Risk and irrigation water use decisions in Arizona : an economic analysis

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RISK AND IRRIGATION
WATER USE DECISIONS
IN ARIZONA: AN
ECONOMIC ANALYSIS

by

Randal Lee Edmond

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ABSTRACT

This thesis considers economic optimization of irrigation water use in Arizona. Attention is given to both the questions of risk resulting from stochastic climatic conditions in the production of field crops and farmers' behavior under risk. The risk attitudes of any particular farmer are assumed to be characterized by either a quadratic or an exponential utility function for profit. This assumption permits a simplified analysis of the decision problem in terms of maximizing expected utility on an efficiency frontier in expectation and variance of profit.

The methodology is applied to a case study involving four hypothetical farmers facing water price increases. Efficiency frontiers corresponding to different water prices are derived using a quadratic programming algorithm. The exponential formulation is used to represent the individual utility functions due to the failure of the quadratic formulation to satisfy positive marginal utility. For each farmer, an optimal irrigation water use plan, specifying crop mix, water applications, and fallow land, is determined at each water price. Case study results indicate that an approach to irrigation water use optimization that considers risk often leads to optimal plans that differ substantially from those plans selected without this consideration.

CHAPTER 1

INTRODUCTION

Water is rapidly becoming scarce in many Western States including Arizona. Present estimates indicate that Arizona annually consumes 5.5 million acre feet of surface and groundwater of which 2.2 million are not replenished (Arizona Water Commission, 1975). Currently, agriculture is responsible for almost 90% of this consumption (Arizona Water Commission, 1975). There are three main factors that have made and will continue to make Arizona's water increasingly scarce economically: the price of electricity is rapidly rising; water tables are deep and declining; and non-agricutural sectors are competing for water.

The price of electricity in recent years has risen sharply. This rise is of critical importance to farmers irrigating with groundwater, who plant nearly one-half of Arizona's cropland (Arizona Crop and Livestock Reporting Service, 1974), since most of their irrigation pumps are electric powered (Ayer and Hoyt, 1981). In addition, approximately 60% of the groundwater pumped by these farmers comes from depths of 300 feet and greater (Arizona Crop and Livestock Reporting Service, 1974). The combined factors of high electricity prices and deep pump depths means high pumping costs and high irrigation costs, since the largest percentage of irrigation costs is pumping (Ayer and Hoyt, 1981).

The third factor affecting water scarcity in Arizona is competition by non-agricultural sectors; the single most important competitor being urban-industrial water users (Arizona Water Commission, 1975). Urban-industrial users can easily afford to pay higher prices for water than can agricultural users, and do so even to the extent of buying farms to acquire the water rights. In addition, as a result of the phenomenal growth of greater Phoenix and Tucson, the political power of urban-industrial users has rapidly increased and the laws governing water rights have recently changed in a manner adverse to agricultural users.

In reaction to Arizona's increasing water scarcity, farmers as well as a number of government agencies are moving to conserve irrigation water. Various policies are now either in effect or in the proposal stage.

An understanding of farmers' behavior will permit the imposition of policies with the rewards and penalties necessary to affect individual farmers' irrigation water use decisions so that the objectives of the policies will be met. Irrigation water use decisions include the decisions of which crops to produce, how much land to plant in each of the crops, and how much water to apply to each crop. Most economic studies have assumed that farmers behave as profit maximizers, basing production decisions upon the expected profits of the alternative plans. However, recent studies have shown that the production decisions of many farmers are based not only upon expected profits, but also upon the associated riskiness of profits. In general, many farmers behave as risk averters (Lin, Dean, and Moore 1974, Brink and McCarl 1978). Thus, of importance in policy analysis are both the individual risk attitudes of farmers and the expected profits and riskiness of profits of alternative irrigation water use plans.

To determine for any particular farmer, the irrigation water use plan that is consistent with the farmer's risk preferences, it is necessary to characterize the risk attitudes of the farmer by a utility function for profit, since an individual's risk preferences are determined by maximizing expected utility. Assuming that either the utility function is quadratic or profit is normally distributed, expected utility is a function of expected profit and variance of profit, and thus, variance is a measure of riskiness.

The expected profit and variance of profit of any particular irrigation water use plan depend upon the stochastic nature of each crop's price and yield. The crop price may be rendered deterministic through a contract, but the crop yield remains stochastic due to various stochastic factors in the relationship between crop yield and water applied. Thus, farmers are always faced with irrigation water use decisions under risk.

It has recently been shown for each of the principal field crops in most irrigated areas of Arizona that a statistically significant stochastic factor in the crop-water relationship is evaporation (Ayer and Hoyt, 1981), which is a function of sunlight, temperature, wind, and humidity conditions, and thus, a proxy for climatic conditions. More specifically, the crop yield is stochastic due at least in part to the interaction between evaporation and the water application.

Research Objectives

An economic analysis of risk and irrigation water use decisions in Arizona is pursued in this thesis. More specifically, the research objectives of this thesis are to:

1. Quantify risk in multi-crop irrigation in Arizona.
2. Develop a methodology to determine optimal irrigation water use under risk.
3. Demonstrate the methodology in a case study.
4. Analyze the effects of water price increases on optimal irrigation water use.
5. Specify conclusions and suggested research.

CHAPTER 2

LITERATURE REVIEW

There are many economic studies on optimal irrigation water use. Based upon the optimization objective, these studies can be divided into three categories. The first category consists of the research which has assumed pure determinism with the implicit objective of profit maximization. In the second category is the research which has recognized certain stochastic factors of the crop-water relationship and then has assumed expected profit maximization as the objective. The third category includes the limited research which has recognized such stochastic factors and then in order to consider risk has assumed the objective of expected utility maximization.

The profit maximization category includes research by Wu and Liang (1972) and Minhas, Parikh, and Srinivasan (1974), in which the water application was considered. In each study, an analytical function was used to determine the water application. Other profit maximization research has considered dated water applications in order to account for different growth stages and water availability during the growing season. Moore (1961) used an analytical function and Stewart (1977) a tabular one to determine dated water applications. Dudley, Howel, and Musgrave (1971a), Biere, Kanemasu, and Morgan (1977), Flinn and Musgrave (1967), Yaron (1971) and Hall and Butcher (1968) used various dynamic programming models to determine the allocation of water among different growth stages. Other studies in this category include Anderson and Maass (1974) and Hartman and Whittelsey (1961) both of whom considered the allocation of water among various crop mixes. Anderson and Maass utilized simulation, while Hartman and Whittelsey utilized linear programming to determine the water allocation.

Some research efforts have recognized certain stochastic factors of the crop-water relationship and then have taken an expected profit maximizing approach to optimization. Burt and Stauber (1971) and Delucia (1969) dealt with precipitation. Dudley, Howel, and Musgrave (1971b) considered the stochastic factors of precipitation and evapotranspiration (evaporation combined with plant transpiration). In each of these studies, dynamic programming was utilized to determine the intraseasonal allocation and timing of water. Mantanga and Marino (1977) examined the stochastic factor of annual precipitation and used a linear programming model to determine the intraseasonal allocation of water between various crops. Andersen, Hiskey, and Lackawathna (1971) considered precipitation and utilized Bayesian decision theory to determine the crop mix when the annual water allotment was restricted. Other research in this category includes Yaron et al. (1973) who examined the stochastic factors of precipitation and evapotranspiration, and Ayer and Hoyt (1981) who dealt with evaporation. In each study, an analytical function was used to determine the water application.

Nuthall (1972) is one of two research efforts that have recognized certain stochastic factors of the crop-water relationship and then in order to consider risk have taken an expected utility maximizing approach to optimization. Nuthall considered evaporation and used a simulation model to determine the expected profits and variance of profits associated with alternative water applications. Although utility functions were not directly incorporated, Nuthall pointed out that when farmers are risk averters, variance of profit is an important consideration.

English (1978) recognized several stochastic factors contributing to risk including supplemental water supply (antecedent soil moisture and precipitation), root depth, climatic conditions (wind, sunlight, humidity, and temperature), and critical dates (planting, emergence, full cover, and harvest). English utilized Bayesian decision theory to determine the expected profits and variance of profits associated with alternative water applications on alternative mixes of two crops when the annual water allotment was restricted. The quadratic utility functions of seven farmers were directly incorporated by English and their expected utility maximizing plans presented, which in most cases were substantially different from the expected profit maximizing plans.

CHAPTER 3

METHODOLOGY

It is assumed that a farmer's objective is to maximize expected utility with respect to the set of alternative production plans where utility is a function of profit. Two alternative formulations of the utility function, the quadratic and the exponential, are considered.

Quadratic Utility Function

Assume that the utility function is quadratic, that is,

$$U(\pi) = \pi - \alpha\pi^2 \tag{3.1}$$

where

U = utility,

π = profit, and

α = risk attitude parameter, $\alpha > 0$.

Thus, the expected utility function is of the form

$$\begin{aligned} E(U(\pi)) &= E(\pi) - \alpha E(\pi^2) \\ &= E(\pi) - \alpha(V(\pi) + (E(\pi))^2) \end{aligned} \tag{3.2}$$

where

$E(\ )$ = expectation operator and

$V(\ )$ = variance operator.

And thus, $E(U(\pi))$ is maximized by maximizing Equation 3.2 with respect to the set of alternative production plans. This maximization can be done in four steps:

1. For each of the alternative production plans, determine $E(\pi)$ and $V(\pi)$.
2. For each $E(\pi)$ level, find the minimum $V(\pi)$. The result is an efficiency set in $E(\pi)$ and $V(\pi)$, that is, an E-V efficiency frontier as illustrated in Figure 3.1.
3. For each of the points on the efficiency frontier, evaluate Equation 3.2.
4. Select that point which maximizes Equation 3.2.

Alternatively, the efficiency frontier can be represented as the locus of points defined by the function

$$E(\pi) = F[V(\pi)]. \tag{3.3}$$

Thus, $E(U(\pi))$ is now maximized by maximizing

$$E(U(\pi)) = F[V(\pi)] - \alpha(V(\pi) + (F[V(\pi)])^2). \tag{3.4}$$

A necessary condition for maximizing $E(U(\pi))$ is

$$\frac{dE(U(\pi))}{dV(\pi)} = F'[V(\pi)] - \alpha - 2\alpha F[V(\pi)]F'[V(\pi)] = 0, \tag{3.5}$$

which yields

$$F'[V(\pi)] = \frac{\alpha}{1 - 2\alpha F[V(\pi)]} . \tag{3.6}$$

Note that totally differentiating Equation 3.2 with respect to $E(U(\pi))$, $E(\pi)$, and $V(\pi)$ and setting the result equal to zero, that is,

$$dE(U(\pi)) = dE(\pi) - 2E(\pi)\alpha dE(\pi) - \alpha dV(\pi) = 0, \tag{3.7}$$

yields

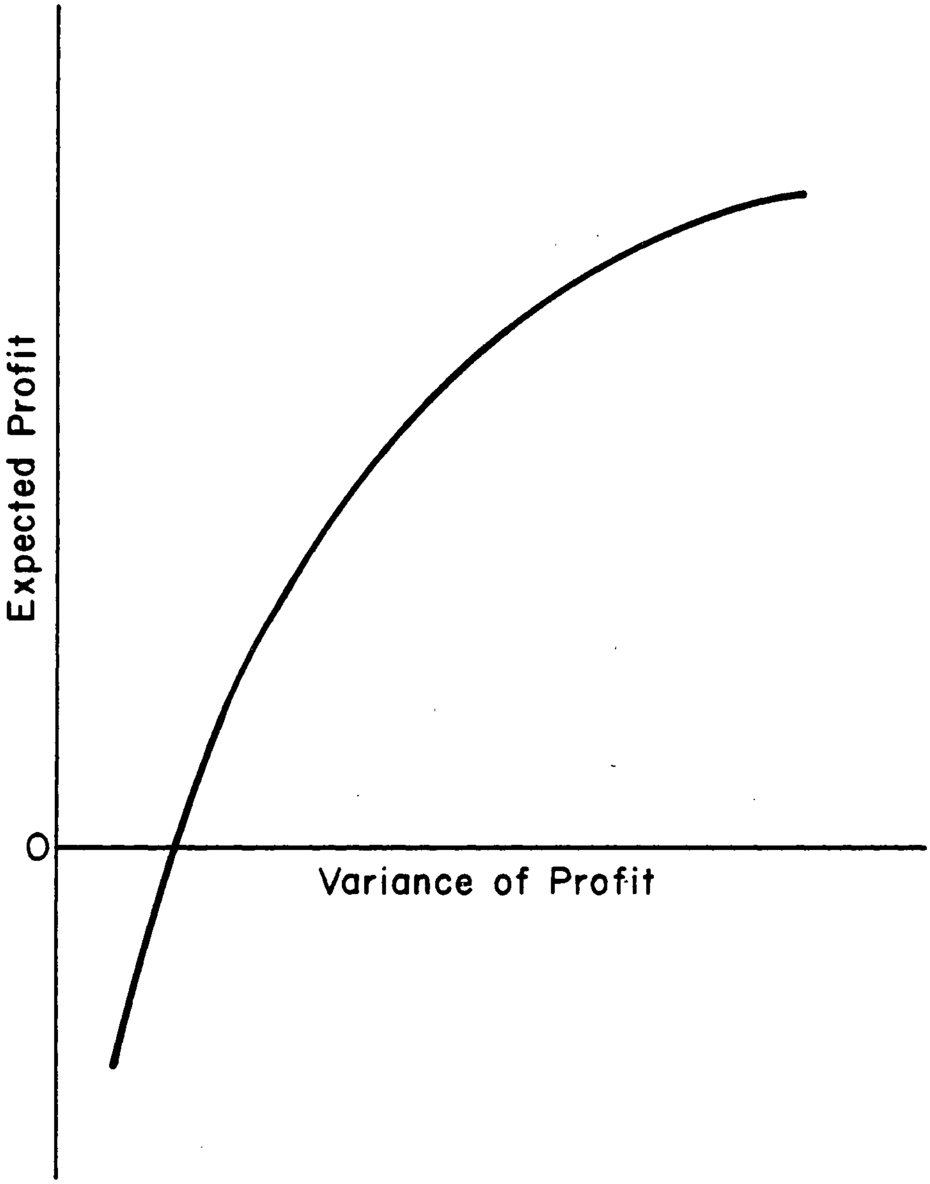

Figure 3.1. An E-V Efficiency Frontier.

$$\frac{dE(\pi)}{dV(\pi)} = \frac{\alpha}{1 - 2\alpha E(\pi)} \quad , \tag{3.8}$$

which is the slope of an indifference curve in E-V space. Thus, as a necessary condition for maximizing $E(U(\pi))$, Equation 3.6 states that the slope of the efficiency frontier should be set equal to the slope of an indifference curve in E-V space, that is, the efficiency frontier should be set tangent to an indifference curve in E-V space. This necessary condition is illustrated in Figure 3.2.

Assuming that an $E(U(\pi))$ maximum exists, a sufficient condition for a unique maximum is

$$\begin{aligned}\frac{d^2E(U(\pi))}{dV^2(\pi)} &= F''[V(\pi)] - 2\alpha(F'[V(\pi)])^2 - 2\alpha F[V(\pi)]\ F''[V(\pi)] \\ &= (1 - 2\alpha F[V(\pi)])F''[V(\pi)] - 2\alpha(F'[V(\pi)])^2 \\ &< 0. \end{aligned} \tag{3.9}$$

For $\alpha = 0$, Equation 3.9 requires that $F''[V(\pi)] < 0$, that is, the efficiency frontier must be concave to the origin. For $\alpha > 0$, the sufficient condition is satisfied when $F''[V(\pi)] < 0$ and $1 - 2\alpha F[V(\pi)] > 0$. Positive marginal utility requires that the first derivative of Equation 3.1 be greater than zero at all relevant π, that is, $U'(\pi) = 1 - 2\alpha\pi > 0$. Since $E(\pi)$ is less than the maximum relevant π, it follows that $1 - 2\alpha E(\pi) > 0$. Thus for $\alpha > 0$, Equation 3.9 holds where the efficiency frontier is concave to the origin and marginal utility is positive.

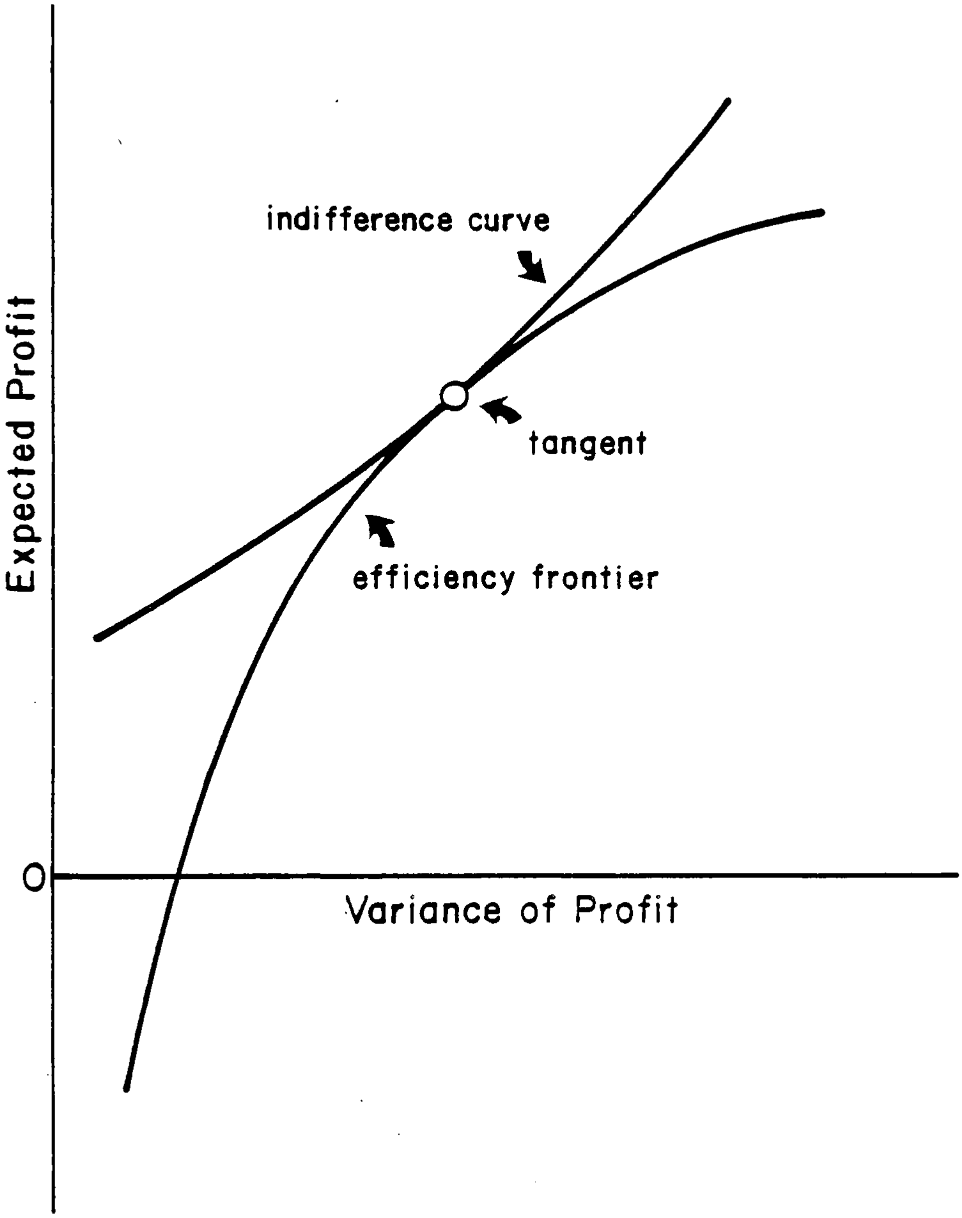

Figure 3.2. An E-V Efficiency Frontier Tangent to an Indifference Curve in E-V Space.

Exponential Utility Function

Assume alternatively that $U(\pi)$ is not quadratic, but exponential, that is,

$$U(\pi) = \begin{cases} 1 - e^{-\gamma\pi}, \text{ if } \gamma > 0 \text{ and} \\ \pi, \text{ if } \gamma = 0 \end{cases} \tag{3.10}$$

where

γ = risk attitude parameter.

Further assume that π is normally distributed, and thus, $E(U(\pi))$ is of the form

$$E(U(\pi)) = \begin{cases} {}_{-\infty}\int^{\infty}(1 - e^{-\gamma\pi})e^{-(\pi - E(\pi))^2/2V(\pi)}d\pi, \text{ if } \gamma > 0 \text{ and} \\ E(\pi), \text{ if } \gamma = 0. \end{cases} \tag{3.11}$$

Maximizing Equation 3.11 with respect to the set of alternative production plans is equivalent to maximizing

$$E(U^*(\pi)) = E(\pi) - \frac{\gamma}{2}V(\pi) \tag{3.12}$$

(Freund 1956), that is, the efficiency set for Equation 3.10 is also defined in E-V space. This maximization can be done in four steps:

1. For each of the alternative production plans, determine $E(\pi)$ and $V(\pi)$.
2. For each $E(\pi)$ level, find the minimum $V(\pi)$. The result is the E-V efficiency set, that is, the E-V efficiency frontier.
3. For each of the points on the efficiency frontier, evaluate Equation 3.12.
4. Select that point which maximizes Equation 3.12.

Alternatively, the efficiency frontier can be represented by Equation 3.3, and thus, $E(U(\pi))$ is now maximized by maximizing

$$E(U^*(\pi)) = F[V(\pi)] - \frac{\gamma}{2}V(\pi). \tag{3.13}$$

A necessary condition for maximizing $E(U(\pi))$ is

$$\frac{dE(U^*(\pi))}{dV(\pi)} = F'[V(\pi)] - \frac{\gamma}{2} = 0, \tag{3.14}$$

which yields

$$F'[V(\pi)] = \frac{\gamma}{2} . \tag{3.15}$$

Note that totally differentiating Equation 3.12 with respect to $E(U^*(\pi))$, $E(\pi)$, and $V(\pi)$ and setting the result equal to zero, that is,

$$dE(U^*(\pi)) = dE(\pi) - \frac{\gamma}{2}dV(\pi) = 0, \tag{3.16}$$

yields

$$\frac{dE(\pi)}{dV(\pi)} = \frac{\gamma}{2}, \tag{3.17}$$

which is the slope of an indifference curve in E-V space. Thus, as a necessary condition for maximizing $E(U(\pi))$, Equation 3.15 states that the slope of the efficiency frontier should be set equal to the slope of an indifference curve in E-V space.

Assuming that an $E(U(\pi))$ maximum exists, a sufficient condition for a unique maximum is

$$\frac{d^2E(U^*(\pi))}{dV^2(\pi)} = F''[V(\pi)] < 0, \tag{3.18}$$

that is, the efficiency frontier must be concave to the origin.

Profit Equation

Assume again that $E(U(\pi))$ is a function of $E(\pi)$ and $V(\pi)$. Let the π equation be given by

$$\pi = TR - TVC - TFC \tag{3.19}$$

where

TR = total return,

TVC = total variable cost, and

TFC = total fixed cost.

Assume that TVC is both linear in acreage and deterministic, so that Equation 3.19 becomes

$$\pi = \sum_{i=1}^{I} \sum_{j=1}^{J_i} p_i y_{ij} x_{ij} - \sum_{i=1}^{I} \sum_{j=1}^{J_i} \sum_{k=1}^{K} r_k z_{ijk} x_{ij} - TFC \tag{3.20}$$

where

I = total number of crops,

J_i = total number of methods available to produce the i^{th} crop,

p_i = price per unit of the i^{th} crop,

y_{ij} = yield per acre of the i^{th} crop produced with the j^{th} method,

x_{ij} = acreage of the i^{th} crop produced with the j^{th} method,

K = total number of inputs,

r_k = price per unit of the k^{th} input, and

z_{ijk} = level per acre of the k^{th} input required to produce the i^{th} crop with the j^{th} method.

Grouping terms in Equation 3.20 results in

$$\pi = \sum_{i=1}^{I} \sum_{j=1}^{J_i} (p_i y_{ij} - \sum_{k=1}^{K} r_k z_{ijk}) x_{ij} - TFC. \tag{3.21}$$

Now let

$$c_{ij} = p_i y_{ij} - \sum_{k=1}^{K} r_k z_{ijk}$$

= return above variable cost per acre of the i^{th} crop produced with the j^{th} method,

and thus, Equation 3.21 becomes

$$\pi = \sum_{i=1}^{I} \sum_{j=1}^{J_i} c_{ij}x_{ij} - TFC, \tag{3.22}$$

which in matrix notation is equivalent to

$$\pi = C'X - t \tag{3.23}$$

where

' = transpose operator,

$C' = [c_{11}, c_{12}, \ldots, c_{1J_1}, \ldots, c_{ij}, \ldots, c_{I1}, c_{I2}, \ldots, c_{IJ_I}]$

= 1 x L vector of the c_{ij}'s in which $L = \sum_{i=1}^{I} J_I$,

$X' = [x_{11}, x_{12}, \ldots, x_{1J_1}, \ldots, x_{ij}, \ldots, x_{I1}, x_{I2}, \ldots, x_{IJ_I}]$

= 1 x L vector of x_{ij}'s, and

t = TFC.

Thus,

$$\begin{aligned} E(\pi) &= E(C'X - t) \\ &= E(C'X) - t \end{aligned} \tag{3.24}$$

and

$$\begin{aligned} V(\pi) &= V(C'X - t) \\ &= V(C'X) \\ &= E(C'X - E(C'X))^2. \end{aligned} \tag{3.25}$$

Assume that the vector X is to be determined, so that Equation 3.24 becomes

$$E(\pi) = E(C')X - t \tag{3.26}$$

where

$E(C') = 1 \times L$ vector of the expected c_{ij}'s and Equation 3.25

becomes

$$V(\pi) = X'(E(CC') - E(C)E(C'))X$$

$$= X'DX \tag{3.27}$$

where

$D = L \times L$ variance - covariance matrix of the c_{ij}'s.

Now refer to Steps 2 above, in which $V(\pi)$ is minimized for each $E(\pi)$ level, that is,

$$\min V(\pi) \tag{3.28}$$

$$\text{subject to } E(\pi) = E^*$$

where

E^* = level of $E(\pi)$.

Substituting $E(\pi)$ and $V(\pi)$ from Equations 3.26 and 3.27 respectively into Equation 3.28 yields in matrix notation

$$\min X'DX \tag{3.29}$$

$$\text{subject to } E(C')X - t = e^*$$

or alternatively since t is a scalar,

$$\min X'DX \tag{3.30}$$

$$\text{subject to } E(C')X = e^* + t$$

where

$e^* + t$ = level of expected total return above total variable cost.

Quadratic Programming

Stating $E(C')X = e^* + t$ of Equation 3.30 as an inequality, that is, $E(C')X \geq e^* + t$, specifies a quadratic programming, QP, problem. Note that additional constraints $AX \leq B, X \geq 0$ can also be considered where A is a matrix of input-output coefficients and B a vector of input-output levels. Since the general QP problem is specified by

$$\begin{aligned} &\min M'W + 1/2\, W'NW \\ &\text{subject to } GW \geq H \\ &\qquad\qquad\quad W \geq 0 \end{aligned} \tag{3.31}$$

(Tomlin, 1976), let

$M = 0,$

$W = X,$

$N = 2D,$

$$G = \begin{bmatrix} E(C') \\ -A \end{bmatrix}, \text{ and}$$

$$H = \begin{bmatrix} e^* + t \\ -B \end{bmatrix},$$

and thus, Equation 3.31 becomes

$$\begin{aligned} &\min X'DX \\ &\text{subject to } E(C')X \geq e^* + t \\ &\qquad\qquad\quad AX \leq B \\ &\qquad\qquad\quad X \geq 0. \end{aligned} \tag{3.32}$$

Solving Equation 3.32 results in a production plan represented by the vector X which achieves the minumum $V(\pi)$ while realizing the maximum level of expected total return above total variable cost, $e^* +$

t. Note that subtracting total fixed cost, t, from $e^* + t$ results in e^*, the maximum level of $E(\pi)$ realized.

CHAPTER 4

DATA

The methodology developed in the foregoing chapter to determine a farmer's optimal production plan under risk is applied to an irrigation water use decision problem in a real world setting.

Setting

The case study site is in east-central Arizona in Graham county. This location is chosen because the necessary crop-water production functions for the principal irrigated crops of the county have been estimated (Ayer and Hoyt 1981) and good climatic data exist. Moreover, the county is one in which irrigation costs are rapidly rising and farmer response to water conservation policy is an important issue.

The primary purposes of the case study are to demonstrate the methodology developed in the preceeding chapter and in so doing gain some perspective on the relevance of the expected utility maximizing approach to optimal irrigation water use in Arizona. The modeling effort and assessment of risk in the case study are quite adequate for these purposes.

The case study deals with a hypothetical problem, but data used in the analysis are real and the dimensions of the decision problem are quite realistic. It is postulated that a farmer in Graham county has the capacity to produce wheat, cotton, and alfalfa; 300 cultivable acres; and an unlimited supply of water. The farmer must decide which of the crops to produce, how much land to plant in each of the crops, and how much water to apply to each crop. Three water prices are considered in the analysis.

The irrigation water use plan which maximizes expected utility differs from one farmer to another, depending upon individual risk attitudes. Four hypothetical farmers are considered in the analysis, ranging in risk attitudes from risk neutral (profit maximizing) to very risk averse. The optimal plans for these hypothetical farmers are contrasted in the case study.

Production Functions

Crop-water production functions in Table 4.1 are from Ayer and Hoyt (1981) and are used to represent the crop yields at alternative water applications for wheat, cotton, and alfalfa. In addition to a water input variable, which includes water applied plus effective precipitation (continual precipitation in excess of .25 inches), these quadratic functions include an interaction term between the water input variable and the climatic conditions variable, evaporation. For each of the three crops, effective precipitation is negligble (Turner 1980), and thus, each crop's yield becomes a function of water applied and evaporation. Nitrogen applied is also included for wheat and cotton.

Table 4.1. Crop-Water Production Functions for Wheat, Cotton, and Alfalfa.

Wheat

$$Y_W = -\underset{(1521.32)}{\overset{***}{4385.796}} + \underset{(94.05)}{\overset{***}{495.812}}\text{WAT} - \underset{(1.28)}{\overset{***}{3.752}}\text{WAT}^2 - \underset{(.28)}{\overset{***}{2.778}}\text{WATEVAP} + \underset{(2.06)}{\overset{***}{5.819}}\text{NIT}$$

$$- \underset{(.007)}{\overset{**}{.016}}\text{NIT}^2$$

$\bar{R}^2 = .71 \quad F = 42.80$

Cotton

$$Y_C = -\underset{(177.83)}{\overset{**}{380.377}} + \underset{(13.01)}{\overset{***}{35.032}}\text{WAT} - \underset{(.14)}{\overset{***}{.499}}\text{WAT}^2 + \underset{(.14)}{\overset{**}{.307}}\text{WATEVAP} + \underset{(.48)}{\overset{***}{2.262}}\text{NIT}$$

$$- \underset{(.002)}{\overset{***}{.007}}\text{NIT}^2$$

$\bar{R}^2 = .93 \quad F = 147.52$

Alfalfa

$$Y_A = -\underset{(1.62)}{\overset{**}{4.4285}} - \underset{(.0005)}{\overset{*}{.0010}}\text{WAT}^2 + \underset{(.0007)}{\overset{***}{.0030}}\text{WATEVAP}$$

$\bar{R}^2 = .95 \quad F = 147.30$

Table 4.1--Continued.

Note:

Y_W = yield of wheat in pounds per acre.

Y_C = yield of cotton in pounds of lint per acre.

Y_A = yield of alfalfa in tons per acre.

WAT = water applied plus effective precipitation in acre inches per acre from preplant irrigation to harvest.

EVAP = evaporation for the growing season in inches as measured by a Class A pan.

WATEVAP = WAT·EVAP.

NIT = nitrogen applied in pounds per acre from preplant fetilization to harvest.

Number in parenthesis = standard error of the estimate.

*** = coefficient is statistically significant at the 1 percent level, two-tailed test.

** = coefficient is statistically significant at the 2 percent level, two-tailed test.

* = coefficient is statistically significant at the 10 percent level, two-tailed test.

Source: Ayer and Hoyt (1981).

The expected evaporation and variance of evaporation for each of the crops and the covariance of evaporation between each of the crops are given in Table 4.2. These statistical parameters are based on eight years (December 1971 to November 1979) of daily Class A pan evaporation recorded at the town of Safford in Graham county (Turner 1980) and the growing seasons of December 15 to June 15 for wheat, April 1 to November 15 for cotton, and February 1 to November 15 for alfalfa (Dennis 1980).

The alternative water applications for the crops are given in Table 4.3. These water applications vary in irrigations of six inches, which reflects common irrigation practice (Hathorn and Cluff, 1979). The range used is from the minimum water applications needed to grow the crops (Dennis 1980) to the expected returns above variable costs maximizing ones for wheat and cotton as determined by Ayer and Hoyt using typical surface water prices. For alfalfa, the largest common practice water application from Hathorn and Cluff (1979) is used, since maximizing expected return above variable cost results in an application that is significantly in excess of common practice due to the almost linear relationship between alfalfa yield and water applied (Ayer and Hoyt 1981). The nitrogen applications for wheat and cotton are from Ayer and Hoyt. These applications are 50 pounds per acre for wheat and 125 pounds per acre for cotton.

Prices and Costs

Crop prices are assumed fixed by marketing contracts. The prices used are for late summer 1979 from Ayer and Hoyt (1981). These

Table 4.2. Evaporation Statistical Parameters for Wheat, Cotton, and Alfalfa at Safford, Arizona.

Crop	Expected Evaporation (inches)	Variance-Covariance of Evaporation (inches)		
		Wheat	Cotton	Alfalfa
Wheat	46.18	13.00	-3.78	3.52
Cotton	81.26	-3.78	8.77	4.88
Alfalfa	93.09	3.52	4.88	6.65

Based on: Dennis (1980) and Turner (1980).

Table 4.3. Alternative Water Applications for Wheat, Cotton, and Alfalfa.

Crop	Water Application 1	2	3	4	5
	- - - - - - - - - -acre inches per acre - - - - - - - - -				
Wheat	24	30	36	42	48
Cotton	36	42	48	54	60
Alfalfa	60	66	72	78	84

Based on: Ayer and Hoyt (1981), Dennis (1980), and Hathorn and Cluff (1979).

prices are respectively \$.07 per pound of wheat, \$.65 for combined lint and seed per pound of cotton lint, and \$75.00 per ton of alfalfa.

The water prices are also from Ayer and Hoyt. These prices are \$.50, \$2.50, and \$5.00 per acre inch and are typical water prices for surface water, water pumped from 300 feet, and water pumped from 600 feet respectively (Ayer and Hoyt 1981). The nitrogen price of \$.30 per pound is from Hathorn and Cluff (1979).

There are other variable costs incurred in the production of the crops, in addition to water and nitrogen costs. These costs include land preparation, seed, planting, cultivating, labor and machinery, other fertilizers and chemicals, and harvesting. The other variable costs of \$85.00 per acre for wheat, \$308.00 per acre for cotton, and \$87.00 per acre for alfalfa are also from Hathorn and Cluff.

Fixed cost of \$200.00 per cultivable acre, which includes taxes and insurance, machinery depreciation, and interest on capital investment, is from Hathorn (1980).

Expected Returns

Expected returns above variable costs, excluding water costs, for the alternative water applications for the crops are given in Table 4.4. These expected returns are based on the above production functions, expectations of evaporation, nitrogen applications, crop and nitrogen prices, and other variable costs.

Table 4.4. Expected Returns above Variable Costs, Excluding Water Costs, for Alternative Water Applications for Wheat, Cotton, and Alfalfa.

Crop	Water Application 1	2	3	4	5
	- - - - - - - - - - - -	- - - - - -	$ per acre - - - - -	- - - - - -	- - - - - -
Wheat	76.72	145.99	196.34	217.78	261.62
Cotton	503.10	585.22	643.99	678.40	691.46
Alfalfa	567.62	636.59	700.16	758.33	811.10

Based on: Ayer and Hoyt (1981), Dennis (1980), Hathorn and Cluff (1979), and Turner (1980).

CHAPTER 5

RESULTS AND ANALYSIS

The E-V efficiency frontiers corresponding to the different water prices are derived using a quadratic programming algorithm (Tomlin 1976). Expected profit is varied for each efficiency frontier in \$10,000 levels. The efficiency frontiers are illustrated in Figure 5.1 and given point by point in Appendix Table A.1. Associated with each point is a specific irrigation water use plan. Appendix Table A.2 gives the details of each plan.

Utility Functions

Assuming that a quadratic utility function, Equation 3.1, characterizes a farmer's risk attitudes, the farmer's expected utility maximizing point on any one of the efficiency frontiers is determined by first evaluating the expected utility function, Equation 3.2, at each point on the efficiency frontier, and then selecting that point which maximizes Equation 3.2. The quadratic utility function, however, is untenable. Each point on the efficiency frontier involves negative marginal utility at the upper end of the distribution of profit, and thus, it is not possible to satisfy the requirement that marginal utility be positive at all relevent profit levels. An exponential utility function, Equation 3.10, is thus assumed to characterize the

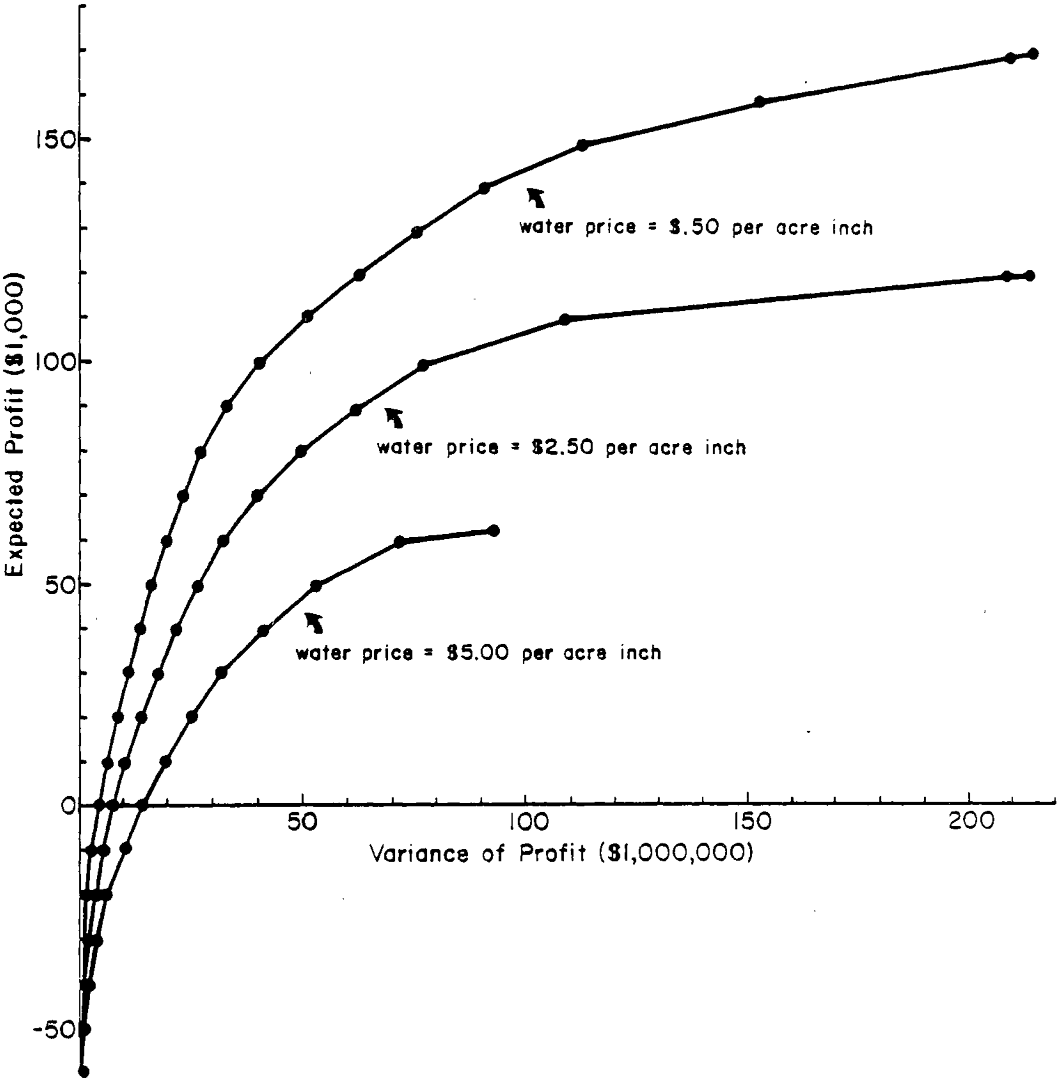

Figure 5.1. E-V Efficiency Frontiers Corresponding to Different Water Prices.

farmer's risk attitudes, since the nature of this function guarantees that marginal utility is positive at all profit levels. Normality of profit, however, is required to be consistent with the use of the exponential utility function. Thus, it is assumed that profit is normally distributed. The farmer's expected utility maximizing point is determined by first evaluating the expected utility equivalency function, Equation 3.12, at each point on the efficiency frontier, and then selecting that point which maximizes Equation 3.12.

The individual risk attitudes of four farmers are selected for purposes of further analysis where the first farmer is risk neutral (risk attitude parameter $\gamma = 0$), that is, profit maximizing; the second, mildly risk averse ($\gamma = .0008$); the third, moderately risk averse ($\gamma = .0024$); and the fourth, very risk averse ($\gamma = .0072$). The farmers' expected utility maximizing points on each of the efficiency frontiers are determined as above and are illustrated in Figure 5.2. Appendix Table A.3 gives the expected utility maximizing point on each efficiency frontier for any particular value of γ.

Optimal Plans

The irrigation water use plans associated with the four farmers' expected utility maximizing points on each efficiency frontier, that is, the farmers' optimal irrigation water use plans, expected profits, and variance of profits at each water price, are given in Table 5.1.

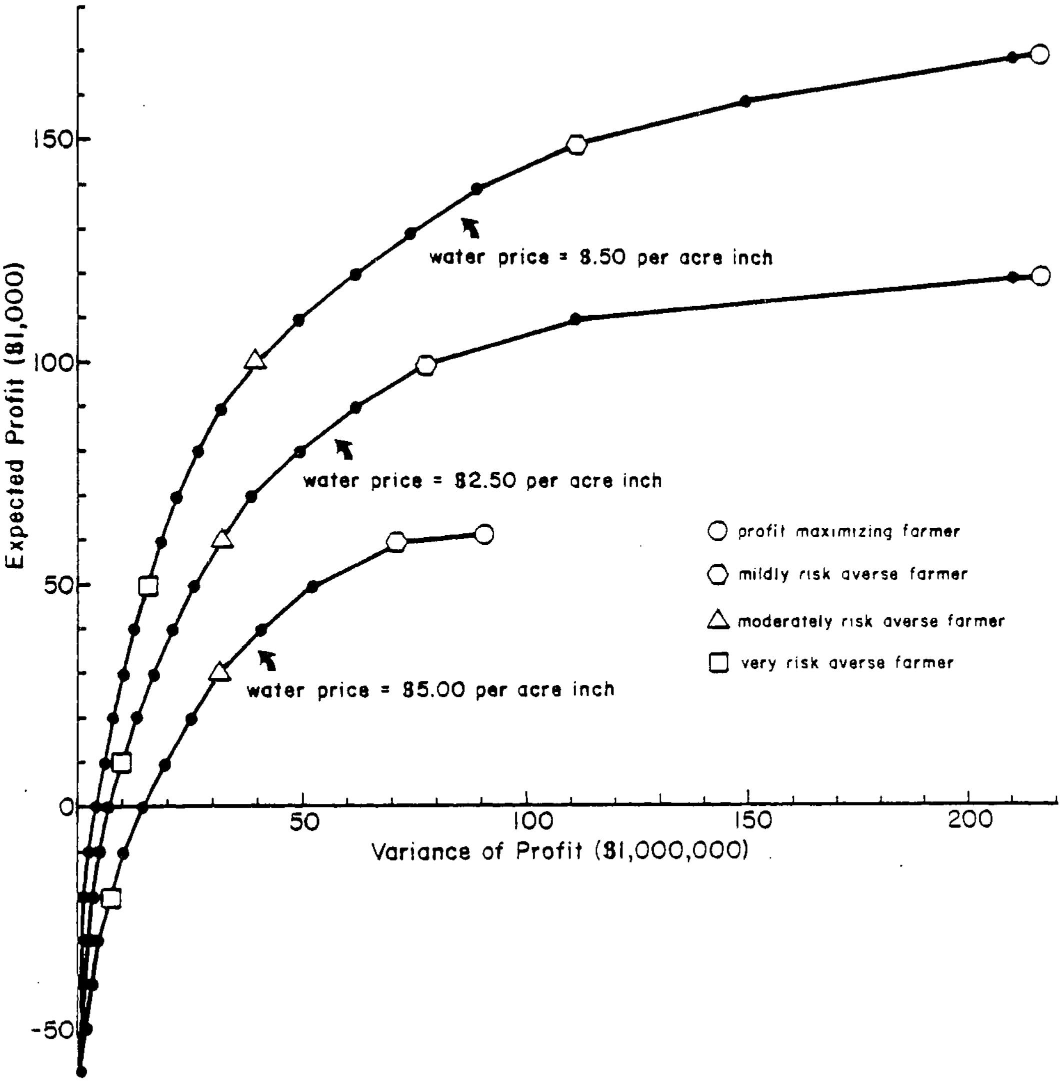

Figure 5.2. Expected Utility Maximizing Points on E-V Efficiency Frontiers, Corresponding to Different Water Prices, for Four Farmers.

able 5.1. Optimal Irrigation Water Use Plans, Expected Profits, and Variance of Profits for Four Farmers at Different Water Prices.

Farmer	Land Use (acres)				Water Applied (acre inches per acre)			Expected Profit ($1,000)	Variance of Profit ($1,000,000)
	Fallow	Wheat	Cotton	Alfalfa	Wheat	Cotton	Alfalfa		
A. Water Price = $.50 per acre inch									
Profit Maximizing				300			84	170.70	213.79
Mildly Risk Averse			178	122		54	84	150.00	110.89
Moderately Risk Averse		64	236		48	48		100.00	39.12
Very Risk Averse	13	96	191		36	36		50.00	15.48
B. Water Price = $2.50 per acre inch									
Profit Maximizing				300			84	120.30	213.79
Mildly Risk Averse			263	37		48	84	100.00	76.03
Moderately Risk Averse		67	233		42	42		60.00	29.18
Very Risk Averse	80	68	152		36	36		10.00	9.47

Table 5.1--Continued.

Farmer	Land Use (acres)				Water Applied (acre inches per acre)			Expected Profit ($1,000)	Variance of Profit ($1,000,000)
	Fallow	Wheat	Cotton	Alfalfa	Wheat	Cotton	Alfalfa		
C. Water Price = $5.00 per acre inch									
Profit Maximizing				300		54		62.80	91.65
Mildly Risk Averse				41		42		60.00	69.98
				259		48			
Moderately Risk Averse		63		237	42	42		30.00	30.29
Very Risk Averse	138	40	122		36	36		-20.00	5.88

The general analysis of the decision problem can be demonstrated by using Table 5.1. Consider the following example, in which the low water price ($.50 per acre inch) is used. Suppose the individual in question is the profit maximizing farmer. The optimal plan is the expected profit maximizing one, that is, to plant the 300 acres in alfalfa with 84 acre inches of water applied to each acre. Expected profit is $170,700. If, however, the individual is the mildly risk averse farmer, the optimal plan is to plant 178 acres of cotton and 122 acres in alfalfa with respectively 54 and 84 acre inches of water applied per acre. Expected profit is $150,000, which indicates the farmer is willing to forego $20,700 of the maximum expected profit in order to reduce risk as measured by variance of profit. This example clearly illustrates an important point. A farmer's optimal plan may be different from the expected profit maximizing plan as the farmer may be willing to forego part of the maximum expected profit in order to reduce risk. This point is even more strongly made by considering the other two risk averse farmers. The optimal plan for the moderately risk averse farmer and the one for the very averse farmer at the low water price (see Table 5.1) are dramatically different from the expected profit maximizing plan as both farmers are willing to sacrifice a substantial part of the maximum expected profit in order to reduce risk.

The optimal plans for all three of the risk averse farmers at the medium water price ($2.50 per acre inch) differ dramatically from the expected profit maximizing plan (see Table 5.1). This optimal plan for the profit maximizing farmer is unchanged from the low water price. Expected profit, though, is $50,400 less ($120,300 instead of $170,700). The risk averter's optimal plans, however, have undergone substantial changes from the low water price. The mildly risk averse farmer plants more cotton and less alfalfa and applies less water per acre to the cotton, the moderately averse one applies less water per acre to both wheat and cotton, and the very averse farmer leaves more land in fallow than at the low water price. Expected profits for these three farmers are significantly less than at the low water price. More specifically, expected profit for the mildly risk averse farmer is $50,000 less ($100,000 instead of $150,000); for the moderately averse one, $40,000 less ($60,000 instead of $100,000); and for the very averse farmer, $40,000 less ($10,000 instead of $50,000) than at the low water price.

The risk averse farmers' optimal plans at the high water price ($5.00 per acre inch) also differ from the profit maximizing farmer's one (see Table 5.1), though not as dramatically as at the medium water price. The expected profit maximizing plan has changed dramatically from the medium water price as the 300 acres are now planted in cotton with 54 acre inches of water applied to each acre instead of in alfalfa with 84 acre inches of water applied per acre. Expected profit is $57,500 less ($62,800 instead of $120,300). Though not as dramatic as the changes in the profit maximizer's optimal plan, the risk averters' optimal plans have also undergone changes from the medium water price. An exception is that the optimal plan for the moderately risk averse farmer is for all practical purposes unchanged. Expected profit, though, is \$30,000 less (\$30,000 instead of \$60,000). The mildly averse farmer now plants all cotton instead of cotton and alfalfa and applies less water per acre to some of the cotton than at the medium water price. Expected profit is \$40,000 less (\$60,000 instead of \$100,000). The very averse farmer leaves more land in fallow than at the medium water price. Expected profit is \$30,000 less (-\$20,000 instead of \$10,000).

It is clear from the preceding analysis that at any one of the water prices there is no one optimal plan for all four farmers. It should in particular be noted that the optimal plan for the profit maximizer is different from those for the risk averters as these farmers are willing to forego a part of the maximum expected profit in order to reduce risk.

Alternative strategies for reducing risk are demonstrated in Table 5.1. One strategy is to adjust the crop mix; another, the water applications; and another, the fallow land. Which of these strategies a risk averse farmer uses and to what degree depends upon the degree of risk aversion. The mildly risk averse farmer uses the first two strategies to a minor degree; the moderately averse farmer, also the first two, but to a greater degree; and the very averse farmer, all three strategies to a major degree.

A fundamental tenent of this thesis is that an optimal irrigation water use plan is one which maximizes expected utility. In the past, most irrigation water use optimization models have been designed to select an expected profit maximizing plan. It is clear from the foregoing analysis that an expected profit maximizing model would not have selected the optimal plans for three of the four farmers considered. In fact, the optimal plans for these three farmers were often dramatically different from the expected profit maximizing plan. This result has important implications for those government agencies that are involved in proposing or implementing policies to conserve irrigation water.

Conservation

Policies to conserve irrigation water include financial ones to increase the price of surface water in federal irrigation districts or increase the effective price of groundwater through pumping taxes. Thus, it is important to analyze the effects on quantity of water demanded, by each of the four farmers when the water price is increased from \$.50 to \$2.50 to \$5.00 per acre inch.

Quantity of water demanded by each farmer at each water price is given in Table 5.2. These quantities are based on the optimal plans for the farmers given in Table 5.1.

When the water price is increased from \$.50 to \$2.50 per acre inch there is no effect on quantity of water demanded by the profit maximizer (25,200 acre inches), but there are substantial effects on that demanded by each of the three risk averters. More specifically, quantity of water demanded by the mildly risk averse farmer is decreased by 4,128 acre inches (from 19,860 to 15,732); that demanded by the moderately averse farmer, by 1,800 acre inches (from 14,400 to 12,600);

Table 5.2. Quantities of Water Demanded by Four Farmers at Different Water Prices.

Farmer	Water Price ($ per acre inch) .50	2.50	5.00
	- - - - - - - - -acre inches	- - - - - - -	
Profit Maximizing	25,200	25,200	16,200
Mildly Risk Averse	19,860	15,732	14,154
Moderately Risk Averse	14,400	12,600	12,600
Very Risk Averse	10,332	7,920	5,832

and that demanded by the very averse farmer, by 2,412 acre inches (from 10,332 to 7,920). In summary, when the water price is increased from \$.50 to \$2.50 per acre inch, irrigation water savings range from zero to 4,128 acre inches.

When the water price is further increased, that is, from \$2.50 to \$5.00 per acre inch, there is no effect on quantity of water demanded by the moderately risk averse farmer (12,600 acre inches), but there are dramatic effects on that demanded by the profit maximizer as well as substantial effects on that demanded by each of the other two risk averters. More specifically, quantity of water demanded by the profit maximizing farmer is decreased by 9,000 acre inches (from 25,200 to 16,200); that demanded by the mildly risk averse farmer, by 1,578 acre inches (from 15,732 to 14,154); and that demanded by the very averse farmer, by 2,088 acre inches (from 7,920 to 5,832). In summary, when the water price is increased from \$2.50 to \$5.00 per acre inch, irrigation water savings range from 1,578 to 9,000 acre inches.

It is clear from the preceding analysis that an expected profit maximizing model would not have been an accurate predictor of the irrigation water savings per farmer brought about by the increases in the water price.

CHAPTER 6

SUMMARY AND CONCLUSIONS

Farmers as well as a number of government agencies are moving to conserve irrigation water in Arizona in reaction to increasing water scarcity. Success of any policy to conserve irrigation water will depend upon farmer behavior. There is sufficient evidence to indicate that many farmers do not behave as profit maximizers, but instead as risk averters. In conjunction, it has been shown that climatic conditions are a statistically significant stochastic factor contributing to risk in the production of Arizona's major field crops. Thus, both the individual risk attitudes of farmers and the expected profits and riskiness of profits associated with alternative irrigation water use plans must be taken into account in policy analysis. Otherwise, there is little reason to expect that a recommended irrigation water use plan will be consistent with an individual's risk preferences. The case study demonstrates this argument dramatically. Irrigation water use decisions made with consideration given to risk were substantially different than those decisions made by a profit maximizer. Furthermore, the decisions made with this consideration differed substantially, depending upon the degree of risk aversion.

When considering risk it becomes necessary to determine farmers' utility functions for profit in order to characterize individual risk attitudes. Futhermore, to fully utilize the methodology developed in this thesis, it is necessary to represent the individual utility functions by either a quadratic or an exponential formulation.

In addition to the necessity of determining farmers' utility functions, the expected utility maximizing approach to optimal irrigation water use outlined herein requires the derivation of an efficiency frontier in expectation and variance of profit from which to determine the farmers' expected utility maximizing points. In order to derive the efficiency frontier, it is first necessary to determine the expectation and variance of returns above variable costs associated with the alternative water applications for the different crops considered as well as to determine the covariance of returns above variable costs between the alternatives. These statistical parameters are then used in conjunction with a quadratic programming algorithm to derive the efficiency frontier point by point.

Though it was originally assumed in the case study that a farmer's utility function could be represented by the quadratic formulation, it was found that this assumption is untenable. Each point on each of the efficiency frontiers derived (where each efficiency frontier corresponded to a different water price) resulted in negative marginal utility at some profit levels, and thus, it was not possible to satisfy the requirement that marginal utility be positive at all relevent profit levels. The exponential formulation was then assumed as this formulation guarantees positive marginal utility at all profit levels. However, normality of profit is required with the exponential formulation. It remains to be seen whether imposing this requirement significantly affects the results.

Though the differences were more substantial at the low and medium water prices considered than at the high one, risk averse farmers' optimal irrigation water use plans always differed from those for a profit maximizing farmer. These differences can be attributed to the desire of risk averters to reduce risk. By adjusting crop mix, water applications, or fallow land, risk can be reduced at the expense of forfeiting part of the maximum expected profit.

Quantity of water demanded by each of the risk averters at each water price usually differed substantially from that demanded by the profit maximizer. Consequently, if a farmer is risk averse, an expected utility maximizing approach to optimal irrigation water use would more accurately predict the irrigation water savings, resulting from an increase in the water price, than would an expected profit maximizing approach.

Suggested Research

The following topics are suggested for future research:

1) A basis needs to be established for accepting or rejecting the assumption that individual utility functions can be represented by the exponential formulation.

2) The impact of stochastic crop prices on irrigation water use plans needs to be defined and integrated into the optimization model, since stochastic prices may contribute more to risk than stochastic yields.

3) The scheduling of irrigations may be as important as the amount of water applied. Thus, dated production functions should be developed for use in an optimization model. These production functions should include all stochastic factors that contribute significantly to risk.

4) It may be appropriate to look at the consequences of alternative irrigation water use plans within a framework of a multi-year optimization model, since planning is an annual decision. This framework would thus allow inclusion of discount rates, desired rate of return, and probability of farm survival.

5) Risk may be measured by a number of methods other than variance of profit. Thus, the feasibility of using these alternative methods in an optimization model and the consequences of their use with regards to the formulation of individual utility functions needs to be explored.

APPENDIX

Table A.1. Points on E-V Efficiency Frontiers Corresponding to Different Water Prices.

Point	Expected Profit ($1,000)	Variance of Profit ($1,000,000)
A. Water Price = $.50 per acre inch		
A0	-60.00	0
A1	-50.00	.13
A2	-40.00	.51
A3	-30.00	1.15
A4	-20.00	2.05
A5	-10.00	3.20
A6	0	4.61
A7	10.00	6.27
A8	20.00	8.19
A9	30.00	10.36
A10	40.00	12.79
A11	50.00	15.48
A12	60.00	18.45
A13	70.00	21.74
A14	80.00	25.88
A15	90.00	31.85
A16	100.00	39.12
A17	110.00	49.00
A18	120.00	60.47
A19	130.00	73.41
A20	140.00	89.22
A21	150.00	110.89
A22	160.00	149.33
A23	170.00	208.35
A24	170.70	213.79

Table A.1--Continued.

Point	Expected Profit ($1,000)	Variance of Profit ($1,000,000)
B. Water Price = $2.50 per acre inch		
B0	-60.00	0
B1	-50.00	.19
B2	-40.00	.77
B3	-30.00	1.74
B4	-20.00	3.09
B5	-10.00	4.83
B6	0	6.96
B7	10.00	9.47
B8	20.00	12.37
B9	30.00	15.65
B10	40.00	19.41
B11	50.00	23.57
B12	60.00	29.18
B13	70.00	37.61
B14	80.00	47.97
B15	90.00	60.90
B16	100.00	76.03
B17	110.00	109.41
B18	120.00	208.35
B19	120.30	213.79
C. Water Price = $.50 per acre inch		
C0	-60.00	0
C1	-50.00	.37
C2	-40.00	1.47
C3	-30.00	3.31
C4	-20.00	5.88

Table A.1--Continued.

Point	Expected Profit ($1,000)	Variance of Profit ($1,000,000)
C5	-10.00	9.19
C6	0	13.23
C7	10.00	18.01
C8	20.00	23.65
C9	30.00	30.29
C10	40.00	39.48
C11	50.00	51.81
C12	60.00	69.98
C13	62.80	91.65

Table A.2. Irrigation Water Use Plans Associated with Points on E-V Efficiency Frontiers Corresponding to Different Water Prices.

Point	Land Use (acres)				Water Applied (acre inches per acre)		
	Fallow	Wheat	Cotton	Alfalfa	Wheat	Cotton	Alfalfa
A. Water Price = $.50 per acre inch							
A0	300						
A1	274	9	17		36	36	
A2	247	18	35		36	36	
A3	222	26	52		36	36	
A4	195	35	70		36	36	
A5	169	44	87		36	36	
A6	143	53	104		36	36	
A7	117	61	122		36	36	
A8	91	70	139		36	36	
A9	64	79	157		36	36	
A10	38	88	174		36	36	
A11	13	96	191		36	36	
A12		9	209		36	36	
		82			42		
A13		97	58		42	36	
			145			42	
A14		62	218		42	42	
		20					
A15		76	98		48	42	
			126			48	
A16		64	236		48	48	
A17		44	243	12	48	48	84
A18		26	242	31	48	48	84
A19		9	241	50	48	48	84

Table A.2--Continued.

Point	Land Use (acres)				Water Applied (acre inches per acre)		
	Fallow	Wheat	Cotton	Alfalfa	Wheat	Cotton	Alfalfa
A20			176	86		48	84
			38			54	
A21			178	122		54	84
A22			92	208		54	84
A23			7	293		54	84
A24				300			84
B. Water Price = $2.50 per acre inch							
B0	300						
B1	268	10	22		36	36	
B2	238	19	43		36	36	
B3	206	29	65		36	36	
B4	174	39	87		36	36	
B5	143	48	109		36	36	
B6	112	58	130		36	36	
B7	80	68	152		36	36	
B8	49	77	174		36	36	
B9	17	87	196		36	36	
B10		82	218		42	36	
B11		90	28		42	36	
			182			42	
B12		67	233		42	42	
B13		46	199		48	42	
			55			48	
B14		43	257		48	48	
B15		20	271	9	48	48	84
B16			263	37		48	84

Table A.2—Continued.

Point	Land Use (acres)				Water Applied (acre inches per acre)		
	Fallow	Wheat	Cotton	Alfalfa	Wheat	Cotton	Alfalfa
B17			182	118		54	84
B18			7	293		54	84
B19				300			84
C. Water Price = $5.00 per acre inch							
C0	300						
C1	260	10	30		36	36	
C2	219	20	61		36	36	
C3	179	30	91		36	36	
C4	138	40	122		36	36	
C5	98	50	152		36	36	
C6	57	60	183		36	36	
C7	17	70	213		36	36	
C8		65	178		42	36	
			57			42	
C9		63	237		42	42	
C10		35	265		42	42	
C11		7	293		42	42	
C12			41			42	
			259			48	
C13			300			54	

Table A.3. Expected Utility Maximizing Points on E-V Efficiency Frontiers, Corresponding to Different Water Prices, for Different Values of the Risk Attitude Parameter γ.

	Water Price ($ per acre inch)		
Value of γ	.50	2.50	5.00
0-.000109	A24	B19	C13
.000110	A24	B19-B18	C13
.000111-.000201	A24	B18	C13
.000202	A24	B18-B17	C13
.000203-.000255	A24	B17	C13
.000256	A24-A23	B17	C13-C12
.000256-.000337	A23	B17	C12
.000338	A23-A22	B17	C12
.000339-.000519	A22	B17	C12
.000520	A22-A21	B17	C12
.000521-.000599	A21	B17	C12
.000600	A21	B17-B16	C12
.000601-.000921	A21	B16	C12
.000922	A21-A20	B16	C12
.000923-.001099	A20	B16	C12
.001100	A20	B16	C12-C11
.001101-.001265	A20	B16	C11
.001266	A20-A19	B16	C11
.001267-.001321	A19	B16	C11
.001322	A19	B16-B15	C11
.001323-.001545	A19	B15	C11
.001546	A19-A18	B15-B14	C11
.001547-.001621	A18	B14	C11
.001622	A18	B14	C11-C10
.001623-.001745	A18	B14	C10
.001746	A18-A17	B14	C10

Table A.3--Continued.

Value of γ	Water Price ($ per acre inch) .50	2.50	5.00
.001747-.001929	A17	B14	C10
.001930	A17	B14-B13	C10
.001931-.002023	A17	B13	C10
.002024	A17-A16	B13	C10
.002025-.002175	A16	B13	C10
.002176	A16	B13	C10-C9
.002177-.002371	A16	B13	C9
.002372	A16	B13-B12	C9
.002373-.002751	A16	B12	C9
.002752	A16-A15	B12	C9
.002753-.003011	A15	B12	C9
.003012	A15	B12	C9-C8
.003013-.003349	A15	B12	C8
.003350	A15-A14	B12	C8
.003351-.003545	A14	B12	C8
.003546	A14	B12	C8-C7
.003547-.003565	A14	B12	C7
.003566	A14	B12-B11	C7
.003567-.004183	A14	B11	C7
.004184	A14	B11	C7-C6
.004185-.004807	A14	B11	C6
.004808	A14	B11-B10	C6
.004809-.004829	A14	B10	C6
.004830	A14-A13	B10	C6
.004831-.004949	A13	B10	C6
.004950	A13	B10	C6-C5
.004951-.005319	A13	B10	C5
.005320	A13	B10-B9	C5

Table A.3--Continued.

Value of γ	Water Price ($ per acre inch)		
	.50	2.50	5.00
.005321-.006041	A13	B9	C5
.006042	A13	B9	C5-C4
.006043-.006079	A13	B9	C4
.006080	A13-A12	B9	C4
.006081-.006097	A12	B9	C4
.006098	A12	B9-B8	C4
.006099-.006733	A12	B8	C4
.006734	A12-A11	B8	C4
.006735-.006895	A11	B8	C4
.006896	A11	B8-B7	C4
.006897-.007433	A11	B7	C4
.007434	A11-A10	B7	C4
.007435-.007781	A10	B7	C4
.007782	A10	B7	C4-C3
.007783-.007967	A10	B7	C3
.007968	A10	B7-B6	C3
.007969-.008229	A10	B6	C3
.008230	A10-A9	B6	C3
.008231-.009215	A9	B6	C3
.009216	A9-A8	B6	C3
.009217-.009389	A8	B6	C3
.009390	A8	B6-B5	C3
.009391-.010415	A8	B5	C3
.010416	A8-A7	B5	C3
.010417-.010869	A7	B5	C3
.010870	A7	B5	C3-C2
.010871-.011493	A7	B5	C2
.011494	A7	B5-B4	C2

Table A.3--Continued.

Value of γ	Water Price ($ per acre inch) .50	2.50	5.00
.011495-.012047	A7	B4	C2
.012048	A7-A6	B4	C2
.012049-.014183	A6	B4	C2
.014184	A6-A5	B4	C2
.014185-.014813	A5	B4	C2
.014814	A5	B4-B3	C2
.014815-.017391	A5	B3	C2
.017392	A5-A4	B3	C2
.017393-.018181	A4	B3	C2
.018182	A4	B3	C2-C1
.018183-.020617	A4	B3	C1
.020618	A4	B3-B2	C1
.020619-.022221	A4	B2	C1
.022222	A4-A3	B2	C1
.022223-.031249	A3	B2	C1
.031250	A3-A2	B2	C1
.031251-.034481	A2	B2	C1
.034482	A2	B2-B1	C1
.034483-.052631	A2	B1	C1
.052632	A2-A1	B1	C1
.052633-.054053	A1	B1	C1
.054054	A1	B1	C1-C0
.054055-.105263	A1	B1	C0
.105264	A1	B1-B0	C0
.105265-.153845	A1	B0	C0
.153846	A1-A0	B0	C0
.153847-∞	A0	B0	C0

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