NATIONAL MARKETS AND THE IMPACTS OF STATE LAND USE AND ENVIRONMENTAL PROGRAMS*

Earl O. Heady, V.S.S.V. Nagadevara and Kenneth J. Nicol

Environmental and resource quality recently have become special public concerns. A few states have already enacted legislation posing land use-environmental restrictions. Vermont, Hawaii, Colorado, Maine, Massachusetts and New York, passed land use laws. Illinois formed a Pollution Control Board to quantify nutrients and sediment polluting streams and suggest action. In 1971, the Iowa Legislature passed the "Conservancy District Act," creating soil conservancy districts "to preserve and protect public interest in soil and water resources for future generations." Legislation centers on soil erosion and sedimentation. Erosion is declared a nuisance if it results in siltation damage. The law sets allowable soil loss limits on land at one to five tons per acre per year, depending on soil type [4].

If a state enacts and implements such laws apart from the nation, what will the economic impact be? Will legislated restraints have little effect on productivity and bring the state's farmers as much income as before? Or, will restraints in one state, without similar restraints elsewhere, cause losses to the farmer in production and income, as citizens elsewhere enjoy enhanced environment quality?

This study is directed to these questions, using Iowa's conservancy law as an example [6]. A broader question raised is: for certain problems of resource use, particularly those relating to large production adjustments whose impacts are felt in national markets, can legislation be equitable or effective on other than a national basis? If demand for the commodity is inelastic, this question is posed where the legislating state has a large land area and an important portion of the nation's commodity output.

ALTERNATIVE FUTURES ANALYZED

A programming model is specified for the purpose. Seven alternative futures, where special restraints are applied in Iowa but not elsewhere, are analyzed. Results are project to 1985, with a population of 242 million. The per capita income and demand levels of the Bureau of Economics Analysis are used [17]. The seven alternatives analyzed are summarized in Table 1.

MODEL USED

The programming model applies to all major resources, commodity and producing regions of the United States. Iowa was divided into the 12 conservancy-producing areas in Figure 1. Each soil group in each conservancy-producing area, an average of nine per area, was maintained as a separate entity and treated separately in the analysis.

The model then selected those cropping systems and conservation practices which met the stated soil loss or nitrogen and pesticide restriction, with profits otherwise maximized in each soil area within each conservancy-producing area. The rest of the United States was divided into the production areas shown in Figure 2 with an average of nine soil resource groups also differentiated in each area. The optimum resource use was programmed in these 102 regions, including their nine soil groups, as well as in Iowa (actually 918 soil regions). This detail allowed both comparative advantage among regions and determination of which regions of other states would absorb production sacrificed in individual soil areas of Iowa's

Authors are Director, Staff Economist and Assistant Professor, respectively, The Center for Agricultural and Rural Development, Iowa State University.

*Journal Paper Number J-8478 of the Iowa Agricultural and Home Economics Experiment Stations, Project Number 2106.

TABLE 1. LEVEL OF SOIL LOSS, USE OF NITROGEN AND PESTICIDES ALLOWED IN IOWA, AND EXPORT LEVELS FOR ALTERNATIVE MODELS

Model	Soil loss allowed per acre	Nitrogen allowed per acre	Pesticide allowed use	Export levels[a]
A	Unlimited	Unlimited	Unlimited	Normal
B1	5.0 tons	Unlimited	Unlimited	Normal
B2	2.5 tons	Unlimited	Unlimited	Normal
C	5.0 tons	100 pounds	Unlimited	Normal
D	5.0 tons	100 pounds	Restricted	Normal
E	5.0 tons	Unlimited	Unlimited	High
F	5.0 tons	100 pounds	Restricted	High

[a]Exports are adjusted only for feed grains, wheat, and soybeans at the national level. Normal exports are defined at 1969-72 average levels. High exports are defined such that the entire land base of the United States is effectively utilized.

conservancy districts, with environmental restraints applied.

The model causes every U.S. region and land resource group (918) to be interdependent. Interdependence is established by incorporation of national and regional demands, and a complete transportation submodel in the overall model. Production must move most economically from producing regions to market regions. The U.S. is separated into 29 market regions, based on the central place theory. These are delineated around the major metropolitan areas of the United States (Figure 3).

We define 35 separate irrigated water supply regions (Figure 4) to approximate physical regions with water supplies. These regions are aggregations of contiguous producing areas. Subdivision of the 18 major river basins of the Water Resource Council forms the basis of these regions [18]. Activities creating the demand for and supply of water, along with buying and transportation activities, are defined within these regions.

Crop Production Sector

Crop activities are for different rotations for each land group in each producing area and for different tillage and conservation practices both for irrigated and dry land. These activities or variables relate to barley, corn, cotton, legume hay or pasture in rotation. They also relate to oats, sorghum, sorghum silage, wheat, soybean and sugar beets in rotational combinations produced by numerous technologies. Other crop commodities are handled exogenously. A crop management system (activity vector) is defined

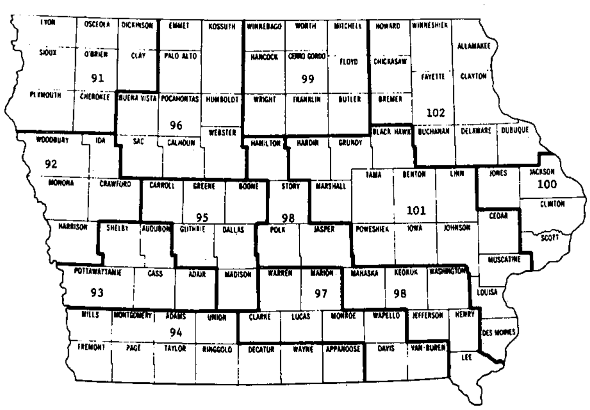

FIGURE 1. THE 12 CONSERVANCY-PRODUCING AREAS IN IOWA

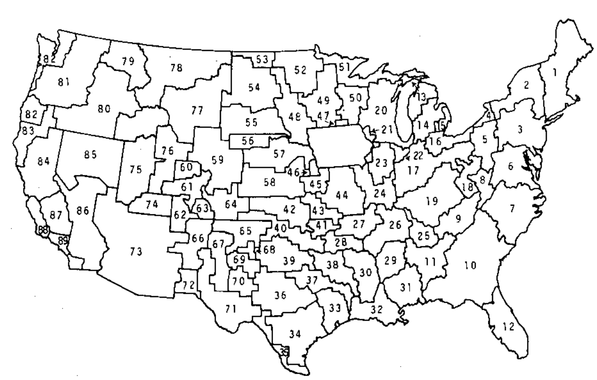

FIGURE 2. THE 102 PRODUCING AREAS FOR THE REST OF THE U.S.

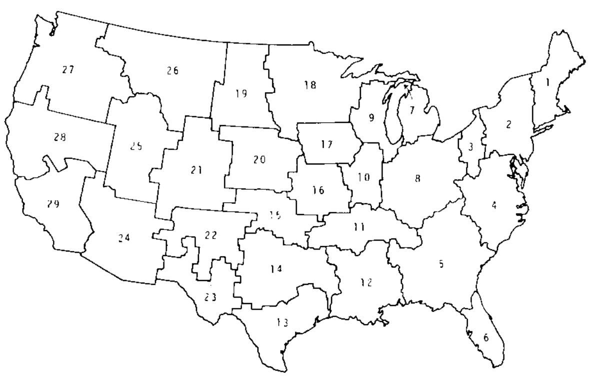

FIGURE 3. THE 29 CONSUMING REGIONS

FIGURE 4. THE 35 WATER SUPPLY REGIONS

as a unique combination of a rotation with a specific tillage and conservation practice on irrigated or dryland. Soil physical characteristics (type, slope gradient, length of slope and natural fertility) along with technological factors (various inputs, fertilizer response, tillage and conservation practices) and natural possibilities (quantity and distribution of rainfall, etc.) are used in defining each crop management system and tillage method, and associated per acre yields and soil losses [5, 6].

Objective Function

The model allocates land and water optimally on a national basis. This is done to meet domestic and foreign export demand in a manner that (1) produces and transports commodities at the lowest total production and transport costs subject to restraints on availability of land, water and nitrogen resources, Iowa environmental goals, a transportation network, technology implied in the defined activities, and domestic and foreign demands; and (2) so that equilibrium exists as each unit of resource used in agriculture is returned its market price. Hence, a certain amount of a particular crop will be allocated to the Central Valley of California and another to the Marshall Salt Loam area of southwest Iowa, if such allocation allows optimization in the national sense. Optimization is viewed in terms of the most efficient production pattern for the nation, in use of land and water resources, when conservancy or environmental improvement laws are enforced in Iowa [4] but not for the rest of the nation. The objective function, OF in equation (1), is in terms of national welfare, rather than income to Iowa farmers.

$$\min OF = \sum_i \left(\sum_j C^C_{ij} X_{ij} + \sum_k C^L_{ik} Y_{ik} + \sum_m C^F_m F_m\right) + \sum_\ell \left(C^B_l W^B_l + C^D_l W^D_l + C^T_l W^T_l\right) + \sum_m \sum_p \sum_q C^t_{mpq} T_{mpq} \qquad (1)$$

$i = 1, \ldots, 102$ for producing areas
$j = 1, \ldots,$ for crop management systems
$k = 1, \ldots,$ for livestock activities
$l = 1, \ldots, 35$ for water supply region
$m = 1, \ldots, 29$ for consuming regions
$p = 1, \ldots,$ for commodities considered,

and

$q = 1, \ldots,$ for transportation activities.

Where:

C^C_{ij} = per unit cost of j^{th} crop management system in i^{th} producing area
X_{ij} = level of j^{th} crop management system in i^{th} producing area
C^L_{ik} = per unit cost of k^{th} livestock activity in i^{th} producing area
Y_{ik} = level of k^{th} livestock activity in i^{th} producing area
C^F_m = cost per unit of nitrogen fertilizer purchased in m^{th} consuming region
F_m = level of nitrogen fertilizer buying activity in m^{th} consuming region
C^B_l = cost per acre foot of water buying activity in l^{th} water supply region
W^B_l = level of water buying activity in l^{th} water supply region
W^D_l = level of water desalting activity in l^{th} water supply region
C^D_l = cost of desalting one acre foot of water in l^{th} water supply region
C^T_l = cost of transporting one acre foot of water in l^{th} water supply region
W^T_l = level of water transfer through natural flow, interbasin transfers or exports in l^{th} water supply
C^t_{mpq} = cost of moving one unit of p^{th} commodity in m^{th} consuming region through q^{th} route, and
T_{mpq} = net movement of p^{th} commodity in m^{th} consuming region through q^{th} route.

Soil Loss Sector

Each crop activity on each land group in each producing area of both Iowa and the rest of the U.S. has a soil loss coefficient. Gross soil loss represents the average number of tons of soil leaving the field over a one-year period. This is determined using the Universal Soil Loss Equation developed by Wischmeier and Smith [20], with the data obtained from the Soil Conservation Service.

Soil loss is computed from SCS data for each land resource area for each feasible crop management system on each soil class [9]. The soil loss by crop management system is weighted to a producing area level from the SCS data area. Coefficients are attached to the appropriate crop management system. They reflect the severity of erosion for those conditions on which the crop management system is defined. Crop yields are estimated from a set of state fertilizer yield functions developed by Stoecker [16].

Nitrogen fertilizer coefficients for the interaction between crop management systems and nitrogen fertilizer restrictions are obtained as a by-product of the yield estimates. The optimum level of fertilizer going into the regional yield response function is used to estimate these interaction coefficients. Level of commercial fertilizer required to meet projected yields is obtained by subtracting the amount of nitrogen fertilizer equivalent provided by legumes, if any, in the rotation, from the optimum level of fertilizer.

Legume nitrogen data are obtained from the results reported in [13, 14, 15]. All components of the total crop cost including terracing, tiling, etc. are included. For Models E, F, where use of pesticides and insecticides is restricted in Iowa, Iowa yields are adjusted by data supplied by technical specialists.

Livestock Production Sector

Endogenous livestock activities include beef cow and calf production, beef feeding, hog and dairy operations. These activities, in turn, produce feeders, fed beef, non-fed beef, pork and milk products [2, 3]. The model selects least-cost rations in each region, as recommended by the National Academy of Sciences [10, 11]. Livestock activities are subject to the restriction that nitrogen wastes, using the conventional handling systems, must be utilized in crop production. Data expressing daily production of nitrogen wastes for the different classes of livestock are adjusted for the efficiency of the handling systems and for the feeding time and pattern of the activity [19].

Regional Restraints

Restraints are defined at different regional levels such as producing areas, consuming regions, water supply regions and at the national level. These restraints restrict the use of land, domestic and international demand, water buying and interregional transfer, use of nitrogen and pesticides and soil loss.

Restraints at Area Level. Three types of restraints are imposed at the producing area level: restraints on land availability by each of nine land groups; retraints on both water in each water supply area and on maximum allowable soil loss per acre and nitrogen and pesticides use in Iowa. The restraint on available land is defined for each producing area by land group (an average of nine in each area). These restraints form the model's base and provide a means of expanding or contracting the agricultural output. They are of the type:

$$\sum_{k} A_{ijk} X_{ijk} \leqq L_{ij}$$

where

A_{ijk} = acres of cropland defined in k^{th} crop management system on j^{th} land group in i^{th} producing area

X_{ijk} = level of k^{th} crop management system defined on j^{th} land group in i^{th} producing area, and

L_{ij} = net availability of cropland on j^{th} land group in i^{th} producing area.

Eighteen land groups are defined, one through nine for the dryland activities and 10 through 18 for the potentially irrigated activities [6, 9, 12]. Dryland activities are also defined on potentially irrigated land, such that when the entire water supply is utilized before available land is exhausted, unused land could be shifted to rainfed crops. Another producing area restraint is the soil loss restriction imposed on 12 producing areas (91 through 102) in Iowa's soil conservancy districts.

Restraints Imposed in Water Supplies. One restraint each is defined at the water supply region level. It regulates the supply of and demand for water and is detailed in [12]. This restraint is of the form:

$$W_l^B \pm W_l^T \pm W_l^I - W_l^O - W_l^X - W_l^E - \sum_{i \in l} \sum_{j} \sum_{m} X_{ijm}$$

$$- \sum_{i \in l} \sum_{k} W_{ik}^Y Y_{ik} - \sum_{i \in l} W_i^P P_i \geq 0 \qquad (2)$$

where

W_l^B = level of water buying activity in l^{th} water supply region

W_l^T = level of net natural water transfer associated with l^{th} water supply region

W_l^I = level of net interbasin transfer of water associated with l^{th} water supply region

W_l^O = level of onsite water use in l^{th} water supply region

W_l^E = level of water export associated with l^{th} water supply region

W_l^X = level of water use for exogenous crops and livestock in l^{th} water supply region

W_{ijm} = per-acre water requirement for the j^{th} crop management system on m^{th} land group in i^{th} producing area

X_{ijm} = level of j^{th} crop management system on m^{th} land group in i^{th} producing area

W_{ik}^Y = per-unit water requirement by k^{th} livestock activity in i^{th} producing area

Y_{ik} = level of k^{th} livestock activity in i^{th} producing area

W_i^P = level of water use per person in i^{th} producing area, and

P_i = number of persons in i^{th} producing area.

All units are in acre-feet of water; and ϵ [epsilon] refers to "within."

Of the activities interacting in this model, water buying, water transfer, interbasin flow, water for onsite uses, water exports [2], and water for exogenous crops and livestock are bounded by an upper limit.

Restraints Imposed at Consuming Regions. Restraints for consuming regions balance production and distribution of commodities and allow for interaction of the commodities as intermediate goods. These restraints are of the form:

$$\sum_{i \epsilon m} \sum_{j} C_{ijl}^C X_{ij} \pm \sum_{k} C_{mkl}^L Y_{mk} \pm \sum_{n} T_{lmn}$$

$$\pm E_{lm} - \sum_{i \epsilon m} P_{il} N_i - X_{lm}^E \geq 0 \qquad (3)$$

where

m = 1, . . . ,29 for the consuming regions
n = 1, . . . , for transportation activities
k = 1, . . . ,5 for livestock activities

C_{ijl}^C = per-unit production of l^{th} commodity by j^{th} crop management system in i^{th} producing area

X_{ij} = level of j^{th} crop management system in i^{th} producing area

C_{mkl}^L = per-unit production or use of l^{th} commodity by k^{th} livestock activity in m^{th} consuming region

Y_{mk} = level of k^{th} livestock activity in m^{th} consuming region

T_{lmn} = net movement of l^{th} commodity in m^{th} consuming region by n^{th} route

E_{lm} = net export of l^{th} commodity from m^{th} consuming region

P_{il} = per capita consumption of l^{th} commodity in l^{th} producing area

N_i = population level in i^{th} producing area, and

X_{lm}^E = net use of l^{th} commodity by the exogenous livestock in m^{th} consuming region.

The second restriction defined at the consuming region level is on nitrogen fertilizer [12]. This restriction balances production and purchase of nitrogen fertilizer on the supply side, and use on the demand side, considering nitrogen from livestock wastes, legumes and purchased chemicals. There were 4,441 equations in the model, including 1,000 fixed bounds and 37,000 activities.

RESULTS SUMMARY

Because of inelastic demands and the important role of Iowa in the nation's agriculture, each alternative future increases income to the rest of the nation but reduces it it Iowa. Iowa is forced to use less intensive crops (such as hays and small grains) rather than corn and soybeans on major areas of its soil. Also, it has to invest in more extensive soil conservation practices and adapt its livestock production in manners not required for the rest of the nation. In addition, as Iowa reduces soil erosion through environmental restraints, soil loss increases over the rest of the nation. Iowa shifts importantly from straight row methods to contouring, strip cropping, terracing, and minimum tillage methods. At a five-ton soil loss limit, 178,000 acres are taken out of crop production in Iowa; at 2½-ton soil loss limit, 250,000 is shifted out and soil loss declines by 314 million tons.

Imposition of soil loss limits lessens profitability of Iowa farming relative to the rest of the nation (Table 2), as both income and costs change. Net farm income in Iowa decreases with the imposition of soil

TABLE 2. TOTAL COSTS OF PRODUCTION AND NET INCOME OF IOWA AND THE REST OF THE COUNTRY UNDER THE SEVEN ALTERNATIVES ($ MILLION)

Item	Alternative A	B1	B2	C	D	E	F
Iowa							
Crop costs	1,677	1,756	1,812	1,813	1,741	2,324	2,070
Livestock costs	4,459	4,727	4,050	4,378	4,727	3,162	3,274
Net income	2,019	1,964	1,890	1,913	1,882	5,311	5,066
Rest of U.S.							
Crop costs	18,005	17,906	17,892	17,944	17,921	26,026	26,308
Livestock costs	32,582	32,234	32,809	32,803	32,261	43,526	45,202
Net income	17,791	17,854	17,887	18,461	18,947	43,552	48,139

loss restriction, from $2,019 million under A (with no soil loss restrictions) to $1,890 million with the imposition of a 2.5 ton restriction (Table 2). At the same time, farming in the rest of the country becomes somewhat more profitable. Iowa produces less in a market with an inelastic demand and the rest of the country gains from higher prices if the state retains production at previous levels or increases it slightly. A redistribution of income thus takes place as soil is conserved and the environment is improved through implementation of a 2.5-ton soil loss limit in Iowa alone. With the imposition (Alternative D) of limits on the use of nitrogen and pesticides, as well as a five ton soil loss, Iowa farming is even less profitable relative to the rest of the country (but at about the 2½-ton soil loss limit).

With exports at a very high level, income in both Iowa and the rest of the country increases. In comparison with Alternative A, income in Iowa increases 163 percent, with only restrictions on soil loss (E), and by 151 percent when restrictions are both soil loss and chemical inputs (F). The rest of the country has a much larger absolute increase in both cases of high exports, but gains by 145 percent when Iowa enacts only soil loss restraints, and by 171 percent when both soil loss and chemical restraints are applied in Iowa. Hence, a redistribution of income occurs, absolutely under normal exports (A) and imposition of environmental limits (D) and relatively when exports are high. Of course, compensation and other policies could be used to restore the income position of Iowa farmers. However, it seems more likely that major environmental or land use programs need to be national in scope.

REFERENCES

[1] Heady, E. O., H. C. Madsen, K. J. Nicol, and S. H. Hargrove. "Agricultural Water Demands," National Technical Information Service, Springfield, Virginia, Report No. PB 206-790, November 1971.

[2] Heady, Earl O., H. C. Madsen, Kenneth J. Nicol, and S. H. Hargrove. *Agricultural and Water Policies and the Environment*, CARD Report No. 40T, Center for Agricultural and Rural Development, Iowa State University, June 1972.

[3] Heady, Earl O., H. C. Madsen, Kenneth J. Nicol, and S. H. Hargrove. "Nation and Interregional Models of Water Demand, Land Use, and Agricultural Policies," *Water Resources Research*, Volume 9, August 1973.

[4] "Iowa's New Conservancy Districts and Soil Loss Limit Regulations," Iowa State University, Cooperative Extension Service, PM-536, June 1972.

[5] Movers, C. A. "The Effects of Various Legumes on the Yields of Corn," Tennessee Agricultural Experiment Station Bulletin No. 142, February 1930.

[6] Nagadevara, V.S.S.V. "A Modeling Approach to the Economic Impacts of Local Environmental Controls in Iowa and the Rest of the Country," Ph.D. dissertation, Iowa State University, 1974, Appendix X, (Unpublished).

[7] Ibid., Appendix 3.

[8] Ibid., Appendix 7.

[9] Nagadevara, V.S.S.V., Earl O. Heady, and Kenneth J. Nicol, *Implications of Application of Soil Conservancy and Environmental Regulations in Iowa within a National Framework*, CARD Report 57, Center for Agricultural and Rural Development, Iowa State University, June 1975.

[10] National Academy of Sciences. *Nutrient Requirements of Domestic Animals, No. 2*, "Nutrient Requirements of Swine, Sixth Revised Edition," National Academy of Sciences-National Research Service Publication 1599, 1968.

[11] National Academy of Sciences. *Nutrient Requirements of Domestic Animals, No. 3*, "Nutrient Requirements of Dairy Cattle, Fourth Revised Edition," National Academy of Sciences-National Research Service, 1971.

[12] Nicol, Kenneth J., Heady, Earl O., and Madsen, Howard C. *Models of Soil Loss and Water Use, Spatial Agricultural Structure, and the Environment*, CARD Report 49T, Iowa State University, Ames, Iowa, 1974, Appendix 3, p. 213.

[13] Shrader, W. D. "Legumes—How Much N Do They Provide?" Iowa Cooperation Extension Service, EC-810t, January 1973.

[14] Shrader, W. D. and R. D. Voss. "Soybeans May Supply 50 Pounds of Nitrogen for Next Year's Corn," Wallaces Farmer, 97, No. 18, September 23, 1972.

[15] Shrader, W. D., W. A. Fuller, and F. B. Cady. "Estimation of Common Nitrogen Reponse Function for Corn (*Zea mays*) Different Crop Rotations," *Agronomy Journal*, 58:397-404, 1966.

[16] Stoecker, A. L. "A Quadratic Programming Model of U.S. Agriculture in 1980: Theory and Application," Ph.D. dissertation, Iowa State University, 1974, (Unpublished).

[17] U.S. Dept. of Commerce, Bureau of Economic Analysis. "The Economic Base of Selected Geographic Areas, Histrocial and Projected-1929 to 2020," Preliminary Report to the Water Resources Council. Washington, D.C.: U.S. Dept. of Commerce, 1968.

[18] U.S. Water Resources Council. "Water Resources: Regional and Subregions for the National Assessment of Water and Related Land Resources," Washington, D.C.: Government Printing Office, July 1970.

[19] Vanderholm, D. A. "Area Needed for Land Disposal of Beef and Swine Wastes," Iowa Cooperative Extension Service, PM 522, January 1973.

[20] Wischmeier, W. H. and D. D. Smith. "Predicting Rainfall Erosion Losses From Cropland East of Rocky Mountain," USDA Agricultural Handbook No. 282, May 1965.