.

In some instances, there is the possibility for manipulating the uncertain climatic future. Weather modification is one means for trying to alter the weather in a purposeful fashion. The point of departure will be to use changes in the precipitation variables in the crop model developed above to simulate the likely impact of weather modification activities. It should be noted that a very similar approach could be followed to estimate the likely impacts from a particular type of climatic variation from "average" or "typical" conditions, e.g., a drought or a wet spell of specified magnitude. This should be borne in mind as attention in the next chapter turns to how the framework developed here can be used to help in the evaluation and design of an operational weather modification program.

CHAPTER VI

POTENTIAL APPLICATIONS TO AN OPERATIONAL WEATHER MODIFICATION PROGRAM

In the preceding chapter, a set of crop models was used to draw conclusions about the impacts of natural climatic variability over an historical period of record. The same approach can be easily adapted to evaluate an operational weather modification program. A weather modification program could be expected to have some impact on the precipitation variable values in the crop models. If these precipitation changes could be quantitatively estimated, then economic assessments could be readily performed. The main complicating factor is that the historical data base is lacking to make firm estimates of the anticipated precipitation changes. Provisional estimates can be made using a set of considerations developed by Bark, Buller, and Vanderlip (1979). The focus of this study was Kansas, but the conclusions were meant to apply over much of the Great Plains area. The assumption that this approach casts light on conditions in Oklahoma is central to the discussion that follows.

Drawing on a variety of insights from cloud physics, dynamic meteorology, and analyses of experimental weather modification projects, Bark has made estimates of the change in precipitation expected from a storm event based on whether the precipitation would normally have fallen in one of four precipitation categories. This information is summarized in Table VI-1.

Range of Normal Precipitation (in 1000ths of inches)		Change in Precipitation Anticipated from Weather Modification
1) less than or equal to	100	+75%
2) greater than less than or equal to	100 500	+30%
3) greater than less than or equal to	500 1000	+10%
4) greater than	1000	-10%

TABLE VI-1: Anticipated precipitation changes for rainfall events falling into four categories.

Bark usually interprets his rainfall or storm events as clouds. For present purposes, a rainfall event will be interpreted as the precipitation reported from an observing station over a 24-hour period. This is not exactly what Bark had in mind, but is not felt to induce appreciable distortions into the analysis.

The next step is to use these percent change estimators in conjunction with historical data to estimate precipitation changes that can then be used in the crop models developed in the preceeding chapter. This was accomplished using the Oklahoma Climatological Survey's interpolated daily tapes for Oklahoma, from which the weekly tapes used in Chapter V were developed. For each precipitation variable in the crop models, the percentage change figures in Table VI-1 were applied to the daily precipitation values for all the reporting stations within a particular crop area. Those daily changes were averaged over the pertinent reporting stations and then cumulated to derive weekly estimates.

This process was applied over the whole period of record. Summary statistics are given for each crop in Tables VI-2 to VI-5.

WINTER WHEAT

Week 43:

mean	0.0543 (IN)
s.d.	0.0474 (IN)
median	0.0520 (IN)
maximum	0.1860 (IN)
minimum	0.0000 (IN)

TABLE VI-2: Summary statistics for winter wheat precipitation variable changes.

SORGHUM

Week 43:

mean	0.0415 (IN)
s.d.	0.0381 (IN)
median	0.0320 (IN)
maximum	0.1440 (IN)
minimum	-0.0110 (IN)

Week 34:

mean	0.0389 (IN)
s.d.	0.0306 (IN)
median	0.0350 (IN)
maximum	0.1130 (IN)
minimum	-0.0050 (IN)

Week 36:

mean	0.0328 (IN)
s.d.	0.03457 (IN)
median	0.0210 (IN)
maximum	0.1380 (IN)
minimum	-0.0430 (IN)

TABLE VI-3: Summary statistics for sorghum precipitation variable changes.

COTTON

Week 45:

mean	0.0328
s.d.	0.0345
median	0.0210
maximum	0.1380
minimum	-0.0430

TABLE VI-4: Summary statistics for cotton precipitation variable changes.

HAY

Week 27:

mean	0.0284
s.d.	0.0216
median	0.0270
maximum	0.0660
minimum	-0.0180

Week 33:

mean	0.0340
s.d.	0.0285
median	0.0350
maximum	0.0830
minimum	-0.0570

TABLE VI-5: Summary statistics for hay precipitation variable changes.

For each crop-area variable, the implication is that weather modification could, on the average, add several hundredths of an inch of precipitation during critical crop development periods. It should be frankly admitted that this is not an enormous amount of extra rainfall. The implication is that if one were expecting increases on the order to an inch or more, one would be disappointed. Before dismissing weather modification as a waste of effort, however, the economic implications of these modest changes in precipitation warrant examination.

One thing to bear in mind is that only positive changes in yields can lead to positive economic impacts. On the average, positive changes in precipitation were indicated for all the crop-area precipitation variables. For most of the crops, extra precipitation translates into increased yields and, hence, positive economic benefits. This is not the case for the cotton precipitation variable. Extra precipitation during the boll opening period leads to decreases in yield. This suggests that an operational weather modification program would probably want to avoid seeding during this period. For the other crops, examination of the minimum precipitation change values in the tables above shows that at times there are negative impacts on normal precipitation. Following the logic of Dean Bark's methodology, one would conclude that such negative changes were associated with seeding larger cloud systems. Positive changes are only expected where the normal rainfall yields would be under an inch. This implies that if feasible, an operational weather modification program should avoid larger storm systems.

This suggests considering two types of weather modification applications. In the first application, all seeding opportunities would be exploited. In the second application, only selected seeding opportunities would be used. Seeding during the cotton boll opening period would be avoided. Larger cloud systems would also be avoided. While such a goal makes sense from a logical point of view, its perfect implementation might not be technologically feasible. It is probably not always possible to tell in advance whether a "normal" cloud will yield more than an inch of rain. Operationally, one would make mistakes, sometimes seeding a cloud one shouldn't, sometimes missing an opportunity. Therefore, in the select opportunities case, I have tried to approximate the avoidance of seeding large clouds by setting instances of negative yield impacts for wheat, sorghum, and hay to zero. In the case of wheat, which only has one precipitation variable in its yield model, this is equivalent to a perfect avoidance of large cloud systems. The other models have more than one precipitation variable, so that an incident of a positive yield impact for a given year may combine the impacts of both positive and negative results for the various time periods in the model. This adds an element of conservatism to the comparisons between the all opportunities and the select opportunities cases and also a degree of technological realism. The economic implications of these two alternatives will be summarized.

The alternative of using all seeding opportunities is summarized in sets of graphs and tables. The graphs (see Figs. VI-1 to VI-19) show time series plots for the impacts on crop yields, production, the direct dollar value of the product changes, and impacts on various overall economic variables derived through input-output techniques. The tabular display (see Table VI-6) then gives summary statistics for the information in each graphical display.

For the selected seeded opportunities option, a set of graphical time plots is given in Figures VI-20 to VI-35. Statistical summary information is given in Table VI-7. It should be emphasized that

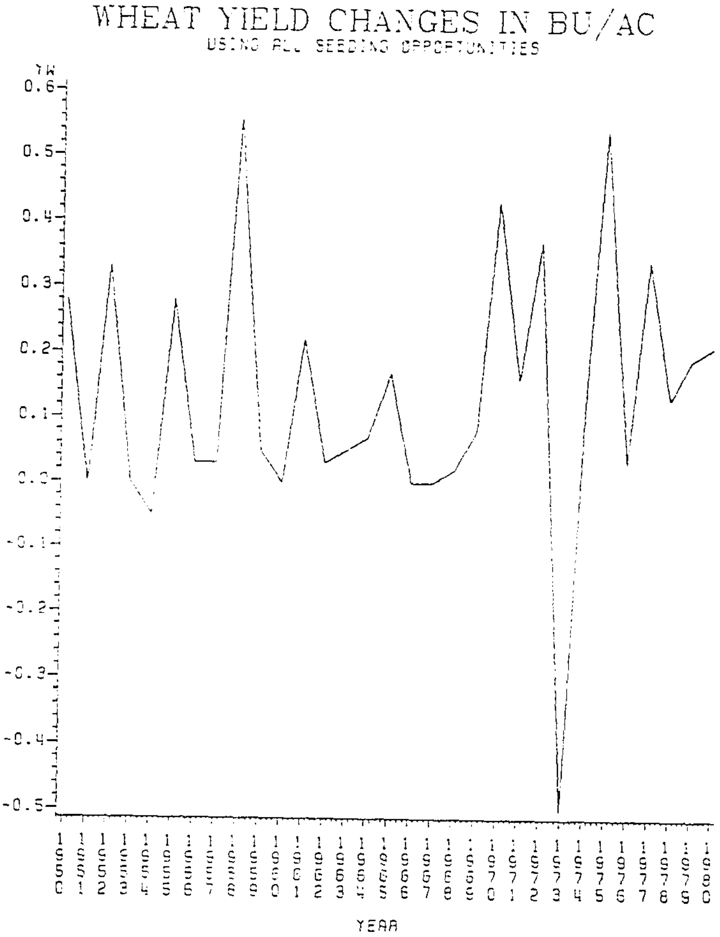

FIGURE VI-1: Wheat Yield Changes in BU/AC Using all Seeding Opportunities.

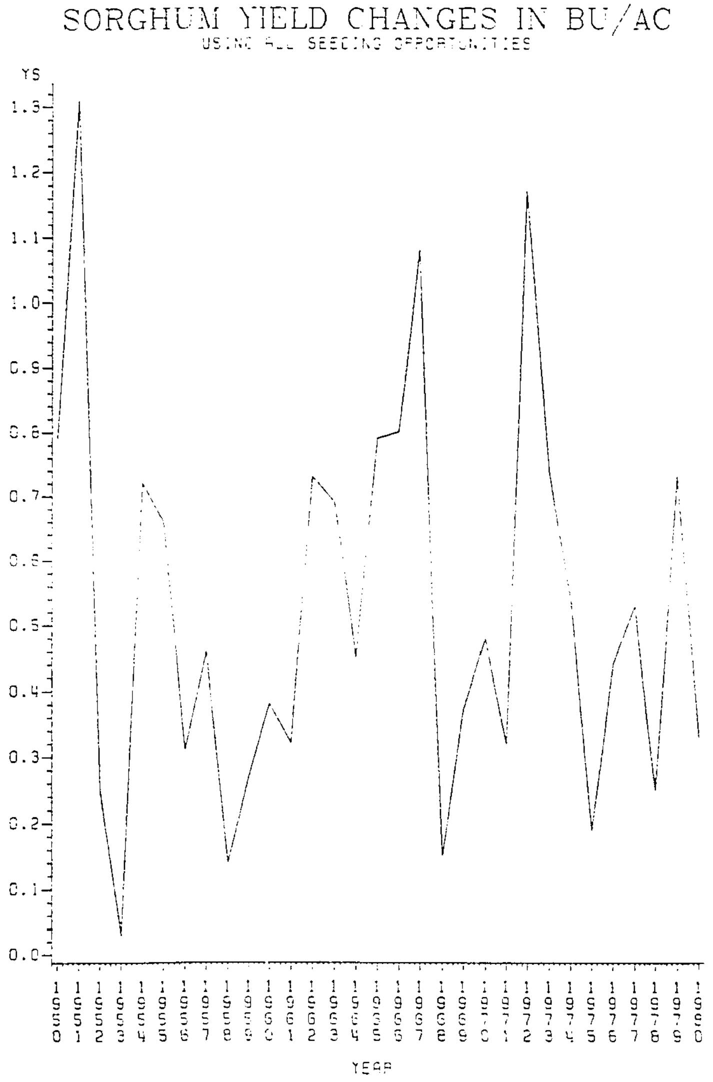

FIGURE VI-2: Sorghum Yield Changes in BU/AC Using all Seeding Opportunities.

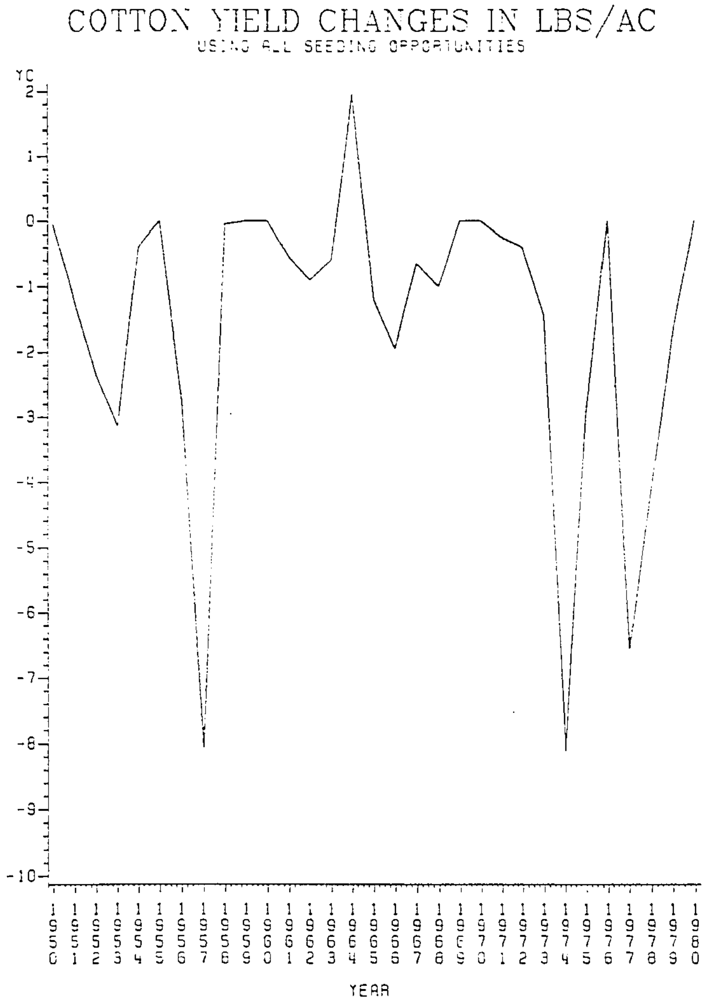

FIGURE VI-3: Cotton Yield Changes in Lbs/AC Using all Seeding Opportunities.

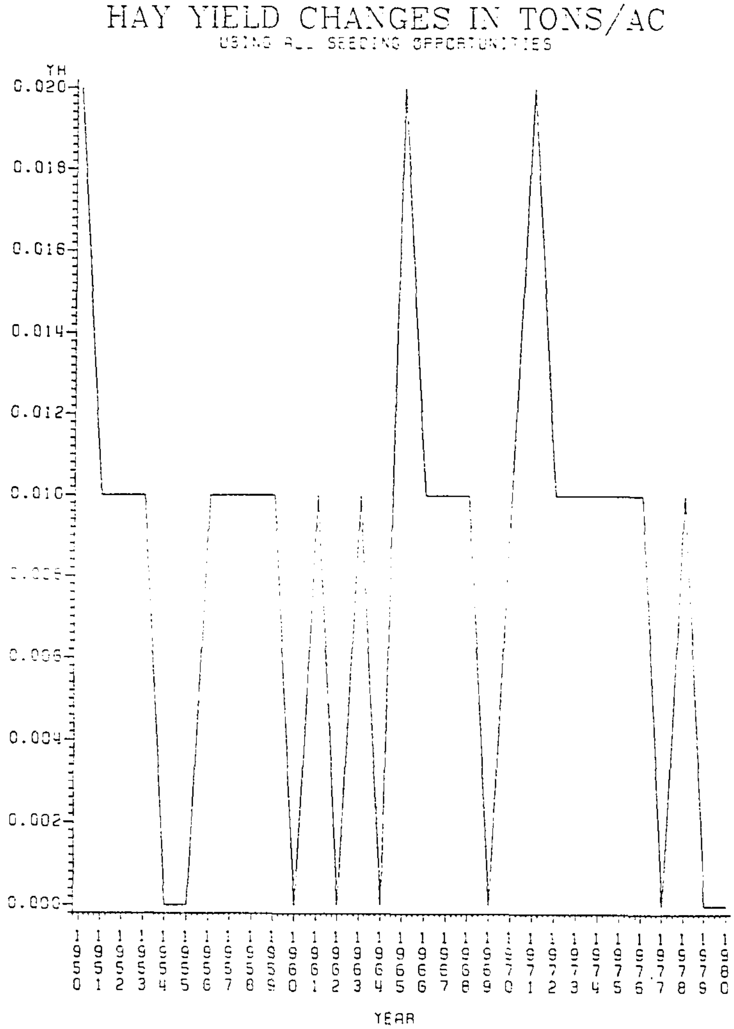

FIGURE VI-4: Hay Yield Changes in Tons/AC Using all Seeding Opportunities.

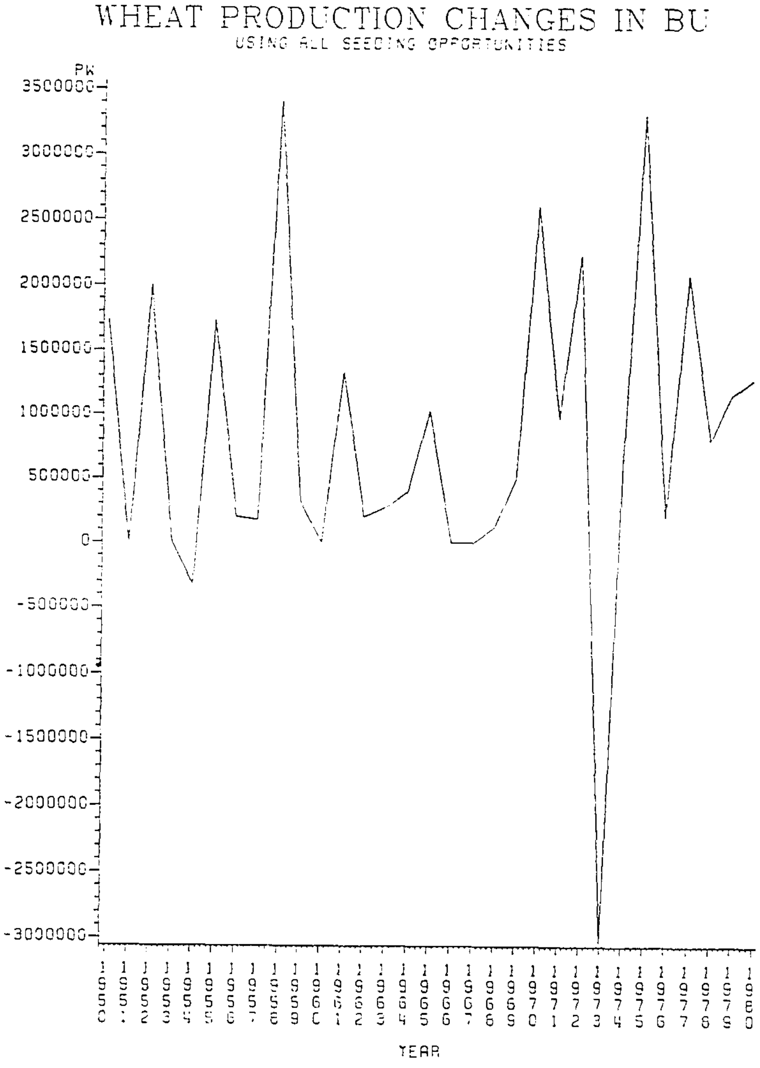

FIGURE VI-5: Wheat Production Changes in BU Using all Seeding Opportunities.

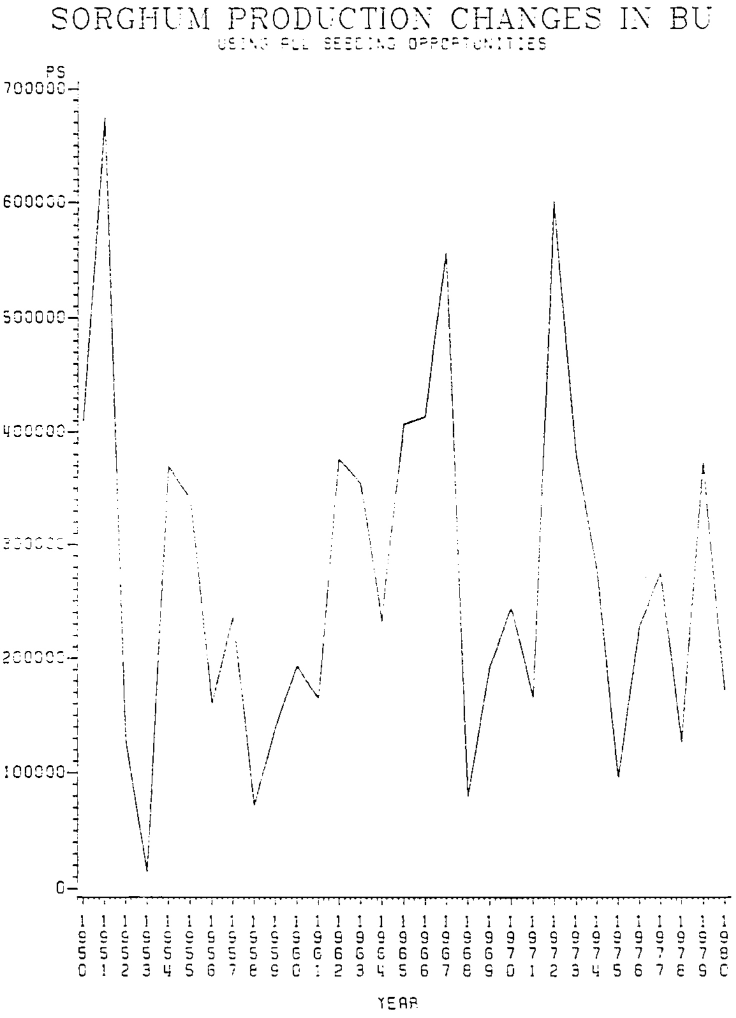

FIGURE VI-6: Sorghum Production Changes in BU Using all Seeding Opportunities.

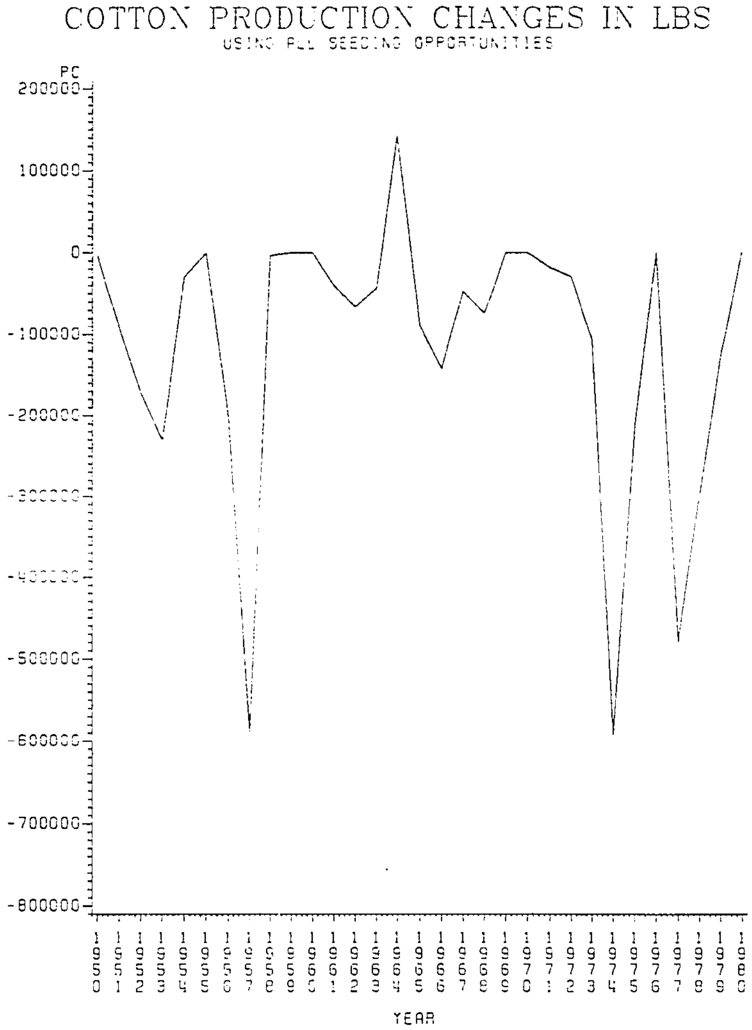

FIGURE VI-7: Cotton Production Changes in Lbs Using all Seeding Opportunities.

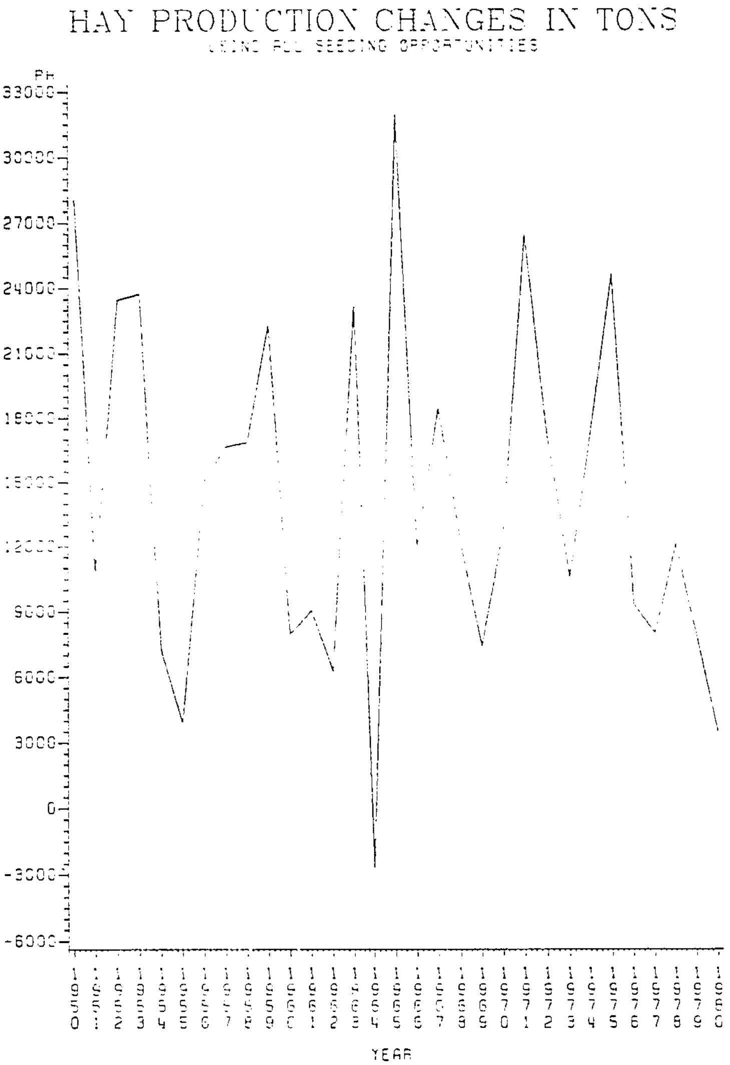

FIGURE VI-8: Hay Production Changes in Tons Using all Seeding Opportunities.

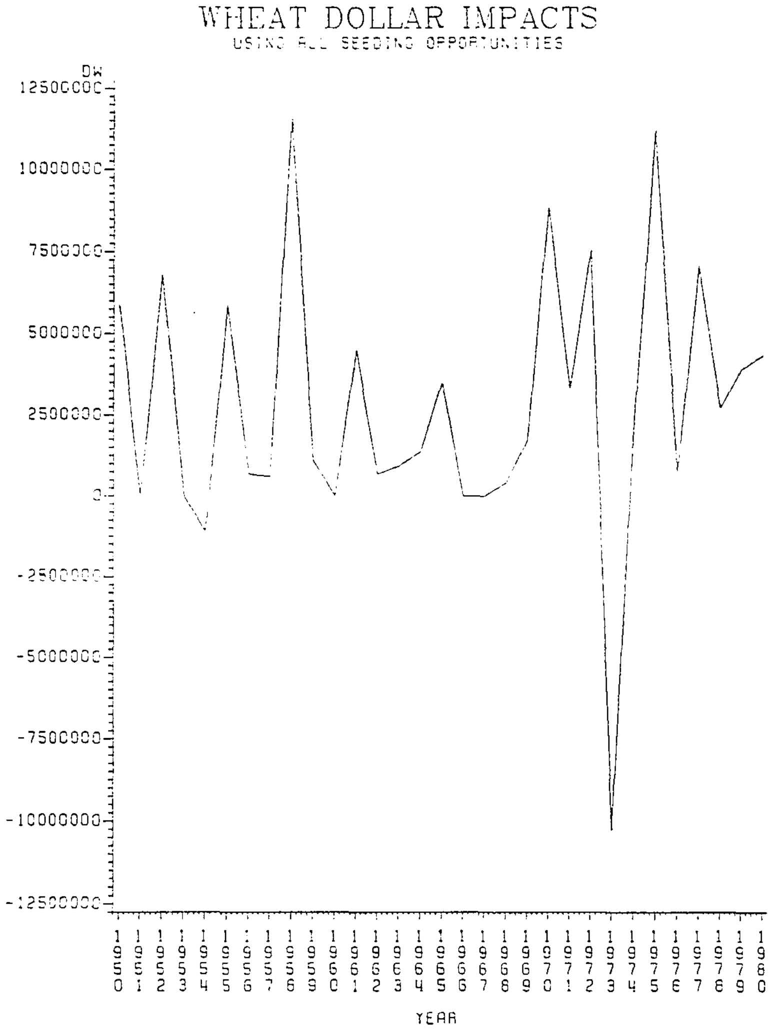

FIGURE VI-9: Wheat Dollar Impacts Using All Seeding Opportunities.

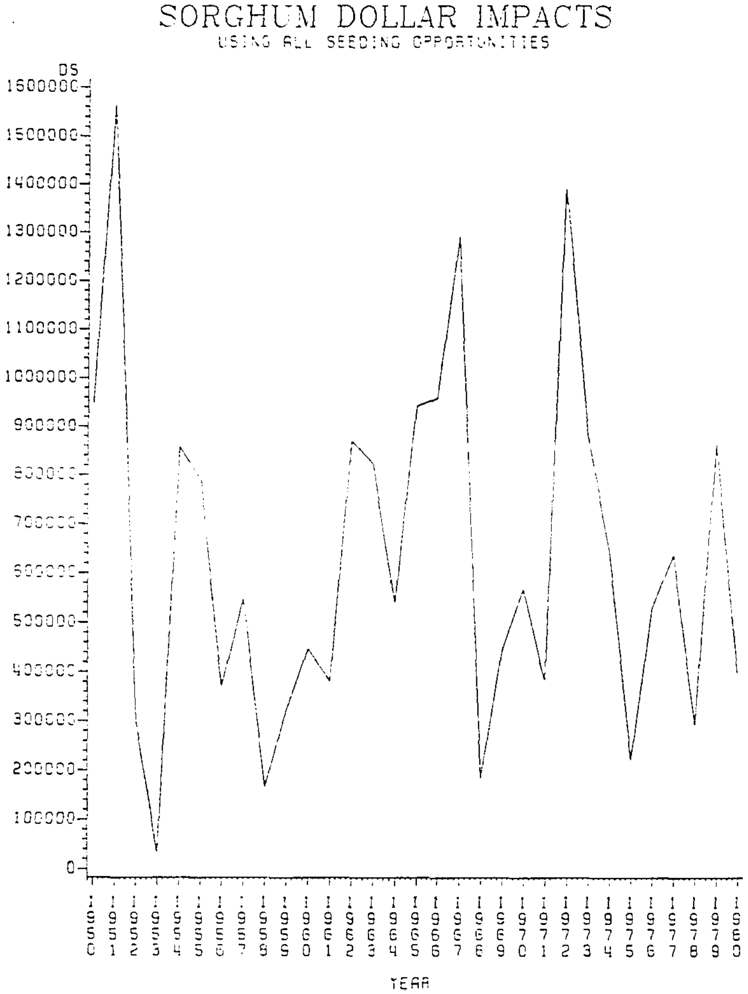

FIGURE VI-10: Sorghum Dollar Impacts Using all Seeding Opportunities.

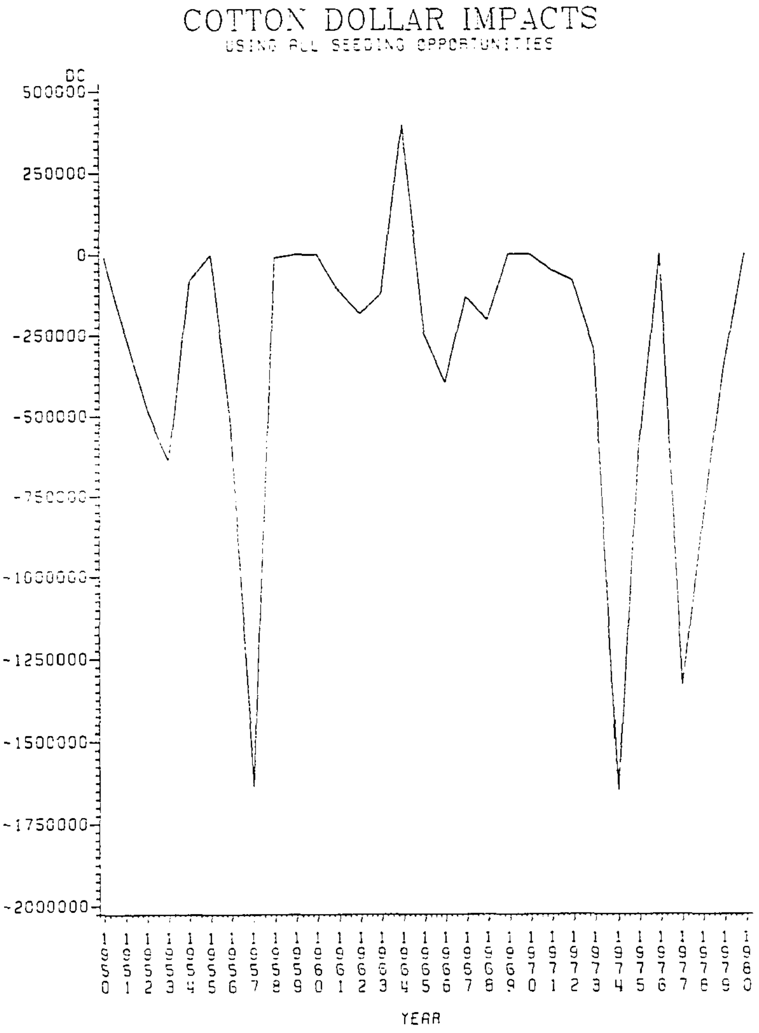

FIGURE VI-11: Cotton Dollar Impacts Using All Seeding Opportunities.

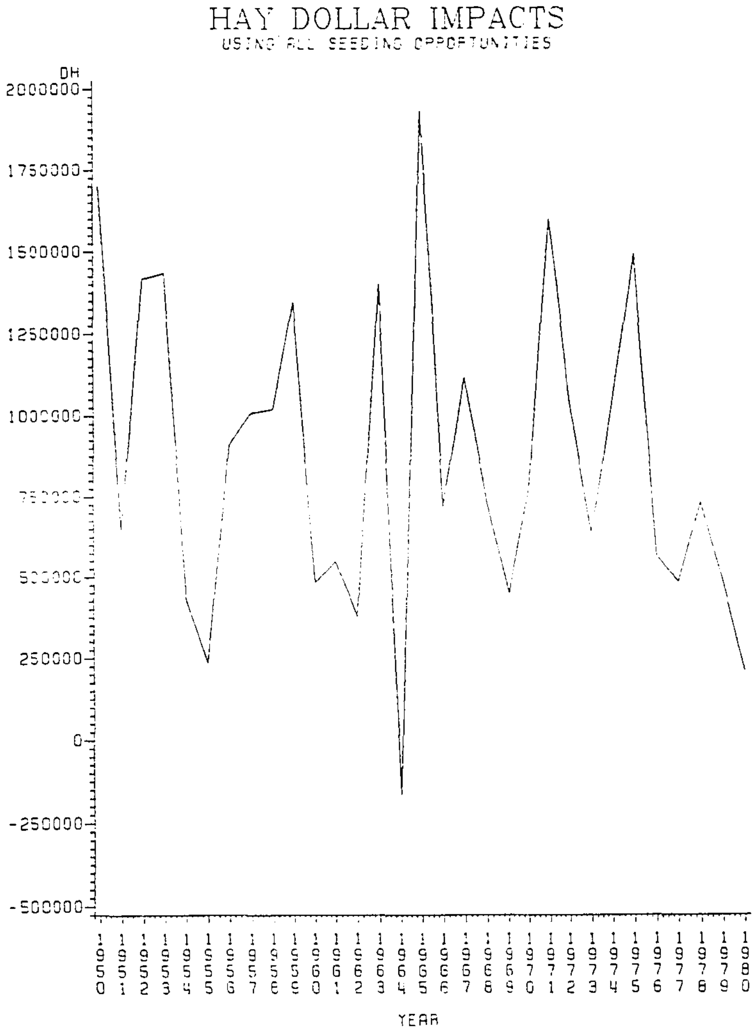

FIGURE VI-12: Hay Dollar Impacts Using all Seeding Opportunities.

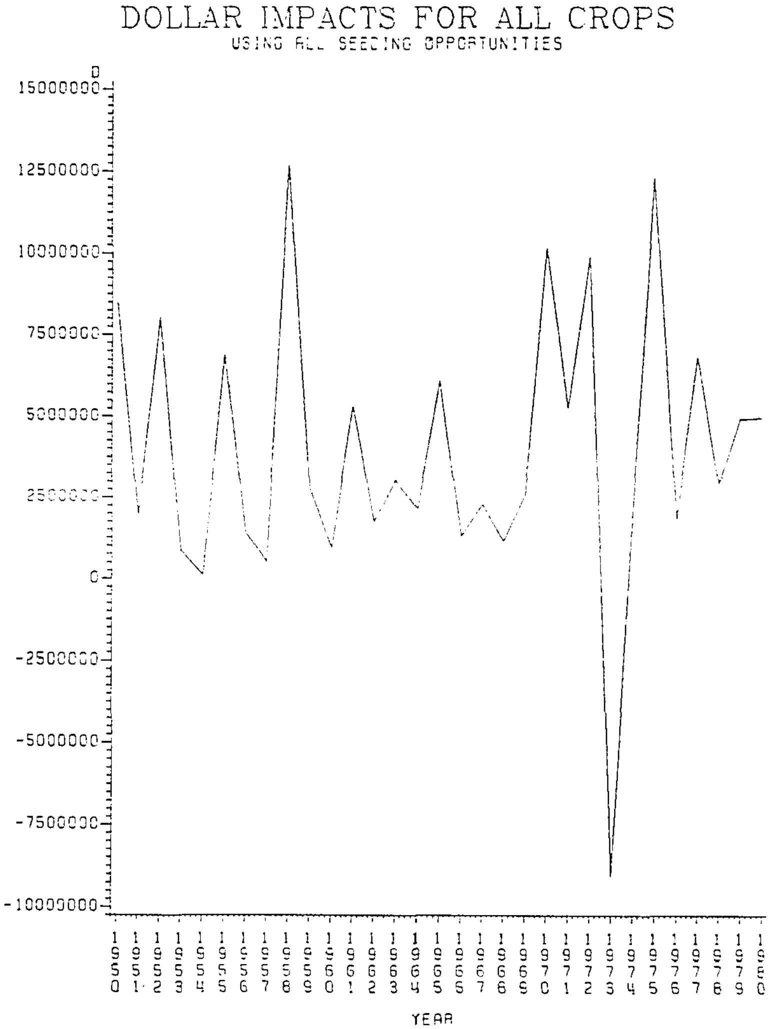

FIGURE VI-13: Dollar Impacts for all Crops Using all Seeding Opportunities.

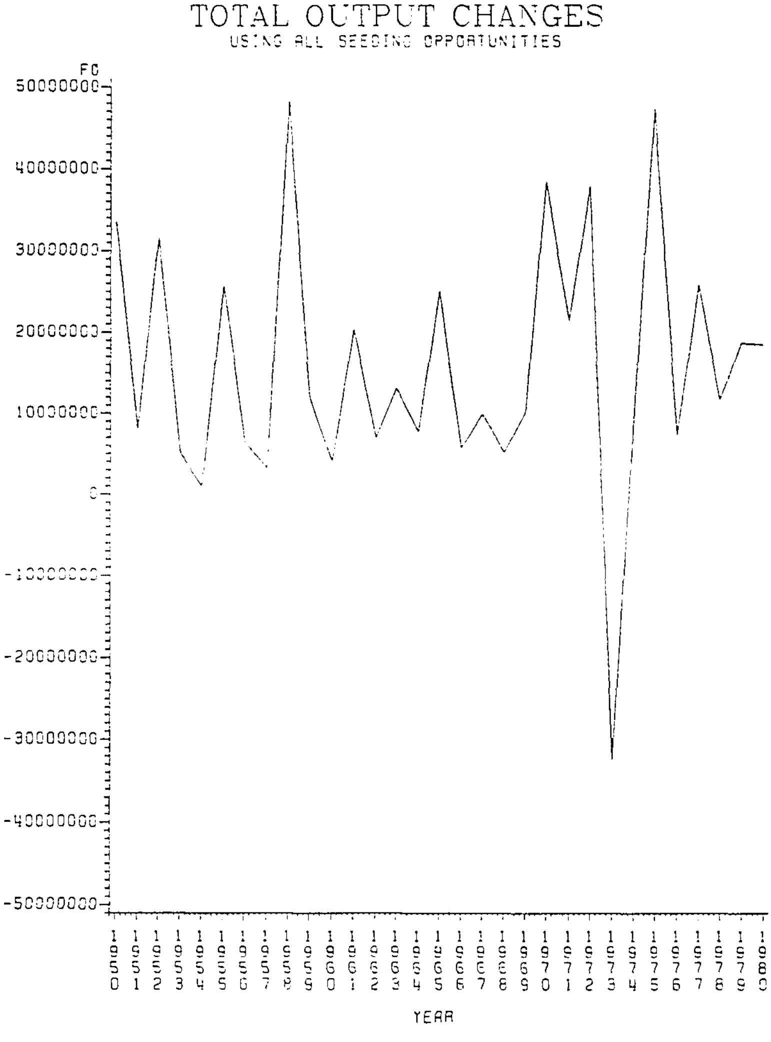

FIGURE VI-14: Total Output Changes Using all Seeding Opportunities.

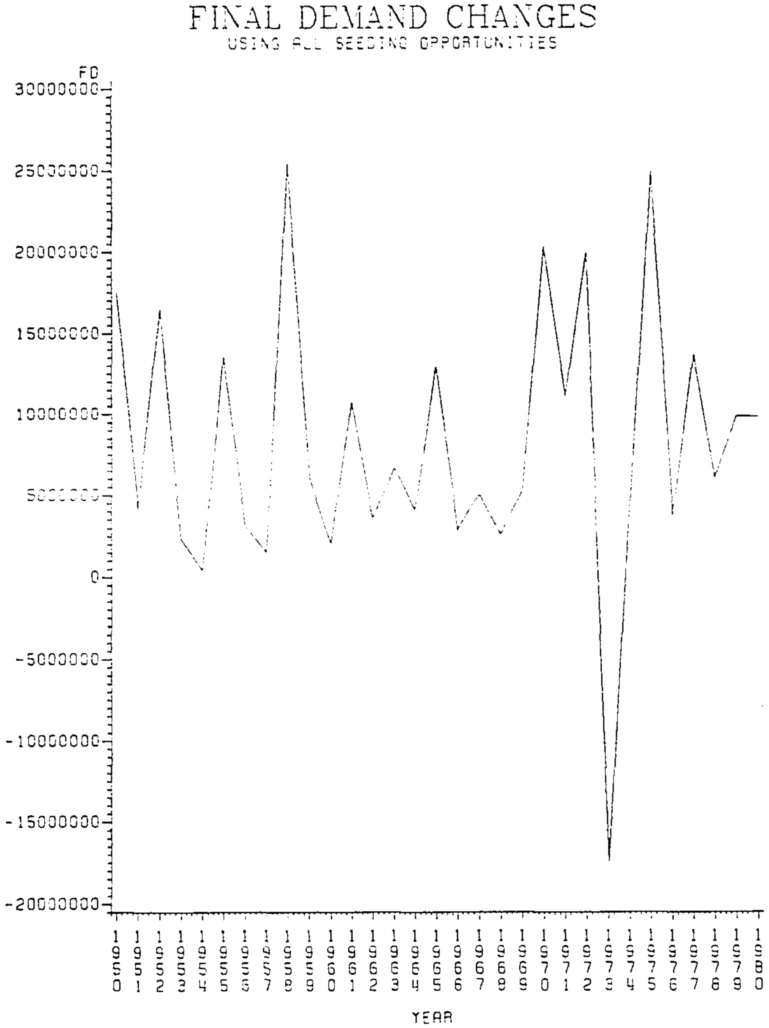

FIGURE VI-15: Final Demand Changes Using all Seeding Opportunities.

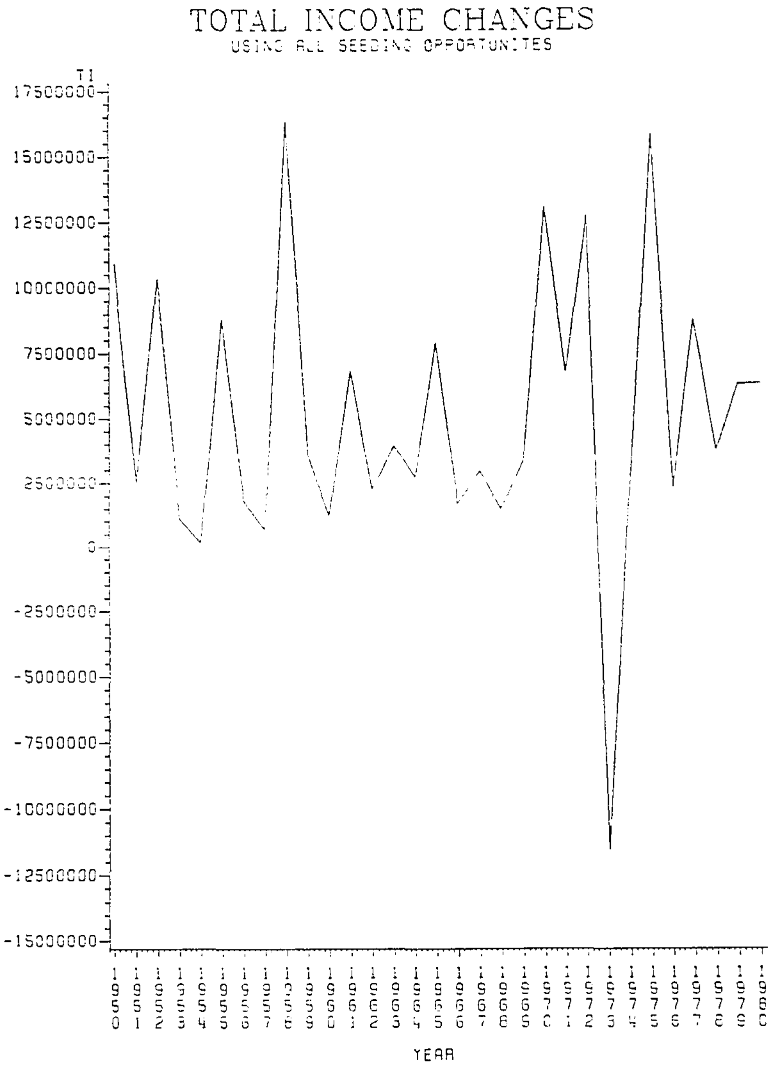

FIGURE VI-16: Total Income Changes Using all Seeding Opportunities.

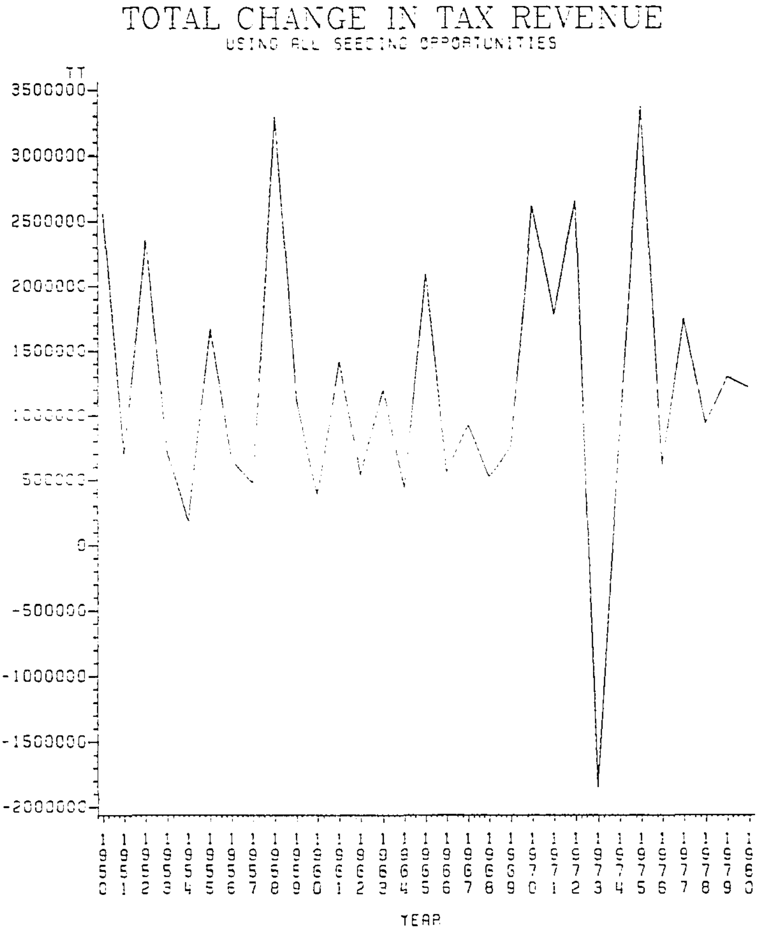

FIGURE VI-17: Total Change in Tax Revenue Using all Seeding Opportunities.

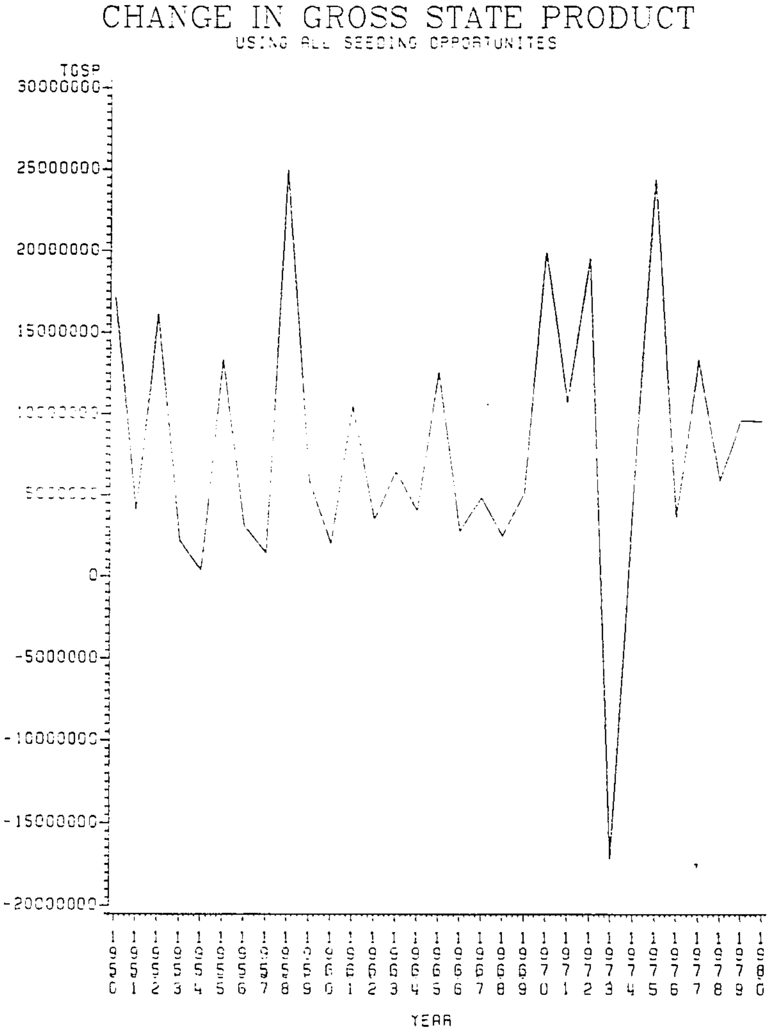

FIGURE VI-18: Change in Gross State Product Using all Seeding Opportunities.

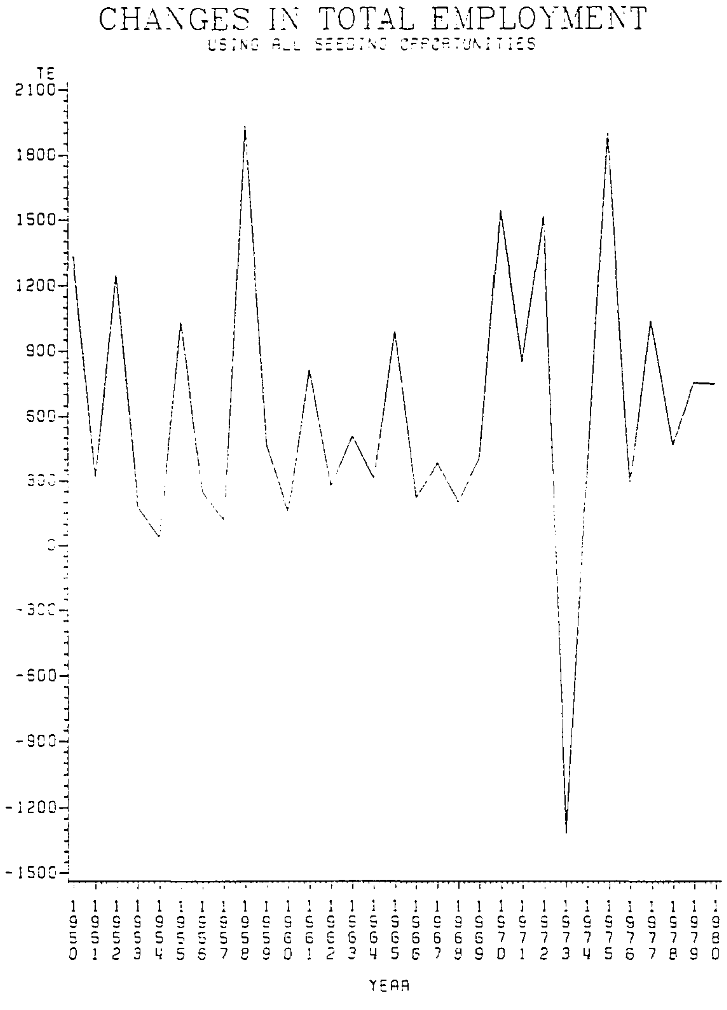

FIGURE VI-19: Changes in Total Employment Using all Seeding Opportunities.

CHANGES IN YIELDS

	Wheat (BU/AC)	Sorghum (BU/AC)	Cotton (LBS/AC)	Hay (TONS/AC)
mean	0.1338	0.5296	-1.5658	0.0081
s.d	0.2029	0.3090	2.3482	0.0060
median	0.0800	0.4600	-0.6500	0.0100
maximum	0.5600	1.3100	1.9500	0.0200
minimum	-0.5000	0.0300	-8.1100	0.0

CHANGES IN PRODUCTION

	Wheat (BU)	Sorghum (BU)	Cotton (LBS)	Hay (TONS)
mean	816,035	272,616	-114,354	14,300
s.d.	1,234,772	159,054	171,422	8,188
median	500,932	236,108	-47,509	12,113
maximum	3,406,342	674,327	142,530	31,954
minimum	-3,030,642	14,171	-592,046	-2,686

VALUE OF PRODUCTION CHANGES

	Wheat ($)	Sorghum ($)	Cotton ($)	Hay ($)	All Crops ($)
mean	2,766,354	632,468	-317,903	865,155	3,946,078
s.d.	4,185,877	369,004	476,552	495,385	4,286,724
median	1,698,160	547,769	-132,077	732,829	2,773,521
maximum	11,547,500	1,564,438	396,232	1,933,208	12,723,961
minimum	-10,273,877	32,878	-1,645,886	-162,506	-9,044,246

OVERALL ECONOMIC IMPACTS

	Output ($)	Final Demand ($)	Income ($)	Taxation ($)	Product ($)	Jobs ($)
mean	15,683,291	8,168,247	5,081,687	1,217,311	7,989,599	621
s.d.	15,965,999	8,468,554	5,585,043	1,051,420	8,328,980	642
median	11,689,296	6,069,531	3,599,644	931,094	5,931,283	462
maximum	48,211,072	25,458,992	16,327,357	3,367,401	25,005,888	1,932
minimum	-32,418,480	-17,403,328	-11,552,735	-1,850,415	-17,176,704	-1,317

TABLE VI-6: Summary statistics on production and economic impacts using all seeding opportunities.

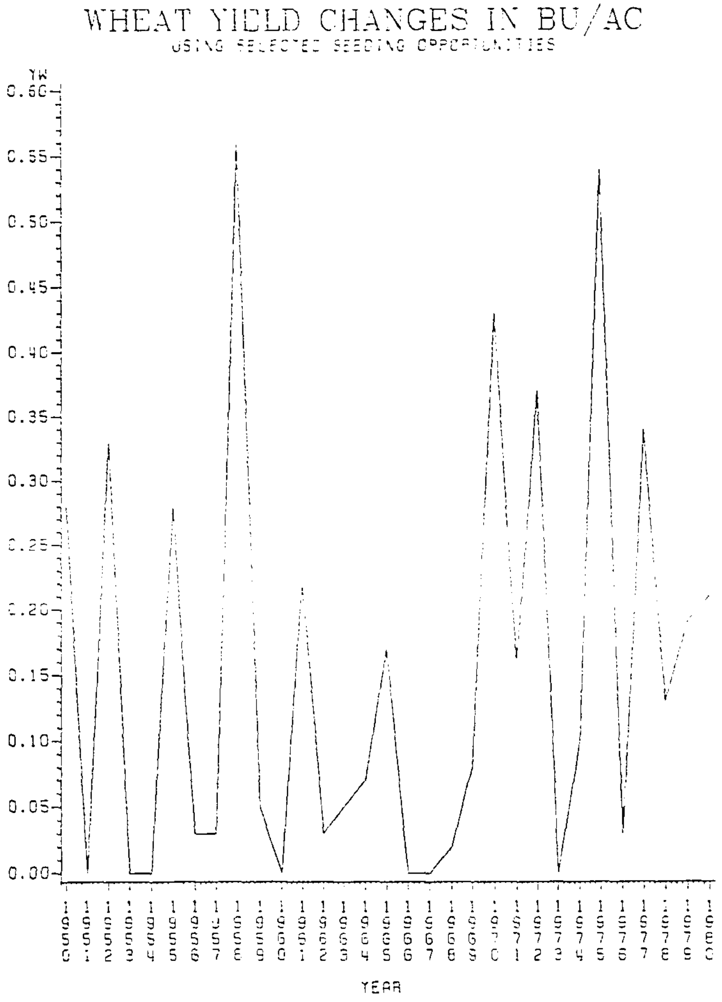

FIGURE VI-20: Wheat Yield Changes in BU/AC Using Selected Seeding Opportunities.

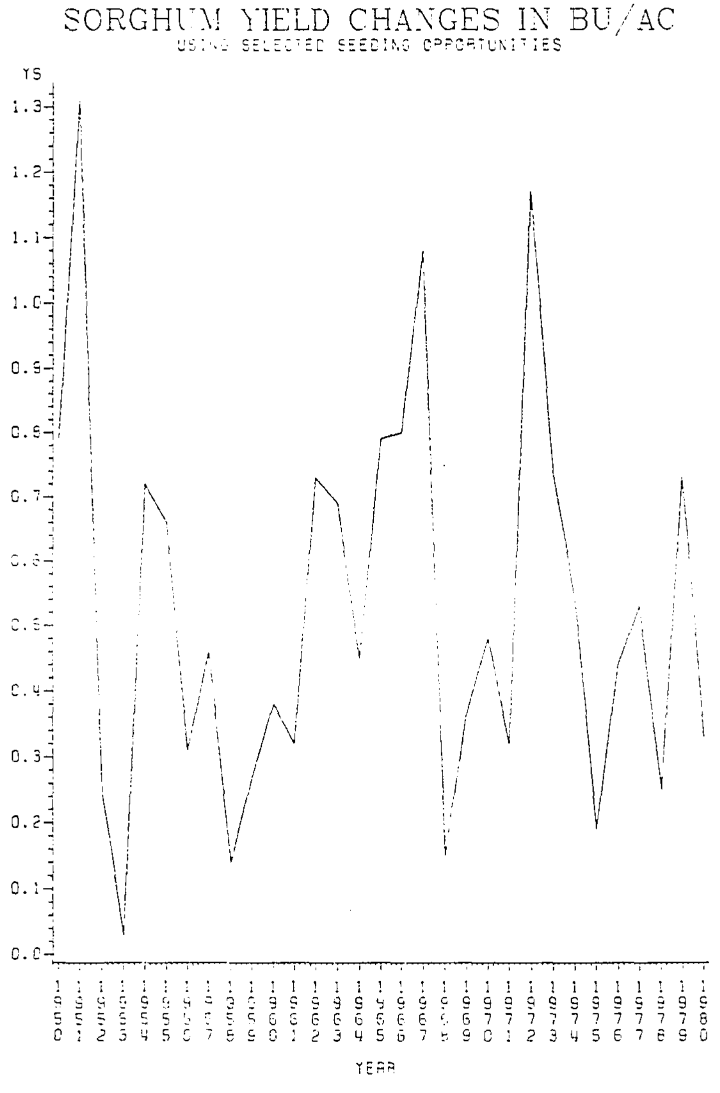

FIGURE VI-21: Sorghum Yield Changes in BU/AC Using Selected Seeding Opportunities.

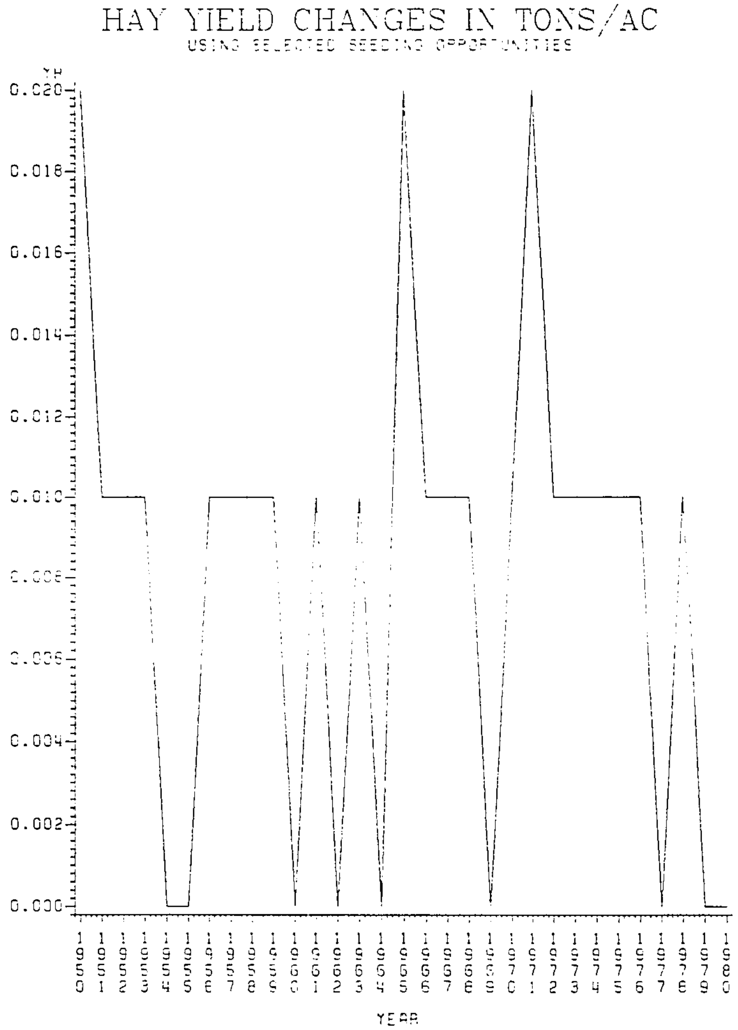

FIGURE VI-22: Hay Yield Changes in Tons/AC Using Selected Seeding Opportunities.

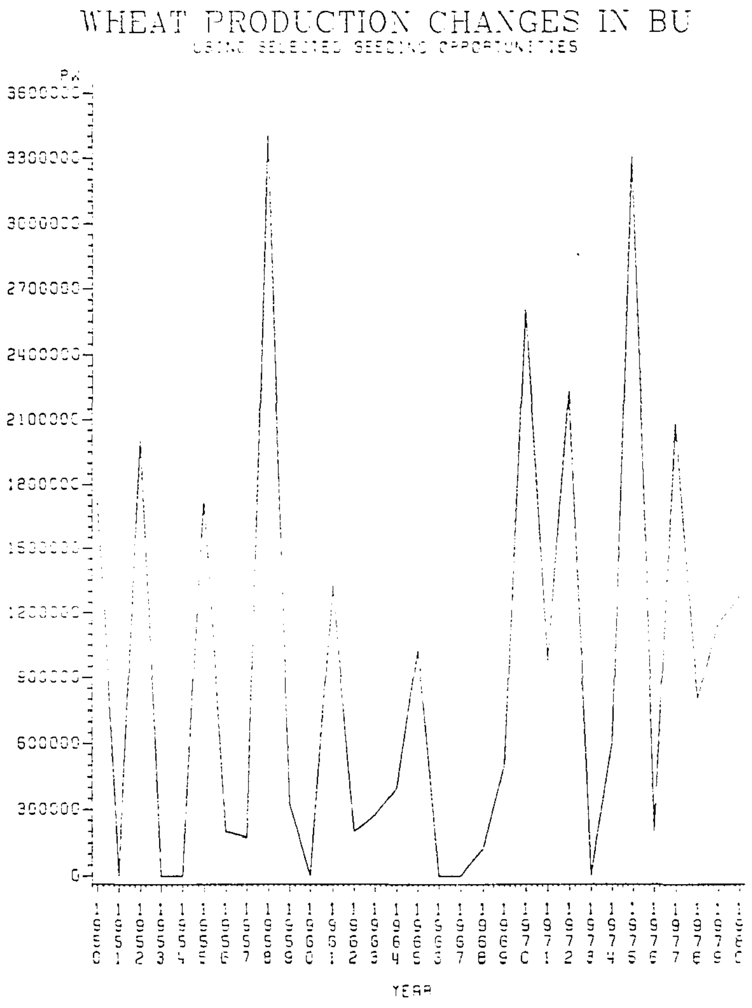

FIGURE VI-23: Wheat Production Changes in BU Using Selected Seeding Opportunities.

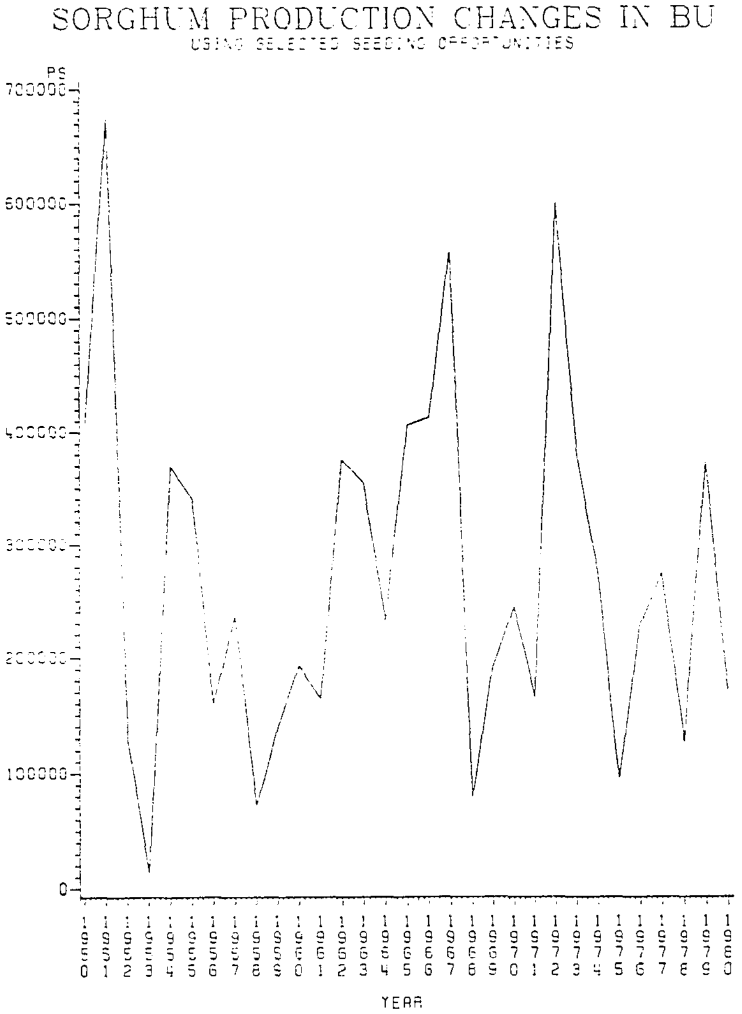

FIGURE VI-24: Sorghum Production Changes in BU Using Selected Seeding Opportunities.

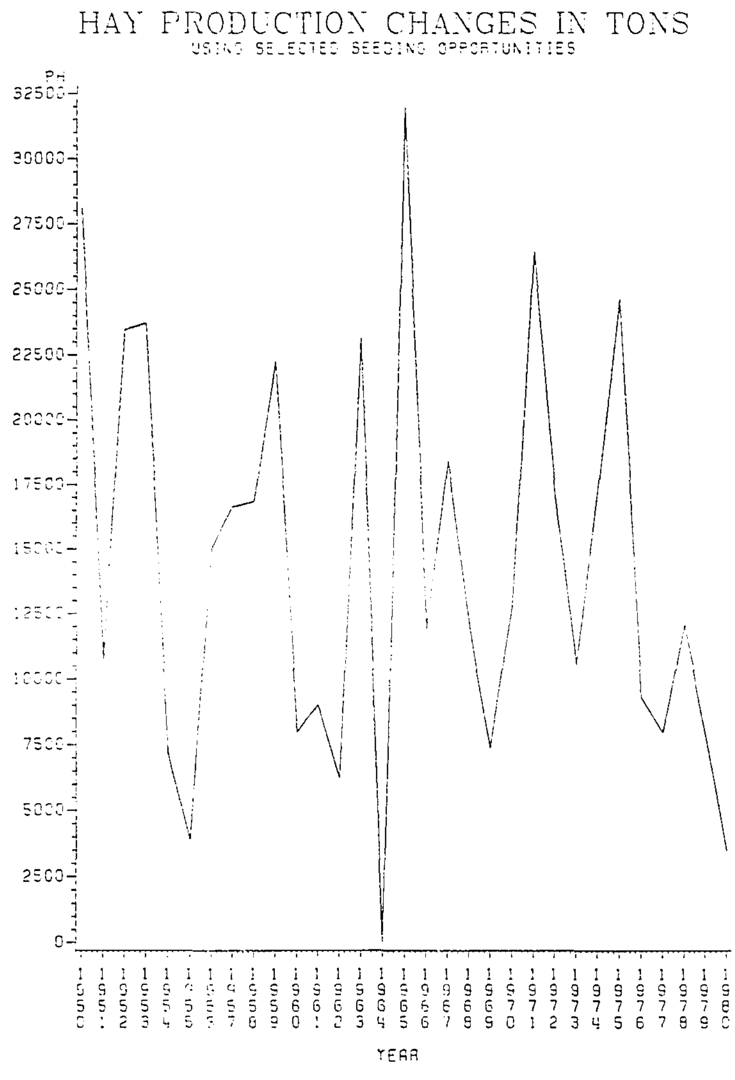

FIGURE VI-25: Hay Production Changes in Tons Using Selected Seeding Opportunities.

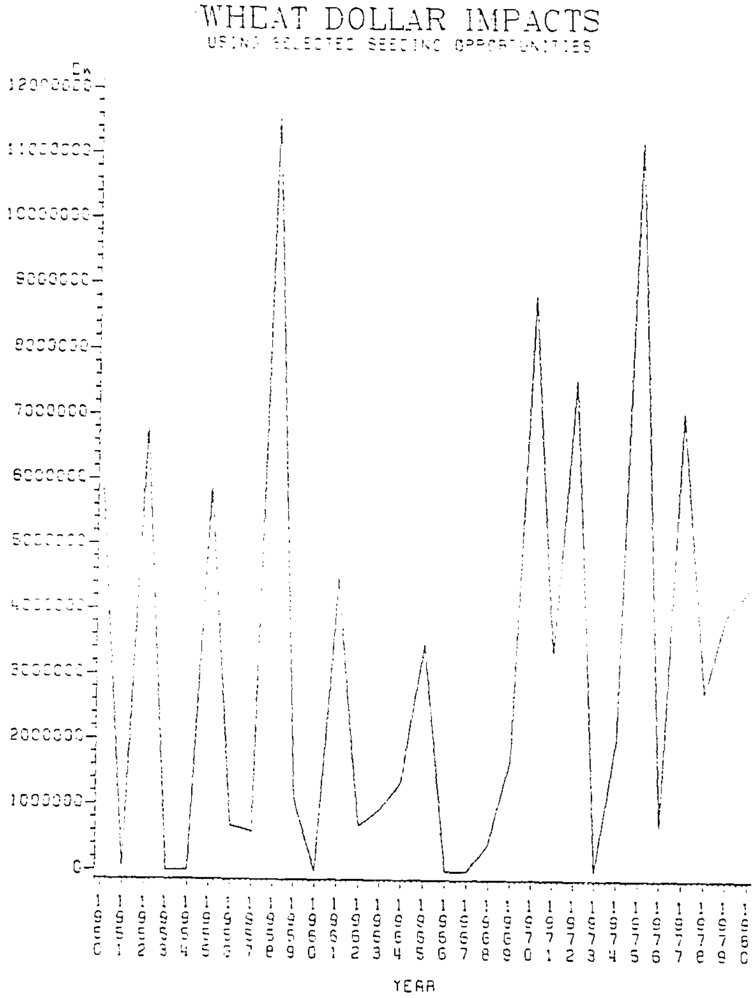

FIGURE VI-26: Wheat Dollar Impacts Using Selected Seeding Opportunities.

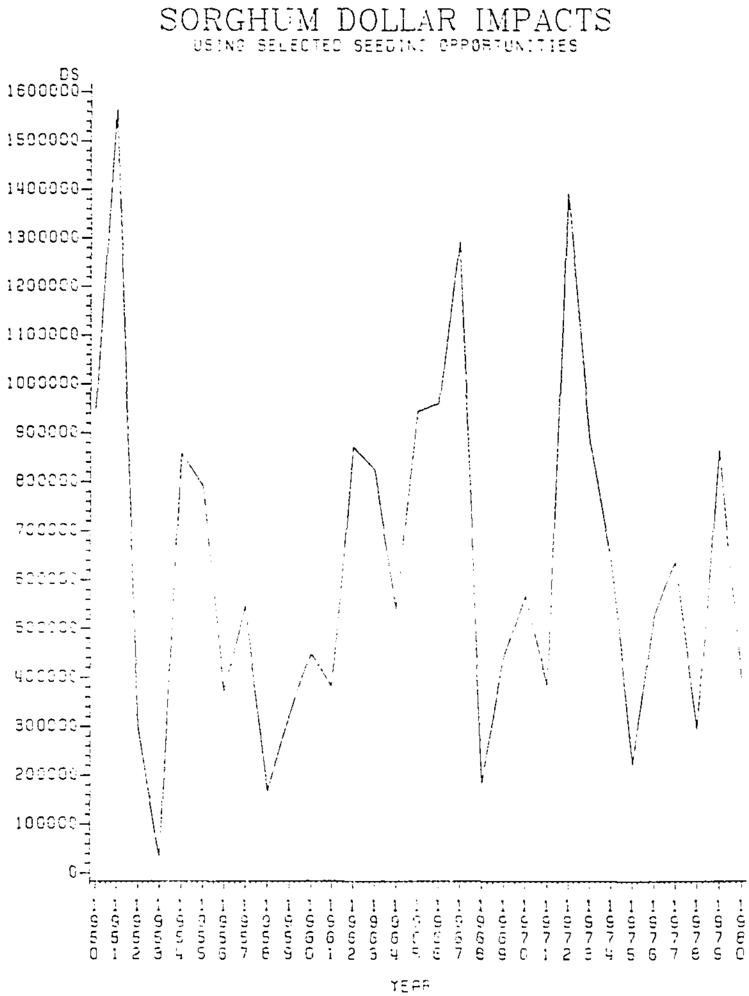

FIGURE VI-27: Sorghum Dollar Impacts Using Selected Seeding Opportunities.

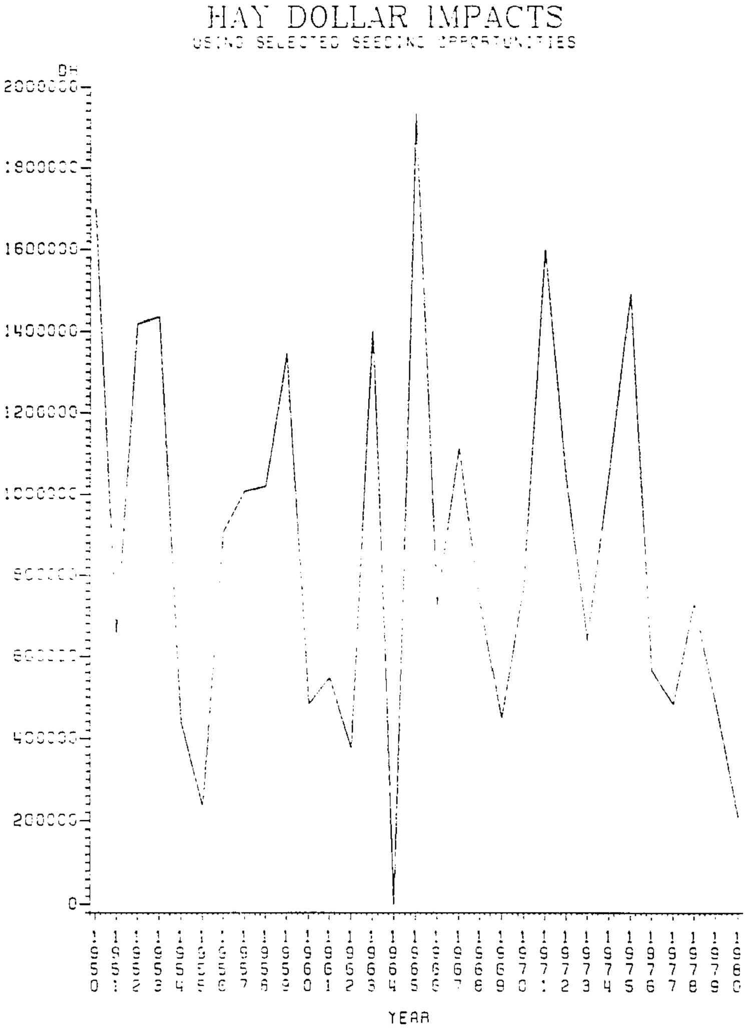

FIGURE VI-28: Hay Dollar Impacts Using Selected Seeding Opportunities.

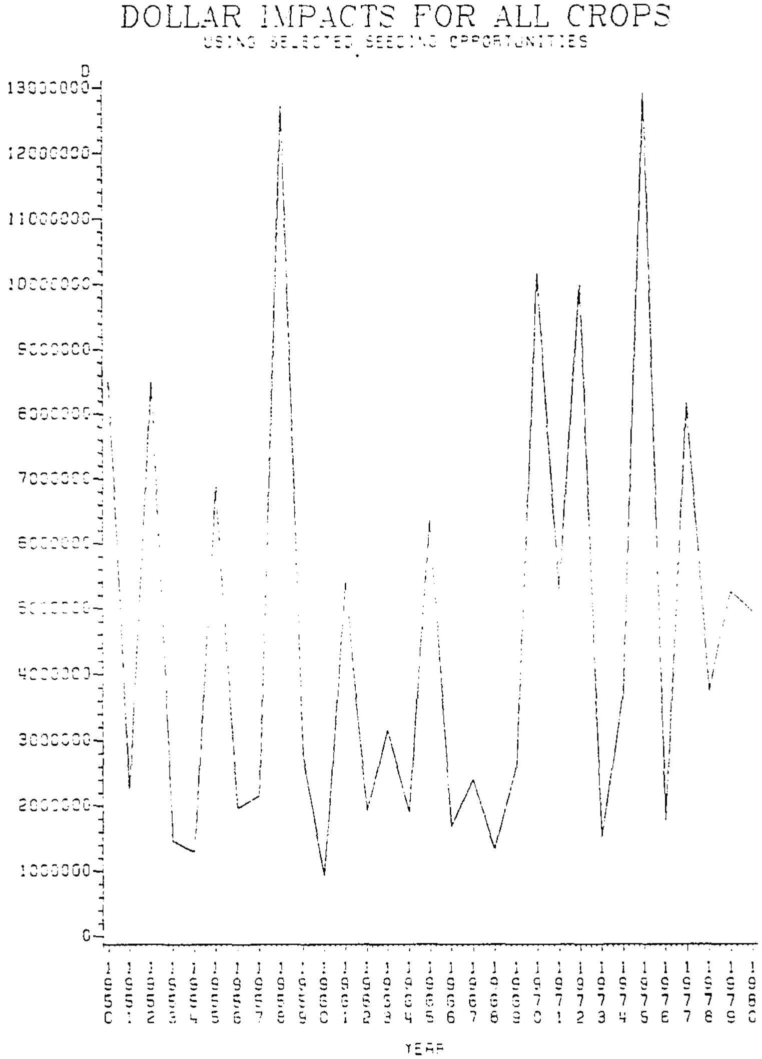

FIGURE VI-29: Dollar Impacts for All Crops Using Selected Seeding Opportunities.

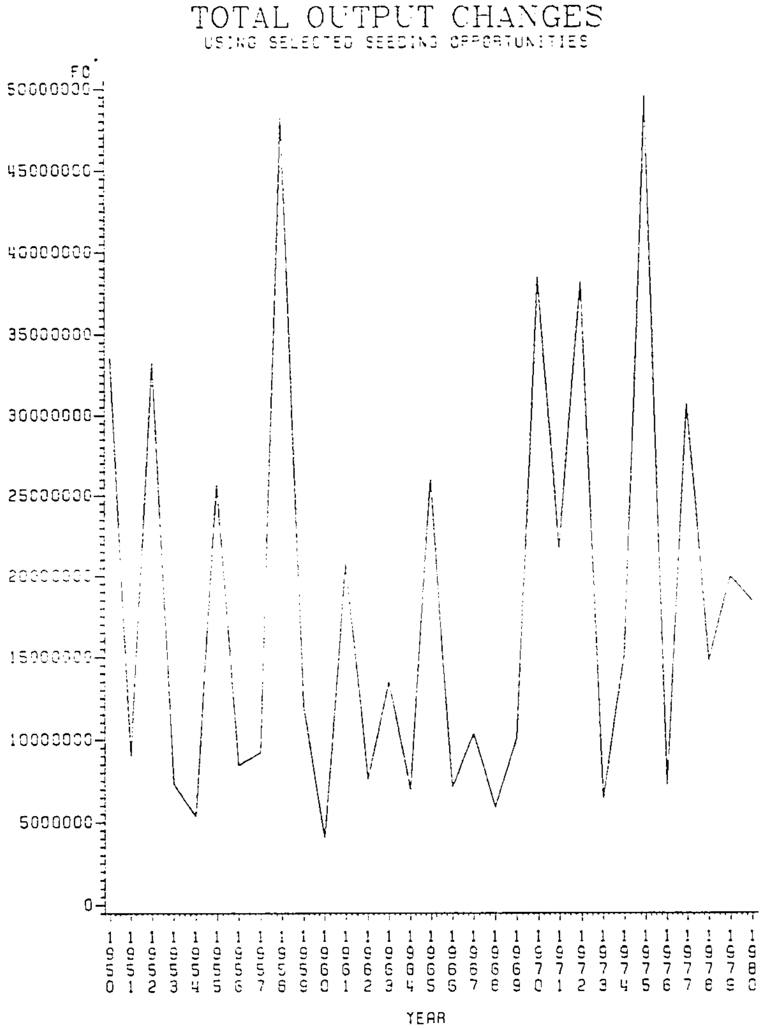

FIGURE VI-30: Total Output Changes Using Selected Seeding Opportunities.

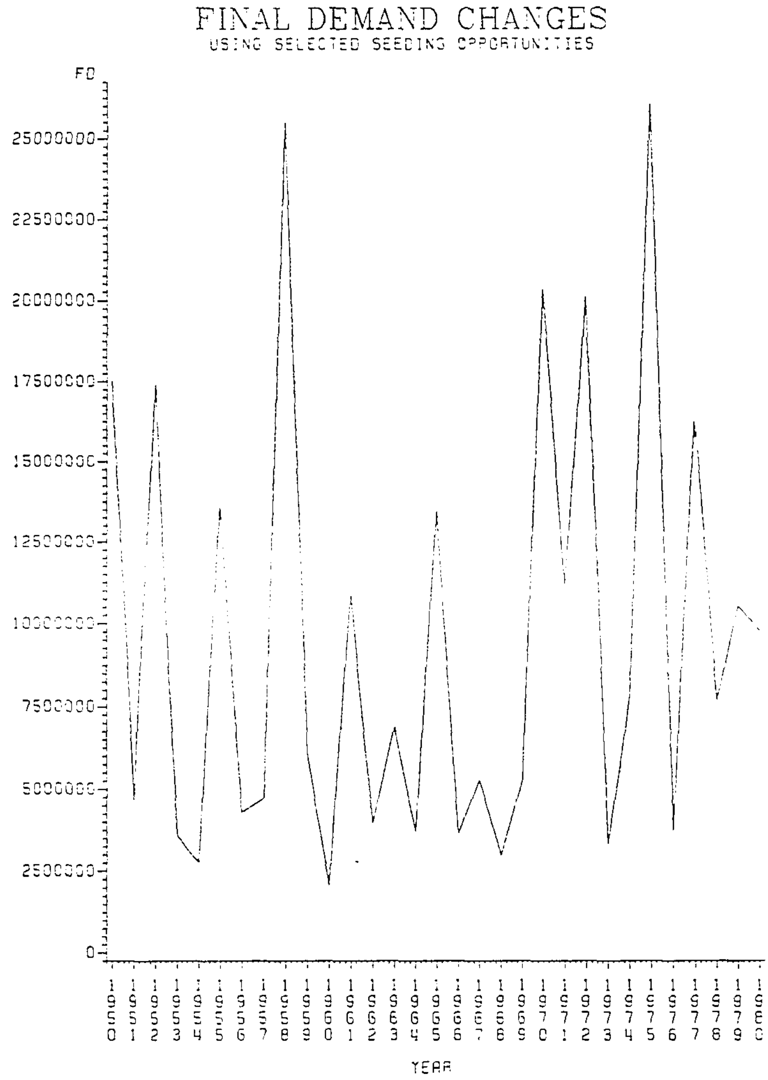

FIGURE VI-31: Final Demand Changes Using Selected Seeding Opportunities.

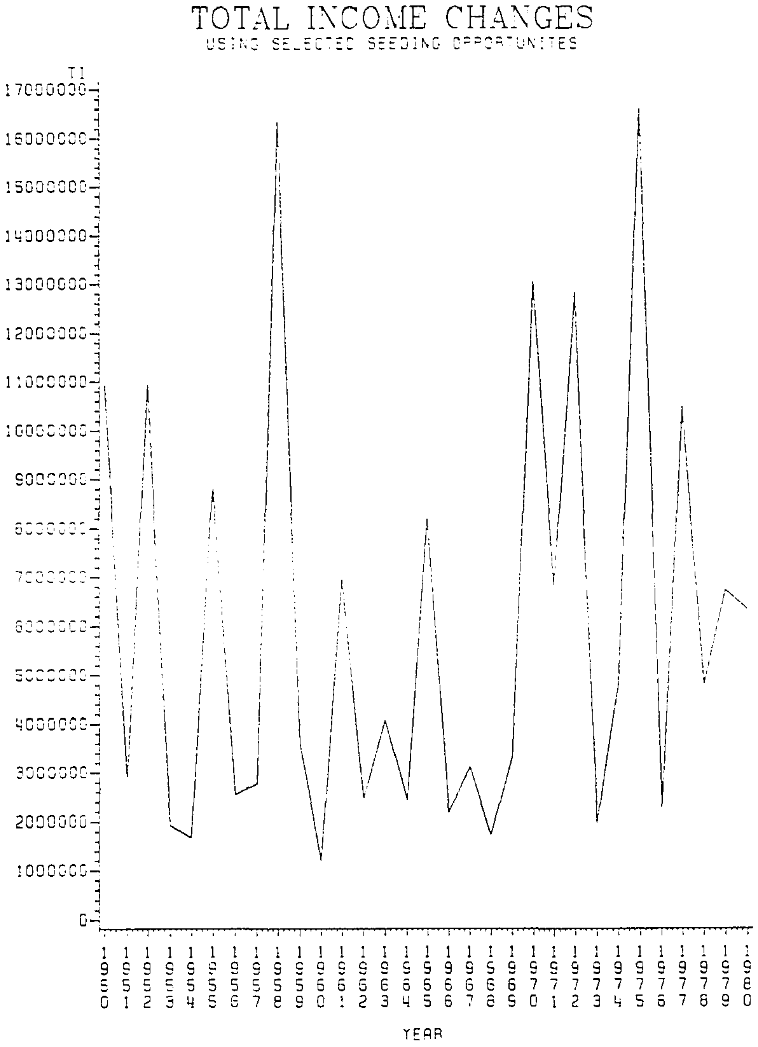

FIGURE VI-32: Total Income Changes Using Selected Seeding Opportunities.

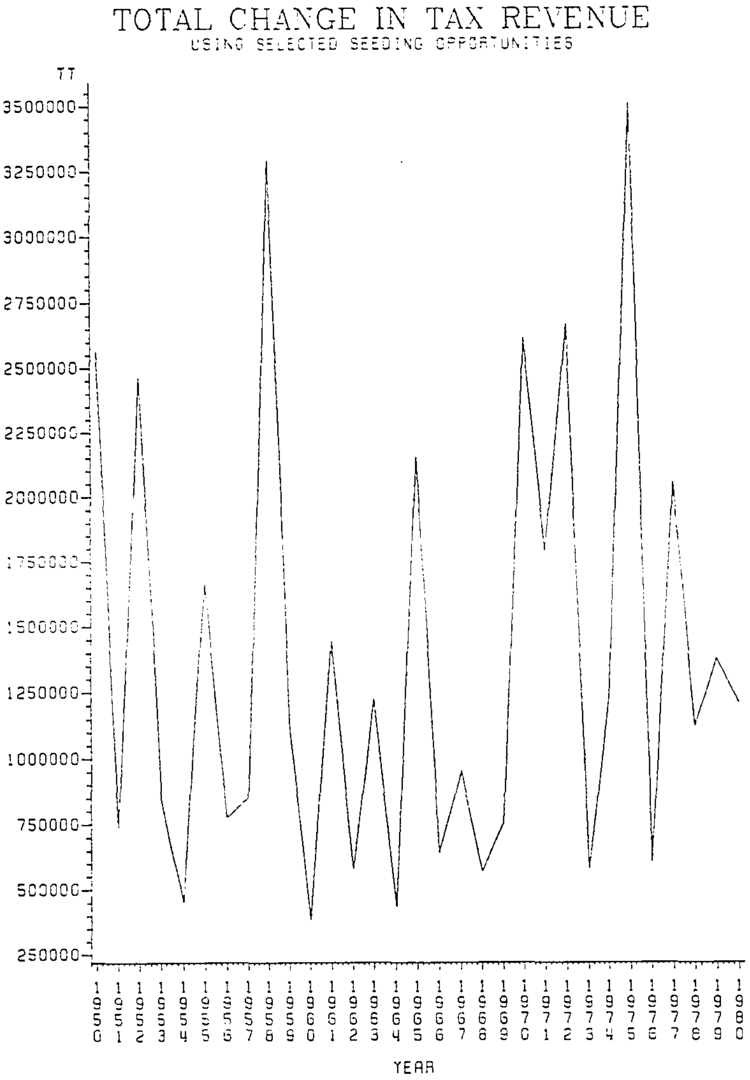

FIGURE VI-33: Total Change in Tax Revenue Using Selected Seeding Opportunities.

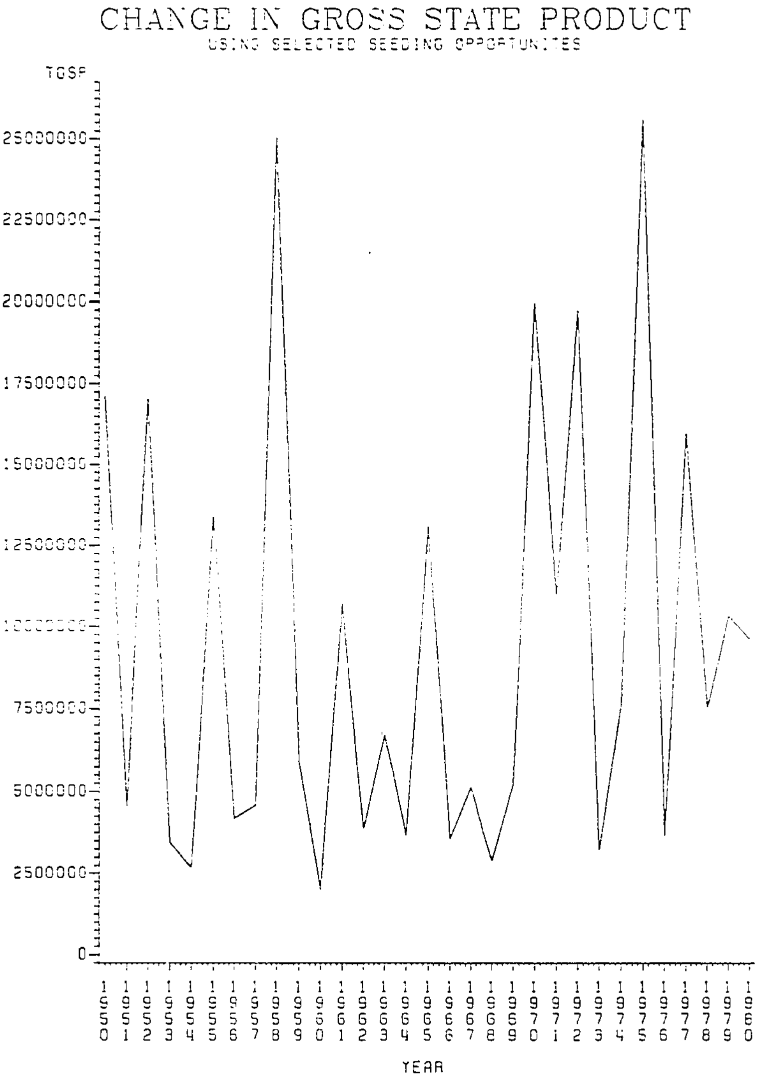

FIGURE VI-34: Change in Gross State Product Using Selected Seeding Opportunities.

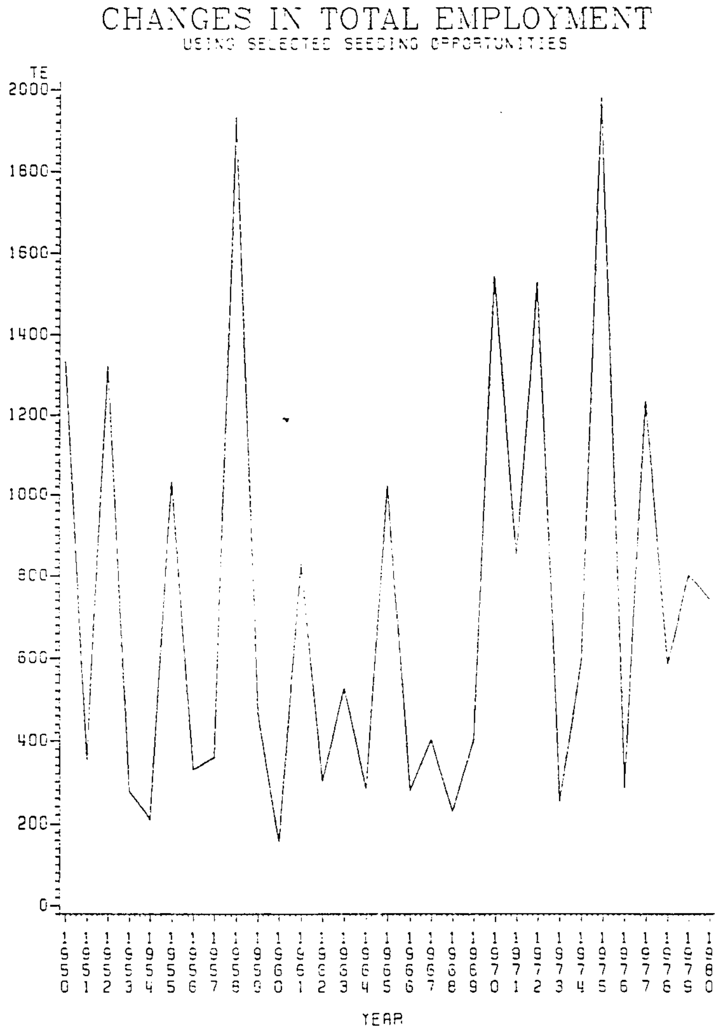

FIGURE VI-35: Changes in Total Employment Using Selected Seeding Opportunities.

CHANGES IN YIELDS

	Wheat (BU/AC)	Sorghum (BU/AC)	Hay (BU/AC)
mean	0.1516	0.5296	0.0081
s.d.	0.1659	0.3090	0.0060
median	0.0800	0.4600	0.0100
maximum	0.5600	1.3100	0.0200
minimum	0.0	0.0300	0.0

CHANGES IN PRODUCTION

	Wheat (BU)	Sorghum (BU)	Hay (BU)
mean	924,301	272,616	14,300
s.d.	1,010,083	159,054	8,188
median	500,932	236,108	12,113
maximum	3,406,342	674,327	31,954
minimum	0.0	14,171	0.0

VALUE OF PRODUCTION CHANGES

	Wheat ($)	Sorghum ($)	Hay ($)	All Crops ($)
mean	3,133,381	632,468	870,397	4,636,246
s.d.	3,424,182	369,004	484,897	3,504,259
median	1,698,160	547,769	732,829	3,158,534
maximum	11,547,500	1,564,438	1,933,208	12,920,589
minimum	0	32,878	0	0

OVERALL ECONOMIC IMPACTS

	Output ($)	Final Demand ($)	Income ($)	Taxation ($)	Gross State Product ($)	Employment (Jobs)
mean	18,229,432	9,523,253	5,965,100	1,377,843	9,323,550	724
s.d.	13,128,433	6,954,035	4,491,925	879,166	6,836,739	527
median	13,497,690	6,889,963	4,090,713	1,122,707	6,697,741	526
maximum	49,548,720	26,071,680	16,591,105	3,505,270	25,580,240	1980
minimum	4,067,765	2,063,651	1,207,037	386,221	2,002,215	158

TABLE VI-7: Summary statistics on production and economic impacts using selected seeding opportunities.

the graphical plots involving dollar amounts are not genuinely "historical." One is simply displaying the estimated responses typical of a current baseline period to a series of climate variations that were derived from an historical time series. Any type of truly historical economic treatment would obviously have to take into account the changing value of the dollar and the agricultural commodities. No such degree of elaboration is presumed in the present treatment.

As might be expected, the select opportunities option increases the positive benefits of the seeding program. For instance, the mean value for the production change value of all crops has increased from just under $4 million to a bit over $4.6 million. About one half this $600,000 increase is attributable to avoiding all seeding during the cotton boll opening period. The remainder is due almost entirely to the avoidance of seeding large rainfall producing events around the wheat planting period. The gain from taking into account the impact of rainfall on specific crops and trying to tailor the program to the types of clouds present is around 15%. This is an appreciable increase and shows the importance of taking into account the economic relevance of a weather modification program instead of pursuing it as an abstract scientific exercise.

Still, when all is said and done, the impact estimates given above do not suggest that weather modification in Oklahoma would be an economic bonanza. The gains are fairly modest. Two issues must be addressed: First, to give an explanation of why the gains are not larger; second, to give at least a preliminary assessment of whether these modest gains would warrant pursuing an actual, operational program.

Examination of Tables VI-2 to VI-5 gives a fairly clear indication of why the gains are modest. The mean increases in precipitation are in the hundredths of inches. This means that the rainfall events involved were themselves generally in the tenths of inches at best. In fact, examination of the raw data would show many occurrences of daily rainfalls at the levels of traces or even none at all. During the critical crop periods in question, therefore, there is ordinarily little natural rainfall and, hence, little potential for inducing large amounts of extra rainfall through cloud seeding. One would expect the gains in precipitation to be modest, and they are.

In addressing the question of whether such modest gains are worth going after, it should be borne in mind that the present analysis is partial. The crop models are not the last word in sophistication. Further research could undoubtedly pinpoint additional significant critical weather variables. Also, only four crops were even considered. As additional crop models become available, the benefits that would be estimated would likely increase. Finally, the range of benefits should eventually be extended to other economic activities. Extra rainfall could help fill stockponds and reservoirs. This could bring benefits to the livestock industry, the tourism and recreation industry, and to cities and towns that use surface impoundments for drinking water supplies. The materials in hand undoubtedly under-estimate the potential benefits of an operational weather modification program. If the present, partial estimates show promise for weather modification, then its promise will likely have been estimated very conservatively.

Obviously, the benefits of cloud seeding should exceed its costs. North Dakota has supported an operational weather modification program for some time, and in recent years, the annual costs of running the program are on the order of $500,000 (Lynn Rose, North Dakota Weather Modification Board, personal communication). The next question is what number to use for the "benefits" in setting up a benefit-to-cost ratio?

Neo-classical economists have developed a variety of ways to adapt abstract principles of economic theory to cost-benefit analysis (see, for instance, Silberberg, 1978, or Henderson and Quandt, 1971). Little of this applied "welfare economics" is directly transferable to the type of economic approach pursued in the present study, centered as it is in input-output modeling. Input-output analysis lacks the theoretical gloss of welfare economics, but has been applied in a number of states, particularly in Texas (see H. Grubb, 1980) to help clarify whether a project is economically promising or an economic boondoggle. The key to using input-output analysis to such an end is to keep in mind who is paying for the project and to get some feeling that the beneficiaries far outnumber the parties that could be adversely affected.

An operational weather modification project in Oklahoma would likely be paid for either by the government (the state perhaps with some federal assistance) or local taxpayers. In the present example, one would want the farmers and the government to benefit and for no other parties to show major detriments. The preceding analysis shows that on the average, the general populace always gains from cloud seeding. More jobs are created, more income is generated, and more final demand, output, and gross state product accrues. If the program is properly targeted, e.g., to avoid seeding during the cotton boll opening period, the farmers always benefit on the average. The government also shows returns in the form of extra taxes.

In the select opportunity case outlined previously, the direct benefits to farmers were, on the average, around $4.6 million. The government gained nearly $1.4 million in extra taxation on the average. For a $500,000 program, the benefit-to-cost ratios would be around 9.2/1 and 2.8/1 respectively. On this basis, weather modification would appear to be an option well worth considering. The total gains are not gigantic, but relative to the costs of achieving them, they are appreciable. Careful controls must be kept, however, on the sophistication of the program. If made too elaborate, the favorable benefit-to-cost ratios could easily evaporate. The program would also need to be scheduled to guarantee that seeding was being carried out at times and places likely to produce positive economic impacts. Ongoing work on improved crop yield models, overall economic modeling, and basic climatology would be warranted to maximize the gains. Once again, though, the costs of this background research should be kept in check.

This chapter is the first to apply the input-output assessment techniques to a practical, real-world problem. The next several chapters will consider other climate-sensitive applications. In these chapters, as in the present one, a major goal will be to ascertain whether the costs of using climatological principles, techniques, and information can lead to appreciable (even if modest) pay-offs.

CHAPTER VII

THE ECONOMIC IMPLICATIONS OF A CLIMATE CONSCIOUS IRRIGATION SCHEDULING

In Chapter III, three major types of "models" were introduced (Models I, II, and III) representing variants on the conventional input-output model. Various combinations of the features of these three model types were then used in Chapter IV to define five types of situations (Types I, II, III, IV, and V). The situations or scenarios associated with Types I, II, and III were used in the two previous chapters. Scenario Type IV was defined as follows:

> Estimates are supplied on changes in input purchases and total value of production by the crop agriculture sector associated with climate-conscious irrigation scheduling. Indirect changes in economic activity are then estimated using Model I techniques.

The idea here is that using climatological information to gage when to irrigate and how much to irrigate can save the farmer money, especially in the pumping costs required to draw water from a well or distribute it over his fields. The level of crop production may stay the same, but the farmer has derived extra income which he can then spend on various categories of final demands. This extra money for household consumption final demand, however, comes from a decline in the agricultural crop sector's demand for the output of the utility sector. In this situation, the overall economic impacts are the combination of a gain for one sector and a loss for another. Within the logic of Model I, these gains and losses both translate into "demands" on the rest of the economy.

Table VII-1 gives a set of multipliers for a one dollar savings by the agricultural farm sector in purchases from the utility sector. Impacts on total taxation and employment were practically nil, so multipliers are not presented for these impacts.

Category	Multiplier
Output	-0.59
Final Demand	1.13
Income	0.90
GSP	1.12

TABLE VII-1: Aggregate impacts for a $1 savings in crop sector utility demand.

To implement these input-output results, an estimate is needed of the savings possible from irrigation scheduling. This would be a substantial study in itself. Luckily, the groundwork has been largely laid in two studies, one by Kenyla, *et al.* (1970) dealing with the Big Spring-Snyder area of Texas, and by Slogget (1979), a U.S.D.A. study dealing with energy use in U.S. irrigation agriculture. These reports, and the research they cite, lead the present author to assume that a 20% reduction in water use is possible from irrigation scheduling.

The next problem is to estimate how much water was actually used for irrigation in Oklahoma in the period around 1980. Background information was obtained from the publication *Reported Water Use in*

Oklahoma (Oklahoma Water Resources Board, 1980) and the 1977 and 1978 Irrigation Survey of Oklahoma (Schwab, n.d.) assembled at Oklahoma State University Extension Service. Examination of these documents and conversations with the researchers that had assembled them revealed that the reported figures are very crude estimates. Irrigation use is almost definitely underestimated, but by how much is impossible to say. The O.S.U. Irrigation Survey indicates that the predominant delivery system in Oklahoma is a sprinkler-irrigation pumping technology using groundwater. This technology requires more energy than other systems, but it is felt that a somewhat liberal estimate of pumping costs will be balanced out by the conservative nature of published water use statistics.

In the Texas study (Kenyla, et al., 1979) pumping energy requirements were made for electric power pumps in a sprinkler system for a lift of approximately 200 feet. Sloggett (1979) pegs the mean pumping lift for Oklahoma at around 200 feet. The following figure, then, is deemed appropriate for Oklahoma:

Pumping Energy Requirement = 51.92 kwh/acre-inch.

For the baseline period selected, electricity costs in the Texas-Oklahoma region were about 3.5¢ per kwh. Twenty percent of the reported groundwater use level by irrigated agriculture in Oklahoma around 1980 was about 208,126 acre-feet. If electricity were the sole source of the pumping energy, this would mean that irrigation scheduling techniques could likely save about 1.2967×10^8 kwh of electricity with a total value of some $4,538,478.80.

A complication emerges since only 20% of the pumping in Oklahoma is accomplished using electricity, the remaining 80% utilizing natural gas or similar fossil fuels. In the study by Slogget (1979), though, it is shown that the costs of natural gas fueled pumping is approximately one-half that of using electricity. From this, one can weight the cost figure given above. If the figure above is labeled CE, then an estimate of the actual cost, C, is:

$$C = 0.2 * CE + 0.8 * (CE/2)$$

or

$$C = 0.6 * CE$$

The resulting estimate for energy savings for Oklahoma, then, is $2,723,087.30.

Using the multipliers in Table VII-1 above, the overall economic effects resulting from this savings in crop sector purchases from the utility sector can be estimated. These figures are summarized in Table VII-2.

Aggregate	Impact
Output	-$1,606,621.50
Final Demand	$3,077,088.60
Income	$2,450,778.60
GSP	$3,415,840.70

TABLE VII-2: Aggregate Impacts from Crop Sector Energy Savings.

These results give mixed signals. The impacts on final demand and GSP are favorable. The impact on income looks favorable at first sight, but the picture changes when it is recalled that $2.7 million of this involves the extra income to the farm sector. This means that wage earners in other sectors are actually losing $272,308.72 in income. The impact on output is definitely negative due primarily to the negative impact on the utility sector and the ripple effects of this through the rest of the economy. Farmers are definitely the major beneficiaries while the utility industry suffers and wage earners in other sectors face at least modest sacrifices.

The negative impacts would disappear if it could be assumed that the utility industry could easily find alternative markets, either in other states or in urban/industrial markets within the state. If the savings in irrigation water also led to sizable increases in crop production, these extra gains could further help erase the negative impacts. The first alternative is not out of the question provided the current economic slump is arrested and a new phase of growth provides the necessary non-agricultural markets. The second alternative seems unlikely; it is probably enough to hope that current levels of crop production could be maintained.

It seems inevitable, though, that in the future farmers will try to cut back on the energy-intensive use of irrigation water. The alternative would be to abandon high productivity irrigation farming altogether and revert entirely to less productive dryland farming. The economic losses in this eventually would be enormous. For governmental policy makers, then, it would seem that irrigation scheduling and other water-conserving practices should be promoted even if there are some economic drawbacks; the alternative would entail even greater drawbacks.

Putting irrigation scheduling into practice is in part a matter of technology but is largely a matter of using information on local climatology, soil types, and crop responses to decide when and how much to irrigate. Governmental agencies could justifiably be expected to help provide pertinent information and general suggestions on how to use it. Since the farmers would be the primary beneficiaries, the ultimate responsibility for turning this information to good use must rest with them.

The present modeling results give no strong indications as to the exact level of appropriate governmental support. A major, multimillion dollar effort does not seem justified, but some investment, at least to the tune of $100,000 per year or so would seem warranted, if nothing else to ward off the possibility of a precipitous decline in irrigation farming. The most pleasant types of economic analyses are those that show ways to make everybody a winner. The present analysis is more akin to game theory, where the goal may simply be to minimize one's losses. Learning how to absorb minor losses instead of being overwhelmed by a major calamity, though, is still well worth the effort. Such knowledge is simply harder to sell.

CHAPTER VIII

THE ECONOMIC IMPLICATIONS OF ENERGY SAVINGS THROUGH HOUSE RETROFITTING AND EXTRA ENERGY DEMANDS FROM CLIMATIC VARIABILITY

This chapter will use the input-output approach defined in Chapter III as "Model III" to a situation outlined in Chapter IV as "Type V." The scenarios this model variant can handle were summarized as follows:

> Estimates are supplied on changes in consumer final demand spending associated with climate-sensitive changes in utility final demand. Estimates of economy-wide impacts are made using the techniques of Model III.

The idea here is that home retrofitting will decrease the money households pay to the utility sector for space heating or cooling. They can then spend these savings for other categories of final demand. The input-output household coefficients are used to estimate these shifts in spending. The savings in utility bills are apportioned over the remaining final demand spending categories using the household coefficients as weights. This process will need to be repeated in an iterative fashion since the coefficients used do not sum to unity and some residual will be left over. The residuals are successively reallocated until the final residual is insignificant (a cut-off point of 0.1¢ was used). The decrease in utility sector demand plus the estimated patterns of spending on the other sectors is then taken as the driving vector of demands on the economy in Model III. Table VIII-1 gives a set of multipliers associated with a $1 decrease in consumer final demand for utility sector output. The employment multiplier was practically nil and is not presented.

Aggregate	Multiplier
Output	-0.07
Final Demand	0.38
Income	0.12
Taxation	0.05
GSP *	0.34

TABLE VIII-1: Multipliers for a $1 decrease in utility final demand.
*Gross State Product (G.S.P.) ≡ Final Demand - Imports

The small size of the multipliers and the negative impact on total output show that as in the irrigation scheduling scenario explored in the previous chapter, this situation is a composite balance between negative impacts for some sectors and positive impacts for others. Since most of the impacts are positive, retrofitting looks much more promising. As will be seen, the real challenge is not so much in making a case that retrofitting serves the general good as in convincing individual homeowners that it is worth the initial investment.

While the major thrust of this chapter focuses on the economic implications of a purposeful human adaptation in the face of climatic factors, it should be borne in mind that very similar techniques can be used to estimate the economic impacts of actual climatic variations. To underscore this point, a brief example will be presented, that seeks to estimate the magnitude of the economic impacts for Oklahoma stemming from the substantial increase in residential natural gas consumption for space heating during the extremely cold winter conditions of December, 1983.

The first step is to derive estimates of the increase in natural gas use associated with December, 1983 climatic departures from normal. NOAA's Assessment and Information Services Center branch in Columbia, Missouri has developed statistical regression models which, among other things, relate gas use to a heating degree day variable (using a 65° F base). The techniques used and the actual operational model are described in Warren and LeDuc (1981) and in manuscript materials kindly supplied to the author by Dr. S. LeDuc. These modeling techniques are currently being used to supply estimates of regional and national level climate impacts to NOAA and other federal agencies. Work is ongoing to develop disaggregation schemes to produce estimates for smaller geographic areas (e.g., states or Climate Reporting Districts). The present discussion will adapt the available materials to yield an estimate for Oklahoma for December, 1983.

The NOAA/AISC researchers estimate that each 1,000 HDD's induce some 20.389 million BTU's of natural gas consumption per residential natural gas customer. The climatological HDD norm for December in Oklahoma is 747 HDD's; the December, 1983 figure was 1,144 HDD's (information kindly supplied by Dr. S. LeDuc). The 1983 figure is slightly better than 150% of the norm. The difference between these two figures of 397 HDD's leads to an estimated extra natural gas consumption in Oklahoma of some 8.1 million BTU's per customer. Consultation with staff at the Oklahoma Corporation Commission, which regulates natural gas prices to consumers in Oklahoma, suggested that a reasonable price figure *circa* 1983 would be $6/million BTU's. The dollar impact, then, can be estimated at about $48.54 per customer. Information supplied by Ellen Cooter of the Oklahoma Climatological Survey indicates that *circa* 1983 there were about 746,100 residential natural gas customers in the state. The estimated direct impact for the state as a whole, then, is $36,215,694 for the month of December, 1983.

This extra spending on gas utility bills was likely counterbalanced by reduced spending on other final demand categories. Granted this assumption, input-output techniques can be applied to estimate the overall economic impacts. In Table VIII-1 above, input-output multipliers were presented for a case where *decreases* in utility spending were then redirected to increased final demand for the output of other sectors. For the case in hand, the positive or negative sense of the multipliers would be reversed. This leads to the following results for changes in various economic aggregate measures:

1) Output change: $ 2,535,098.60
2) Final demand change: (-)$13,761,964.00
3) Income change: (-)$ 4,345,883.30
4) Taxation change: (-)$ 1,810,784.70
5) GSP change: (-)$12,313,336.00

These results are very interesting indeed. The overall implication is that an exceptionally cold winter has negative impacts on the Oklahoma economy; however, the initial size of the direct impact (some $40 million) is significantly reduced (e.g., the income impact is under

$5 million). This emphasizes the importance of trying to capture the total economic picture. When a climatic variation can lead to increases in demand for some sectors and decreases for others, a tool like input-output analysis is very helpful in estimating the net effects. The clear implication is that a very bad winter can have overall bad economic effects; but a moderately adverse winter might lead to overall impacts that are very minor. With these points in mind, the discussion will now return to the primary topic of evaluating the effects of residential retrofitting.

Developing a direct impacts "model" for relating retrofitting practices to changes in utility demand will occupy the next few sections. Since one is talking about a phenomenon not well reflected in historical data sets assembled by governments or utility industries, the only feasible approach seemed to be to estimate statewide impacts from extrapolations from an engineering-oriented building load model. A vast array of such models either exist or are becoming available. Their common denominator is the use of basic thermodynamical principles to assess the energy-flux properties of the components that make up a building. A house is dissected into its ceiling, roof, floor, walls, doors, and windows. Heating or cooling loads are determined for all these components depending on the temperature gradients between the interior and exterior. These component loads are then aggregated to assess the properties of the whole structure.

Available models differ widely in their sophistication. At one extreme are such models as the NBSLD model (Kusuda, 1976), which can be used to examine design features on structures up to the size of skyscrapers while taking into account environmental inputs ranging from temperatures to solar radiation. At the other extreme are techniques such as those developed by ASHRAE (1979), which require only temperature data and, being geared to hand calculation, are aimed primarily at assessments of single-family houses. For present purposes, the ASHRAE techniques more than suffice.

Nearly all these building models were created with the primary goal of designing a structure for comfort under the extremes of local climatological conditions. A set of structural components is specified. These are then subjected to extreme exterior environmental stresses, and the adequacy of the overall structure is assessed in terms of maintaining a desirable interior "climate." As used by architects, then, one may only be interested in running a set of calculations for a region's extreme summer or winter conditions. This is one reason that many existing models can afford to be so complex; analyses will only be performed for sets of seasonal extremes. The same models could equally well be turned to analyzing a structure's performance under actual or simulated climatic conditions over a period of time. Such an application obviously increases the number of rounds of calculations enormously. Even when the model is computerized, the burden of calculation may become prohibitive for highly sophisticated models. The relative simplicity of the ASHRAE techniques helps reduce the computational load, but even here, if the minimal time period of interest is reduced to the level of hours, days, or even weeks, the task can still become onerous. This handicap is magnified since the ASHRAE techniques do not readily lend themselves to computer algorithms, especially for the cooling load calculations. To reduce the computational load, certain rather stringent simplifying assumptions will be made.

For each month of the year, a long-term daily average temperature is selected (drawing on data used by the Oklahoma Climatological Survey in the preparation of their Monthly Climate Summary), for Oklahoma City, which is assumed to be representative of the state as a whole. Given a range of desired internal temperatures, these representative monthly external temperatures are used to calculate the interior/exterior temperature gradients required as environmental inputs to the model. This information is then used to estimate a set of up to 12 daily heating or cooling loads. Each load is then distributed over its associated month to derive monthly load estimates. These monthly loads (in BTU's) are then converted to kwh's (an all electric house is assumed). The kwh's are then given a dollar value (at 4¢ per kwh). From this an estimate can be made of the annual utility bill for space conditioning. The utility bills for different structures and different interior comfort conditions can then be compared. This is obviously a simple approach, but it provides, if anything, a conservative under-estimation of the total utility bills. In the examples that follow, the author was quite satisfied if the impacts are estimated as conservative lower limits. If clear policy implications result, then these implications would only be reinforced by more precise figures.

This basic calculation approach will be applied to a set of likely structural and behavioral modifications. Drawing on suggestions from E. Cooter (personal communication), a house plan was developed felt to be fairly typical of existing, older housing. Retrofitting improvements were then developed that would bring the "old house" up to the level of most newly constructed homes or homes that have been adequately retrofitted. The behavioral options involve sets of interior temperature levels (or thermostat settings) for the heating and cooling seasons. The less well constructed house is called the Old House; the other structure the New House. The acronym HS is used for the heating season, CS for the cooling season. The options studied are summarized in Table VIII-2. A formal description of the structural components of the old and new houses, along with other information needed to implement the ASHRAE model is given in an Appendix.

The differences in the two structures involve levels of ceiling insulation and whether the windows are single or double glazed. The differences between actual old and new housing would probably be even more pronounced, extending to the wall insulation as well. Once again, this leads to a conservative estimation of the differences in the two

STRUCTURAL OPTIONS

	Old House interior temperature (°F)		New House interior temperature (°F)	
Behavioral Options	HS	CS	HS	CS
	72	72	72	72
	65	72	65	72
	72	78	72	78
	65	78	65	78

TABLE VIII-2: Structural and behavioral options considered.

	Comparison	Savings (or Loss)
1.	d-A	-$340.58
2.	d-B	-$167.23
3.	c-A	-$128.73
4.	d-C	-$101.81
5.	b-A	-$ 56.02
6.	c-B	$ 44.62
7.	B-c	$ 65.42
8.	b-c	$ 72.71
9.	d-D	$101.52
10.	c-C	$110.04
11.	b-B	$117.33
12.	a-A	$155.72
13.	A-B	$173.35
14.	b-C	$182.72
15.	C-D	$203.33
16.	a-b	$211.74
17.	c-d	$211.85
18.	A-C	$238.77
19.	B-D	$268.75
20.	a-c	$284.42
21.	b-d	$284.56
22.	c-D	$313.37
23.	a-B	$329.07
24.	b-D	$385.08
25.	a-C	$394.49
26.	A-D	$442.10
27.	a-d	$496.30
28.	a-D	$597.82

TABLE VIII-3: Comparison of space conditioning savings or losses.

structures. It does capture, though, types of retrofitting practices that are the most easy to accomplish, would make the most notable improvements, and are likely within the cost constraints of a larger number of homeowners.

Both structures are less complete houses than house shells. The focus is less on describing real, finished structures than on isolating salient components and considering the <u>differences</u> in performance. This allows the ready assessment of the value of the structural improvements subject to an overlay of various behavioral options. The results for the annual spacing conditioning bills for all the options outlined in Table VIII-2 are summarized in Table VIII-3. Each option is given a letter code (e.g., a-d or A-D) for future reference.

From Table VIII-3, one can derive a set of 28 cost differentials (e.g., a-A, a-B, etc.). These differences are summarized in Table VIII-4.

The most salient feature that emerges from these cost differentials is that structural improvements in and of themselves do not automatically guarantee savings in one's utility bills. For instance, if one were living in an Old House and had adapted to a HS interior temperature of 65°F and a CS interior temperature of 78°F, then retrofitted the house but switched to a year round interior temperature of 72°F, one would not save money; one would in fact lost some $340 per year (see comparison #1 (d-A) in Table VIII-3). Clearly, behavioral patterns have an enormous impact on the success or failure of a retrofitting strategy. Consideration of a few other select comparisons underscores this conclusion.

STRUCTURAL OPTIONS

Behavioral Options	Old House		New House	
	HS	CS	HS	CS
	72	72	72	72
	$1,370.73 (a)		$1,215.01 (A)	
	HS	CS	HS	CS
	65	72	65	72
	$1,158.99 (b)		$1,041.66 (B)	
	HS	CS	HS	CS
	72	78	72	78
	$1,086.28 (c)		$ 976.24 (C)	
	HS	CS	HS	CS
	65	78	65	78
	$ 874.43 (d)		$ 772.91 (D)	

TABLE VIII-4: Estimated annual space conditioning costs for Old House vs. New House.

For instance, assume a family in an Old House had adapted to one of the four HS/CS options. If their adaptation were HS 72°F and CS 72°F and they retrofitted their house to New House criteria, their savings would be $155.72 (comparison #12 (a-A) in Table VIII-3). For HS 65°F and CS 72°F, a similar structural change would save $117.33 (comparison #11 (b-B) in Table VIII-3). For HS 72°F and CS 78°F, the savings would be $110.04 (comparison #10 (c-C) in Table VIII-3). For HS 65°F and CS 78°F, the savings would be only $101.52 (comparison #9 (d-D) in Table VIII-3).

Similarly, if a family in an Old House simply adjusted their interior temperatures from 72°F year round to HS 65°F and CS 78°F, they would save $496.30 (comparison #27 (a-d) in Table VIII-3). The same adjustment in a New House would save $442.10 (comparison #26 (A-D) in Table VIII-3). The only other strategies that would save more money than the latter two would be a savings of $597.82 for a family living in an Old House that had kept interior temperatures at 72°F year round retrofitting their home and changing their interior temperature requirements to HS 65° and CS 78° (see comparison #28 (a-D) in Table VIII-3).

These factors have an enormous bearing both for the task of promoting a retrofitting program and in assessing its overall economic impacts. Promoting structural modifications without at the same time stressing the implications of behavioral adaptations could easily turn such a program into an economic liability. For purposes of the overall economic analysis, two strategies will be highlighted. In both cases, it will be assumed that initially one is dealing with families in old houses that maintain year round interior conditions at 72°F. In the first strategy, assume that the behavior remained the same while the families retrofitted their homes, adding storm windows and extra ceiling insulation to bring their structure up to New House standards. The annual savings in utility bills would be $155.72 (comparison #12 (a-A) in Table VIII-3). In the second strategy, the same structural modifications are assumed, but the family now adjusts their interior comfort requirements to HS 65°F and CS 78°F. The annual savings in this case would be $597.82 (comparison #28 (a-D) in Table VIII-3).

The first strategy results in a savings of 11.36% in annual utility expenses. The second strategy results in an annual savings of

43.61%. If these savings levels, arguably typical for housing in the central Oklahoma area can also be assumed to be typical, on balance, for all of Oklahoma, then a rough estimate can be made of the changes in statewide residential utility purchases. It should be noted that the estimates to this point have almost definitely been on the conservative side. This is because the simplicity of the modeling approach does not take into account diurnal temperature changes during the spring and fall months. Minor space conditioning needs were predicted for these periods, making the annual estimates conservative. In extrapolating the results for a single model structure to the entire state, a measure of liberalism must be introduced. This is because the author has been unable to find any reliable statistics on the relative percentages of less well insulated versus adequately insulated housing in the state. The Census Bureau keeps fairly careful tabs on things like the prevalence of indoor toilets but no one seems to be gathering comprehensive statistics on the thermal properties of homes throughout the state. Most of the housing built before the mid-1970's, however, lacked the insulation features now included routinely in new homes. Most of Oklahoma's existing residences, therefore, could stand some retrofitting improvements to bring them up to current standards. Consequently, the two potential savings of 11.36% and 43.61% will be taken as a feasible statewide goal. This is a liberal estimate, but the underlying conservatism of the model house comparisons, it is felt, should adequately cooperate.

Using historical statistics from the Oklahoma Statistical Abstract (C.E.M.R., 1980), total residential electric utility sales for 1977 (the most current year for which such figures are available at the time of writing) were 10,300,000,000 kwh. At a price of 4¢ per kwh, this would amount to $412,000,000. A savings of 11.36% would be $46,803,200; a savings of 43.61% would be $179,673,200. Obviously, people use fuels like natural gas, especially for space heating in the winter. Potential savings here will be ignored. It is hoped that this will further temper the liberalism of the following estimates of overall economic impacts.

Under the assumptions outlined above, the information is now in hand to use the multipliers given in Table VIII-1 to derive estimates of the overall economic impacts of (a), an 11.36% savings in residential utility bills and (b), a 43.61% savings in utility bills. These estimates are summarized in Table VIII-5.

On balance, if such changes could be effected, either strategy would benefit the state's economy. Especially encouraging are the increases of several millions of dollars to income and taxation. These results assume, of course, that the changes involved in the two retrofitting strategies have somehow been put in place. To do this would require individual households making the initial investments. To achieve this, the per household savings become a far more important inducement than the general economic benefits.

Conversations with several local building construction and home improvement firms in the metropolitan Oklahoma City area indicate that the per house cost, including materials and labor necessary to upgrade the Old House to the New House standards, would be at least $1,000. While not an enormous amount of money, it is fairly obvious

Impact	(a) For 11.36% Savings	(b) For 43.61% Savings
Utility savings	$46,803,200	$179,673,200
Output	-$ 3,276,224	-$ 12,577,124
Final demand	$17,785,216	$ 68,275,816
Income	$ 5,616,384	$ 21,560,784
Taxation	$ 2,340,160	$ 8,983,666
GSP	$15,913,088	$ 61,088,888

TABLE VIII-5: Economic impacts for two levels of savings in residential utility bills.

that promoting a retrofitting strategy would be relatively easy if the annual per residence savings were $597.82 as opposed to only $155.72. For the higher figure, the homeowner could expect to recoup his investment in less than two years. For the lower figure, the recovery period would stretch out to five years or so.

This has a number of interesting implications, both for the householder and for government policy makers. The householder needs to be made aware of the importance of combining structural improvements with behavioral adaptations. If the government is truly interested in promoting a successful retrofitting program, it would seem to have a vested interest in spelling out these implications to the public as forcefully as possible. Especially if the government moves, as it has in recent years at the Federal level, to encourage retrofitting through tax incentives, a public information effort should be mounted to emphasize the vital role that simple adaptations like turning back the thermostat can play in making retrofitting an economically efficient venture.

The results of the input-output analysis also indicate that, from the viewpoint of government, total public involvement for retrofitting programs in a state like Oklahoma is not warranted beyond an annual expenditure in the range of a few million dollars. This would suggest that the government's main responsibility should be an informational one. A mass of Federal booklets released through the Superintendent of Documents from the Department of Energy move in this direction. Still, since the D.O.E. has no local offices analogous to the U.S.D.A.'s network of County Extension Offices, state-level informational activities would seem in order. Annual expenditures of even a few tens of thousands of dollars on such regionally focused informational programs could help insure that the government, both state and federal, realizes revenue gains instead of losses and that the homeowner indeed adds to his income instead of frittering away an appreciable structural investment through unwise behavioral habits.

CHAPTER IX

WATER RESOURCE CONSTRAINTS MODELING APPROACHES

The major goal of this chapter is to present results from a prototype multiregional water resource constraints model for Oklahoma. This model will be used to address the implications of a set of alternative futures scenarios for state economic growth and, concomitantly, pressures on available water resources. Climate conscious water conservation measures will figure in the consideration of these growth options.

A prominent aim of the prototype model is to suggest when water resource bottlenecks can be expected to occur within the various scenarios. If the bottlenecks involve, say, the virtual exhaustion of groundwater resources for regions heavily dependent on groundwater supplies, then few policy options suggest themselves to mollify or surmount the bottlenecks. Where the bottlenecks are episodic in nature or where sufficient water resources remain, it becomes a matter of some interest to consider what different available options entail in terms of changes in economic performance. One might also be interested in trying to identify some particular "optimal" option. The second section of this chapter will explore the use of linear programming techniques in isolating the more promising responses to a water resource dictated economic bottleneck. The first section, then, merely aims to suggest when chronic water resource bottlenecks might materialize given various assumptions about economic growth patterns. The second section attempts to suggest what to do in the face of a bottleneck, which could be the end product of a given economic scenario or a shorter term phenomenon induced, say, by a climatological drought episode.

A. A Prototype Multiregional Water Resource Constraints Model for Oklahoma

The classic application of input-output analysis is to relate economic change, as reflected in changes in levels of sectoral final demand, to changes in overall economic performance. These monetary measures of performance can also be related to the physical qualities of materials used in the production of goods and services. It is possible to derive estimates of the physical quantities of water needed by a sector to produce a dollar's worth of output. If input-output analysis can yield estimates of the total monetary value of output for a sector, then an estimate is forthcoming of a sector's total water use. By summing up the amounts for all sectors, an estimate of total regional water requirements is obtained. If, in addition, one can specify that a particular sector draws on so much surface water or so much groundwater to produce a dollar's worth of output, then estimates can be made of the total regional use of surface and groundwater resources. One can then compare the requirements with the water actually available. If the water required is dangerously close to, or actually exceeds, the water available, then the regional economy could not likely sustain the associated levels of economic performance and a bottleneck would occur.

A critical planning problem facing Oklahoma is to decide whether water supplies can keep pace with anticipated patterns of economic growth. One common way of describing economic growth is to assume various trends for the increase in final demand sales by the sectors of an economic system. Such an approach lends itself readily to input-output analysis and to the technique of water resource bookkeeping, outlined above.

A prototype application of such an approach was constructed wherein the State of Oklahoma was divided into two regions (see Figure IX-1). The division was made so that Region I would comprise the more arid west while the remaining and less arid portions fall into Region II. Region I is predominantly dependent on groundwater while Region II can draw more extensively on supplies of renewable surface water. In this prototype model, the simplifying assumption was made that Region I is entirely dependent on groundwater while Region II is made entirely dependent on surface water. While an obvious oversimplification, this assumption is not wholly unrealistic and provides results that, while approximate, are still worth serious consideration.

The next step was to adapt existing input-output models to the desired two-region framework. A three-region model was available in Doeksen and Little (1969). Coefficients for Region I in this study were adopted from their western region. Coefficients for Region II in this study were adopted from their control region. From their estimates for final demands circa 1978, a set of baseline final demand estimates were also derived, Region I's coming from their western region, Region II's coming from the aggregate of their central and eastern

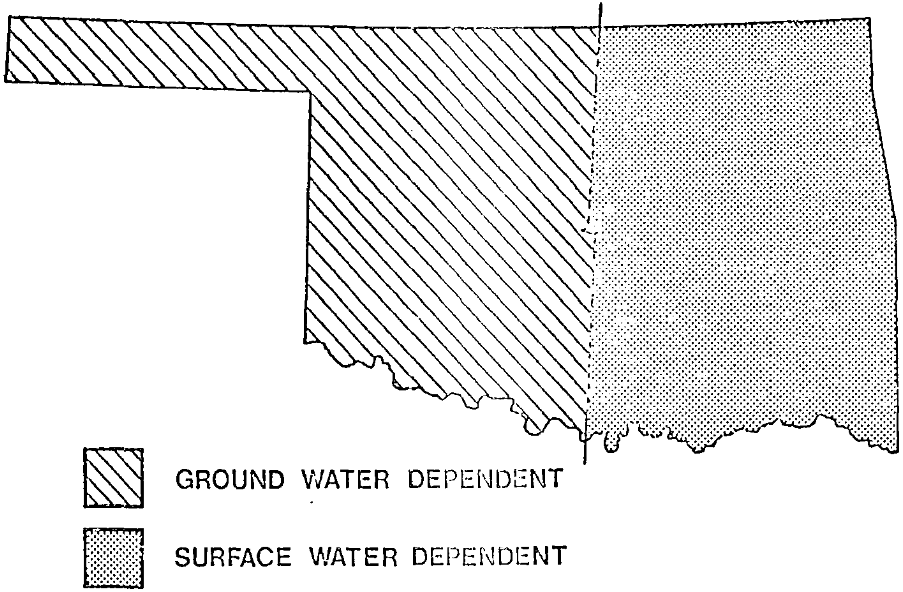

Figure IX-1: Division of Oklahoma into a Ground Water Dependent and a Surface Water Dependent Region.

regions. The set of economic sectors used in the input-output model is given in Table IX-1. The technical coefficients are given in Table IX-2 (a and b). The baseline final demands are given in Table IX-3 (a and b).

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1) Livestock
2) Dryland Farming
3) Irrigated Farming
4) Agricultural Processing
5) Manufacturing
6) Transportation, Communication and Utilities
7) Real Estate, Finance, and Insurance
8) Services
9) Wholesale and Retail Trade
10) Mining

TABLE IX-1: Economic Sectors for Two-Region Input-Output Model.

Given these input-output materials, the next task was to estimate sets of water use coefficients relating sectoral outputs to water resource requirements. Actual estimates of such coefficients for Oklahoma have, to the best of this author's knowledge, never been made. Estimates were available for Texas (Texas Water Development Board, 1977), California (Lofting and McGauhey, 1963), and Colorado (Milan, 1972). Drawing primarily on the Texas materials, an educated guess was made as to a set of coefficients for Oklahoma. These estimated water coefficients for the two Oklahoma regions are given in Table IX-4.

a)

	Sector 1	Sector 2	Sector 3	Sector 4	Sector 5	Sector 6	Sector 7	Sector 8	Sector 9	Sector 10
Sector 1	0.20391	0	0	0.22772	2E-04	0	0.01067	5E-04	0	0
Sector 2	0.11646	0.02442	0.02441	0.05901	0.00192	3E-04	0.00786	5E-04	9E-04	0
Sector 3	0.11646	0.02441	0.02442	0.059	0.00192	3E-04	0.00785	5E-04	9E-04	0
Sector 4	0.02394	0	0	0.04104	2E-04	5E-04	2E-04	0.00686	0.00181	0
Sector 5	0.00396	0.02963	0.03963	0.01739	0.04029	0.02178	0.02657	0.04706	0.0244	0.03337
Sector 6	0.03481	0.03295	0.04	0.03827	0.04349	0.12962	0.02609	0.07701	0.04374	0.0525
Sector 7	0.00667	0.02088	0.0209	0.00496	0.00852	0.01337	0.07287	0.00951	0.01492	0.01602
Sector 8	0.00288	0.01126	0.01	0.01572	0.01138	0.02223	0.02006	0.03868	0.04204	0.05477
Sector 9	0.02673	0.04456	0.04	0.02491	0.05282	0.02448	0.02967	0.02457	0.02617	0.0454
Sector 10	2E-04	0.00399	0.004	7E-04	0.187	0.0338	0.00197	5E-04	1E-04	0.07285
Income	0.30993	0.55619	0.5001	0.24798	0.39491	0.26164	0.40793	0.49102	0.59794	0.35482
Government	0.03223	0.053	0.053	0.03431	0.0308	0.23893	0.11489	0.01304	0.05659	0.08108
Imports	0.12177	0.19871	0.24354	0.22901	0.2265	0.25304	0.27335	0.2903	0.19055	0.28919

Region I Technical Coefficients

b)

	Sector 1	Sector 2	Sector 3	Sector 4	Sector 5	Sector 6	Sector 7	Sector 8	Sector 9	Sector 10
Sector 1	0.20739	0	0	0.21658	3E-04	0	0.00745	5E-04	0	0
Sector 2	0.17	0.03261	0.03261	0.07547	0.00305	4E-04	0.00509	5E-04	6E-04	0
Sector 3	0.061	0.02	0.02	0.06	0.002	10E-05	0.009	5E-04	9E-04	0
Sector 4	0.08588	0	0	0.03861	0.00131	0.00142	7E-04	0.0244	0.00544	0
Sector 5	0.01647	0.1308	0.19	0.00313	0.23035	0.0606	0.10124	0.20136	0.08885	0.11105
Sector 6	0.01441	0.03152	0.036	0.04148	0.02223	0.0964	0.02306	0.07724	0.03713	0.04086
Sector 7	0.00719	0.02621	0.026	0.00726	0.01544	0.0135	0.08772	0.0129	0.01718	0.01642
Sector 8	0.00564	0.02594	0.02	0.01345	0.03454	0.03741	0.04042	0.06	0.08017	0.09652
Sector 9	0.03568	0.06016	0.06	0.03647	0.09454	0.02458	0.03455	0.0332	0.02196	0.04766
Sector 10	2E-04	0.00404	0.003	8E-04	0.15053	0.02516	0.0017	5E-04	10E-05	0.05672
Income	0.26214	0.45065	0.44865	0.16679	0.18920	0.42041	0.40434	0.38955	0.51863	0.32782
Government	0.02269	0.05388	0.05388	0.03708	0.04129	0.17765	0.10202	0.0131	0.04815	0.0621
Imports	0.11126	0.16419	0.10986	0.2229	0.21516	0.1424	0.18272	0.18625	0.18084	0.24085

Region II Technical Coefficients

TABLE IX-2: Regional Technical Coefficients.

Region I Transactions Table (circa 1978); in $\$10^6$

		Final Demand
	Sector 1	$200.00
	Sector 2	50.00
	Sector 3	150.00
	Sector 4	50.00
a)	Sector 5	200.00
	Sector 6	60.00
	Sector 7	40.00
	Sector 8	90.00
	Sector 9	150.00
	Sector 10	1200.00

Region II Transactions Table (circa 1978); in $\$10^6$

		Final Demand
	Sector 1	$300.00
	Sector 2	100.00
	Sector 3	100.00
	Sector 4	350.00
b)	Sector 5	1600.00
	Sector 6	475.00
	Sector 7	350.00
	Sector 8	900.00
	Sector 9	1200.00
	Sector 10	500.00

TABLE IX-3: Regional Baseline Transactions Tables.

Direct Water Use Requirements (Ac-Ft/$\$10^6$ Output)

Region I

Sector 1	Sector 2	Sector 3	Sector 4	Sector 5
300.00	20.00	18,000.00	16.41	26.50
Sector 6	**Sector 7**	**Sector 8**	**Sector 9**	**Sector 10**
460.53	13.16	13.16	8.14	16.00

Region II

Sector 1	Sector 2	Sector 3	Sector 4	Sector 5
300.00	20.00	16,000.00	16.41	26.50
Sector 6	**Sector 7**	**Sector 8**	**Sector 9**	**Sector 10**
460.53	13.16	13.16	8.14	16.00

TABLE IX-4: Regional Water Use Coefficients

The next step was to provide estimates of groundwater supplies for the western region circa 1978 baseline period and estimates of total dependable yield for surface water sources in the eastern region. This information was developed from the Oklahoma Comprehensive Water Plan (OWRB, 1980). Baseline groundwater reserves for major exploitable aquifers in the Northwest and Southwest OWRB Planning Regions (approximately the same as Region I) were about 80 million acre-feet. For the remainder of the state (approximately the same as Region II), the combined estimated annual surface water yield was about 10 million acre-feet.

Given all the information summarized above, one can make estimates of the baseline water use levels required to support the baseline regional final demand levels. From this baseline configuration, one can then build in features to define sets of alternative economic growth patterns. One could, for instance, define some single scenario of interest to some particular governmental planning agency. For present purposes, a more general purpose set of alternatives was implemented. This set will probably not exactly mimic any existing "official" anticipations; but these alternative futures are felt to bracket fairly well a range of reasonable and interesting possibilities.

Three major classes of features were fit into the scenario options. First was a set of options posed purely in terms of expansion in sectoral final demands over time. The first such economic variant would be to let final demand for all sectors grow at a rate of 5% per year. Such a level of growth is commonly taken to reflect a dynamic, expansive economic performance, and a figure at or about 5% is commonly used to gage the vitality of the economic performances of advanced, industrial societies, say, in Western Europe, Japan, or the United States. Such a pattern of growth is obviously nonlinear, and, given resource constraints for capital, land, or water, one might well expect that not all sectors could maintain growth at such a clip indefinitely. Given such checks to unbridled growth, a likely response would be a logistics-curve pattern, where growth begins along an exponential trajectory, then slows down and asymptotically approaches a stable level of performance. Such logistic formulations have been widely used in economic modeling (e.g., see Intrilagator, 1978) and are the stock in trade of analogous modeling activities in the demographics of human or natural populations.

As an alternative to exponential economic growth, then, a logistics equation was set up that begins with 5% per year growth but approaches a steady level within about ten years. An equation of the following general form was selected to model the logistic rate of sectoral growth:

$$g(X) = 0.1 - 0.1/(1 + e^{(-0.25 * (X-1))}) \qquad (1)$$

where X = years from the baseline period (e.g., 1, 2, 3, ...)

During the first year from the baseline period, the growth rate is 5%. After about ten years, the growth rate is practically zero. For any given period, X, the new level of sectoral final demand; $FD_t(X)$, is:

$$FD_t(X) = FD_{(t-1)}(X) + g(X) * FD_{(t-1)}(X) \qquad (2)$$

Economic growth option variants were defined wherein all sectors <u>other than</u> irrigated agriculture experienced 5% per year increases in final demand while irrigated agriculture grew logistically; and wherein all sectors were constrained to grow logistically. Finally, the case was considered where all sectors simply maintained their baseline levels of final demand; i.e., a no-growth option.

The next class of scenario features focused on potentially attainable levels of water conservation in irrigated agriculture. Over the past decade or so, considerable research has gone into estimating the amount of "waste" associated with agricultural irrigation practices. In some parts of the country, such losses can reach alarming levels. These losses can sometimes be attributed to technically antiquated water conveyance or application methods, e.g., as in parts of the Colorado Basin where well over half the water may never even reach the field from inefficient open irrigation ditches and field flooding practices (e.g., see GAO, 1979b). Distribution losses are generally less severe where groundwater is the source since pumps may be conveniently sited in proximity to fields. Still, until recently, abundant groundwater supplies and cheap sources of fossil fuels or electricity for pumping often did not provide strong incentives for farmers to schedule carefully their irrigation applications. Application rates far in excess of the crop consumptive needs were often the rule. With soaring energy costs and steady increases in well depths, however, there are now ample incentives to make sure that applications are more carefully scheduled.

Part of the solution is technological, involving better pumps and delivery equipment. An equally substantial role, though, can come from timing applications according to critical phases in crop development keyed in turn to climatological and soil moisture conditions. Given an appreciation of how much water is needed at particular growth stages, application rates may be substantially reduced with no significant reduction in yields. Techniques for accomplishing such savings range from the simple to the complex. In many states (e.g., see Erie, French, and Harris, 1976 for Arizona or the USDA Soil Conservation Service's 1981 Oklahoma Irrigation Guide) simple methods derived from Blaney and Criddle (1956) use long term climatological average temperatures and precipitations to estimate application rates for particular crop stages. Elaborations generally involve more accurate *in situ* measurements of soil moisture and attention to particular conveyance systems and tillage practices (e.g., see Interagency Task Force on Irrigation Efficiency, 1979 or Fischbach, 1980). The more sophisticated techniques can obviously become expensive. Still, even using fairly simple systems involving only casual inspection of the fields, assessment of the overall stage of crop development and fairly readily available climatological and current meteorological information, research suggests (see Interagency Task Force on Irrigation Efficiency, 1979) that irrigation scheduling coupled with a reasonable technical application system can achieve water savings of somewhere between 15-25%. For the purpose of the present modeling scenario, a liberal savings of 30% is used from good irrigation practices.

Two water conservation alternatives were built into the scenarios. On the one hand, no conservation measures in irrigation agriculture could be assumed. On the other hand, the option is considered of reducing baseline water use coefficients for irrigation agriculture in both Regions I and II by 30%. This figure could be adjusted to any desired level. While perhaps liberal, the 30% level serves the function of making the scenarios in which it is employed conservative in their estimation of the length of time a given configuration of options could be maintained. As will be seen, even this conservative bias results in some soberingly short lifespans for a number of alternative futures possibilities.

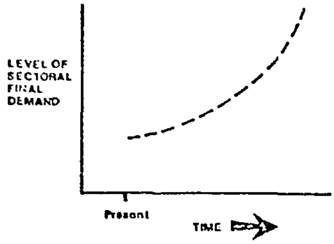
The final set of option features involves the presence or absence of a statewide water conveyance system. The details of such a proposed system are explained in depth in the Oklahoma Comprehensive Water Plan (OWRB, 1980). The present study does not propose to assess the complicated issues surrounding the enormous capital and operating costs that would attend implementation of such a system. The present study simply assumes that such a system could be in place at some time in the future from the baseline period or that such a system will be lacking entirely. If such a system were in place, the maximum amount of water that could be transferred from the eastern to the western part of the state is estimated at around 2.5 million acre-feet per year (OWRB, 1980). Given this amount of water available for the western part (Region I) of the state, it is assumed here that the sole customer would be the irrigated agriculture sector and that the full amount of this transferred water would be utilized before supplementary drawdowns on local groundwater supplies would be resorted to.

A critical issue in assessing the feasibility of a transfer plan is whether it could be made operational before the western (Region I) groundwater supplies have been seriously depleted. Under the best of conditions, the transfer system is not expected to meet all the water needs of western Oklahoma. Its goal is simply to prolong the viability of current or projected economic patterns well into the 21st century. In the present study, three options were deemed adequate to gage the transfer plan's impacts on alternative futures possibilities: (1) no transfer system; (2) a transfer system in place and operational _immediately_; and (3) a ten year delay from the baseline period before an operational system is in place. The rationale for not considering longer lag times in system implementation will become clear in the subsequent discussion.

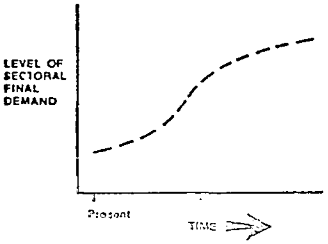
All the various combinations of the scenario option features may be conveniently summarized in the following outline form:

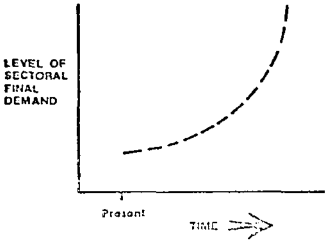
A. GROWTH OPTIONS

1) Let all sectors experience a growth in final demand of 5% per year.

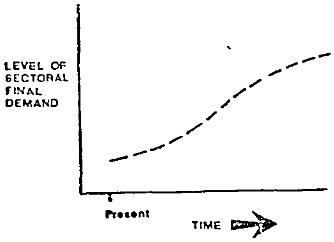


2) Let growth for irrigated agricultural damp-out in a logistic fashion while all other sectors continue to grow at the rate of 5% per year.





3) Let all sectors experience a logistic growth pattern.



4) Let all sectors maintain the current levels of economic activity.

B. CONSERVATION OPTIONS

1) No conservation for any sectors (maintain current use patterns).

2) Conservation measures in irrigated agriculture are implemented allowing a 30% reduction in base year use rates (obviously, climate-attuned irrigation scheduling could play a large role in achieving these savings).

C. WATER TRANSFER PLAN OPTIONS

1) No transfer plan.
2) A transfer plan can be put into place immediately.
3) A ten year delay before transfer plan is operational.

Using all possible combinations of these options, 24 different scenarios can be defined. One scenario would be the combination of A1-B1-C1, i.e., 5% per year growth in final demand for all sectors, no water conservation measures, and no water transfer plan. Scenario runs were terminated when one or both regions (invariably Region I caused the termination) were living beyond their means in terms of the available water resources. A wealth of data can be generated from these scenario runs, but the item of paramount interest is simply how long each scenario lasted in years from the baseline period (circa 1978). This information is given in tabular form in Table IX-5.

These results are more easily grasped from the graphical representation given in Figure IX-2. The implications of these prototype scenarios is, frankly, sobering. The only scenario options that have appreciably long durations involve:

a) No economic growth, conservation, and a water transfer plan in place immediately (scenario number 23 with a duration of greater than 300 years)
b) No economic growth, conservation, water transfer plan in place 10 years from the present (scenario number 24 with duration of 250 years).

DURATION OF SCENARIO RUNS

Scenario Number	Involving Options	Duration (Years)
1	A1-B1-C1	14
2	A1-B2-C1	18
3	A1-B1-C2	20
4	A1-B1-C3	17
5	A1-B2-C2	27
6	A1-B2-C3	23
7	A2-B1-C1	16
8	A2-B2-C1	21
9	A2-B1-C2	27
10	A2-B1-C3	21
11	A2-B2-C2	35
12	A2-B2-C3	32
13	A3-B1-C1	17
14	A3-B2-C1	23
15	A3-B1-C2	34
16	A3-B1-C3	24
17	A3-B2-C2	78
18	A3-B2-C3	52
19	A4-B1-C1	21
20	A4-B2-C1	30
21	A4-B1-C2	66
22	A4-B1-C3	45
23	A4-B2-C2	300+
24	A4-B2-C3	250

TABLE IX-5: Duration of Scenarios.

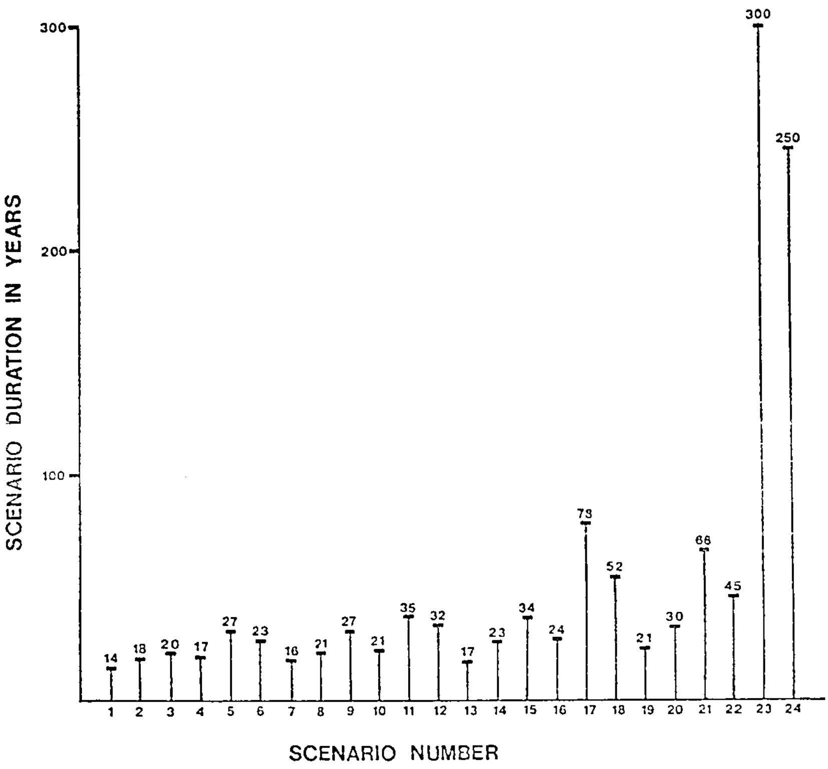


Figure IX-2: Graphical Representation of Scenario Durations.

The only options other than these that allow 50 years or more duration are:

a) scenario number 17: limited growth in all sectors; conservation; water transfer plan in place immediately (duration of 78 years)

b) scenario number 18: limited growth in all sectors; conservation; 10 year delay in implementing water transfer plan (duration of 52 years)

c) scenario number 21: no growth; no conservation; immediate implementation of a water transfer plan (duration of 66 years).

Without a water transfer program, the longest duration is for:

scenario number 20: no growth, conservation; no water transfer plan (duration of 30 years).

All these numbers are provisional: they should be accepted with due caution; but they cannot be lightly dismissed. There is the clear implication that water resource constraints will soon begin to place limits to unbridled economic growth in the State of Oklahoma. Even maintaining the current status quo could see the western part of the state running into major difficulties within 2 to 3 decades.

Initially, it had been anticipated that the prototype study presented above would form merely the first step toward the creation of a more elaborate model. Such a model would have broken Oklahoma down into more regions. This could have made the economic information more useful to policy makers and, more importantly, could have allowed more intelligent incorporation of localized data or modeling dealing with hydrology, geohydrology, and climatology. The prototype results coupled with recently published findings by other researchers (e.g., see Olson, 1981 and Center for Economic Management Research, 1981) would seem to suggest such efforts are a waste of time. Western Oklahoma, at least many regions of it, are faced with the grim reality of groundwater depletion by about the turn of the century at the latest. A water transfer plan cannot be implemented soon enough to cushion the blow and is probably unjustifiable economically in any event.

Since water resource bottlenecks seem inevitable in many regions of the state, it seems more reasonable to pay attention to the best ways to cope with the bottlenecks once they occur rather than merely split hairs over whether they can be put off for a few more years. The remainder of this chapter will be directed to suggesting the general outlines of modeling approaches that could suggest desirable responses to water resource bottlenecks, bottlenecks that could be the result of absolute decline in local water supplies or episodes induced by climatological drought.

B. Modeling "Optimal" Responses to Regional Water Resource Bottlenecks

To begin with, one must define at least roughly the types of bottlenecks amenable to formal modeling. If the bottlenecks are extremely localized, or are of extremely short duration (say a week or so), or have less to do with climate induced shortages or genuine depletion of available resources than with mechanical breakdowns in water treatment or distribution systems, formal modeling may be futile. The responses are likely to be extremely chaotic; further, over the course of a year, these emergency responses may "wash out." Minor or temporary dislocation may be made good in subsequent periods, at least in economic terms. Formal modeling may be worth the effort where the bottlenecks are longer-lived, say, of the order of several months at least and affecting sizable regions within a state. Dislocations from episodes of this sort, the severe drought in Oklahoma during 1980 being a good case in point, can be expected to leave persistent impacts on the economic performance of a region. The effects are unlikely to be made up in the course of a year, and policy makers would welcome a planning tool that could help pinpoint the more desirable courses of action.

To grapple with the idea of a best or an optimal strategy suggests a constrained optimization framework. One framework that lends itself rather easily to input-output analyses is linear programming (L.P.). The idea of converting input-output analysis techniques into an optimal decision making tool is hardly new. Applications of this approach using water use coefficients to relate economic growth patterns to water supply and demand began in the 1960's. Perhaps the most sophisticated implementations have been by Lofting and McGanhey (1968) and Millan (1972). Millan's study in particular tried to relate climate variations explicitly to variations in the hydrological yield of the upper Colorado River.

While the two studies cited above rank as impressive applied efforts, there are several issues bearing on the proper use of such a constrained optimization approach that perhaps have not received the attention they deserve. In particular, previous studies have, in the author's opinion, not given sufficient attention to exactly what features of the L.P. formulation are of greatest importance in yielding particular "optimal" solutions. Common sensically, one might presume that the "objective function" carried the greatest weight. In fact, a case can be made that certain features of the system of constraints carry far greater weight. In fact, for a given set of constraints, an L.P. formulation is "robust" to the substitution of many different types of objective functions. While this may, at this point, seem perplexing, this is in many ways a welcome outcome. As will be pointed out below, if the objective function were truly that important, there would be strong grounds, stemming from neo-classical economic theory, to reject as misleading this whole type of constrained optimization approach. Given the fundamental nature of these problems, no substantive L.P. model, i.e., a model using real data and for a real region, will be developed here. Instead, an idealized set of numerical examples will be explored to help pinpoint the general points raised above.

The examples will center around a hypothetical two-sector economy in which one sector consists of firms that are heavy users of water, e.g., irrigated agriculture, while sector two consists of other municipal and industrial sectors, e.g., manufacturers, retail and wholesale firms, services, etc., that use far less water per dollar of output. This two sector economy is assumed to operate in economic equilibrium so that it would satisfy the following input-output condition:

$$(I - A)\,X - Y = 0 \qquad (3)$$

where A is a matrix of technical coefficients
X is a vector of sectoral outputs
and Y is a vector of sectoral final demands.

In addition, if some finite quantity of water available, WA, and water use coefficients, c_1 and c_2 (for a two sector model), were available, one could specify the following constraint:

$$c_1X_1 + c_2X_2 \leq WA \qquad (4)$$

where X_1 and X_2 are the output levels for sectors 1 and 2

A simple linear programming formulation would be as follows:

Max(imize): W(elfare)

S(ubject) t(o):

$$(I-A)X - Y = 0 \qquad (5)$$

$$c_1X_1 + c_2X_2 \leq WA$$

with the usual nonnegativity constraints.

In this formulation, W is some sort of social welfare function, an example of which could be: $W = X_1 + X_2$, i.e., maximize the equally weighted sum of sectoral outputs. With the addition of extra constraints to identify other variables, one could also attempt to maximize total incomes, final demands, taxes, or Gross Regional Product.

In general, deciding what to use as a social welfare function presents a thorny theoretical issue (see the discussion of points raised by Kenneth Arrow in Henderson and Quandt, 1971). In standard neoclassical economics, one commonly deals with constrained optimization problems designed to maximize the utility of some particular consumer. At first sight, it would seem a natural extension of this sort of exercise to construct a social welfare function aiming to maximize the utilities of all consumers. Maximizing sectoral outputs, final demands, and so forth would represent an extension of this sort. Unfortunately, such theorists as Kenneth Arrow have raised strenuous objections to aggregate measures of welfare. Researchers who have used input-output analysis in a constrained optimization format have not, to the author's knowledge, attempted to counter these objections.

Consider some possible objections that are even more simple-minded than anything Kenneth Arrow might raise. For instance, in an objective function of the sort $W = X_1 + X_2$, one could object to giving equal weights to the sectoral outputs. One could raise similar objections to almost any other weighting scheme involving final demands, taxes, incomes or Gross Regional Product. In a non-centralized, free enterprise economy, of the sort at least approximated for nearly all sizable regions in the United States, there is lacking any single decision maker whose selection of a weighting scheme would be in accord with the subjective evaluations of all pertinent firms and consumers. In addition, there looms the possibility that different "optimal" solutions might result depending on whether one wanted to maximize outputs or some other measure of aggregate social welfare.

Fortunately, the water resource related problem outlined above can be made relatively insensitive to the exact form of the objective function. The theoretical problems should still be borne in mind, but these problems, in this type of situation, largely become non sequitors. In the example outlined above, it will generally be the case that $C_1 > C_2$, in fact, C_1 will generally be several orders of magnitude greater than C_2. Such a situation is often encountered in the real world, where the water use coefficients for heavy water using sectors dwarf those of other commercial sectors. Given a sectoral scheme that separates sectors according to the magnitudes of their water use coefficients, unless there is something decidedly odd about the regional economy, the same set of overall economic transactions would result given virtually any form of objective function employed. In all common cases of interest (e.g., maximizing some linear combination of outputs, incomes, final demands, etc.), production would shift, as far as constraints allowed, to the less heavy water-using sectors. In fact, in the simple L.P. formulation above, only enough production would take place in sector one to underwrite the inputs required by sector two. This implication has been noted by such researchers as Kelso, Martin and Mack (1973); who have explored possible options for the water limited Arizona economy. Even in a very simplistic model, one can see that one longterm option for a regional economy faced with water constraints is to shift production to sectors that are more frugal in their water consumption requirements.

For shorter term planning, or even for sensible long term planning, it may be unrealistic to expect such wholesale shifts in production. There may be various sources of friction entailed in realigning resources or labor from heavy to lighter water using sectors. These sources of friction can be incorporated into the model by adding extra constraints. These extra constraints will, in a sense, embody ancillary normative criteria. The overall L.P. formulation can then be employed to check the constraints for feasibility and to select optimal feasible strategies. One could also perform sensitivity analyses, checking to see by how much the fixed coefficients in the L.P. formulation could be perturbed in order to preserve feasibility or optimality for a given solution.

The subsequent discussion will shift to some simple numerical examples, exploring the possibilities of a conjoined input-output, L.P. format. A baseline configuration for the hypothetical two-region economy will be defined. The water resource constraint on the economy will then be changed to reflect the impact on the economy of a phenomenon like a drought. Various types of alternative strategies will be introduced. The model will then be used to select feasible alternatives. The potentials of this approach for selecting planning goals that are in some sense "optimized" will then be assessed.

The following examples are patterned after work by Millan (1972) and Lofting and McGauhey (1968). The examples will be highly simplified but will illustrate how variations in constraint parameters can be used to reflect realistic problems associated with climate-induced drought impacts. A hypothetical two sector economy will be used where sector one is a heavy water-using sector, for instance, irrigated agriculture, while sector two uses less water per dollar of output and can be considered a municipal-industrial sector. The baseline technical coefficients for this regional economy are given in Figure IX-3, below.

	1	2
Sector 1	0.1	0.2
Sector 2	0.5	0.3
Income	0.2	0.2
Imports	0.2	0.2

Figure IX-3: Baseline Technical Coefficients

Assume that the water supply for the region is drawn from a rechargeable groundwater source. The potential amount of water available over a yearly period during normal climatic conditions is 1,000 water units. A drought episode could reduce the recharge and, therefore, reduce the number of potentially available units of water. It is further assumed that the amount of water available from the groundwater source decreases as withdrawals increase. Since the water is withdrawn from point-source well-heads, increased pumping would create draw-down (see Linsley, Kohler, and Paulhus, 1975). As these draw-down cones become pronounced, the amount of water that can be economically pumped from the aquifer decreases. This in effect decreases the amount of water actually available. Such an effect would constitute a form of externality on the operation of the regional economy. To model such an effect, assume that for sector one the water use coefficient is 10 (water units)/($ output) and for sector two, 1 (water unit)/($ output). If the total output for sector one is x_1 and for sector two x_2; the amount of water utilized by both sectors is an amount WU (water units); and the amount of water actually available is WA (water units), then the following three water use constraints can be constructed:

$$10x_1 + x_2 - WU = 0 \tag{6a}$$

$$WU - WA \leq 0 \tag{6b}$$

$$0.1WU + WA = 1000 \tag{6c}$$

In (6c), one finds that for every unit of water utilized, the amount of water actually available (or exploitable) decreases 0.1 unit from the potentially available normal supply of 1,000 water units. In reality, (6c) would probably be nonlinear in form, but the present linear formulation can be taken as an approximation and certainly facilitates use of standard L.P. algorithms.

Assume that under normal, baseline conditions the economy has as a goal to produce at least 20 monetary units of output from both sectors one and two. These goals would exist with an eye to satisfying local consumption demands or to meeting these demands plus export goals or obligations. If the final demands for the sectors are, respectively, y_1 and y_2, the following constraints are forthcoming:

$$y_1 \leq 20 \tag{7a}$$

$$y_2 \geq 20 \tag{7b}$$

In addition, assume that there were 57 total available labor units (which could be in terms of multiples of man-hours, numbers of workers, etc.) and that certain employment goals were to be sought. Assume that for sector one and sector two the labor requirements were 0.2 (labor units)/($ output). Assume that the economy had as a goal employing at least 54 labor units in both sectors combined, a goal translating into holding unemployment to less than about 5% overall. Further assume that sector one aimed to maintain an employment of at least 13 labor units. The following set of labor constraints would result:

$$0.2x_1 + 0.2x_2 \leq 57 \tag{8a}$$

$$0.2x_1 + 0.2x_2 \geq 54 \tag{8b}$$

$$0.2x_1 \geq 13 \tag{8c}$$

Within the framework of an input-output system, the above constraints would need to be compatible with identities of the sort of (5b) in the preceding section. In the present example, this would entail:

$$0.9x_1 - 0.2x_2 - y_1 = 0 \tag{9a}$$

$$-0.5x_1 + 0.7x_2 - y_2 = 0 \tag{9b}$$

All these decision variables are assumed to be non-negative. The objective would be to maximize total output. The resulting baseline L.P. problem would be as in Figure IX-4 below.

$$\text{maximize:} \quad Z = x_1 + x_2$$

$$\begin{aligned}
&\text{s.t.:}\\
&0.9x_1 - 0.2x_2 - y_1 = 0\\
&-0.5x_1 + 0.7x_2 - y_2 = 0\\
&10x_1 + x_2 - WU = 0\\
&WU - WA \leq 0\\
&0.1WU + WA = 1000\\
&y_1 \geq 20\\
&y_2 \geq 20\\
&0.2x_1 + 0.2x_2 \leq 57\\
&0.2x_1 + 0.2x_2 \geq 54\\
&0.2x_1 \qquad\quad\;\; \geq 13
\end{aligned}$$

(all decision variables non-negative)

Figure IX-4: Problem I, Baseline Conditions

Using a linear programming algorithm described in Eddy and Shannon (1975), the following values for the decision variables are obtained (see Figure IX-5 below):

$Z = x_1 + x_2 = 282.7587$

$x_1 = 69.5925$

$x_2 = 213.1662$

$y_1 = 20$

$y_2 = 114.4204$

$WU = WA = 909.0906$

Figure IX-5: Optimal Decision Variable Values for Problem I

This information can be used to construct the baseline input-output table given in Figure IX-6:

	1	2	Final Demand	Total Output
Sector 1	6.9593	42.6332	20	69.5925
Sector 2	34.7963	63.9497	114.202	213.1662
Income	13.9185	42.6332		
Imports	13.9185	63.9499		
Total Inputs	69.5925	213.1662		

$\sum = 282.7587$

Employment	
13.9185	42.6332

$\sum = 56.5517$

Figure IX-6: Baseline Input-Output Information

In the baseline case, the final demand goals have been met. Overall unemployment is under 1%, and the employment goal for agriculture (sector one) has been exceeded. These baseline conditions are assumed to prevail for normal climate conditions. Now assume that a drought occurred that reduced the potentially available water supply to 800 water units (a 20% reduction). A set of strategies will now be considered involving alternative responses that might be taken by the region to cope with the drought.

Strategy I would be to try to preserve the constraint parameters for final demand and employment embodied in the baseline conditions. It was found that no feasible solution could be obtained now that the potentially available water supply had dropped from 1,000 to 800 units. If the employment goal for sector one is maintained (i.e., $0.2x_1 \geq 13$), it was found that no feasible solution was possible even if the overall employment goal was dropped to zero. This means that given the final demand goals and the employment goal for agriculture, no amount of cutback in the output of sector two could yield a feasible economic solution. Clearly, some reduction in the goals for either agricultural employment or final demand levels must take place.

In Strategy II, the final demand goals are maintained (i.e., y_1 and $y_2 \geq 20$), but the employment goal for agriculture was dropped to 11. Given this change, a linear programming formulation of the sort given in Figure IX-7 is feasible. The decision variable values for this strategy are given in Figure IX-8. This information can be used to construct the input-output table in Figure IX-9.

The overall unemployment resulting from Strategy II is around 25%. While feasible, such a solution may not be desirable if other alternatives are available. One such alternative could be Strategy III. In this strategy, the final demand goal for agriculture is dropped to zero. This change would allow the feasibility of a linear programming formulation as in Figure IX-10. The resulting decision variable values are given in Figure IX-11. This information can be used to construct the input-output table given in Figure IX-12.

maximize: $Z = x_1 + x_2$

s.t.:

$0.9x_1 - 0.2x_2 - y_1 = 0$

$-0.5x_1 + 0.7x_2 - y_2 = 0$

$10x_1 + x_2 - WU = 0$

$WU - WA \leq 0$

$0.1WU + WA = 800$

$y_1 \geq 20$

$y_2 \geq 20$

$0.2x_1 + 0.2x_2 \leq 57$

$0.2x_1 + 0.2x_2 \geq 42$

$0.2x_1 \geq 11$

(all decision variables non-negative)

Figure IX-7: Problem II, L.P. Formulation for Strategy II

$Z = x_1 + x_2 = 213.7931$

$x_1 = 57.0533$

$x_2 = 156.7398$

$y_1 = 20$

$y_2 = 81.1913$

$WU = WA = 727.2727$

Figure IX-8: Optimal Decision Variable Values for Problem II

	1	2	Final Demand	Total Output
Sector 1	5.7053	31.3480	20	57.0533
Sector 2	28.5266	47.0219	81.1913	156.7398
Income	11.4107	31.3480		
Imports	11.4107	47.0219		
Total Inputs	57.0533	156.7398		

$\sum = 213.7931$

Employment	
11.4107	31.3480

$\sum = 42.7587$

Figure IX-9: Input-Output Information for Strategy II

maximize: $Z = x_1 + x_2$

s.t.:

$0.9x_1 - 0.2x_2 - y_1 = 0$

$-0.5x_1 + 0.7x_2 - y_2 = 0$

$10x_1 + x_2 - WU = 0$

$WU - WA \leq 0$

$0.1WU + WA = 800$

$y_1 \geq 0$

$y_2 \geq 20$

$0.2x_1 + 0.2x_2 \leq 54$

$0.2x_1 + 0.2x_2 \geq 54$

$0.2x_1 \geq 10$

(all decision variables non-negative)

Figure IX-10: Problem III, L.P. Formulation for Strategy III

$Z = x_1 + x_2 = 275.8621$

$x_1 = 50.1568$

$x_2 = 225.7053$

$y_1 = 0$

$y_2 = 132.9154$

$WU = WA = 727.2727$

Figure IX-11: Optimal Decision Variable Values for Problem III

	1	2	Final Demand	Total Output
Sector 1	5.0157	45.1411	0	50.1568
Sector 2	25.0784	67.7116	132.9154	225.7053
Income	10.0314	45.1411		
Imports	10.0314	67.7116		
Total Inputs	50.1568	225.7053		

$\sum = 275.8621$

Employment	
10.0314	45.1411

$\sum = 55.1725$

Figure IX-12: Input-Output Information for Strategy III

Strategy III results in an overall unemployment rate of around 3.2%. This clearly seems an improvement over Strategy II. On the other hand, only enough production has taken place in agriculture to satisfy interindustry demands. There is no agricultural output left for final demand sales. It may well be the case that such a situation could create severe hardships for the region. It would be interesting to see how high the final demand sales for agriculture could be raised.

In Strategy IV, the final demand sales by agriculture are raised to 10. With sector one final demand at this level, however, the overall employment goal must be relaxed. A feasible L.P. formulation is given in Figure IX-13. Decision variable values are given in Figure IX-14. The associated input-output information is given in Figure IX-15.

maximize: $Z = x_1 + x_2$

s.t.:

$0.9x_1 - 0.2x_2 - y_1 = 0$

$-0.5x_1 + 0.7x_2 + y_2 = 0$

$10x_1 + x_2 - WU = 0$

$WU - WA \leq 0$

$0.1WU + WA = 800$

$y_1 \geq 0$

$y_2 \geq 20$

$0.2x_1 + 0.2x_2 \leq 57$

$0.2x_1 + 0.2x_2 \geq 48$

$0.2x_1 \geq 10$

(all decision variables non-negative)

Figure IX-13: Problem IV, L.P. Formulation for Strategy IV

$Z = x_1 + x_2 = 244.8275$

$x_1 = 53.6050$

$x_2 = 191.2225$

$y_1 = 10$

$y_2 = 107.0533$

$WU = WA = 727.2729$

IX-14: Optimal Decision Variable Values for Problem IV

	1	2	Final Demand	Total Output
Sector 1	5.3605	38.2445	10	53.6050
Sector 2	26.8025	57.3668	107.0533	191.2225
Income	10.7201	38.2445		
Imports	10.7201	57.3668		
Total Inputs	53.6050	191.2225		

$\sum = 244.8275$

Employment	
10.7201	38.2445

$\sum = 48.9646$

Figure IX-15: Input-Output Information for Strategy IV

This change has now driven overall unemployment to just over 14%. Furthermore, feasibility is lost if the employment goal for agriculture is raised to not much over 10. Agriculture has in fact lost employment compared with Strategy III, and the economy as a whole has, likewise, suffered.

In Strategy V, a possible way out of these difficulties is offered. In Strategy V, it is assumed that the inputs that sector two normally buys from the local agricultural sector can be obtained from outside the region. This would change the regional technical coefficients to those given in Figure IX-16. Given these new technical coefficients, a linear programming problem of the sort of Figure IX-17 could be formulated. Decision variable values are given in Figure IX-18 and input-output information in Figure IX-19.

	1	2
Sector 1	0.1	0
Sector 2	0.5	0.3
Income	0.2	0.2
Imports	0.2	0.5

Figure IX-16: New Technical Coefficients

maximize: $Z = x_1 + x_2$

s.t.:

$0.9x_1 - y_1 = 0$

$-0.5x_1 + 0.7x_2 - y_2 = 0$

$10x_1 + x_2 - WU = 0$

$WU - WA \leq 0$

$0.1WU + WA = 800$

$y_1 \geq 20$

$y_2 \geq 20$

$0.2x_1 + 0.2x_2 \leq 57$

$0.2x_1 + 0.2x_2 \geq 57$

$0.2x_1 \geq 9$

(all decision variables non-negative)

Figure IX-17: Problem V, L.P. Formulation for Strategy V

$Z = x_1 + x_2 = 277.2729$

$x_1 = 49.9999$

$x_2 = 227.2730$

$y_1 = 45$

$y_2 = 134.0912$

$WU = WA = 727.2727$

Figure IX-18: Optimal Decision Variable Values for Problem V

	1	2	Final Demand	Total Output
Sector 1	4.9999	0	45	49.9999
Sector 2	24.9999	68.1819	134.0912	227.2730
Income	9.9999	45.4546	$\sum = 227.2729$	
Imports	9.9999	113.6365		
Total Inputs	49.9999	227.2730		

Employment		
9.9999	45.4546	$\sum = 55.4545$

Figure IX-19: Input-Output Information for Strategy V

In Strategy V, the final demand and overall employment goals of the original, baseline conditions are now attainable. Overall unemployment is now at only around 2.7%. Employment in agriculture, however, is reduced to just under 10 units, indicating a sizable bleedoff of workers into sector two.

A final strategy, Strategy VI, investigates the effects of decreasing this bleedoff of agricultural employment. It was found that feasibility could be attained keeping agricultural employment at just under 11 units although with a concomitant increase in overall unemployment. A feasible L.P. formulation is given in Figure IX-20. Decision variable values are given in Figure IX-21 and input-output information in Figure IX-22.

maximize: $Z = x_1 + x_2$

s.t.:

$0.9x_1 - y_1 = 0$

$-0.5x_1 + 0.7x_2 - y_2 = 0$

$10x_1 + x_2 - WU = 0$

$WU - WA \leq 0$

$0.1WU + WA = 800$

$y_1 \geq 20$

$y_2 \geq 20$

$0.2x_1 + 0.2x_2 \leq 57$

$0.2x_1 + 0.2x_2 \geq 46$

$0.2x_1 \geq 10.9$

(all decision variables non-negative)

Figure IX-20: Problem VI, L.P. Formulation for Strategy VI

$Z = x_1 + x_2 = 232.2738$

$x_1 = 54.998$

$x_2 = 177.2740$

$y_1 = 49.4999$

$y_2 = 96.5918$

$WU = WA = 727.2720$

Figure IX-21: Optimal Decision Variable Values for Problem VI

	1	2	Final Demand	Total Output
Sector 1	5.4999	0	49.4999	54.9998
Sector 2	27.4999	53.1822	96.5918	177.2740
Income	10.9999	35.4548	$\sum$ = 232.2738	
Imports	10.9999	88.6370		
Total Inputs	54.9998	177.2740		

Employment		
10.9999	35.4548	$\sum$ = 46.4547

Figure IX-22: Input-Output Information for Strategy VI

In Strategy VI, a gain of about one unit in agricultural output has increased overall unemployment to around 18.5%. Recall that in Strategy V, overall unemployment had been reduced to around 2.7%.

The foregoing discussion has focused on five feasible strategies (II-VI). Given the reduced water supply associated with the drought, these feasible strategies were obtained through combinations of adjusting goals for employment, final demand sales, and changes in sectoral technologies. Strategies IV and V seem, in many ways, the most promising since both reduce overall unemployment to fairly tolerable levels. Strategy IV, however, may reduce final demand sales by agriculture to unreasonably low levels while Strategy V imposes a shift in input patterns for sector two that may not be sustainable on a long standing basis. Both strategies entail some movement of labor from agriculture to the municipal/industrial sector. Many other feasible strategies could be constructed and sensitivity analyses performed on these feasible strategies. The examples presented above, though, illustrate the basic rules of the game in applying a conjoined input-output, linear programming format.

Even in these simple examples, a considerable degree of realism is possible in the construction of ancillary goals embodied in the constraints. Trade-offs between final demand sales, employment, and import patterns are just the types of features that must be assessed in plotting an appropriate response for a region faced with an episodic drought. The model presents no clear-cut "best" strategy. Each feasible strategy hinges on hard decisions involving the ancillary constraint parameters. The acceptance of any set of parameters would properly rest on the sanctions provided by socio-political processes and institutions. Changes of parameters represent matters as fundamental as losses or gains in employment by households drawing their incomes from particular sectors. Unrealistic goals maintained by particular groups may, in the extreme, create completely unworkable economic dilemmas. For instance, unrealistically high unemployment goals by agriculture, perhaps buttressed by farmers' legal rights to groundwater supplies, may drive unemployment to intolerable levels in other sectors. Reduced employment goals by farmers, likewise, may require movements of labor from agriculture to municipal-industrial sectors: these sectors must be willing and able to absorb this extra employment. Climate-induced water resource constraints can create conflicts of interest (see the discussion in Howe, 1979), whose resolution may require compromise and accommodation by all constituents of the regional economy and the regional society.

The approaches outlined above do not necessarily lead to some single "best" solution to a water supply bottleneck; and they certainly do not appeal to the panacea of isolating solutions that are superior because "efficient" in the sense of neoclassical Pareto optima. As has been hinted in the present discussion and, more extensively, by other authors (e.g., Bromley, 1979 or d'Arge and Hunt, 1971), however, the hope that efficiency criteria pure and simple are the ultimate solutions to natural resource problems may well be a chimera. The present models are less ambitious; they help in elucidating the detailed implications of strategies that are at least feasible and in some sense optimal (see the similar arguments by Grubb, 1979). The models can be refined to provide such information for a large number of regions and real world problems where input-output materials and water resource data are available. A range of possible alternatives can be explored to address likely contingencies. The citizenry of an affected region and their elected representatives can then be hoped to reach more enlightened choices (compare Leontief, 1976) armed with these insights.

CHAPTER X

CONCLUSIONS AND SUGGESTIONS FOR FURTHER STUDIES

By this point, it is hoped that the reader will agree that the input-output oriented modeling approaches developed in the preceding chapters can be adapted to shed light on a variety of important climatic-economic scenarios. Briefly, the types of applied problems covered have have included:

1) Estimates of impacts from "natural" (or historical) climatic variability on the agricultural crop sector and residential energy consumption
2) Estimates of likely impacts from an operational weather modification program
3) Estimates of likely impacts from the implementation of climate-conscious irrigation scheduling strategies
4) Estimates of likely impacts resulting from climate-conscious residential retrofitting
5) The feasibility of instituting a statewide water transfer program, including consideration of the impact of scenarios involving climate-conscious irrigation scheduling
6) A general consideration of using input-output techniques as an "optimal" decision-making tool for regional planners faced with coping with climate-related water shortages.

While these applications do not exhaust the potential for the use of input-output analysis, they do cover a significant amount of topical territory and certainly suggest a number of promising research areas for the future. Much of this future effort should undoubtedly focus on improving the accuracy of the various components in the individual modeling structures. Wherever possible, an attempt has been made to produce actual dollar estimates geared to the Oklahoma climate, the technology of Oklahoma economic sectors, the behavior of Oklahoma consumers, and the overall structure of the Oklahoma economy. To cover all this territory is a sizable task, and improvements are possible for each "module" in each of the modeling structures presented above. This has been a prototype undertaking, designed mainly to demonstrate what can be done and to show, at least in a preliminary fashion, how to do it using actual climatic and economic data. Future work could be expected to make better use of available climate information, produce more detailed crop yield models, tap more detailed or more current input-output models, and so forth. For the vast majority of the modeling structures presented, the modular techniques employed allow one to proceed in a piecemeal fashion depending on one's appraisal of where the greatest gains in improved accuracy are likely to occur.

For instance, the crop models developed in this study could certainly be improved upon. Additional crops could be added. Models could also be developed, if possible, for the livestock sector. The techniques to estimate climate-conscious energy savings in irrigation agriculture could be elaborated upon and improved. More sophisticated approaches could be applied to estimate residential energy savings from retrofitting strategies. Finally, improvements in the techniques for estimating the impacts on agriculture from weather modification activities are certainly possible.

Each of these areas constitutes a research topic in itself. Each could be pursued in a piecemeal fashion and then used to drive the input-output techniques using the multipliers already in hand. The author personally sees this area of developing good direct input "functions" as the most pressing immediate need and as the area where the biggest pay-offs are possible for the effort expended.

The regional input-output materials could also stand some updating and elaboration however. The materials employed in the present study are, admittedly, somewhat dated. New input-output tables are definitely needed in order to improve the confidence in the exact dollar figures generated from the input-output multipliers. The problem here, though, is that such an undertaking is largely beyond the competence of a climatologist: the task is best left to trained regional economists. Once the economists have developed the appropriate input-output tables, then the climatologist can easily adapt them to develop materials like the multipliers presented in this study.

For this process to work, however, the input-output materials developed must be appropriate for the climatologist's needs. In particular, the sectors developed in the input-output models should bear a close resemblance to the sectors for which the climatologist is seeking to develop direct impact functions. At the very least, such sectors as dryland agriculture, irrigated agriculture, livestock, and utilities should be explicitly broken out. The author experienced great difficulties in finding such materials. The materials finally employed at least distinguished between crop and livestock sectors since they were developed by agricultural economists. The "utility" sector, unfortunately, included a few other closely related economic enterprises, e.g., communications utilities, as well as the desired energy utilities.

In the author's judgment, Oklahoma lags sadly behind other states like Texas or Kansas in developing regional input-output models. In many neighboring states, there is on-going state-level support to create and update the input-output materials, often carried out by staff within state agencies. In Oklahoma, there is really no state agency that has the in-house capability to develop and maintain input-output or econometric models. Such models as are available have been the outgrowth of university research projects, largely funded from one-time federal grants. As a result, the models have generally been created to explore some abstract, theoretical point or to tackle some highly specialized application at a given point in time. In light of this, it is hardly surprising that the climatologist is hard-pressed to find a model that has exactly the type of sectoral aggregation structure desired or that it is problematical whether the most suitable models available will ever be updated.

It can only be hoped that the present study can help to fuel interest in the development of better and more up-to-date input-output materials for Oklahoma. Perhaps one reason that interest has lagged at the state level is that the traditional applications of input-output analysis have been geared to studying how changes in "final demand," usually in response to national-level trends, can impact the regional economy. Until recently, there was at least some optimism that government, even government at the state level, could act to stabilize the extent of such business cycle trends. This author thinks it is fair to conclude that governments are now far more pessimistic, even fatalistic, about engineering economic growth or stability; indeed, government may often have been a chief cause for economic stagnation or decline. Such an atmosphere hardly encourages a state like Oklahoma to underwrite work in applied economic modeling. There is probably little or nothing the State of Oklahoma could do directly to damp out national economic cycles and their regional ramifications through Keynesian-type tinkerings with final demand.

Still, while the general level of economic well-being in Oklahoma may well be dictated by poorly understood, and seemingly uncontrollable, national and international upturns and downturns, a state like Oklahoma can do some things to promote the welfare of its citizens. Particularly in the area of the wise use of its natural resources, including its climatic resources, the state can do something. Such economic gains may not, in and of themselves, fill the state's coffers, but the gains, for its citizenry and the state itself, can certainly be very rewarding.

Throughout this study, efforts have been made to assess whether a given climate-sensitive strategy looked economically promising. Three basic criteria were used:

1) What were the levels of direct benefits or costs to particular economic sectors or groups.
2) What were the levels of overall benefits or costs to the citizenry as reflected in changes in such things as employment, final demand, output, income and Gross State Product.

3) What were the benefits to government from increases in or losses to tax revenues.

Most of the climate-related strategies considered would, or could, involve some degree of governmental (federal, state, or local) involvement. Governments are more likely to become enthusiastic about programs that can be shown to bring rewards to individual constituencies, the general populace, and themselves through enhanced tax revenues. Since the federal government can operate in the red, it may even be willing to encourage programs that touch base with the first two of these areas even if the public purse suffers somewhat. State governments cannot usually afford such a luxury: the State of Oklahoma, in particular, is constitutionally forbidden from operating in the red. Since a major concern of this study is to focus attention on programs that are desirable at the state and local level, it behooves an applied climatologist to be able to show that an outlay of state or local money has a good chance of allowing the government to at least recoup its outlay. If the enhancement in revenue outpaces the outlay, then all the better.

In the case of weather modification (see Chapter VI), it was estimated that the benefit-to-cost ratio for government was around 2.8/1. Although the absolute size of the economic benefits was not overwhelming, this seems like a very good rate of return. For irrigation-scheduling (see Chapter VIII), the changes in government tax revenue were so negligible that they were not even reported. Government support in this area can only be justified in order to prevent the headlong decline of irrigation agriculture and the undermining of the economic infrastructure in much of western Oklahoma. Still, since Oklahoma state government cannot operate in the red, its involvement should remain modest; federal involvement would seem much more appropriate. In the case of residential retrofitting (see Chapter VIII), modest gains in governmental income are possible in the range of $2-9 million for Oklahoma. Governmental outlays in promoting retrofitting, then, should probably not exceed one or two million dollars per year. In Chapter IX, the conclusion was that it is already too late for a water-transfer program to sustain irrigation agriculture in western Oklahoma. Any expenditure of public monies to this end would likely be sheer waste. Federal and state governments would be better advised to promote weather modification programs and irrigation-scheduling.

Further research could help refine the exact dollar figures on which the above conclusions were based. The author doubts, however, that further research would alter the general policy implications for federal or state planners. Using what are very simple-minded cost/benefit techniques, then, some very solid and important recommendations can be made on how governments should use public monies to support the wise use of climatic resources and climatic information. Rough estimates can also be made of the appropriate level of public outlay for specific programs and whether the outlays should come from the federal level or from a combination of federal, state, and local involvement.

The input-output materials employed did not allow a breakdown as to the division of governmental taxation enhancements vis-a-vis the various levels of government. This is another desirable feature the applied climatologist would want in updated input-output tables. Given this situation, it is hard to say exactly how much per year the State of

Oklahoma could reasonably be expected to spend on climate-related programs. A reasonable guess might be something aroung $500,000. Matching federal monies might swell the total annual outlay to something between one to two million dollars. This figure would probably be enough to support a modest, but effective, state climatological survey, some applications-oriented research at state universities, and support activities in such state natural resource agencies as the Oklahoma Water Resources Board. The present study, it is felt, supports the conclusion that sensible outlays of public monies aimed at such programs as weather modification, irrigation scheduling, and residential retrofitting can be shown to bring economic benefits to specific constituencies within the state (e.g., farmers and utility rate-payers), promote the general economic well-being of Oklahoma's citizens, and pay for themselves through enhanced tax revenues.

Some brief comments are also in order as to how the models presented here for Oklahoma might best be applied to other contexts. Obviously, similar models could be developed for other states, probably even for multi-state regions. As the geographical scale increased, however, some of the basic model assumptions, especially as they apply to the agricultural sectors, would bear close scrutiny. For a single state, it is unlikely that its production of a commodity, for instance, winter wheat, would constitute the majority of national production. For a multi-regional or national model, one would have to give more attention to the impacts of production changes on commodity prices and on whether markets could be found for extra production. Since the prices of many agricultural commodities are regulated through government price support programs, these policy matters would also bear scrutiny. The present approach offers a solid beginning, but for larger scale modeling applications, it would obviously need additional refinement.

Further research is recommended to help clarify these conclusions. An immediate need is better direct impact models. It is hoped that the arguments presented above could also encourage the development of more adequate input-output materials geared to the specific needs of the applied climatologist. The present study is only a prototype effort, but it has helped point the way to areas where future endeavor can be not only of academic interest but of general economic benefit as well. If it has accomplished this, then it has been well worth the effort.

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APPENDIX:

INFORMATION NEEDED TO APPLY TECHNIQUES FROM THE ASHRAE COOLING AND HEATING LOAD CALCULATION MANUAL TO THE SITUATIONS ENCOUNTERED IN CHAPTER VIII

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APPENDIX

The ASHRAE Cooling and Heating Load Calculation Manual (ASHRAE, 1979) was created to help design engineers and architects fit a structure with the types of insulation, ventilation, and heating and cooling equipment needed to maintain specified interior comfort conditions under extreme winter or summer weather conditions. While not explicitly created as a climatological building load model, the materials in the handbook, and particularly Chapter 7, can be adapted to serve this purpose. Two types of input data are needed:

1) specification of the physical components of the structure and their thermal properties.
2) specification of the external temperatures.

For the external temperatures, monthly average climatological "normal" temperatures for Oklahoma City, Will Rogers Airport were obtained from Ellen Cooter of the Oklahoma Climatological Survey. These temperatures are listed in Table A-1.

The structure was the outer "shell" (walls, ceiling, floor, etc.) of a "typical" house. Once again, the assistance of Ellen Cooter was solicited in deciding what such a typical house shell would amount to.

Month	Average Temperature (°F)
January	35.5
February	40.9
March	48.8
April	60.4
June	76.8
July	81.6
August	80.7
September	73.3
October	62.5
November	48.9
December	40.1

TABLE A-1: Monthly Average External Temperatures Used in Chapter VIII.

A rectilinear structure, with the four walls oriented squarely to the north, south, east and west was selected, with the larger walls, in terms of area, on the east and west. The north wall was given two standard windows, the west wall two standard windows, and the south wall a door, a standard window and a smaller "kitchen" window. Two doors were placed on the east wall. The ASHRAE techniques break the structure into individual components. Technically, it makes no difference exactly where along the walls the various doors and windows are placed. The pertinent physical characteristics of the house shell are summarized in Table A-2.

The differences between the OLD and NEW houses of Chapter VIII involve the insulation (or "R" values) for the windows and the ceiling. The thermal characteristics for the walls, doors, and the floor were held constant. The R value for the walls was set at 21.95; for the doors at 2.13; and the thermal loss in winter through the floor was set at 2,695 BTU/hr. The OLD house R value for single glazed windows was

Direction	Component	Area (ft^2)
North	Windows	34.40
	Walls	240.00
South	Window 1	17.20
	Window 2	10.83
	Door A	21.65
	Wall	240.00
East	Door A	21.65
	Door B	21.65
	Wall	362.00
West	Windows	34.40
	Wall	362.00

Other Dimensions:		
	Volume:	11,280 ft^3
	Roof Area:	1,550 ft^3
	Floor Perimeter:	154 linear feet

TABLE A-2: *Physical Characteristics of House "Shells".*

0.9; for the double glazed windows on the NEW house at 1.92. The OLD house R value for the ceiling was set at 21.34; for the NEW house at 41.34.

Given these physical and thermal data, different internal temperatures for the various scenarios were selected. For each scenario, which months would fall into the "heating" season versus the "cooling" season would vary depending on whether the desired internal temperatures were greater than the external temperature (heating) or vice versa (cooling). Using the techniques in the ASHRAE Manual, thermal loads in BTU/hr were calculated for the structures month by month. These were converted to BTU's per month depending on the number of days in a month. The monthly BTU amounts were then converted to Kwh's. Given a price per Kwh, monthly and yearly total dollar estimates for utility expenses were forthcoming. All computations were performed by hand using a pocket calculator.

It should be noted that if the desired internal temperature is set at a constant level year round, every month (unless the external and internal temperatures are identical) will be characterized as either a "heating" or a "cooling" season month. If there is a spread in the desired temperatures, say, external temperatures less than 65° require heating while external temperatures greater than 72° require cooling, then for months with intermediate temperatures, no heating or cooling will be required. This explains the blanks in the tables to be introduced below.

A large number of intermediate computational values are generated in arriving at a monthly utility bill figure for each scenario configuration of the OLD or NEW houses. Only the overall monthly and annual total dollar amounts will be summarized here. For each house there are four internal temperature options in terms of heating season (HS) and cooling season (CS) requirements:

A: HS = 72° CS = 72°
B: HS = 65° CS = 72°
C: HS = 72° CS = 78°
D: HS = 65° CS = 78°

These will be indicated as options A to D in the tables that follow.

	OPTIONS			
	A	B	C	D
January	$ 156.91	130.4	156.91	130.30
February	$ 123.90	100.79	123.90	100.79
March	$ 108.30	82.70	108.30	82.70
April	$ 63.77	39.0	63.77	39.00
May	$ 36.66	-	36.66	-
June	$ 138.52	138.52	-	-
July	$ 157.65	157.65	148.87	148.87
August	$ 153.48	153.48	145.10	145.10
September	$ 128.77	128.77	-	-
October	$ 58.22	32.64	58.22	32.64
November	$ 104.45	80.53	104.45	80.53
December	$ 140.10	114.50	140.10	114.50
TOTALS	$1,370.3	1,158.99	1,086.28	874.43

TABLE A-3: Utility Bill Estimates for OLD House.

	OPTIONS			
	A	B	C	D
January	$ 127.53	107.58	127.53	107.58
February	$ 101.29	80.14	101.29	80.14
March	$ 89.62	69.67	89.62	69.67
April	$ 54.74	35.43	54.74	35.43
May	$ 33.76	-	33.76	-
June	$ 131.36	131.36	-	-
July	$ 151.26	151.24	144.85	144.85
August	$ 148.22	148.22	142.99	142.99
September	$ 125.77	125.77	-	-
October	$ 50.58	30.63	50.58	30.63
November	$ 86.46	67.15	86.46	67.15
December	$ 114.42	94.47	114.42	94.47
TOTALS	$1,215.01	1,041.66	976.24	772.91

TABLE A-4: Utility Bill Estimates for NEW House.