NATIONAL ENVIRONMENTAL MODELS OF AGRICULTURAL POLICY, LAND USE AND WATER QUALITY

CENTER FOR AGRICULTURAL AND RURAL DEVELOPMENT
IOWA STATE UNIVERSITY

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PROJECT SUMMARY

Large-scale computer environmental-resource use models were developed and applied to U.S. agriculture and its resources. The major models are mathematical programming in nature. However, an econometrically estimated simulation model at the national level has also been developed. The programming models include up to 223 agricultural producing regions delineated on the basis of soils, climate and water. They include 51 water supply regions for surface water. Groundwater supplies also are defined. Each producing region includes nine land classes. Demands defined for the 35 market regions and the transportation submodel cause the 223 producing regions to be interdependent in their production patterns, use of resources, levels of income and resource values. Soil loss, water use, nitrogen relationships are defined for a large set of crop, livestock, erosion control and technological activities in each producing region. The land and water base of each region defines its production possibilities.

The models are applied to agriculture at national, watershed, state, substate, and producing region levels. They trace the impacts among regions of different physical market and policy conditions affecting water and land use, sedimentation and erosion control, chemical and pesticide application, animal waste conversion, farm income resource values, energy, and community income and employment.

The models have been used to evaluate U.S. food producing capacity, resource use and environmental quality under a wide set of scenarios relating

to energy supplies and prices, organic farming, chemical use and environmental enhancement. A larger number of subject matter studies were completed and reported in publications, at conferences and seminars, and by other means. The models had numerous and intensive outside users. Included were the Environmental Protection Agency, the National Commission on Water Quality, the Water Resources Council, the Economics Research Service, the Soil Conservation Service, and the Office of the Secretary of Agriculture at the national level. The North Central Regional Center for Rural Development and the Midwest Governors' Conference have been users at regional levels. Several states also have been users.

The models show that under appropriate policies, the nation can improve environmental quality through agriculture over a considerable range without driving the real price of food to high levels. However, trade-offs are involved and environmental enhancement can be pushed to levels high enough to cause food costs to rise sharply or to require large cutbacks in exports. Even though modest environmental enhancement policies do not strain resource use or drive food prices to high levels, the impact varies greatly among regions. The Southeast and southern Corn Belt generally sacrifice income while the Great Plains gains as sediment control programs are implemented. Programs which restrict the supplies or increase the prices of energy cause income sacrifices in the pump irrigated regions of the Great Plains but allow gains, especially in the central Corn Belt and the South Atlantic regions. While the models have been used to analyze a wide range of export, water and land use, fertilizer and pesticide application, export and general economics and regulatory conditions and policies, they can be used for many more.

NATURE OF PROBLEM

Modern agriculture bears complex relationships with land and water use and the environment. These interactions are encouraged through the ongoing technological transformation of agriculture and domestic and trade policies for the sector. In recent decades under low real prices for energy, U.S. agriculture has come to rest heavily on chemicals. Use of chemical fertilizers and pesticides not only has reduced the number of cultivations required for crops but also has substituted for crop rotations. In earlier decades, row crops were grown in rotation with legumes and the hays to provide nitrogen and to combat various crop diseases and insects. With chemicals substituted for rotations, new systems of land and water use evolved. Farmers began practicing monoculture with a single row crop grown continuously or with two crops such as corn and soybeans grown in a row crop system. Under these systems the proportion of grain crops increased and the proportion of forage crops declined. Greater runoff thus was encouraged and soil loss increased dramatically. Hence, agriculture is the major contributor to nonpoint pollution in the form of suspended sediment in streams and water bodies. Soil particles also serve as a transportation medium for nitrogen and phosphate fertilizers and pesticides.

The development of chemical fertilizers and pesticides also interact with land use. They can be substituted for crop rotations for supplying nutrients to plants and in lessening damage by weeds and insects. As substitutes for rotations, modern agricultural chemicals thus allow more continuous row cropping which leads to greater soil erosion, movement of sediment to streams and lakes and other impacts on the environment.

Agricultural technology also has interacted with the economic and social environment surrounding rural communities. As modern technology swept over them, it caused farms to become larger and more specialized. This transformation thus caused farms to use less labor. Consequently, as the farm labor force declines, the volume of business and employment of nonfarm sectors of rural communities also declined. Large capital losses have burdened owners of business, housing and other real estate in towns of farm communities. With the decline in employment opportunities and population, services available to rural residents often have diminished in amount and quality but increased in costs. The development of large-scale animal enterprises and the concentration of wastes has been accompanied by point pollution, the nitrification of local water supplies and atmospheric pollution.

The use of land and water resources has, of course, interacted with export opportunities and other conditions of commodity and factor markets. United States agriculture has great producing power. The nation has been exporting the product of about one from each of three crop acres. During periods of large exports and high prices, additional land was planted to crops and further soil erosion was encouraged. These conditions attracted large investments in farm land and irrigation development. Then as export demand receded somewhat and farm commodity prices declined, the downward pressure on farm income has caused resources in agriculture to continue in intensive use.

The technology which encourages chemical agriculture and allows these capital inputs to substitute for land has helped increase the supply capacity of American agriculture. This supply capacity is so large that in times of normal export demands for grains, U.S. farm commodity prices prevail at levels which are unacceptable to farmers. To alleviate these conditions, the public has implemented land retirement or supply control programs to reduce farm output and increase prices and incomes. Generally this land retirement has been spread over the whole of the United States. This "surplus capacity," rather than being alloted to supply control programs could be used in many other ways beneficial to society at large. While the public generally has worried that the shift of prime farm lands to nonfarm uses endangers the nation's food supply, this obviously is not yet so. Hence, the land and water resources representing the "surplus capacity" of American agriculture could be used for green belts and recreational facilities, to allow fragile lands to be withheld from agricultural production or to encourage agricultural systems which are less conducive to sedimentation and environmental impairment. Thus, agricultural policy and environmental policy have opportunity to and should be meshed. Obstacles to this meshing prevail because of varying resource endowments and economic impacts by agricultural regions. A policy which spreads land retirement for agricultural supply control purposes over the entire nation has less negative impact on local community income and employment generation than will one which concentrates on removal of fragile lands at specific locations from production; or one which shifts water used for agricultural production for environmental enhancement purposes.

The technology, structure, policy, resource use, environmental impacts, and energy conditions for agriculture are highly interrelated. These facets of agriculture also interact with the spatial characteristics of the sector and its regional differences. Hence, a program directed at reducing non-point pollution through soil loss abatement will impact most heavily in the Southeast where winters are open, rainfall is large and much of the land is hilly. Severe reductions in soil erosion will cause reduced farm incomes and asset values in this region. In contrast, a soil loss abatement policy may actually bring greater income and asset values to regions of the Great Plains where rainfall is less and more land is level. This region, which generally is the "surplus region" of the nation because of its thinly populated areas, can produce a large share of the crops which must recede from the Southeast.

On the other hand, a policy or market conditions causing higher energy prices or restrained energy supplies will have greatest negative economic impact on irrigated regions of the Great Plains which rest on use of groundwater supplies. With greater outlays for energy, irrigation costs can increase until land must be shifted to less productive dryland operations. Greater demand then is put on use of land in other regions. Income thus can be redistributed between irrigated and dryland sectors. Soil erosion and nonpoint pollution thus may be encouraged in regions of the Southeast and Corn Belt.

MODELS FOR INTERRELATED SECTORS

Obviously, analysis of potentials and policies for agriculture can be best made by models which are capable of picking up these interrelations among producing regions and among problems of income, land use, soil erosion, nonpoint pollution, energy supplies and prices, water supplies and use, agricultural and export policies, rural employment and the physical and social environments. This project funded by the National Science Foundation was directed towards this end. A family of models were developed which provide detail in outcomes at national and regional levels, trace the impact of policies implemented in one region on resource use, income, resource values, and environmental conditions in other regions thousands of miles distant. This family includes a set of linear programming models, quadratic programming models and several variations of an econometrically-based simulation model.

The practical goal of the project has been to trace the effects of alternative conditions of the market, various governmental policies, developing technologies of agriculture, export levels, prevailing and potential environmental policies on the use of resources, environmental quality, farm income, consumer food costs and related variables at national watershed, state, substate and production area levels. The goals generally have been met. The models have been used in a large number of subject matter studies to evaluate alternative policies and conditions as they affect resource use and the environment. They have been and continue to be applied to the problems of concern to or being analyzed by various state, regional and national users.

PHASES OF PROJECT

This project was carried out in three phases. The first phase involved the specification, development and quantification of the basic 233 producing region model. Data requirements were vast since restraints and coefficients had to be estimated for each of the nine land classes (18 in irrigated regions), the 223 producing regions, the 30 market regions, and the 51 water supply regions. Some of the versions of this model used included up to 75,000 real variables and 5,000 equations. One user application (the Environmental Protection Agency) was made during this phase and several subject matter studies (analysis of specific "real world" environmental, resource use and agricultural policy problems) were initiated during this period. The second phase involved an extremely large-scale user activity (the Water Resources Council and the National Water Assessment), several smaller user activities and the completion and initiation of several subject matter studies. Also during this period, large inputs were devoted to developing (a) a 105 producing region model with nine land classes conforming to the needs of the Water Resources Council, (b) a 150 region model with one land class per region for certain lower-cost policy analyses, (c) the conversion of a quadratic programming model tq capabilities of analyzing resource use and environmental problems, and (d) extending a simulation model which could stand alone in agricultural policy and resource use analysis and which could later be linked with the national and interregional programming models. A dozen major subject matter studies were completed, published and put to use over the nation during this phase.

The third phase, covering the period July 1, 1976, through June 30, 1978, involved updating and modifying the models so they covered a greater range of user needs, collaborating with the Economic Research Service (now the Economic Statistical Cooperative Service--ESCS) in extending OBERS projections and analyses for the Water Resources Council and for the Department of Agriculture, initiating and completing a very large users activity (the land use study for the Midwest Governors' Conference) and completing major subject matter studies. The project was funded on a reduced basis during this phase. However, model modification and development and subject matter studies progressed at an unabated pace during this period. Over a dozen major analyses were completed and some were initiated to be completed after grant termination. Finally, the first generation linkage of the national simulation model and the national interregional programming model was completed during this period while the second one was initiated.

While the third phase was particularly oriented to providing models for use by the ESCS in their general OBERS projections for the U.S. Department of Agriculture, it also was extended for use by other federal agencies. A pesticide impact group has been formed in the Natural Resources Economics Development (NRED) of the Economic Statistics Cooperative Service (ESCS) of USDA. This group then serves to make analyses for the Environmental Protection Agency (EPA). The EPA can posit various potential bans on chemicals and pesticides in agriculture. NRED and ESCS can input them to one of the ISU-NSF-RANN LP models and obtain solutions accordingly. Thus, EPA will become more or less a continuous user with the accessing completed through ESCS. This pesticide analysis is being set up so that it can be run from remote locations away from Iowa State University.

NRED of ESCS will continue to be an intensive user of the system in the future. It has plans for a wide variety of uses of the system during the few years ahead, including: weather analysis, irrigation development and analyses of individual water resource regions.

Ten subject matter studies were initiated by the Iowa State University project staff during the third phase. These subject matter studies included a wide coverage of problems including: an extended study of energy policies for agriculture in relation to resource use and especially irrigation, an evaluation using agricultural biomass as an energy source, a multigoal model for analysis of trade-offs between soil loss and nonpoint pollution and food producing efficiency, an evaluation of different policy mechanisms (outright legislation, subsidies or taxation) for limiting soil loss, a study of the conformance between supply control and price support policies for agriculture and attainment of national nonpoint pollution abatement goals (through soil loss control) and comparisons of consumers' and producers' surpluses, a macro evaluation of organic farming possibilities for U.S. agriculture, a measurement of interactions between national grain storage policy and environmental improvement, and others. Six of these subject matter studies have been completed and are written up in CARD reports. The others are nearing completion while some will be expanded into much larger studies and extended models over the future.

SUMMARY OF MODELS DEVELOPED

A family of models was built to meet the objectives of the project, fit the needs of various users, conform in specification of problems from the real world, and mesh with funds available for computations. The major work involved linear programming models. The two base linear programming models had 223 and 105 producing regions, respectively, nine land groups per producing region, and soil loss, irrigation and livestock production activities which were endogenous to the model. However, two linear programming models had 150 producing regions, one land class per producing region, exogenous livestock and irrigation sectors and no soil loss considerations. One programming model, converted to an agricultural energy model, included endogenous soil loss and irrigation sectors (with separate subsectors for surface and groundwater), an endogenous energy sector relating to energy from different sources, and an exogenous livestock sector. A model applied to potentials of pesticide use had irrigation, soil loss and livestock endogenous in 105 producing regions but had only five land classes per region. An extension of this model had an objective function embracing multiple goals. A quadratic programming model included commodity demand equations, 103 crop producing regions with one land class each and endogenous determination of equilibrium prices. During the last year, a revision of the general 105 region model had involved reduction of land classes to five and converting livestock production to an exogenous basis. A simulation model based on statistically estimated supply, demand and other relationships was modified for linkage with a reduced interregional programming model.

These models and variations have been reported in the publications which follow and in special documentations and CARD reports.[1] Hence, only three models will be summarized in this report: the 223 region and 105 region base linear programming models and the quadratic programming model. They are not summarized in the same detail as in their original publications and their data sets are not explained here.

The Base 223 Producing Region Model

The 223 region base model incorporates three sets of operational regions in delineating the interactions of production, marketing, and resource sectors. Restraints are included at the appropriate regional level on the availability of dry and irrigated cropland by quality class, pasture, permanent hay, water, nitrogen for fertilizer, and the demands for the crop and livestock commodities. A restraint imposed exogenous to the model initially screens all crop production activities, eliminating those which develop environmental parameters (soil loss levels) above the allowable limit. Activities, besides those for crop production, define the possibilities for livestock production; fertilizer and water purchase; demand

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[1]These models and their variations are explained in detail in the following reports (and in publications listed at the end of this report): Kenneth J. Nicol and Earl O. Heady. A Model for Regional Agricultural Analysis of Land and Water Use, Agricultural Structure and the Environment: A Documentation. Center for Agricultural and Rural Development, Iowa State University Press, Ames, 1975; Anton D. Meister and Kenneth J. Nicol. A Documentation of the National Water Assessment Model of Regional Agricultural Production, Land and Water Use and Environmental Interaction. Center for Agricultural and Rural Development, Iowa State University, Ames, 1976;

generation as related to population, industry, and international trade activities; the transfer of resources or commodities among regions; and requirements for the resources and agricultural goods for uses not specifically quantified in the model. A sector and restraint group delineation of the above-implied interactions is given in Figure 1. The model divides into three macro sectors including the resource availability; the production, the transfer, and transformation; and the demand generating sectors.

The resource availability sector indicates the number of acres of land in each region that is available for cropland production, including cropland hay and pasture. The land base is adjusted for the requirements of the crops whose regional distribution is not specifically determined endogenously while solving the model. Also included in this section is nitrogen fertilizer availability which determines the source and price of the nitrogen fertilizer component. Additional resource determinations include the land available for nonrotation hay and pasture and forest land grazed by region. Water supply by water region also is determined in the resource availability sector.

The production and product transfer sector utilizes the resources to produce the crop and livestock commodities for both intermediate and final uses. Included in this section are the crop and livestock production

footnote 1 continued.
Kent D. Olson, Earl O. Heady, Carl C. Chen, and Anton D. Meister. Estimated Impacts of Two Environmental Alternatives In Agriculture: A Quadratic Programming Analysis. CARD Report 72. Center for Agricultural and Rural Development, Iowa State University, Ames, 1977; Dan Dvoskin and Earl O. Heady. U.S. Agriculture Under Limited Energy Supplies, High Energy Prices, and Expanding Exports. CARD Report 69. Center for Agricultural and Rural Development, Iowa State University, Ames, 1976; Gary Vocke, Earl O. Heady, William G. Boggess, and Harold Stockdale. Economics Impacts on U.S.

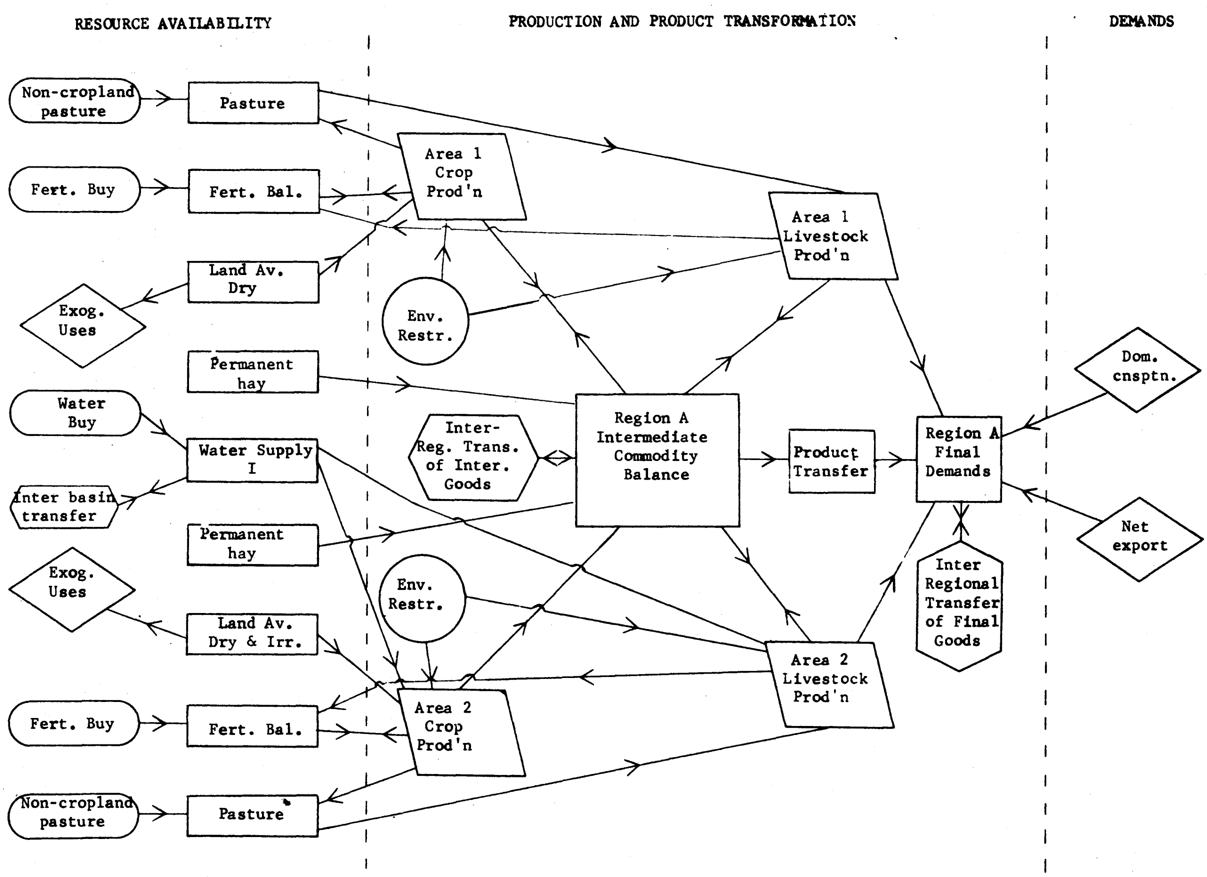

Figure 1. A schematic interaction outline of the NSF-CARD model

alternatives as related to the environmental considerations, interregional transportation for the transferable commodities, and product transformation activities.

The driving force for the model is the demand sector which provides base levels for the final demand commodities. The commodity demands are determined by considering the per capita consumption levels for the commodities, the domestic requirement for the nonendogenous livestock production alternatives, and the requirement to meet the level of exports specified for the analysis.

Abbreviated tableau

The interrelationships can be further delineated in the context of a linear programming tableau, Figure 2. The restraints in the model are represented by rows in the tableau, and the production, demand, and transformation alternatives are represented by the columns. Figure 2 gives an outline of such a tableau for the CARD-RANN model interactions based on three producing areas, two water supply regions, and two market or demand regions.

The restraints that control the allocation within the model are defined to include cropland by quality class, pasture, and fertilizer nitrogen at the producing area level; water supplies by water supply region; and the commodities endogenously constrained at the market region level,

footnote 1 continued.
Agriculture from Insecticide, Fertilizer, Soil Loss and Animal Waste Regulatory Policies. CARD Report No. 73. Center for Agricultural and Rural Development, Iowa State University, Ames, Iowa, 1977; Thomas M. Reynolds and Donald O. Mitchell. Alternative Futures for American Agricultural Structure, Policies, Income, Employment and Exports. CARD Report No. 56. Center for Agricultural and Rural Development, Iowa State University, Ames, Iowa, 1975.

except cotton, sugar beets, and spring wheat which have national markets and restraints. Soil loss restraints on a per acre basis are implied by controlling the crop production activities, thereby allowing only those meeting the restraint to be included. Additional restraints are included to regulate the level of the population, international trade, exogenous crop and livestock production, water availability, water transfers and exports, and nonrotation hay and pasture production. The form of the restraints is indicated in Figure 2 as being either upper (U) or lower (L) restraints, and all activities have the additional restraint implied in the standard linear programming formulation which requires all activities to be greater than zero. (The default can be changed to allow negative levels, but for our modeling the greater-than-zero restraint holds for all activities.)

The activities in the model (the columns in Figure 2) represent the demand generating, commodity production and transfer, and resource purchase alternatives. In the tableau, the interaction of the activities with each of the resources is indicated by a positive or negative sign appropriate with the formulation.

The first four activity categories and their associated lower bounds represent the demand sector of the model which must be satisfied by the appropriate incorporation of the other activities. Population and industry activities, defined by producing area, interact with the market regions to create a demand for the commodities and, with the water supply regions, to create a water use requirement representing municipal and industrial needs. The per capita use coefficients and the population bound insert an accumulation of demands into the appropriate market or water regions.

1, 2, 3-producing areas
A, B-market regions
I, II-water supply regions
i for the 18 land classes

	popln & ind. 1	popln & ind. 2	popln & ind. 3	intnl trade A	intnl trade B	exog. lvstk A	exog. lvstk B	exog. crops A	exog. crops B	crop prodn 1 i	crop prodn 2 i	crop prodn 3 i	livestock 1	livestock 2	livestock 3	buy fert. 1	buy fert. 2	buy fert. 3	buy water I	buy water II	water export I	water transfer I-II	comm. transp. A-B	comm. transp. B-A	non-rotn past 1	non-rotn past 2	non-rotn past 3	non-rotn hay 1	non-rotn hay 2	non-rotn hay 3	beef quality transfer A	beef quality transfer B	
Cropland 1 i										+																							≦ i
Cropland 2 i											+																						≦ i
Cropland 3 i												+																					≦ i
Pasture 1						-				+			-												+								≧ 0
Pasture 2						-					+			-												+							≧ 0
Pasture 3							-					+			-												+						≧ 0
Water I		-				-		-		-			-						+		-	-			-			-					≧ 0
Water II			-								-			-						+		+				-			-				≧ 0
Fertilizer 1						+		-		-			+			+																	≧ 0
Fertilizer 2						+		-			-			+			+																≧ 0
Fertilizer 3							+		-			-			+			+															≧ 0
Commodities A	-	-		-		-				+	+		±	±									-	+				+	+		∓		≧ 0
Commodities B			-		-		-					+			±								+	-						+		∓	≧ 0
Cost										+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+			
Bound	L	L	L	L	L	L	L	L	L										U	U	L	U			U	U	U	U	U	U			

Figure 2. Interactions within the agricultural sectors on a regional basis using a LP tableau approach

The international trade activities are expressed as net export levels and are formulated with bound limits on the activities which represent net export of the commodities: corn, sorghum, oats, barley, oilmeals, wheat, and cotton. International trade for each of the commodities not allocated endogenously to the central model is determined, and their level of domestic requirement is adjusted to reflect this option. The export activities are defined by consuming region, and the relative magnitude of each bound determines the regional distribution of the net export as based on the shipments from the major ports in the region.

The exogenous livestock classes are represented by a set of activities that simulate a fixed level of production of broilers, turkeys, eggs, sheep and lambs, and an "other livestock" category. These alternatives utilize pasture, water, and the commodities that are relevant for the type of livestock and the typical regional production method. These livestock activities also produce nitrogen into the regional fertilizer balance at a level approximating the production of nitrogen equivalents from their wastes. The lower bound forces in the required level of production by market region and is representative of the region's proportionate share of each of the exogenous livestock groups.

The exogenous crop sector accounts for the water and fertilizer requirements of those crops that have small production levels or whose production patterns are concentrated in one or two areas. Included in this category are such crops as broomcorn, buckwheat, cowpeas, dry beans, dry peas, flax, hops, orchards and vineyards, peanuts, potatoes, proso-millet, rice, rye, safflower, sugar cane, sunflowers, sweet potatoes, tobacco, and vegetables. The activities representing the aggregate production patterns of these crops indicate the utilization of water and fertilizer by these crops. This crop sector does not interact with the land base because the land base is defined as land available for crop production after these exogenous commodities have been allocated their acreage.

The next two sectors named in Figure 2 indicate the heart of the model's production sector. These two sectors produce the endogenous crop and livestock commodities to satisfy the demand levels determined in the demand generating sector. The crop production sector produces the endogenous commodities: barley, corn, corn silage, cotton, legume hay, nonlegume hay, oats, sorghum, sorghum silage, soybeans, sugar beets, wheat (both spring and winter), and summerfallow. The cropping activities are defined to represent rotations ranging from one to eight years in length, incorporating the above-named crops in appropriate combinations to give the desired rotational effect. Alternative conservation and tillage practices are combined with the regions' rotations to provide a spectrum of crop management systems each reflecting a different soil loss level. The crop production activities interact with the relevant land group utilizing an acre of this land and the other resources, water and fertilizer, as is appropriate for the defined crop management system. These activities produce commodities based on the cropping system and also produce aftermath pasture in a quantity variable with the crops included in the rotation and the historic utilization of this pasture alternative.

The livestock alternatives include dairy cow, beef cow, beef feeding, and pork enterprises. The livestock activities utilize water, pasture, and the feed commodities that are appropriate for their defined rations and location. They produce intermediate commodity feeders; the final demand commodities, dairy products, fed and nonfed beef (a secondary product of the beef cow and dairy operations) and pork; and the by-product residual nitrogen available for fertilizer.

The remaining activities incorporate the resource availability and commodity or resource transfer sectors. The fertilizer and water-buy sectors represent the purchase of the particular resource at the relevant regional price. The upper bound for water is consistent with the available water supply. The water export sector represents contractual water laws requiring the transfer of water from within the water supply regions to other areas external to the water supply region. The water transfer activities represent both natural flow and developed interbasin transfer networks to move water between the relevant water supply regions. Similarly, the commodity transport sector represents the movement of the intermediate or final goods from market region to market region as is consistent with the transport networks and the feasibility of transferring the commodities. The nonrotation hay and pasture activities represent the production of roughage from lands not presently defined as being under cultivation. They provide roughage in nonlegume hay equivalents into the nonlegume hay or pasture balance markets and utilize water for those lands which have historically produced these commodities under irrigation.

The final sector represents the transfer of fed beef from its market into the nonfed or cull beef category. This activity allows for the balancing of the two meat markets without having a surplus of the primary products (milk or feeders), as the producing activities attempt to increase production of the cull or nonfed beef while preventing the lower quality beef from satisfying more than its historic proportion of the regional market.

Regional delineations in the model

In completely defining the workings of the model, five separate sets of regions are incorporated. The first represents regions within which the data base is defined; the second, the areas within which the production activities are defined; the third, the regions detailing water availability and transfer possibilities; the fourth, the areas within which the markets are defined; and the fifth, the regions into which the results are aggregated for reporting.

The data regions

These regions represent many sets of political and geographic areas within which data is tabulated by the collecting agencies. They include the counties and states of the continental United States within which census and commodity production data are tabulated. An additional set of regions included in this group is the county approximations of the major land resource areas as used for data collection by the Soil Conservation Service, U.S. Department of Agriculture (Figure 3). These regions divide the land in the continental United States into 164 areas based on soil type and management characteristics. It is from these regions that the data used in calculating the soil loss by alternative cropping activity is developed.

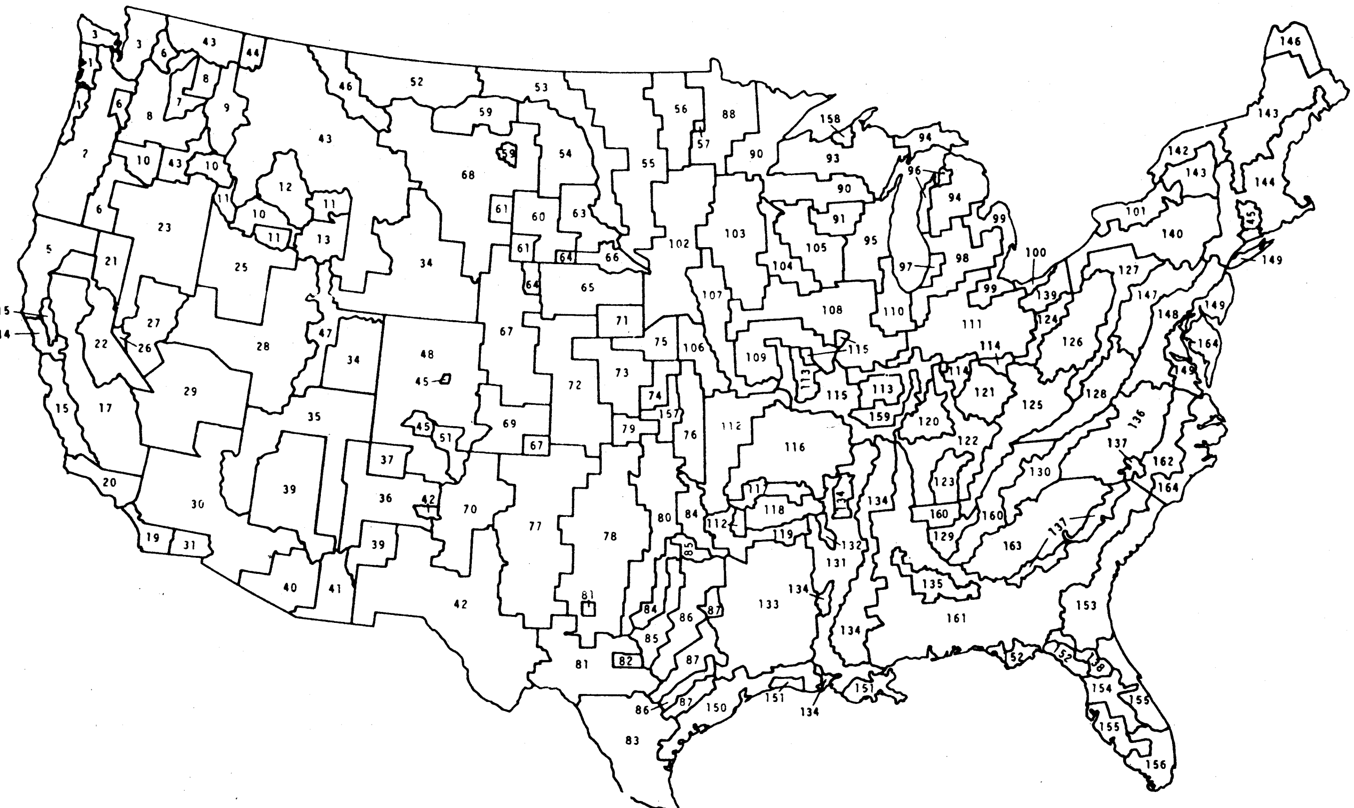

Figure 3. The SCS data collection areas

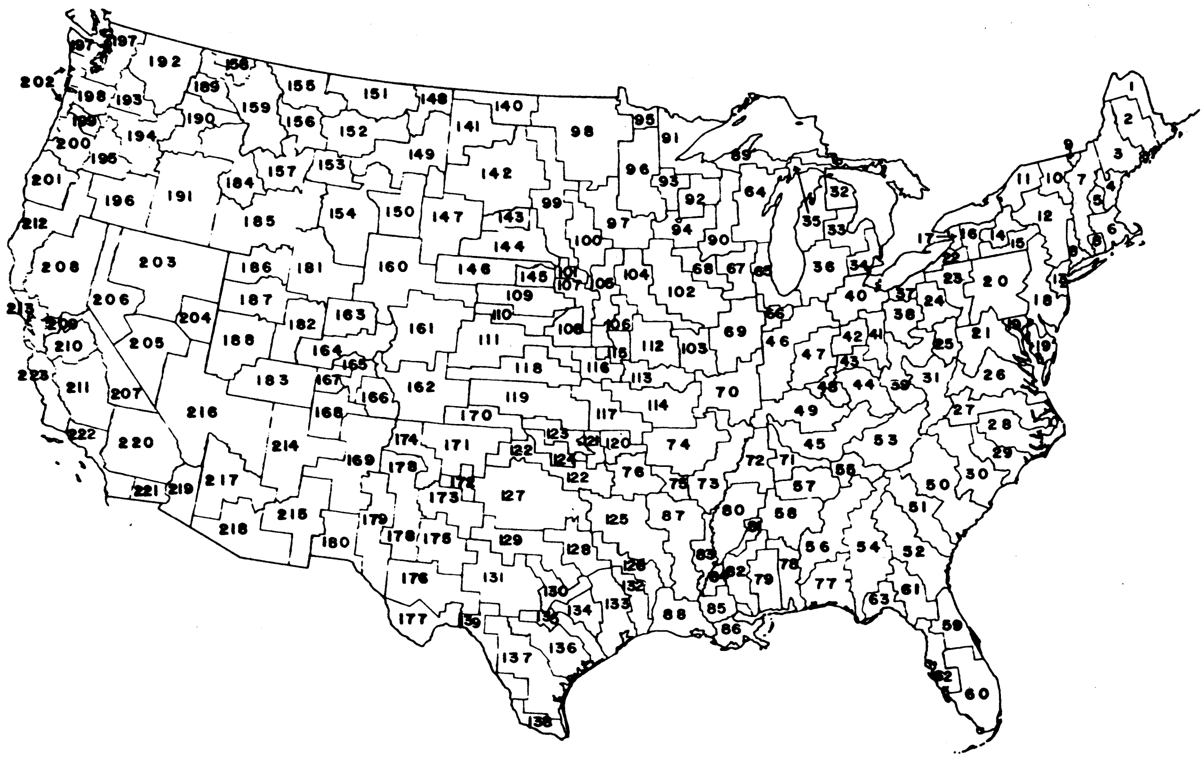

Figure 4. The 223 producing areas

Sets of weights based on relevant data relationships are used to transfer data from the regions in which they are obtained into the common resource or producing areas where the data are used in the model or in combination with other data to generate coefficients to be used in the model.

The producing areas

Figure 4 illustrates the 223 producing areas defined in the model. These areas are based on county approximations of the Water Resources Council's subareas modified to be consistent with the water supply regions and the market regions. Each producing area is an aggregation of contiguous counties contained in a watershed draining to a common waterway. The producing areas represent the regions in which crop and livestock production activities and the land by quality class, pasture, and nitrogen balance restraints are defined.

The water supply regions

Fifty-one water supply regions define the areas in the 17 western states where water supplies are determined in the model (Figure 5). These regions are an aggregation of contiguous producing areas within which a water supply can be said to exist. The subdivisions of the 18 major river basins of the Water Resources Council form the basis of these regions.

The market regions

Contiguous producing areas are aggregated into major marketing areas of the United States to give the 30 market regions for the model (Figure 6). It is within these regions that the market balance restraints are defined

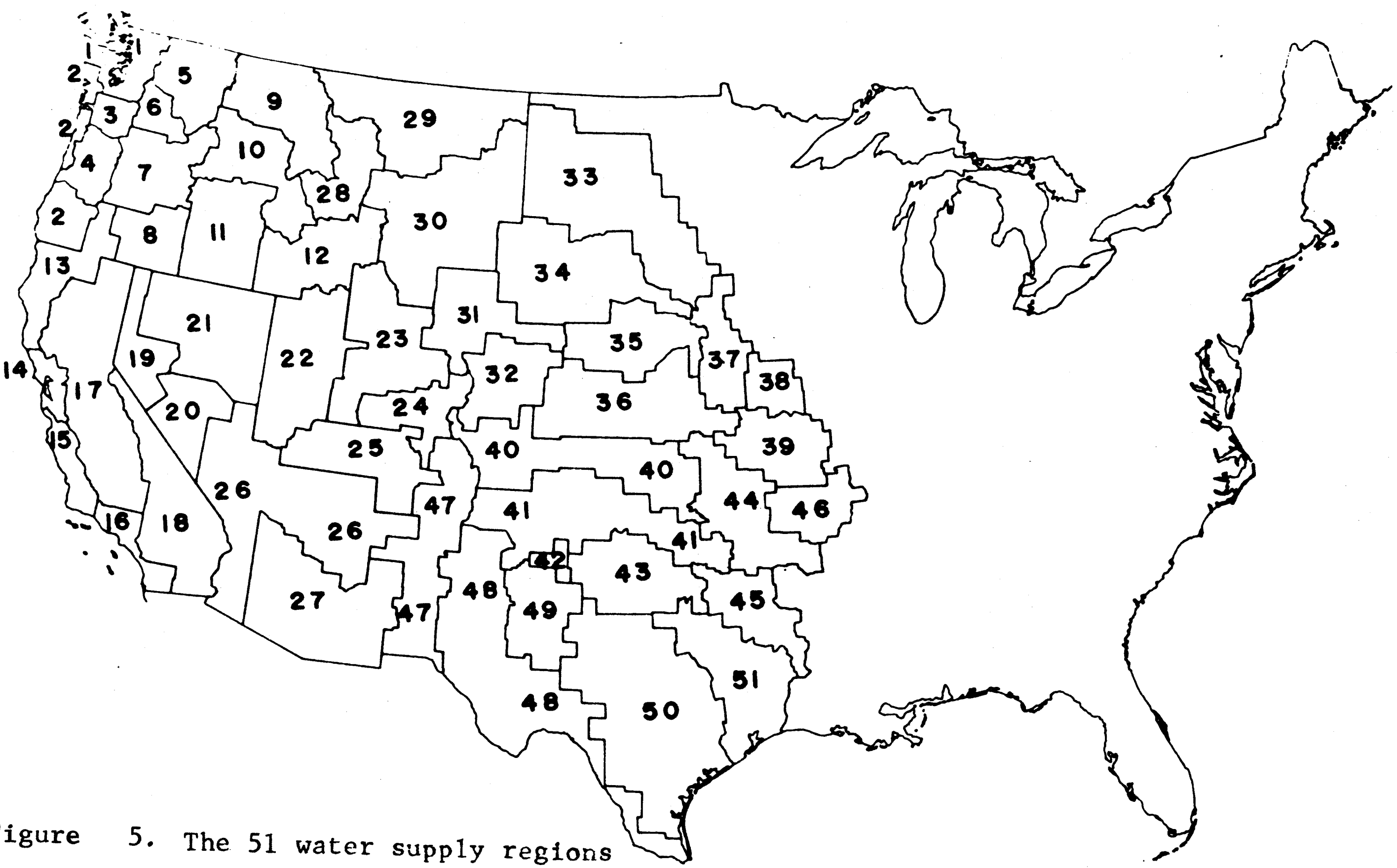

Figure 5. The 51 water supply regions

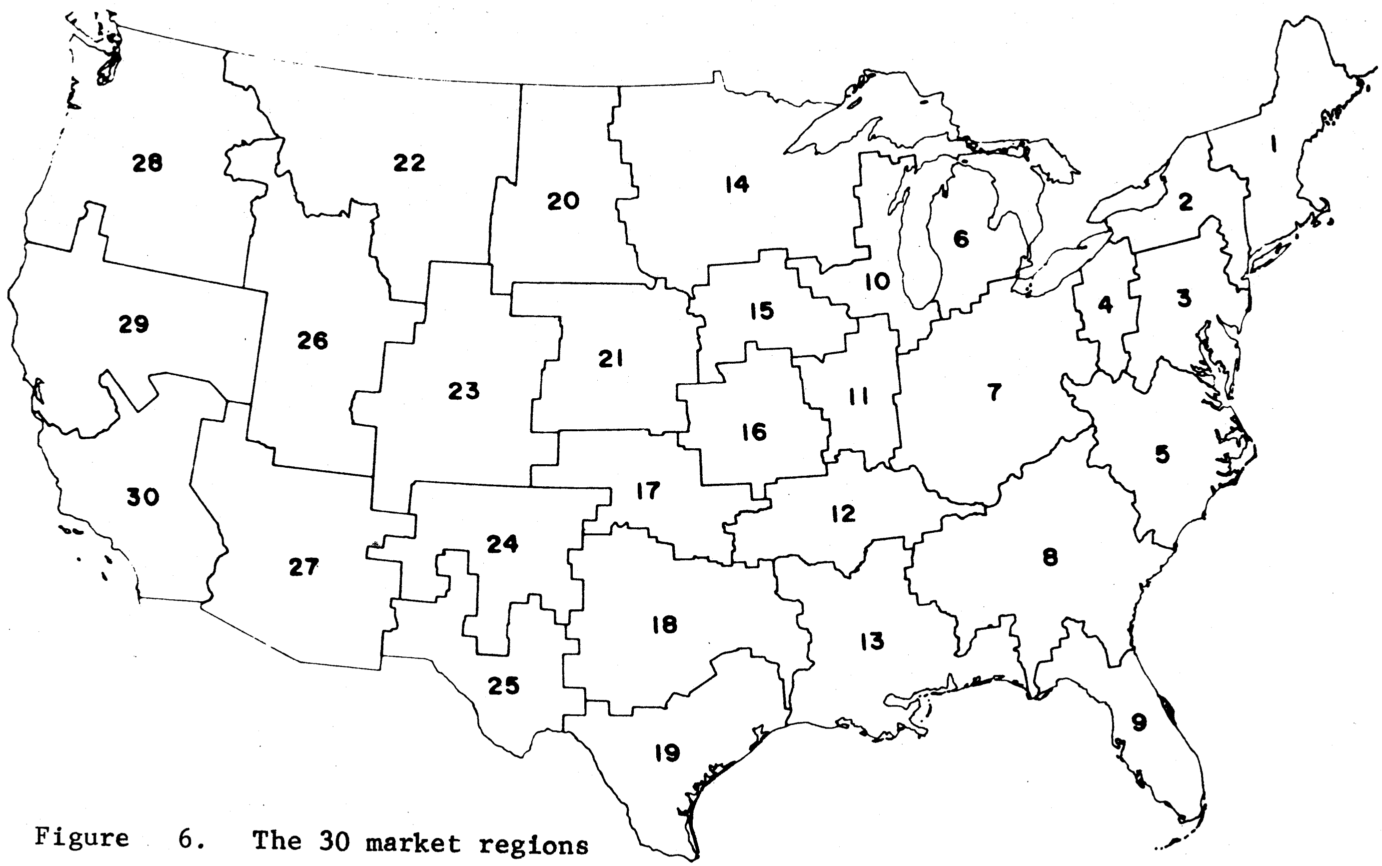

Figure 6. The 30 market regions

for the major commodities analyzed. The regions also have as their market center a city that serves as a hub in the existing national transportation network. The commodity transfer section of the model uses these centers as points between which commodities are moved as the model adjusts its production pattern to account for each region's comparative advantage.

The reporting regions

These regions represent aggregations of the market regions such that regional similarities in agricultural production possibilities are maintained. The resulting seven regions form a manageable number between which regional comparisons can be defined while neither completely over aggregating the production impacts nor creating a reporting system completely overpowered by numbers. An approximation of these regions is given in Figure 7.

Mathematical explanation of the model

A linear programming problem forms a simple simultaneous equation network representing the group of restraints, with one of the equations designated as the functional relationship that is to be optimized over those activities in the final basis (solution). The following sections outline the objective function and the restraints that are combined to provide the interrelationships encompassing this model.

The objective function The objective function of the basic model is defined to minimize the cost of producing the given demands subject to the restraints on the availability of land, water, fertilizer, pasture, and the intermediate commodities. It represents a minimization of the cost

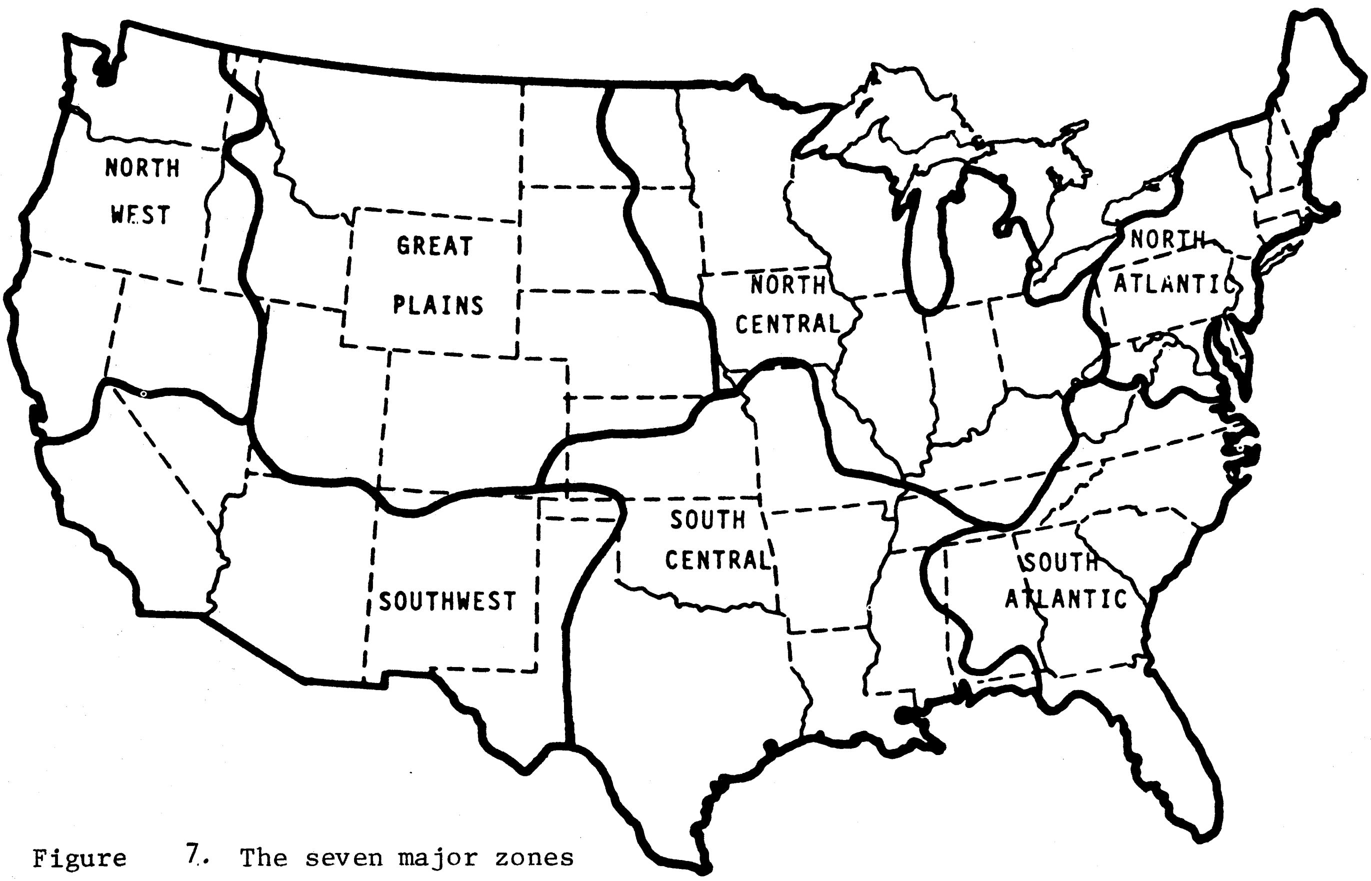

Figure 7. The seven major zones

of producing and transporting the intermediate products and the final commodities of the model, including the costs of obtaining and transferring water. It simulates competitive equilibrium since all costs of production (including return on the farm families' labor) must be covered. The function can be represented by:

$$\min \Sigma_i \left(\Sigma_k \Sigma_m X_{ikm} XC_{ikm} + \Sigma_n Y_{ikn} YC_{ikn} + \Sigma_m Z_{ikm} ZC_{ikm}\right)$$

$$+ \Sigma_p L_{ip} LC_{ip} + DPP_i PAC_i + IPP_i PAC_i + DWH_i PAC_i$$

$$+ IWH_i PAC_i + FLG_i PAC_i + FP_i UC_i) + \sum_w (WB_w WC_w + WD_w WC_w + WT_w WC_w)$$

$$+ \sum_t \sum_c T_{tc} TC_{tc} \qquad (1)$$

c = 1, 2, ..., 17 for the endogenous commodities,[1]
i = 1, 2, ..., 223 for the producing areas,
j = 1, 2, ..., 30 for the market regions,
k = 1, 2, ..., 9 for the land classes in each producing area,
m = 1, 2, ..., for the dryland crop management systems defined on a land class in a producing area,
n = 1, 2, ..., for the irrigated crop management systems on a land class in a producing area,
p = 1, 2, ..., for the livestock activities defined in the purchasing area,
w = 1, 2, ..., 51 for the water supply regions, and
t = 1, 2, ..., 458 for the transportation routes.

Where:

X_{ikm} is the number of acres of dryland crop management system m on land class k employed in producing area i;

XC_{ikm} is the per acre cost of dryland crop management system m on land class k in producing area i;

Y_{ikn} is the number of acres of irrigated crop management system n on land class k employed in producing area i;

YC_{ikn} is the per acre cost of irrigated crop management system n on land class k in producing area i;

Z_{ikm} is the number of acres of dryland crop management system m on irrigated land class k employed in producing area i;

ZC_{ikm} is the cost per acre of dryland crop management system m on irrigated land class k in producing area i;

L_{ip} is the number of units of livestock activity p employed in producing area i;

[1]Barley, corn, cotton, dairy products, fed beef, legume hay, oats, nonfed beef, nonlegume hay, oilmeal, pork, silage, sorghum, soybeans, sugar beets, and wheat.

LC_{ip} is the unit cost of livestock activity p in producing area i;

DPP_i is the number of acres of dryland permanent pasture employed in producing area i;

IPP_i is the number of acres of irrigated permanent pasture employed in producing area i;

DWH_i is the number of acres of dryland wild hay employed in producing area i;

IWH_i is the number of acres of irrigated wild hay employed in producing area i;

PLG_i is the number of acres of forest land grazed employed in producing area i;

PAC_i is the per acre cost of the respective permanent roughage source in producing area i;

FP_i is the number of pounds of nitrogen fertilizer purchased in producing area i;

UC_i is the unit cost of fertilizer in producing area i;

WB_w is the number of acre feet of water purchased for use in water supply region w;

WD_w is the number of acre feet of water generated from desalting in water supply region w;

WT_w is the number of acre feet of water transferred from water supply region w;

WC_w is the cost per acre foot of the associated water activity in water supply region w;

T_{tc} is the net movement of commodity c over transport route t expressed in the units of the commodity; and

TC_{tc} is the per unit cost of transporting commodity c over transport route t.

Restraints at the activity level in the model Restraints on the level of an activity or group of activities are included in the linear programming model at the activity, producing area, water supply region, market region, and national level. Each crop management system activity and certain other activities, such as population-industry, water-buy, water-transfer, commodity-export, nonrotation pasture production, and nonrotation hay production, are regulated at the individual component level.

The population-industry activities represent the interaction of the consumer and manufacturing sectors of the economy with the agricultural sector. One activity is defined for each of the producing areas and is of the form:

$$PN_i \geq LPN_i \qquad (2)$$

i = 1, 2, ..., 223 for the producing areas.

Where:

PN_i is the level of population in producing area i; and

LPN_i is the lower level of population allowed in producing area i.

The lower limit on the regional population activity is set at a level consistent with the Bureau of Economic Analysis's population projections for the area.

A set of activities, closely related to the population-industry activities, generates a demand for water in each of the 51 water supply regions to reflect the increased demand for water navigation, wetlands, and other onsite water consuming activities. The onsite demand for water reflects a use over and above the level in 1969, because the 1969 level of use is not part of the calculated available supply. These restraints are of the form:

$$WO_w \geq RWO_w \quad (3)$$

$w = 1, 2, \ldots, 51$ for the water supply regions.

Where:

WO_w is the level of water used for wetland, navigation, and other onsite uses in water supply region w; and

RWO_w is the required minimum level of water needed for wetland, navigation and other onsite uses in water supply region w.

The foreign trade sector of the model adjusts the commodity demands to reflect the international aspects of agricultural equilibrium. For the base model, trade of all commodities is held at a level equal to the 1969 to 1971 annual average net trade.

The export demands for the commodities corn, sorghum, barley, oats, wheat, and oilmeals are allocated to the market regions where they are restrained as:

$$E_{jc} \geq EX_{jc} \quad (4)$$

$j = 1, 2, \ldots, 30$ for the market regions,
$c = 1, 2, \ldots, 17$ for the commodities.

Where:

E_{jc} is the level of export of commodity c from market region j; and

EX_{jc} is the regional minimum level of export of commodity c from market region j.

The activities controlling the export of water to areas outside the water resource areas are bound with restraints of the form:

$$WE_w \geq LWE_w \qquad (5)$$

$w = 1, 2, \ldots, 51$ for the water supply regions.

Where:

WE_w is the level of export of water from water supply region w; and

LWE_w is the lower limit arranged by compact for export of water from water supply region w.

The exogenous crop sector, representing the production of crops not included in the model, adjusts for water and fertilizer requirements through restraining activities of the following form:

$$EC_{ih} \geq PEC_{ih} \qquad (6)$$

$i = 1, 2, \ldots, 223$ for the producing areas,
$h = 1, 2, \ldots, 19$ for the exogenous crop groups in the model.

Where:

EC_{ih} is the level of the activity for exogenous crop group h in producing area i; and

PEC_{ih} is the required minimum level of the exogenous crop group h in producing area i.

Similarly, the exogenous livestock sector, representing production of the livestock commodities not endogenously allocated, is restrained to account for feed, pasture, and water requirements and the production of nitrogen equivalent wastes as:

$$EL_{ie} \geq PEL_{ie} \qquad (7)$$

i = 1, 2, ..., 223 for the producing areas,
e = 1, 2, ..., 5 for the exogenous livestock groups considered.

Where:

EL_{ie} is the level of exogenous livestock activity e in purchasing area i; and

PEL_{ie} is the prespecified minimum level of exogenous livestock activity e in producing area i.

Restraints are defined on the water purchase activities in each water supply region to control the level of water use at a level consistent with the regions' water resources. This restraint is of the form:

$$WP_w \leq WS_w \qquad (8)$$

w = 1, 2, ..., 51 for the water supply regions.

Where:

WP_w is the number of acre feet of water purchased in water supply region w; and

WS_w is the number of acre feet of water in the predetermined supply in water supply region w.

Restraints for the irrigated and dryland native and noncropland roughages are of the forms:

Dryland hay for producing area i:

$$DWH_i \leq ADWH_i \tag{9}$$

Irrigated hay for producing area i in the irrigated area:

$$IWH_i \leq AIWH_i \tag{10}$$

Dryland permanent pasture for producing area i:

$$DPP_i \leq ADPP_i \tag{11}$$

Irrigated permanent pasture for producing area i in the irrigated area:

$$IPP_i \leq AIPP_i\text{, and} \tag{12}$$

Forest land grazed for each producing area i:

$$FLG_i \leq AFLG_i \tag{13}$$

i = 1, 2, ..., 223 for the producing areas,

Where:

DWH_i is the number of acres of dryland wild hay cut in producing area i;

IWH_i is the number of acres of irrigated wild hay cut in producing area i;

DPP_i is the number of acres of dryland permanent pasture grazed in producing area i;

IPP_i is the number of acres of irrigated permanent pasture grazed in producing area i;

FLG_i is the number of acres of forest land grazed in producing area i; and

A is the number of acres of the type of roughage source indicated as corresponding to the above five types in producing area i.

Within the crop production sector two activity restraints exist. The first regulates the per acre soil loss and is of the form:

$$SL_{ikm+n} \leq ASI_{ik} \tag{14}$$

i = 1, 2, ... 223 for the producing areas,
k = 1, 2, ..., 9 for the land classes,
m = 1, 2, ..., for the dryland crop management systems on the land class in the producing area,
n = 1, 2, ..., for the irrigated crop management systems on the land class in the producing area.

Where:

SL_{ikm+n} is the level of soil loss associated with the crop management system in m+n on land class k in producing area i; and

ASI_{ik} is the allowed level of soil loss on land class k in produc-in area i.

The second restraint is not directly incorporated but is implied in the definition of the rotations. This restraint maintains cropping sequences which are agronomically feasible. As an example, it is not a recommended policy to raise continuous soybeans in the Corn Belt. Thus, no crop management system representing soybeans grown alone continuously is defined. The remaining restraints in the model are multiple activity restraints and are defined at the relevant region level.

Restraints defined at the producing area level   The major restraint at the producing area level is the availability of cropland. Within each producing area there exists the possibility of nine land groups in each of the dryland and irrigated agricultural sectors. The nine land groups represent aggregations of the major land class and subclass categories of the Soil Conservation Service, U.S. Department of Agriculture. The dryland restraint by producing area and the land class is of the form:

$$\sum_m X_{ikm} a_m \leq LD_{ik} \qquad (15)$$

i = 1, 2, ..., 223 for the producing areas,
k = 1, 2, ..., 9 for the land groups, and
m = 1, 2, ..., for the dryland crop management systems defined.

Where:

X_{ikm} is the number of units of crop management system m employed on land class k in producing area i;

a_m is the number of acres of land associated with one unit of crop management system m (scaled to be one acre for this formulation); and

LD_{ik} is the number of acres of dryland available in land class k in producing area i.

and the irrigated cropland restraint by producing area by land class is of the form:

$$\sum_n Y_{ikn} a_n + \sum_m Z_{ikm} a_m \leq LR_{ik} \qquad (16)$$

i = 1, 2, ..., 223 for the producing areas,
k = 1, 2, ..., 9 for the land groups,
m = 1, 2, ..., for the dryland crop management systems, and
n = 1, 2, ..., for the irrigated crop management systems.

Where:

Y_{ikn} is the number of units of irrigated crop management system n employed on land class k in producing area i;

a_n is the number of acres of land associated with one unit of irrigated crop management system n;

Z_{ikm} is the number of units of dryland crop management system m employed on irrigated land class k in producing area i;

a_m is the number of acres of land associated with one unit of dryland crop management system m; and

LR_{ik} is the number of acres of irrigated land available in land class k in producing area i.

The nitrogen fertilizer balance is also defined at the producing area level and has the form:

$$FP_i + \sum_p L_{ip} b_{ip} + \sum_e EL_{ie} b_e - \sum_h EC_{ih} f_{ij} - \sum_k (\sum_m X_{ikm} fx_{im}$$

$$+ \sum_n Y_{ikn} fy_{in} + \sum_m Z_{ikm} fx_{im}) - DPP_i ff_i - IPP_i ff_i$$

$$- DWH_i ff_i - IWH_i ff_i - FLG_i ff_i = 0 \qquad (17)$$

$e = 1, 2, \ldots, \ \ 5$ for the exogenous livestock groups considered,
$i = 1, 2, \ldots, 223$ for the producing areas,
$k = 1, 2, \ldots, \ \ 9$ for the land groups,
$m = 1, 2, \ldots,$ for the dryland crop management systems defined,
$n = 1, 2, \ldots,$ for the irrigated crop management systems defined, and
$p = 1, 2, \ldots,$ for the livestock activities defined.

Where:

FP_i is the number of pounds of fertilizer purchased in producing area i;

L_{ip} is the number of units of livestock type p in producing area i;

b_p is the number of pounds of fertilizer per unit of livestock type p;

EL_{ie} is the number of units of exogenous livestock group e in producing area i;

b_e is the number of pounds of fertilizer per unit of livestock type e;

EC_{ih} is the number of acres of exogenous crop group h in producing area i;

f_{ih} is the number of pounds of fertilizer nitrogen required per acre of exogenous crop group h in producing area i;

X_{ikm} is the level of crop management system m employed on land class k in producing region i;

fx_{im} is the pounds of nitrogen required per unit of crop management system m in producing area i;

Y_{ikn} is the level of crop management system n employed on land class k in producing area i;

fy_{in} is the pounds of nitrogen required per acre of crop management system n in producing area i;

Z_{ikm} is the level of crop management system m employed on irrigated land class k in producing area i;

DPP_i is the acres of dryland permanent pasture grazed in producing area i;

IPP_i is the acres of irrigated permanent pasture grazed in producing area i;

DWH_i is the acres of dryland permanent hayland cut in producing area i;

IWH_i is the acres of irrigated permanent hayland cut in producing area i;

FLG_i is the acres of forest land grazed in producing area i; and

ff_i is the pounds of nitrogen required per acre for the corresponding noncropland roughage source.

The final restraint defined at the producing area level controls the use of the pasture-associated roughages and is of the form:

$$\sum_k (\sum_m X_{ikm} rx_{ikm} + \sum_n Y_{ikn} ry_{ikn} + \sum_m Z_{ikm} rx_{ikm}$$

$$+ DPP_i r_i + IPP_i r_i + FLG_i r_i - \sum_p L_{ip} qf_{ip} - EL_{ei} q_{ei} \geq 0 \qquad (18)$$

i = 1, 2, ..., 223 for the producing areas,
k = 1, 2, ..., 9 for the land groups,
m = 1, 2, ..., for the dryland crop management systems,
n = 1, 2, ..., for the irrigated crop management systems, and
p = 1, 2, ..., for the livestock activities.

Where:

X_{ikm} is the level of dryland crop management system m on land group k in producing area i;

CX_{ikm} is the yield of aftermath pasture from dryland crop management system m on land group k in producing area i;

Y_{ikn} is the level of irrigated crop management system n on land group k in producing area i;

ry_{ikn} is the yield of aftermath pasture from dryland crop management system n on land group k in producing area i;

Z_{ikm} is the level of dryland crop management system m on irrigated land in land group k in producing area i;

DPP_i is the number of acres of dryland pasture grazed in producing area i;

IPP_i is the number of acres of irrigated pasture grazed in producing area i;

FLG_i is the number of acres of forest land grazed in producing area i;

r_i is the yield of nonlegume hay equivalent roughage per acre of the respective pasture type in producing area i;

L_{ip} is the number of units of livestock type p in producing area i;

gf_{ip} is the quantity of pasture consumed by livestock type p in producing area i;

EL_{ie} is the number of units of exogenous livestock type e in producing area i;

q_{ie} is the quantity of pasture consumed by exogenous livestock type e in producing area i; and

rx_{ikn} is the yield of aftermath pasture from irrigated crop management system n on land group k in producing area i;

Restraints defined by water suppy region   The water supply regions control the availability of water and regulate the flow and allocation of transfers. The water use restraint for region w is of the form:

$$WB_w \pm WT_w \pm WI_w - WO_w - WX_w - WE_w + WD_w$$

$$- \sum_{i \varepsilon w} (IWH_i d_i - IPP_i d_i - \sum_k \sum_n Y_{ikn} dy_{in}$$

$$- \sum_p L_{ip} dl_{ip} - PN_i d_{ip}) \geq 0 \qquad (19)$$

i = 1, 2, ..., 223 for the producing area,
k = 1, 2, ..., 9 for the land groups,
n = 1, 2, ..., for the irrigated crop management systems,
p = 1, 2, ..., for the livestock activities,
w = 1, 2, ..., 51 for the water supply regions, and
ε = a symbol for "included in."

Where:

WB_w is the number of acre feet of water purchased to generate the water supply in region w;

WT_w is the number of acre feet of gross water transfer from region w;

WI_w is the number of acre feet of gross interbasin flows from region w;

WO_w is the number of acre feet of water used for onsite requirements in region w;

WE_w is the number of acre feet of water exported under compact from region w;

WX_w is the number of acre feet of water required for use by the exogenous crops and livestock in the region w;

WD_w is the number of acre feet of water developed through desalting in water region w;

IWH_i is the number of acres of irrigated wild hay in producing area i;

IPP_i is the number of acres of irrigated permanent pasture grazed in producing area i;

d_i is the number of acre feet of water required per acre of the respective permanent roughage crops;

Y_{ikn} is the number of acres of irrigated crop management system n on land group k in producing area i;

dy_{in} is the number of acre feet of water required per acre of crop management system n in producing area i;

L_{ip} is the number of units of livestock type p in producing area i;

dl_{ip} is the number of acre feet of water required per unit of livestock type p in producing area i;

PN_i is the level of population in producing area i; and

dp_i is the number of acre feet of water required per capita for municipal and industrial needs in producing area i;

The water transfer restraint in each region w is of the form:

$$WT_w + WI_w + WE_w \leq .75WS_w \qquad (20)$$

Where:

WT_w is the number of acre feet of natural flow transfers from region w;

WI_w is the number of acre feet of interbasin flows from region w; and

WE_w is the number of acre feet of water exports from region w.

Restraints by market region The only set of restraints defined at the market region level represents the commodity market balance for all the endogenously allocated commodities except cotton, sugar beets, and spring wheat. The restraint for commodity c is of the form:

$$\sum_{i\varepsilon j} (\Sigma (\sum_m X_{ikm} cx_{ikmc} + \sum_n Y_{ikn} cy_{iknc} + \sum_m Z_{ikm} cx_{ikmc})$$

$$\pm \sum_p L_{ip} cl_{ipc} - PN_i cp_{ic}) \pm \sum_{t\varepsilon j} T_{tc} \pm E_{jc} - EL_{ej} cy_{ejc} \geq 0 \qquad (21)$$

e = 1, 2, ..., 5 for the exogenous livestock types,
i = 1, 2, ..., 223 for the producing areas,
j = 1, 2, ..., 30 for the market regions,
k = 1, 2, ..., 9 for the land groups,
m = 1, 2, ..., for the dryland crop management systems,
n = 1, 2, ..., for the irrigated crop management systems,
p = 1, 2, ..., for the livestock activities defined endogenously,
t = 1, 2, ..., 458 for the transportation routes in the model, and
ε = a symbol for "included in."

Where:

X_{ikm} is the level of dryland crop management system m on land class k in producing area i;

CX_{ikmc} is the yield of commodity c per unit of crop management system m on land class k in producing area i;

Y_{ikn} is the level of irrigated crop management system n on land class k in producing area i;

CY_{iknc} is the yield of commodity c per unit of crop management system n on land class k in producing area i;

Z_{ikm} is the level of dryland crop management system m on land class k in producing area i;

L_{ip} is the level of livestock activity p in producing area i;

cl_{ipc} is the yield of, or requirement for, commodity c by livestock activity p in producing area i;

PN_i is the level of population in producing area i;

cp_{ic} is the per capita requirement for commodity c in producing area i;

T_{tc} is the net transfer of commodity c from market region j through transportation activity t;

E_{jc} is the net international export of commodity c from market region j;

EL_{ej} is the level of employment of exogenous livestock activity e in market region j; and

cy_{ejc} is the requirement of commodity c by exogenous livestock activity e in market region j.

Restraints at a national level The restraints at the national level include international trade restraints and the national commodity balances for cotton, sugar beets, and spring wheat. The commodity balances are of the form:

$$\sum_i \left(\sum_k \left(\sum_m X_{ikm} cx_{ikmc} + \sum_n Y_{ink} cy_{inkc} + \sum_m Z_{ikm} cx_{ikmc}\right) - PN_i cp_{ic}\right) - E_c \geq 0 \qquad (22)$$

where all variables are defined in equation 21 except c + 4, 10, and 12.

The export restraints are of the form:

$$\sum_i E_{jc} \geq EX_c \qquad (23)$$

c = 1, 2, ..., 17 for the commodities (see footnote 1, p. 12),
j = 1, 2, ..., 30 for the market regions.

Where:

E_{jc} is the export level of commodity c from market region j; and

EX_c is the national export level of commodity c stipulated;

and the imports are of the form:

$$\sum_i E_{ic} \leq IM_c \qquad (24)$$

c = 1, 2, ..., 17 for the commodities,
and
i = 1, 2, ..., 223 for the producing areas.

Where:

E_{ic} is the net export level for commodity c from producing area i;

and

IM_c is the national import level of commodity c stipulated.

Each of the above variables is also regulated by the nonnegativity restraints consistent with the model formulation as follows;

$$X_{ikm}, Y_{ikn}, Z_{ikm}, L_{ip}, DWH_i, IWH_i, IPP_i, FLG_I, FP_i, EL_i, WB_w, DDP_i,$$

$$WT_w, WI_w, WD_w, WX_w, WE_w, PN_i, T_{tc}, E_{jc}, EC_i, EL_i \geq 0 \qquad (25)$$

The Base 105 Producing Region Model

The 105 region base model incorporates two sets of operational regions in delineating the required interactions; producing regions and market regions. At the different regional levels, restraints are defined on the availability of dry and irrigated cropland by quality class, permanent hay, water, nitrogen for fertilizer, adjustment limits on certain crop and livestock activities, and the regional demands for final products. All crop activities were initially screened by a restraint, imposed exogenously to the model, which eliminates those activities which develop environmental parameters (soil loss levels) above the allowable limit. In addition to crop production, other activities defined the possibilities for livestock production; fertilizer and water purchase; land development; and the transfer of resources or commodities between regions. The model divides into three macro sectors, including the resource availability; the production, transfer and transformation; and the demand-generating sectors.

The resource availability sector indicates the number of acres of land in each region which is available for cropland production, including cropland hay and pasture. The land base is adjusted for the requirements of the crops whose regional distribution is not specifically determined endogenously while solving the model. Also included in this section is the nitrogen fertilizer availability which determines the source and price of the nitrogen fertilizer component. Additional resource determinations include the amount of feed available from nonrotation hay, and the pasture and forest land grazed by region. Water supply by water region is also determined in the resource-availability sector.

The production and product transfer sector utilizes the resources to produce the crop and livestock commodities for both intermediate and final uses. Included in this section are the crop and livestock production alternatives as related to the environmental considerations, interregional transportation for the transferable commodities, and production transformation activities.

The driving force for the model is the demand sector which provides base levels for the final demand commodities. The commodity demands are determined by considering the per capita consumption levels for the commodities, the domestic requirement for the nonendogenous livestock production alternatives, and the requirement to meet the level of exports determined for the analysis.

Abbreviated tableau

The interrelationships in the model can also be presented in the form of a linear programming tableau, Figures 8 and 9. The tableau in Figure 8 is a schematic representation of the complete linear programming model. The restraints are represented by rows in the tableau and the production, development and transportation activities are represented by columns. The blocks on the diagonal are the producing areas PA_1, PA_2, ..., PA_{105}. Sets of producing areas form market regions; MR_1, MR_2, ..., MR_{28}. The specific geographic location and meaning of these regions will be explained in detail later in this section.

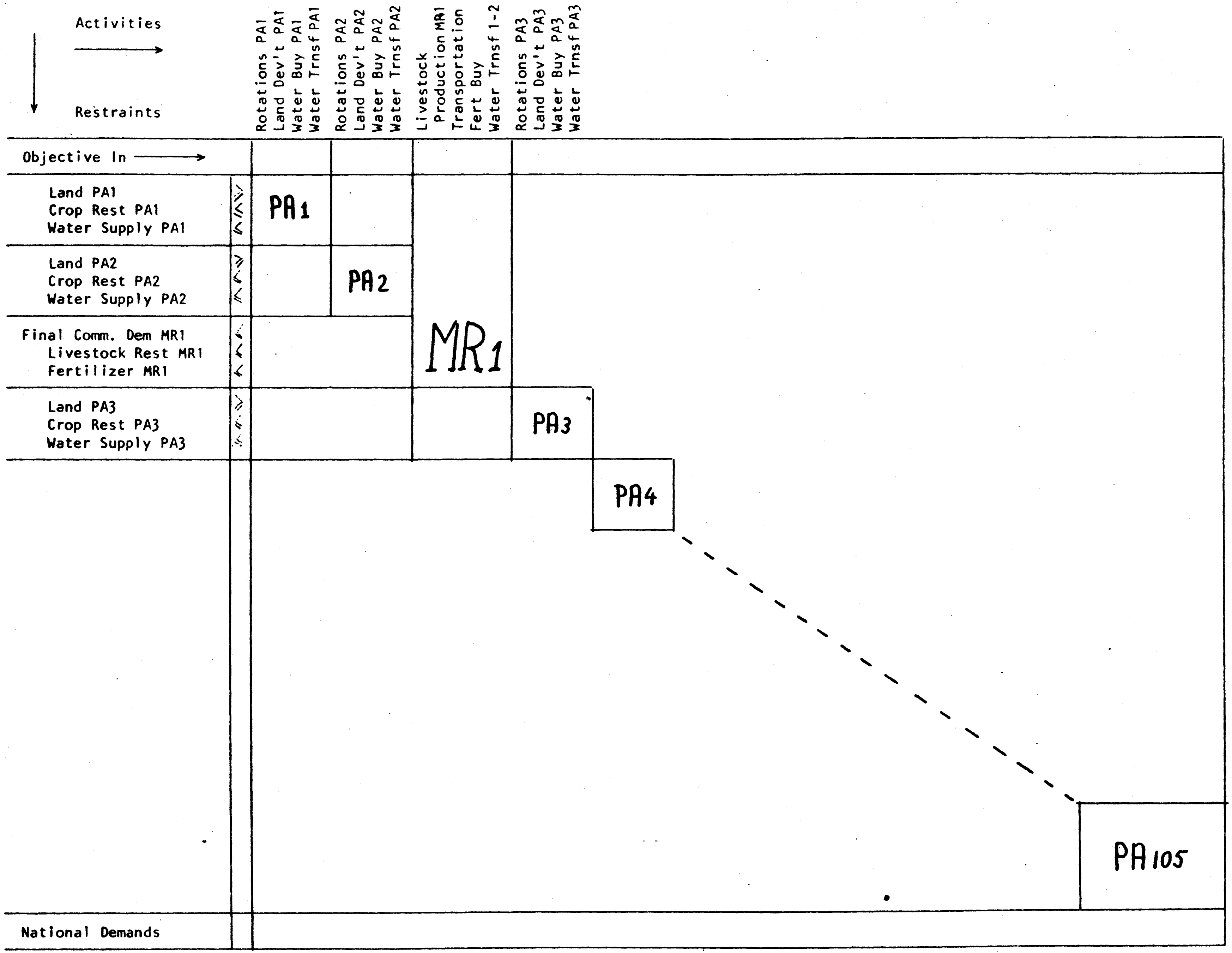

Figure 8. A schematic representation of the linear programming model, indicating regional delineations

Restraints \ Activities	100 Wht	50 Wht-50 Corn	75 Corn-25 NLH	75 Lhay-25 Wht	100 Wht	50 Wht-50 Corn	75 Corn-25 NLH	75 Lhay-25 Wht	100 Wht	50 Wht-50 Corn	75 Corn-25 NLH	75 Lhay-25 Wht	Water Trnsfr 1	Irrig Dev't	Wetland Dev't	Water Buy	100 Corn	34 Corn-66 NLH	66 Lhay-33 Wht	100 Corn	34 Corn-66 NLH	66 Lhay-33 Wht	100 Cotton	Water Trnsfr 2	Irrig Dev't	Wetland Dev't	Water Buy	Beef Prod'n 11	Beef Prod'n 12	Dairy Prod'n 11	Dairy Prod'n 12	Hog Prod'n 11	Trnsp Beef 1-2	Trnsp Dairy 1-2	Buy Fert 1	Fed Beef Trnsfr	Trnsp Wht 1-2	Trnsp Wht 2-1	Trnsp Corn 1-2	Water Trnsfr 1-2	Ranges
Costs	c	c	c	c	c	c	c	c	c	c	c	c		c	c	c	c	c	c	c	c	c			c	c	c	c	c	c	c	c	c	c			c	c	c	c	
Dland 11	1	1	1											.3	-1																										
Dland 12					1	1	1							.2																											
Dland 19									1	1	1																														
Iland 11				1										-.5																											
Iland 12								1						-.2																											
Iland 19												1																													
Wht Rest 1	1	.5		.25	1	.5		.25	1	.5		.25																													u
Corn Rest 1		.5	.75			.5	.75			.5	.75																														u
Hay Rest 1			.25	-			.25	-			.25	-																													u
Water Supply 1				-				-				-	-			+												-	-	-	-	-									
Water Trnsfr 1													1																											-1	
Dland 21																	1	1							.4	-1															
Dland 22																				1	1		1		.2																
Dland 29																																									
Iland 21																			1					-	.3																
Iland 22																						1		-	.6																
Iland 29																																									
Wht Rest 2																			.33			.33																			u
Corn Rest 2																	1	.34		1	.34																				u
Hay Rest 2																		.66	-		.66	-																			u
Water Supply 2																			-			-		-			+	-	-	-	-	-									
Water Trnsfr 2																								1																1	
Wht Dem MRI	+	+		+	+	+		+	+	+		+							+			+						-	-	-	-						-1	1			
Corn Dem MRI		+	+			+	+			+	+						+	+		+	+																				
Lhay Dem MRI				+				+				+							+			+																			
Hay Dem MRI			+				+				+				-			+			+					-		-	-	-	-										
Beef Dem MRI																												+	+				-1			-1					
NFB Dem																																		-1		+1					
Dairy Dem MRI																														+	+										
Hog Dem MRI																																+									
Beef Rest 1																												1	1												u
Hog Rest 1																																1									u
Fertilizer	-	-	-	-	-	-	-	-	-	-	-	-					-	-	-	-	-	-						+	+	+	+	+			1						
Interaction with the rest of the model																																	1	1			1	-1			
Cotton Dem Nat																							+																		
Sugar Dem Nat																																									
Activity Rest													u	u	u	u								u	u	u	u														

Figure 9. A schematic representation of market region 1 showing the interaction between activities and resources

Figure 9 displays in more detail the interrelations within market region 1 (Figure 8). The restraints which control the allocation of production within the region are defined at different levels. At the producing area level, restraints are defined on cropland by quality class and on the water supply available. Further, certain crops, specific to the region, are restrained to have solution acreages that fall between prespecified upper and lower limits. At the market region level, restraints are defined on commodity demands and fertilizer. Also livestock production is restrained to fall between prespecified upper and lower limits similar to the restraints on crop activities. Two final demand commodities, cotton and sugar beets, are restrained at the national level. Soil loss restraints on a per acre basis are implied by controlling the crop activities so as to allow only those meeting the restraint to be included. The form of the row restraints is indicated by the direction of the inequality sign in Figure 8. In addition, each activity can be constrained to have an upper or lower bound. In a standard linear programming formulation, the implied restraint on the activities requires all activities to be greater than zero. (This default can be changed to allow negative levels, but for our modeling the greater than zero restraint holds for all activities.)

The activities in the model, the columns in Figure 9, represent commodity production and transfer, resource purchase, and land development alternatives. In the tableau the interaction of the activities with each of the resources is indicated by a positive or negative sign (or coefficient) appropriate with the formulation.

The first set of columns shows examples of possible production activities. These activities, or rotations, supply the endogenous crop commodities to satisfy the demand levels. The crop production sector produces the endogenous commodities barley, corn, corn silage, cotton, legume hay, nonlegume hay, oats, sorghum, sorghum silage, soybeans, sugar beets, wheat, and summerfallow. These cropping activities are defined to represent rotations ranging from one to eight years in length, incorporating the above crops alone or in appropriate combinations to give the desired rotational effect. The rotations are then combined with alternative conservation and tillage practices to provide a spectrum of soil losses consistent with the defined cropping management system. The crop production activities interact with the relevant land group utilizing an acre of this land, and the other resources--water and fertilizer--as is appropriate for the defined activity. These activities produce commodities based on the cropping system and also produce aftermath pasture in a quantity variable with the crops included in the rotation and the historic utilization of this pasture alternative.

Endogenous livestock enterprises include dairy, beef feeders, beef cows, and pork. Livestock activities utilize water, pasture and the feed commodities as appropriate for their defined ration and location. They produce the final demand commodities (dairy products, fed and nonfed beef, and pork); the by-product residual fertilizer; and the intermediate commodity feeders.

The next group of activities incorporates the resource availability and commodity or resource transfer sectors. The fertilizer and water-buy sectors represent the purchase of the resource at the relevant regional price; for water, the upper bound is consistent with the available water supply. Water transfer activities represent both natural flow and developed interbasin transfer networks to move water between the relevant water supply regions. Similarly, the commodity transport sector represents the movement of the intermediate or final goods from market region to market region as is consistent with the transport networks and the feasibility of transferring the commodities.

The land development group represents (a) the addition of new irrigated land and (b) the conversion of forest and pasture land to cropland. New irrigated land development is reflected in the activities which add new land to the irrigated land base and at the same time remove land from the dry cropland base. Land conversion takes place on forest or wetlands which are cleared and drained. This newly converted land is added to the class I category of the cropland base, and appropriate adjustments are made for the amount of hay lost because of the loss of grazeable forest land.

The final sector represents the transfer of fed beef from its market into the nonfed or cull beef category. This activity allows for the balancing of the two meat markets without having a surplus of the primary products (milk or feeder) as the producing activities attempt to increase production of the cull or nonfed beef.

Last, the left column of the model contains the levels of commodities demanded and resources available. These levels play an important role, because the force that drives the whole model can be said to be the attempt to allocate production and to determine transfers of commodities and resources to satisfy these final commodity demand levels, this all subject to the restraints imposed. The calculation of the demands will be discussed in a later section. However, to complete the discussion of the model, it is necessary to briefly summarize their calculation.

Final commodity demands are the sum total of domestic consumption (per capita consumption times population), other uses (industrial, etc.), demand for feed by exogenous livestock, and net exports. The exogenous livestock are broilers, eggs, sheep and lambs, and an "other livestock" category. These animals utilize pasture, water, and the commodities as relevant for the type of livestock and the regional production methods. Therefore, the demand for the resources has to be adjusted for the production of the livestock commodities.

The same type of adjustments have to be made, to the resource levels available, to account for the exogenous crop sector. Crops included in this section are rye, rice, fruit and nuts, vegetables, flaxseed, peanuts, sugar cane, tobacco, Irish potatoes, sweet potatoes, dry beans, dry peas, and other crops. All these adjustments will be discussed in detail in later sections.

Regions of the model

In completely defining the workings of the model, four separate sets of regions are incorporated. The first represents regions within which the data base is defined; the second, the areas within which the production activities are defined; the third, the regions detailing water availability and transfer possibilities; and the fourth, the areas within which the markets are defined.

The data regions These regions again represent many sets of political and geographic areas within which data are tabulated by the collecting agencies. They include the counties and states of the continental United States within which census and commodity production data are tabulated. An additional set of regions included in this group is the county approximations of the major land resource areas as used for data collection by the Soil Conservation Service, U.S. Department of Agriculture, Figure 3. These regions divide the continental United States into 164 areas based on soil type and management characteristics. It is from these regions that the data used in calculating the soil loss by alternative cropping activity are developed.

Sets of weights based on relevant data relationships are used to transfer data from the regions in which they are obtained into the common resource or producing areas where the data are used in the model or in combination with other data to generate coefficients to be used in the model.

The producing areas Figure 10 includes the 105 producing areas. These areas are based on the 99 Water Resource Council's aggregate subareas (ASA's) modified to 105 areas to be consistent with the agricultural patterns experienced in six of the ASA's. Each producing area again is an aggregation of contiguous counties which sum to both ASA's and major river basins (Figures 11 through 13). Crop production activities, crop acreage restraints, water availability, and the land base are defined within each producing

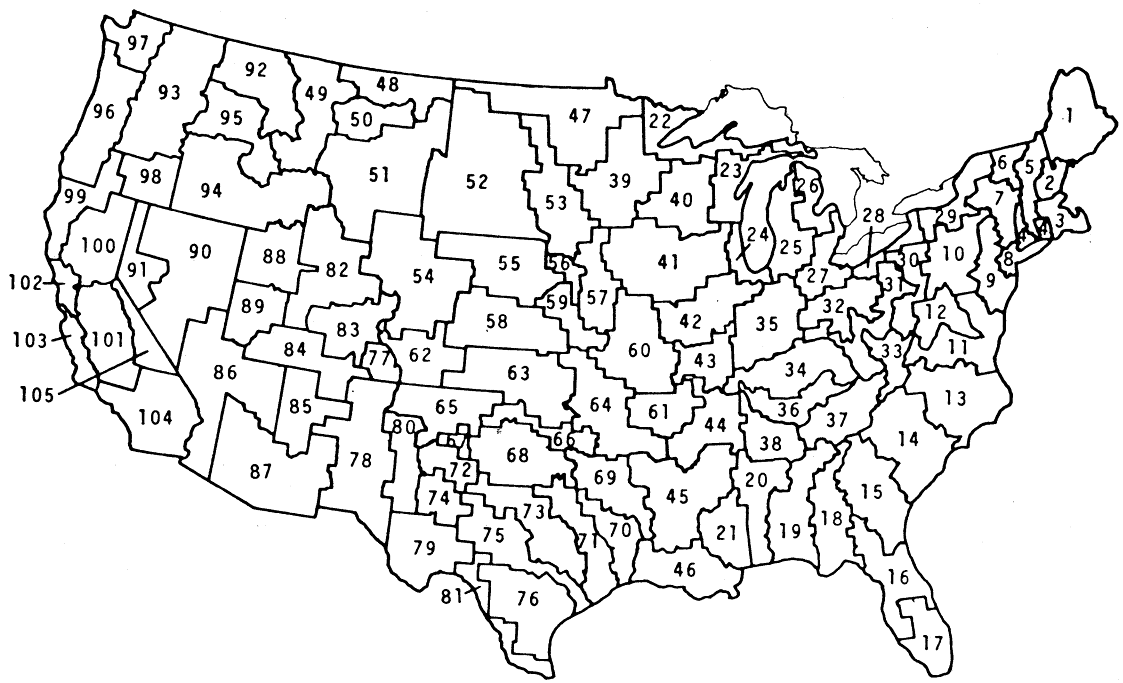

Figure 10. The 105 producing areas

Figure 11. Water Resource Council's aggregated subareas

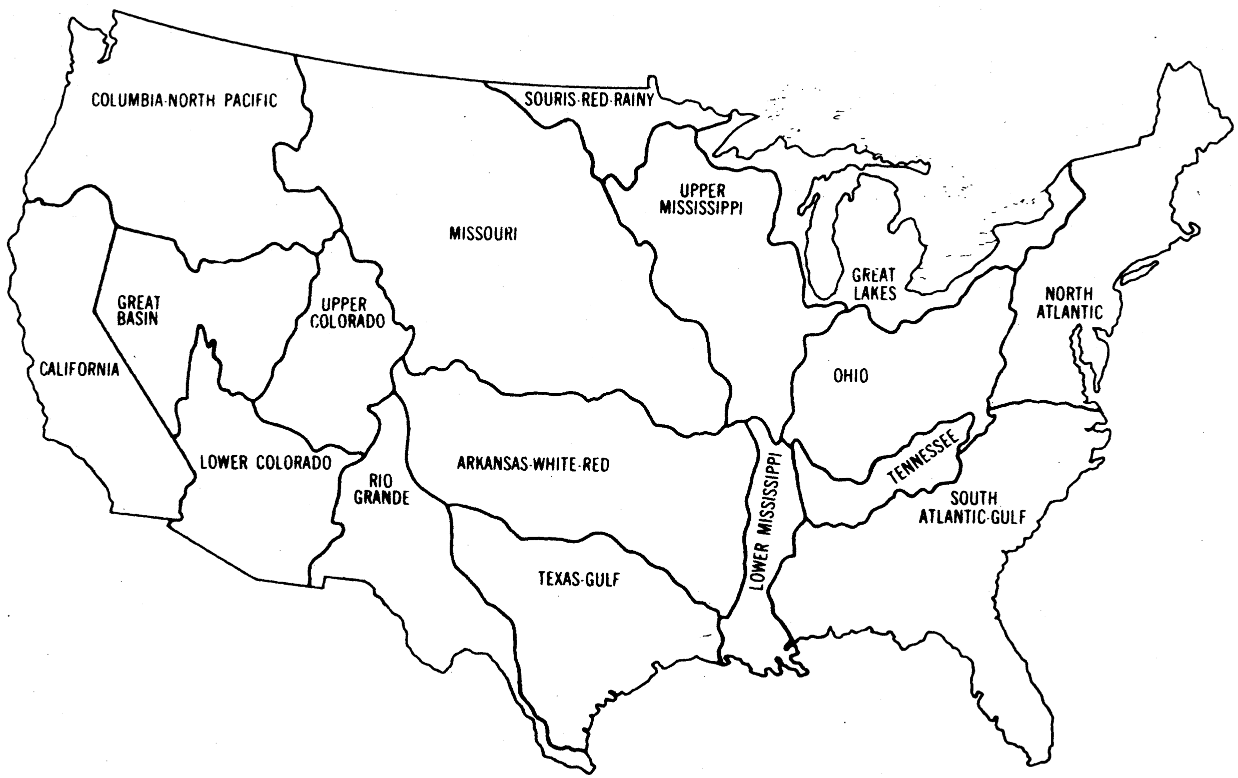

Figure 12. River basins in the United States as defined by the Water Resources Council

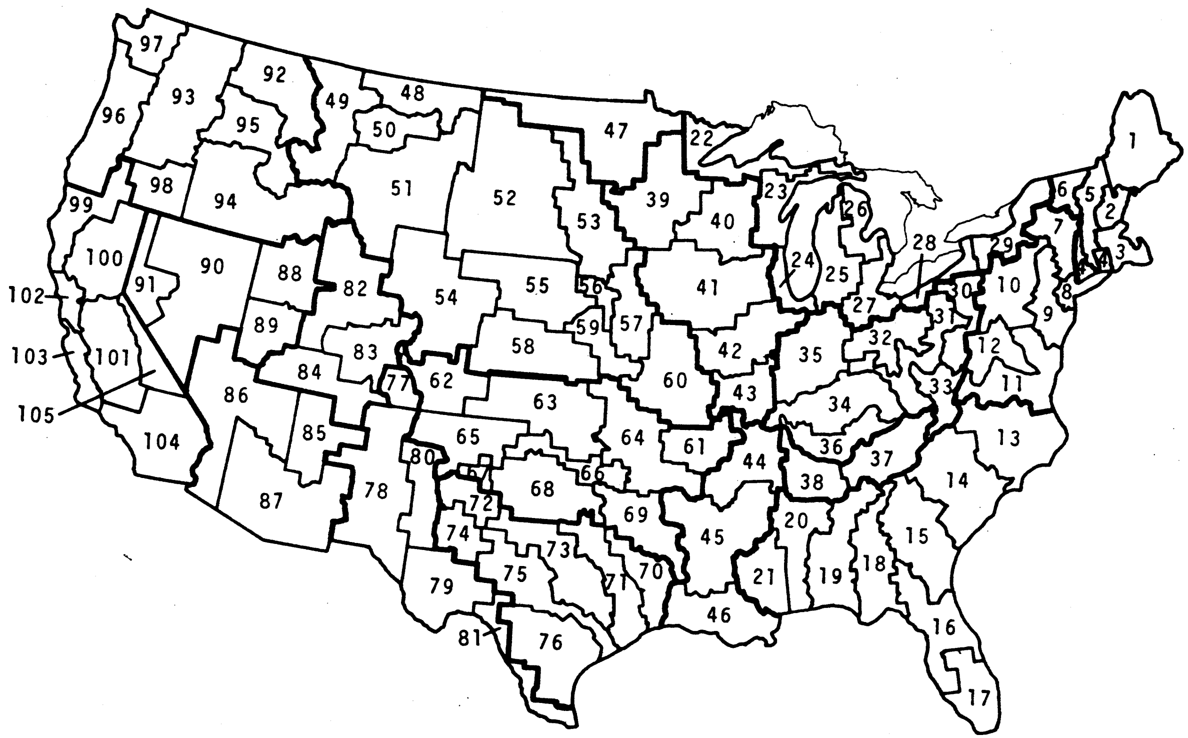

Figure 13. River basins with enclosed producing areas

areas. The water supply regions, consistent with the producing areas in the western ASA's, are those in Figure 14.

The market regions Contiguous producing areas are aggregated into major marketing areas of the United States resulting in 28 market regions for the model (Figure 15). It is within these regions that the market balance restraints are defined for the major commodities analyzed. The commodity transfer section of the model uses these centers as points between which commodities are moved as the model adjusts its production pattern to account for each region's comparative advantage.

Mathematical summary of model

The following sections summarize the objective function and the restraints of the 105 region base model.

The objective function The objective function again is defined to minimize the cost of producing the given demands subject to the restraints on the availability of land, water, fertilizer, amount of crop and livestock adjustment allowed, and the intermediate commodities demanded:

$$\min F = \sum_i \sum_j \sum_k \sum_m X_{ijkm} + \sum_n \sum_p \sum_q L_{npq} LC_{npq} + W_r WC_r$$

$$+ F_n FC_n + IB_r IC_r + \sum_n \sum_s \sum_t T_{nst} TC_{nst}$$

$$+ \sum_i (LD_i DC_i + RD_i RC_i) \qquad (26)$$

$i = 1, \ldots,$ 105 for the producing areas,
$j = 1, \ldots,$ 18 for the land classes,
$k = 1, \ldots,$ 330 for the rotations defined,
$m = 1, \ldots,$ 12 for the conservation and tillage alternatives per rotations,

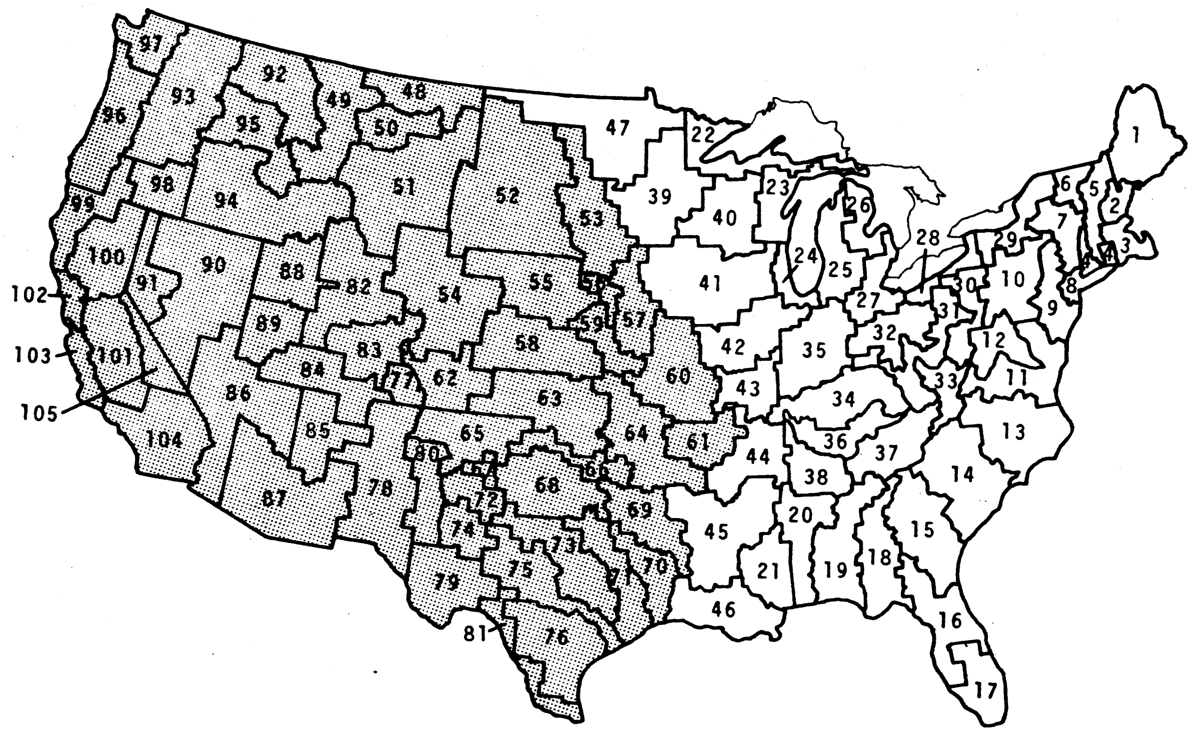

Figure 14. The producing areas with irrigated lands in which water supplies are defined

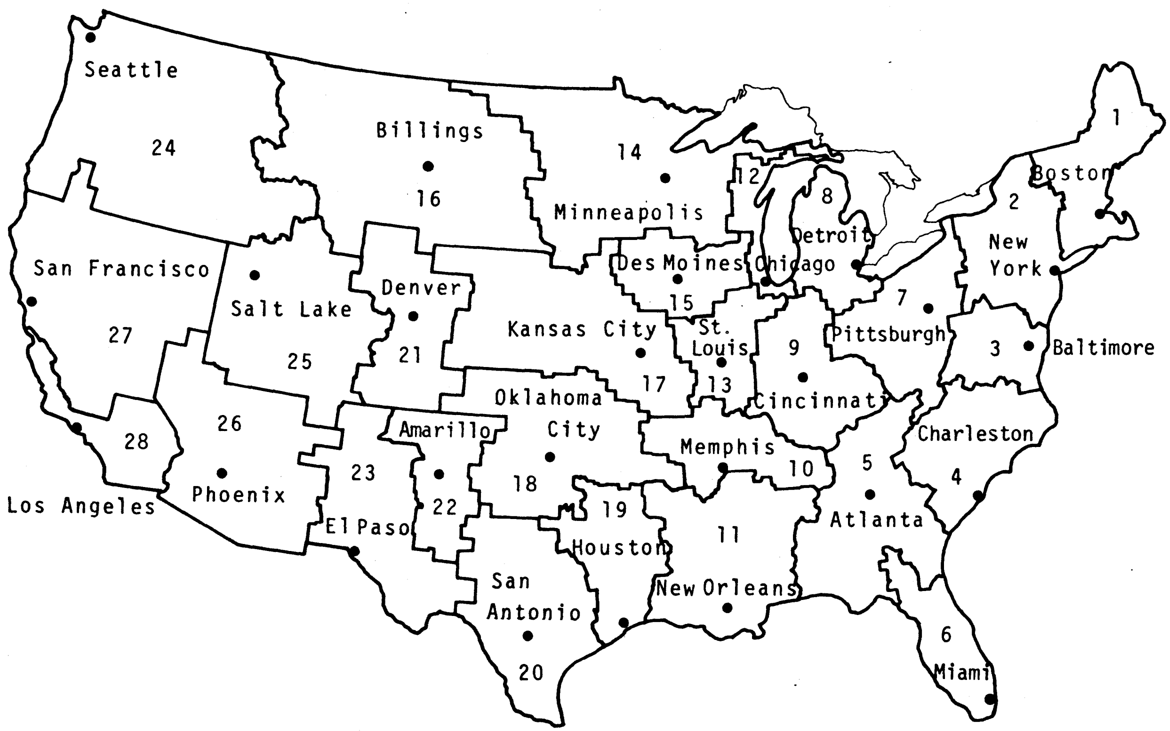

Figure 15. The 28 market regions with central cities indicated

$n = 1, \ldots,$ 28 for the market regions,
$p = 1, \ldots,$ 4 for the endogenous livestock classes,
$q = 1, \ldots,$ 32 for the livestock rations,
$r = 1, \ldots,$ 58 for the water supply regions,
$s = 1, 2, 4, 5, 7, 8, 10, 11, 13, 14, 15$ for the commodities transported,[1] and
$t = 1, \ldots, 176$ for the transportation routes defined.

Where:

X_{ijkm} is the number of acres of rotation k with conservation-tillage practice m in producing area i on land class j;

XC_{ijkm} is the cost per acre of rotation k with conservation-tillage practice m in producing area i on land class j;

L_{npq} is the number of units of livestock activity p receiving ration q in market region n;

LC_{npq} is the cost per unit of livestock activity p receiving ration q in market region n;

W_r is the number of acre feet of water purchased in water supply region r;

WC_r is the cost per acre foot of water purchased in water supply region r;

F_n is the number of pounds of nitrogen fertilizer purchased in market region n;

FC_n is the cost per pound of nitrogen fertilizer purchased in market region n;

IB_r is the acre feet of water transferred out of water supply region r;

---

[1]The commodities include barley, corn, cotton, dairy products, fed beef, legume hay, oats, nonfed beef, nonlegume hay, oilmeal, pork, silage, sorghum, sugar beets, and wheat.

IC_r is the cost differential on a per acre foot basis for water in water supply region r;

T_{nst} is the number of units of commodity s transported over route t from market region n;

TC_{nst} is the cost per unit of commodity s transported over route t from market region n;

LD_i is the number of acres of land drained and converted to cropland in producing area i;

DC_i is the cost per acre for draining land and converting it to cropland in producing area i;

RD_i is the number of acres developed for irrigation under private development in producing area i; and

RC_i is the cost per acre for private irrigation development in producing area i.

A partial competitive equilibrium is simulated, subject to the restraints detailed elsewhere, wherein all resources used in the production of agricultural commodities and in their transportation will receive market rates of return. The costs associated with each activity represent the returns to resources and inputs not endogenously allocated to the alternative activities during solution of the model. The model thus can select among different field methods or technologies representing alternative methods of arresting soil loss and representing dryland or irrigated production. Inherent in the objective function are "sub" objective functions that minimize the cost of the livestock ration, from imported or local feed stuffs, and the transportation cost of a market region's bill of goods. The location or spatial distribution of production and the interregional land and water use pattern is a function of a transportation submodel in interaction with a commodity and resource allocation model for agriculture. Rents or values for land and water do not enter the objective function directly, since they are determined endogenously in the model.

Producing area Each producing area has restraints for land availability by the nine dry and irrigated land classes, restraints to control the level of production of eight crops, and a restraint to define a minimum irrigated acreage. The equations for the ith producing area are:

Dryland restraint by land class

$$\sum_k \sum_m X_{ijkm} AD_{ijkm} + LD_i LDP_{ij} - RD_i RDP_{ij} \leq DA_{ij} \tag{27}$$

i = 1, ..., 105 for the producing areas,
j = 1, ..., 9 for the land classes,
k = 1, ..., 330 for the rotations defined, and
m = 1, ..., 12 for the conservation-tillage alternatives.

Irrigated land restraint by land class

$$\sum_k \sum_m X_{ijkm} AI_{ijkm} + RD_i RDP_{ij} \leq IA_{ij} \tag{28}$$

i = ..., 105 for the producing area,
j = 1, ..., 18 for the land classes,
k = 1, ..., 330 for the rotations defined, and
m = 1, ..., 12 for the conservation-tillage alternatives.

Cropland acreage restraints

$$MINA_{iu} \leq \sum_{j} \sum_{k} \sum_{m} X_{ijkm} W_{ijkmu} \leq MAXA_{iu} \tag{29}$$

i = 1, ..., 105 for the producing area,
j = 1, ..., 18 for the land classes,
k = 1, ..., 330 for the rotations defined,
m = 1, ..., 12 for the conservation-tillage alternatives, and
u = 2, 4, 11, 13, 14, 15, for the crops.[1]

Hay acreage restraint

$$\sum_{j} \sum_{k} \sum_{m} X_{ijkm} W_{ijkm5} \leq HR_i \left[\sum_{j} \sum_{k} \sum_{m} X_{ijkm} W_{ijkm6} + \sum_{j} \sum_{k} \sum_{m} X_{ijkm} W_{ijkm5} \right] \tag{30}$$

i = 1, ..., 105 for the producing areas,
j = 1, ..., 18 for the land classes,
k = 1, ..., 330 for the rotation defined, and
m = 1, ..., 12 for the conservation-tillage alternatives.

Irrigated acreage restraint

$$\sum_{j} \sum_{k} \sum_{m} X_{ijkm} AI_{ijkm} \geq \sum_{u} AIC_{iu} \tag{31}$$

i = 48, ..., 105 for the producing areas,
j = 9, ..., 18 for the land classes,
k = 1, ..., 330 for the rotations defined,
m = 1, ..., 12 for the conservation-tillage alternatives, and
u = 1, ..., 6, 8, 11, ..., 15 for the crops irrigated.

Where:

X_{ijkm} is the level of rotation k using conservation-tillage method m on land class j in producing area i;

---

[1] The crops include corn, silage (corn and sorghum silage), cotton, sorghum, soybeans, sugar beets, and wheat. Barley, oats, and nonlegume hay are restrained at the market region level.

AD_{ijkm} is the acres of dryland used per unit of rotation k using conservation-tillage method m on land class j in producing area i;

AI_{ijkm} is the acres of irrigated land used per unit of rotation k using conservation-tillage method m on land class j in producing area i;

DA_{ij} is the acres of dryland available on land class j in producing area i;

IA_{ij} is the acres of irrigated land available on land class j in producing area i;

LD_{i} is the level of land drainage in producing area i;

LDP_{ij} is the proportion of the land drainage in producing area i which is on land class j;

RD_{i} is the level of irrigated land development in producing area i;

RDP_{ij} is the proportion of the irrigated land developed in producing area i which is in land class j;

W_{ijkmu} is the rotation weight for crop u in rotation k using conservation-tillage method m on land class j in producing area i;

$MINA_{ij}$ is the minimum acreage of crop u required in producing area i;

$MAXA_{iu}$ is the maximum acreage of crop u required in producing area i;

HR_{i} is the proportion of all hay which can be legume hay in producing area i; and

AIC_{iu} is the acres of crop u in producing area i as reported in the 1969 Census of Agriculture.

In producing areas 48-105, water supplies and irrigation activities are defined. The following equation controls the allocation of water to the endogenously determined agricultural uses.

$$\sum_{j}\sum_{k}\sum_{m}\sum_{u} X_{ijkm} W_{ijkmu} CWU_{iu} + \sum_{n}\sum_{p}\sum_{q} Y_{npq} LW_{npr}$$

$$- WH_r WA_r \leq WS_r \qquad (32)$$

i = 48, ..., 105 for the producing areas,
j = 1, ..., 18 for the land classes,
k = 1, ..., 330 for the rotations defined,
m = 1, ..., 12 for the conservation-tillage alternatives,
n = 1, ..., 28 for the market regions,
p = 1, ..., 4 for the endogenous livestock types,
q = 1, ..., 32 for the livestock rations,
r = i-47 to give the water supply region number, and
u = 1, ..., 15 for the possible irrigated crops.

Where:

X_{ijkm} is the level of crop rotation k using conservation-tillage method m on land class j in producing area i;

W_{ijkmu} is the rotation weight for crop u in rotation k using conservation-tillage method m on land class j in producing area i;

CWU_{iu} is the acre feet per acre water use coefficient for crop u in producing area i;

Y_{npq} is the level of livestock type p consuming ration q in market region n;

LWU_{npq} is the acre feet per unit water use coefficient for livestock type p consuming ration q in market region n;

WS_r is the per acre feet of water available for use by the endogenous agricultural sector;

LW_{npr} is the proportion of livestock type p from market region n falling in water supply region r;

WH_r is the level of irrigated to dryland pasture conversion in water supply region r; and

WA_r is the per acre water release coefficient when converting one acre of irrigated pasture to dryland pasture in water supply region r.

Commodity market regions To reflect demand based on per capita use as a function of income and commodity substitution and foreign trade movements through the region, each commodity market region has a set of equations to balance the supply and demand of the commodities. Each region also has a set of equations to control the level of livestock production in the region. The equations are:

Commodity balance equation

$$\sum_i \sum_j \sum_k \sum_m X_{ijkmn} W_{ijkmu} CY_{ijkmsu} + \sum_p \sum_q Y_{npq} LY_{npqs}$$

$$- \sum_t T_{nst} - \sum_r WH_r DA_{rs} \geq CD_{ns} \qquad (33)$$

i = 1, ..., 105 for the producing areas,
j = 1, ..., 18 for the land classes,
k = 1, ..., 330 for the rotations,
m = 1, ..., 12 for the conservation-tillage alternatives,
n = 1, ..., 28 for the market regions,
p = 1, ..., 4 for the endogenous livestock types,
q = 1, ..., 32 for the livestock rations,
r = 1, ..., 58 for the water supply regions,
s = 1, 2, 4, ..., 9, 11, ..., 15 for the commodities balanced at the market region,
u = 1, ..., 15 for the crops, and
t = 1, ..., 176 for the transportation activities defined.

Livestock production equation

$$MINL_{np} \leq \sum_{p} \sum_{q} Y_{npq} \cdot LU_{np} \leq MAXL_{np} \qquad (34)$$

$n = 1, \ldots, 28$ for the market regions,
$p = 1, \ldots, 4$ for the livestock types, and
$q = 1, \ldots, 32$ for the livestock rations.

Where:

X_{ijkmn} is the level of crop rotation k using conservation-tillage method m on land class j in producing area i which is included in market region n;

W_{ijkmu} is the weight of crop u in rotation k using conservation-tillage method m on land class j in producing area i;

CY_{ijkmsu} is the per acre production of commodity s from crop u in rotation k using conservation-tillage method m on land class j in producing area i;

Y_{npq} is the level of production of livestock type p using ration q in market region n;

LY_{npqs} is the per unit interaction coefficient for commodity s with livestock type p consuming ration q in market region n (this will be positive for the livestock products and negative for the ration components);

CD_{ns} is the exogenously determined demand for commodity s in market region n;

T_{nst} is the net export of commodity s over transportation route t defined in market region n;

WH_r is the level of irrigated to dryland pasture conversion in water region r;

DA_{ra} is the reduction in hay yield associated with the conversion of an acre of irrigated pasture to dryland pasture in water supply region r. $DA_{rs} = 0$ for all $s \neq 5$;

LU_{np} is the conversion factor to express the production of livestock type p in market region n in terms of the restraint units;

$MINL_{np}$ is the minimum number of units of livestock type p required in market region n; and

$MAXL_{np}$ is the maximum number of units of livestock type p allowed in market region n.

National equations As mentioned previously, the equations which are defined at the national level to balance commodity supply and demand are as follows:

$$\sum_i \sum_j \sum_k \sum_m X_{ijkm} W_{ijkmu} CY_{ijkmsu} \geq CD_s \qquad (35)$$

i = 1, ..., 105 for the producing areas,
j = 1, ..., 18 for the land classes,
k = 1, ..., 330 for the rotations defined,
m = 1, ..., 12 for the conservation-tillage alternatives,
s = 3, 14 for the commodities cotton and sugar beets, and
u = 4, 14 for the crops cotton and sugar beets.

Where:

X_{ijkm} is the level of crop rotation k using conservation-tillage practice m on land class j in producing area i;

W_{ijkmu} is the rotation weight for crop u in rotation k using conservation-tillage method m on land class j in producing area i;

CY_{ijkmsu} is the per acre production of commodity s from crop u in rotation k using conservation-tillage method m on land class j in producing area i; and

CD_s is the demand for commodity s at a national level.

Quadratic Programming Model

The 48 continental states and the District of Columbia are divided into 10 spatially separated consuming regions (CRs) shown in Figure 16. These 10 consuming regions are further subdivided into 103 producing areas (PAs) in Figure 17. The 17 Western states are divided into 10 irrigated crop producing areas (Figure 18).

Crop production is defined on the producing area level and on the irrigated area level. Livestock production is defined on the consuming region level. Producers of a commodity within an area or a region are assumed to be homogenous with respect to technology. The crop and livestock production activities constitute a constant technology matrix and these activities are technologically independent.

Commodities used in, or produced by, activities are classified according to their use. These classes are primary, intermediate, and final (or desired) commodities. The commodities in the model are listed by classes in Table 1.

Transportation is defined between the 10 consuming regions for specific final and intermediate commodities. It is assumed that corn, oats, and

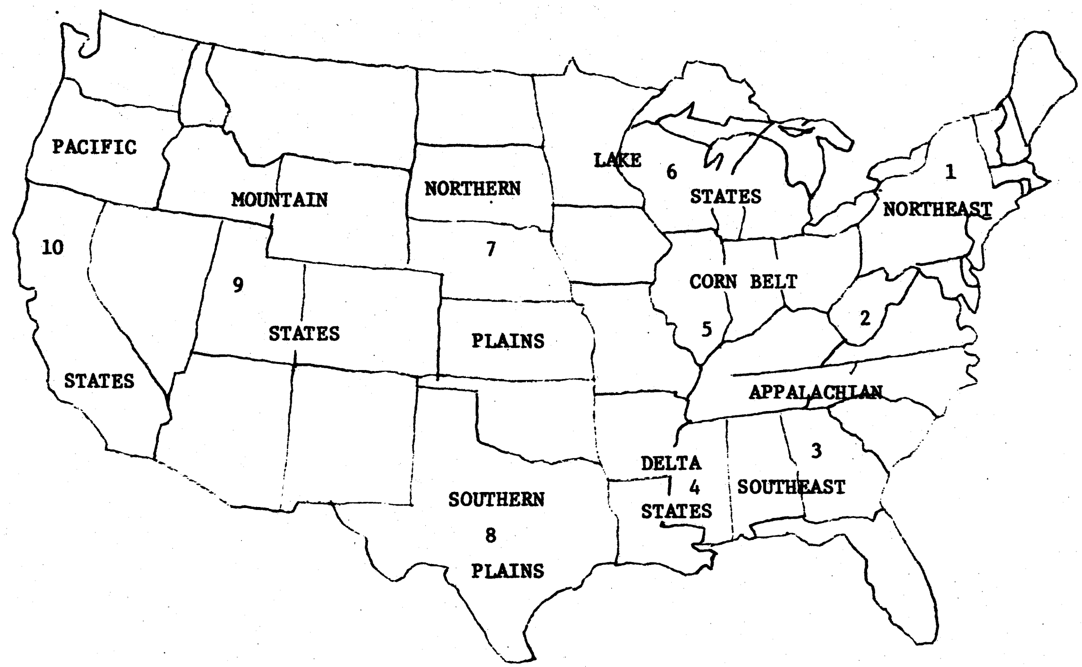

Figure 16. Location of consuming regions and livestock producing regions

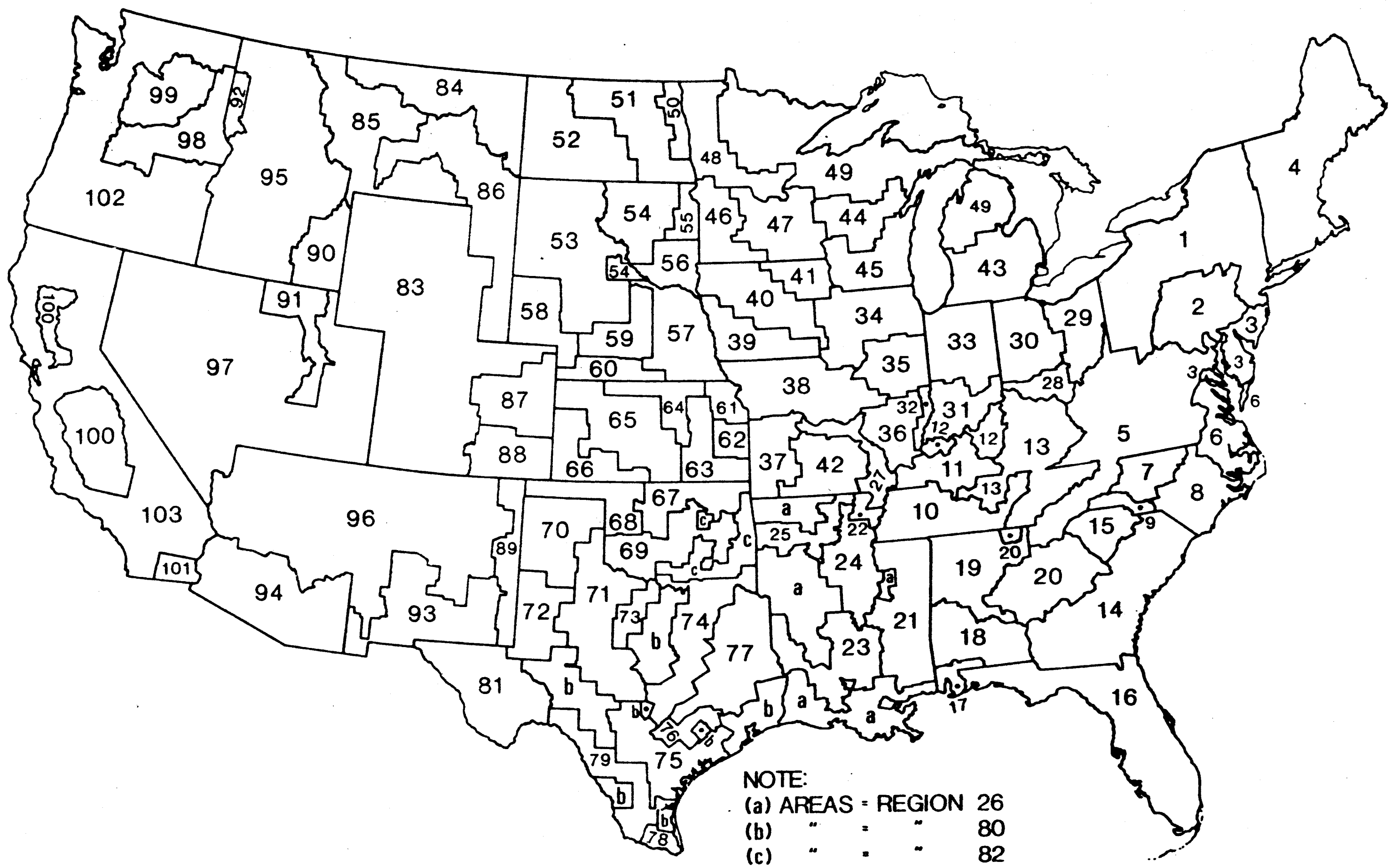

Figure 17. The 103 crop producing areas

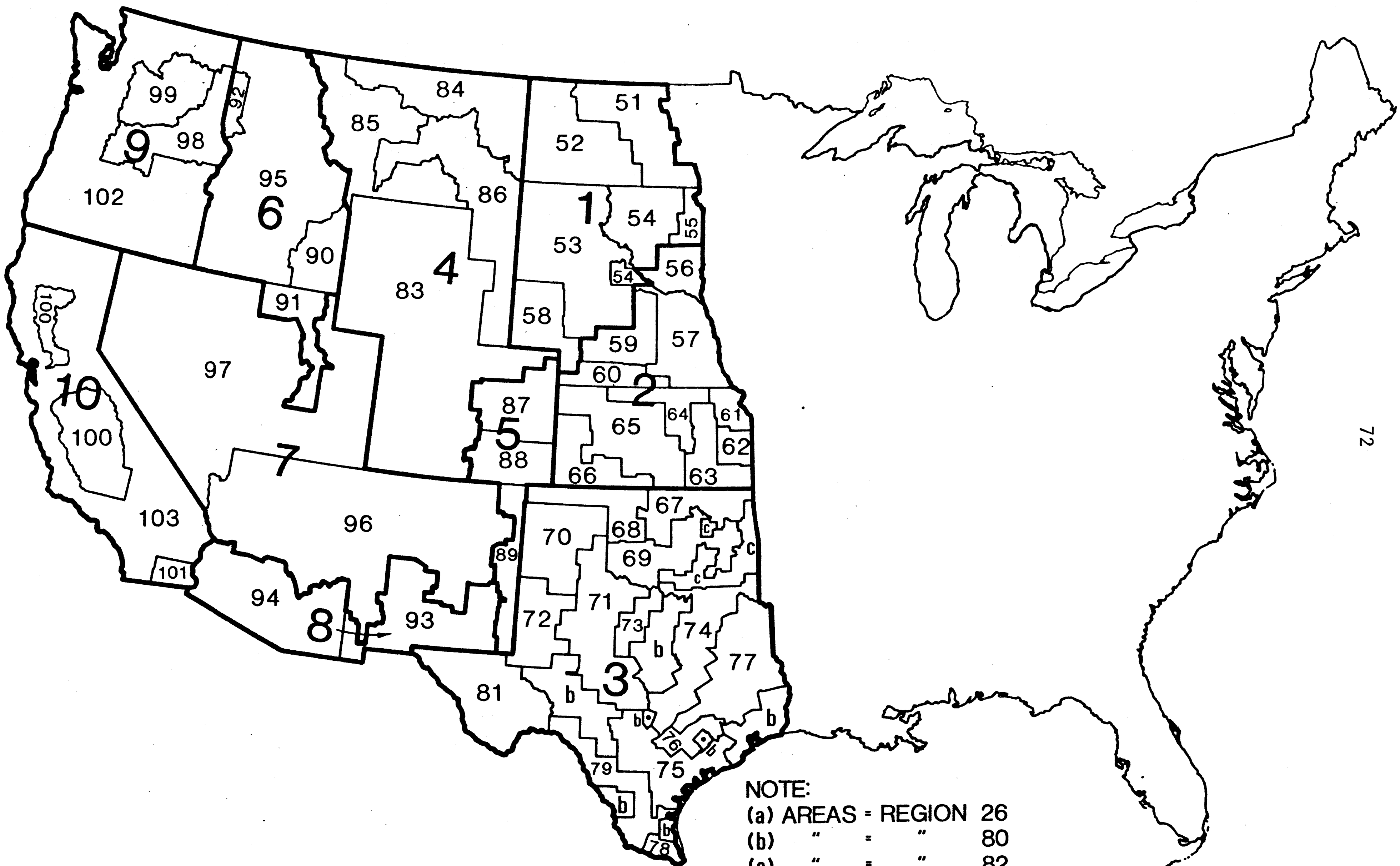

Figure 18. The 10 irrigated crop producing areas

barley for food are perfect substitutes for corn, oats, and barley for feed, respectively, and vice versa. Wheat can also be used as a feed source. Demand can be satisfied by production within a region and(or) through commodities shipped from outside the region. Feed exogenous to the model can be purchased by the appropriate activity in the model. Inputs exogenous to the model are considered to be unlimited in quantity and at a given set price.

Table 1. Classification of commodities

Final or Desired	Intermediate	Primary
Cattle	Feed grains[a]	All cropland
Calves	Oilmeals[b]	All hayland
Hogs	Roughage	Irrigated cropland
Fluid milk	Feeder calves	Irrigated hayland
Manufactured milk[c]	Yearlings	Wild hayland
Wheat		Cotton land
Vegetable oils[d]		Pasture
Corn for food		Beef cow capacity
Oats for food		Milk cow capacity
Barley for food		Fed beef capacity
Sheep and lambs		Hog capacity
Chickens and turkeys		
Eggs		
Cotton lint		

[a]Feed grains include corn, oats, barley, and grain sorghum for feed.

[b]Soybean oilmeal and cottonseed oilmeal.

[c]Evaporated and condensed milk, cheese, ice cream, and butter.

[d]Soybean oil, cottonseed oil, and other food oils.

Definition of activities

A crop activity is defined for a producing area if 1,000 acres or more of that crop was reported in the area in 1964. The set of possible crop activities is: (a) wheat, (b) corn, (c) oats, (d) barley, (e) feed grain (corn, oats, barley, grain sorghum), (f) feed grain-soybean rotation, (g) feed grain-hay rotation, (h) feed grain-silage rotation, and (i) hay-silage rotation. Irrigated crop activities are defined similarly. If cotton was grown in a consuming region in 1953, a cotton production activity is defined for that region.

A livestock activity is defined for a consuming region if 1,000 or more units of that activity were reported in that region on an annual basis between 1959-1968. The set of possible livestock activities is: (a) beef cow production, (b) fluid milk production, (c) manufactured milk production, (d) hog production, (e) yearling calf production, (f) Eastern deferred-fed cattle, (g) Southern deferred-fed cattle, (h) cattle on extended silage, (i) yearlings on silage, (j) calves on silage, and (k) yearlings with no silage. The following livestock activities are defined at the national level: hens and chickens, broilers and turkeys, and sheep and lambs.

Mathematical summary of the model

The objective function maximizes net aggregate producer profit. Net aggregate producer profit consists of revenue from sale of desired commodities plus value of intermediate commodities minus transportation costs. This objective function is maximized subject to the market equilibrium conditions. The mathematical model is summarized after definition of some terms. Subscripts and(or) superscripts are:

h = producing area = 1, ..., 103;

k = consuming region = 1, ..., 10;

d = desired commodity = 1, ..., 14;

i = intermediate commodity = 1, ..., 5;

s = substitutable commodity between intermediate and desired commodities = 1, 2, 3; and

j = primary commodity = 1, ..., 11.

The terms are:

p^k, w^k, p_s^k, $u^{h \text{ or } k}$ = vectors of imputed prices for desired, intermediate, substitutable, and primary commodities, respectively, in region k or area h.

$x^{h \text{ or } k}$ = vector of production activities in area h for crop production and in region k for livestock production.

D = a matrix of demand slope coefficients with the vector of intercepts, d. This demand matrix is partitioned into submatrices for regional, regional-national, and national relationships.

z_1^k = transfer activity for food grains to feed grain markets.

z_2^k = transfer activity for feed grains to food grain markets.

z_3^k = transfer activity for converting feed grains into the units of TDN and protein by a conversion matrix, A_c, for livestock production.

e^k and e_s^k = vectors of exogenous demands for intermediate and substitutable commodities, respectively.

$r^{h \text{ or } k}$ = vector of primary resources in area h or region k.

$A_d^{h \text{ or } k}$, $A_i^{h \text{ or } k}$, $A_s^{h \text{ or } k}$, $A_j^{h \text{ or } k}$ = matrix of technical coefficients relating primary resources and other inputs into intermediate and desired commodities through production or transfer activities x and z in area h or region k.

$c^{h \text{ or } k}$ = vector of unit activity costs for intermediate and desired commodities in area h or region k.

$q_d^{kk'}$, $q_i^{kk'}$, $q_s^{kk'}$ = vectors of interregional shipment levels of desired intermediate, and substitutable commodities, respectively, from k to k' where $k \neq k'$.

t_d, t_i, t_s = vectors of transportation costs for those desired, intermediate, and substitutable commodities, respectively, for which transportation is defined.

$T_d^{kk'}$, $T_i^{kk'}$, $T_s^{kk'}$ = transportation matrices for the respective commodities.

To simplify reading, area and regional subscripts and superscripts are dropped; it is implied that the terms are expanded to have one set for each producing area or consuming region as is appropriate to the activity or imputed price vector. The objective function of the model is thus:

$$\text{Maximize } f(p, w, p_s, u, x, z_1, z_2, z_3, q_d, q_i, q_s) \qquad (36)$$

$$= p(d + Dp) + w'e + p_s'e_s - u'r - x'c - q_d't_d - q_i't_i - q_s't_s$$

subject to:

$$D_p \quad - A_d x + z_1 - z_2 \quad - T_d'q_d \leq -d \qquad (37)$$

$$- A_i x \quad - A_c z_3 \quad - T_i'q_i \leq -e \qquad (38)$$

$$- A_s x - z_1 + z_2 - z_3 \quad -T_s'q_s \leq -e_s \qquad (39)$$

$$A_j'x \leq r \qquad (40)$$

$$A_d'p + A_i'w + A_s'p_s - A_j'u \leq c \qquad (41)$$

$$-p + p_s = 0 \qquad (42)$$

$$A_c'w - p_s \leq 0 \qquad (43)$$

$$T_d p \leq t_d \qquad (44)$$

$$T_i w \leq t_w \qquad (45)$$

$$T_s p_s \leq t_s \qquad (46)$$

$$p, w, p_s, u, x, z_1, z_2, z_3, q_d, q_i, q_s \geq 0 \qquad (47)$$

Constraint (37) states that the supply of desired commodities must be greater than or equal to the demand for desired commodities. Constraints (38) and (39) state that the supply of intermediate and substitutable commodities must be greater than or equal to the demand for intermediate and substitutable commodities, respectively. Constraint (40) states that there is a limited supply of primary resources and no more than this maximum can be used in production.

Constraint (41) can be rewritten as:

$$A_d'p + A_i'w - A_j'u \leq c \qquad (41a)$$

$$A_s'p_s - A_j'u \leq c_s \qquad (41b)$$

The requirement is that the marginal revenue must be equal to or less than marginal cost plus rent of primary resources.

Equality constraints (42) are required because of the assumed perfect substitutability between corn, oats, and barley for food and feed. Constraint (43) cannot be used to equate internal prices ($A_c w$) and final prices (p_s) because of problems of internal prices being zero if there is any excess supply. Constraints (44) through (46) are requirements for trade equilibrium.

The Kuhn-Tucker conditions for optimality in quadratic programming are included for this model.[1] Taking these conditions and the affirmative test for the D matrix being negative semi-definite, the programming tableau used in the computer is shown in Table 2. The skew symmetric properties needed in the constraint set for the self-dual problem are easily seen.

[1]Kuhn, H. W. and A.W. Tucker. Nonlinear programming. In (J. Neyman, ed.), Proceedings of the Second Symposium on Mathematical Statistics and Probability. University of California Press, Berkeley, 1951.

Table 2. Structure of the present model in the programming tableau format

	Primal variables				Langrangian variables						
	Final commodity prices	Intermediate commodity prices	Substitutable commodity prices	Primary commodity prices	Production activities	Transfer activities			Transportation activities		
RHS	p	w	p_s	u	x	z_1	z_2	z_3	q_d	q_i	q_s
$-d_o \geq$	D				$-A_d$	I	-I		$-T_d$		
$-e \geq$					$-A_i$			$-A_c$		$-T_i$	
$-e_s \geq$					$-A_s$	-I	I	I			$-T_s$
$r \geq$					A_j						
$c \geq$	A'_d	A'_i	A'_s	$-A'_j$							
$0 \geq$	-I		I								
$0 \geq$	I		-I								
$0 \geq$		A'_c	-I								
$t_d \geq$	T'_d										
$t_i \geq$		T'_i									
$t_s \geq$			T'_s								

Demand data

Brandow published his set of direct price and cross-price elasticities for 28 major U.S. farm products in 1961.[1] The demand was described as a function of own price, the prices of the other 27 commodities, consumer income, and the index of nonfood prices. These demand estimates encompassed changes in population growth, increases in consumer income, and changes in tastes. For this study, alternative forms of the Brandow system are analyzed. Demand equations for the following 13 commodities or commodity aggregates were used: cattle, calves, hogs, sheep and lambs, chickens and turkeys, eggs, fluid milk, manufactured milk, vegetable oils, wheat for food, corn for food and industrial use, oats for food and industrial use, and barley for food and industrial use.

Revised time trends (shifts in the demand equation intercepts) affected by changes in taste were estimated while the other parameters of the Brandow system were retained. Reestimation equations used are given below where (49) is derived from (48) and then the time trend equation for the demand intercept is given.

$$q_{it} = d_{it} + D_i P_t \tag{48}$$

$$d_{it} = q_{it} - D_i P_t = a_o + a_1 T + e_t \tag{49}$$

Where:

q_{it} is the total quantity of the ith commodity demanded in year t;

d_{it} is the demand intercept of commodity i in year t;

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[1]Brandow, G. E. Interrelations among demands for farm and implications for control of market supply. Pennsylvania Agricultural Experiment Station Bulletin 680.

D_i is the ith row of the demand matrix, D; and

P_t is the set of prices, consumer income, and the index of nonfood prices in year t.

Ordinary least squares is the estimation procedure used. If the Durbin-Watson statistic showed that autocorrelation was present, a one-step autocorrelated error model was used.

For the demand matrix itself, Stoecker (p. 34-38) describes the method of selecting the variation of Brandow's system.[1] Briefly, three algebraic forms of the demand equations are viewd: (a) constant elasticities, (b) Brandow's slopes, and (c) Hall's slopes.[2] Two other alternatives also were examined: nominal vs. deflated farm level prices and constant total farm level demand slopes vs. constant per capita demand slopes.

Comparisons between results from the variations were based on the Theil's U statistics, the standard error of the equation, the average relative error, and the absence of first order autocorrelation. The per capita form of the demand equation was selected because of its greater consistency with the idea of the representative consumer and its performance was slightly better than the total market demand forms. Nominal prices generally performed better than deflated prices.

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[1]Stoecker, A.L. A Quadratic Programming Model of United States Agriculture in 1980: Theory and Application. Unpublished Ph.D. dissertation. Iowa State University Library. Ames, 1974.

[2]Hall, H.H., E. O. Heady, and Y. Plessner. Quadratic Programming Solution of Competitive Equilibrium for U.S. Agriculture. American Journal of Agricultural Economics, Vol. 50, pp. 341-356.

The national demand matrix so derived was then partitioned on the basis of population into regional demand matrices for 10 commodities. Demand for other desired commodities was defined as follows: cotton lint demand was fixed at a national level; demand equations for chickens and turkeys, eggs, and sheep and lambs were specified on the national level.

The regional demand matrix was partitioned into the submatrices below:

$$B_k' = \left(\begin{array}{c|c} D_{rk} & C_k \\ \hline R_k & D_{nk} \end{array}\right) \qquad (50)$$

Where:

B_k' is a 13 x 13 matrix of demand slopes for consuming region k, k = 1, 2, ..., 10;

D_{rk} is a 10 x 10 matrix measuring the effect on regional demand in terms of regional prices;

C_k is a 10 x 3 matrix relating the effect of national prices to quantities demanded in region k;

R_k is a 3 x 10 matrix relating the effect of prices in region k to national demands; and

D_{nk} is a 3 x 3 subregion demand matrix. Summation of D_{nk} over k equals D_n.

C_k, R_k, and D_{nk} are necessary due to the specification of demand of three commodities on the national level and not on the regional level.

The regional demand matrices, B_k', are derived from the national demand matrix by the following relationship:

$$B_k' = w_k * D \tag{51}$$

Where:

w_k is the proportion of total population in region k; and

D is the national demand matrix.

The regional demand intercepts are derived in a manner similar to the regional slopes, but the intercepts are also adjusted for expected regional differences in personal disposable income:

$$d_k = w_k \; d + I_d(I_k - I_{us}) \tag{52}$$

Where new terms are defined as:

d_k is the regional demand intercept;

d is the national demand intercept;

I_d is the regional factor relating changes in personal disposable income to the quantity demanded at the national level;

I_k is the expected personal disposable income per capita for consuming region k; and

I_{us} is the expected personal disposable income per capita for 48 states and District of Columbia.

The schemata following shows how the regional demand matrices were fitted together to yield regional and national price relationships.

Region	RHS	Regional Prices					National Prices
NE	d_1	D_{r1}					C_1
AP	d_2		D_{r2}				C_2
SE	d_3			D_{r3}			C_3
⋮	⋮				⋱		⋮
DC	d_{10}					D_{r10}	C_{10}
US	$d_{Nat'l}$	R_1	R_2	R_3	. . .	R_{10}	D_n

SUBJECT MATTER STUDIES

Three types of activities were pursued during the duration of the project. These included (a) model development, modification and quantification, (b) participation in user activities, and (c) conduct of subject matter studies. The subject matter studies represented major national problems which the ISU-NSF-RANN project staff analyzed by means of the models. A total of 27 major subject matter studies were completed during the duration of the project or are in the process of completion. (Only three of the current set remain to be completed.) To indicate the general nature of these studies, the summary of published reports of several are included on the following pages.

Models of Soil Loss, Land and Water Use, Spatial Agricultural Structure, and the Environment

The study was undertaken to develop and test a model capable of simulating the changes in national and regional variables relating to agricultural production with the control of the level of sheet and rill erosion from cultivated lands. The model incorporates the major agricultural commodities and determines their pattern of production in 223 areas of the continental United States. Within each area, nine land classes were defined based on the erosion characteristics of the soils. The production of the alternative crops is allocated to these areas and land classes based on their economic advantage and compatibility with restraints.

The results indicate that agriculture can meet present and expanded levels of demand while maintaining a gross field loss of soil set at a level below 5 tons per acre. The analysis consisted of reducing the allowed level of per acre soil loss from no limit to 10 tons per acre, to 5 tons per acres, and finally to 3 tons per acre. Then, impacts of these restraints were traced to the implied shifts in such national and regional parameters as soil loss levels, crop production patterns, farming methods used, land and water resources and capital inputs required, and changes in the farm level prices of agricultural commodities. Changes in these parameters are also determined when export levels are increased. The soil loss analysis used the 1969-71 average level of exports as a base and the export alternatives consider increases in exports to three times this level.

Total soil loss can be reduced substantially through shifts to the use of contouring, strip cropping, terracing or reduced tillage methods on the cultivated lands. Some shifts are indicated in crops grown as the more erosive row crops, especially the silages and other crops leaving little or no residue cover, are substituted for less erosive crops.

Regionally, the shifts in production level and pattern are more pronounced in the high moisture-high runoff areas such as the South Central, South Atlantic and North Central regions of the nation. These highly erosive regions do experience exports, but their proportionate increase in acreage is not as large as for the more arid regions. The more arid regions, where runoff is correspondingly lower, gain in production as the soil loss restriction level is reduced. Also, in all regions the more erosive lands are used progressively less as they lose competitive advantage to the less erosive lands. As exports increase, some of the more erosive lands are returned to production before lands of low erosion characteristics which are at a transportation disadvantage relative to the projected export ports.

The environmental impacts associated with the soil loss restriction are twofold. First, the level of sediment available to enter the waterways is reduced, as well as the level of other materials for which sediment serves as a transport mechanism. The second impact is not favorable from an environmental aspect. The reduction in sheet and rill erosion is accomplished through an increase in the use of reduced tillage methods and a corresponding increase in the use of pesticides to control weeds and insects. These had formerly been partially controlled through tillage practices. Reduced tillage requires a much greater chemical application per acre and presents a greater exposure possibility for the agricultural laborers handling and applying the chemicals.

The distribution of returns to the agricultural sector shifts with the imposition of a soil loss restraint which becomes progressively more limiting. The return to labor and water declines slightly while the return to land increases greatly. For land owners, shifts in returns result as the lands which can comply at low cost command a higher rent and those which require intensive operations command a reduced rent or no rent at all if the restriction forces the land into a nonuse status. The imposition of a soil loss restraint could place a heavy burden on certain regions or farm operators.

The general trend is for little change in the farm level price of agricultural goods until the allowable soil loss level is reduced to 5 tons per acre or less. As the export levels were increased in conjunction with the 5 tons soil loss restraint, the farm price of the agricultural commodities increased significantly when the feed grain, wheat, and oilmeal exports reach a level exceeding two times the base level.

A National Model of Sediment and Water Quality: Impacts on American Agriculture

The large-scale linear programming model of agricultural production is augmented with a stream sediment subsector in year 2000 for this 105 region model. This model provides both completeness and flexibility in the agricultural sector for meeting problems of environmental stream water quality. To assess the workability of the model and to evaluate possible environmental policies, five alternatives were analyzed for stream sediment loads, agricultural land use, crop production patterns, and total social cost. These alternatives provide a basic starting point from which interested analysts and policymakers can suggest additional options. The Unrestricted Alternative provides a starting point from which agricultural changes can be evaluated using alternate policy formulations. In this alternative, no restrictions are placed on agricultural production, soil loss, or stream sediment loads. The results simulate an agricultural sector that has undergone trend changes to the year 2000, but has not experienced change to meet sediment water quality goals. The stream sediment loads in this alternative closely approximate the average levels recorded in historic data. From this alternative it is apparent that not all agricultural regions are affected equally by environmental controls placed on cropland erosion and stream quality. In many areas either cropland acres are so few or erosion potential from cropland is so low that modifying cropland use does not modify stream sediment loads significantly. The midwestern and southern United States encompassing the Mississippi River drainage area and the Southeastern states, do have significant cropland erosion problems and suitable cropland management could reduce the sediment loads. The production patterns in this unrestrained alternative are suitable approximations to historic patterns for use as a point of departure for comparative analysis.

The alternatives considered are possible policies that simulate a variety of environmental goals for the year 2000. Each alternative produces some change in the makeup of the agricultural system. The most drastic changes occur when the goal is minimization of the sediment outflow of all U.S. river basins under a fixed demand for agricultural commodities, the second alternative. To accomplish this extreme environmental goal, large-scale redistribution of agricultural production is required. Stream sediment loads are drastically reduced under the assumed conditions of this alternative in most areas of the country with the total national sediment load reduced 23.3 percent. Significantly, almost all lands that can be terraced are terraced, large acreages are cropped using contouring, and reduced tillage is common among the tillage practices. Such shifts require the full cropland base to be cropped both to reduce erosion and to make up for production lost as land use shifts to less intensive cropping systems.

The livestock feeding system is changed drastically. Use of more grains (particularly small grains) and hay roughage and less silage is required. Total cost of producing agricultural commodities is 42.2 percent higher than in the Unrestricted Alternative.

The third alternative limits soil loss in tons per acre per year from each crop production activity to the level that will allow crop production on the land to continue indefinitely. These levels are established by the Soil Conservation Service. Such restrictions constitute limits placed on the allowed cropping technologies available at the farm level. Although not as extreme as the Minimum Sediment Alternative, several significant agricultural changes occur. Regions of the country normally experiencing low soil loss are at a comparative economic advantage. Thus, some of the cropping traditionally in high erosion areas such as the Southeast is shifted to areas of the West and Southwest. Sediment loads in the former areas are significantly reduced while loads in western areas either increase or fail to decline significantly. Regional and technical shifts in crop production and land use are significant, although total required land for commodity production does not increase much above the Unrestricted Alternative. Total commodity production cost is increased 2.9 percent while total sediment load decreases 9.3 percent as compared to the Unrestricted Alternative.

The two final alternatives are designed to evaluate two additional goals in reducing sediment loads. In the first, the cropland portion of the sediment outflow from each subriver basin (producing area) is restricted to 80 percent of the level estimated for the Unrestricted Alternative.

This limit places the burden of sediment control on each subriver basin in proportion to its cropland sources of erosion. The result is a 20 percent reduction in the total national cropland sediment load with each subriver basin modifying the technologies used and crops produced just enough to meet the locally required 20 percent reduction in agriculturally-produced sediment loads. Total national sediment load is reduced only 5.1 percent since the restraints are placed on the agricultural produced load only. The cost of producing all commodities increases only .3 percent and total national land used for crops is only slightly higher than for the Unrestricted Alternative.

The final alternative calls for a reduction in sediment load similar to the previous alternative except the 80 percent limit is placed on each major river basin. The national total sediment load reduction is identical to the previously described alternative. However, the total cost of commodity production is increased only .1 percent. Total land required for crop production actually decreases from the Unrestricted Alternative. This alternative points up the trade-offs in achieving desired stream quality goals when various levels of policy administration are applied. With the flexibility to choose which subriver basins reduced sediment loads under optimal economic conditions and those that are unchanged or increased, the model causes some regions to be used as "sediment control" regions as the required commodities are produced in efficient but still erosive areas. The "sediment control" areas produce less erosive crops and reduce stream flows. The water quality goal is accomplished, but the cost is less than in the former alternative.

Under the modeled linkage between cropland agriculture and stream sediment water quality, agriculture can be used to reduce sediment loads and meet environmental goals. The cost to agriculture and, thus to society, can be high for extreme environmental control.

Quadratic Programming Model Applied to Three Environmental Alternatives

Three solutions to reflect three possible alternatives of environmental control were made. Solution I reflects U.S. agriculture in 1980 with no government-imposed restrictions, payments, price supports, or other programs. Solution II estimates the impact of setting maximum rates of nitrogen fertilization on crops: 110 pounds of nitrogen on corn and sorghum (both grain and silage); 80 pounds on cotton; 55 pounds on wheat, oats, and barley; and no nitrogen on soybeans. Solution III estimates the impact of removing four organochlorine insecticides (aldrin, dieldrin, chlordane, and heptachlor) from the market.

The effects on prices by the limited fertilization rate were greater than the effects by the insecticide removal. The largest price increase due to the removal of the organochlorines was for roughage, an increase of $3.33 per ton. This price increase was due to increased costs of roughage production as other acreages expand and push silage and hay onto less productive lands.

The nitrogen restriction caused small price increases in all commodities except soybeans and oil. Lower yields resulting from lower fertilization rates together with lower but fairly constant domestic consumption cause less productive land to be used, production patterns to change, and prices to rise for all crops.

Price changes are modest under both the fertilizer and insecticide limitations because the export demand levels are modest compared to recent years. Hence, agriculture produces with a capacity that is large relative to domestic and foreign demands in the model. Agricultural supply prices are quite constant at this level of capacity and do not rise sharply until production pushes more tightly against capacity. If export demands were set at the levels of recent years, the price effects of the environmental restraints would be much greater. Hence, as further applications are made with the quadratic programming model developed for this study, evaluations need to be made with several different levels of export demands for 1980.

National production of commodities under the nitrogen restriction generally decreases in the face of higher prices. Corn production decreased by 276 million bushels. Per capita consumption of livestock remains fairly constant. Livestock demand for feedstuffs changes significantly because of the fertilizer limit. Use of barley in feeds more than doubles to 1,911 million bushels, while corn and grain sorghum use decreases.

Regionally, crop production patterns change because of relative shifts in comparative advantage under a fertilization limit. Wheat production decreases by 118 million bushels in the Corn Belt. Although part of this wheat acreage is shifted to corn, corn production still declines by 380 million bushels in the Corn Belt. Corn production in the Northeast, Mountain, and Pacific regions increases by 229, 36, and 7 million bushels, respecitvely. Other regions decrease corn production. The Appalachian and Northern Plains regions increase barley production by 47 and 336 million bushels, respectively, while the Northern Plains also increases oat production by 92 million bushels. Cotton production moves out of the Appalachian states and into the Southeast states while remaining in the Delta, Corn Belt, and Pacific regions.

Under the nitrogen restriction, wheat production shifts out of the Corn Belt. However, under the insecticide restriction wheat production in the Corn Belt is greater than under the nitrogen restriction or the base solution. Under the insecticide limitation, the Northern Plains increases wheat production by 8 million bushels while the Delta states decrease production by 36 million bushels. Corn acreage declines by 337,000 acres in the Corn Belt with the insecticide restraint and is replaced by wheat, however, corn production increases in the Northeast, Appalachian, and Delta regions. Barley production increases by 22 million bushels in the Northern Plains. Production of soybeans decreases in the Northern Plains, but increases in the Appalachian and Delta regions with the insecticide restraint.

The nitrogen restriction has a greater impact on production than does the insecticide restriction. Removal of the four organochlorine insecticides causes a higher total crop production cost. Both restrictions increase total crop production costs, but these increases come in different magnitudes. Under the fertilizer restriction, fertilizer costs decrease by $488 million, but labor and capital costs increase by $534 million for a net total increase of $46 million. Fertilizer costs decrease by $2 million under the insecticide restriction while labor and capital costs increase by $72 million for a net total increase of $71 million. Pesticide costs increase by $33 million because of the insecticide restriction and $30 million of this increase occurs in the Corn Belt.

The value of national production increases for all commodities except soybeans under the fertilizer restraint. Soybeans do not increase in value under the nitrogen restriction because of an excess supply of soybean oil.

Consumer food costs increase only slightly as the fertilizer and insecticide restrictions are applied. These food costs are based on changes in farm-level prices; it is assumed that processing costs would remain constant.

In conclusion: under the conditions of (a) normal trends in exports and (b) absence of government programs of supply control and(or) price support, either restriction on nitrogen or insecticide use could be applied with only slight increases in farm commodity prices and consumer food costs. Regional production patterns would be altered under either restriction with the nitrogen restriction giving the major changes.

As with all potential policies, there are certain trade-offs that must be remembered. Under the nitrogen restriction, more land is needed to meet domestic and export demands; these additional lands may be from the fragile land and marginal land areas. As an aggregate, more labor and capital are needed to produce, handle, and transport agricultural commodities. But in regions particularly dependent upon high nitrogen usage for crop production, income and unemployment would decline. Similar impacts would occur under the insecticide limitation, although interregional shifts in production would not be as great under the nitrogen limitation.

United States Agricultural Production and Resource Use Under Alternative Water, Environmental and Export Policies

The main objective of this study was to evaluate the nation's resource capability relative to future magnitudes of various variables affecting agriculture and its resources and technologies. Particular emphasis is placed on land and water resources.

To accomplish this objective a model was built that was capable of analyzing interregional interaction. The model incorporates 105 producing areas based on the U.S. Water Resources Council's aggregate subareas, 28 market regions, 57 regions with water demands and supplies defined, a transportation submodel, crops and livestock submodels, and all of the agricultural land and irrigation water of the nation.

The model analyzes changes required in land and water uses of individual regions, agricultural commodity production, interregional production shifts, regional and national soil loss, required conservation practices by regions, commodity prices, resource returns, and other relevant parameters.

To evaluate future resource adequacies, a base model and several alternative futures were determined. In each of these alternative futures, one or two parameters were changed with respect to the basic conditions in the base model. The base model represents a continuation of present trends in yields, per capita food consumption, and exports. Per capita consumption and export levels are obtained from the OBERS projections.[1]

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[1]The OBERS projections were derived for the Water Resources Council by the Office of Business Economics of the Department of Commerce and the Economics Research Service of the U.S. Department of Agriculture.

For our purposes, two of these projections were used, the OBERS E and the OBERS E'. The E' projections were prepared at a later date and represent, on the whole, higher domestic and export consumption levels. The base model was solved for the years 1985 and 2000.

The alternative futures can be combined into three groups. The first group analyzes changes in projected demand and export levels on interregional production patterns, land and water use, and prices. In two alternative futures, high export levels are introduced while all other basic conditions stay constant. This high export alternative is solved for both 1985 and 2000. The third future analyzes lower demand levels (using OBERS E instead of OBERS E' projections) for the year 2000, only.

The second group deals with water quality, increased water use efficiency, and energy water demand. Water quality is assumed directly related to sheet and rill erosion from cultivated lands. To simulate increases in quality (or decreases in erosion) within each of the 105 producing areas, the dryland and irrigated cultivated lands are each allocated to nine land groups based on their erodibility characteristics. Activities are defined within each producing area and land group to simulate rotations producing alternative crop combinations under alternative conservation and tillage practices. Each rotation has a specific level of associated gross field soil loss as determined from the Universal Soil Loss Equation. The results from the solution indicate national and regional impacts of any restrictions on soil erosion. Two alternatives in this group analyze the impacts of a soil loss restriction of "t" tons per acre per year, where "t" stands for an amount of soil loss that will not reduce the productive capacity of the particular region over time. This factor varies among producing regions. Simultaneously in this alternative, a higher water use efficiency is assumed to analyze the impact of a water conservancy policy. These two alternatives, called the land and water conservation alternatives, are solved for the year 1985 and the year 2000. Also included in this group is an energy alternative in which water is allocated to energy development and agriculture is left with a smaller water supply for irrigation purposes.

The third group deals with the enhancement of environmental quality. The environmental parameters involved are soil erosion, wet soil development, animal waste disposal, and minimum stream flow requirements to preserve fish and wildlife habitats. Restrictions on all of the above are incorporated in the model and three alternatives analyze the impacts of such restrictions. The first alternative analyzes this situation for the year 1985, the second for the year 2000, and the third also analyzes the year 2000, but now under the lower set of demand requirements (OBERS E).

The results of the base model and the alternatives indicate that agriculture has a large capacity to produce higher levels of output while at the same time contributing to reduced gross filed loss of soil and increased environmental quality. If this increased output and higher environmental quality were to be required by the year 2000, the results show that the high levels could be attained with only small increases in the farm level prices. If, however, the achievement of greater output and higher water quality is required by 1985, prices will increase sharply, and drastic changes would be needed in land use and cropping patterns.

With respect to land resources, the results of the model alternatives indicate that there is sufficient land, especially cropland, to produce projected increases in food and fiber demand for the years 1985 and 2000. The 1985 high export alternative effectively exhausts all available cropland.

The high export alternative and the environmental enhancement alternative represent two extremes in land use. The first of these two alternatives analyzes the impact of an all-time high level of exports with no environmental restrictions, while the second alternative analyzes a future with many environmental restrictions and a lower level of exports. The results show that although total available land supply is not exhausted, the 1985 alternatives come close to using land up to its full capacity. These results, however, are based on specific assumptions about other forces competing for land. If the demand for land for urban, transportation, park and wildlife increases at a rate higher than incorporated in the models, the results may no longer apply. But in such a case, the alternative futures analyzed can still serve as a benchmark against which changes in the base assumptions or various policies can be evaluated.

The overall results on land use show that cropland available is not a limiting factor in achieving high exports or a higher quality of the environment by the years 1985 and 2000 while simultaneously meeting projected food and fiber demand.

The base models and all alternatives show that total water supply at the U.S. level is adequate to produce the projected level of food and fiber demand for 1985 and 2000 under the alternatives considered. The results of the alternatives considered indicate that the simultaneous achievement of a set of policies to enhance the environment and expanded export levels may not be easily attained. This is an important result, but one that has to be viewed in light of the conditions underlying the assumptions. The crucial condition or requirement is that high priority be given to water demands by fish and wildlife. Some of these demands are of magnitudes several times larger than the projected water deficits within specific producing areas. Hence, small reductions in the minimum stream flow requirements will allow simultaneous achievement of a slightly lower level of environmental enhancement yet allow projected demands to be attained.

Comparison of the net water balances of the conservation and environmental alternatives shows that the surpluses reported, at the river basin level, in the conservation alternative are larger than the deficits reported in the environmental alternative. The difference in assumptions between the two sets of alternatives is that in the conservation alternative water supplies are decreased to maintain minimum stream flow levels for fish and wildlife. The comparison of the net water balances leads to the conclusion that if high water use efficiency can be reached, i.e., higher than presently assumed in the environmental alternatives, the simultaneous achievement of the environmental enhancement restraints and the production of projected demand levels is a possibility.

Economic Impacts on U.S. Agriculture from Insecticide, Fertilizer, Soil Loss, and Animal Waste Regulatory Policies

The objective of this study is the analysis of policies designed to curb pollution problems created by excessive erosion of the soil, persistence of certain organochlorine insecticides in the environment, feedlot runoff, and the pollution of water supplies with nitrates. A modified 105 region programming model was used. There were five land classes in each producing area.

Alternative Futures

Six alternative futures were analyzed in this study to determine the effect conservation and environmental improvement policies might have on U.S. agriculture. The alternatives analyzed are: (a) Base Alternative where ongoing trends are assumed and no environmental restraints are imposed; (b) Soil Conservation Alternative where ongoing trends are the same as in the Base Alternative but soil erosion is restricted; (c) Nitrogen Restriction Alternative where ongoing trends are the same as in the Base Alternative but no more than 50 pounds of nitrogen can be applied per acre on any crop; (d) Insecticide Restriction Alternative where ongoing trends are the same as in the Base Alternative but farmers are denied the use of organochlorine insecticides Chlordane and Heptachlor; (e) Feedlot Runoff Control Alternative where ongoing trends are the same as in the Base Alternative but feedlot operators are required to control the runoff from their feedlots; (f) High Export Alternative where all cropland is planted to crops but no environmental restraints are imposed; and (g) Restricted Export Alternative where the soil loss, nitrogen and insecticide restrictions and the feedlot runoff control are the same as in the other alternatives outlined above. The same model is used in analyzing each of these seven alternatives.

Soil Conservation Alternative

The changes in cropping practices result in regional shifts in crop and livestock production. Small grain and hay production increase substantially in the Corn Belt offsetting a declining production of the row crops: corn, sorghum, and soybeans. This substitution of crops is needed because of the erosion problems caused by row cropping. The smaller erosion problems of the Northern Plains favor the production of corn, sorghum, and soybeans. For the same reason, cotton production shifts some from the Appalachian and Southeast regions to the Pacific region.

Beef cattle replace hogs to an extent in the Corn Belt because of the substitution of hay for corn production. Most of the displaced hogs move to the Northern Plains because of the region's increased feed grain production in the Soil Conservation Alternative. The beef cattle industry declines in the Northern Plains. Both beef cattle and hog production increase in the Appalachian region.

These shifts result in a moderate increase in the total value of agricultural commodities produced in the Corn Belt and Lake States regions and a substantial increase in the Appalachian and Northern Plains regions.

In comparison with the Base Alternative, results for the Soil Conservation Alternative indicate that total soil erosion might be reduced by 55 percent when agriculture complies with the soil conservation policy. However, to continue to meet domestic and foreign commodity demands an additional 15 million acres of land must be planted to crops. Also, agriculture needs to use 14 percent more nitrogen and 7 percent more pesticides.

This increase in the use of resources is needed to compensate for declining crop yields as crop production moves to regions of lower productivity, particularly as corn and soybean production shifts from the Corn Belt to the Northern Plains. A consequence of these production shifts to areas of lower productivity is rising supply prices, especially for soybeans.

The results from the analysis also imply capital gains and losses for current landowners. The return to land subject to excessive erosion falls because of the additional expense of controlling soil erosion and land not subject to excessive erosion has a higher return. Higher returns to land occur in the Appalachian, Lake States, and Delta States regions. Regions which have reductions in land returns as a result of conservation policy are the New England, Southeast, Southern Plains, and Northwest regions.

Nitrogen Restriction Alternative

A policy restricting the use of nitrogen to 50 pounds per acre to reduce the possibility of nitrate pollution results in lower crop yields. Lower yields require more land for crops to maintain the total output of agriculture and alter regional production patterns. Corn production decreases in the Corn Belt and the Appalachian regions while small grain, hay, and silage production increases. In response to the changed crop mix, beef cattle are substituted partially for hogs in the Corn Belt and Appalachian regions. Some hogs shift into the Lake States and Northern Plains regions. The result of these and other shifts is a substantial increase in the total value of agricultural commodities produced in the Appalachian, Lake States, Corn Belt, and Northern Plains regions in the Nitrogen Restriction Alternative compared to the Base Alternative.

In comparison to the Base Alternative, the Nitrogen Restriction Alternative reduces total nitrogen use by 26 percent, but requires that 25 million additional acres be cultivated and that pesticide expenditures increase by 8 percent to compensate for lower crop yields. Because these additional acres are of lower productivity and because 50 pounds of nitrogen per acre is less than the economic optimum for some crops the supply prices for farm commodities rises, especially for cotton.

Insecticide Restriction Alternative

Banning the agricultural use of Chlordane and Heptachlor under the Insecticide Restriction Alternative affects corn production, especially in the Midwest. Substitutes for these insecticides are more expensive and equally effective except for two insect problems. These insect problems are the first year insect complex of wireworms and grubs in corn following a grass crop and cutworm damage to corn grown in lowland areas.

In comparison with the Base Alternative, agriculture adjusts to the insecticide substitutes by replacing corn production in the lowland areas with soybeans and small grain and by reducing the acres of first year corn following grass. The additional costs of corn production in the Midwest cause a slight shift of corn production away from the Corn Belt and a replacement of it by small grains and soybeans.

The results indicate few major changes in total resource use in agriculture or in the supply prices of commodities, including corn, under the Insecticide Restriction Alternative. However, these small adjustments do not account for the losses that will be incurred by some corn producers.

On the average, the crop losses are small, but because insect damage may range from zero to a total loss, there is the possibility that the incomes of some farmers may be significantly reduced by a ban on Heptachlor and Chlordane.

Feedlot Runoff Control Alternative

Requiring feedlot operators to control the runoff from their feedlots to reduce pollution of nearby waterways raises the cost of livestock production. The increase in costs varies with regional differences in average size of livestock enterprises, the proportion of livestock in feedlots whose runoff may enter a waterway, and climate. When these costs are included in the model for the Feedlot Runoff Control Alternative, there is a slight shift of beef cattle from the Lake States to the Corn Belt and from the Northern Plains to the Southern Plains. There also is a small shift of hog production from the Corn Belt to the Northern Plains.

Comparison of the results from the Feedlot Runoff Control Alternative with the Base Alternative indicates few important changes in total resource use in agriculture or in the supply prices of commodities, including beef and pork. The small increase in the shadow price of livestock products does not mean that all livestock producers would be unaffected. Because of the expense for runoff control facilities, farmers will be earning a lower rate of return than expected on their investments in feedlot facilities. Small operators would be most affected because the cost of runoff control facilities increases sharply with decreasing lot size.

Export Potential Alternatives

The analysis requires the development of two export alternatives, both allowing the exports of corn, wheat, oilmeal, and sorghum to expand until production costs equal a predetermined export price. The first alternative, the High Export Alternative, is formulated with an export price high enough to bring almost all the available cropland into production. This expanded use of cropland is made without consideration of environmental consequences. The second alternative, the Restricted Export Alternative, is formulated to require that agriculture complies with the four environmental restriants reviewed earlier as output increases. Because each of the restraints raises production costs, the effect of compliance is to lower the potential export capacity of U.S. agriculture.

High Export Alternative The High Export Alternative uses 67 million more acres than does the Base Alternative. However, the expansion of exports requires more than land. The High Export Alternative uses 29 percent more nitrogen and increases pesticide expenditures by 50 percent. Most of the nitrogen increase is due to the high requirements of corn and sorghum. The largest proportion of the increase in pesticide expenditures is for corn, sorghum, and soybeans.

Regional crop production patterns are stable except for a relatively large increase of corn and sorghum in the Northern Plains and an increase in the concentration of cotton production in the Delta States region. The soil management practices change in the High Export Alternative relative to the Base Alternative. Continuous row cropping increases as the production of corn, sorghum, and soybeans for export expands. The number of acres protected by strip cropping and terracing rises in the High Export Alternative because of the increased row cropping of land especially susceptible to soil erosion compared to the Base Alternative. Because of the large increase in cultivated acres not protected by soil conservation practices, total soil erosion increases by 21 percent in the High Export Alternative as an average for the United States.

Restricted Export Alternative The reduced export capacity of the Restricted Export Alternative relative to the High Export Alternative is due partly to reduced land utilization since cropland having severe soil erosion problems is not cropped. The Restricted Export Alternative also has considerable tillage land which is not cropped. The nitrogen restriction reduces crop yields to the extent that many acres of marginal land cannot produce enough to cover the cost of the required soil conservation practices. As the result of these factors, there is a considerable shift of corn, sorghum, and soybean production from the Corn Belt to the Northern Plains where fewer erosion problems exist. These crops replace the small grains produced in the Northern Plains in the Base Alternative. Some small grains shift to the Corn Belt to reduce the erosion hazard.

Hog production shifts partly away from the Corn Belt to the Northern Plains and the Lake States in line with changes in corn production. Both the Corn Belt and the Delta States regions feed fewer cattle because of the erosion hazard of growing the corn grain and corn silage to feed them. These displaced feeders are dispersed across the United States with the largest number going to the Pacific region.

Soil erosion declines by 49 percent compared to the Base Alternative even though 55 million additional acres are cropped in the Restricted Export Alternative.

Imposing the environmental restraints on agriculture in the Restricted Export Alternative reduces the dollar value of exports by 40 percent, thus potentially affecting the nation's trade position. The environmental restraints make crop production unprofitable on 12.6 million acres of available cropland. They also cause a 25 percent decline in land return as compared to the High Export Alternative. A 60 percent decline in soil erosion and a 30 percent reduction in nitrogen used for crop production in the Restricted Export Alternative as compared to the High Export Alternative imply improved water quality and greater soil conservation.

Agricultural Production and Resource Use Under Limited Energy Supplies, High Energy Prices and Varying Export Levels

This study analyzed the potential long-run behavior of U.S. agricultural production under various energy scenarios. The study concentrates on four basic issues: (a) minimization of the total energy use in crop production, (b) agricultural production subject to an energy shortage, (c) agricultural production under high energy prices, and (d) high agricultural exports accompanied by high energy prices. Other policies (e.g., restriction on regional energy use, reduction in the supply of a specific energy source, etc.) also could be examined. The alternatives examine some of the more fundamental issues U.S. agriculture is likely to face in the near future. The analysis investigates resource use and prices, crop location and utilization, food costs, commodity prices, irrigation and water use, farming methods, and environmental impacts.

The interregional model is a modified version of the 105 region base model. Five different alternatives (models) are evaluated: a base run (Model A), energy minimization (Model B), 10 percent energy cut (Model C), high energy prices (Model D), and high exports accompanied by high energy prices (Model E).

Four of these alternatives, Models A, C, D, and E, minimize the total cost of crop production and transportation. These models suppose a competitive equilibrium wherein all agricultural resources receive their market rate of return. Land return, however, is determined endogenously by the model. One alternative, Model B, minimizes the total amount of fossil fuel energy (in KCAL) consumed in crop production and transportation. The minimization procedure is subject to a set of linear restraints corresponding to the availability of land, water, fertilizer, and energy supplies by regions, production requirements by location, the nature of crop production, and a final set controlling domestic and foreign demands through commodity supply-demand equilibrating restraints.

Activities in the model simulate crop rotations, water transfer and distribution, commodity transportation, chemical nitrogen supplies, manure nitrogen supplies, and energy supplies. There are 10,700 activities in the model. Endogenous crop activities are corn grain, sorghum grain, corn sialge, wheat, soybeans, cotton, sugar beets, oats, barley, legume and nonlegume hay. The projected production and regional distribution of all other crops and livestock are exogenously determined.

All alternatives assume a U.S. population of 232.2 million by 1985. All results refer to 1985. Models A, B, C, and D assume agricultural exports at 1985 OBERS E' levels; and Model E assumes exports at 1985 OBERS E' high levels. Because of the identical export levels and the minimization nature of the study, the production levels for the first four alternatives are the same (Table 3). They differ, however, from the high export alternative. Cost of production, transportation, and other inputs are in terms of 1972 prices. However, energy adjustments have been made to reflect the relative price changes of energy to other imputs between 1972 and 1974.[1]

Table 3. Crop production in 1975, under "normal" export (Models A, B, C, and D) and high exports (Model E) in 1985

Crop	Unit	1975	Model A, B, C, D	Model E
			(1,000 Units)	
Corn grain	bushels	5,809,637	5,800,197	6,598,797
Sorghum grain	bushels	758,454	1,043,516	1,375,269
Barley	bushels	382,980	1,045,602	1,124,363
Oats	bushels	656,862	952,847	1,013,885
Wheat	bushels	2,133,803	1,709,475	2,306,715
Soybeans	bushels	1,521,370	1,613,103	2,565,568
Hay	tons	132,917	342,775	373,743
Silage	tons	120,595	125,709	74,113
Cotton	bales	8,327	10,911	11,015
Sugar beets	tons	29,270	33,583	33,583

The base run (Model A) is the control alternative used for comparison with the other alternatives. The base run represents the normal long run adjustment of agricultural production if energy prices do not increase above

[1]Between 1972 and 1974 the index of prices paid by farmers increased by less than 40 percent while fuel prices more than doubled.

1974 levels, no restrictions are imposed on the amount of energy used in agricultural production and exports remain "normal." Energy minimization (Model B) represents the maximum possible achievement of energy savings subject to the technology defined in the study. It minimizes the total energy (KCAL) required for field operations, irrigation, fertilizers, drying, transportation, and pesticides regardless of how high the cost of food might be. A somewhat similar situation, but one which minimizes the cost of food and fibers, is analyzed under the 10 percent energy cut alternative (Model C). Under this alternative, the amount of energy (KCAL) available to agricultural production is restricted to only 90 percent of the base run. The very likely situation of much higher energy prices in the future is examined in Model D. With the high energy price alternative (Model D), the cost per KCAL is assumed to double relative to the base run. The high export alternative (Model E) retains high energy prices and also assumes exports of agricultural products to increase substantially from the base run by 1985.

Energy crisis, commodity prices, and food costs

The study demonstrates the great difference between an energy reduction policy and a high energy price policy. Even a 10 percent energy reduction for agriculture leads to a sharp increase in programmed commodity prices. However, doubling energy prices results in a much smaller relative increase in programmed commodity prices.[1] This phenomenon is explained by a very

[1]The term programmed prices is used to indicate that the prices are weighted shadow prices determined in the model. Hence, they are normative supply prices. They are not market equilibrium prices.

low demand elasticity for energy in agricultural production. For example, doubling energy prices leads to only a 5 percent reduction in the total energy use in agriculture. The derived energy demand curve in agricultural production becomes more inelastic as energy use declines. Hence, additional energy reductions can be achieved only by successively larger increases in commodity prices (Figure 19). The first 5 percent reduction in energy use (from 100 to 95 percent) results in about a 13 percent increase in commodity prices. Another 5 percent reduction (from 95 to 90 percent) results in an additional 42 percent increase in commodity prices. An additional 5 percent reduction (from 90 to 85 percent) results in such a large increase in commodity prices that it would seem unlikely to be acceptable even under the most severe energy shortage.

Possible increases in food retail costs cannot be obtained directly from the above results. However, most of the marketing processes such as transportation, freezing, canning, etc., are much more energy intensive than onfarm production. If restrictions under an energy crisis were not limited to onfarm production but also were applied to food processing and transportation, increases in food cost would be larger than indicated above for farm products only.

Resource use in agricultural production

Changes in energy supplies and prices have major impacts on resource use in agriculture and their costs. The most important energy-saving "strategy" that occurs in the model is reduction in energy use for irrigation and commercial nitrogen purchase (Table 4). A 10 percent energy reduction is accompanied by a 41 percent reduction in irrigated acres. Even the 5 percent energy reduction that results from doubling energy prices (Model D) leads to a 22 percent reduction in irrigated acres. This situation could be substantially different if U.S. agriculture were to face high export demands. Under high exports, irrigated acres increase 12 percent above the base run even when energy prices are twice their 1974 levels.

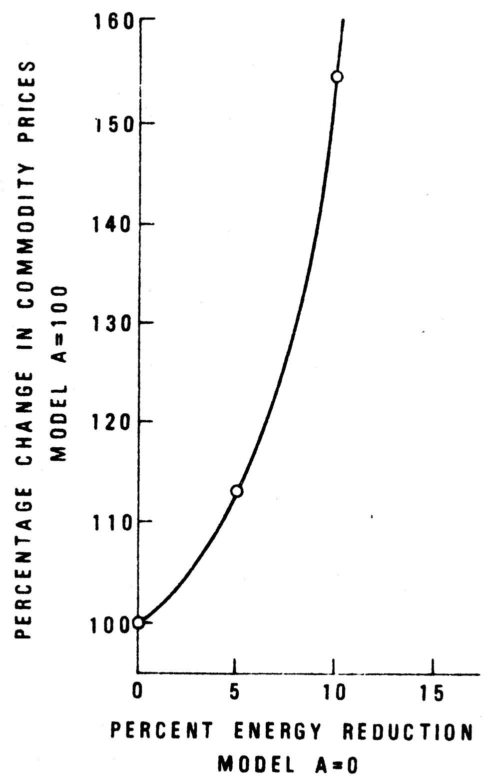

Figure 19. Effect of energy reduction on percentage change in programmed commodity prices

Table 4. Land use, water use, nitrogen use, changes from the base run (Model A) and resource prices in 1985, United States averages

Item	Unit	Base Run (Model A)	Energy Min. (Model B)	Energy Cut (Model C)	High Energy Prices (Model D)	High Exports (Model E)
				1,000 Units		
Dryland used	acres	320,707	347,453	338,181	329,026	341,988
Irr. land used	"	22,894	9,622	13,495	17,905	25,615
Total land used	"	343,601	357,075	351,676	346,931	367,603
Slack land	"	25,965	12,490	17,889	22,634	1,962
Water used	acre-feet	47,421	22,598	30,377	36,890	51,389
Nitrogen used	tons	6,743	6,438	6,470	6,520	10,554
Nitrogen purchased	"	2,126	1,396	1,569	1,829	5,573
				Changes from Model A		
Dryland used	percent	100.00	108.34	105.44	102.59	106.63
Irri. land used	"	100.00	42.03	58.95	78.21	111.88
Total land used	"	100.00	103.92	102.35	100.97	106.98
Slack land	"	100.00	48.10	68.90	87.17	7.56
Water used	"	100.00	47.65	64.06	77.79	108.37
Nitrogen used	"	100.00	95.48	95.95	96.69	156.52
Nitrogen purchased	"	100.00	65.66	73.80	86.03	262.14
				Resource Prices		
Average land rent	$/acre	16.78	N.A.	31.88	20.00	101.58
Average water price	$/acre-foot	9.29	N.A.	10.59	9.70	12.75
Nitrogen price	¢/lb.	12.14	N.A.	36.94	18.21	19.47

In all the alternatives analyzed, cropland currently not in crop production is substituted for other resources, water, fertilizers, and especially energy (Figure 20). An important part of the changes, however, involves converting irrigated land to dryland crops. For example, under the 10 percent energy reduction (Model C) irrigated crops decline by 9.4 million acres while dryland crops increase by 17.5 million acres (Table 4). Undoubtedly, such changes would have great impacts on irrigated farming and rural communities in the western states.

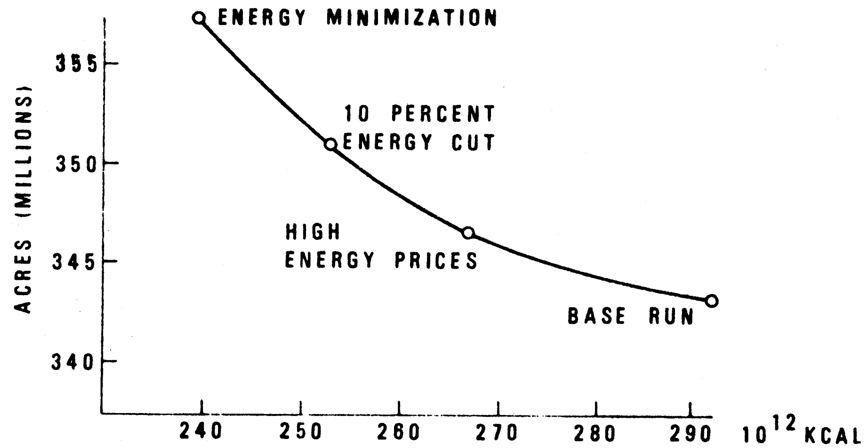

Figure 20. Energy-cropland substitution among different alternatives

The rate of resources utilized (described above) is clearly related to the value of resources in terms of shadow prices (supply prices, Table 4). Substantial increases in land rents take place both under the 10 percent energy cut (up to 90 percent) and under the high exports (up by more than 605 percent). Water prices vary only slightly under both the 10 percent energy cut and high energy price alternatives as production is moved away from irrigated cropland toward dryland crops. The sharp increase in nitrogen price under the 10 percent energy cut (Table 4) is entirely because of the increase in direct energy costs.

Among the most important results of this study are the energy shadow prices (Table 5) derived under the 10 percent energy cut alternative (Model C). The price of 1,000 KCAL more than quadruples from .858 cents in the base run (Model A) to 3.505 cents per 1,000 KCAL (Model C). The distribution of energy use in agricultural production among the different input categories is shown in Table 6. Tractors, combines, and other self-propelled farm machinery consume about two-thirds of all the energy in agricultural production. The amount of energy required for fertilizers varies according to the energy and export alternatives. Under energy minimization (Model B), energy use for nitrogen fertilizers declines sharply as chemical nitrogen application is reduced and more nitrogen is replaced by manure and legume crops. However, high exports (Model E) require about 262 percent more energy for nitrogen fertilizers than does the base run (Model A).

Table 5. Energy sources use, changes from the base run (Model A), and prices under different alternatives in 1985, United States averages

Fuel Source	Unit	Base Run (Model A)[a]	Energy Min. (Model B)	Energy Cut (Model C)	High Energy Prices (Model D)	High Exports (Model E)
				Energy Use		
Diesel	million gallon	5,377	5,179	5,340	5,407	5,964
Nat. gas	million ft.^{3}	180,060	111,198	124,332	152,966	400,458
LPG	million gallon	657	534	571	625	740
Electricity	million KWH	12,014	5,738	7,607	8,915	13,025
Total KCAL	10^{12}	292.438	249.622	263.194	277.354	377.544
				Changes from Model A		
Diesel	A = 100	100.00	96.32	99.31	100.56	110.92
Nat. gas	"	100.00	61.76	69.05	84.95	222.40
LPG	"	100.00	81.28	86.91	95.13	112.63
Electricity	"	100.00	47.76	63.32	74.21	108.42
Total 1000 KCAL	"	100.00	85.36	90.00	94.84	129.10
				Energy Prices		
Diesel	¢/gallon	35.614	N.A.	136.829	68.267	77.858
Nat. gas	¢/1000 ft^3	62.554	N.A.	240.333	119.906	136.753
LPG	¢/gallon	30.008	N.A.	115.291	57.521	65.602
Electricity	¢/KWH	2.387	N.A.	9.171	4.576	5.218
Total 1000 KCAL	¢/1000 KCAL	.858	N.A.	3.505	1.716	1.716

[a]Energy prices are based on 1974 prices

Table 6. Energy use in crop production and percent distribution for different alternatives in 1985, United States totals

Inputs	Base Run (Model A)	Energy Min. (Model B)	Energy Cut (Model C)	High Energy Prices (Model D)	High Exports (Model E)
			10^{12} KCAL		
Fuel for machinery	169.573	164.956	169.435	171.520	184.465
Pesticides	7.374	9.405	7.896	7.518	7.875
Nitrogen fertilizers[a]	36.455	11.969	26.904	31.363	95.563
Nonnitrogen fertilizers	7.207	7.287	7.036	7.060	8.019
Crop drying	13.056	12.148	12.610	12.933	14.320
Irrigation	41.456	.416	21.737	29.849	44.862
Transportation	17.317	43.441	17.576	17.110	22.440
Total	292.438	249.622	263.194	277.353	373.544
			Percent Distribution		
Fuel for machinery	57.99	66.07	64.38	61.84	48.86
Pesticides	2.52	3.77	3.00	2.71	2.09
Nitrogen fertilizers	12.47	4.79	10.22	11.31	25.31
Nonnitrogen fertilizers	2.46	2.92	2.67	2.55	2.12
Crop drying	4.46	4.87	4.79	4.66	3.79
Irrigation	14.18	.17	8.26	10.76	11.89
Transportation	5.92	17.41	6.68	6.17	5.94
Total	100.00	100.00	100.00	100.00	100.00

[a]Energy for nitrogen fertilizers indicates energy for commercialy purchased nitrogen fertilizers only

Regional impacts

The energy alternatives have severe impacts on the regional distribution of crop production. The main factors responsible for the regional shifts are changes in the size and the location of irrigated farming. Only very small changes in dry cropland take place in the eastern regions (Table 7). For the western regions, however, changes in dry cropland use are substantial. The increase of dryland used in western regions is much greater than the reduction in irrigated cropland use. This occurs because more than one acre of dry cropland must be substituted for every irrigated acre taken out of production in order to maintain previous production levels.

Under the 10 percent energy cut and high energy prices, irrigated cropland declines substantially in the South Central, Great Plains, Northwest, and the Southwest. Regional changes in irrigated cropland can be compared in Figures 21 and 22. Changes under the 10 percent energy cut (Model C, Figure 22) are somewhat less severe than those under energy minimization. The large reduction in irrigated cropland in the South Central region (Texas, Oklahoma, and Kansas) is mainly because of groundwater depth as well as the great proportion of groundwater in the total water supply to agriculture.

Important changes also take place in farm income. Total return[1] to land, water, and labor increases by 57 percent under the 10 percent energy cut, 15 percent under high energy prices, and 460 percent under the high exports, as compared to the base run. Whether farmers are actually better

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[1]Total return to resources is the amount of the resources used times their respective supply prices (shadow prices).

Table 7. Regional distribution of dry and irrigated endogenous cropland for different alternatives in 1985 [a]

	Base Run (Model A)	Energy Min. (Model B)	Energy Cut (Model C)	High Energy Prices (Model D)	High Exports (Model E)
			Dryland 1,000 acres		
North Atlantic	11,420	11,373	11,382	11,431	11,473
South Atlantic	40,790	41,359	40,789	40,788	43,640
North Central	135,470	138,239	137,342	135,157	141,311
South Central	47,902	55,282	52,574	48,869	55,244
Great Plains	67,736	72,126	70,935	71,013	69,600
Northwest	7,525	13,960	12,718	11,962	12,634
Southwest	2,090	6,017	3,484	2,154	3,546
United States	312,931	338,352	329,221	321,372	337,446
			Irrigated Land 1,000 acres		
North Atlantic	N.A.	N.A.	N.A.	N.A.	N.A.
South Atlantic	N.A.	N.A.	N.A.	N.A.	N.A.
North Central	138	0	138	138	138
South Central	5,665	1,098	1,928	4,849	7,166
Great Plains	6,331	3,850	5,314	5,326	8,502
Northwest	4,152	398	448	1,123	2,520
Southwest	6,608	4,276	5,668	6,469	7,290
United States	22,894	9,622	13,495	17,905	25,615

[a]Dry cropland does not include summer fallow

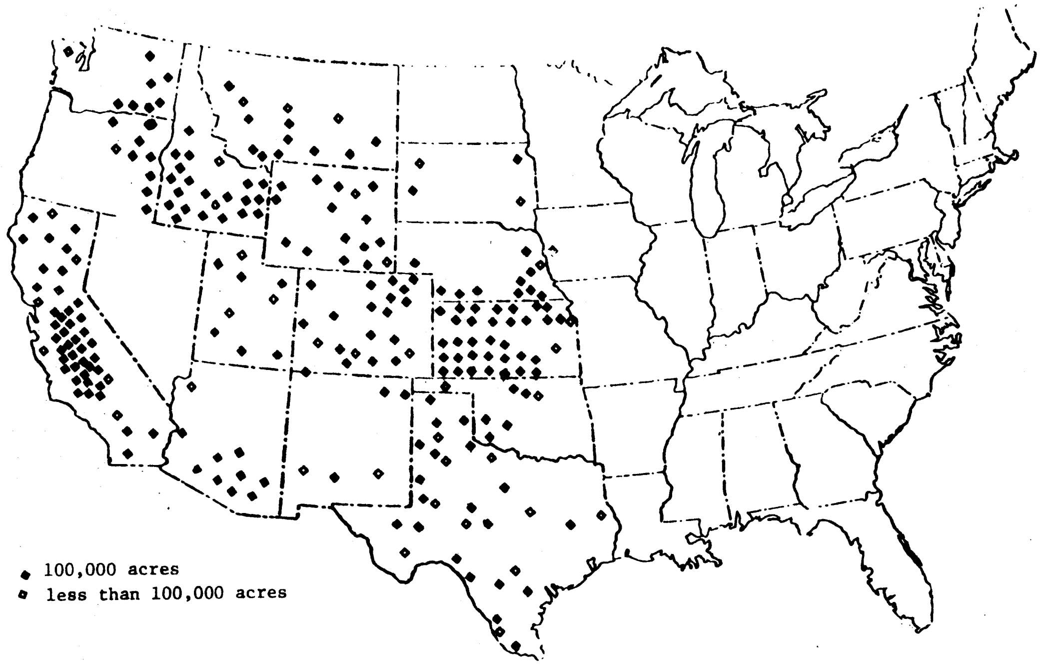

Figure 21. Location of endogenous irrigated cropland under the base run (Model A) in 1985

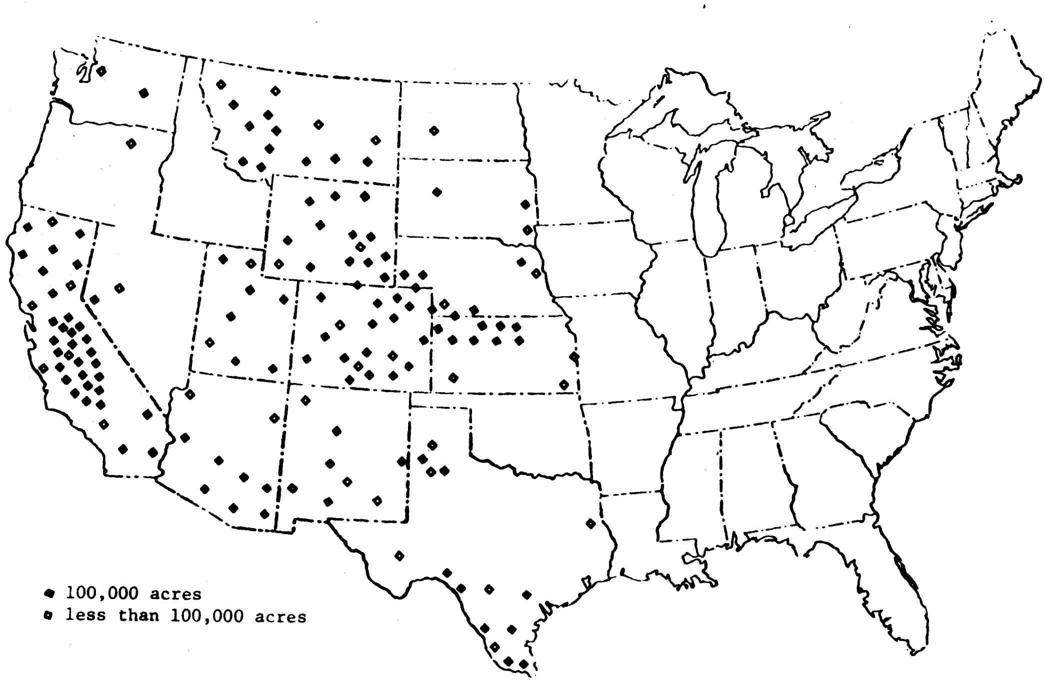

Figure 22. Location of endogenous irrigated cropland under 10 percent energy reduction (Model C) in 1985

off under an energy shortage or high energy prices basically depends on what happens to the cost of farm inputs as well as on their ability to pass the additional costs to consumers. Energy shortages as well as high energy prices have a great impact on the regional farm income distribution (Figure 23). The four western regions (South Central, Great Plains, Northwest, and Southwest) lose in relative income shares under both the energy cut and high energy prices. However, under the high export alternative these regions increase their relative income share while the eastern regions (North Atlantic, South Atlantic, and the North Central) reduce their relative income share. Clearly the regional income distribution is related to the proportion of irrigated farming relative to dryland farming in each region. Thus, a shift from irrigated crops to dryland crops due to an energy crisis also leads to a shift in the relative income share in favor of the dryland farming regions.

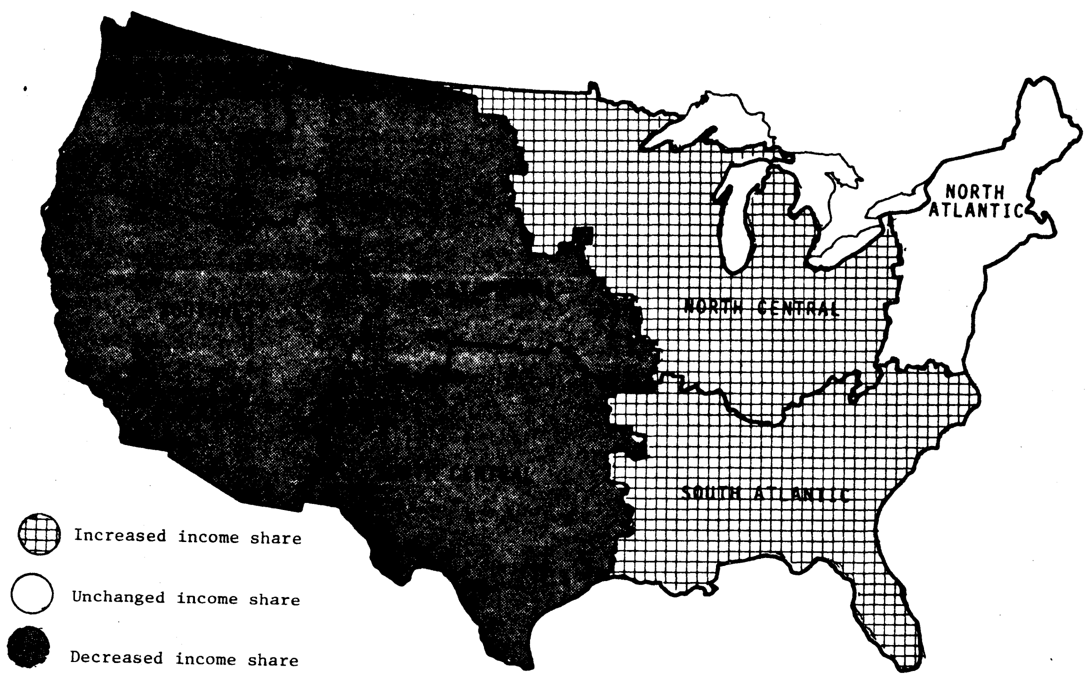

Figure 23. Changes in farm regional income share under 10 percent energy cut (Model C) and high energy prices (Model D) compared with the base run (Model A)

Multigoal Programming Model with Measurement of Trade-Offs Between Production Efficiency and Soil Loss

The major objectives of the study were to generate explicit trade-off information between (a) the cost of producing and transporting the nation's food supplies and (b) the maintenance of a more productive land base and a higher quality environment through soil loss control. The study was accomplished with a multigoal interregional linear programming model of U.S. agriculture. In the specification of the model, land resources were grouped into five quality classes for each of the 105 producing areas. Contiguous producing areas are aggregated to form 28 market regions. The model incorporates a transportation submodel linking all regions. Crop production activities are defined by land quality class in each producing area. The demands for the commodities are defined in the market regions according to per capita consumption and population projections for 1985.

Crop production activities produce barley, corn, cotton, and legume hay. The crop activities use one of three tillage practices: conventional tillage with residue removed, conventional tillage with residue left or reduced tillage. They also use one of four conservation practices: straight-row farming, contour farming, strip cropping, or terracing. Each crop production activity has a different soil erosion coefficient consistent with the factors: land quality, slope gradient, length of slope, rainfall, rotations, tillage practice, and conservation practice. The soil erosion coefficient indicates the tons of soil lost per acre per year under the combination of tillage and conservation practices and crop rotation represented by each activity. Production cost for each activity includes market rates of return to all resources used in agriculture except land. Land returns are determined endogenously in the model.

To derive the trade-off curve, the multi-goal programming employs the prior weighting technique. The two goals are combined into a single objective function by assigning explicit weights to each goal. The prior weighting technique can be summarized algebraically as:

$$\text{Min } F = [F_1(x),\ F_2(x)]^T = Cx \tag{53}$$

$$\text{Subject to } Ax \leq b \tag{54}$$

where F is a 2 x 1 column vector of F_1 and F_2, the goal functions for cost of production and transportation and soil erosion, respectively; C is a 2 x n matrix; x is an n x 1 vector of decision variables; A is an m x n matrix; and b is an m x 1 vector. In the multigoal problem the concept of optimality is replaced by the concept of efficiency. That is, the technique identified an efficient set of points, or efficient vector x* within which the solution lies. The x* is efficient if there is no other feasible vector x** such that

$$f_i(x^{**}) \geq f_i(x^*) \qquad \text{for all } i = 1, 2$$

$$f_i(x^{**}) > f_i(x^*) \qquad \text{for some } i$$

where $f_i(x)$ is the ith goal function.

The generation of the efficient set to (53) begins by transforming the vector-valued objective function in (53) to the scalar-valued function in (55).

$$\text{Min} \sum_{i=1}^{2} w_i f_i(x) \qquad (55)$$

where the w_i's are the relative weights assigned to each objective and all $w_i \geq 0$ and at least one $w_i > 0$. Systematically varying the w_i's in (55) will yield a trade-off curve. In this study w_i is selected to be equal to unity making F_1 (i.e., the cost of production and transportation) the numeric goal.

To generate the trade-off curve in Figure 24, six linear programming solutions each obtained with a different weight assigned to the soil erosion goal are considered in this study. The analysis is summarized around the five solutions setting different weights on (a) farming efficiency as reflected in the organization of the nation's agriculture to minimize the cost of food production and (b) soil loss.[1] The weights used in the six solutions are: Solution 1 has a weight of \$1.00 for the farming efficiency goal and zero for the soil loss goal. In Solutions 2, 3, 4, and 5 the weights on the efficiency goal are kept at \$1.00, but the weights on the soil loss goal are \$2.50, \$5.00, \$10.00, and \$20.00, respectively. As the magnitude of soil loss goal increases, society is placing a penalty on soil erosion. For Solution 6, the efficiency goal has a zero weight while the the soil loss goal has a weight of \$1.00. Hence, in Solution 6, society is giving zero weight to the efficiency goal. Each solution is an efficient point between the two goals and, when plotted, can be used to draw the

[1]The results of Solution 6 are not applicable to the real world because production costs do not enter into the optimization. For this reason the results of Solution 6 are not presented in this study.

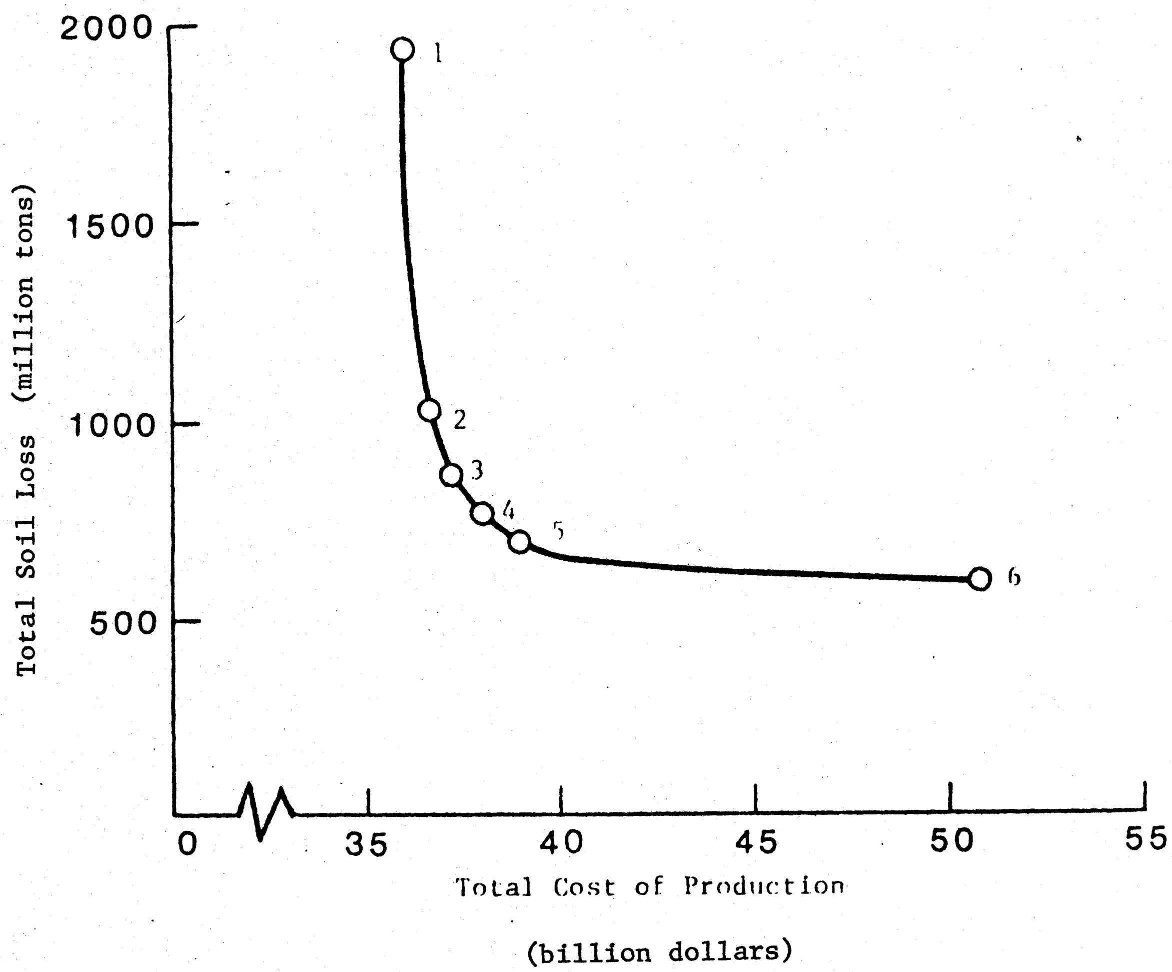

Figure 24. Trade-off frontier between goals for cost of production and soil conservation in an efficient agriculture. Totals for the United States

trade-off curve between the goals. The shape of this trade-off curve as indicated in Figure 24 implies that society may need to make a sizable sacrifice in one goal in order to optimize the other goal taken alone. If society is interested only in economic efficiency in U.S. agriculture, then minimizing only the cost of production (Point 1 in Figure 24) results in high rates of soil erosion from U.S. cropland. Conversely, if a high level of soil conservation alone is desired (Point 6 in Figure 24), then minimizing only the soil loss goal greatly increases the cost of production. The intermediate solutions indicated a "corner" for the trade-off curve between the goals.

Changes in soil loss and farming practices

The results obtained from the alternative solutions indicate that U.S. agriculture needs to make major adjustments in farming methods and cropping patterns to significantly improve soil conservation. Reduced tillage practices are substituted for conventional tillage practices to increase the quantity of plant residues on the soil surface. Contour farming is substituted for straight-row farming on land with a relatively small erosion hazard, while terracing is used on those field subject to severe erosion problems but have soil deep enough to support it. In Solution 1, 33 percent of the cropland is under straight-row farming. Straight-row farming drops to 23 percent of the cropland in Solution 5. Cropland acres protected by terracing increase from 11 percent of the total in Solution 1 to 23 percent in Solution 5. Terracing offers more effective production against erosion than strip cropping or contouring but is more expensive.

Changes in land utilization and production patterns

Assigning a cost penalty per ton of soil eroded significantly alters the comparative advantage of growing crops in those regions most susceptible and least susceptible to soil erosion. The high erosion hazard associated with row cropping in the South Atlantic region results in a substantial shift of soybeans and cotton production away from the South Atlantic region. Legume hay, grass and small grains substitute for these crops because of the protection they provide for the topsoil. This changing crop mix favors the further development of beef cattle in the South Atlantic region.

The low erosion hazard of row cropping gives a relative advantage to corn and sorghum grain production in the Great Plains, in those parts of the region adapted to these crops in terms of moisture, under a national soil conservation policy for U.S. agriculture. The acreage of small grains declines slightly in the Great Plains because production shifts to the South Atlantic and North Central regions as a soil conservation measure. Some shift in wheat from the Great Plains to more humid regions would change somewhat the mix of soft and hard red winter wheat produced. However, the amount of hard wheat would still far exceed domestic demand and the slight increase in soft wheat would substitute for hard wheat in exports and livestock feed.

Acrages of legume hay, grass and small grains increase in the North Central region as the agriculture in the region shifts away from continuous row crop rotations of corn and soybeans to lessen erosion. The increasing availability of grass and hay, as the emphasis on soil conservation increases, favors expansion of beef cow herds in the North Central region. At the same time, the beef feeding industry in this region declines because of the reduced acreage of corn. While the corn produced is ample to feed livestock produced in the region under other solutions, the comparative advantage of the region in feeding shifts with the reallocation of some grain production and the complex of transport costs which prevail relative to the point and level of exports.

Supply prices

Changes in farm practices (such as the increased use of terracing, and adjustments in cropping patterns, growing corn in rotation with grass and hay and shifting some of the corn acreage in the North Central region to the Great Plains) cause only modest increases in the cost of producing crops in the United States up to Solution 3. However, between Solution 3 and Solution 5 supply prices increase by a large amount (Table 8). These large cost increases would raise food costs for U.S. consumers and disadvantage U.S. agriculture in world commodity markets.

Table 8. Index of supply prices for the major agricultural commodities in the alternative solutions in 1985 (Solution 1 = 100)

Commodities	Solutions 1	2	3	4	5
Corn	100	104	115	144	198
Soybeans	100	113	134	184	280
Cotton	100	92	104	115	136
Pork	100	105	113	133	174
Beef	100	101	107	123	155

Implications of Implementing a State Land Use and Environmental Program Within a National Framework

This study was made mainly to determine the economic impacts of legislation by a single state to improve land use and environmental conditions. Will such measures enacted in a single state such as Iowa cause its producers to sacrifice in income as land use and farm practices are restricted while farmers elsewhere gain from the reduced output? What is the impact on consumers? How are these conditions altered as export levels change? It examines outcomes at the state and national levels as environmental controls are applied at different levels and combinations in Iowa but not elsewhere in the nation. The environmental controls considered are (a) soil loss per acre as specified in the Iowa Soil Conservancy Law of 1971, (b) limits on nitrogen use at 100 pounds per acre, and (c) pesticides restricted to organophosphates and carbomates in Iowa.

The subject matter analysis was made with the base 105 producing region model. However, Iowa was divided into 12 producing regions or areas to conform with the conservancy districts to which Iowa land use laws apply. Hence, the linear programming model has a total of 102 producing regions--12 in Iowa and 90 in the rest of the nation. It has 29 market regions and 35 water supply regions.

Erosion and erosion control methods

Erosion per acre with no restriction in Iowa averages 13.3 tons annually. With imposition of soil loss limits of 5 tons and 2.5 tons per acre, average soil loss per acre in Iowa declines to 3.9 tons and 2.2 tons per acre, respectively. Gross soil loss in Iowa is estimated at 362 million tons annually with no restrictions on soil loss. This quantity is reduced to 108 million tons per year under the 5-ton soil loss restriction and to 60 million tons with the 2.5-ton restriction in Iowa.

Control of erosion and reduction in soil loss is brought about through a shift from conventional tillage to reduced tillage and, within the tillage method, a shift away from straight-row farming. Under the unrestricted alternative, 85.4 percent of the total cropped area in Iowa is farmed under straight-row practices. This practice drops to 61.6 percent for the 5-ton soil loss restriction and to 32.5 percent under the 2.5-ton restriction in Iowa. The use of contouring in Iowa increases from .08 percent of the total cropped area under the unrestricted alternative to 20.4 percent with the 5-ton restriction and to 27.6 percent under the 2.5-ton restriction. Acreage under strip cropping and terracing also increases when we move from the unrestricted alternative to 5-ton restriction and 2.5-ton restriction in Iowa.

Use of nitrogen in Iowa

Total use of nitrogen in Iowa is 712 thousand tons under the unrestricted alternative (Model A). With the imposition of the 2.5-ton soil loss restriction (Model B2), the use of nitrogen increases to 777,000 tons. As erosion is controlled, the level of fertilizer application increases as farmers shift to reduced tillage methods. With the imposed limits on nitrogen use in Iowa (Model D), use of nitrogen in Iowa declines to 637,000 tons annually. The average per acre application of nitrogen in Iowa declines from 60.4

pounds under the unrestricted alternative to 51.5 pounds under Model D, where use of nitrogen is limited to 100 pounds per acre in Iowa. There is a further reduction in nitrogen application with the imposition of restrictions on pesticide use in Iowa. Average Iowa yields decline with the imposition of environmental restrictions in the state. Most of the crops are grown in rotation with legumes to supplement the availability of nitrogen.

Cost of production and farm income

Imposition of environmental restrictions in Iowa makes farming less profitable in Iowa and more profitable in other states. Cost of production of crops in Iowa increases from $1,367 million under the unrestricted alternative to $1,812 million with the imposition of the 2.5-ton soil loss restriction over the entire state for 1985. This increase in cost of production is brought about by increased labor and machinery costs required to achieve the reduction in soil loss through shifts in farming practices. At the same time, cost of crop production in the rest of the country decreases from $18,005 million to $17,892 million. The shifts toward soil-conserving practices in Iowa result in increased yields in the state. But the increase in Iowa yields are not large enough to offset the cost increases. As a result, farm income in Iowa declines. Iowa farm income decreases from $2,043 million under the unrestricted alternative to $1,929 million under 2.5-ton alternative (Model B2). Farm income in the rest of the country increases slightly between these two models. The reduction in Iowa farm income is even more drastic with the imposition of restrictions on the use of nitrogen and pesticides in Iowa.

Iowa policy implications

It is possible that farmers in some states will refuse, through legislation (causing the full burden of environmental improvement to fall on them while others are not similarly requested to sacrifice), to participate greatly in state programs. Single state programs tend to place the cost of environmental controls on the farmers of the state where they are applied but bring benefits in income to resource owners elsewhere in the country. This is not a major problem when only a few farmers and a small land area are affected, as has been true thus far in Iowa. But it could become serious if individual states impose restrictions on land use and environmental controls fully and effectively over all farmers. Federal legislation which can be applied uniformly to all farmers in all states may be required if this large issue arises in the future.

Income and Structure of American Agriculture Under Alternative Futures of Farm Size, Policies and Exports

The objective of this analysis made in 1973 was to examine possible impacts of alternative futures for three basic parameters of the American agricultural industry. These parameters are export levels, farm size and structure, and government farm policies. To compare these differing futures, seven separate situations are defined to form a set of contrasts, relating to the future of American agriculture.

To provide quantitative estimates for these alternatives, the interregional linear programming model describing the wheat, feed grains, soybeans and cotton sectors of American agriculture was adapted to the problem.

The model used has 150 producing regions with one land class each. Livestock and their feed demands are determined exogenously. The model incorporates a transportation submodel, and the fulfillment of consumer demands in 31 market regions. Production costs, crop yields, and consumer demands in the model are based on parameters estimated for the year 1980.

For each alternative situation, the model provides estimates of the value of key farm and nonfarm variables. Variables directly related to farming include farm commodity prices, production quantities and location, demand for agricultural inputs, number of commercial farms, and net farm income. Although these variables are directly related to farming, their value under alternative situations is also of major concern to those rural communities and nonfarm sectors which serve the farming industry. Nonfarm variables discussed include consumer food expeditures, changes in the level of gross soil loss, and changes in the amount of income generated by production of the model's four endogenous commodities. Table 9 presents a summary of the major parameters and national results estimated for this analysis. This table details the major trade-offs resulting (at the national level) among the alternative futures analyzed. Only results at the national level are summarized. Generally, the same results are availabe for each of the 150 producing regions.

<u>Export alternatives</u>

Alternative A represents the base situation for the analysis. It incorporates the assumption of trend growth in agricultural exports, technology, and average farm size. Soybean and feed grain production estimates

Table 9. Summary table of parameters and selected national results for the seven alternative futures examined in this analysis

	Alternative A	Alternative B	Alternative C	Alternative D	Alternative E	Alternative F	Alternative G
Export level	trend	trend + 25%	trend + 25%	trend + 25%	trend + 25%	trend	trend
Farm-size structure	typical	typical	medium	large	large (with no mobility restraints)	medium	medium
Government farm programs	none	none	none	none	none	direct payments	acreage quotas
Acreage required	100	110	110	110	108	100	101
Cost of producing the model commodities	100	156	154	134	110	99	104
Total net farm income	100	159	157	166	152	103	113
Number of commercial farms	100	110	130	62	61	117	117
Net farm income per commercial farm	100	144	120	266	247	88	97
Value of purchased inputs	100	109	109	94	91	100	101
Hours of labor required	100	111	106	92	90	97	95
Secondary income generation	100	156	152	131	109	98	105

[a]All results presented in this table are expressed in index form with the estimate under Alternative A = 100.

in this situation are well above 1972 levels, reflecting very strong foreign and domestic demands for the commodities. Wheat production, however, is nearly equal to that of 1972 and cotton and lint production is two million bushels less than in 1972. In total, the production levels of this situation require 26.5 million more acres than were harvested in 1972. These additional acres are concentrated in the Corn Belt, Lake States, Northern Plains, Southern Plains, and Mountain regions.

Wheat and feed grains supply prices in this situation are estimated at levels equivalent to 1972 prices while the estimated price of cotton lint is 7 percent above the 1972 price. The price of soybeans is estimated to be much lower than in 1972, in part due to the availability of cropland diverted from production in that year. Net farm income for this situation is nearly equal to the 1972 income--even though no government payments to agriculture are included in the model estimate. And since farm numbers are estimated to decline by 112,300 units in this base situation, per farm net income, $12,193, is $1,094 above that of 1972.

A major objective of this analysis is to examine the impact of export levels large enough to totally utilize the model's supply capacity. In Alternative B, therefore, exports of each of the model commodities are forced to be 25 percent greater than trend level exports. (This percentage increase is just sufficient to exhaust the programming model's land base.) These expanded export demands induce increases in production for all four crop commodities. Feed grain production in this circumstance, however, is only slightly greater than in the trend export situation because of reduced domestic demand for livestock in the supply capacity situation. This alternative requires 22.7 million more acres than the trend export situation. These additional acres tend to be concentrated in regions (the Appalachian, Southeast, and Northern Plains) which have excess capacity in the trend export situation.

Supply prices

As production is expanded onto more marginal, higher cost areas in the maximum production situation, the supply price of the commodities rise sharply. The largest relative increase is estimated for soybeans whose supply price jumps by 64 percent for the maximum export situation. Expanded production and higher farm prices lead to sharply higher income estimates for this situation. Per farm net income for the expanded export case, $17,565, is $5,372 greater than for the trend export situation.

As production and farm income increase, the total income generating potential of the model commodities increases. Nationally the increase in income generation is estimated at 56 percent for the maximum export case. Since the Appalachian, Southeast, and Northern Plains regions would have relatively large production increases in the maximum export case, they also have relatively large increases in their income generating potential. This estimate, coupled with increased input usage associated with expanded exports, implies an increase over Alterantive A in the level of economic activity in rural communities.

The expanded export situation does not have entirely positive outcomes, however, even though consumption levels are reduced, consumer food expenditures in this instance are estimated to increase by $21 per person over the trend export situation. Also, expansion of production places increased stress on the nation's land and water resources. Nationally, the gross soil loss estimate under maximum production is 11 percent greater than for the trend export situation. Estimated increases in soil loss in the Appalachian and Southeast regions are well above the national increase as these regions tend to be relatively more susceptible to erosion and runoff.

Farm sizes

Three different farm-size situations were defined for the analysis. One (Alternative D) assumes all farming operations are large, one (Alternative C) assumes all farms are medium-sized, and the third (Alternative B) assumes a range of farm sizes exists. These farm-size specifications are compared under the assumption that exports are at the maximum level. Outcomes are estimated to be nearly equal for the situation where all farms are medium-sized and when a mix of farm sizes exists. Since average farm size is smaller for the former case, however, per farm net income for the medium farm-size situation is estimated to be only 77 percent as large as when a range of farm sizes is assumed. The generally consistent results estimated for all the other output variables, however, do imply that the four model commodities could be supplied equally well in either of the two situations.

When all farms are assumed to be large, substantial differences are estimated for many variables--even though demands for the model commodities are held constant in the three alternatives. For each commodity, lower supply prices are estimated than in the other farm-size situations.

Cents per unit price reductions are 33 for wheat, 28 for feed grains, 74 for soybeans and 6.9 for cotton lint. These price reductions result in decreases in total cash receipts for the farming sector but that decrease is more than offset by reduced production expenses. And since the number of farming units in the large farm situation is 827,000 less than when a mix of farm sizes exists, per farm net income is 85 percent greater in the large farm case.

For six of the model's seven alternatives, resource mobility restraints are imposed to force the location of production in the model situation to be partially influenced by past production patterns. However, in one situation (Alternative E), these artificial constraints are removed to indicate the most efficient production distribution available in the programming model. Even though the same demand quantities are used for both situations, removal of these restraints allows 5.2 million acres that are required in Alternative D to be freed from production in this situation. Areas concentrate on production of commodities for which they have the greatest advantage and per acre yields increase. In addition, fewer inputs are needed for this "most efficient" situation. Supply prices, therefore, decrease for commodities. Compared to the alternative with identical parameters except for resource mobility restraints, cents per unit supply price declines are 55 for wheat, 25 for feed grains, 67 for soybeans, and 6.9 for cotton lint when the mobility constraints are removed. These lower supply prices imply lower consumer food expenditures and reduced levels of income generation for rural communities.

Farm policies

The third parameter considered was the method of implementing a government farm policy designed to attain desired farm prices. The set of prices chosen was the target prices of the 1972 Agricultural and Consumer Protection Act. One situation (Alternative F) assumed the market operates to achieve a set of market-clearing prices and deficiency payments to producers are used to raise the market prices to the desired level. Another situation (Alternative G) incorporated acreage allotments to force market prices to equal the target prices. In both situations, export demands were set at trend levels.

Per unit supply prices determined in the deficiency payment situation were less, in cents, that the target level by 26 for wheat, 3 for feed grains, 22 for soybeans, and 5 for cotton lint. Supply prices for the acreage allotment case, of course, are equal to the desired levels. The higher feedstuff prices of the latter situation are translated into reduced livestock product and livestock feed demands than for the deficiency payment alternative.

Both situations would require government payments to the agricultural sector. Deficiency payments of $812.5 million are required in the first alternative and a payment of $687 million is assumed to be necessary to insure that acreage is idled in the acreage allotment system. For the latter situation, the average per acre return estimated in the programming model was used to compute the acreage diversion payment.

An interesting contrast is presented when the same farm structure as is assumed for the last two alternatives is combined with the maximum export assumption (Alternative C). Adoption of the supply capacity assumption allows near fulfillment of the target price goal with no government payment to the farming sector. Per unit supply prices for wheat and feed grains in the maximum export situation exceed the target levels by 58 cents for wheat, 62 cents for feed grains, and $1.56 for soybeans while the price of cotton lint is only 2 cents less than the target price of 38 cents.

Other Subject Matter Studies

Other major subject matter studies completed during the period are listed below.

Simulated Effects of Alternative Policy and Economics Environments on U.S. Agriculture. CARD 46T. March 1974. 80 pages.

American Farm-Size Structure in Relation to Income and Employment Opportunities of Farms, Rural Communities and Other Sectors. CARD 48. June 1974. 102 pages.

Alternative Crop Exports, Land Use, Production Capacity, and Programmed Prices of U.S. Agriculture for 1975. CARD 50. October 1974. 115 pages.

Alternative Futures for American Agricultural Structure, Policies, Income, Employment, and Exports: A Recursive Simulation. CARD 56. June 1975. 144 pages.

A World Food Analysis: Grain Supply and Export Capacity of American Agriculture Under Various Production and Consumption Alternative. CARD 60. September 1975. 93 pages.

U.S. Agricultural Exports Capabilities Under Various Price Alternatives, Regional Production Variations, and Fertilzier-Use Restrictions. CARD 63. December 1975. 149 pages.

Impact of Water Rights and Legal Institutions on Land and Water Use in 2000. CARD 70. November 1976. 105 pages.

Economics and the Environment: Impacts of Erosion Restraints on Crop Production in River Basins. CARD 75. December 1977. 54 pages.

A Study of the Interaction of Weather with Alternative Environmental and Grain Reserve Policies. CARD 77. January 1978. 88 pages.

Energy Use in U.S. Agriculture: An Evaluation of National and Regional Impacts from Alternative Energy Policies. CARD 78. March 1978. 121 pages.

The Conceptualization and Quantification of a Water Supply Sector for a National Agricultural Analysis Model Involving Water Resources. June 1976. Miscellaneous report. 75 pages.

Land Use: Ongoing Developments in the North Central Region. September 1976. 300 pages.

Energy Requirements of Irrigated Crops in the Western United States. November 1976. Miscellaneous report. 33 pages.

Water Rights Institutions and the Transferability of Water. November 1976. Miscellaneous report. 48 pages.

Alternative Crop Exports and Fertilizer Restrictions in 1980: Effects on Farm Prices, Food Costs, and Farm Income. February 1977. Miscellaneous report. 109 pages.

American Agriculture in 1980 Under a Fertilizer Allocation System. August 1977. Miscellaneous report. 40 pages.

National and Regional Water Production Functions Reflecting Weather Conditions. September 1977. Miscellaneous report. 57 pages.

USER ACTIVITIES

Numerous practical user applications have been made with the models developed. An early user application was for the state of Illinois and the University of Illinois. The model was used, on request of personnel from the University of Illinois, to make solutions showing the potential outcomes if the per acre amount of nitrogen and phosphate fertilizers was restricted in the state of Illinois. This was a policy being considered by the Illinois Environmental Protection Agency at the time. The solutions showed that if only the state of Illinois restricted fertilizer use, crop production and farm income would decline in the state but increase in other states. Subsequently, University of Illinois specialists developed their own regional model in the context of the linear programming-soil loss context of the ISU-NSF-RANN models.

A special summary of model solutions was made for the Office of Fiscal Affairs of the New Jersey State Legislation in order that the State Assembly could evaluate alternative policies for the state's farm land use. Specifically, interpretative summaries were provided for soil regions 140, 147 and 149, for producing areas 13 and 18, and market regions 2 and 3. Ability to lift material from solutions of a national model to throw light on legislative possibilities for small regions of New Jersey emphasize the utility of the model construction.

At the request of the Iowa Conservation Commission, a parallel application was made for Iowa. Iowa legislation has established 12 soil conservancy districts to implement erosion control. While funds are not fully available, these conservancy districts have potential powers to enforce restraints on soil loss. The user application was made to determine the outcome if Iowa should fully implement its conservancy law while other states do not apply similar measures. The application indicated that full implementation of the Iowa conservancy law, in the absence of similar measures in other states, would cause farm income and land values in Iowa to decline while these quantities would increase in other states due to (a) a somewhat reduced national output, (b) a considerable reduction in Iowa farm output, (c) some increase in output in other states, and (d) inelastic demands for farm products. The Illinois and Iowa user applications suggest that land use legislation needs to be on a national basis if an inequitable distribution of costs and benefits is not to be generated.

State Uses

Special data were supplied the Office of Fiscal Affairs, New Jersey State Legislature. Personnel from this office asked for printouts and summaris of results for producing regions 13 and 18, soils regions 140, 147, 148 and 149, and market regions 2 and 3 of the national model. Results for alternatives were supplied this office for purposes of enhancing overall regional development and environmental preservation.

Water Resources Council and Economic Research Service

A very large user activity involved the National Water Assessment, made with and for the Water Resources Council. The application, made in close association with the Council, was implemented especially through the Economic Research Service of the U.S. Department of Agriculture and close interaction with the Soil Conservation Service, the Bureau of Reclamation, the Fish and Wildlife Service, and other relevant federal agencies. Sets of projections were completed for both 1985 and 2000. A group designated as the Agricultural Resources Assessment System (ARAS) Technical Committee met nearly monthly in Washington, D.C. to represent the Water Resources Council in helping specify the problems and model for application in the projections. The ARAS Committee which met with ISU-NSF-RANN project personnel included: Roger Strohbehn of the Economic Research Service, U.S. Department of Agriculture, chairman; R. Mac Gray, Soil Conservation Service, U.S. Department of Agriculture; Adrian Haught, Forest Service, U.S. Department of Agriculture; Alan P. Kleinman, Bureau of Reclamation, U.S. Department of Interior; Rodney W. Olson, Fish and Wildlife Service, U.S. Department of Interior; Arden Weiss, Water Resources Council; and Larry W. Tombaugh, RANN Program of the National Science Foundation. The thrust of the activity was to complete the National Water Assessment, a periodic responsibility of the Water Resources Council, for this time by the national-interregional model developed under the ISU-NSF-RANN project. The goal was to assess the nation's resource capability for the future, with special reference to agriculture and land and water use, under alternative economic environments. The analysis and evaluation is being published by the Water Resources Council and related federal agencies in several volumes titled "Agricultural Resource Assessment System: Trends and Modified Cases."[1] The Water Resources Council provided the funds necessary to do the computations and summarization of the results.

Midwest Governors Conference Use

A large user's activity also revolved around the North Central Land Use Study. The Midwest Governors Conference initially came to the CARD unit of Iowa State University and inquired whether its models could be used to make a large-scale study of land use in the Midwest. Initially, the Midwest Governors Conference was concerned with the use of the region's prime lands, including their transfer to nonagricultural uses and their potential contribution to exports and alleviation of world hunger. They eventually widened their concern to a broad set of alternative uses of the region's agricultural lands. They decided to ask their individual states to finance the study through the ISU-NSF-RANN models. No institutional financing scheme exists for the Midwest Governors Conference region which includes West Virginia, Kentucky and Oklahoma. Hence, the group asked the North Central Region agricultural experiment stations of the land grant universities to sponsor the study. This group did so in collaboration with the North Central Regional Center for Rural Development. With

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[1] A summary analysis was published by CARD of Iowa State University as: Anton D. Meister, Earl O. Heady, Kenneth J. Nicol, and Roger W. Strohbehn. U.S. Agricultural Production in Relation to Alternative Water, Environmental and Export Policies. CARD Report 65. Center for Agricultural and Rural Development, Iowa State University. For the documentation see: Anton D. Meister and Kenneth J. Nicol. A Documenation of the National Water Assessment Model of Regional Agricultural Production, Land and Water Use and Environmental Interaction. Center for Agricultural and Rural Development, Iowa State University.

financing from these sources, the ISU-NSF-RANN models were used to analyze five alternatives for the North Central Region agricultural lands: (a) prime lands retention where this class of land could not be used for non-agricultural uses, (b) increased exports with the North Central Region making a larger contribution to them, (c) use of more land to provide environmental corridors, more recreational area and open space for future generations of towns and urban populations, (d) improved conservation and erosion control for agricultural land, and (e) preservation and conservation of fragile lands. These alternatives were analyzed for the states, and subregions thereof, North Dakota, South Dakota, Nebraska, Kansas, Minnesota, Iowa, Missouri, Wisconsin, Illinois, Michigan, Indiana, and Ohio. A general summary of the regional results was prepared. Then, three subregional meetings were held to explian results to state personnel and deliver detailed state and substate results to the respective state representatives. The state representatives then could make further analysis for their state or subregions of it. State representatives at these meetings included personnel from the governors' offices, state planning agencies, federal agencies located in states, land grant universities, land use and community development organizations, community leaders, and others. Regional representatives have expressed interest in having the study extended to other facets of the regions resource problems.

Environmental Protection Agency

The Environmental Protection Agency financed use of the ISU-NSF-RANN models for an analysis of potential control of nonpoint pollution through soil loss control. A model was modified to cover soil loss in nine land classes in each of the 225 producing areas of the United States. The economic consequences of applying several soil loss abatement programs were then evaluated. As outlined elsewhere, the Environmental Protection Agency will remain a user of the system through the Economic Research Service. In a contract with ERS, the EPA will be able to evaluate potential economic and other impacts under the prohibition or approval of alternative pesticides it wishes evaluated and the latter will generate the appropriate technical matrices and access the ISU-NSF-RANN models to make immediate evaluations. The ISU models have been set up for pesticide policy analysis. The Pesticide Impact Group in NRED of ESCS is required to analyze the economic effects of proposed EPA pesticide bans within very short time frames. Using partial budget analysis, researchers posit crop yield and production cost changes in affected areas. These are input to the ISU models and a new solution obtained. Analysis is conducted in terms of comparisons with a base run. This pesticide analysis system is being set up so that it can be run from remote locations away from ISU, most likely Washington, D.C.

National Water Quality Commission

The National Water Quality Commission also made a contract through project personnel to evaluate various alternatives and data relating to water return flows from irrigated agriculture. It was possible to make this analysis in the context of national agricultural markets and identify impacts on commodity prices, land and water values and agricultural production patterns.

Extended Uses for States

Numerous of the above user activities involved statement of environmental or resource use problems to which the models were adapted. Solutions then were obtained from the models in a manner that the potential of policies, economic changes or government programs could be evaluated. The problems posed to the models generally were those relayed by the users at the outset of their communication with us. However, the models also were used to solve a wide range of environmental, resource use, policy, export and related alternatives or futures specified by the ISU-NSF-RANN project personnel. We tried to formulate forward looking problems of importance to the nation's agriculture or its major regions. Hence, with model solutions on hand for these, it was unnecessary for other persons in other states and in other locations to formulate the same problem, specify a model appropriate to it, and obtain solutions accordingly. For each major problem set analyzed, we wrote an analysis of the results and prepared a CARD report which was available to persons over the nation. We also published a large number of journal articles and other reports as is obvious in the publication list which follows. These publications also represent a very large user activity. The reports have been employed widely over the nation in educational programs, policy analysis, legislative approaches, and other public uses. ISU personnel also have traveled to many other states and locations to make further interpretations, extend the analyses to local conditions, summarize additional data, conduct seminars, participate in workshops, present papers and other ways of communicating results and applications to other users of the results of model solutions. Over 100 reports and articles have already been published, three dozen have been written and are in process and a large number of others are to be written as projects or phases underwhat are completed. It is expected that the literature generated by the project will have user impacts over the next decade or longer.

Staff members gave 61 papers at invited conferences, workshops and scientific meetings on results obtained from the study. These papers have been published and are available for general public use.

Continued ESCS and EPA Uses

Following completion of the National Water Assessment, the general area of work has continued through cooperative agreements of the Economic Research Service (now Economic Statistics Cooperative Service--ESCS) of the U.S. Department of Agriculture. The ESCS has stationed added personnel at Iowa State University to continue and help make extensions of the models. One major extension underway is the linking of mathematical programming models with simulation models of U.S. agriculture. A first generation linked model was built by ISU staff during the 1976-77 year and an ESCS staff member has been appointed to continue development of the model family.

During the 1976-78 period or third phase, a number of OBERS projections were made from the LP models by ESCS. These included a set of regionally disaggregated national production and resource use projections for the years 1985, 1990 and 2000.

These models also have been set up for continuous use by ESCS on behalf of the U.S. Department of Agriculture and for the EPA. The EPA will pose potential chemical and pesticide bans to the ESCS which will then put them through the ISU-NSF-RANN models to provide the potential impacts. These pesticide analyses are set up so that they can be used from remote locations away from Iowa State University (probably mostly in Washington, D.C.). Similarly, regional specific analyses will be made for ESCS and SCS analysis units over the country. Larger user activities in this framework are being prepared for the future.

In 1976, we initiated an effort linking together a national-interregional programming model with a national, recursive simulation model. The programming models retain their regional identities relating to land, water, soil loss, fertilizer and pesticide relationships, and production patterns, but also incorporate a market sector for resources and commodities through an econometrically estimated simulation component. The programming model generates supplies of commodities and demands for resources which feed into the market sector of the simulation model. The market sector then determines the prices which are fed back into the programming network--with commodity supplies and resource demands again generated for the simulation market sector. The first phase of this work was completed by ISU personnel. ESCS then stationed an additional staff member at ISU to help carry forward this work and to make applications of the linked model for particular problem areas of concern to USDA.

LAWREMS Models

Indirectly, the ISU-NSF-RANN models are making a contribution to the Land and Water Resources and Economic Modeling System (LAWREMS). The team involved in developing this system includes the following groups of the U.S. Department of Agriculture: ASCS, ESCS, FS, OBPE, SCS, and SEA. This interagency team is charged with promoting cooperation among agencies in uses and linkages of existing models and in recommending model development to permit land and water program evaluation and impact analysis. A major model set posed as input for these purposes is that developed under the ISU-NSF-RANN effort.

Soil Conservation Service

While the Soil Conservation Service was an active participant in use of the ISU-NSF-RANN models in the execution of the National Water Assessment for the Water Resource Council, we also have begun to provide SCS special services and activities. SCS has responsibility of monitoring programs and potential programs under the "Clean Water Act." Accordingly, after seminars by ISU and SCS personnel in April 1978, the ISU-NSF-RANN models were used to provide a dozen model solutions relating to national and watershed sedimentation levels for the SCS current evaluations. The solutions were delivered to SCS within a period of two weeks after their request to and seminar with ISU personnel.

As a longer-run activity, SCS must make reports in 1979 and 1985 on alternative programs to limit sedimentation. Evaluations are to be made of the amount of funds required to finance alternative programs in attaining various levels of sedimentation control. Analysis will also be made on (a) the ability of agriculture to supply commodities for domestic consumption and export purposes, (b) the impact on resource demands and adequacy, (c) supply prices of commodities, and (d) differential regional effects. Apparently, estimates of the kind desired for the analysis and reports can be best made by the ISU-NSF-RANN models. We have agreed to provide solutions to SCS accordingly.

Miscellaneous Other User Actions

Other user activities also have been underway. Two private economic consulting firms have contacted us relative to employment of the model set for the upcoming study relating to the Ogallala aquifer. This study will project the productivity, energy, resource use, community development impacts over the Great Plains region as the water level of the aquifer declines and water withdrawals must be lowered to recharge rates. The ISU models provide the regional specific detail and interregional impacts needed for this large-scale study.

Personnel from the ISU modeling group have carried on continuous dialogue with ESCS on methods to carry future financing and institutional use of the models developed and being formulated. One possibility posed is to make a proposal to ESCOP (Experiment Station Committee on Policy) that the land grant university system and CSRS (Cooperative States Research Service, but now in SEA) have funds appropriated for this purpose.

Some Iowa State University personnel who have worked on the U.S. models have spent tours of duty in Thailand building a parallel national and interregional programming model for the agricultural sector to be used for policy purposes. This model is now in place and is being used to develop five-year plans and evaluate agricultural development policies. Information on these models has been carried to seminars in Singapore and the Philippines and other Southeast Asia countries are working to initiate similar programs and models.

A number of foreign institutions have sent personnel to study the ISU models. FAO deputized two people to spend a term at CARD to learn the specification and operation of the models. During the past year, research personnel from Japan, Germany, Yugoslavia, Australia, Brazil, and Iran have served as visiting scientists for these purposes.

PERSONNEL INVOLVED

A large number of personnel at Iowa State University have been involved in the project. Numerous of these persons have moved on to other universities, and even to other countries, where they are involved in large-scale modeling activities and(or) policy analyses. A total of 17 persons have received Ph.D. degrees from various phases of the project. Personnel at Iowa State University who have been actively engaged in the project are listed on the following page.

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Mathematical Modeling and Computer Programmer Specialist

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In addition to the above ERS personnel stationed at Iowa State University who worked actively on the project, numerous ERS staff members in Washington, D.C. have been direct participants in the work. Especially involved were Roger Strohbehn, Howard Hogg, Reuben Wiesz, and Merlin Hanson.

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