ECONOMIC MODELS OF CROP RESPONSE TO IRRIGATION: A STATE-OF-THE-ARTS ASSESSMENT

paper presented at the
symposium on

Crop Response to Irrigation: A State-of-the-Arts
Assessment of What is Known and Practiced

Annual Meetings of the
American Agricultural Economics Association
and
Canadian Agricultural Economics Society

Blacksburg, Virginia, August 8, 1978

Harry W. Ayer
Agricultural Economist
NRED-ESCS-USDA

ECONOMIC MODELS OF CROP RESPONSE TO IRRIGATION:
A STATE-OF-THE-ARTS ASSESSMENT

Introduction

An economic assessment of crop response to irrigation is important if some form if an optimum irrigation strategy is sought, given limited resources. Usually, economists argue that an optimum is reached only if profits and/or utility are maximized. Both profits and utility are affected by the costs of limited factors of production. The importance of water costs in some irrigated agriculture is easily shown. In Pima County, Arizona, water costs were 20 and 34 percent respectively of the total variable costs of production of cotton and wheat.[1/] Water costs are of similar importance in many other pump irrigated areas.

Irrigation strategies which maximize profits will not necessarily maximize utility. The discrepancy occurs if utility is not a linear function of profits and profits are stochastic in nature. Theoretically, the marginal utility of profits is expected to decrease, and limited empirical research on farmer utility bears out this conclusion (Lin). Even for irrigated agriculture, there are many reasons (weather, soil, inability to accurately apply inputs, changing prices) why profits are stochastic in nature. Estimates for three of Arizona's most important crops, cotton, wheat and grain sorghum indicate that the standard deviation of profits as a percent of mean profits are 16, 65 and 34 percent respectively (Wildermuth, et.al.).

[1/] Computed from Hathorn and Armstrong.

Economic models, in contrast to purely physical models, may account for both prices and risk,[2/] plus the important production response relationships.

Economic models to maximize profits or utility are useful at both the farm and regional level of decision making. Farm level decisions pertain to water use per acre, scheduling, crop patterns, leaching of salts, water mixing and irrigation techniques. Regional policy decisions concern the development of reservoirs and accompanying canal systems, water pricing, and the implementation of policies to control water quality by decreasing the quantity or increasing the quality of irrigation return flow.

The objective of this paper is to review and assess economic models of crop response to irrigation. The review separates models into five categories: (1) basic production function models, (2) dated production function models, (3) salinity models, (4) multicrop models, (5) and models which include risk and uncertainty. Basic model features and the usefulness, strengths and weak..ess of each model type are given. The paper concludes with a summary assessment of the state-of-the-arts and a list of references.

Models

Basic production function models

Basic crop-water production functions have been estimated and used in economic analyses by Delaney, et.al., Dyke, Hexem and Heady, Holloway and Stevens, Hogg and Vieth, Shipley, Wu and Ling, and Yaron, et.al. All of these are recent studies, having been published since 1972.

[2/] Although, as will be shown later, very few economic studies of production response to irrigation have accounted for risk.

Basic production function models are characterized by their simplicity--yield is postulated to be a function of annual water applied and perhaps some non-water inputs. The impact of water scheduling, water quality, multi-crop decisions and risk are ignored. In general, the underlying production function is estimated by regression analysis with units of observation being experimental plots, farm fields, or counties. In some cases, the total response curve is not estimated, and simple averages of yields at particular water applications used to describe yield response. Optimum levels of water application are estimated with the regression production functions by setting water applications such that the marginal value product of water (MVP) equals water price. Partial budgeting analysis is used to determine the most profitable water application if only point estimates of the production function are available.

These economic models have several important advantages over the purely physical models of crop response to irrigation (of which there are many). First, prices are considered so that profit maximization may be estimated. Second, and most important, economic models must express water inputs in units subject to manager control. Most purely physical crop-water response models have been estimated with yield as the dependent variable and evapotranspiration (ET) as the independent variable. ET is affected by irrigation levels, but it is also affected by a host of other factors (growth stage, climatic factors, soil, etc.). Typically, these models have not gone on to complete the link between ET and water application, so that the effect of the decision variable (irrigation level) and its price on profits cannot be assessed. In the above economic models, either irrigation level is specified directly as an input, or the relationship between

ET and irrigation level is specified.

The basic production function models are best used for regional vs. on-farm analysis. Estimates of the average MVP for the region can be made and compared to the price of providing more public irrigation facilities. If the MVP is greater than the price, more facilities may be justified. The aggregate crop-water production function may also be used to determine the impacts of water pricing policy on yields and input use. Water pricing is currently an important decision variable. Utility companies (gas or electric) may greatly affect pumping costs in pump irrigated areas. And irrigation districts are under increasing pressure to price water to better reflect its social cost. Pricing policy is attempting to conserve water and improve its quality.

The basic models are not useful for on-farm decisions. Farm managers and/or irrigators must decide not only how much water to apply annually, but, just as importantly, how much water to apply at particular times. Agronomic research has shown that the timing of irrigations affects yields as much as annual quantities of water, and to ignore scheduling simply ignores reality. The basic production function models also omit multi-crop situations and the riskiness of production decisions--both important factors in on-farm decisions which themselves affect the optimum total amount of water to apply.

Dated production function models

Dudley, et.al., Flinn and Musgrave; Hall and Butcher; Minhas, et.al.; Moore; Moore, Snyder and Sun; and Stewart, Hagan and Pruitt have all estimated economic models based upon dated crop-water production functions. The dated functions recognize the fact that plants develop in growth stages (such as vegetative, pollination and maturation stages) and that the same quantity of water will result in different yields depending upon when it is applied. Some of this work (Stewart, Hagan and Pruitt) also recognizes that the amount of water applied in one period will affect yield response to water applied in subsequent periods, but most of these studies ignore this "conditioning" effect.

Dated production function studies typically use water applied (or ET) per growth period as the independent variable. The determination of yield response to water by growth stage greatly increases the complexity of experiments to determine crop response, and other variables are usually held constant. Production functions are usually estimated by regression analysis from experimental data, or, in some studies point estimates of yield response to water applied per time period were estimated by educated guesses.

Economic optimums are estimated by setting the MVP of water per growth period equal to the marginal factor cost (MFC) of supplying water during that period, or, when point estimates of crop response are used, partial budgeting techniques are employed. Dynamic programming has also been used to handle the intertemporal nature of scheduling water. In the studies, water restrictions, both by periods within the year and total for the year, plus water prices per time period, are key consideration.

Dated production function models are usually not applicable to on-farm decision making in spite of their improvement over the basic production functions and in spite of claims to the contrary. Most of the studies fail to recognize the interdependence of growth stages, most are deterministic rather than recognizing the riskiness of crop production, and most omit many of the climatic, soil and other factors which distinguish one field from another and affect irrigation decisions. These models do, however, help lay the foundation for more sophisticated farm level models.

Salinity models

Many researchers have estimated the economic impacts of water or soil water salinity in irrigated areas. Contributions have been made by Andersen and Hanks; Boster and Martin; Bressler and Yaron; Llop, Paris and Horner; Lorenston; Moore, Snyder and Sun; Noel, et.al.; Pincock; Yaron; Yaron and Bressler; Yaron and Olian; and Young, et.al. Nearly all of these studies have been made in the mid seventies, reflecting the rising importance of the salinity issue. Estimates suggest that one-fifth of the irrigated land in the U.S. and one-third of the irrigated land in the world are affected by salinity problems (Yaron, p. 60). Not only is yield affected by salinity, but irrigation return flows in saline areas adds salt to water used downstream. This has resulted in political pressure to reduce return flow salt loads through irrigation management.

The key feature of these models is the inclusion of water or soil salinity in crop response functions. Some of the models account for salt accumulation in the soil over time, and the leaching effects of adequate quantities of water. Soil type, frequency of irrigation and root depth have also been included as explanatory factors. The physical part of the model--the production function--is estimated by regression techniques or point estimates made by salinity experts. Maas and Hoffman have recently provided an exhaustive assessment of what is known about the physical response of various crops to salinity. Nearly all response estimates are based upon experimental results, vs. farm or regional units of observation.

Empirical models have utilized partial budgeting, linear programming, economic production function analysis, dynamic programming, and statistical demand analysis.

The models are most useful for regional policy analysis. Water quality issues addressed include: the effect of alternative irrigation management strategies which might be imposed by the Environmental Protection Agency; the effect of large scale irrigation schemes such as the Central Arizona Project on water mixing strategies (saline with nonsaline water) and on short and long run economic impacts on farming; and the effect of water pricing policies to control downstream pollution from irrigation return flow.

These models make yet another important step toward on-farm applicability. Theoretically, they provide estimates of farm-level water mixing strategies and the optimum quantity of water to apply for leaching as well as for water as a direct input. But, these models are not truly operational at the farm level because they omit important irrigation decisions variables, such as soil and climatic factors and risk.

Multi-crop models

More economic studies fall into this category than any other. Anderson and Maas; Anderson and Hanks; Andersen and Wilson; Ayer and Cormier; Ayer and Gapp; Boster and Martin; Cummings and Gisser; Hedges; Hedges and Moore; Maas and Anderson; Moore Snyder and Sun; Noel _et.al._; Trava, _et.al._; and Young and Bredehoeft have all made contributions.

These profit maximizing models select the optimum combination and acreage of different crops, besides specifying the profit maximizing quantity of water to apply to each crop activity. The models explicitly recognize water and other resource constraints within which an optimum must be determined. A few of the studies include irrigation scheduling and variables to measure salinity impacts. Linear programming is the most common empirical tool employed, although simulation studies which encompass both farm and irrigation district decisions have also been used. Regression estimates of yield impacts on alternative water quantities are used in the LP models to specify separate crop activities. Perhaps one of the best examples of these models is that of Moore, Snyder and Sun. They use a linear programming model to maximize expected profits in the Imperial Valley of California. Several crop activities are included for each crop based upon production function estimates of yield from alternative water quantities and levels of salinity. Constraints within the model include farm size, total water supply for the region, total and peak seasonal water supply for each farm size, and constraints on acreage for particular crops. A sample of the output from their model is shown in Figure 1. The functional relationship between regional returns to water and land and the quantity and salinity of water is shown.

Models of this type are applicable to regional analysis. They may be used to determine the impacts of the 160 acre limitation, water quantity and price policies, rising energy prices which increase pumping costs, water quality policies, and to evaluate the benefits of irrigation scheduling services.

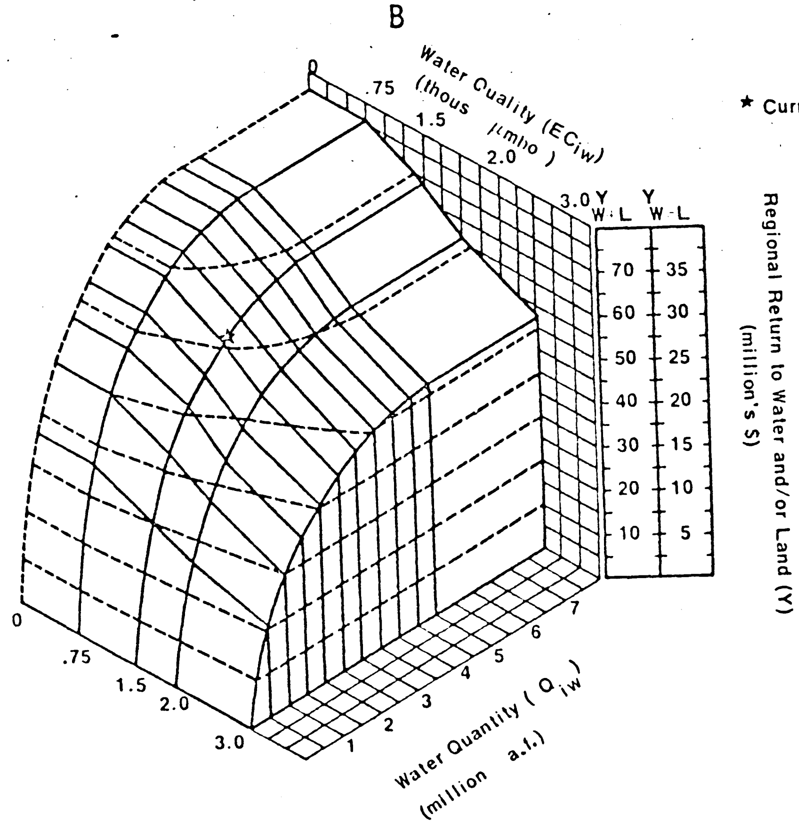

Figure 1. Water quantity, quality, and regional return to water and land, Imperial Valley, California.

Source: Moore, et.al., p. 141.

These models add another degree of reality for on-farm use. A variety of crops can be included in the evaluation, as can the effects of alternative irrigation technologies and water application levels, water quality and timing. The models to date still are limited in that the underlying production functions generally refer to average conditions rather than those for a specific farm. Risk is also not considered.

Risk and uncertainty models

Anderson, et.al., DeLucia, Dudley, et.al. and English have conducted most of the very few economic studies of crop response to irrigation which include the stochastic nature of the production-marketing environment. These researchers and others make convincing arguments that production in irrigated areas takes place in an environment of risk and uncertainty, and that farm decisions are based not only upon expected profits, but also the riskiness of obtaining a particular profit level.

The most recent study (1978) in this category is that of English. His decision theory model recognizes several sources of risk and uncertainty including antecedent soil moisture, planting dates, and the weather factors of wind, sun, solar radiation, humidity, temperature and rainfall. English argues that the best (highest R^2) production functions are obtained when evapotranspiration, rather than water level, is specified as the independent variable in crop-water production function. But an economic model must also include the relationship between ET and the amount of irrigation water applied. This functional relationship depends upon the previously mentioned stochastic variables plus others considered "determined," such as soil type and application efficiency. Profit levels and the variance of profits are then estimated through the water--ET--production functions for alternative levels of water. The English model then attempts to determine a utility maximizing optimum by relating different water-induced combinations of mean profits and profit variability to utility functions of particular farmers.

Tables 1 and 2 give some of the results from the English model. These results indicate that water applications which maximize profits may be quite different from levels which maximize utility. Hence the importance of stochastic modeling. His model is presented in the hopes that it will be one of the first with true on-farm applicability. Linking ET to several decision

Table 1. Relationship of Water Use, Land Area Put into Production, Mean and Variance of Profits and Expected Utility.*

IRRIGATED AREA (ACRES)	WATER USE (AC-INCHES PER IRRIGATED ACRE)	EXPECTED PROFIT (DOLLARS PER IRRIGATED ACRE)	VARIANCE OF PROFITS ($ / AC.)	TOTAL PROFIT ($ 1000)	TOTAL VARIANCE ($ 1 x 10^{-6})	EXPECTED UTILITY
200	12	41.30	31790	8.26	1272	47.53
171	14	46.90	34600	8.02	1012	49.64
150	16	51.50	35810	7.73	806	51.13
133	18	54.90	37680	7.30	667	51.71
120	20	57.20	39250	6.86	565	51.90
109	22	58.75	40620	6.40	483	51.86
100	25	59.60	41800	5.96	418	51.69
92	26	59.80	42880	5.50	363	51.38
86	28	59.55	44050	5.12	326	51.04

Source: English, p. 136.

Note: *Assumes water allotment of 12 ac-in. per acre, 200 acres of land available; utility function of grower No. 1 used; only one crop considered: beans.

Table 2. Mean and Variance of Profits and Expected Utility from Alternative Crop Combinations and Water Levels.

Option	μ_{Π} ($)	σ^2_{Π} (\$x10-^{6})	$E(u(\Pi))$
Option 1: 200 acres planted entirely in beans (maximum profit)	$8260	1272	47.53
Option 2: 109 acres planted entirely in sugar beets (maximum utility with sugar beets)	3260	32	50.42
Option 3: 120 acres planted entirely in beans (maximum utility with beans)	6860	565	51.90
Option 4: 127.7 acres planted 60% in beans and 40% in sugar beets (maximum utility with a portfolio combination)	5550	238	52.69

Source: English, p. 140.

variables to yield, plus the explicit recognition of the impact of risk and uncertainty upon farm level decisions are very important contributions. However, the English model is applied to a rather unrealistic farm situation. Only two crops are considered; the effect of scheduling is not empirically brought into the model; and salinity is not considered in the case study.

State-of-the-Arts: A Summary Assessment

The state-of-the-arts of economic models of crop response to irrigation is at a high level with respect to regional analysis and decision making. A number of excellent models specify the key policy variables and their impact upon yields and other items of interest. These models indicate whether or not greater public investment should be made in reservoirs and accompanying canal systems. The impact of alternating irrigation technologies and management schemes, water prices, water quantity restrictions, and the 160 acre limitation on farms profits, crop supply, and irrigation return flow levels and salinity can all be evaluated with existing models. Decisions made at the regional level, and even at the national level, should head the policy implications of these models. Perhaps the one caveat to this optimistic assessment is that most models have not included risk and utility maximization. As Just and others have argued, estimates of aggregate supply and input use will be different when estimated with decision theoretic models than when estimated with pure profit maximizing ones.

The state-of-the-arts of farm level, economic models of crop response to irrigation has advanced considerably during the past decade.

Much of this advance is due to agronomic research which has improved our knowledge of crop response to irrigation scheduling and salinity, besides total water applied. Further, advancements have been made by applying linear and dynamic programming and simulation techniques to farm decisions which must consider multi-crop possibilities and limited resources. The recent application of decision theory to management decisions surrounded by risk and uncertainty makes an important advancement.

But models for on-farm use have not been used by commercial or government irrigation scheduling services, nor, to the best of our knowledge, by individual farmers. Several explanations are hypothesized. First, personnel of most scheduling services have an engineering or agronomic background, rather than one emphasizing economics. Second, most of the research and literature pertaining to crop response to irrigation is based upon ways to maximize crop yields, not profits or utility. Most economic studies have been done in the last five to ten years and there are very few which include most of the key irrigation decision variables peculiar to a particular farm. In large part, the physical production function relationship for a specific irrigators field is still difficult to accurately estimate with minimum expense. The recent work by Stewart, Hagan and Pruitt and their colleagues at other western experimental sites has gone the farthest in resolving this issue. Hopefully their recent results (since mid 70's) will soon be incorporated into more economic studies. Finally, more economic models need to consider risk and uncertainty in production and farmer attitudes about them.

REFERENCES

Andersen, Jay C. and R. John Hanks. "Modeling the Soil-Water-Plant Relationships in Irrigation Return Flows in the Colorado River Basin." Proceedings of the Seminar of the Colorado River Basin Modelling Studies, Utah State University, July 16-18, 1975, pp. 321-369.

Andersen, Jay C., Harold H. Hiskey and Suwaphot Lackawathana. "Application of Statistical Decision Theory to Water Use Analysis in Sevier County, Utah." Water Resources Research, Vol. 7, No. 3, June 1971, pp. 443-452.

Andersen, Jay C., and David L. Wilson. "Evaluating Increments of Irrigation Water, Sevier River Basin, Utah." Proceedings of the Committee on The Economics of Water Resources Development of the Western Agricultural Economis Research Council, San Francisco, California, December 12, 13, 1967, pp. 101-114.

Anderson, Raymond L. "A Simulation Program to Establish Optimum Crop Patterns on Irrigated Farms Based on Preseason Estimates of Water Supply." American Journal of Agricultural Economics, December 1968, pp. 1586-1590.

Anderson, Raymond L. and Arthur Maass. A Simulation of Irrigation Systems: The Effect of Water Supply and Operating Rules on Production and Income on Irrigated Farms. USDA, ERS Tech. Bull. No. 1431, January 1971.

Anderson, Raymond L., Dan Yaron, and Robert Young. Models Designed to Efficiently Allocate Irrigation Water Use Based on Crop Response to Soil Moisture Stress. USDA, ERS, Tech. Rep. No. 8, May 1977.

Ayer, Harry W., and David J. Cormier. "Impacts of Increasing Energy Scarcity in Irrigated Agriculture: An Empirical Study from the Arid Southwest." Proceedings of the International Conference, Energy Use Management, Vol. I, New York, Pergamon Press, 1977, pp. 709-718.

Ayer, Harry W., and David W. Gapp. "Rising Energy Prices, Water Demand by Peri-Urban Agriculture, and Implications for Urban Water Supply: The Tucson Case." Hydrology and Water Resources in Arizona and the Southwest, in press.

Biere, Arlo W. "Economic Irrigation Scheduling and the Demand for Irrigation Water." Unpublished paper, mimeographed, no date.

Boster, Mark A. and William E. Martin. Economic Analysis of the Conjunctive Use of Surface Water and Ground Water of Differing Prices and Qualities: A Coming Problem for Arizona Agriculture. Arizona Agricultural Experiment Station, Tech. Bull. 235, University of Arizona, 1977.

Boster, Mark A. and William E. Martin. "Supplemental Colorado River Water for a Developed Groundwater Agriculture: A Problem of Quantities, Qualities and Conjunctive Use." <u>Advances in Water Resources</u>, Vol. 1, no. 2, 1977, pp. 103-109.

Bresler, E., and D. Yaron. "Soil Water Regime in Economic Evaluation of Salinity in Irrigation." <u>Water Resources Research</u>, Vol. 8, no. 4, August 1972, pp. 791-800.

Cummings, R. G. and M. Gisser. <u>Reductions of Water Allocations to Irrigated Agriculture in New Mexico: Impacts and Technological Change</u>. Final report to New Mexico Energy Resources Board, No. ERB #75-116, December 1976.

Delaney, Ronald H., James J. Jacobs, John Borrelli, Richard T. Clark, and Warren E. Hedstrom. "Economic and Agronomic Effects of High Irrigation Levels on Alfalfa and Barley." <u>Water Resources Research Institute</u>, Research Journal No. 121, Laramie, Wyoming, January 1978.

DeLucia, R. J. "Operating Policies for Irrigation Systems Under Stochastic Regimes." Ph.D. dissertation, Division of Engineering and Applied Physics, Harvard University, Cambridge, Massachusetts, 1969.

Dudley, Norman J., David T. Howell, and Warren F. Musgrave. "Irrigation Planning 2: Choosing Optimal Acreages within a Season." <u>Water Resources Research</u>, Vol. 7, no. 5, October 1971, pp. 1051-1063.

Dudley, Norman J., David T. Howell and Warren F. Musgrave. "Optimal Intraseasonal Irrigation Water Allocation." <u>Water Resources Research</u>, Vol. 7, no. 4, August 1971, pp. 770-788.

Dyke, Paul T. "Yield Response Handbook." Prepared for Western Governor Drought Conference, Denver, Colorado, December 1-3, 1977.

English, Marshall Joseph. "Application of Decision Theory in Irrigation Optimization." Ph.D. dissertation, Engineering, University of California, Davis, California, 1978.

English, M., G. Horner, <u>et.al</u>. "A Regional Assessment of the Economic and Environmental Benefits of an Irrigation Scheduling Service," Environmental Protection Technology Series, U.S. Environmental Protection Agency, forthcoming.

Flinn, J. C. and W. F. Musgrave. "Development and Analysis of Input-Output Relations for Irrigation Water." <u>The Australian Journal of Agricultural Economics</u>, Vol. 11, no. 1, June 1967, pp. 1-19.

Hall, Warren A., and William S. Butcher. "Optimal Timing of Irrigation." <u>Journal of the Irrigation and Drainage Division</u>, June, 1968, pp. 267-275.

Hathorn, Scott, Jr. and James F. Armstrong. <u>1977 Arizona Field Crop Budgets Pima County</u>. Cooperative Extension Service, The University of Arizona, Tucson, May, 1977.

Heady, Earl O., and Roger W. Mexem. <u>Water Production Functions for Irrigated Agriculture</u>. Ames, Iowa: The Iowa State University Press, 1978.

Hedges, Trimble R. Water Supplies and Costs in Relation to Farm Resource Decisions and Profits on Sacramento Valley Farms. California Agricultural Experiment Station, Giannini Foundation Research Report No. 322, June 1977.

Hedges, Trimble R. and Charles V. Moore. Economics of On-Farm Irrigation Water Availability and Costs, and Related Farm Adjustments. California Agricultural Experiment Station, Giannini Foundation Research Report No. 257, September 1962.

Hogg, Howard C., and Gary R. Vieth. "Method for Evaluating Irrigation Projects." Journal of the Irrigation and Drainage Division, March 1977, pp. 43-52.

Holloway, Milton L. and Joe B. Stevens. An Analysis of Water Resource Productivity and Efficiency of Use in Pacific Northwest Agriculture. Agricultural Experiment Station, Special Report 383, USDA, NRED, ERS, Oregon State University, Corvallis, Oregon, May 1973.

Howell, T. A., E. A. Hiler and D. L. Reddell. "Optimization of Water Use Efficiency Under High Frequency Irrigation--II. System Simulation and Dynamic Programming." Transactions of the ASAE, Vol. 18, no. 5, 1975, pp. 879-887.

Just, R. E. "An Investigation of the Importance of Risk in Farmers' Decisions." American Journal of Agricultural Economics, 1974, pp. 14-25.

Just, R. E. "Risk Response Models and their Use in Agricultural Policy Evaluation." American Journal of Agricultural Economics, 1975, pp. 836-843.

Llop, Armando A., Auirino Paris and Gerald L. Horner. Economics of Irrigation Under Saline Conditions. Unpublished paper.

Maas , Arthur and Raymond L. Anderson. . . . and the Desert Shall Rejoice: Conflict, Growth, and Justice in Arid Environments. Cambridge, Mass.: The MIT Press, 1978.

Maas, E. V. and G. J. Hoffman. "Crop Salt Tolerance--Current Assessment," Journal of the Irrigation and Drainage Division, June 1977, pp. 115-134.

Matango, G. B. and M. A. Marino, Application of Optimization and Simulation Techniques to Irrigation Management. Water Science and Engineering Papers, No. 5003, Department of Water Science and Engineering, University of California, Davis, 1977.

Minhas, B. S., K. S. Parikh, and T. N. Srinivasan. "Toward the Structure of a Production Function for Wheat Yields with Dated Inputs of Irrigation Water." Water Resources Research, Vol. 10, no. 3, June 1974, pp. 383-393.

Moore, Charles V. A General Analytical Framework for Estimating the Production Function for Crops Using Irrigation Water. California Agricultural Experiment Station, Giannini Foundation Paper No. 210,

Moore, Charles V. and J. Herbert Snyder. "Economic Problems of Seawater Intrusion--A Case Study of the Salinas Valley, California." Proceedings of the Committee on the Economics of Water Resources Development of the Western Agricultural Economics Research Council, San Francisco, California, December 12-13, 1967, pp. 39-56.

Moore, C. V., J. H. Snyder and Peter Sun. "Effects of Colorado River Water Quality and Supply on Irrigated Agriculture." Water Resources Research, Vol. 10, no. 2, April 1974, pp. 137-144.

Noel, Jay, Charles V. Moore, Frank Robinson and J. H. Snyder. "The Effect of Water Quality and Irrigation Frequency on Farm Income in the Imperial Valley." California Agriculture, Vol. 20, no. 11, University of California Experiment Station, November 1975, pp. 12-14.

Pincock, M. Glade. "Assessing Impacts of Declining Water Quality on Gross Value Output of Agriculture, A Case Study." Water Resources Research, Vol. 5, no. 1, February 1969, pp. 1-12.

Shipley, John. Economic Considerations in the Irrigation of Grain Sorghum and Corn, Texas High Plains. Texas Agricultural Experiment Station, Tech. Art. No. 13840, Texas A & M University.

Stewart, J. I., et.al. Optimizing Crop Production Through Control of Water and Salinity Levels in the Soil. Utah Water Research Laboratory Utah State University, Logan, Utah, September 1977.

Stewart, J. Ian, Robert M. Hagan, and William O. Pruitt. "Functions to Predict Optimal Irrigation Programs." Journal of the Irrigation and Drainage Division, June 1974, pp. 179-199.

Stewart, J. Ian, Robert M. Hagan, and W. O. Pruitt. Water Production Functions and Predicted Irrigation Programs for Principal Crops as Required for Water Resources Planning and Increased Water Use Efficiency. Final report prepared for USDI, Bureau of Reclamation, Engineering and Research Center, Denver, Colorado, July 1976.

Thomas, Howard R. "Economic Productivity of Water and Related Inputs in the Agriculture of Southern Idaho." Unpublished paper, mimeographed, 1974.

Trava, Jose, Dale F. Heermann, and John W. Labadie. "Optimal On-farm Allocation of Irrigation Water." Transactions of the ASAE, 1977, pp. 85-88, 95.

Wildermuth, John, Richard Shane and Russell Gum. "Risk and Diversification in Arizona Crop Farm Planning." Progressive Agriculture in Arizona, Vol. XXIII, no. 5, September-October, 1971, pp. 8-10.

Wu, I-pai, M. ASCE and Tung Liang. "Optimal Irrigation Quantity and Frequency." Journal of the Irrigation and Drainage Division, March 1972, pp. 117-144.

Yaron, Dan. "Economic Analysis of Optimal Use of Saline Water in Irrigation and the Evaluation of Water Quality." Proceedings of the 15th Annual Western Resources Conference at the University of Colorado, Merriman Publishing Company, 1974, pp. 60-85.

Yaron, Dan. "Economics of Irrigation and the Institutional and Pricing Systems of Water in Israel." Unpublished paper.

Yaron, D. and E. Bresler. "A Model for the Economic Evaluation of Water Quality in Irrigation." The Australian Journal of Agricultural Economics, June 1970, pp. 53-62.

Yaron, D. and A. Olian. "Application of Dynamic Programming in Markov Chains to the Evaluation of Water Quality in Irrigation." The American Journal of Agricultural Economics, Vol. 55, 1973, pp. 467-471.

Yaron, D. and G. Strateener. "Wheat Response to Soil Moisture and the Optimal Irrigation Policy under Conditions of Unstable Rainfall." Water Resources Research, Vol. 9, no. 5, October 1973, pp. 1145-1154.

Young, R. A., W. T. Franklin and K. C. Nobe. Assessing Economic Effects of Salinity on Irrigated Agriculture in the Colorado River Basin: Agronomic and Economic Considerations. Report to the Bureau of Reclamation, USDI, Contract No. 14-06-D-7341, August 1973.

Young, Robert A. and William E. Martin. "Modeling Production Response Relations for Irrigation Water: Review and Implications." Proceedings of the Committee on the Economics of Water Resources Development of the Western Agricultural Economics Research Council, San Francisco, California, December 12-13, 1967, pp. 1-24.