ANALYSES AND MODELS OF LAND USE TO ATTAIN ENVIRONMENTAL QUALITY GOALS*

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Land use and environmentally-related models can range from the micro or site-specific analysis of a particular urban fringe or small watershed to macro or national models. Detailed computer land use and environmental models have emphasized site-specific or spatially localized problems and resource areas. Several factors contribute to this tendency: particular problems do relate to specific locations and must be solved at this level of disaggregation; research workers frequently do not have planning horizons allowing them to consider spatially extended models; and the time required and the intense data needs restricts analysts to localized problems and prevents extension to larger models and broader problems.

We have underway a set of models which incorporates both (a) national or macro dimensions, and (b) local areas (regions) and their agro-climatic and economic dimensions. These models currently emphasize land and water use, technological and environmental impacts, food supplies, farm costs and income and employment effects as they relate to the nation's agricultural sector. However, they have great promise for analyzing the nation's total land and water use potentials as these relate to spatial distributions of population and economic activity, environmental standards and related problems. The models have the capacity to evaluate simultaneously variables and outcomes in (a) national markets, prices, incomes and employment, and (b) production patterns, resouce use and economic structure of rather small

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resource regions, under the posed imposition of alternative policies or futures. We believe that models with these characteristics and capabilities are extremely important for the future as national, state and local entities evaluate and consider implementation of environmental, land use, water and other resource and technological restraints related to problems emerging under the nation's advanced state of economic development. Otherwise, the programs and policies imposed by states, municipalities and regional planning bodies will encounter unexpected economic effects, causing them to be nullified because they give inequitable distributions of the costs and benefits of the goals attained. For example, initial solutions of our models pose the certainty that individual states which impose restrained patterns of land use, water runoff, sedimentation and technologies will find that, through market impacts, producers and resource owners of other states and locations will realize economic gains while those of the imposing state will bear the costs in lower incomes and reduced resource prices. Even for certain quality controls imposed at the national level, relative returns can be positive in some regions and negative in other regions.

While our models currently under construction emphasize land use, water technology and environmental quality as they relate to the agricultural sector, with some modifications to accommodate sedimentation generated by highway and urban construction, they can be adapted eventually to incorporate a major share of society's aggregate land use planning problems at the national level. They can, given various national objective functions and with planning restrained to conform with local goals in land use and technology, trace the impacts back to individual land and water resource

regions. Or, conversely, the models also can trace the impacts of plans imposed independently at region or area levels to other regions and to the aggregate national level. Optimal patterns of land, water and technology (fertilizer, insecticides, livestock scale and dispersion, etc.) use can be evaluated whether they relate to discrete regulations or pricing mechanisms imposed by the public. The models under construction also allow examination of the effect of different environmental and land use programs on employment and income generation in rural areas and the potential reflection of these impacts through various agricultural structures as represented by different farm size and employment patterns.

We believe these models which specify possibilities and outcomes at both the national and local levels will prove extremely important in future years and decades as the nation and states come to explore and require particular environmental quality and land use controls. These models, financed under an NSF-RANN grant, will be developed as ongoing operational models available to various users. Not only can a range of problems at the national level be analyzed through them but also detailed land use plans and potentials of localized areas can be inserted in them, to allow estimation of economic interactions through national markets and interrelationships with other areas.

Role and Nature of Land Use Studies

Studies relating to the use and planning of land and environmental quality fall into four major categories: (a) Inventory and descriptive studies which quantify the physical amount and characteristics of land or its subclasses. Largely, the inventory-descriptive activities suggest the

restraints on use in terms of upper limits on availability or physical suitability to various uses. Mapping of land according to potentials in use through physical limits and characteristics also falls in the inventory-descriptive category. (b) Predictive (usually statistical) studies which explain behavior in the use of land as it relates to economic, social, policy, climatic and other variables. (c) Normative, optimizing models which explain how land ought to and could be used relative to variables and parameters which relate its potential use to physical, economic and institutional restraints while considering the various goals or objectives (objective functions) of society, regional or other particular groups. These models when applied quantitatively, also could be termed allocation models. Including their allocation and optimization features, they can be (a) purely physical in terms of land and spatial characteristics, (b) economic and social through incorporation of demand, policy and related variables, and/or (c) simulation models which portray outcomes when variables surrounding land use take on various values. Both the normative programming and more conventional simulation models can be used to indicate outcomes when different policies or futures are to be examined or posed. Of course, other combinations of the above categories also can prevail. For example, descriptive studies of land indicate the quantity of each productivity group to serve as supply equations or restraints in a programming or allocative model. The predictive or statistical study can supply demand functions for the objective function of a nonlinear land or water allocation or normative study; or it can provide behaviorial equations for a statistically-based simulation model. Even a normative allocation model is an attempt to

predict or estimate potentials in land use and environmental attainment relative to limits in land supply, food demand, exports, publicly improved limits and other bounds. It incorporates both (a) physical features in terms of land characteristics, climatic variables, water supplies and technology, and (b) economic and social features in terms of demand relations, resource costs and public policies and goals.

The model summarized in this paper largely is of the third category and indicates optimal spatial allocation of agricultural production and technology and land use patterns relative to restraints in markets (demand), natural resource supplies and locations, environmental quality controls, alternatives in domestic and export policies, etc. It can be used to simulate outcomes under various economic, policy technology and natural endowment parameters and possibilities (or can be linked with other types of simulation models). Largely, however, models of this type specify optimal and potential land and water use and environmental possibilities relative to amounts and qualities of land classes, the distribution of population and economic activity, per capita income and food demand, transportation costs and facilities, capital and labor costs and other relevant conditions which can be quantified. While only a model of a deterministic and single time period nature is reviewed, this general class of models also can incorporate time and stochastic characteristics (but grow in size accordingly).

Purposes and Conditions of Land Use Planning

Land and water use and environmental planning to attain major public purposes and social objectives needs to have some means to relate the particular use for a specific region of these resources to (a) alternative uses

of this same resource set at the given location, and (b) the use of land, water and technology at this specific location relative to their use at other locations, whether far or near. Hence, some set of criteria must be available wherein users of water, land and other resources and consumers of the products of these resources and policy makers can reflect their preferences. While land, for example, can be classed physically to place bounds on use for specific purposes, some set of weights or criteria, reflecting demand and consumer preferences, which can be expressed numerically, are needed for final determination of whether land at a specific location should be shifted from an existing or posed employment in competition with the potentials of land at a distant location.

The models reviewed in this paper encompass the whole of U.S. agriculture and the land and water use relating thereto. These demand-allocation models incorporate all major agricultural commodities into a supply-demand, resource use and environmental quality interaction reflecting restraints in resources for 223 agricultural producing regions, soil characteristics in 1891 land resource groups, water resources for 51 water supply regions in the 17 Western States, and demand or commodity balances in 30 consumer market regions. The models, which incorporate a transportation sub-model for commodities and water and product transfer activities, allow selection of optimal resource use patterns and environmental quality impacts for the nation in future time periods. They also reflect comparative advantage in the allocation of land and water to competing alternatives as represented in relative yields, general technologies, environmentally restrained technologies, production costs, transport costs and imposed

environmental restraints. They allow substitution of land at one location for water at another location a thousand miles away (or vice versa). Similarly, they allow and analyze these substitutions when environmental restraints are applied to restrain the technologies used in any one resource region. Finally, they allow evaluation of various policy alternatives in use of land and water resources, and environmental quality controls in interaction with commercial agricultural policies, export goals and domestic demands in both regional and national markets.

Objectives

Our overall objectives in building these models are to determine (a) whether the nation has enough land and water resources to meet domestic and export food needs when various environmental quality restraints are imposed, (b) the optimum spatial allocation, for the nation and internally for each individual producing, land and water region, of these resources accordingly, (c) the extent to which sacrifices must be made in environmental quality goals as other goals (food prices, exports, treasury costs, farm income, energy use, resource values, income distribution, etc.) are attained--or vice versa, (d) the cost to regions and the nation as various land use patterns and environmental quality goals are attained, (e) the optimal selection among alternative producing technologies and land use patterns, for each region and for the nation, as various environmental quality restraints are imposed, and (f) miscellaneous impacts including those relating to farm size and income, the distribution of the costs and benefits of these patterns or allocations, employment and income generation in rural areas.

The models in process of quantification incorporate variables relating to sediment loss, livestock wastes, irrigated and dryland farming, alternatives in farm and enterprises sizes, technologies using various levels of chemical fertilizers and pesticides--as well as all major crop and livestock commodities produced in each of 223 producing regions, 1891 land resource groups and 51 water supply regions in the Western states. Obviously, these models grow to very large size and can soon mount to thousands of equations and variables. The final models which we quantify and solve will depend on computer considerations--including costs and efficiency of different programs. We are maintaining a flexible stance, in the sense that the process of quantification can proceed and decision on the extent of aggregation required to meet computer time and cost restraints can be made later. For operational models which will be kept ongoing for various users we may emphasize a basic model of restricted equations and variables, and still have great flexibility in problems analyzed and retain reasonableness in solution costs. We summarize a model of modest size emphasizing land use selection in this paper to illustrate the general nature of the models involved. It includes 3800 equations and 30,000 real variables, including transportation. The land and water use submodel of our overall models are basic and "stationary" in the sense their structure and nature remains more or less the same regardless of other features of the models. For example, the land and water components remains essentially the same if we analyze problems relating to (a) a free market and our only concern is in defining optimal land use patterns for the nation and each of its producing regions under these conditions when policies relating to commercial agriculture,

environmental quality, farm structure, rural communities, etc. are absent, (b) the public imposition of programs relating to environmental quality and natural resource (land and water) use, (c) the public imposition of programs relating to other economic or social goals such as farm sector income, farm size, exports, and rural employment, or (d) any combination of these. However, the optimal use of land in any one producing region, as for the nation as a whole, will differ greatly depending on the environmental, economic or social policy imposed. For example, the economic optimal use or allocation of land under free market conditions and a full reflection of comparative advantage calls, under recent levels of national economic variables, for greater specialization in food production and land use. Optimal land allocation under a free market would call for a complete shift of many Great Plains areas from small grains to grass and grazing. It also would call for shift from field crops of many localized areas in the Southeast and Atlantic Coast regions. In contrast, an optimal national land use plan under the restraint of supply controls to attain farm price and income goals and an "equitable" contribution of each farming region to this attainment disperses basic farm commodities over the land of all regions. Environmental quality controls based on runoff and sediment transport, for example, will have direct impact on crops produced and technology used on erodible lands (e.g., slope of land and amount and intensity of rainfall). However, these environmental restraints also will have "chain reactions" in optimal land use in regions 100 or 1,000 miles away which are not subject to runoff and sediment loss since, nationally, a new configuration of comparative advantages will be created in relation to both the environmental restraints

and commodity and resource markets. Land with characteristics giving rise to runoff and sediment loss may be required to shift to more forages, livestock production or forest products--although the outcome also will depend on row crop yields, costs and returns under mechanical erosion control practices. In the "chain reaction" or regional interdependence relationships, land at one distant location not subject to erosion which once produced cotton may now optimally be allocated to soybeans to meet national demands while at a different location, nonerodible land once allocated to wheat now may be specified for feed grains as the national livestock ration and export demands are met. Restraints on chemical fertilizers and pesticides have similar remote and complex interactions in resource use among the many different land regions of the nation. Generally those regions of ample rainfall and irrigation water will be shifted towards a less intensive use of land while adapted regions with less runoff and relatively less dependence on imported technological inputs will tend towards more intensive land use (e.g., more grain and less forage and livestock production).

Because of these regional interdependencies, it is impossible to plan nationally efficient uses of land and environmental quality controls on a region-by-region or regionally independent basis. The models used for analysis and planning need to incorporate these interdependencies among the hundreds of land resource regions and allow for both direct and indirect impacts among regions whether they are contiguous or distant from each other. Not only do they need to incorporate these interdependencies among land resource regions, water regions and market regions, but also they need to allow them among resources and commodities. They need to allow substitution

of land at one location for water at a different and distant location, since a policy restraint which limits the use of capital technology on land at one location can be offset by a reallocation or extended use of water at another location--or vice versa. Great flexibility prevails in the national livestock ration, the major demand determinant in national land use, and shifts in or restraints on land use can allow or cause limits on grain production in one location to be replaced by soybean, forage or a substitute feed grain in another location. An efficient land use-environmental quality model needs to allow all of these interdependencies over the nation with reflection back to optimal land employment for each land resource region.

Our models allow a full range of these substitutions and interrelations, not only among the land resources of the many regions of the nation but also among land, water and capital technology and among the many commodities of agriculture. Impacts of the type mentioned previously are all reflected in land use-environmental quality models which we have solved. It is not uncommon for a change in land use of the central Cornbelt to cause a further shift in the Piedmont--to be followed by subsequent "chain effect" or inter-linked shifts in the Central Valley of California and thence in the Pacific Northwest. Optimal or potential national land use and environmental quality programs or plans can be determined only by models which contain these possibilities and specifications. Hence, we provide an example of this type of model. While it is less complex than others we have underway, it is sufficiently detailed to allow all of the types of interrelationships summarized above and to allow optimal land use-environmental

quality programs for the nation which are reflected back in determinations for each individual land resource region.

Nature of Models

To illustrate the general nature of the models involved, under the restraint of presentation time, we use a model projecting to the year 2000 for a population of 284 million, free market conditions with trend levels of agricultural technology in each of 223 agricultural producing regions, 1891 land resource groups and 51 water supply regions. This model, only one in a series we are building, emphasizes optimal land use patterns, agricultural water allocation, agricultural technology and soil conservation methods under environmentally restrained soil loss. (Subsequent formulations of the model set includes environmental limits on chemical fertilizers, pesticides and livestock wastes.) The objective function in equation (1) minimizes the cost of producing and transporting the various crop and livestock commodities among producing and land resource regions of origin, regions of processing, and regions of consumption. The costs allow the system to consider different technologies (cropping or land use systems and mechanical practices) in restraining soil loss to alternative environmental quality levels. The costs of water consumption and transfer also are included in equation (1). The programming prices and costs cover all factor costs (except land rents which are reflected in shadow prices) and thus allow simulation of a long-run market equilibrium for each commodity with a national allocation reflecting the comparative advantage of each of the 223 producing regions, 1891 land regions and the 51 water supply regions--subject to environmental restraints and the level and location of

consumer demands. The objective function is minimize OF where:

$$OF = \sum_i \Big(\sum_k \Big(\sum_m X_{ikm}\, UC_{ikm} + \sum_n Y_{ikn}\, UC_{ikm} + \sum_m Z_{ikm}\, UC_{ikm} \Big) + \sum_p L_{ip}\, UC_{ip} + DPP_i\, UC_i$$

$$+ IFP_i\, UC_i + DWH_i\, UC_i + IWH_i\, UC_i + FLG_i\, UC_i + FP_i\, UC_i \Big) \qquad (1)$$

$$+ \sum_w \Big(WB_w\, UC_w + WD_w\, UC_w + WT_w UC_w \Big) + \sum_t \sum_c T_{tc}\, UC_{tc}$$

where the variables, parameters, and other terms are defined in a following aection.

Restraints and variables

Each land group has alternative crop management systems producing commodities with associated yeilds and soil loss subject to the aoil types, average weather prevailing and conservation tillage practices utilized. Data were developed in conjunction with the Soil Conservation Service, U.S.D.A., to represent soil loss per acre under various mechanical practices and rotations or land use systems. The soil loss alternatives are evaluated through a universal soil loss equation (2). The equation used for each crop management system is of the form

$$SL = K \cdot L \cdot S \cdot R \cdot C \cdot P \qquad (2)$$

where

SL is the per acre gross soil loss;
K is the erodibility factor associated with the soil type;
L is the computed value relating slope length to soil loss control;
S is derived from a nonlinear function relating slope gradient to level of soil loss;
R is an index of erodibility for the rainfall of the area accounting for varying levels of intensity, duration and measured rainfall;
C is an adjustment factor giving an index of the relative ability of alternative cropping patterns to reduce soil loss;
P is an adjustment factor to account for the potential soil loss reduction from adopting conservation practices.

Each activity in the model represents an alternative crop management system which incorporates a given rotation, crop tillage method and a conservation practice for an individual land resource group. The rotation and tillage method combine to give the unique C value and the conservation practice determines the P factor. The K, L and S factor are dependent on the soil characteristics and the regional rainfall patterns determine the R factor.

Associated with the alternative crop management systems are specific per acre crop costs and crop yields. The average regional cost and yield data adapted from other modeling efforts completed in the Center for Agricultural and Rural Development. The cost data reflect expenditures on machinery, labor, pesticides, non-nitrogen fertilizers (nitrogen is balanced endogenous to the model), and miscellaneous production items. The component costs reflect different efficiencies of farming resulting from working land in straight rows, contours, strip cropping or with terraces. The alternative costs also reflect the higher pesticide requirements and lower machinery and labor requirements for crops under a reduced tillage cultivation pattern. The costs sum to an aggregate which depends on the particular cropping management system and when combined with the outputs from the system, reflect the comparative advantage of each system on each land class in each region.

The outputs from the system reflect yields of each crop and the associated quantity of gross soil loss. The interaction within the system also is reflected in a nitrogen balance subsector where the nitrogen flows in the model are examined. The entire cost and yield section of the model is interlocked with alternative technologies, levels of resource input and

alternative input uses to meet domestic and export demands. As an example of other interrelationships in the model, consider the nitrogen-fertilizer-crop yield section. Nitrogen available in an individual region is an independent variable in the crop yield equation but the source of the nitrogen may vary. It can be supplied from chemical fertilizers, livestock wastes and from nitrogen fixation by legumes. For legumes the amount of nitrogen produced is dependent on their yield which in turn is dependent on the early spring nitrogen availability (through fertilizer) and the non-nitrogen fertilizer availability over the growing season. The livestock wastes available are dependent on the type and quantity of feed available for livestock and the concentration of the animals in the region. Also affecting the yields of the crop is the land class on which it is grown and the conservation and tillage practice associated with the cropping management system.

Both dryland and irrigated crop variables are included for producing regions in the 17 Western States which grow irrigated crops and the model allows selection among dryland or irrigated farming for each region. A range of livestock rations (variables) is allowed in all producing regions since the least-cost feed mix can be drawn from various grain, forage and pasture crops grown in the region or imported (where allowed) from others. The model includes variables representing various cropping systems and technologies affecting soil loss, livestock production, commodity transportation, water transfers, consumer demand fulfillment and alternative export levels.

Each of the 223 producing regions has land restraints of the nature indicated in equations 3-9. Each region has a soil loss restraint as in

equation (10), a nitrogen balance equation as in (11) and a pasture restraint as in (23). Each water supply region has a water restraint as in equation (13), where variables and parameters are defined subsequently.

Each of the 30 consuming regions has net demand equations, for all of the relevant crop and livestock activities as illustrated by equation (14). Regional consumer demand quantities were determined exogenously from geographic and national projections of population, economic activity, per capita incomes and international exports through the region for 2000. National demands were defined for cotton and sugar beets as indicated in equation (15). Poultry products, sheep, and other livestock were regulated at the consuming region level. International trade was regulated at the regional levels as indicated in equations (16) and (17).

Commodities included in the endogenous analysis are soil loss, nitrogen, water, corn, sorghum, wheat, barley, oats, soybeans, cotton, sugar beets, tame hay, wild hay, improved pasture, unimproved and woodland pasture, cropland pasture, public grazing lands, forest lands grazed, all dairy products, pork, and beef. Also accounted for prior to solution of the model are other crops including fruits, nuts, vegetables, rice, flax and broilers, turkeys, egg production, sheep and other livestock.

Dryland cropland restraint, each region by land class:

$$\sum_m X_{ikm} a_{ikm} \leq LD_{ik} \qquad (3)$$

Irrigated cropland restraint, each region by land class:

$$\sum_n Y_{ikn} a_{ikn} + \sum_m Z_{ikm} a_{ikm} \leq LR_{ik} \qquad (4)$$

Dryland wild hay restraint, each region:

$$DWH_i \; a_i \leqq ADWH_i \tag{5}$$

Irrigated wild hay restraint, each region:

$$IWH_i \; a_i \leqq AIWH_i \tag{6}$$

Dryland permanent pasture restraint, each region:

$$DPP_i \; a_i \leqq ADPP_i \tag{7}$$

Irrigated permanent pasture restraint, each region:

$$IPP_i \; a_i \leqq AIPP_i \tag{8}$$

Forest land grazed restraint, each region:

$$FLG_i \; a_i \leqq AFLG_i \tag{9}$$

Soil loss restraint, each region, each land class, each activity:

$$SL_{ikm+n} \leqq ASL_{ikm+n} \tag{10}$$

Nitrogen balance restraint, by region:

$$FP_i + \sum_p b_{ip} L_{ip} + EL_{ibi} - EC_{ifi} - \sum_k \left(\sum_m X_{ikm} f_{ikm} + \sum_n Y_{ikn} f_{ibn} + \sum_m Z_{ikm} f_{ikm} \right)$$
$$- DPP_i \; f_i - IPP_i \; f_i - DWH_i \; f_i - IWH_i \; f_i - FLG_i \; f_i = 0 \tag{11}$$

Pasture use restraint, each region:

$$\sum_k \left(\sum_m X_{ikm} \; r_{ikm} + \sum_n Y_{ikn} \; r_{ikn} + \sum_m Z_{ikm} \; r_{ikm} \right) + DPP_i \; r_i + IPP_i \; r_i + FLG_i \; r_i$$
$$- \sum_p L_{ip} \; q_{ip} - EL_i \; q_i \geqq 0 \tag{12}$$

Water use restraint, by water region:

$$WB_w \pm WT_w \pm WI_w - WO_w - WX_w - WE_w + WD_w - \sum_{i \epsilon w} IWH_i \; d_i - \sum_{i \epsilon w} IPP_i \; d_i$$
$$- \sum_k \sum_{i \epsilon w} \left(\sum_m X_{ikm} \; d_{ikm} + \sum_n Y_{ikn} \; d_{ikn} + \sum_m Z \; F_{ikm} \; d_{ikm} \right) - \sum_{i \epsilon w} \sum_p L_{ip} \; d_{ip}$$
$$- \sum_{i \epsilon w} PN_i \; d_i \geqq 0 \tag{13}$$

Commodity balance restraint, each consuming region:

$$\sum_k \sum_{i \epsilon j} \left(\sum_m X_{ikm} \; cy_{ikmc} + \sum_n Y_{ikn} \; cy_{iknc} + \sum_m Z_{ikm} \; cy_{ikmc} \right) \pm \sum_{i \epsilon j} \sum_p L_{ip} cy_{ipc}$$
$$\pm \sum_{t \epsilon j} T_{tc} \pm E_{jc} - \sum_{i \epsilon j} PN_i \; cy_{ic} - EL_j \; cy_{jc} \geqq 0 \tag{14}$$

National commodity balance restraints, for cotton, sugar beets and spring wheat:

$$\sum_i \sum_k \left(\sum_m X_{ikm}\, cy_{ikmg} + \sum_n Y_{ikn}\, cy_{iknng} + \sum_m Z_{ikm}\, cy_{ikmg} \right) - \sum_i PN_i\, cy_{ig} - EX_c \geqq 0 \quad (15)$$

National export restraints:

$$\sum_j E_{jc} \geqq EX_c \quad (16)$$

National import restraints:

$$\sum_i E_{icte} \leqq IM_{cte} \quad (17)$$

Non-negativity restraints:

$$X_{ikm},\ Y_{ikn},\ Z_{ikm},\ L_{ip},\ DWH_i,\ IWH_i,\ DPP_i,\ IPP_i,\ FLG_i,\ FP_i,\ EL_i,\ WB_w,$$

$$WT_w,\ WI_w,\ WD_w,\ WX_w,\ WE_w,\ PN_i,\ T_{tc},\ E_{jc},\ E_{icre} \geqq 0 \quad (18)$$

The subscripts and variables for the above equations are defined in the section below.

Subscripts and variables of the model

The subscripts and variables relating to the equations in the text are those which follow:

subscripts

c = 1,2,...,15 for the endogenous commodities in the model,
e = 1,2,...,5 for the exogenous livestock alternatives considered,
g = 1,2,3 for the commodities balanced at the national level,
i = 1,2,...,223 for the producing areas of the model,
j = 1,2,...,30 for the consuming regions of the model,
k = 1,2,...,9 for the land classes in each producing area,
m = 1,2,...,for the dryland crop management systems 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 producing area,
t = 1,2,...,458 for the transportation routes in the model
w = 1,2,...,51 for the water supply regions in the model.

variables

a, the amount of land used by the associated activity from the land base as indicated by the subscripts;
AIPP, the number of acres of irrigated permanent pasture available in the subscripted producing area;
ADWH, the number of acres of dryland wild (non-cropland) hay available in the subscripted producing area;
AFLG, the number of acres of forest land available for grazing in the subscripted producing area;
ADPP, the number of acres of dryland permanent pasture available for use in the subscripted producing area;
AIWH, the number of acres of irrigated wild (non-cropland) hay available in the subscripted producing area;
ASL, the per acre allowable soil loss subscripted for land class, producing area and activity;
b, the units of nitrogen equivalent fertilizer produced by livestock, subscripted for producing area and activity;
cy, interaction coefficient (yield or use) of the relevant commodity as regulated by the associated activity and specified by the subscripts;
d, the per unit of activity water use coefficient as regulated by the associated activity and specified by the subscripts;
DPP, level of use of dryland permanent pasture in the subscripted producing area;
DWH, level of use of dryland wild (non-cropland) hay in the subscripted producing area;
E, level of net export for the associated commodity in the associated region as specified by the subscripts;
EC, level of exogenous crop production by subscripted region;
EL, level of exogenous livestock production consistent with the subscripted region;
EX, the level of national net export for the subscripted commodity as determined exogenous to the model;
f, the units of nitrogen equivalent fertilizer required by the associated activity and specified by the subscripts;
FLG, level of forest land grazed in the subscripted producing area;
FP, number of pounds of nitrogen equivalent fertilizer purchased in the subscripted producing area;
IM, level of national net imports for the subscripted commodities as determined exogenous to the model;
IPP, level of use of the irrigated permanent pasture in the subscripted region;
IWH, level of use of the irrigated wild (non-cropland) hay in the subscripted region;
L, level of the livestock activity with the type and region dependent on the subscripts;
LD, number of areas of dryland cropland available for use as specified by the region and land class subscripts;

LR, number of acres of irrigated cropland available for use as specified by the region and land class subscripts;
PN, level of population projected to be in the subscripted region;
q, units of pasture, in hay equivalents, consumed by the associated livestock activity and specified by the subscripts;
r, units of aftermath or regular pasture, in hay equivalents, produced by the associated cropping or pasture activity and identified by the subscripts;
SL, level of soil loss associated with any activity over the range m+n in the region and land class designated by the subscripts;
T, level of transportation of a unit of the commodity either into or out of the consuming region designated by the subscripts;
WB, level of water purchase for use in the water balance of the water supply region designated by the subscript;
WD, level of desalting of ocean water in the water supply region designated by the subscript;
WE, level of water to be exported from the water supply region subscripted;
WI, level of movement of water in or out of the water supply region through the interbasin transfer network;
WO, level of water requirement for onsite uses such as mining, navigation and estuary maintenance in the water supply region subscripted;
WX, level of water use for the exogenous agricultural crops and livestock in the water supply region subscripted;
X, level of employment of the dryland crop management system, rotation, in the region and on the land class as designated by the subscripts;
Y, level of employment of the irrigated crop management system, rotation, in the region and on the land class as designated by the subscripts;
Z, level of employment of the dryland crop management system, rotation, on the land class in the region as designated by the subscripts when the land has been designated as available for irrigated cropping patterns.

Illustration of Results

Solution of the model provides indication of optimal land use in each producing region and each land resource group at prescribed levels of environmental quality restraints, consumer demand and distribution, export levels and other policy, or market and technology parameters. Our illustration is in the case where the only environmental restraint is soil loss. It also designates the level of production in each region and the

optimal flows of commodities to consuming regions and export markets. For purposes of illustration, we refer to solutions where (a) soil loss is not restricted, and (b) soil loss is restricted to 5 tons per acre per year for each soil resource group and exports are at a given level. While land use could be mapped or indicated by each of the 1891 land resource groups, we illustrate on the basis of the 223 producing regions only. The model indicates not only land devoted to each crop use in each region and group, but also can indicate technologies for each such as dryland or irrigated, alternative rotations, conventional or reduced tillage methods and others which affect land and water use and sedimentation.

Figure 1 indicates an optimal distribution of row crop acreage among the 223 producing regions and figure 2 indicates an optimal distribution of the close grown crops and figure 3 giving the hayland distribution when no restraints are placed on soil loss or chemical nitrogen use. In a later publication, we will depict distribution of land uses and technologies by land resource groups. The models are able to generate large amounts of data of this type which reflect optimal land use and environmental restraint distributions among individual natural resource regions when goals and markets prevail at the national level. Mapping models can be formulated so that location and extent of use of land in each region by each crop can be indicated automatically when national and environmental goals or policies are imposed and national and regional markets are reflected. These maps, which we do not present here, also can detail by regions the optimum method of soil loss control by individual regions--considering the physical nature of soil and climatic variables in all regions and the comparative advantage

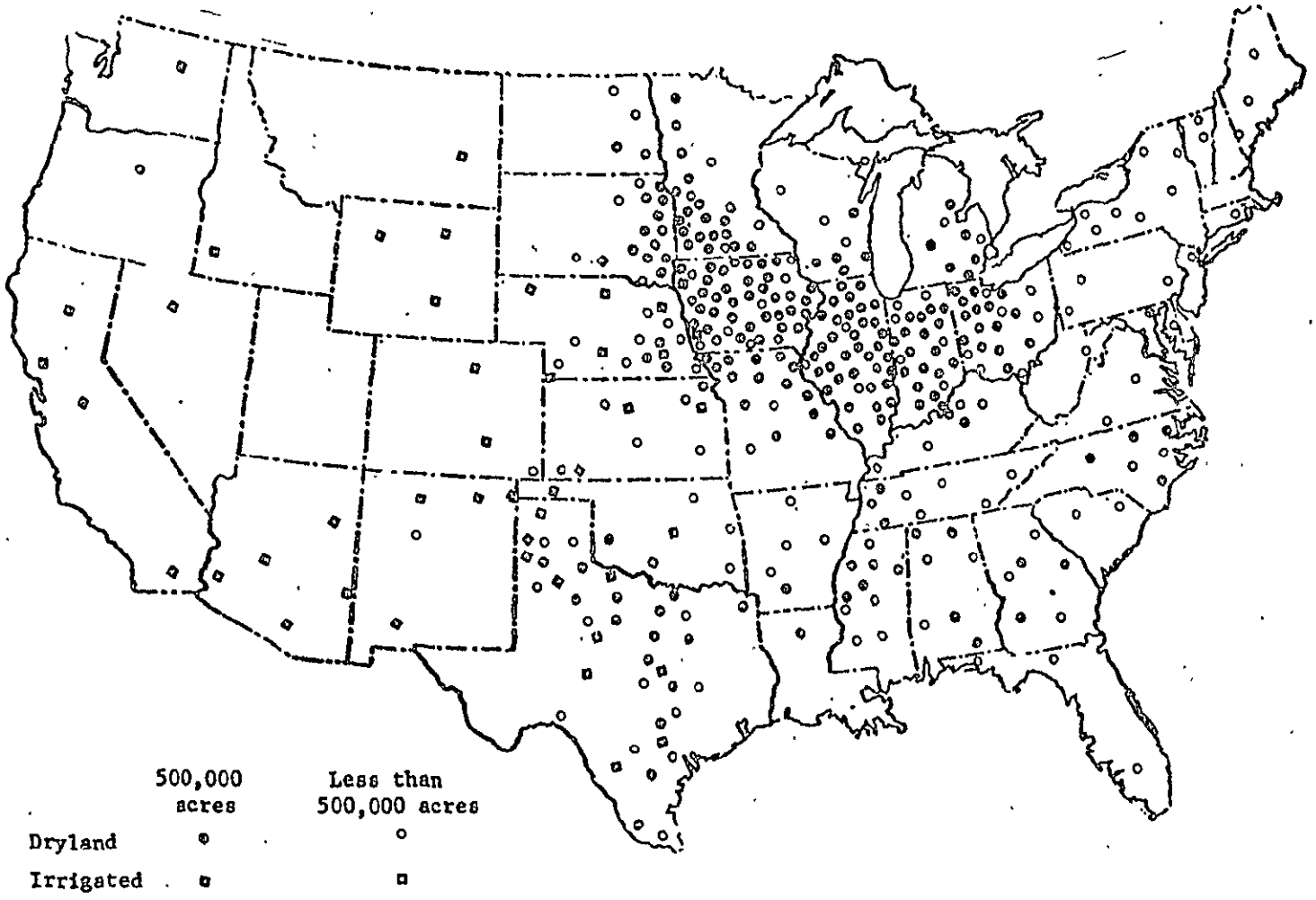

Figure 1. Location of dryland and irrigated row crops with no soil loss restriction in 2000.

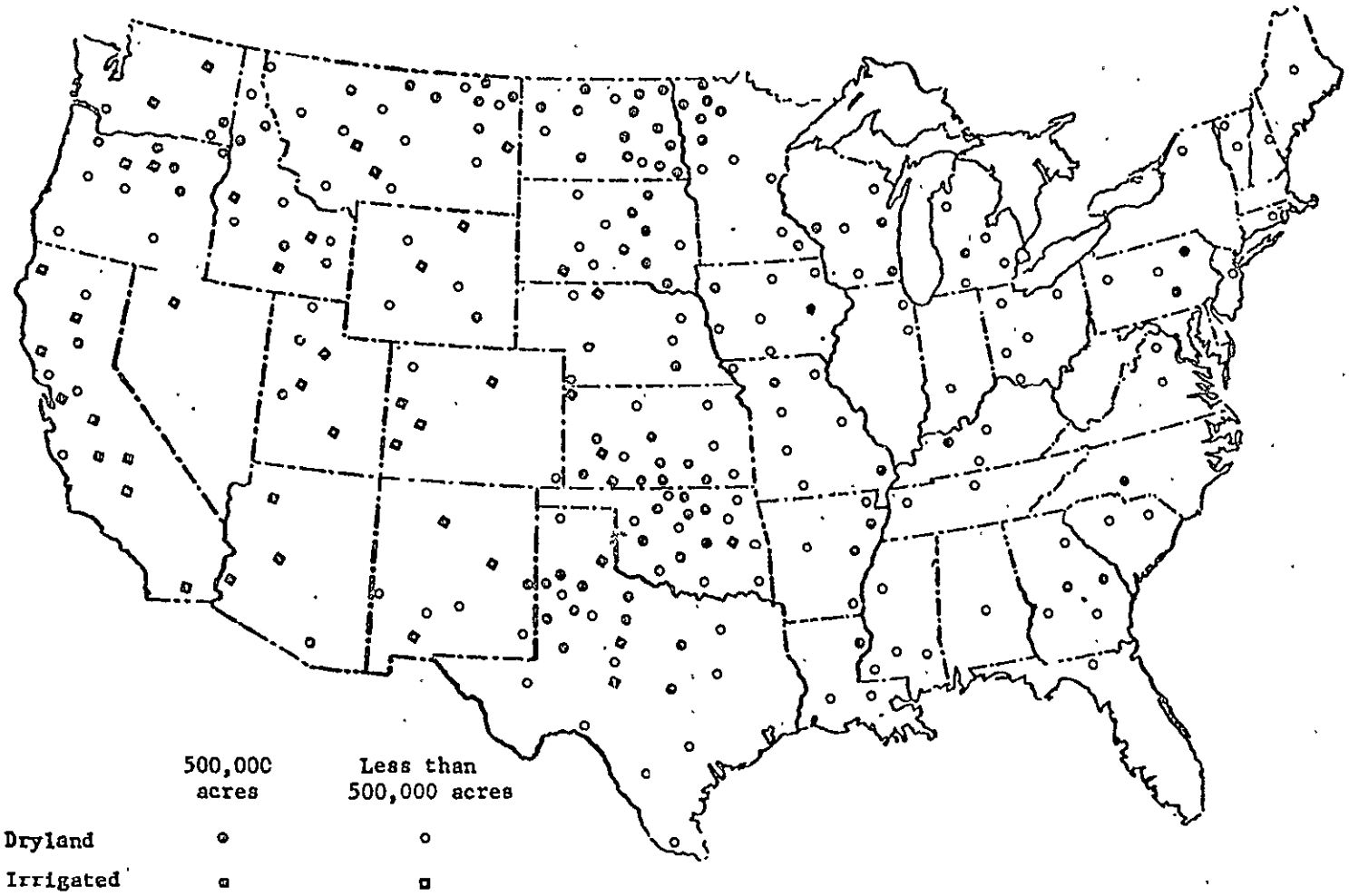

Figure 2. Location of dryland and irrigated close grown crops with no soil loss restriction in 2000.

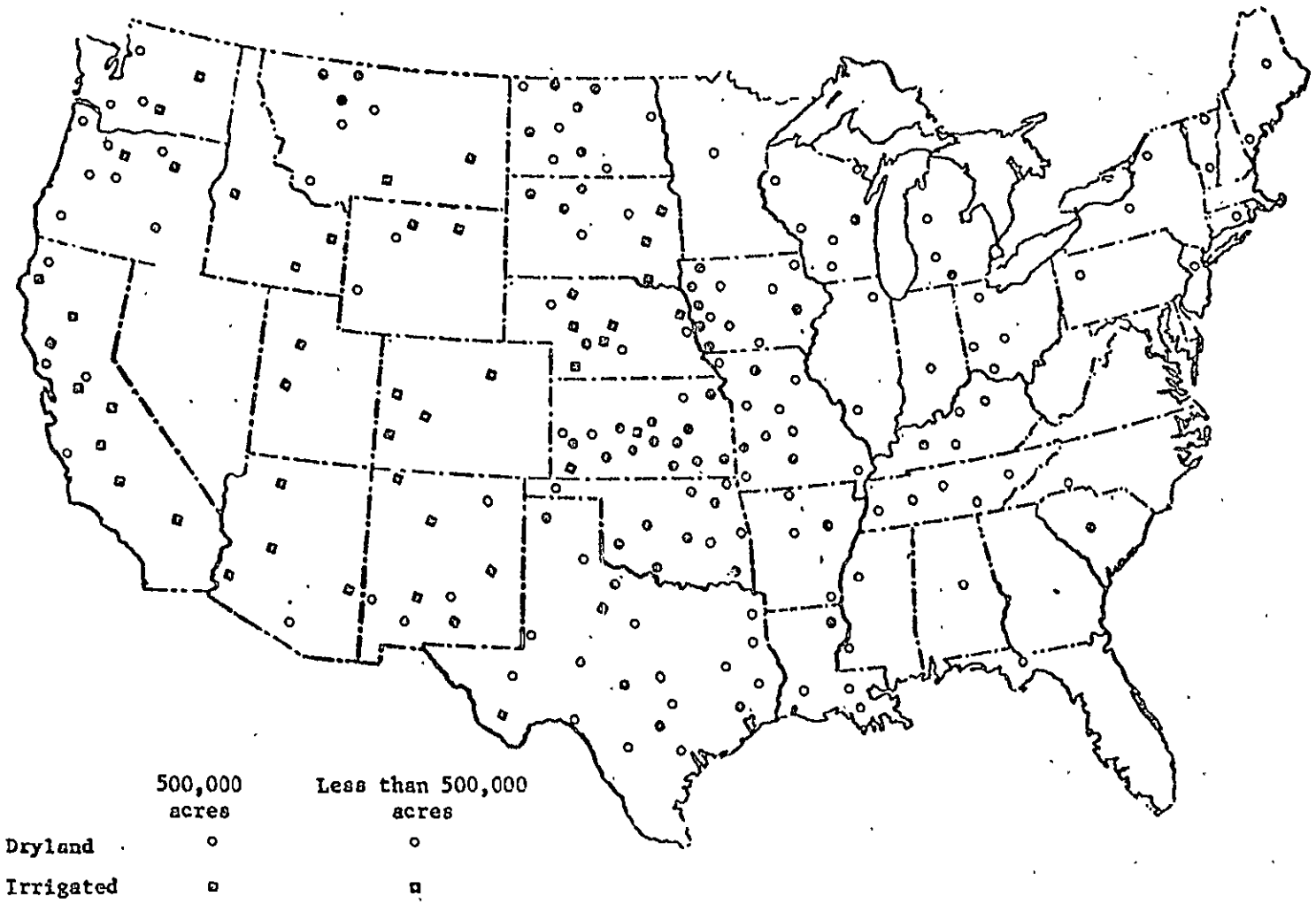

Figure 3. Location of dryland and irrigated hay with no soil loss restriction in 2000.

of each in terms of land characteristics, yields, production and transportation costs, and national and regional markets.

Soil loss

While land use, tillage methods and soil loss are generated in the models by producing regions and land resource groups, we summarize results only for seven major geographic regions of the U.S. because of time and space restraints. While solutions of the model were made for several soil loss, export and nitrogen restriction levels, we similarly summarize solutions only for two soil loss levels, one export level and unrestrained nitrogen use (except for nitrogen balance within a producing region).

Restricting soil loss per acre to five tons would distribute land use and technologies interregionally to reduce national soil loss to 727 million tons. Without the restriction, interregional land use allocations and technologies to meet export demands would generate a national soil loss 3.5 times greater, or 2,677 million tons. As table 1 indicates the reduction in average per acre soil loss, as a source of sedimentation, would be extremely large on land classes V-VIII which are most erosive. While we do not do so here, our models allow indication of soil loss changes by each individual region.

Regional variation in reduced soil loss per acre is great. Largest reductions take place in the South Atlantic (18.2 tons) and South Central (11.5 tons) regions where land and current land use methods give rise to serious erosion (table 2). The reduction in soil loss when a 5 ton per acre limit is imposed is attained especially by a switch from conventional tillage-straight row farming to contour, strip-cropping and terraces (table 3).

Table 1. National soil loss total and average per acre by land resource groups for two levels of soil loss restriction, 2000.

Item	Unrestricted soil loss	5 ton soil loss
Total tons (million ton)	2677	727
Average tons per acre		
class I & II land	6.2	2.7
IIIE & IVE land	17.8	3.1
other III & IV land	15.6	2.8
V - VIII land.	28.5	1.5
national average	9.9	2.8

Table 2. Average per acre soil loss by major region for two levels of soil loss restriction models, 2000.

Region	Unrestricted soil loss	5 ton soil loss
National	9.9	2.8
North Atlantic	9.0	3.5
South Atlantic	21.5	3.3
North Central	9.2	2.8
South Central	15.1	3.6
Great Plains	3.2	1.5
North West	2.3	1.7
South West	3.3	2.6

There also is a significant shift to reduced tillage farming practices to attain the environmentally attained soil loss of five tons per acre. Acres receiving reduced tillage practices increase from around 21 million in the unrestricted solution to near 58 million acres under the five-ton solution. Conventional tillage practices decline from 248 million acres under the unrestricted soil loss to 201 million acres under the solution for a five-ton soil loss. Within the conventional tillage group, straight row farming is nearly halved. Contouring is tripled and strip cropping-terracing practices are increased 1000 percent to meet soil loss restrictions (table 3). While reduced tillage nearly triples and very large increases occur in contouring, terracing and strip cropping, straight-row methods of reduced tillage do not increase importantly.

Table 3. Thousand acres of cultivated land by conservation - tillage practices for two levels of soil loss restriction, 2000.

Conservation tillage	Unrestricted soil loss	5 ton soil loss
Conventional tillage	247,894	201,238
straight row	233,475	129,120
contoured	11,254	37,116
strip cropped & terraced	3,165	35,002
Reduced tillage	21,219	57,644
straight row	21,219	24,822
contoured	0	18,902
strip cropped & terraced	0	13,920

The shift in acreages (table 4) is partly hidden in the reduction of 16.5 million acres used for grain crops and a corresponding increase of only 5.5 million acres in hay on cultivated lands (table 4). Part of the production required to meet national demands comes from an increase in non-cropland roughage production (permanent hay and pasture). More of the reduced acreage required to meet the demand for agricultural products results because of the shift in production to the higher cost and higher yielding erosion control practices. Also a shift in acreage between land classes puts the grain crops on the higher yielding and less erosive lands.

Table 4. National production of row crops, close grown crops and rotation roughage crops for two levels of soil loss restriction, 2000.[1]

Land use	Unrestricted soil loss	5 ton soil loss
Acres cultivated (000)	269,113	258,882
Row crops (000)	148,226	136,035
Close grown crops (000)	75,535	73,478
Rotation roughage crops (000)	45,352	49,369
Non-rotation roughage crops (000)	303,060	310,697

[1]Demand levels are based on projected per capita food consumption levels, 284 million people in 2000 and international trade of grains equal to the 1969-1971 annual averages.

Costs of production, in conjunction with the transportation network and the soil loss restrictions imposed, determine the national equilibrium prices for the commodities. Table 5 indicates the relative equilibrium prices of the commodities generated by the model under the two levels of soil loss and a single export level. Soil loss restrictions have the largest effect on prices for commodities which concentrate on land with

high soil loss potential. Compared to absence of soil loss restrictions, cotton and soybean prices increase over 20 percent while wheat and hay crops increase by less than 10 percent. The increase in grain prices result in corresponding increases in cattle prices. In evaluating the effect of any environmental policy alternative, the effect on the desired parameter and the change in farm price of agricultural products are two easily observed changes in our models.

Table 5. Relative farm level prices for some agricultural commodities with two levels of soil loss restriction, 2000.

Commodity	Unrestricted soil loss	5 ton soil loss
Corn	100	107
Wheat	100	103
Soybeans	100	115
Cotton	100	112
Hay	100	101
Cattle	100	104
Hogs	100	105
Milk	100	100

Changes summarized at the national level do not, of course, reflect the effects in particular regions and on individual enterprises. These, however, are all available from our models. The shift in production from one region to another results in income repercussions on the rural community affected. The effect of such a shift depends on the degree of multiple level resource use. As grain production shifts, livestock activities also may drift away from the region and underemployment of resources may occur

in one region as prosperity is promoted in another rural area.

The data in tables 1-5 indicate that American agriculture has great capacity and flexibility in adapting to certain environmental quality goals. By shifting land use among the many producing regions and land resource groups in terms of their comparative advantage in yields, commodity costs, location, and transportation, national and regional demands can be met without large increases in food prices and costs for consumers at the export level examined. The level of exports per se may have greater impact on consumer food costs than does a relatively wide adaptation of agriculture and land use to environmental quality goals. We will, however, provide quantitative analysis of these possibilities, along with other environmental quality practices, in upcoming presentations.

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9. ABSTRACT
We have underway a set of models which incorporates both (a) national or macro dimensions, and (b) local areas (regions) and their agro-climatic and economic dimensions. These models currently emphasize land and water use, technological and environmental impacts, food supplies, farm costs and income and employment effects as they relate to the nation's agricultural sector. However, they have great promise for analyzing the nation's total land and water use potentials as these relate to spatial distributions of population and economic activity, environmental standards and related problems. The models have the capacity to evaluate simultaneously variables and outcomes in (a) national markets, prices, incomes and employment, and (b) production patterns, resource use and economic structure of rather small resource regions, under the posed imposition of alternative policies or futures. The data in tables 1-5 indicate that American agriculture has great capacity and flexibility in adapting to certain environmental quality goals. By shifting land use among the many producing regions and land resource group in terms of their comparative advantage in yields, commodity costs, location, and transportation, national and regional demands can be met without large increases in food prices and costs for consumers at the export level examined. The level of exports per se may have greater impact on consumer food costs than does a relatively wide adaptation of agriculture and land use to environmental quality goals.

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