Alternative management strategies for a farm utilizing a solar powered irrigation system

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ALTERNATIVE MANAGEMENT STRATEGIES FOR A FARM UTILIZING A SOLAR POWERED IRRIGATION SYSTEM

by

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wonderful knack of making a seemingly tedious task appear instead to be a challenging and rewarding endeavor.

This thesis is dedicated to the author's parents.

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ABSTRACT

Substitutes for conventional energy inputs will become more important as conventional energy inputs undergo variable price increases. Solar energy is one possible substitute for conventional energy inputs used in various farm activities.

A representative farm for Pinal County, Arizona, is developed using information obtained from interviews with Pinal County farmers. A solar irrigation system is modeled into the representative farm. The solar irrigation system provides power to operate three wells on the representative farm.

Alternative management strategies are analyzed for the representative farm. The alternatives include: (1) a non-solar farm; (2) using conventional and solar power for irrigation and allowing excess solar power to be sold to the local utility; (3) using conventional and solar power for irrigation with no selling of excess solar power to the local utility; (4) using solar power only for irrigation with no selling of excess solar power to the local utility; and (5) using solar power only for irrigation but allowing excess solar power to be sold to the local utility.

Net returns above variable costs are compared for each management alternative. The results show that net returns are increased when both conventional and solar power are used compared to returns for the non-solar farm alternative alone.

CHAPTER 1

INTRODUCTION

Successful farm management requires that the owner of a farm make timely and wise decisions concerning a variety of farming activities. What crop mix to produce, how to most efficiently combine inputs such as fertilizer, seed, and water to produce the desired crop mix and when to harvest and market the final crop are some of the basic decisions that farmers make.

Another input use decision that by no means can be omitted concerns the use of energy inputs that are consumed in the agricultural crop production process. Conventional energy inputs are consumed in the daily activity of all farms whether the activity be running a diesel tractor, using a farm pickup, drying crops, heating farm buildings, or powering irrigation pumps. Regardless of the farm activity that is performed, the consumption of increasingly scarce energy inputs is inexorably a part of the farm activity.

Conventional energy inputs also have an impact on the capital investment decisions of farm managers. For example, an administrative worker at Tucson Gas and Electric (TG&E) has said that as natural gas wells break down or come in need of major repair, farmers in Pima County, Arizona are beginning to make decisions on investing in new power units for irrigation pumping. These decisions to invest in new power units arise because natural gas is becoming increasingly expensive according to the spokesman for TG&E. Also as increasing costs for electricity become the rule instead of the exception, alternatives to electrical power must be considered to keep farms profitable. Consequently, capital investment decisions for farm irrigation systems will be affected directly by the availability and cost of alternative sources of energy. Therefore, the impact of energy input cost on investment decisions cannot be ignored.

The analysis of this report is specifically directed towards the farmer's management of energy inputs used to power on-the-farm irrigation wells. Essentially all crop land agriculture in Arizona is irrigated as shown in Table 1. Electricity and natural gas are the two major conventional energy inputs used to power irrigation wells. Approximately one-third of Arizona's irrigation pumps are powered by natural gas (Larson and Sands 1977, p. 751). Approximately two-thirds of Arizona's farm wells are electric powered (Towle 1976, p. 5).

The energy cost for such inputs will have a direct impact on production costs per acre of irrigated crops grown in Arizona. "Energy price increases and potential natural gas cutoffs have forced many farmers to reconsider their use and source of energy" (Larson et al. 1978, p. 2).

Since the OPEC oil embargo of 1973-1974 energy costs have risen dramatically. Table 2 shows that since 1973 the average annual percentage change in the price of all energy has been rising upward in contrast to the change in all energy prices before 1973. Before 1973 the average annual percentage change in price of all energy had been decreasing. The table shows that prices have since begun to increase

Table 1. Proportion of total irrigated crop land to total irrigated land in Arizona.

	1969	1974
Total Farms[a]	4,252	4,321
Farms irrigated	2,894	2,984
Proportion of farms	68.0	69.1
Total land irrigated	1,128,696	1,109,978
Crop land irrigated[b]	1,118,638	1,098,836
Proportion of total irrigated crop land to total land irrigated[c]	99.1	98.9

[a] Includes non-crop land farms and ranches.

[b] Includes harvested crop land, crop land pasture, and other crop land irrigated.

[c] Estimate added to table by author.

Source: United States Department of Commerce 1977b, pp. 1-12.

Table 2. Average annual percent change in consumer prices for all energy and selected energy inputs.*

	1958-1973	1973-1976	1976-1977
All energy	- .8	6.2	2.9
Fuel oil and coal	.0	12.9	6.1
Natural gas	- .4	7.1	11.6
Electricity	-1.2	3.5	.1
Gasoline and motor oil	-1.0	5.1	- .8

*Consumer prices have been deflated by the consumer price index.

Source: Economic Report of the President . . . 1978, p. 181.

with the exception of gasoline and motor oil which have decreased slightly.

The rise in the price of conventional energy inputs -- electricity, natural gas, LP gas, and diesel -- most commonly used to power irrigation wells, has dictated that farm managers place an even greater emphasis on the efficient utilization of these energy inputs. Table 3 shows that the prices for these energy inputs is also increasing.

Substitutes for conventional energy inputs are less susceptible to variable price rises. The development of more plentiful energy substitutes for agriculture is an urgent and important priority in the development of a comprehensive national energy program.

As President Carter said in his Economic Report to Congress in January 1978:

> It has now been over four years since our economy was buffeted by the oil embargo and its aftermath of sharply increased oil prices. . . . The U.S. has no choice but to adjust to the new era of expensive energy. . . . If we act today we have time to make a gradual transition to more efficient energy use--by conserving energy, increasing domestic energy production, and developing alternative sources of energy (Economic Report of the President . . . 1978, pp. 6-7).

and from the same report,

> The economic consequences of the 1973 oil embargo and the quadrupling of world oil prices by the Organization of Petroleum Exporting Countries (OPEC) have dramatically demonstrated the importance of energy to the U.S. and world economies. In the United States, higher prices of imported crude oil prompted major increases in the prices of all other fuels, aggravated inflationary pressures, and contributed to the deepest recession since the Depression (Economic Report of the President 1978, pp. 179-194).

Solar power is one alternative energy source that is available for development as a substitute for conventional energy inputs.

Table 3. Prices for selected energy inputs for December 1975-1977.

Energy Type	Dec. 1975	Dec. 1976	Dec. 1977
Natural gas[a]	87.6	117.8	132.2
Diesel[b]	25.5	36.7	41.4
Propane[c]	19.7	20.6	25.0
Butane[c]	19.4	21.9	25.3
Utility fossil fuels[d]	106.9	118.6	144.2

[a] Sales from resellers in cents per 1000 cubic feet.

[b] No. 1 diesel in cents per gallon excluding tax. This is the retail price at which company-owned and operated retail dealers sell to consumers.

[c] Refers to the price at which refiners, resellers, retailers, and gas plants sell to one another including sales to agricultural and industrial accounts in average cents per gallon.

[d] Cost of all fossil fuels delivered to steam electric utility plants. The figures are a national average in cents per million BTU.

Source: United States Department of Energy 1978.

> We are aware as never before of the living conditions in other parts of the world, and the industrialized countries are eager to help the non-industrialized countries become more productive and achieve a higher economic level. More mechanical or electrical power would be a very effective means of help. Though the industrialized countries do not seriously need more fuel now as the non-industrialized countries do, they are in a good position to give important practical help through research and developing the means for using solar energy. . . . The immediate urgency for research in solar energy is for use in the economically less developed countries. A long-range need for research in solar energy is in the highly industrialized countries, because the fossil fuels will not last indefinitely and will certainly increase in cost (Daniels 1964, pp. 2-3).

Hathorn (1977, 1978) budgeted the energy price per kilowatt hour electric (KWH_e) (kilowatt hour of electricity is a measure of the amount of work that can be performed by one kilowatt of electricity in one hour) for pumping water in the Coolidge Area of Pinal County, Arizona, as $.01050 including a 4% sales tax in 1977, and as $.01600 in 1978 including a 4% sales tax. In one year the price of electricity per KWH_e for irrigation pumps increased 52%.

From the farm interviews conducted in Pinal County in this study, a price of electric power of $.01824 per KWH_e including a 4% sales tax was chosen as a representative figure. Rates for electric farm power vary throughout Pinal County. During the interviews some farmers indicated that they were expecting rate increases in the near future. The $.01824 is a representative figure for the entire county reflecting expected future increases in rates. This is an increase of 14% over the $.01600 KWH_e budgeted for the spring of 1978. The trend of these cost figures indicates that energy prices are escalating upward in Pinal County. Or more correctly, energy prices can be expected to increase in Pinal County.

When new hydro-electric contracts between electric utilities such as Electrical District Number 2 (ED2) and suppliers of hydro-electric power are renegotiated in the near future, it is projected that irrigation electricity cost from ED2 may increase to almost 40 mills per KWH_e by 1980 (Acurex Corporation 1977, p. 2.2-5). The rising cost for conventional energy inputs makes it imperative that low cost substitutes be found. Solar energy may be one such relatively low-cost energy substitute.

This thesis analyzes a solar powered irrigation system for a representative farm in Pinal County, Arizona.

> The best locations for solar thermal power plants are probably not simply those receiving more sunshine, but those receiving more direct ray sunlight. Unfortunately less data on direct solar radiation /most measurements are of total solar radiation which includes direct and indirect solar radiation/ are available, but regions having clear skies and low humidity a large portion of the time, such as Arizona deserts, receive relatively more direct solar radiation (Larson and Sands 1977, p. 752).

Arizona is an obvious choice as a location for the installation, operation, and monitoring of a solar powered irrigation system.

By late 1979, Arizona will have two operational solar irrigation systems. The first, located near Gila Bend, Arizona, is an operational 50 KW_e (kilowatts of electricity. This refers to the power output of the plant) solar thermal power plant, and the second, to be located near Coolidge, Arizona, a 150 KW_e solar thermal power plant, is scheduled to begin operation sometime in August 1979. It is toward this latter project that this thesis is directed. The Coolidge area solar thermal power plant will provide power to run three on farm irrigation pumps at least part time.

A Brief Background on Solar Energy Research

The first major experiments using solar energy to perform work began over a century ago. Daniels (1964, Chap. 2) presents a short but informative history of solar energy research and experiments. The first large-scale solar experiment occurred in 1872 with the construction of a solar distilling operation in Chile. Daniels chronicles the various scientists who have carried on solar energy research since those early days.

The considerable amount of solar research mentioned by Daniels was the forerunner to a number of international solar symposia held throughout the 1950's and very early 1960's. These symposia "have led to an active and rapidly increasing interest on the part of scientists and engineers, and of the general public as well, in the direct use of the sun's energy" (Daniels 1964, p. 9).

Even though there has been much research in the past in utilizing solar energy for different needs, as mentioned above, there has been a renewed interest in the last few years in such research. The energy crisis of 1973-1974 spurred interest in developing alternative sources of energy including solar power. But other goals and problems have added to the renewed interest.

> Our energy problems will worsen in the years to come unless we curb our appetite for oil and gas. Without decisive action, we will put additional pressure on the world oil market, aggravate inflationary pressures at home, and increase our vulnerability to the threat of oil supply disruptions. Together, these forces could severely limit the potential for continued economic progress over the coming decade (Economic Report of the President 1978, p. 7).

Macro-economic goals of growth and control of inflation are not the only reasons for renewed interest in research in solar energy.

> Two developments in energy production are impinging on the consciousness of the industrialized world which makes a reexamination of our fuel resources imperative: (1) we are rapidly exhausting our finite fuel reserves. While coal is still available in large quantities, the United States is presently using the last half of its known crude oil and natural gas reserves at a rate which is still increasing. (2) As our energy demands grow, we are increasingly aware of the immense spoilage of our environment which using and recovering fossil fuels entail. . . . The most satisfactory response to these problems is to find an energy source which is not in short supply and which can provide a major fraction of our energy needs without causing major environmental deterioration. . . . The primary motivation for contemporary activity /in solar energy utilization and research/ is is the lack of fossil fuels in certain areas of the world (Ford and Kane 1971, p. 27).

Apart from these more general reasons for increased interest in solar energy research more specific attempts are being contemplated in this country to make solar energy use a reality. A publication which presents an overview of the economic and financial incentives being considered by the government which could aid in making solar energy use more attractive is "Interim Policy Options for Commercialization of Solar Heating and Cooling Systems" (Energy Research and Development Administration 1977a).

Such incentives include tax incentives, loan guarantees, government procurement programs, federal reimbursement for state and local property and sales tax, low interest loans and interest subsidies, direct subsidies, and deregulation of fossil fuel prices and/or increased tax on fossil fuels. See also <u>Solar Energy in America's Future, A Preliminary Assessment</u> (Energy Research and Development Administration 1977b) which studies the potential roles that solar energy technologies could have for meeting United States energy needs over the next 45 years.

Besides adopting solar energy for home and business use, the agricultural sector in the United States has been using solar energy directly for various tasks. While the use is not widespread, predictions have been made by the Department of Energy that solar energy could supply 5% of the total agricultural energy demand by 1985 and 25% by the year 2000 (Rex Fogerty, March 1978, p. 4).

The renewed interest in solar energy is not likely to diminish as time goes on but will continue to gain in both support and importance in a comprehensive energy plan for the United States and other nations of the world.

Objectives of This Study

The general objectives of the present study are:

1. To develop an analytical tool for analyzing a representative solar irrigated farm.

2. To analyze some alternative strategies for managing a solar irrigated farm to determine a general range of farm operating characteristics for a solar powered unit like the one being designed and installed near Coolidge, Pinal County, Arizona.

3. To make recommendations on changes in management decisions that might result from the adoption of a solar irrigation pumping system. These general objectives will be met by the following specific means:

a. Developing for a representative farm in Pinal County, a summary of the per acre cost of production and receipts per unit of output per acre for various crops. This summary is developed from a field crop budget for the farm utilizing the budgeting system of Hathorn (1978) for Arizona field crops.

b. Developing an economic model of a representative solar farm in Pinal County.

    (1) Developing a basic linear programming model of the representative farm which does not use solar energy. This model will maximize net returns above variable costs.

    (2) Adding a solar sector to the model consisting of pumping activities and solar energy selling activities.

c. Analyzing alternative management strategies for a farm utilizing a solar irrigation system using the results obtained from the linear programming model of the representative farm for the analysis. The results obtained from the linear programming model of the representative farm will be interpreted, and the conclusions will be presented.

CHAPTER 2

DESCRIPTION OF SOLAR IRRIGATION SYSTEM[1]

The solar irrigation system studied here is designed by the Acurex Corporation. The subsystems are: (1) solar collection; (2) thermal storage; (3) power generation; (4) power distribution; and (5) cooling. A description of each subsystem is presented below.

1. Solar collection. The solar collector subsystem will have a surface area of approximately 48,960 square feet. The solar collectors will be made up of parabolic trough single-axis tracking concentrators. These concentrators will be situated in a north-south orientation in order to collect the most energy during the summer months when the energy is most needed for irrigation. Heat transfer oil, Caloria HT-43, will be pumped through the collector field and heated to 550 degrees Fahrenheit. The heated oil is then transferred into the thermal storage tank or sent directly to an organic Rankine-cycle power generation unit.

2. Thermal storage. The thermal storage subsystem consists of an 11-foot diameter by 50-foot high 30,000-gallon fluid tank. The storage capacity provided will permit the system to operate approximately 6 hours after the sun goes down or in periods of little or no sunlight.

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[1] The following description is based on published data from the Acurex Corporation (1977) and from personal communication with Charles D. Sands II, Department of Soils, Water and Engineering, University of Arizona, Tucson (1978).

3. Power generation. The power generator subsystem will use an organic Rankine-cycle power conversion system. The thermal energy gathered from the collector field is directed into a heat exchanger. At this point, the thermal energy in the heat transfer oil is transferred to an organic working fluid, toluene. The toluene is converted from a liquid to a gaseous state. This gas powers the turbine which rotates the generator and produces electricity (see Fig. 1). The remainder of the organic working fluid cycle is taken up with additional heat exchangers, consisting of a regenerator and a vapor condenser, which convert the fluid from a gas back to a liquid. The fluid is then ready for subsequent absorption of thermal energy and conversion from a liquid state back into a gaseous state.

4. Power distribution. The power distribution subsystem will be made up of a generator system that furnishes enough power for the three farm pumps. The power generator system will feed directly into an electrical substation. This direct feed will allow for the flow of utility power to the solar powered wells to provide supplementary power. In addition, the direct feed will permit the output of the solar generating system to be transferred directly into the electrical utility grid during the off-season when the pumps are not being used for irrigation.

5. Cooling. To condense the toluene the cooling subsystem will use a vapor condenser, to convert the toluene from a gas back to a liquid to be used again.

The solar irrigation system, used on the model farm, is technically feasible, because the component parts have been thoroughly

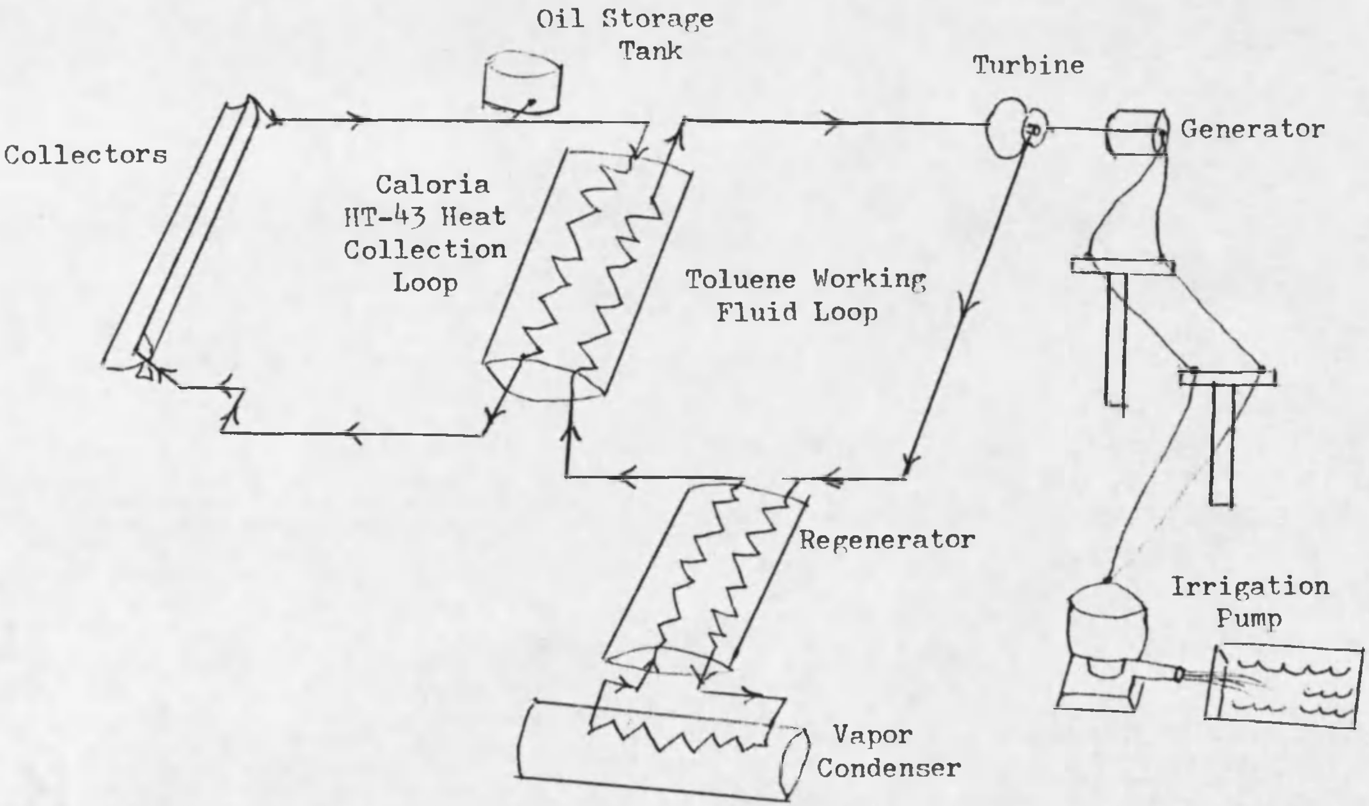

Figure 1. Solar irrigation unit to be located at Coolidge, Arizona. -- Arizona Solar Energy Research Commission 1978.

tested. Replacement parts are available quite readily, and most repairs will be relatively easy. The farmer will be able to maintain the unit with ordinary tools. Only a major problem in the power generation subsystem will necessitate calling in a trained mechanic.

At the present time, the solar irrigation system does not appear economically competitive with existing sources of electrical power (or other conventional energy inputs). The primary reason that solar power is not economically competitive today is because conventional energy inputs while becoming increasingly expensive are still less expensive relative to the price of solar power. While a representative price of solar generated power is not known due to a lack of data, it has been estimated that the price could be as high as 50 mills[2] per KWH_e[3] (Towle 1976, p. 91). This figure is in sharp contrast to the prevailing rates for conventional electric power in the Coolidge area of Pinal County, Arizona. Prevailing rates for electricity are still below 20 mills per KWH_e in this area at the time of this study.

The solar irrigation system described above will be operational in August, 1979, barring any unforeseen delays or last-minute alterations in design.

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[2] A mill is a measurement of the price of electrical power equal to one-tenth of one cent. For example, a price of $.01000 for electricity is 10 mills (.01000/.001).

[3] Towle estimates that the basic solar plant alone could supply electricity at a price of around 38 mills/KWH_e, while the entire solar-powered irrigation system carries a "price" of about 50 mills/KWH_e.

CHAPTER 3

THE REPRESENTATIVE FARM

Cost of Crop Production

The objective of developing a representative farm budget is to determine costs of production and the profitability per acre of various crops on the farm. The costs and returns, determined from the budgeting process are used to specify the objective function of a linear programming model of the representative farm. Identification of alternative management strategies for a farm utilizing a solar irrigation system is the overall objective of the study. So the development of a budget summary is essential to attaining the overall objective of the study.

Enterprise budgets for the commonly grown field crops on the representative farm are constructed using the system developed by Dr. Scott Hathorn at The University of Arizona, Department of Agricultural Economics.

Description of Data

The input data for developing a representative farm budget comes from surveying several farms in Pinal County, Arizona and area and state extension specialists. The information from all of these sources is aggregated to form a composite or representative farm.

A complete farm budget is developed for a 1,854 acre farm, having 16 operational wells. The power and implement combinations and the calendar of operations for each crop grown are developed using the information from a sample of growers. A total of eight crops are budgeted. For crops which none of the growers interviewed produced, such as alfalfa hay, the calendar of operations presented in the 1978 Pinal County Field Crop Budget is used.

Summary of Budget for the Representative Farm

A complete summary of the budget for the representative farm is included in Appendix A.

Input data for the representative farm budget comes from three sources: (1) the farm interviews; (2) data values used in Hathorn's farm budgets; and (3) personal communication with local trade people dealing in wells and pumps.

Special effort is made to formulate the representative well and pump data from the farm interviews into representative figures. A 385 foot pumping lift with 830 gallons pumped per minute are average values per well used for the 16 wells for the representative farm. Each well is assumed to operate an average of 16 hours per day. The average well can operate in each of 150 twenty-four hour periods each year. This means the average well on the representative farm can operate 3,600 hours a year. Kleinman (1964, p. 53) estimated that the average operating well in his sample of operational Central Arizona (Salt River and Lower Santa Cruz area) wells ran for 3,753 hours per year. Hathorn (1978, p. 3) cites commercial pump suppliers as indicating that 3,500 to 5,000 hours of pump operation is rather common. The water volume pumped annually from the average well on the representative farm is calculated to be 552 acre feet for this study (Appendix B).

Depreciation of well, pump assembly, power unit, and bowls are assumed to be 25, 15, 25, and 3 years respectively. The salvage values for the same four components are 0, 3, 3, and 0 percent of the new prices, respectively. The installation labor and site costs and starter cost are given data values used in Dr. Hathorn's farm budget. The depreciation and salvage values are data values used in Dr. Hathorn's farm budget, also.

Table 4 shows pertinent well data for the average well on the representative farm.

On the basis of commercial pump suppliers' information the most representative casing size, bowl diameter, and pump assembly column diameter were chosen to be 16, 9, and 10 inches respectively. These specific components are sized and priced depending on power unit size (horsepower size), pumping capacity measured in gallons per minute, and whether a well is a domestic or commercial/industrial type.

The percent overall efficiency of electric powered pumps is calculated to be 68% in this study. The percent overall efficiency figure is a measure of how well the component parts of the well work together. This percent is calculated from information obtained from commercial pump dealers. A 90% efficiency is estimated for the motor, 75-80% efficiency for the pump, and 100% for the drive line.

Table 4. Summary of well data for an average well for the representative farm, Pinal County, Arizona.

Well Item	Specifications and Assumptions
Well depth	585 feet
Bowl depth	385 feet
Pumping lift	385 feet
Well casing size	16 inches
Pump assembly column size	10 inches
Bowl size	9 inches
Power unit size	150 horsepower
Gallons pumped per minute	830 gallons
Acre feet pumped annually	552 acre feet

This author's budget of representative farm, Pinal County, Arizona.

The percent overall efficiency is calculated as follows:

90 x 75 x 100 = 67.5 (rounded to 68%)

The 75% estimate of pump efficiency is used as an estimate.

Towle (1976, p. 5) indicated an overall efficiency for electric powered wells of about 57%. Kleinman (1964, p. 51) found electric powered well efficiency to vary from 22.5% to 75.5% while the average efficiency for electric powered wells was 51.5%. Hathorn (1978, p. 4) used 54% efficiency for electric powered wells. However, Hathorn indicated that 60% efficiency is acceptable for a unit that has been reasonably maintained. The 68% overall efficiency is used, though compared to the other estimates it is somewhat higher.

Towle (1976, p. 82) cites Nelson and Busch (1967), "OPE's /overall pumping efficiencies/ found in Arizona vary from under .30 to over .70." Further, "to some extent OPE's are beyond the control of the farmer since they depend on the design characteristics of the electric motor and the geological formation from which the well draws water. To a surprising extent, however, OPE can be controlled by an active maintenance program. Under ideal conditions OPE can approach .75." Towle (1976, p. 83) states,

> Hathorn /1978/ puts great emphasis on the importance of monitoring OPE on the farm and of taking remedial action, i.e., replacing bowls, when the OPE falls below a certain economically critical level. Such an OPE-awareness program would certainly seem to be one of the first and highest priority energy conservation steps for the farmer to take with respect to reducing the energy used in irrigating crops. It would be expected that with rising energy prices investment in well durability and maintenance will increase the OPE's will trend upward. The .54 typical OPE figure . . . is an average figure from the mid-1970's that should tend in the future to be characteristic of only the less well managed farms.

In light of the above it seems reasonable to assume that larger, well-managed farms could afford to stress a so-called OPE-awareness program. The sample of farmers interviewed for this study reflected one common attribute, and that is, an interest in management techniques that could improve the overall performance of their farms. An OPE-awareness program could quite possibly be just such a management alternative. The 68% OPE could, in fact, reflect conditions on many of the farms in the sample interview.

Energy Costs for Pinal County

The cost of energy used here is based on prevailing rate structures in Pinal County, and the rate structures reflect some unique characteristics. Table 5 summarizes: (1) total variable cost per acre, (2) total irrigation cost per acre (includes fixed and variable costs); (3) variable energy cost for pumping; and (4) energy cost as a percentage of total variable cost. This table highlights total variable cost per acre of producing eight crops. Total variable costs minus the energy cost of electricity constitute the variable cost of non-energy inputs in the management decision model.

The last column of the table shows the ratio of the energy cost of electricity to total variable cost. Towle (1976, p. 49) stated that Pinal County electrical rates exhibit two unusual aspects; first, the electrical districts (ED2 in this case) charge one flat rate no matter the quantity of electricity consumed. (This flat rate is charged to area farmers whereas residential and industrial users' charges are based on a different rate structure.) Towle indicated

Table 5. Energy cost of electricity, for selected field crops, per acre: Coolidge area, 385 ft. lift electric power, assuming cost of $.01824 per KWH_e.

Crop	Total Variable Cost	Fixed and Variable Cost of Irrigation	Energy Cost of Electricity for Pumping	Ratio of Energy Cost of Electricity to Total Variable Cost in Percent
(1)	(2)	(3)	(4)	(5)
Alfalfa hay	$354.37	$204.45	$95.34	26.9
Upland cotton	387.37	145.70	67.30	17.4
Pima cotton	387.26	145.80	67.30	17.4
Barley	141.70	78.50	35.89	25.3
Wheat	153.83	92.99	42.63	27.7
Late Milo	144.07	107.12	49.35	34.3
Safflower	175.78	136.77	62.81	35.7
Sugar beets	366.46	166.05	76.28	20.8

This author's budget of representative farm, Pinal County, Arizona.

that it is more typical to encounter declining block rate pricing schedules. Simply put, the more KWH_e used the less the cost per KWH_e in a declining block rate schedule. The declining block structure is most typical while a flat rate charge, such as ED2 charges area farmers, is most atypical.

A declining block rate is charged by Tucson Gas and Electric (TG&E) for its Irrigation Pumping Electric Rate No. 30. This electric rate is applicable for: (1) all irrigation customers for pumping water for irrigation purposes and incidental domestic water purposes; and (2) for farm use, where a farm is any tract of land of three or more acres used mainly to produce agricultural products, or any tract of less than three acres on which agricultural products valued at $250.00 or more per year are produced and sold (Tucson Gas and Electric Co. 1961). TG&E data are used for two reasons: (1) to show a declining block rate structure; and (2) to show the total rate per KWH_e in mills for a declining block rate structure compared to the flat rate of 16 mills charged by ED2 to its farm customers using electric power for irrigation. The difference between the two rate structures is an indication of the relatively low price for electricity charged farmers by ED2 in Pinal County. The typical rate structure as of June 1978, for TG&E customers using electric power for irrigation is shown in Table 6.

The second unusual aspect of Pinal County electrical rates is these prices are relatively low when compared to prices for similar service. Towle (1976, p. 49) cited information from Conn and Kulcinski (1976) that nationwide the cost of electricity generation is typically 20 to 25 mills per KWH_e. Towle indicated that electricity prices in

Table 6. Irrigation pumping electric rate No. 30 (frozen rate).

		Cost Adjustment per kwh			
	Base Rate	Fuel and Purchased Power	New Mexico Generation Tax	Total Rate per kwh	Total Rate in Mills*
Service at Primary Voltage, Primary Metering and Customer Furnishes Transformers					
First 900 kwh per H.P. connected per year	@ 4.8131c	-.00998c	+.01414c	4.81726c	48.1726
Next 1,500 kwh per H.P. connected per year	@ 4.2196c	-.00998c	+.01414c	4.22376c	42.2376
Next 1,200 kwh per H.P. connected per year	@ 3.589c	-.00998c	+.01414c	3.59356c	35.9356
All additional kwh per year	@ 3.0934c	-.00998c	+.01414c	3.09756c	30.9756
Service at Secondary Voltage, Secondary Metering and Company Furnishes Transformers					
First 900 kwh per H.P. connected per year	@ 5.2862c	-.00998c	+.01414c	5.29036c	52.9036
Next 1,500 kwh per H.P. connected per year	@ 4.5825c	-.00998c	+.01414c	4.58666c	45.8666
Next 1,200 kwh per H.P. connected per year	@ 3.589c	-.00998c	+.01414c	3.59356c	35,9356
All additional kwh per year	@ 3.0934c	-.00998c	+.01414c	3.09756c	30.9756

*Addition to data.

Source: Tucson Gas and Electric Co. 1961. (Electric rate schedule No. 30 first effective on Nov. 1, 1961) other Arizona counties work out to flat rate equivalents of from 23.0 to 27.7 mills per KWH_e. Recalling that the flat rate for electricity in the Coolidge area is 16.00 mills per KWH_e, and the representative rate chosen in this study for Pinal County is 18.24 mills per KWH_e, these figures would indicate the current seeming advantage that Pinal County farmers enjoy relative to energy costs.

CHAPTER 4

THE LINEAR PROGRAMMING MODEL FOR THE REPRESENTATIVE FARM

Graphical Description of Linear Programming

The analysis of management decisions for the representative farm begins with development of a linear programming model, which is used to determine an optimal set of decision variables or an optimal solution.

The best, or optimal, solution means that one chooses the best solution from among all feasible solutions. A feasible solution is any value of the variables x_i, $(i = 1,\ldots,n)$ which satisfy both the resource constraints and the non-negativity constraints of a linear programming problem. For example, take two variables x_1 and x_2 which are to be chosen to maximize some objective function z, say net revenue. The choice of x_1 and x_2 will be constrained by resource constraints and non-negativity constraints.

Figure 2 shows an x_1x_2 surface on which two linear constraints have been drawn, or

$$a_{11}x_1 + a_{12}x_2 \leq k_1$$
$$a_{21}x_1 + a_{22}x_2 \leq k_2$$

where k_1 and k_2 are constants.

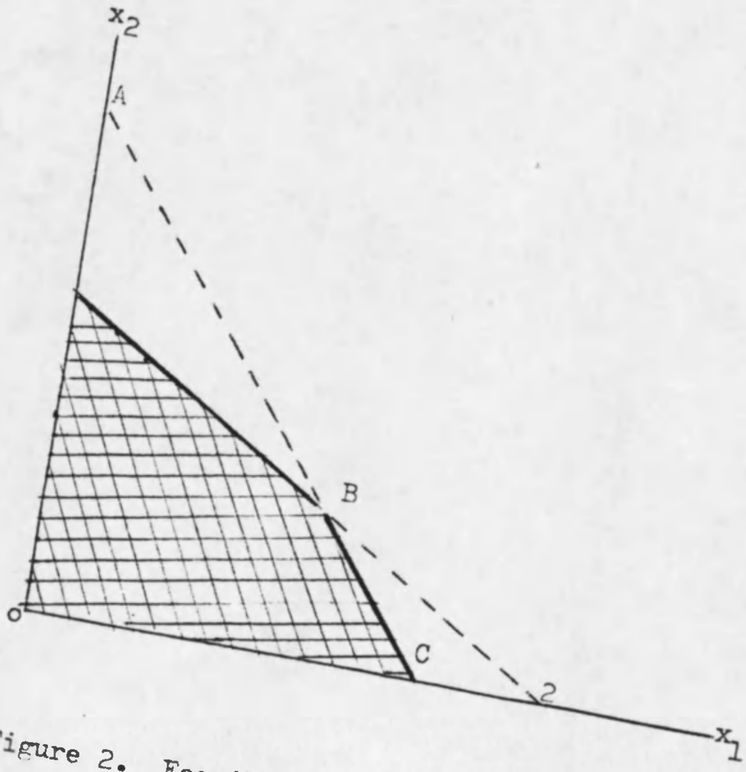

Figure 2. Feasible region in a linear programming problem.

These are the resource constraints. In addition, non-negativity constraints exist such that,

$$x_i \geq 0, \ i = 1,2$$

Given these constraints the feasible solutions lie in the shaded region including points on the line segment ABC. The dark line defines the production possibilities frontier. Therefore, when the best solution is arrived at the solution comes from the line segment ABC.

The entire maximization problem can be represented by adding iso-net revenue lines (net revenue is to be maximized). Any points on these lines represent x_1, x_2 combinations which yield the same net revenue. In linear programming problems these iso-net revenue lines are straight lines and they are parallel to each other. These lines are represented by equations for different levels of net revenue such that,

$$ax_1 + bx_2 = N$$

where a and b are coefficients (specifically in this case they are the revenue per unit of x_1 and x_2) and N is a given level of net revenue. These lines represent the objective function z which is to be maximized. Solving the above equation for x_2 gives,

$$x_2 = \frac{N}{b} - \frac{ax_1}{b}$$

These iso-net revenue lines have slope $-\frac{a}{b}$. A series of these lines with slope $-\frac{a}{b}$ are drawn in Figure 3.

The best, or optimal, solution will occur at one of the corners O,A,B,C, or along one of the segments AB or BC. The optimal solution will occur where the highest valued iso-net revenue line is tangent to

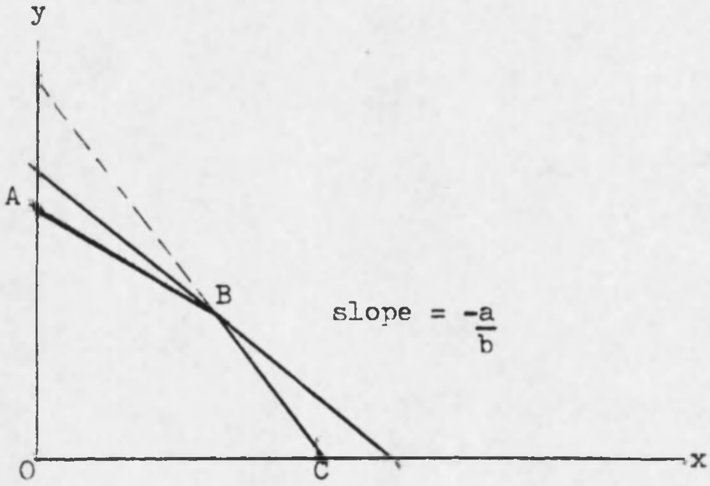

Figure 3. Feasible solution in a linear programming problem.

either a corner or one of the line segments of the feasible region's boundary. The fact that the optimal solution lies at one of the corners or along one of the line segments of the feasible region's boundary is an important result called the basic theorem of linear programming. In searching for the optimal solution the points within the shaded area of the feasible region can be ignored. The optimal solution can be sought at the corners or on one of the line segments of the feasible region's boundary (Baumol 1977, Chap. 5).

General Mathematical Description of Linear Programming

Linear programming can be defined as a,

> . . . technique that deals with the problem of optimizing a linear function of a finite number of variables subject to constraints that are linear inequalities. Linear programming problems often involve allocating scarce resources among activities that vary in profitability and in the amount of each resource needed to produce one unit of the activity. The constraint inequalities represent the restriction that the total amount of each resource used must not exceed the limited supply (Skrapek, Korkie and Daniel 1976, p.227).

> Programming, both linear and nonlinear, is entirely a mathematical technique. Its economic content is therefore nil . . . . Like the calculus or any other branch of mathematics, it can only help us to find the implications of the economic information which we already have or are willing to assume (Baumol 1977, p. 72).

Since linear programming is essentially a general mathematical technique, a generalized linear programming model of m constraints and n variables can be expressed (from Skrapek et al. 1976) as follows.

. . . find $(x_1, x_2, \ldots, x_n)$ so as to maximize

$$z = c_1x_1 + c_2x_2 + \ldots + c_nx_n$$

subject to

$$a_{11}x_1 + a_{12}\,x_2 + \ldots + a_{1n}x_n \leq b_1$$

$$a_{21}x_1 + a_{22}x_2 + \ldots + a_{2n}x_n \leq b_2$$

$$\vdots$$

$$a_{m1}x_1 + a_{m2}x_2 + \ldots + a_{mn}x_n \leq b_m$$

and

$$x_1 > 0,\ x_2 > 0,\ \ldots,\ x_n > 0$$

where a_{ij}, b_i, and c_j are given constants.

> The function z is the objective function, the first m inequalities are the constraints, and the final n inequalities are the nonnegativity restrictions. A problem arranged in the above form is in linear programming format. . . . continu[ing] the resource allocation interpretation. The x_j represent quantities (to be determined) of n different activities to be undertaken, c_j are the per-unit profitabilities of the corresponding activities, b_i are the amounts of each m resource available, and a_{ij} are the units of resource i required per unit of activity (Skrapek et al. 1976, pp. 227-228).

> Programming, then, is the mathematical method for the analysis and computation of optimal decisions which do not violate the limitations imposed by inequality side conditions [resource constraints] (Baumol 1977, p. 76).

In general, then, it is the transformation of physical data into a mathematical framework, or a linear programming design, that underlies the economic analysis of the results of the linear programming solution.

Description of Management Decision Model for this Study

In order to analyze alternative management strategies on a representative farm utilizing solar power, a mathematical model of a representative solar farm was developed. A detailed description of the model is found in Appendix C.

This model is a linear programming model that maximizes net returns above variable costs for the representative farm.

This model allows wells to be powered by either conventional electricity or electricity produced by the solar facility. Excess solar power can also be sold to the utility in this model. The model can be altered by removing either of the pumping activities, or the solar selling activity.

The objective function of the model is subject to given land constraints, crop yield constraints, water application rate constraints, solar energy and water availability constraints. Each of these constraints are explained more fully in Appendix C.

The base linear programming model of the representative farm is for a strictly non-solar farm. There is neither use of solar power for irrigation purposes nor selling of excess solar power to the local utility. The optimal solution maximizes net returns of revenues over the variable costs of crop production including the cost of pumping water for irrigation. The optimal solution for the base linear programming model can be used as a benchmark in comparing the solar farm results and in measuring the effect of including a solar pumping and selling activity, and in what direction the base solution result changes with the solar activity included.

The irrigation cost consists of two parts: (1) the cost of repairs and maintenance (R&M) per acre inch of water pumped; and (2) the variable cost of energy per kilowatt hour electric (KWH_e), times the number of kilowatt hours electric needed to pump an acre inch of water in order to satisfy crop water requirements. Each of eight crops requires water application specified on semi-monthly periods. There are periods in which no water is required by the crops. Total water required for each crop in the various time periods must not exceed the total water pumped by the wells on the farm.

The electricity price per KWH_e assumed for the base linear programming model is \$.01824 cents per KWH_e. The amount of electricity in KWH_e needed to pump an acre-inch of water in any semi-monthly period is calculated to be 48.31 KWH_e.

The objective function value of the optimal linear programming solution is the maximum net returns above variable costs that will accrue to the representative farm given the alternative activities of the representative farm. These activities are constrained by physical resource scarcity, and, as in the case of the Pima cotton acreage constraint, by governmental limitation, or by the personal preference of the farmer. An acreage restraint is placed on Pima cotton to prevent all Pima cotton and wheat solutions in the linear programming models, and because, as Professor Robert Firch (personal communication 1978) noted, Pima cotton has a very small domestic and export market demand. By including this constraint, Upland cotton, Pima cotton and wheat are produced. The entire acreage allotment for Pima cotton is planted. This would seem to hold true in the long run. "In fact, farmers tend to restrict cotton acreage close to allotment acreage because of their perception of risk" (Martin and Boster 1978, p. 31).

Throughout this study returns are maximized above total variable cost. Fixed costs are assumed paid in advance without regard to the production activities chosen for the representative farm.

CHAPTER 5

ANALYSIS OF THE SOLAR IRRIGATION FARM

The objective of this study is to analyze management strategies for a representative farm utilizing a solar irrigation system.

The following tables (7 and 8) summarize six alternatives considered for the solar farm. In addition, the results of the non-solar base farm are included. Therefore, the seven management alternatives, discussed separately below, include: (1) the non-solar farm; (2) solar farm with the Acurex Corporation estimate of available KWH_e for the solar unit; (3) solar farm, with estimates of available KWH_e for solar unit based on climatological data of average semi-monthly sunlight hours for Phoenix, Arizona; (4) solar farm, with the selling of excess solar power to the electric utility; (5) solar farm, without selling excess solar power to the electric utility; (6) solar farm, with no purchase of conventional electric power for irrigation or selling excess solar power to the electric utility; and (7) solar farm with no purchase of conventional electric power for irrigation but with selling excess solar power to the electric utility. Table 7 summarizes the alternatives analyzed for the representative farm along with important characteristics of each alternative. Projected net returns above variable costs for each alternative solution follows in Table 8.

It is assumed that the total cost of solar energy will be, or can be, competitive with conventional energy sources. Since data is

Table 7. Summary of description of solutions for the representative farm, Pinal County, Arizona.

Solution	Climatological Data for KWH_e	Acurex Estimate for KWH_e	Conventional Electric Pumping	VC for Solar Power (mills)	Solar Pumping	Solar Selling
Base Farm	No	No	Yes	-	No	No
Solar Farm 1	No	Yes	Yes	0	Yes	Yes
Solar Farm 2	Yes	No	Yes	0	Yes	Yes
Solar Farm 3*						
a	Yes	No	Yes	0	Yes	Yes
b	Yes	No	Yes	10	Yes	Yes
c	Yes	No	Yes	20	Yes	Yes
d	Yes	No	Yes	30	Yes	Yes
e	Yes	No	Yes	40	Yes	Yes
Solar Farm 4						
a	Yes	No	Yes	0	Yes	No
b	Yes	No	Yes	10	Yes	No
c	Yes	No	Yes	20	Yes	No
d	Yes	No	Yes	30	Yes	No
e	Yes	No	Yes	40	Yes	No
Solar Farm 5						
a	Yes	No	No	0	Yes	No
b	Yes	No	No	10	Yes	No
c	Yes	No	No	20	Yes	No
d	Yes	No	No	30	Yes	No
e	Yes	No	No	40	Yes	No

Table 7--Continued.

Solution	Climatological Data for KWH_e	Acurex Estimate for KWH_e	Conventional Electric Pumping	VC for Solar Power (mills)	Solar Pumping	Solar Selling
Solar Farm 6						
a	Yes	No	No	0	Yes	Yes
b	Yes	No	No	10	Yes	Yes
c	Yes	No	No	20	Yes	Yes
d	Yes	No	No	30	Yes	Yes
e	Yes	No	No	40	Yes	Yes

*Includes Solar Farm 2 results for variable cost for solar of zero.

This author's representative farm linear programming models.

Table 8. Projected net returns* above variable costs for the representative farm, Pinal County, Arizona.

Type of Farm	Net Returns Above Variable Costs (dollars)	Size of Farm Cropped Acres	Crops Produced Acres			
			Upland Cotton	Pima Cotton	Wheat	Milo
Base Farm	218,330.28	1212	1035	60	117	
Solar Farm 1	229,639.09	1212	1035	60	117	
Solar Farm 2	228,951.07	1212	1035	60	117	
Solar Farm 3						
a	228,951.07	1212	1035	60	117	
b	223,128.27	1212	1035	60	117	
c	218,330.28	1212	1035	60	117	
d	218,330.28	1212	1035	60	117	
e	218,330.28	1212	1035	60	117	
Solar Farm 4						
a	226,608.10	1290	1035	60	117	78
b	222,025.13	1290	1035	60	117	78
c	218,330.28	1212	1035	60	117	
d	218,330.28	1212	1035	60	117	
e	218,330.28	1212	1035	60	117	
Solar Farm 5						
a	26,737.05	113	1	60	36	16
b	23,792.22	113	1	60	36	16
c	20,923.88	97	1	60	36	
d	18,318.95	97	1	60	36	
e	15,714.03	97	1	60	36	

Table 8--Continued.

Type of Farm	Net Returns Above Variable Costs (dollars)	Size of Farm Cropped Acres	Crops Produced Acres			
			Upland Cotton	Pima Cotton	Wheat	Milo
Solar Farm 6						
a	32,003.13	97	1	60	36	
b	26,180.33	97	1	60	36	
c	20,923.88	97	1	60	36	
d	18,318.95	97	1	60	36	
e	15,714.03	97	1	60	36	

*Figures rounded to nearest integer values.

This author's representative farm linear programming models.

lacking that can pinpoint a representative cost per unit of electricity produced by a solar unit, a price parameterization is used in this study. The cost excluding investment cost (the fixed investment cost of the solar unit is not included in this study; it is assumed that this investment cost has been met and that the solar unit is in place and operating on the representative farm) per unit of solar generated electricity is varied from zero to 40 mills, which is more than double the 18.24 mill charge used as a representative figure for the cost of electricity in Pinal County in this study.

The solar pumping activity is divided into two cost components: (1) the variable cost of pump repairs and maintenance (R&M) per irrigation well; and (2) the variable cost of energy or the variable cost per KWH_e produced by the solar-powered facility. The first cost component is identical to the cost charged to the wells in the basic non-solar farm. The variable cost of R&M per irrigation well is $.24 per unit of water pumped. The variable cost per unit of electricity produced by the solar facility is not known for certain because sufficient data on which to base an estimate is lacking.

Analysis of Alternative Farm Results

Base Farm Alternative

This base solution assumes there is no solar power unit in operation on the representative farm. The other characteristics of the representative farm are as described in Chapter 3.

The net returns above variable costs for the non-solar representative farm are $218,330. Cropped acres total 1,212 with 1,035 acres of Upland cotton, 60 acres of Pima cotton, and 117 acres of wheat being grown.

Table 9 compares the size of the representative farm with actual survey data for the average size farm in Pinal County for 1974. Table 9 shows the representative farm to be larger than the survey farm for Pinal County in 1974 by 369 acres. One possible explanation for this size difference is the fact that most of the farmers interviewed for this study operated larger farms than the average size farm indicated in Table 9. The size of the representative farm reflects the relatively large farm operations of the sample survey.

Table 9. Size of an average farm in Pinal County, Arizona, 1974.

Farms	Cropland Acres	Average Size
428	360,752	843 acres

Source: United States Department of Commerce 1977b.

Solar Farm 1 Alternative

This solar farm uses solar power for irrigation and the selling of excess solar power to the electric utility. The estimates of solar availability are from Acurex Corporation data obtained from Dr. Dennis Larson (personal communication 1978). The calculation of solar availability using this data is found in Appendix D.

The output of electricity from the solar unit varies with the estimate of the average amount of sunlight hours. The more sunlight hours available to the solar unit, the greater the output of electricity. The Acurex Corporation has estimated about 4,133 annual sunshine hours will be available to the solar unit. The solar unit will produce a daily output of 150 kilowatts electric (KWe). Therefore, the unit will produce roughly 620,000 KWH_e annually (4,133 x 150). So the total availability of solar power for irrigation cannot exceed 620,000 KWH_e. It is assumed that the variable cost for using solar power for irrigation purposes is zero since no exact estimates of the variable cost of solar power for irrigation are available.

The net returns above variable costs are $229,639. This is an increase of about $11,308 or 5% above net returns for the non-solar farm, the difference being the cost of purchasing the electricity since the number of cropped acres are the same as the non-solar farm.

Solar Farm 2 Alternative

This solar farm also allows the use of solar power for irrigation and the selling of excess solar power to the electric utility. The output of electricity from the solar unit is based on climatological data obtained from the National Oceanic and Atmospheric Administration (NOAA). These data are based on the daily sunshine hours measured at Phoenix, Arizona, from 1976-1977. Details of the calculation of total solar availability using this data is found in Appendix E. The average total solar availability is calculated to be 582,280 KWH_e.

The net returns above variable costs are $228,951.07. The variable cost for using solar power is assumed to be zero. The net returns for this solution are increased $10,620 over the non-solar farm solution. The $10,620 increase in net returns results from the fact that of the total 76,761 acre inches of water used on the solar farm in one year, 9,017 acre inches are pumped using solar power. It takes 48.31 KWH_e to pump one unit of water and each KWH_e costs \$.01824. The variable cost for solar power is zero in this alternative. Thus, a savings of \$7,945 (9,017 AI ∘ 48.31 $\frac{KWH_e}{AI}$ ∘ \$.01824 $\frac{\text{dollars}}{KWH_e}$) accrues to the representative farm. This is a variable cost savings. The solar farm also receives \$2,675 from selling excess solar power to the electric utility. The total savings in variable costs and of revenue received from selling excess solar power is \$10,620 or the amount that net returns are increased over the non-solar farm solution.

Climatological data are used in this case since these data measure the incidence of available KWH_e as it might actually occur during a given year. This measure and the Acurex projected measure of available KWH_e are shown in Figure 4.

Solar Farm 3 Alternative

This solar farm alternative allows the use of both conventional electric power and solar power for irrigation and the selling of excess solar power to the electric utility. The variable cost of pumping with solar power is varied from zero to 40 mills. Varying the cost of solar power provides a range over which solar power is competitive with conventional electric power.

The changing solution values are summarized in Table 8. After 20 mills, the same solution results. The reason for this is that the solar farm can purchase power from the electric utility for 18.24 mills, and a variable cost of 20 mills makes use of solar power uneconomical and unfeasible. No solar power is used for irrigation at a variable

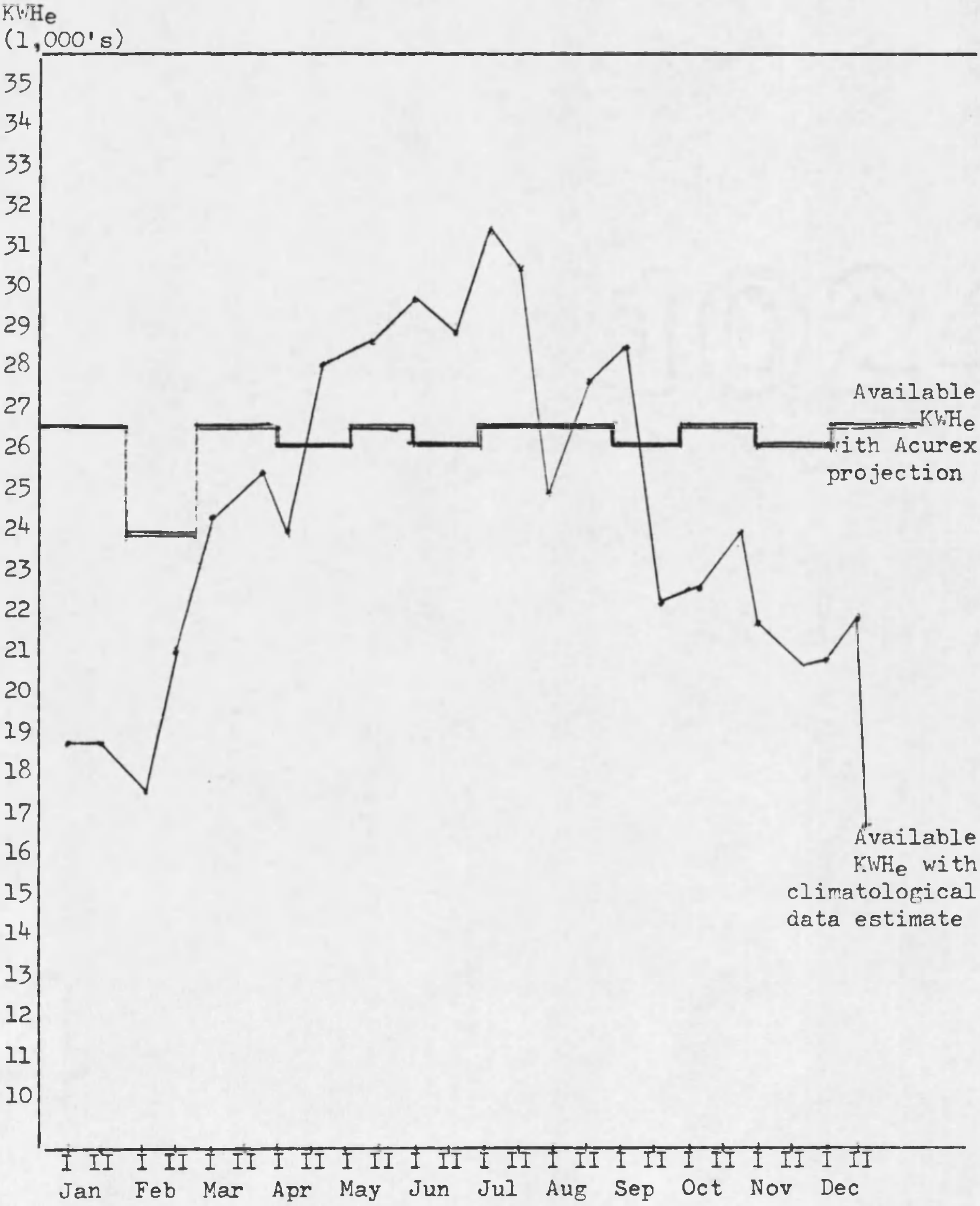

Figure 4. Comparative levels of available KWH$_e$ with two alternative estimates. -- Sources: U.S. Department of Commerce 1976; 1977a. Author's calculations based on Acurex estimate.

cost for solar power of 20, 30, and 40 mils. The farm is non-solar at these levels. A look at Table 8 verifies that, in fact, the solution values at 20 mills or greater is exactly the base non-solar farm result.

The net returns at zero mills is the same as Solar Farm 2 above, \$228,951. The net returns at 10 mills is \$223,128, a decrease of \$5,823 or 2.5% from \$228,951. The net returns at 20 mills is \$218,330, a decrease of \$10,621 or 4.6% from \$228,951.

The \$5,823 decrease in net returns at 10 mills occurs because the KWH_e that it takes to pump 9,017 units of water now costs \$.01000. Part of the decrease occurs since it costs the solar farm \$4,356 to pump water with solar power (9,017 AI $\cdot$ 48.31 $\frac{KWH_e}{AI}$ $\cdot$ \$.01000 $\frac{\text{dollars}}{KWH_e}$). The additional \$1,467 decrease occurs since the solar farm now sells excess solar power to the electric utility at a net price of \$.00824. This is the difference between selling excess power at \$.01824 when the variable cost of solar power is zero and selling excess power when the variable cost of solar power is \$.01000. A total of 146,665 KWH_e of excess solar power is sold to the utility. When the variable cost of solar power is zero \$2,675 accrues to the solar farm. But when the cost of solar power is \$.01000 the net price that the excess solar power can be sold at is \$.01824-\$.01000 or \$.00824.

The farm loses \$1,467 in revenue (146,665 KWH_e $\cdot$ \$.01824 $\frac{\text{dollars}}{KWH_e}$) - (146,665 KWH_e $\cdot$ \$.00824 $\frac{\text{dollars}}{KWH_e}$) = \$2,675 - \$1,208 = \$1,467. The total decrease in net returns is \$4,356 plus \$1,467 or \$5,823.

At a variable cost for solar power of 20 mills a decrease of \$10,621 results. At a variable cost of 20 mills no solar power is used since it costs more to purchase solar power than what the solar power can be sold for. The loss to the farm is $582{,}280 \text{ KWH}_e \cdot \$.01824 \, \frac{\text{dollars}}{\text{KWH}_e}$ or $10,620.

Solar Farm 4 Alternative

This alternative allows for the use of both conventional electric power and solar power for irrigation but without the selling of excess solar power to the electric utility.

The variable cost for using solar power again varies from zero to 40 mils per KWH_e. But the solar selling activity is not included in these solutions. The solutions shown in Table 8 give the same solution value for variable cost for solar of 20 mills and above. The reason is the same as stated above under the Solar Farm 3 alternative.

The net returns for variable cost of solar of zero are $226,608. This is $2,343 or 1% lower than for zero variable cost with selling of excess solar power to the electric utility. The elimination of the solar power selling activity lowers net returns only slightly. The net returns at 10 mills are $222,025 which is just $1,103 lower than the net return at 10 mills with a solar selling activity.

It should be noted that for the Solar Farm 4 alternative the number of cropped acres increases from 1212 to 1290. Therefore, 78 acres of late milo are substituted for the elimination of the solar selling activity on the solar farm.

Solar Farm 5 Alternative

For this solution the conventional pumping activities are eliminated. The representative farm is now a solar-only farm. The solar electric generating system is the only source of power for irrigation purposes and there is no selling of excess solar power to the electric utility. The variable cost of solar power is again varied from zero to 40 mills.

The net returns for each variable cost level are presented in Table 8. The number of cropped acres decreases significantly to 113 acres for a variable cost of zero and 10 mills and to 97 acres for 20, 30, and 40 mills. The reason for the significant decrease in acres is due to the limited electrical output of the solar irrigation system. The system is a 150 KWH_e system that is sized to power three wells. Therefore, when only three of the 16 wells operate the number of cropped acres decreases significantly.

Solar Farm 6 Alternative

This solar farm is identical to the Solar Farm 5 alternative above except that a solar selling activity is added to the farm. Excess solar power is once again sold to the electric utility.

The net returns are again summarized in Table 8. It should be noted that the farm size is now 97 acres for each level of variable cost for solar power.

Net returns increase by a greater percentage for the solar farm when solar selling is added to the Solar Farm 6 alternative and compared to the Solar Farm 5 alternative than when solar selling for the Solar Farm 3 alternative was compared to the Solar Farm 4 alternative without a solar selling activity.

For example, in the Solar Farm 6 alternative net returns above variable costs at 10 mills increase by $2,388 over the net returns at

10 mills for the Solar Farm 5 alternative. This is an increase of 10%. Comparing the net returns at 10 mills for the Solar Farm 3 alternative and the Solar Farm 4 alternative without the solar selling activity, the increase from selling solar power is only $1,103 or an increase of one half of 1%. The solar selling activity is more important for the solar-only farm with no conventional pumping than when both conventional and solar power are used for pumping. The solar selling activity increases the net returns above variable costs by a greater amount for the solar-only farm than for the farm using both conventional power and solar power for pumping. This suggests that as the farm becomes increasingly dependent on solar power, selling excess solar power becomes more important. The solar-only farm could conceivably act as a utility, i.e., the farm could sell excess power to the local electric utility or other enterprises, such as cotton gins.

Projected Returns to Land, Management, Risk, and the Solar Pumping System

Table 10 summarizes the projected returns to land, management, risk, and the solar pumping system for each alternative analyzed in the previous section. These are projected net returns above total variable and fixed costs. The fixed cost of producing the respective crop mix and the fixed cost of pumping water per unit for both the conventional and the solar irrigation system are included. This is the fixed cost of pumping water with the solar irrigation system, not the fixed cost of solar power. All the fixed costs of the solar plant and other operations must be paid from returns above variable costs. The

Table 10. Projected returns to land, management, risk and solar pumping system for the representative farm, Pinal County, Arizona.

Type of Farm	Projected Returns[a] to Land, Management, Risk, and Solar Pumping System (1)	Value of Crops Produced (2)	Value of KWHe of Solar Sold to ED2 (3)	Variable Cost of Producing Crops (4)	Var. Cost of Pump Repair and Maintenance per AI pumped (5)		Var. Cost of Energy for Irrigation (6)		Fixed Costs of[b] Producing Crops (7)	Fixed Costs of[c] Pumping Water per AI (both ED2 and Solar) (8)
					ED2	Solar	ED2	Solar		
Solar Farm 1	47,485.31	668,070.20	3,194.98	363,481.62	16,212.94	2,209.88	59,526.73	0	107,889.74	74,458.96
Solar Farm 2	46,786.84	668,059.75	2,675.17	363,481.62	16,481.62	2,169.11	59,694.94	0	107,889.74	74,458.96
Solar Farm 3										
a	46,786.84	668,059.75	2,675.17	363,481.62	16,258.71	2,169.11	59,694.94	0	107,889.74	74,458.96
b	42,430.69	668,059.75	2,675.17	363,481.62	16,258.71	2,169.11	59,694.94	4,356.15	107,889.74	74,458.96
c	36,166.04	668,059.75		363,481.62	18,422.83		67,640.56		107,889.74	74,458.96
d	For variable cost levels above 20 mills the figures									
e	are identical to results for 20 mills.									
Solar Farm 4										
a	36,427.13	679,422.45		371,044.50	16,972.35	2,276.76	62,315.11	0	112,588.08	77,798.52
b	31,844.17	679,422.45		371,044.50	16,972.35	2,276.76	62,315.11	4,582.96	112,588.08	77,798.52
c	36,166.04	668,059.75		363,481.62	18,422.83		67,640.56		107,889.74	74,458.96
d	For variable cost levels above 20 mills the figures									
e	are identical to results for 20 mills.									
Solar Farm 5										
a	11,497.09	53,239.60		25,072.59		1,462.94		0	9,294.24	5,912.74
b	8,552.27	53,239.60		25,072.59		1,462.94		2,944.82	9,294.24	5,912.74
c	7,341.68	50,925.03		23,521.23		1,294.09		5,209.85	8,327.90	5,230.28
d	4,736.76	50,925.03		23,521.23		1,294.09		7,814.77	8,327.90	5,230.28
e	2,131.83	50,925.03		23,521.23		1,294.09		10,419.70	8,327.90	5,230.28
Solar Farm 6										
a	18,420.93	50,925.03	5,869.40	23,521.23		1,294.09		0	8,327.90	5,230.28
b	12,598.13	50,925.03	5,869.40	23,521.23		1,294.09		5,822.80	8,327.90	5,230.28
c	7,341.68	50,925.03		23,521.23		1,294.09		5,209.85	8,327.90	5.230.28
d	4,736.76	50,925.03		23,521.23		1,294.09		7,814.77	8,327.90	5,230.28
e	2,131.83	50,925.03		23,521.23		1,294.09		10,419.70	8,327.90	5,230.28

[a] Net returns above total variable and fixed costs.

[b] Based on results of representative farm budget. These are fixed costs minus the fixed costs of pumping water which are considered separately.

[c] Fixed cost is $.97 per acre inch.

This author's representative farm linear programming models.

projected net return figure in Column 1 is derived by adding Column 2 and 3 and subtracting the various costs found in Columns 4 to 8.

The projected net returns for the Solar Farm 1 alternative are slightly higher than the returns for the Solar Farm 2 alternative. The difference between the two is $698.47. Projected net returns for the Solar Farm 1 alternative are slightly higher than the net returns for the Solar Farm 2 alternative because the estimate of KWH_e for the Solar Farm 1 alternative is 620,000, while for the Solar Farm 2 alternative the estimate is 582,280 or a difference of 37,720 KWH_e. Since the variable cost of solar power is zero in both cases these 37,720 KWH_e could be sold to the electric utility for $.01824. This would provide an additional $688 revenue to the solar farm. This $688 is almost exactly the difference between the two estimates of projected return.

The net returns for Solar Farm 3 with zero variable cost of pumping using solar power are $46,786.84. When the variable cost of pumping with solar power increased to 10 mills the net returns are $42,430.69, a decrease of $4,356.15 or 9.3%. When the cost of pumping increases to 20 mills no solar power is used since it costs more for solar power at 20 mills than what the solar farm can sell excess solar power for at 18.2 mills. The net returns are $36,166.04, a decrease of $10,620.80 or 22.7% from $46,786.84.

The net returns for Solar Farm 4 with no solar selling activity are lower at all levels than the returns for Solar Farm 3 which included the selling of solar power. When the variable cost of solar power is zero the net returns are $36,427.13. This is $10,359.71 lower than the same level for Solar Farm 3. The $10,359.71 is a measure of the returns to the solar farm from the solar selling activity when the variable cost of solar power is zero. Net returns are decreased 22% when the solar selling activity is eliminated.

The net returns for Solar Farm 4c are higher than the net returns for Solar Farm 4b. The variable cost for solar power in the latter is $.01000, while for the former it is $.02000. The number of cropped acres decrease from 1290 to 1212. The costs of production decrease. Table 8 confirms the fact that the number of cropped acres decrease. In case b, 78 acres of milo are substituted for the loss of solar selling activity. The savings accruing to the solar farm from reduction in production costs and reduction in costs coming from not pumping with solar power are greater than the losses to the farm resulting from reduction in the value of crops produced and the increased cost of pumping with conventional electric power. On balance, there is an increase of $4,321.87 in projected net returns. These returns accrue to the management of the farm. The representative farm is a non-solar farm when the variable cost of solar power rises above 18.2 mills.

Solar Farm 5 is a solar only farm without the solar selling activity. The net returns when the variable cost of solar power is zero are $11,497.09. When the variable cost of solar power increases to 10 mills the net returns are $8,552.27. This is a decrease of $2,944.82 or 25.6% from $11,497.09. When the variable cost of solar power rises to 20 mills the number of cropped acres on the solar farm decreases from 113 to 97 acres as Table 8 shows. The net returns are

$7,332.29. When the variable cost of solar power is 30 mills net returns are $4,727.37, a decrease of $2,604.92 or 35.5% from $7,332.29. When the variable cost of solar power is 40 mills net returns are $2,122.44, a decrease of $5,209.85 or 71% from $7,332.29.

Solar Farm 6 is a solar-only farm which sells solar power to the local utility. When the variable cost of solar is zero the net returns are $18,420.93. This is an increase of $6,923.84 over the net returns for Solar Farm 5 at a variable cost for solar power of zero. The $6,923.84 is a return to the solar selling activity. Net returns increase 60.2% for the Solar Farm 6. Net returns are $12,598.13 when the variable cost of solar power is 10 mills. This is a decrease of $5,822.80 or 31.6% from $18,420.93. When the variable cost of solar power rises to 20 mills and higher, the Solar Farm 6 ceases to be a seller of solar power. The solar farm would incur a loss if it sold solar power to the utility by the amount of the difference between the variable cost of solar power and the 18.2 mills for which it could be sold to the utility. Instead, the Solar Farm 6 adjusts its use of solar power to simply supply enough for irrigation needs allowing the excess solar power to go unused. The results for Solar Farm 6 are the same as for Solar Farm 5 for a variable cost of 20, 30, and 40 mills.

Analysis of Penalty Costs for the Solar Farm Alternatives

Appendix F gives a detailed summary of the penalty costs of including a unit of a real activity which is not in the optimal solution. "The shadow prices /penalty costs/ on real activities not in the solution indicate by how much income /net returns in this case/

would be penalized were they forced into the plan" (Beneke and Winterboer 1973, p. 119). Successful management strategies require that the decision-maker be aware of the impact marginal decisions have on the optimal or best outcome that can be attained.

For example, the penalty costs for pumping with solar power for the Solar Farm 5 alternative are shown in Table 11.

The penalty costs for including an extra unit of this activity increase as net returns decrease. The critical periods are 2, 21, 22, 23, for solution a and b. These periods are the second half of January, the month of November, and the first part of December. During these periods no units of water are applied to the optimal crop mix. So to use water for irrigation in these periods would decrease the optimal net returns for each solar farm alternative.

In solutions c, d and e, period 19 becomes a critical period while period 22 ceases to be a critical period. The reason is that in alternatives c, d, and e the optimal crop mix changes. Table 7 shows that the optimal crop mix changes from 113 acres to 97 acres as 16 acres of late milo are eliminated from the crop mix. Period 19, the first half of October, becomes critical because previously milo had been included in the optimal crop mix and was irrigated during period 19. But now milo is no longer a part of the optimal crop mix and any water units used for milo would decrease the optimal net return value. Another example is shown in Table 12.

The penalty cost for selling solar power is much greater in period 3 or the first part of February. The reason is because large pre-irrigations on Pima and Upland cotton begin about this time.

Table 11. Penalty costs for pumping with solar power in various periods for the Solar Farm 5 alternative.

Solution	Net Returns (dollars)	Activity	Units	Penalty Cost (dollars)
Solar Farm 5				
a	26,737	Pumping with solar power in period 2, 21, 22, 23	acre inches	.24
b	23,792	same	same	.72
c	20,923	Pumping with solar power in period 2, 19, 21, 23	same	.79
d	18,318	same	same	1.68
e	15,714	same	same	2.17

This author's representative farm linear programming models.

Table 12. Penalty costs for selling solar power in various periods for the Solar Farm 6d alternative.

Solution	Net Returns (dollars)	Activity	Units	Penalty Cost (dollars)
Solar Farm 6				
d	18,318	Selling solar power in period 1-2	KWH_e	.012
		3	same	.44
		4-8	same	.012
		9	same	.095
		10-24	same	.012

This author's representative farm linear programming models.

Therefore, solar power is needed for irrigation during this period. If the farm manager tries to sell a unit of solar power to the electric utility during this period he would decrease the optimal net return by \$.44. The above tables show that marginal decisions do have an impact on the best outcome attainable for a particular management alternative.

Not all incremental units of an activity will decrease the solution value obtainable for a certain farm alternative. Some extra units of an activity or input will actually increase the optimal solution value of a certain farm alternative. Table 13 summarizes one such alternative. This table summarizes the increases and decreases from including an extra unit of an activity upon the optimal solution for the Solar Farm 2. The increases and decreases to the optimal net returns that are forthcoming from having available an extra unit of some activity or input is called a shadow price. Shadow prices might be more conveniently called marginal costs or marginal "benefits", in the sense that a marginal cost decreases the optimal solution and a marginal "benefit" will increase the optimal solution.

As Table 13 shows, extra units of crop production activities will decrease the optimal net return value by the indicated amounts. But an increase of an extra unit of water input or an extra unit of solar radiation converted into KWH_e by the solar unit to be used for power or for sale to the electric utility will increase the optimal net return value.

For example, period 3, the first half of February, is critical for water availability. Pima cotton, Upland cotton, barley, safflower, alfalfa, and sugar beets are irrigated in this period. Because

Table 13. Marginal cost and benefit for various activities and the impact on the optimal solution for the Solar Farm 2 alternative. -- Optimal solution value is $228,951.

Activity	Marginal Cost and Benefit (dollars)	Units	Increase or Decrease on Optimal Net Return Value
Barley production	- 6.16	cwt	decrease
Pima cotton production	- .90	lbs.	decrease
Upland cotton production	- .52	lbs.	decrease
Safflower production	-362.52	ton	decrease
Wheat production	- 4.75	cwt	decrease
Alfalfa production	-216.85	ton	decrease
Sugar beet production	- 25.83	ton	decrease
Milo production	- 4.15	cwt	decrease
Pima cotton acreage	+139.37	acre	increase
Water application rate to optimal crop mix periods 1, 4-8, 10-20, 22, 24	+ 1.12	acre inch	increase
3	+ 24.63	acre inch	increase
9	+ 8.73	acre inch	increase
Water availability period			
3	+ 23.51	acre inch	increase
9	+ 7.61	acre inch	increase
Solar availability periods 1-24	+ .01824	KWH$_e$	increase

Author's representative farm linear programming models.

all these crops require water in the same period, water availability becomes critical for the representative farm. Note that if the water application rate is increased by an extra unit the increase to optimal net returns is higher for period 3 than for the increase from water availability. A possible reason is the representative farm has Pima and Upland cotton in the optimal crop mix. These crops require large pre-irrigations beginning in period 3. Therefore, while an extra unit of available water would increase net returns for a farm raising any one or combination of the six crops listed, net returns are increased more when an extra unit of water can be applied to any of these six crops in the actual optimal crop mix for the representative farm. The shadow prices for the other solar farm alternatives are found in Appendix F.

While the farm manager may not always know the exact effect of increasing production or input use upon net returns he or she should be cognizant of the possible directions such decisions will have upon his or her operation. Being aware of the relative increase or decrease on net returns from a production or input use decision can enhance the management efficiency of the farm manager while improving the performance of his or her operation.

CHAPTER 6

SUMMARY AND CONCLUSIONS

The objective of this study was to analyze alternative management strategies for a farm utilizing a solar irrigation system. Tables 8 and 10 present the results of the linear programming solutions of the representative farm.

If we use the solutions based on the climatological data for total solar availability, the best management alternative for the representative farm is Solar Farm 3 with a variable cost of solar equal to zero. An important assumption of this result is that the variable cost for solar power is, in fact, zero.

Comparison of net returns for zero variable cost under the Solar Farm 3 alternative and the Solar Farm 4 alternative in Table 8 shows a small effect, only $2,343, for selling solar power to the electric utility. Comparing the same entries in Table 10 shows that the return to the solar pumping unit is $10,359.71 between the Solar Farm 3 alternative and the Solar Farm 4 alternative for a variable cost for solar power of zero. Projected returns in Table 10 are affected by about 22.1% when the solar selling alternative is eliminated from alternative 4.

Projected returns are affected even more significantly by eliminating the solar selling activity when considering the Solar Farm 5 alternative and the Solar Farm 6 alternative. These alternatives consider a solar-only farm with no use of conventional power. Comparing projected returns in Table 10 for the Solar Farm 5 alternative and the Solar Farm 6 alternative at a variable cost for solar power of zero returns change by $6,923.84 when the solar selling alternative is eliminated. Elimination of solar selling affects projected returns in Table 10 by about 37.6%.

These results of management alternatives depend on the assumptions made in this study. Given the data and the fact that there has been very little done in the past dealing with solar irrigation system applications to agriculture, they reflect as accurately as possible a representative farm for a county-wide area. Further research will undoubtedly modify or completely alter many of the assumptions used in this study.

A conclusion of this study of alternative management alternatives of a representative farm utilizing a solar irrigation system is that the selling of excess solar power to the utility grid, will increase net returns above variable costs for both a farm using conventional power and solar power, and a solar-power-only farm. While the increase is only 1% in the former case, Solar Farm 4a compared to Solar Farm 3a in Table 8, net returns increase almost 20% in the latter case, Solar Farm 5a compared to Solar Farm 6a in Table 8. This is assuming a variable cost of solar power at zero.

Also selling excess solar power to the electric utility is important to projected returns for land, management, risk, and the solar pumping system. In the case of a farm using both conventional and solar power at a variable cost for solar power of zero, projected returns change by 28.4% with a solar selling activity added: Solar Farm 4a compared to Solar Farm 3a in Table 10. For a solar-power-only farm, projected returns change by 60.2% when a solar selling activity is added to the representative farm at a variable cost of solar of zero: Solar Farm 5a compared to Solar Farm 6a in Table 10.

This result seems to suggest that solar selling activities to local utilities are very important and affect returns to the representative solar farm significantly. The significance of the solar selling activity increases as the farm becomes more and more a solar-power-only farm.

Recommendations for further research include expanding the model to account for elements of risk and uncertainty that could conceivably impinge or deter the investment in a solar irrigation unit. Including an interest rate variable or constraint could alter the management strategies of the representative farm. The interest rate indicates how expensive borrowing money is, and if interest rates are at extraordinarily high levels the investment in a solar irrigation system could be postponed.

Further study could deal with larger solar irrigation units. Changing the size of the unit could change the net returns accruing to the representative farm. Another point to consider, as solar unit size increases is the opportunity cost of the land taken out of production and used as the site for the solar irrigation unit. The opportunity cost would have to be recovered by savings in energy costs or increases in returns from selling excess solar power before larger solar units would be adapted.

The social and legal ramifications of allowing solar power to be sold to an electric utility should be identified. Then the steps needed to be taken to alleviate any difficulties should be identified. Allowing the solar farm to sell excess solar power to an electric utility or to other consumers of electric power such as cotton gins could provide competition with local utilities for consumer's business and would provide consumers with an alternative source of energy inputs.

The results of this study suggest that a solar irrigation system will benefit and increase net returns above variable costs as well as the projected returns to land, management, risk, and the solar pumping system. Comparing net returns for the base non-solar farm with the net returns for the Solar Farm 2 alternative indicates that the net returns increase by about $10,621 or 4.8%. A solar selling activity is an integral part to the successful and most profitable management of a farm utilizing a solar irrigation system. Again, it should be restated that the fixed costs, the investment costs, of the solar irrigation system are not considered in this study.

The above results depend on the variable cost of solar pumping staying below the rate at which solar power can be sold to a utility. If prices for conventional energy inputs continue to rise and if these prices rise to sufficient heights, the importance of alternative energy supplies will grow. The higher the cost of conventional energy inputs the more attractive solar energy will become. If solar power proves to be a viable substitute (at least a partial substitute or supplement if not a total substitute) for conventional energy inputs, like electricity, for farm irrigation activities, the economic benefit of solar irrigation systems with the selling of excess solar power to utilities should increase.

APPENDIX A

SUMMARY OF BUDGET FOR THE REPRESENTATIVE FARM

The following is a summary of the budget printout for the representative farm in Pinal County. Table A-1 presents a summary of the cost for an average well and the total cost for pumping one acre foot of water on the representative farm. Tables A-2 through A-4 summarize the cost of production (fixed and variable) for each of eight crops grown on the representative farm.

Table A-1. Well cost and cost of pumping water. -- a = Default values of Hathorn budget system. This author's budget printout for representative farm, Pinal County.

Average Well for the Representative Farm, Pinal County, Coolidge Area

I. General Information

Type of Power:	Electricity
Depth of Well:	585 feet
Depth of Bowls:	385 feet
Size of Well Casing:	16 inch
Gallons Pumped per Minute:	830
Acre Feet Pumped Annually:	552

Depreciation:

Well	25 years, with 0% salvage value
Pump Assembly	15 years, with 3% salvage value
Power Unit	25 years, with 3& salvage value
Bowls	3 years, with 0% salvage value

II. Cost of Drilling Well

Drilling Cost and Casing Installation	$ 9,799
Casing, Foundation and Test Pumping	15,904
Pump Assembly (10 inch column)	16,200
9 inch Bowls (13 stages)	1,248
Power Unit -- 150 HP motor	3,519
Starter with Compensator and Secondary Power Station and Safety Switch	6,872[a]
Installation Labor and Site Costs	1,057[a]
Total	$54,599

Fixed Costs of Well Annually

Depreciation	$ 2,936
Interest	2,356
Taxes	577
Fire and Lightning Insurance	610
Total Fixed Costs	$ 6,479

III. Cost of Pumping One Acre Foot of Water

Fixed Cost = 6479/552 AF	= $ 11.74
Energy Cost = (1.024 * 385)/.680 * .01824	= 10.57
Repairs = 0.007512 * 385	= 2.89
Total Cost	$ 25.20

Where:

1.024 = KWH to lift 1 acre foot of water 1 foot at 100% overall efficiency
385 = feet of lift
.680 = overall efficiency stated as a decimal
.01824 = power cost per KWH including sales tax
.007512 = cost of plant repairs, maintenance, lubrication, and attendance per foot of lift

Table A-2. Summary of costs of production per acre for crops grown on representative farm. -- a = Variable cost of production minus the variable cost per acre of pumping water. This author's budget printout for representative farm, Pinal County.

	Dollars				
Crop	Total Cost	Fixed Cost	Variable Cost	Variable Cost[a] Minus Water Cost	Variable Cost of Water
Alfalfa Hay	538.02	183.65	354.37	259.03	95.34
Upland Cotton	542.15	154.78	387.37	320.07	67.30
Pima Cotton	545.85	158.59	387.26	319.96	67.30
Barley	239.68	97.98	141.70	105.81	35.89
Wheat	261.83	108.00	153.83	111.20	42.63
Late Milo	247.12	103.05	144.07	94.72	49.35
Safflower	294.12	118.34	175.78	112.97	62.81
Sugar Beets	490.61	124.15	366.46	290.18	76.28

Table A-3. Summary of most likely yield per acre and most likely receipts per unit per acre for crops grown on representative farm. -- a = Total of seven cuttings annually. b = Through personal communication with Charles Robertson (1978), it was learned that the average cotton gin does not differentiate between Upland and Pima cotton seed but treats both seeds as a homogeneous product which receives the Upland seed price per ton. c = Figures for yields were taken from Arizona Crop and Livestock Reporting Service 1977 (1978). This author's budget printout for representative farm, Pinal County.

Crop	Yield[c]	Receipts per Unit
Alfalfa Hay	16.1 ton[a]	$ 55.00/ton
Upland Cotton		
Lint	942 lbs	.52/lb
Seed	1730 lbs	70.00/ton
Pima Cotton		
Lint	699 lbs	.90/lb
Seed	968 lbs	70.00/ton
Barley	3650 lbs	4.60/cwt
Wheat	4200 lbs	4.75/cwt
Late Milo	3500 lbs	4.15/cwt
Safflower	2000 lbs	180.00/ton
Sugar Beets	19 ton	25.00/ton

Table A-4. Itemized summary of cost per acre for producing crops on the representative farm. -- a = Includes itemized summary of per acre cost of alfalfa stand establishment. This author's budget printout for representative farm, Pinal County.

1. Alfalfa Stand Establishment

Cost Item	1978 Cost per Acre (dollars)
Chisel or Rip	5.02
Disk	13.08
Landplane	4.68
Float	4.98
Mulch	5.42
Seed Bed Preparation Total	33.18
Planting	36.79
Planting and Cultivation Total	36.79
Pre-irrigate	28.96
Irrigate	19.30
Make Borders	.60
Crop Irrigation Total	48.86
Fertilizers	21.25
Herbicides	0.00
Chemicals and Application Total	21.25
Preharvest Total	140.08
Harvest and Post Harvest Total	0.00
Pickup Use	6.69
Production Credit	2.24
General Farm Maintenance	0.00
Water Assessment	0.00
Taxes on Land	0.00
Interest on Land	0.00
Management Services	0.00
Overhead Total	9.13
TOTAL COST PER ACRE	149.21

Table A-4--Continued. Itemized summary of cost per acre for producing crops.

2. Alfalfa Hay

Cost Item	1978 Cost per Acre (dollars)
Seed Bed Preparation Total	9.00
Planting	3.68
Renovate	.50
Planting and Cultivation Total	4.18
Irrigate	204.45
Crop Irrigation Total	204.45
Fertilizers	0.00
Herbicides	0.00
Insecticides	12.15
Chemicals and Application Total	12.15
Preharvest Total	220.78
Cubing	209.30
Harvest and Post Harvest Total	209.30
Pickup Use	8.91
Production Credit	2.29
General Farm Maintenance	.85
Water Assessment	0.00
1/3 Stand Establishment Cost	49.74
Taxes on Land	.37
Interest on Land	1.51
Management Services	44.28
Overhead Total	107.94
TOTAL COST PER ACRE	538.02

Table A-4--Continued. Itemized summary of cost per acre for producing crops.

3. Upland Cotton

Cost Item	1978 Cost per Acre (dollars)
Disk	4.36
Landplane	4.68
List or Bed	4.36
Mulch	5.42
Plow	5.99
Seed Bed Preparation Total	24.81
Cultivate	22.91
Planting	7.63
Remove Cap	1.42
Planting and Cultivating Total	31.96
Pre-irrigate	28.96
Irrigate	115.82
Buck Rows	1.02
Crop Irrigation Total	145.80
Fertilizers	16.88
Herbicides	19.23
Insecticides	39.39
Defoliants	10.17
Chemicals and Application Total	85.67
Preharvest Total	288.24
Prepare Ends-harvest	.44
First Cotton Pick	36.37
Second Cotton Pick	24.24
Tramp Trailers	13.38
Rood Cotton	100.00
Hauling	18.97
Residue Disposal	8.31
Harvest and Post Harvest Total	201.71
Pickup Use	13.37
Production Credit	8.58
General Farm Maintenance	.85
Water Assessment	0.00
Taxes on Land	.37
Management Services	1.51
	27.52
Overhead Total	52.20
TOTAL COST PER ACRE	542.15

Table A-4--Continued. Itemized summary of cost per acre for producing crops.

4. Pima Cotton

Cost Item		1978 Cost per Acre (dollars)
Disk		4.36
Landplane		4.68
List or Bed		4.36
Mulch		5.42
Plow		5.99
	Seed Bed Preparation Total	24.81
Cultivate		22.91
Planting		6.70
Remove Cap		1.42
	Planting and Cultivating Total	31.03
Pre-irrigate		28.96
Irrigate		115.82
Buck Rows		1.02
	Crop Irrigation Total	145.80
Fertilizers		16.88
Herbicides		19.23
Insecticides		39.39
Defoliants		10.17
	Chemicals and Application Total	85.67
	Preharvest Total	287.31
Prepare Ends-harvest		.44
First Cotton Pick		36.37
Second Cotton Pick		24.24
Tramp Trailers		13.38
Rood Cotton		104.00
Hauling		14.08
Residue Disposal		8.31
	Harvest and Post Harvest Total	200.82
Pickup Use		13.37
Production Credit		8.52
General Farm Maintenance		.85
Water Assessment		0.00
Taxes on Land		.37
Interest on Land		1.51
Management Services		33.10
	Overhead Total	57.72
	TOTAL COST PER ACRE	545.85

Table A-4--Continued. Itemized summary of cost per acre for producing crops.

5. Barley

Cost Item	1978 Cost per Acre (dollars)
Disk	8.72
List or Bed	4.36
Seed Bed Preparation Total	13.08
Planting	21.45
Planting and Cultivation Total	21.45
Irrigate	77.22
Buck Rows	.68
Make Borders	.60
Crop Irrigation Total	78.50
Fertilizers	31.87
Herbicides	0.00
Chemicals and Application Total	31.87
Preharvest Total	144.90
Prepare Ends-harvest	.44
Combining	29.09
Hauling	39.10
Residue Disposal	4.98
Harvest and Post Harvest Total	73.61
Pickup Use	6.69
Production Credit	3.36
General Farm Maintenance	.85
Water Assessment	0.00
Taxes on Land	.37
Interest on Land	1.51
Management Services	8.40
Overhead Total	21.17
TOTAL COST PER ACRE	239.68

Table A-4--Continued. Itemized summary of cost per acre for producing crops.

6. Wheat

Cost Item	1978 Cost per Acre (dollars)
Disk	8.72
List or Bed	4.36
Seed Bed Preparation Total	13.08
Planting	30.29
Planting and Cultivation Total	30.29
Irrigate	91.71
Buck Rows	.68
Make Borders	.60
Crop Irrigation Total	92.99
Fertilizers	23.11
Herbicides	0.00
Chemicals and Application Total	23.11
Preharvest Total	159.47
Prepare Ends-harvest	.44
Combining	29.09
Hauling	44.99
Residue Disposal	4.98
Harvest and Post Harvest Total	79.50
Pickup Use	6.69
Production Credit	3.47
General Farm Maintenance	.85
Water Assessment	0.00
Taxes on Land	.37
Interest on Land	1.51
Management Services	9.98
Overhead Total	22.86
TOTAL COST PER ACRE	261.83

Table A-4--Continued. Itemized summary of cost per acre for producing crops.

7. Late Milo

Cost Item	1978 Cost per Acre (dollars)
Disk	4.36
List or Bed	4.36
Mulch	5.42
Seed Bed Preparation Total	14.14
Planting	8.24
Planting and Cultivating Total	8.24
Irrigate	106.18
Buck Rows	.34
Make Borders	.60
Crop Irrigation Total	107.12
Fertilizers	20.91
Herbicides	6.85
Chemicals and Application Total	27.76
Preharvest Total	157.26
Prepare Ends-harvest	.44
Combining	29.09
Hauling	37.50
Residue Disposal	3.33
Harvest and Post Harvest Total	70.36
Pickup Use	6.69
Production Credit	2.82
General Farm Maintenance	.85
Water Assessment	0.00
Taxes on Land	.37
Interest on Land	1.51
Management Services	7.26
Overhead Total	19.50
TOTAL COST PER ACRE	247.12

Table A-4--Continued. Itemized summary of cost per acre for producing crops.

8. Safflower

Cost Item	1978 Cost per Acre (dollars)
Chisel or Rip	5.02
Disk	4.36
List or Bed	4.36
Mulch	5.42
Seed Bed Preparation Total	19.16
Cultivate	7.32
Planting	9.88
Planting and Cultivating Total	17.20
Irrigate	135.15
Buck Rows	1.02
Make Borders	.60
Crop Irrigation	136.77
Fertilizers	41.08
Herbicides	0.00
Chemicals and Application Total	41.08
Preharvest Total	214.21
Prepare Ends-harvest	.44
Combining	29.09
Hauling	21.43
Residue Disposal	4.98
Harvest and Post Harvest Total	55.94
Pickup Use	6.99
Production Credit	5.55
General Farm Maintenance	.85
Water Assessment	0.00
Taxes on Land	.37
Interest on Land	1.51
Management Services	9.00
Overhead Total	23.97
TOTAL COST PER ACRE	294.12

Table A-4--Continued. Itemized summary of cost per acre for producing crops.

9. Sugar Beets

Cost Item	1978 Cost per Acre (dollars)
Disk	4.36
Landplane	4.68
Float	4.98
List or Bed	4.36
Mulch	5.42
Plow	5.99
Seed Bed Preparation Total	29.79
Cultivate	19.48
Planting	10.16
Thinning	21.00
Weeding	15.00
Planting and Cultivating Total	65.64
Pre-irrigate	28.96
Irrigate	135.13
Buck Rows	1.36
Make Borders	.60
Crop Irrigation Total	166.05
Fertilizers	47.30
Herbicides	31.41
Insecticides	14.20
Chemicals and Application Total	92.91
Preharvest Total	354.39
Prepare Ends-harvest	.44
Harvesting	30.40
Hauling	50.35
Harvest and Post Harvest Total	81.19
Pickup Use	13.37
Production Credit	15.18
General Farm Maintenance	.85
Water Assessment	0.00
Taxes on Land	.37
Interest on Land	1.51
Management Services	23.75
Overhead Total	55.03
TOTAL COST PER ACRE	490.61

APPENDIX B

CALCULATION OF WATER PUMPED PER WELL PER YEAR FOR THE REPRESENTATIVE FARM

Using the data obtained in the farm interviews it is estimated that for the representative farm each well would operate an average of 3,600 hours per year. This figure is arrived at on the basis of aggregating the data obtained in the farm interviews for the representative farm.

$$3{,}600 \text{ HR} \circ 60 \frac{\text{MIN}}{\text{HR}} = 216{,}000 \frac{\text{MIN}}{\text{YR}} \text{ operation}$$

each well pumps 830 gallons per minute

$$216{,}000 \frac{\text{MIN}}{\text{YR}} \circ 830 \frac{\text{GAL}}{\text{MIN}} = 179{,}280{,}000 \frac{\text{GAL}}{\text{YR}}$$

there are 231 cubic inches in one gallon

$$179{,}280{,}000 \frac{\text{GAL}}{\text{YR}} \circ 231 \frac{\text{CU IN}}{\text{GAL}} = 41{,}413{,}600{,}000 \frac{\text{CU IN}}{\text{YR}}$$

1 cubic inch = .00058 cubic foot

$$41{,}413{,}600{,}000 \frac{\text{CU IN}}{\text{YR}} \circ .00058 \frac{\text{CU FT}}{\text{CU IN}} = 24{,}019{,}888 \frac{\text{CU FT}}{\text{YR}}$$

1 acre foot is a volume measure

43,560 SQ FT in one acre, so there are $43{,}560 \circ 1 \text{ FT} = 43{,}560 \frac{\text{CU FT}}{\text{AC FT}}$

$$24{,}019{,}888 \frac{\text{CU FT}}{\text{YR}} \circ \frac{1}{43{,}560} \frac{\text{AC FT}}{\text{CU FT}} = 551.42 \frac{\text{AC FT}}{\text{YR}} \approx 552 \frac{\text{AC FT}}{\text{YR}}$$

APPENDIX C

MATHEMATICAL MODEL

$$\text{Max. } Z = \sum_{i=1}^{9} P_i \circ QS_i + \sum_{n=1}^{24} PKWHS_n \circ QKWHS_n - \sum_{k=1}^{8} CC_k \circ QC_k - \sum_{n=1}^{24} VCPC_n \circ QWTC_n$$

$$- \sum_{n=1}^{24} VCPS_n \circ QWTS_n - CENGC \circ QENGC - CENGS \circ QENGS$$

Subject to:

Constraint 1: $\sum_{k=1}^{8} QC_k \leq TOTLND$

Constraint 2-10: $Y_{ik} \circ QC_k - QS_i = 0, \; i=1,\ldots,9$

Constraint 11: $QC_k \leq PCR, \; k=2$ (Pima Cotton)

Constraint 12-35: $\sum_{k=1}^{8} WTAP_{kn} \circ QC_k - QWTC_n - QWTS_n = 0, \; n=1,\ldots,24$

Constraint 36-59: $QWTC_n + QWTS_n \leq MW_n, \; n=1,\ldots,24$

Constraint 60: $\sum_{n=1}^{24} EP_n \circ QWTC_n - QENGC = 0$

Constraint 61-84: $EP_n \circ QWTS_n + QKWHS_n \leq MKAVL_n, \; n=1,\ldots,24$

Constraint 85: $\sum_{n=1}^{24} EP_n \circ QWTS_n + \sum_{n=1}^{24} QKWHS_n - QENGS = 0$

Where the variables in the above relationships are:

i = commodity (alfalfa cubes, Pima cotton lint, Upland cotton lint, cotton seed, barley grain, wheat grain, safflower grain, late milo grain, and sugar beets)

k = crop (alfalfa, Pima cotton, Upland cotton, barley, wheat, safflower, late milo, and sugar beets)

n = time period (a cropping year is divided into 24 semi-monthly periods)

Z = net returns above total variable costs

P_i = price of commodity i, (\$/unit)

QS_i = quantity of commodity i, produced and sold (unit)

QC_k = acres of crop k produced (acres)

$QKWHS_n$ = quantity of solar power sold in time period n (KWH_e)

$PKWHS_n$ = price per unit of electricity sold from the solar unit in time period n (\$/KWH_e)

CC_k = variable cost of producing crop k, excluding the variable cost of water (\$/acre)

$VCPC_n$ = variable cost of pump repair and maintenance using conventional electric power (excluding electricity cost) in time period n (\$/acre-inch)

$QWTC_n$ = quantity of water pumped using conventional electric power in time period n (acre-inch/acre)

$VCPS_n$ = variable cost of pump repair and maintenance using solar power (excluding electricity cost) in time period n (\$/acre-inch)

$QWTS_n$ = quantity of water pumped using solar power in time period n (acre-inch/acre)

$CENGC$ = cost of purchasing conventional electrical power in time period n (\$/KWH_e)

$QENGC$ = total quantity of energy purchased for pumping using conventional electric power (KWH_e)

$CENGS$ = cost of solar power (\$/KWH_e)

QENGS = total quantity of solar energy produced (KWH_e)

Y_{ik} = yield of commodity i from crop k

$WTAP_{kn}$ = water application for each crop k in time period n (acre-inch/acre)

TOTLND = total cropland available on representative farm (acres)

PCR = total acreage allotment placed on Pima cotton

MW_n = maximum quantity of water that can be pumped in time period n (acre-inch)

$MKAVL_n$ = maximum electricity available from solar unit in time period n (KWH_e)

EP_n = quantity of electricity required to pump water (KWH_e/acre-inch) in time period n

Explanation of Mathematical Statement

The linear programming model reflects one crop production season. The model attempts to encompass a representative farm for Pinal County, Arizona and in particular for the Coolidge area. The data is an aggregation of data compiled from interviews with farmers in Pinal County.

The mathematical relationships are explained in detail below, one relationship at a time.

The Objective Function

The objective function of the representative linear programming model farm is to maximize the net returns over variable costs given certain physical restrictions for the model farm. The variable cost of water has been removed from each production cost coefficient for each crop. These water costs are included in the objective function as a variable cost for repairs to the pumping unit, per acre inch of water pumped for both conventional electric power and solar power separately. The energy cost for pumping with conventional electric power is included in the objective function. The energy cost for pumping with conventional electric power is measured in cents per KWH_e plus 4% sales tax. This figure is derived from the budgeting system of Hathorn as presented in the 1978 Field Crop Budgets for Pinal County.

The variable cost per KWH_e for solar power is included. A high degree of speculation exists among agricultural economists and agricultural engineers as to just what this variable cost figure will be. The variable cost per KWH_e for solar power was varied within the model. Varying the cost figure was an attempt to test the price sensitivity as to its level or range. Several solutions were obtained. Each solution had a different variable cost per KWH_e solar coefficient. The coefficients for all the variable costs for water including: (1) repair costs to the pumping unit; and (2) energy cost, for both solar power and ED2 power have negative cost coefficients in the objective function.

The objective function also includes selling activities for nine commodities for each of eight budgeted crops. These coefficients are positive. A selling activity for solar power is included also. This activity allows the farmer of the model farm to act as a "utility" by selling KWH_e produced by the solar unit to the electrical utility grid. The coefficient for this activity is also positive. The price at which the farmer can sell this power to the utility is the identical energy cost for pumping with local utility power plus the 4% sales tax, which the representative farm pays to ED2 for power to operate its pumps.

The solutions of the linear programs for the representative model farm represent the maximum net return obtainable to the model farm given the restrictions placed on the model farm.

Constraint 1: Land Restriction

This constraint limits the physical size of the farm to 1854 cropped acres. This figure was an average figure arrived at from the data compiled from the farm interviews. Each farmer's cropped acre total was summed and then divided by the number of farmers in the sample size to give a simple average.

Constraints 2-10: Crop Production and Commodity Selling Restriction

This constraint is a crop production or yield and a commodity selling balance row. This balance row assures that whatever quantity of each budgeted crop that is produced will be sold as a commodity. Cotton seed is treated as a separate commodity. There are eight crops and nine commodities.

Constraint 11: Pima Cotton Acreage Restriction

The purpose for including this constraint is to force another crop into the crop mix. Without this constraint all Pima cotton and wheat are produced. By including this constraint Upland cotton as well as Pima cotton and wheat are produced.

Constraints 12-35: Water Application With Conventional Electric Power or Solar Power

This constraint balances the amount of water applied to each crop times the number of crop acres with the quantity of water pumped with conventional electric power and solar power.

Constraint 36-59: Total Quantity of Water Pumped with Conventional Electric Power and Solar Power

The total quantities of water, expressed in acre inches, pumped with conventional electric power and with solar power are totaled. This total will be less than or equal to the total water supply available in the model for each of the 24 semi-monthly periods. This is assuming an average pumping day of 16 hours.

Constraint 60: Electricity Utility Balance Row

This row balances the total amount of electricity required for pumping times the total quantity of water pumped using conventional electric power with the total quantity of electricity purchased for pumping from the electric utility.

Constraint 61-84: Solar Power Used for Pumping and Solar Power that is Sold to the Utility Grid

This constraint indicates that the amount of KWH_e of solar that is used to pump water to meet crop water demands, in each 24 semi-monthly periods, and that amount of KWH_e of solar that is sold to the electricity utility, in each 24 semi-monthly period, will be less than or equal to the maximum number of KWH_e available to the solar unit in each 24 semi-monthly periods.

Constraint 85: Solar Balance Row

This constraint balances the quantity of solar power used to pump water to meet crop water demands and the amount of solar power sold to the local utility with the total quantity of solar energy produced.

This then is the mathematical model of a representative farm for Pinal County, Arizona used in this study.

Again, the objective function is to maximize the net returns over variable costs of the representative farm. The net returns are maximized subject to certain physical restrictions. The restrictions are: (1) total land available; (2) total quantity of water available; and (3) total quantity of solar power measured in KWH_e available.

APPENDIX D

CALCULATION OF TOTAL SOLAR AVAILABILITY FOR THE REPRESENTATIVE FARM MEASURED IN KWH_e WITH ACUREX ESTIMATE

The solar irrigation system is built so as to produce an output flow of 150 KW_e per day. The measure of KWH_e is a quantity or stock measure. The KW_e measure is converted to KWH_e by multiplying the number of KW_e times the number of hours that these KW_e are used for some kind of work.

The Acurex Corporation is assuming nearly 4,133 hours of annual sunshine time for the solar irrigation system, or,

$$150\ KW_e \cdot 4{,}133.3 \text{ hours} = 6.2 \times 10^5\ KWH_e \text{ annually.}$$

So,

$$620{,}000\ \frac{KWH_e}{YR} \cdot \frac{1}{365}\ \frac{YR}{DAYS} = 1{,}698.6\ \frac{KWH_e}{DAY}$$

and for 31 day months:

$$1{,}698.6\ \frac{KWH_e}{DAY} \cdot 15.5 \text{ DAY} = 26{,}328.8\ KWH_e$$

for 30 day months:

$$1{,}698.6\ \frac{KWH_e}{DAY} \cdot 15 \text{ day} = 25{,}479.5\ KWH_e$$

for 28 day month:

$$1{,}698.6\ \frac{KWH_e}{DAY} \cdot 14 \text{ day} = 23{,}780.8\ KWH_e$$

The measure of KWH_e for 15.5, 15.0, and 14.0 day semi-monthly periods depends on specifying a certain solar power generating capacity for the solar irrigation system unit. In this case, 150 KW_e is the specified generating output capacity of the Acurex model being built on the Coolidge project farm. To be consistent with the project design, a 150 KW_e solar irrigation unit is used for the model (figures obtained from personal communication with Dr. D. Larson 1978).

APPENDIX E

CALCULATION OF TOTAL SOLAR AVAILABILITY FOR THE REPRESENTATIVE FARM MEASURED IN KWH_e WITH CLIMATOLOGICAL DATA

In order to account for variation in the amount of solar radiation or sunshine occurring during each 24 semi-monthly period a recomputation of KWH_e for each period was calculated.

The double line of Figure 4 is labeled "Available KWH_e with Acurex Projection." Acurex is assuming: (1) approximately 4,133 hours of sunshine hours per year; (2) an average operational day for the solar unit of about 11.3 hours; and (3) $150KW_e$ x 4,133.3 hours = 6.2×10^5 KWH_e or about 620,000 KWH_e annually.

The figure of 620,000 is divided by 365 days to give the KWH_e per day available to the solar unit. The KWH_e for each of 24 semi-monthly periods of 15.5, 15.0, and 14.0 days was calculated. These measures are represented as constant amounts.

The single line is labeled "Available KWH_e with climatological data." Acurex model of a 150 KW_e solar unit is assumed. But varying amounts of sunshine hours per semi-monthly period are calculated using local climatological data from the National Oceanic and Atmospheric Administration (NOAA) (United States Department of Commerce 1976; 1977a). Data are measured for Phoenix, Arizona, and the amount of sunshine hours per day per month is tabulated. The amount of sunshine hours for each semi-monthly period of 15.5, 15.0, and 14.0 days is summed from climate data for 1976 and 1977 for Phoenix. An average for each semi-monthly period is found for each year, then an overall average is taken. This measures the average hours of sunshine or solar radiation expected for each semi-monthly period. The variation in the incidence of solar radiation is traced out by the black line. These calculations are found in Table E-1.

Table E-1. Data for recalculated KWH_e solar.

Month	Period 1, Average Hour	Period 2, Average Hour
1. Average hours of sunlight for each 24 semi-monthly periods.*		
Jan	8.0	8.0
Feb	8.4	10.4
Mar	10.4	10.9
Apr	10.7	12.4
May	12.1	12.8
Jun	12.9	13.9
Jul	13.0	10.7
Aug	11.7	12.4
Sep	9.9	10.2
Oct	10.5	9.5
Nov	9.4	9.5
Dec	9.6	7.4
2. Incidence of solar radiation or sunshine for each of 24 semi-monthly periods, measured in KWH_e.		
Month	Period 1	Period 2
Jan	150 KW_e x 15.5 x 8 = 18,600	150 x 15.5 x 8 = 18,600
Feb	150 x 14 x 8.4 = 17,640	150 x 14 x 10.4 = 21,840
Mar	150 x 15.5 x 10.4 = 24,180	150 x 15.5 x 10.9 = 25,342.5
Apr	150 x 15.0 x 10.7 = 24,075	150 x 15.0 x 12.4 = 27,900
May	150 x 15.5 x 12.1 = 28,132.5	150 x 15.5 x 12.8 = 29,760
Jun	150 x 15.0 x 12.9 = 29,025	150 x 15.0 x 13.9 = 31,275
Jul	150 x 15.5 x 13.0 = 30,225	150 x 15.5 x 10.7 = 24,877.5
Aug	150 x 15.5 x 11.7 = 27,202.5	150 x 15.5 x 12.4 = 28,830
Sep	150 x 15.0 x 9.9 = 22,275	150 x 15.0 x 10.2 = 22,950
Oct	150 x 15.5 x 10.5 = 24,412.5	150 x 15.5 x 9.5 = 22,087.5
Nov	150 x 15.0 x 9.4 = 21,150	150 x 15.0 x 9.6 = 22,375
Dec	150 x 15.5 x 9.6 = 22,320	150 x 15.5 x 7.4 = 17,205

*U.S. Department of Commerce, Environmental Data Service 1976-1977a.

APPENDIX F

PENALTY COSTS AND MARGINAL COSTS AND BENEFITS

The decreases in the optimal net returns for each solar farm alternative is measured as a cost of adding one extra or incremental unit of an activity to the solution mix. The penalty cost shows how much the net returns above variable cost will be decreased by adding a unit of the indicated activity (Table F-1). Marginal cost and benefit for various activities and their impact on the optimal solution value for the various solar farm alternatives is shown in Table F-2.

Table F-1. Penalty costs of including activities into the optimal solution for the solar farm. -- This author's representative linear programming models.

Solution	Net Returns (dollars)	Activity	Units	Penalty Cost per Unit of Activity (dollars)
Solar Farm 1	229,639	prod. sugar beets	acre	11.46
		sell barley	cwt	1.56
		sell safflower	ton	182.52
		sell alfalfa	ton	159.41
		sell milo	cwt	.03
		pump with conventional power in period		
		2	acre inch	1.12
		21-23	same	1.12
		pump with solar power in period		
		2	acre inch	1.12
		21-23	same	1.12
Solar Farm 2	228,951	prod. milo	acre	1.04
		sell barley	cwt	1.56
		sell alfalfa	ton	161.85
		sell safflower	ton	182.52
		sell sugar beets	ton	.84
		pump with conventional power in period		
		2	acre inch	1.12
		21-23	same	1.12
		pump with solar power in period		
		2	acre inch	1.12
		21-23	same	1.12
Solar Farm 3				
a	228,951	same as Solar Farm 2		
b	223,128	prod. sugar beets	acre	15.94
		sell barley	cwt	1.56
		sell safflower	ton	182.52
		sell alfalfa	ton	161.85
		sell milo	cwt	.03
		pump with conventional power in period		
		2	acre inch	1.12
		21-23	same	1.12

Table F-1--continued. Penalty costs of including activities.

Solution	Net Returns (dollars)	Activity	Units	Penalty Cost per Unit of Activity (dollars)
Solar Farm 3		pump with solar power in period		
b		2	acre inch	1.12
		21, 23	same	1.12
c	218,330	sell barley	cwt	1.56
		sell alfalfa	ton	161.47
		sell safflower	ton	182.52
		sell sugar beets	ton	.84
		pump with conventional power in period		
		2, 21, 23	acre inch	1.12
		19	same	.17
		pump with solar power in period		
		2, 21, 23	acre inch	1.12
		19	same	.17
		variable cost for solar power	KWH_e	.002

Results are the same for Solar Farm 3d and e.

Solution	Net Returns (dollars)	Activity	Units	Penalty Cost per Unit of Activity (dollars)
Solar Farm 4				
a	226.608	sell barley	cwt	1.49
		sell safflower	ton	172.99
		sell alfalfa	ton	156.10
		sell sugar beets	ton	.48
		pump with conventional power in period		
		2, 21, 23	acre inch	1.12
		4, 8, 19, 20, 22	same	.88
		pump with solar power in period		
		2, 21, 23	acre inch	.24
b	222,025	prod. sugar beets	acre	12.16
		sell barley	cwt	1.53
		sell safflower	ton	178.79
		sell alfalfa	ton	159.25
		pump with conventional power in period		
		2, 21, 23	acre inch	1.12
		4, 8, 19, 20, 22	same	.39

Results are the same for Solar Farm 4c, d, and e as in Solar Farm 3c above.

Table F-1--continued. Penalty costs of including activities.

Solution	Net Returns (dollars)	Activity	Units	Penalty Cost per Unit of Activity (dollars)
Solar Farm 5				
a	26,737	prod. safflower	acre	163.61
		prod. sugar beets	acre	44.14
		sell barley	cwt	1.61
		sell alfalfa	ton	153.66
		pump with solar power in period 2, 21, 22, 23	acre inch	.24
b	23,792	prod. safflower	acre	170.03
		prod. sugar beets	acre	25.46
		sell barley	cwt	1.59
		sell alfalfa	ton	156.81
		pump with solar power in period 2, 21, 22, 23	acre inch	.72
c	20,923	prod. safflower	acre	181.67
		sell barley	cwt	1.53
		sell alfalfa	ton	160.85
		sell sugar beets	ton	.94
		pump with solar power in period 2, 21, 22, 23	acre inch	1.20
		19	same	.79
d	18,318	prod. sugar beets	acre	29.50
		sell barley	cwt	1.35
		sell safflower	ton	176.84
		sell alfalfa	ton	163.12
		sell milo	cwt	.45
		pump with solar power in period 2, 19, 21, 23	acre inch	1.68
e	15,714	prod. sugar beets	acre	41.17
		sell barley	cwt	1.17
		sell safflower	ton	172.01
		sell alfalfa	ton	166.27
		sell milo	cwt	.97
		pump with solar power in period 2, 19, 21, 23	acre inch	2.17

Table F-1--continued. Penalty costs of including activities.

Solution	Net Returns (dollars)	Activity	Units	Penalty Cost per Unit of Activity (dollars)
Solar Farm 6				
a	32,003	prod. safflower	acre	182.52
		prod. sugar beets	acre	11.46
		sell barley	cwt	1.56
		sell alfalfa	ton	159.03
		pumping with solar power in period		
		2, 21, 22, 23	acre inch	1.12
		19	same	.17
		selling solar power in period		
		3	KWH$_e$	.48
		9	same	.15
b	26,180	prod. safflower	acre	182.52
		prod. sugar beets	acre	11.46
		sell barley	cwt	1.56
		sell alfalfa	ton	159.03
		pump with solar power in period		
		2, 21, 22, 23	acre inch	1.12
		19	same	.17
		selling solar power in period		
		3	KWH$_e$	.48
		9	same	.15
c	20,923	prod. safflower	acre	181.67
		sell barley	cwt	1.53
		sell alfalfa	ton	160.85
		sell sugar beets	ton	.94
		pump with solar power in period		
		2, 21, 23	acre inch	1.20
		19	same	.79
		sell solar power in periods		
		1-24	KWH$_e$	.002
d	18,318	prod. sugar beets	acre	29.56
		sell barley	cwt	1.35
		sell safflower	ton	176.84
		sell alfalfa	ton	163.12
		sell milo	cwt	.45

Table F-1--continued. Penalty costs of including activities.

Solution	Net Returns (dollars)	Activity	Units	Penalty Cost per Unit of Activity (dollars)
Solar Farm 6				
d		pump with solar power in period		
		2, 19, 21, 23-23	acre inch	1.682
		sell solar power in period		
		1-2	KWH_e	.012
		3	same	.44
		4-8	same	.012
		9	same	.095
		10-24	same	.012
e	15,714	prod. sugar beets	acre	41.17
		sell barley	cwt	1.17
		sell safflower	ton	172.01
		sell alfalfa	ton	166.27
		sell milo	cwt	.97
		pump with solar power in period		
		2, 19, 21, 23	acre inch	2.17
		sell solar power in period		
		1-2	KWH_e	.022
		3	same	.407
		4-8	same	.022
		9	same	.042
		10-24	same	.022

Table F-2. Marginal cost and benefit for various activities and their impact on the optimal solution value for the various solar farm alternatives. -- This author's representative farm linear programming models.

Activity	Marginal Cost and Benefit (dollars)	Units	Increase or Decrease on Optimal Solution
Solar Farm 1. Optimal Solution Value $229,639			
barley prod.	- 6.16	cwt	decrease
Pima cotton prod.	- .90	lbs	decrease
Upland cotton prod.	- .52	lbs	decrease
safflower prod.	-362.52	ton	decrease
wheat prod.	- 4.75	cwt	decrease
alfalfa prod.	-214.41	ton	decrease
sugar beet prod.	- 25.00	ton	decrease
milo production	- 4.17	cwt	decrease
Pima cotton acreage	+139.37	acre	increase
water application rate in period			
1, 4-8, 10-20, 24	+ 1.12	acre inch	increase
3	+ 24.63	same	increase
9	+ 8.73	same	increase
water availability period			
3	+ 23.51	acre inch	increase
9	+ 7.61	same	increase
solar availability periods			
1-24	+ .01824	KWH_e	increase
Solar Farm 2, in body of thesis			
Solar Farm 3			
a, same as Solar Farm 2			
b, Optimal Solution Value $223,128			
The only activities that change from the above are:			
alfalfa prod.	-216.85	ton	decrease
solar availability periods			
1-24	+ .00824	KWH_e	increase
c, Optimal Solution Value $218,330			
The activities that change from the Solar Farm 1 result are:			
alfalfa prod.	-216.47	ton	decrease
sugar beet prod.	- 25.83	ton	decrease
milo prod.	- 4.15	cwt	decrease

Table F-2--continued. Marginal cost and benefit for various activities.

Activity	Marginal Cost and Benefit (dollars)	Units	Increase or Decrease on Optimal Solution
Solar Farm 3			
c			
water application			
rate period 3	+ 24.63	acre inch	increase
19	+ .94	same	increase
solar activity is not included.			
Results are the same for Solar Farm 3d and e as in Solar Farm 3c.			
Solar Farm 4			
a, Optimal Solution Value $226,608			
The activities that change from the Solar Farm 1 result are:			
barley prod.	- 6.09	cwt	decrease
safflower prod.	-352.99	ton	decrease
alfalfa prod.	-211.10	ton	decrease
sugar beet prod.	- 25.48	ton	decrease
milo prod.	- 4.15	cwt	decrease
water application			
rate in period 3	+ 23.04	acre inch	increase
4	+ .24	same	increase
8	+ .24	same	increase
9	+ 9.61	same	increase
17	+ 1.82	same	increase
19, 20, 22	+ .24	same	increase
water availability			
period 3	+ 21.92	acre inch	increase
9	+ 8.49	same	increase
17	+ .70	same	increase
solar availability period			
1, 3, 5-7, 8-18, 24	+ .01824	KWH_e	increase
b, Optimal Solution Value $222,025			
The activities that change from Solar Farm 4a are:			
barley prod.	- 6.13	cwt	decrease
safflower prod.	-358.79	ton	decrease
alfalfa prod.	-214.25	ton	decrease
sugar beet prod.	- 25.00	ton	decrease
water application			
rate in period 3	+ 24.01	acre inch	increase
4	+ .72	same	increase
8, 19, 20, 22	+ .72	same	increase
17	+ 1.34	same	increase

Table F-2--continued. Marginal cost and benefit for various activities.

Activity	Marginal Cost and Benefit (dollars)	Unit	Increase or Decrease on Optimal Solution
Solar Farm 4			
b			
water availability			
period 3	+ 22.89	acre inch	increase
9	+ 8.01	same	increase
17	+ .22	same	increase
solar availability period			
1, 3, 5-7, 9-18, 24	+ .00824	KWH_e	increase
c, Optimal Solution Value $218,330			
The results for this alternative are identical to those of Solar Farm 3c above.			
Results are the same for the Solar Farm 4d and e as in Solar Farm 3c.			
Solar Farm 5			
a, Optimal Solution Value $26,737			
The activities that change from the above results are:			
barley prod.	- 6.21	cwt	decrease
safflower prod.	-180.00	ton	decrease
alfalfa prod.	-208.66	ton	decrease
sugar beet prod.	- 25.00	ton	decrease
milo prod.	- 4.15	cwt	decrease
water application rate in period			
1, 4-8, 10-16, 18-20 24	+ .24	acre inch	increase
3	+ 21.57	same	increase
9	+ 13.43	same	increase
17	+ 6.52	same	increase
solar availability			
period 3	+ .44	KWH_e	increase
9	+ .27	same	increase
17	+ .13	same	increase
b, Optimal Solution Value $23,792			
Activities that change from Solar Farm 5a are:			
barley prod.	- 6.19	cwt	decrease
alfalfa prod.	-211.81	ton	decrease
water application rate in period			
1, 4-8, 10-16, 18-20, 24	+ .72	acre inch	increase

Table F-2--continued. Marginal cost and benefit for various activities.

Activity	Marginal Cost and Benefit (dollars)	Units	Increase or Decrease on Optimal Solution
Solar Farm 5			
b			
water application rate in period 3	+ 23.35	acre inch	increase
9	+ 10.85	same	increase
17	+ 3.46	same	increase
solar availability period 3	+ .46	KWH_e	increase
9	+ .20	same	increase
17	+ .05	same	increase
c, Optimal Solution Value $20,923			
Activities that change from alternative 5b are:			
barley prod.	- 6.13	cwt	decrease
alfalfa prod.	-215.85	ton	decrease
sugar beet prod.	- 25.94	ton	decrease
water application rate in period 1, 4-8, 10-18, 20, 22, 24	+ 1.26	acre inch	increase
3	+ 24.32	same	increase
9	+ 8.28	same	increase
19	+ .40	same	increase
solar availability period 3	+ .47	KWH_e	increase
9	+ .14	same	increase
d, Optimal Solution Value $18,316			
Activities that change from alternatives above are			
barley prod.	- 5.95	cwt	decrease
safflower prod.	-356.84	ton	decrease
alfalfa prod.	-218.12	ton	decrease
sugar beet prod.	- 25.00	ton	decrease
milo prod.	- 4.60	cwt	decrease
water application rate in period 1, 4-8, 10-18, 20, 22, 24	+ 1.68	acre inch	increase
3	+ 22.55	same	increase
9	+ 5.70	same	increase
solar availability period 3	+ .43	KWH_e	increase
9	+ .08	same	increase

Table F-2--continued. Marginal cost and benefit for various activities.

Activity	Marginal Cost and Benefit (dollars)	Units	Increase or Decrease on Optimal Solution
Solar Farm 5			
e, Optimal Solution Value $15,714			
Activities which change from alternatives above are:			
barley prod.	- 5.77	cwt	decrease
safflower prod.	-352.01	ton	decrease
alfalfa prod.	-221.27	ton	decrease
milo prod.	- 5.12	cwt	decrease
water application rate in period 1, 4-8, 10-18, 20, 22, 24	+ 2.17	acre inch	increase
3	+ 20.78	same	increase
9	+ 3.12	same	increase
solar availability period 3	+ .38	KWH_e	increase
9	+ .01	same	increase
Solar Farm 6			
a, Optimal Solution Value $32,003			
Activities that change are:			
barley prod.	- 6.16	cwt	decrease
safflower prod.	-180.00	ton	decrease
alfalfa prod.	-214.03	ton	decrease
milo prod.	- 4.15	cwt	decrease
water application rate in period 1, 4-8, 10-18, 20, 22, 24	+ 1.12	acre inch	increase
3	+ 24.63	same	increase
9	+ 8.73	same	increase
19	+ .94	same	increase
solar availability period 1, 2, 4-8, 10-24	+ .01824	KWH_e	increase
3	+ .50	same	increase
9	+ .17	same	increase
b, Optimal Solution Value $26,180			
Activities that change from the above results are:			
solar availability period 1, 2, 4-8, 10-24	+ .00824	KWH_e	increase
3	+ .49498	same	increase
9	+ .16	same	increase

Table F-2--continued. Marginal cost and benefit for various activities.

Activity	Marginal Cost and Benefit (dollars)	Units	Increase or Decrease on Optimal Solution
Solar Farm 6			
c, Optilal Solution Value $20,923			
Activities which change from the above results for 6a and b are:			
barley prod.	- 6.13	cwt	decrease
safflower prod.	-180.00	ton	decrease
alfalfa prod.	-215.85	ton	decrease
sugar beet prod.	- 25.94	ton	decrease
water application rate in period 1, 4-8, 10-18, 20, 22, 24	+ 1.20	acre inch	increase
3	+ 24.32	same	increase
9	+ 8.28	same	increase
19	+ .40	same	increase
solar availability period 3	+ .47	KWH_e	increase
9	+ .14	same	increase
d, Optimal Solution Value $18,318			
These results are identical to those of Solar Farm 5d above.			
e, Optimal Solution Value $15,714			
These results are identical to those of Solar Farm 5e above.			

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