An economic evaluation of water harvesting technology

AN ECONOMIC EVALUATION OF WATER HARVESTNG TECHNOLOGY

by

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS v
LIST OF TABLES vi
ABSTRACT vii

1. INTRODUCTION 1

2. SYSTEM DESCRIPTION 6

3. LITERATURE REVIEW 12

Technical Studies 12
Agronomic Studies 24
Socioeconomic Studies 26

4. ANALYTICAL FRAMEWORK 31

Comparative Statics 31
Financial Analysis 40

5. THE PAGE RANCH WATER HARVESTING SYSTEM: AN ECONOMIC CASE STUDY 49

6. GENERAL ANALYSIS - A COMPARATIVE EVALUATION OF THE ECONOMIC AND FINANCIAL PROFITABILITY OF WATER HARVESTING TECHNOLOGY 60

Economic Evaluation 60
Financial Evaluation 75

7. CONCLUSIONS 88

APPENDIX A 91

APPENDIX B 92

LIST OF REFERENCES 95

LIST OF ILLUSTRATIONS

1. Water Harvesting Catchment Design Technologies 2
2. Net cash receipts versus acre-inch requirements 5
3. Catchment Surface Designs 7
4. MVP of Supplemental Irrigation 37
5. Optimal Quantity of Irrigation Water with Varying precipitation Regimes 38
6. Cost Theory Implications to Water Harvesting 41
7. Investment Theory 43
8. Enterprise Budget 58
9. Net Return At Varying Precipitation Regimes 58
10. Enterprise Budgets for Water Harvesting and Conventional Vineyards 71
11. Net Return versus Pumping Depth and Capitalization Rate 73
12. Net Returns Versus Total Cost per Acre-Foot of Irrigation Water 74
13. Net Present Value of a 240 Ton Water Harvesting Vineyard.................................... 77
14. Tax Impacts on the Economics of Water Harvesting 78
15. Net Present Value of a Conventional Vineyard 80
16. NPV Varying Fixed Cost per Acre-Foot of Water 83

LIST OF TABLES

1. Construction Cost Comparisions 21
2. Water Harvesting and Vineyard Construction Budget 51
3. Operational Costs During Vineyard Development:
   Years One and Two 52
   Years Three and Four 53
4. Cost and Returns To Land and Management for an
   Eight acre Vineyard 56
5. Water Requirements for a 110 Acre Vineyard 61
6. Water Requirements for a Forty Acre Vienyard 62
7. Fertilizer Consumption 63
8. Cashflow Budget for a 240 Ton Vineyard Using
   Water Harvesting Technology 67-68
9. Cashflow Budget for a 240 Ton Vineyard Using
   Conventional Irrigation Sources 69-70
10. NPV of a Conventional Vineyard Varying Discount
    Rate and Total Head 81
11. Income Tax Impacts to NPV of a 240 Ton Vineyard
    incorporating Water Harvesting Technology 85
12. Income Tax Impacts to NPV of a 240 Ton Vineyard
    incorporating Conventional Water Sources 86
13. Net Present Value Difference Varying the Income
    Tax Rate and Discount Rate 87
14. Grape Price and Discount Rate Sensitivity of NPV . 92
15. NPV of a Conventional Vineyard and Water Cost
    Relationships 94

ABSTRACT

A economic and financial evaluation is conducted on water harvesting technology comparing it with conventional irrigation resources. The objectives are to estimate comparative profitability of water harvesting and to identify conditions necessary such that water harvesting becomes the preferred technology. Net cashflows from hypothetical 240 ton vineyards using water harvesting technology and conventional water sources are calculated to evaluate economic and financial profitability varying different components of the cost of water, output prices, and discount rates. Results indicate that water harvesting is under present conditions unprofitable compared to conventional sources of irrigation water. The total cost of water from conventional sources required to make water harvesting preferable would have to be six to seven times the 1983 average groundwater prices for southern Arizona. The water harvesting operation is profitable when no other conventional sources of water exist.

CHAPTER ONE

INTRODUCTION

The objective of water harvesting is to provide water to arid land agrisystems from sources other than groundwater or surface water. Plants in arid areas are faced with two problems of water availability, a lack of sufficient total yearly precipitation and a poor seasonal distribution of precipitation. The latter problem is extremely important. Seventy percent of the yearly precipitation for southern Arizona falls in a three month period and therefore a small change in the distribution of precipitation can significantly change the productivity of the desert.

Water harvesting is a technology to provide water to farms and ranches in arid areas by using part of the land to collect and store rain water. The stored reservoir water, is applied during the high consumptive period when there is not sufficient precipitation. The following study is a description of the technology and a prototypical system with an analysis of the economic implications of adopting the technology for agricultural use.

Water harvesting encompasses many different designs. The three main families of designs are the microcatchment system (MCWH), the contoured catchment system (CCWH), and the roaded catchment (RCWH.) Illustrations of the three different designs are given in Figure 1. Microcatchment and contoured catchment have the cultivar located in the collection channel where excess water is channeled into a storage reservoir for use during dry periods. Roaded catchments simply channel water into a storage reservoir.

The advantage of the first two desiigns is that the quantity of water available to the plant relative to the quantity of water from precipitation is maximized. Water flow travels on the roaded catchment farther since, unlike

a. Microcatchment system b. Contoured catchment

c. Roaded Catchment

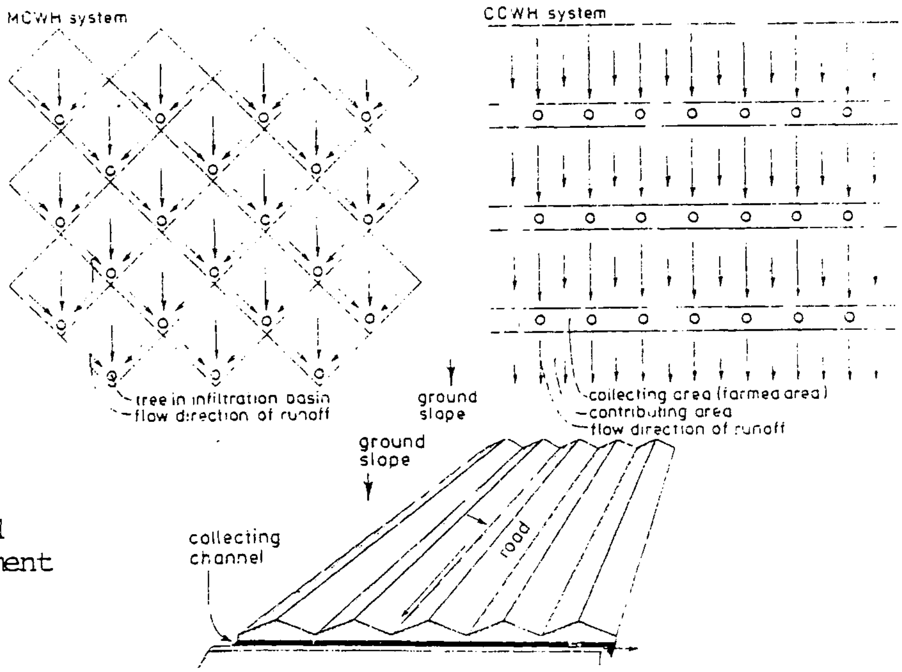

Figure 1 - Water Harvesting Catchment Design Technologies. Microcatchment or micro basin, b. contoured catchment or linear microcatchment, c. Roaded catchment[1].

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[1]Boers, Th., M and J. Ben-Asher, "Harvesting Water in the Desert," in International Institute for Land Reclamation and Improvement Annual Report, 1980, p. 13. The advantage of the first two designs is that the

the former two designs, the roaded catchment does not have the cultivar in the trough of the water collection channel. This longer flow allows more water to be evaporated or lost during seepage. The microcatchment technology circumvents the loss by allowing the seepage to take place around the root system of the plant, thereby increasing soil moisture availability. Plants are thus irrigated by seepage during a rain and then from irrigation during dry periods.

Agrisystems in arid areas must not only contend with ecological and climatological constraints specific to arid areas but with economic constraints. There must be an expected relative gain from adopting the system for farmers to decide in favor of a new technology. The purpose of this analysis is to assess what net benefits may accrue from adoption of such a technology and under what circumstances such a technology may be profitable.

Past research[2] has indicated that water harvesting could be profitable with a high value crop (Karim, 1980.) The ideal crop would be a crop with a high net revenue per acre with a low water requirement to minimize the size of catchment and storage areas necessary, thus reducing the initial capital expenditure for construction. A water harvesting system, in effect, increases the quantity of land

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[2] Karim, Mehboob, "Bayes Simulation of Runoff Volume and Decision Analysis Under Uncertainty," unpublished Masters thesis, System and Industrial Engineering Dept., University of Arizona, 1983, p. 29.

necessary to produce an equal quantity of crop compared with a conventional system.

A survey of crops grown in the arid Southwest shows relatively wide ranges of net returns and water requirements. Net returns and yearly water use for selected Arizona field and fruit crops are plotted in Figure 2. The ideal crop would be a crop in the upper left corner of the graph with a high net return and low water requirement. Most field crops range from 10 to 50 acre-inches with from $300 to $500 of gross revenue per acre. Pecans have a high net revenue but require a lot more water per year (for a mature orchard) than other crops. Crops that do seem to be suitable are wine grapes, pistachios, and apples. Additional factors may restrict the feasibility, such as the initial investment cost and the maturation time for the particular crop. This last factor can become particularly important since revenues do not mature until the crop yield matures. Wine grapes and apples take six years to mature with three years until the first harvest. Pistachios, a very high value crop, take as long as four to six years before a yield begins and do not mature for twelve years.

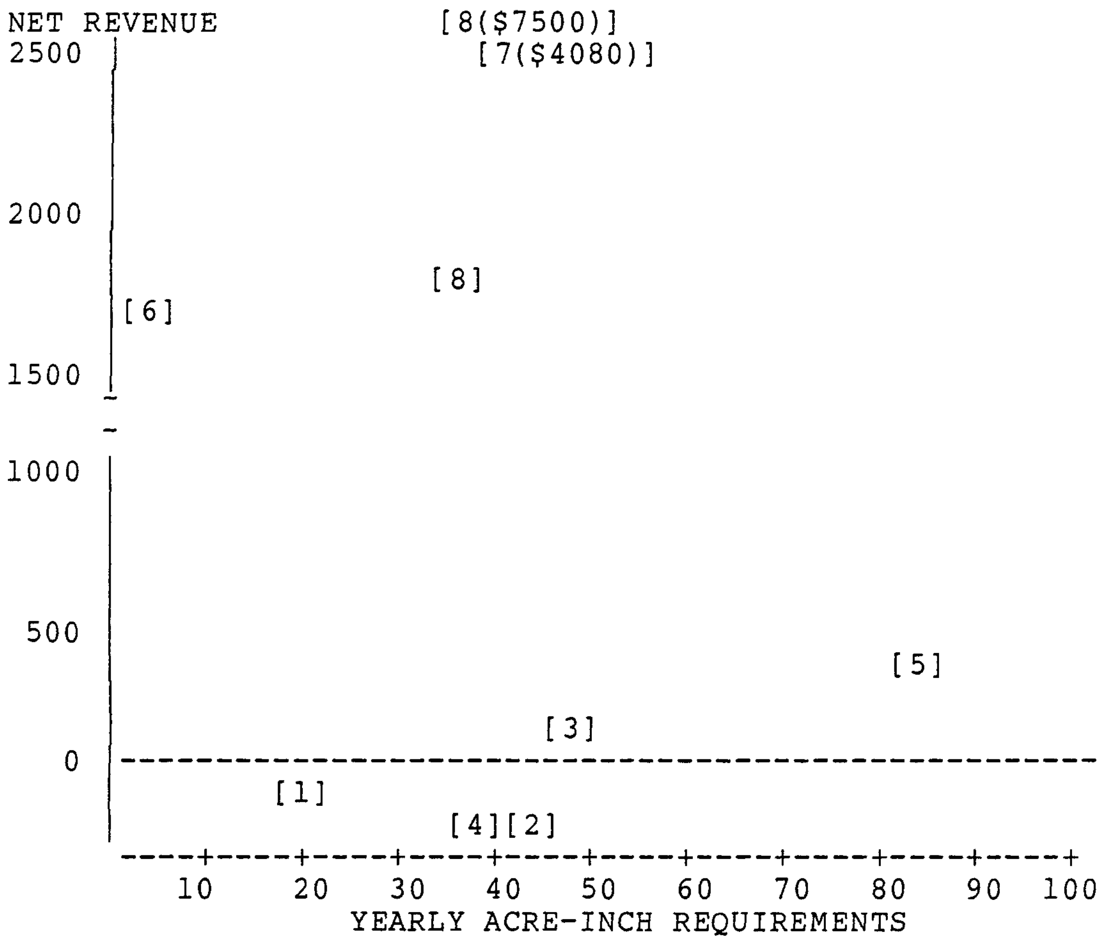

Figure 2 - Net Cash Receipts versus Acre - Inch Requirements Net cash receipts for selected crops grown in Arizona against the yearly water consumption. Paranthetical numbers represent net revenues to save space on the page.The numbers correspond to the crops listed below:

	CROP		COUNTY GROWN
(1)	1.	Alfalfa-hay	Cochise Co.[2]
(1)	2.	Upland Cotton	Cochise Co.[2]
(1)	3.	Pima Cotton	Cochise Co.[2]
(1)	4.	Durham Wheat	Cochise Co.[2]
(2)	5.	Pecans	Pinal Co.[3]
(3)	6.	Wine Grapes	Cochise Co.[4]
(3)	7.	Pistachios	Cochise Co.[4]
(3)	8.	Granny Smith Apple	Cochise Co.[4]

CHAPTER TWO

SYSTEM DESCRIPTION

The water harvesting system to be evaluated is a contoured microcatchment with a sodium treated catchment area and storage reservoir. The catchment area consists of a terrace or gently sloping canal with the sides of the canal used as catchment surfaces. Slopes of catchment surface depends upon the soil characteristics and the precipitation intensity. However, a simplified formula for catchment slope by Shanan and Tadmor (1976) estimate optimal slope equal to:

$$S = 600 / L^2, \text{ where}$$

S is the percentage slope and L is the length of the catchment area.[6]

Catchment configuration varies with the slope (figure 3.) For topographical slopes of less than one percent, the sides of the shallow canal can be used as the catchment area. Surfaces of the canal slope into troughs at a rate of about two to three percent depending upon rainfall

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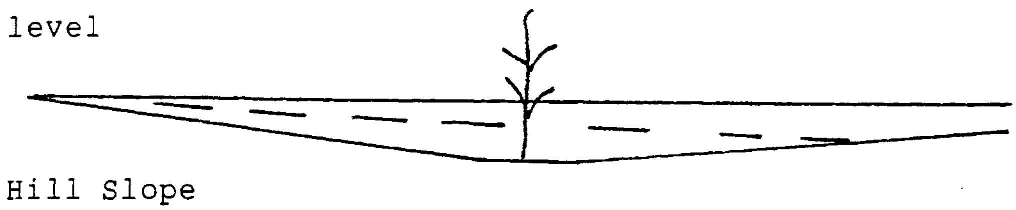
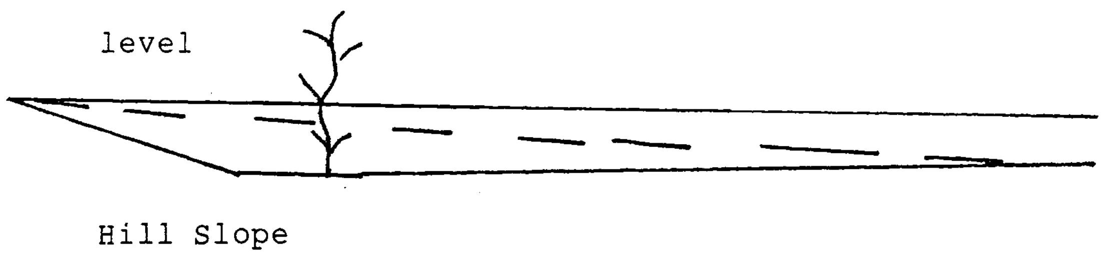
[6]Shanon L. and N.H. Tadmor, Microcatchment Systems for Arid Zone Development, Hebrew University, Jerusalem, 1976 p. 129.

1. Catchment Configuration with slopes of less than one percent.



2. Catchment configuration with slopes of one to two percent.



3. Catchment configuration with slopes of greater than two percent.

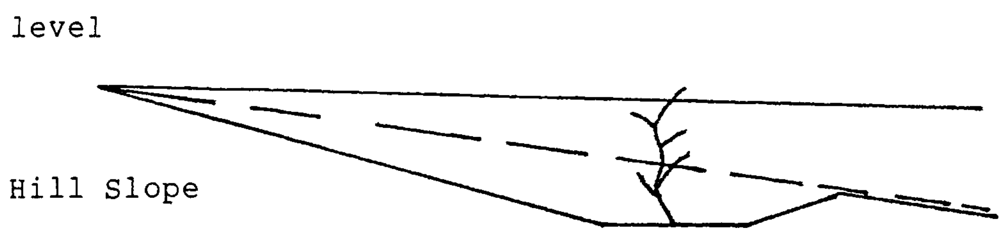


Figure 3. Catchment Surface Design.[7]

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[7] Dutt, Gordon, "Establishment of NaCl-treated Catchments," in Rainfall Collection for Agriculture in Arid and Semiarid Regions, Proceedings of a workshop sponsored by the Commonwealth Agricultural Bureaux, Gordon L. Dutt, C.F. Hutchinson, and M. Anaya Garduño, Editors, 1981.

and soil characteristics. Consequently, the width of the canal or terrace and the catchment surface can be quite large.

On topographical slopes of one to three percent a terrace should be used with the catchment sloping back in toward to the hill. For slopes of greater than three percent, deeper cuts are required to make a terrace so catchment gradient is in the direction of the topographical slope of the hill with a lip on the edge to reduce soil erosion. This design minimizes the disruption of the soil profile.

Catchment length depends upon the quantity of water required by the operation. A simple estimation of catchment length is

$$Cl = (cu/p*\bar{e}) * Cuc$$

where Cl is the catchment length,

cu is the estimated consumptive use of the cultivar in inches per year,

and p is the yearly precipitation rate.

Total efficiency of the water harvesting system, $\bar{e}$ is the product of the catchment and storage efficiencies or

$$\bar{e}= e_S * e_C,$$

where e_S is the catchment efficiency defined as the ratio of quantity of water leaving the catchment area to the quantity of water falling from precipitation and storage efficiency is the ratio of the quantity of water entering the reservoir to the quantity available after evaporation and seepage losses. Cuc is the cultivation area needed to produce the quantity of crop desired.

To reduce seepage and maximize runoff, soil on catchment surfaces is hardened through compaction and chemical treatments such as salt. The recommended quantity of NaCl is eleven tons per hectare. After the first two storms salinity of the water is at a level more than adequate for most agricultural uses.

Water losses result from seepage and evaporation from the catchment surfaces and the reservoir. Runoff efficiency is defined as the quantity of water to flow off the catchment surface relative to the quantity of water falling from precipitation. Runoff efficiency is usually fifty to seventy percent. A Crop is grown in a strip running along the trough of the terrace. Excess water is channeled into a reservoir and stored. The crop therefore, receives water from supplemental irrigation and precipitation, as well as from the seepage resulting from channeling of water from catchment areas.

Water requirements of a crop for a given mean annual rainfall determine the ratio of catchment area to cultivation area. Water harvesting systems are relatively permanent allowing little flexibility to grow different crops on the cultivation area. For instance a system designed for wine grapes, which needs very little water, cannot be used optimally for cotton, which needs more water and therefore, proportionately more catchment area. Given the extreme price variations characteristic of agricultural markets, this lack of flexibility could be a serious problem.

Storage systems can be a single reservoir or compartmentalized reservoirs[7] composed of several small steep walled reservoirs constructed to reduce evaporation (Cluff, et al, 1981). Each reservoir is placed slightly higher than the next with the highest level being filled directly by the runoff. Every time the topmost reservoir is filled, water is let into the lower reservoir until the storage system reaches capacity. Water then is stored for crop needs when it is then pumped back to the cultivation area.

Optimal storage capacity depends upon the maximum difference between water accumulation from runoff and usage. If the time period of use occurs after the primary rainfall period, then storage size should be equal to total irrigation requirements plus storage losses.

Drip irrigaton is an important component of a water harvesting system. By reducing the quantity of supplemental irrigation required through selective application around the root zone of the cultivar, the catchment and storage system

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[8]Cluff, B., "Surface Storage For Water Harvesting Agrisystems," in Rainfall Collection For Agriculture In Arid And Semi-arid Regions G. Dutt, C.F. Hutchinson, and M. Anaya Garduño, Editors, (Commonwealth Agricultural Bureaux, UK, 1981).

can be significantly smaller. Water can either be pumped directly through the drip line to the plant or be pumped to a tank higher than the cultivation area and be gravity fed. Since water is not being pumped from deep beneath the ground, the pump used on a water harvesting system can be of smaller horsepower than otherwise needed. One advantage of the water harvesting system is that pumping costs should be minimal. Pumping either from the reservoir directly into the system or up to a holding tank above the cultivation area to gravity feed down to the system should be less expensive than pumping from anything but a shallow well. This system would therefore be useful in areas where energy costs for ground water pumping, fixed or variable, or where transportation of surface water are prohibitively high.

CHAPTER THREE

LITERATURE REVIEW

The following is a general literature review of the agronomic, engineering, social, and economic aspects of water harvesting technology relavent to this study. For a complete bibliography of literature on water harvesting and runoff farming see A Bibliography of Water Harvesting/Runoff Farming and Small Scale Water Management Systems(1984.)

Technical Studies

Water harvesting is an ancient concept with objectives today very much the same as they were a thousand years ago. New technological innovations and resource scarcity have given it a new relevance in the arid Southwest as well as in the developing world. Boers and Ben-Asher (1980) define three different water harvesting designs: roaded catchment, runoff farming, and microcatchments with a variation of the microcatchment being the linear or contour catchment. The difference between roaded catchments and linear catchment are that crops being grown in linear catchment are grown in the canal used to channel the excess water to the storage reservoir. The objective of water harvesting as stated by the authors is to supplement alternative sources. Ground water resources for instance, are used only when harvested rainwater is deficient or of too low quality.

Microcatchments are designed for intensive agriculture in arid areas. The engineering aspects of different types of hydrophobic catchment surfaces have been investigated extensively. Compacted earth catchments (CE) are simply catchment surfaces compacted to increase the runoff. Compaction destroys the natural soil structure creating monolithic surface that retards infiltration by precipitation. Surface designs like the CE have been used extensively in roaded catchments to collect water for livestock use. Cluff and Dutt (1973) estimated that a catchment surface of this type would have a runoff efficiency of thirty to sixty percent. On an experimental plot 300 feet long with two canals fifty feet wide, a 19 inch yearly precipitation yielded almost seven inches of runoff or a runoff efficiency of 35%. The amount of precipitation required to initiate runoff was 0.2 inches. Construction costs per acre in 1972 dollars were estimated to range from $150 to $250.

Cluff and Frobel (1976) estimated runoff efficiency at 30 to 50 percent. CE designs would not be appropriate for soil types such as heavy clays, friable clays, coarse gravel with little or no clay, and sandy soils. CE surfaces were not a recommended construction design on soils with less than 3 percent clay nor over 25 percent gravel.

Compacted earth - sodium treated catchments (CEST) have been evaluated most extensively in relation to microcatchment systems for intensive agriculture. CLuff and Dutt (1973) report that experimental plots with NaCl at the University of Arizona reduced infiltration of rain into the subsoil but that the effect is temporary. Sodium causes clay lenses in the soil that significantly reduce infiltration rate. The lenses however, move down the soil profile instead of with the runoff and the infiltration rates evenutually returns to their former state. Five tons of sodium per acre is applied using a fertilizer spreader and a rock rake to mix the salt at a depth of two inches. Surfaces are then compacted after a rain.

Water quality of the CEST catchments is low due to the salinity. However, the quality is sufficient for agricultural and livestock use. Cluff and Frobel report that on CEST catchments, water quality is less than 1000 ppm after the first rain and drops to less than 200 ppm after the first two rain showers.

Dutt (1981) discussed proper catchment design and slope for contoured microcatchments. Optimum catchment shape should maximize runoff and minimize soil erosion. Drawing from research conducted by Shanon and Tadmor(1979), catchment lengths were estimated for different water supply rates. These rates are based upon the rainfall intensity observed for a given area.

Dutt also discussed proper catchment design for different slopes. Three designs, discussed in the first chapter depend upon the general slope of the terrain and can be constructed by hand tools or moldboard plow.

Catchment slope can be determined by a number different ways. Cluff and Frobel (1976) drew information from the Western Australia Department of Agriculture to recommend catchment gradients two percent at the top of the catchment to 0.25 percent near the trough to reduce the erosion effect. Dutt (1981) uses formulas by Shanon and Tadmor (1979) that relates catchment slope to length and expected precipitation intensity. Flug (1981) uses a simpler formula to estimate maximum catchment slope which was developed in an earlier study by Shanon and Tadmor (1976). Maximum catchment slope can be estimated by the following equation:

$$S = 600 / L^2$$

where S is the catchment gradient in percent and L is slope length in meters.

Paraffin is another possible treatment surface. Cluff and Frobel (1976) recommend an application of approximately one to two pounds per square yard. High soil temperatures characteristic of arid areas then melt the wax into the soil. Runoff efficiencies of 90% have been observed from wax catchment surfaces. Melted paraffin can also be sprayed onto the surface of the catchment area.

A significant amount of research has been done using synthetic membranes. Though most of the the research has shown synthetic membranes to be too costly, a general description of some of the major types is included here. This review will cover only some of the definitive studies on these synthetic membranes.

Gravel-covered-plastic(GCP) catchments use plastic sheeting with a layer of small gravel 1/2 inch to one inch covering the plastic. Cluff and Dutt (1973) compared several different catchment surfaces and compared effectiveness and amortized construction costs in 1972 dollars per acre and per 1000 gallons of water harvested for compacted earth (CE), compacted earth - sodium treated (CEST), gravel covered plastic (GCP), and asphalt plastic - asphalt chip coat (AP-AC).

Total construction costs for a one acre CE system were estimated to be $250.00 or $0.18 per 1000 gallons. They based they their costs on a twenty year life, a six percent interest rate, and twelve inches yearly precipitation. Catchment efficiency was assumed to be 35 percent. Catchment efficiency is defined as the volume of runoff divided by the volume of precipitation.

The total construction costs for a one acre CEST system were estimated to be $450.00 or $0.16 per 1000 gallons for a twenty-five year life, twelve inches of precipitation, and a six percent interest rate. Catchment efficiency for CEST was estimated to be at fifty percent. Maintenance costs are expected to be higher than the CE system.

Costs for the GCP system were estimated to be at $1000.00 per acre or $0.35 per 1000 gallons. However costs for this type of system will vary greatly depending upon local conditions and local materials prices. Catchment life was expected to be at 25 years and catchment efficiency at 70 percent.

Costs for AP-AC system were estimated to be twice the costs of the GCP system. AP-AC was seen to have several advantages. First, it uses half the gravel of the GCP system. Second, the AP-AC system can be used on any soil type, and thirdly, the estimated life was between 25 - 30 years.

The authors also evaluated three storage designs, plastic lined - rock filled reservoir, cement coated or earth covered plastic, and the sodium treated compacted earth reservoir. Construction designs were then described with different evaporation control methods. The authors concluded that CEST and CE catchments were the most cost effective but were limited to areas where soil conditions were favorable. Clay content in the soil should not exceed 35 percent or be less than 5 percent.

Cluff and Frobel (1978) review seven different catchment construction designs and evaporation and seepage control methods for storage reservoirs. The purpose of the paper was to demonstrate "that there are several viable methods of constructing water harvesting systems that can be cost competitive with more conventional methods of supplying stock or domestic water for small systems."

Land alteration and compacted earth were presented as the basic and least expensive catchment design. Land alteration is simply clearing the vegetation and rocks off the catchment area while CE catchments take the concept one step further and compact the soil to reduce seepage through the catchment.

Sodium salts on CEST catchments are an effective way of increasing the impermeability of soils to increase catchment efficiency. The authors recommend spreading a sodium salt after a rain and then compacting the catchment at a rate of 5 tons per acre. Water quality is more than adequate for agricultural or livestock use. Sodium treatment can be used on soils with a clay content between five to thirty percent. On expanding clays sodium is effective on soils with a clay content between 15 percent and 20 percent.

Pulverized paraffin wax is another relatively inexpensive treatment. The wax can be hand applied at a rate of one to two pounds per square yard. Runoff efficiency of 90 percent has been observed but the authors recommend using wax only on catchment area and not on the storage reservoir. Furthermore wax is better suited for sandy soils.

GCP catchments utilize polyethylene plastic with one half inch to one inch cover of gravel on top. The gravel cover protects the plastic and holds it down. The authors caution that since this design retains a certain amount of precipitation GCP catchments should not be used in climates where a substantial portion of the precipitation falls in increments .25 inches to .50 inches. Two advantages of GCP catchments are that the quality of water is good enough for domestic use and that hand labor alone can be used if machines are not available.

Asphalt based catchments provide the highest runoff efficiency of all the different designs but the materials are the most expensive and requires the most mechanization in constructing the surfaces. Variations of the asphalt surfaces range from the asphalt- rubber and asphalt concrete to fiberglass asphalt chipcoated and the AP-AC surfaces described above.

The authors also compared several kinds of seepage control methods. These methods were CEST linings, bentonite clay, soil cement mixtures, synthetic membranes, concrete liners, and AP-AC linings. The authors investigate the alternative methods of seepage control for the storage reservoirs. Sodium salts provide a good impermeable barrier as in the CEST catchment. The authors recommend an application rate of 2.6 to 3.9 pounds per square yard depending upon the soil requirements.

Bentonite clay also provides a good impermeable barrier when it is available. A treatment rate of one pound per square foot is recommended for high clay soils and three to four pounds per square foot for very sandy soils. Bentonite should not be used on surfaces with alternate periods of wet and dry because the effectiveness of the layer is reduced. Cost comparisons were found to vary substantially ranging from $0.31/ sq. meter to $1.45/ sq. meter for CEST catchments to $0.60/sq. meter to $4.50/ sq. meter for synthetic membranes.

Evaporation control is seen by the authors to be very important because "evaporation losses often exceed the water beneficially consumed." Different evaporation control methods evaluated are compartmented reservoirs, sand and rock filled dams, floating covers, and suspended covers. The estimated capital cost and percent effectiveness were calculated for each. The authors base percent effectiveness on a complete cover compared with evaporation loss with no treatment. The percent effectiveness for compartmented reservoirs ranged for thirty to eighty percent effective and sand and rock filled reservoirs were judged to be eighty to ninety percent effective. Capital costs were not determined since they would be site specific. Floating covers were seventy to one hundred percent effective with capital costs ranging from $0.40/sq. meter for the polyethylene sheeting to $4.00/sq. meter for the lightweight concrete slabs.

suspended covers were estimated to be 95% to 100% effective but were substantially more expensive.

Comparisons of estimated costs between Cluff and Dutt (1973) and Cluff and Frobel (1978) show a large range in purportedly the same design. Since the earlier study did not evaluate costs for storage design, catchment area costs are only shown in Table 1. Cooley, et al (1974) argue that

TYPE	COSTS$ /ACRE	COSTS$ /1000 GAL	LIFE (yrs)	INT* %	PRE** (in)	RUN*** EFF.
Cluff and Dutt						
CE	250	.18	20	6	12	.3
CEST	450	.20	25	6	12	.5
CEST	450	.16	25	6	16	.5
GCP	1000	.35	25	6	12	.9
AP-AC	2000	.70	25	6	12	.9
Cluff and Frobel						
CE	89	.30	20	8	12	.3
CEST	415	.39	20	8	12	.5-.7
GCP	1779	.97	20	8	12	.6-.8
AP-AC	2224	.66	15	8	12	.9-1.0

Table 1 - Construction Cost Comparisions.
Differences in construction costs and assumptions between Cluff and Dutt (1973) and Cluff and Frobel (1976.)
All costs in 1972 dollars.
*Int = amortization rate
** The Yearly precipitation rate in inches
*** Runoff Efficiency

----

evaporation control methods can result in significant cost savings for owners of water storage facilities. He evaluated several different methods and found floating covers generally preferable to suspended covers. Floating covers can provide additional water for one dollar per thousand gallons. Cooley presents a case study of a rancher in central Arizona who hauls water by truck for a distance of four miles. This ranch would realize a cost savings of $55.00 per year if evaporation control methods were incorporated.

Dedrick (1974) discussed the importance of appropriate system sizing in determining the economic feasibility of water harvesting for a given area. An "allowable" rate of water loss through seepage and evaporation was determined based on the initial total construction cost. Costs are based on a 7000 square foot steel catchment with a 16700 gallon storage tank. Dedrick noted a logarithmic increase in cost associated with a linear increase in storage loss due to evaporation and seepage.

Frasier (1974) estimated the cost of water from water harvesting systems in terms of catchment costs and storage costs. Catchment costs were determined to be a function of total precipitation, construction costs, runoff efficiency, and the life of the design. Storage costs are dependent upon construction costs, the life of the storage system, and the number of times the facility will be filled. Frasier concludes that water harvesting systems can cost as little as $1.50 per 1000 liters.

Ryan, Sarin, and Pereira (1979) examined water harvesting potential on different soil types and examined problems of risk and uncertainty for small farmers in the semi-arid tropics of peninsular India. They determined that water harvesting was more viable on alfisols than on vertisols because of the montmorillinitic content of vertisols. Montmorillinite cracks when it dries thus destroying the seal for the water harvesting system. The authors concluded that a water harvesting system could reduce the risk facing the small farmer if the costs were shared over several users.

Dutt (1981) evaluated catchment shape and slope to maximize runoff and minimize soil erosion. Catchment design depends on the shape and slope of the terrain and catchment slope depends upon the soil characteristics. By making the catchment conform to the characteristics of the terrain, the catchment to cultivation area ratio can be reduced.

Water reliability on a water harvesting system can be improved by accounting for the variability of precipitation in the design of the system. Dietterick (1982) developed a simulation model for a roaded catchment and reservoir system with a precipitation rate with a probability distribution of rainfall similar to Arizona. Reliability was measured in the probability and number of dry reservoir days. Two reservoirs sizes were constructed: reservoir one with a capacity of 75% of mean annual runoff from the catchment areas, and reservoir two with a capacity of 36% of mean annual runoff. Demand for water was then varied at 25% of mean annual runoff, 50% mean annual runoff, and 75% of mean annual runoff. Dietterick concluded that the smaller reservoir was adequate at the lower annual demand for water, but that as the requirement increased the larger size was needed to compensate for the variation in rainfall.

Agronomic Studies

Fangmeier (1974) studied the production of various annual crops using a simulated water harvesting agrisystem in an area with a yearly annual rainfall of six inches. A short season grain sorghum was select for the first three years. Canteloupe, cucumbers, squash, and watermelon were selected for the following seven years. Two plots were constructed, one simulating the quantity of water from catchment to cultivation area ratio of three to one and the second simulating a catchment to cultivation area ratio of five to one. Results of the experiment were inconsistent resulting from the faulty experimental design. Fangmeier recommended that more research needed to be done on the design for water harvesting to be viable.

Jones and Hauser (1974) studied grain production on conservation bench terraces (CBT) in an area with an annual precipitation of seven centimeters per year. The objective was to study the effect of increased soil moisture availability on production. Since the design of the CBT is similar to the design of contoured microcatchment without supplemental water storage systems, the results of this experiment were deemed relevant to the study of water harvesting. The authors found that leveling, resulting from the design of the CBT, increases soil moisture availability for plants and therefore, increased yields by as much as eighty percent.

Leubs and Lag (1974) studied water harvesting for barley production in an area of average annual precipitation of 36 centimeters. A plot irrigated by water harvesting and a control plot were set up. They found that the particular agrisystem design exacerbated problem of water availability, i.e. too little water during some periods while too much water during other periods. However, they also noted that barley production doubled by water harvesting on the basis of area cropped, though by including catchment area on total acreage, small yield increases were obtained. The conclusion drawn was that water harvesting can be a viable technology but that more research needed to be done concerning system design.

Mielke and Dutt evaluated deciduous tree and vine fruit production on microcatchment at Page Ranch Experimental Unit. Initial results showed that wine grapes can be adapted to water harvesting agrisystem without noticeable defects in the quality of wine produced. The authors noted that since only 18 percent of the moisture infiltrating the soil at the base of the plant came from supplemental water stored in reservoirs, wine grape production can occur with only supplemental irrigation.

Socioeconomic Studies

Karim (1983) statistically validated a stochastic simulation model of watershed runoff and provided a Bayesian methodology to design water harvesting systems for irrigation. With a minimum of input data and a crop price for sugar beets of $60 per ton, he developed a set of loss functions by varying the infiltration constant. Karim concluded that the model was sound and that minimum economic loss (using loss functions) occurred when twenty percent of the land was in catchment area. He also concluded through sensitivity analysis that water harvesting would pay off with a high value crop.

In a complete economic evaluation Oron, Ben-Asher, Issar, and Boers (1983) estimated net returns per hectare per year on a microcatchment water harvesting system (MCWH) with technology to enhance infiltration and soil moisture storage. The authors evaluated a cellular microcatchment design defined as an area of a few hundred square meters which is used as a water harvesting element for a single tree.

Almonds were produced in two areas, the dry zone (DZ) with a yearly precipitation of 250mm and the the highly dry (HDZ) with a yearly precipitation of 150mm. The catchment area was varied in both areas and infiltration pipes (inserts) were placed in a proportion of the catchment reduce the amount of rainfall loss from evaporation.

In the HDZ, net losses occurred at all catchment area sizes without the insert and all catchment area regardless of whether inserts were present. Income (or loss) improvement from the inserts occured at all catchment sizes.

The net return for the DZ was positive for the MCWH without inserts at only the 250 sq. meter size and positive for all catchment sizes with inserts. Net returns increased significantly for catchment areas below 250 sq. meters, however, as density increases, nutritional qualities of the soil become a limiting factor. Income improvement due to the use of inserts at the catchment area of 100 sq. meters was 162.9%.

Luben and Angus (1983) compared the cost of water from water harvesting to alternative sources of irrigation water available in southern Arizona and outlined an evaluation procedure for estimating the cost of water harvesting. Water costs for different catchment designs were estimated at different levels of precipitation and then compared with domestic water costs for two Arizona communities relying on ground water: Avra Valley and Tucson, Central Arizona Project (CAP) water costs, and average pump water costs in the area. Water costs for compacted earth structures were found to be competitive to Avra Valley and Tucson domestic water at precipitation rates of 210mm and 365mm and competitive to CAP water at 750 mm. CEST designs were found to be competitive to Avra Valley and Tucson domestic water for areas with precipitation rates above 171mm and 235mm respectively. None of the synthetic membranes were found to be competitive with subsidized CAP water costs or average pump water costs for the area.

Luben and Angus then compared a water harvesting system with five different wells, each producing different quantities of water and one that produces about as much water as the water harvesting system constructed by researchers at the University of Arizona. Total annual costs per acre foot of water from the water harvesting system were estimated to be approximately three times higher than water produced from a well. Construction costs were also estimated to be three times higher than well costs.

Wright, Karpiscak, and Foster (1983) estimated construction costs for a water harvesting agrisystem including the pre-planting costs on retired farmland in Avra Valley, Arizona. The city of Tucson purchased the water rights for urban use so the development of the system is an attempt to return the land back to agricultural production without dependence upon ground water or CAP water. Real cConstruction costs for the first five acres are $10,056 and for the second five acres, $8890. The authors believe that significant economies of size could be achieved.

The introduction of irrigation projects can have a significant impact upon society in terms of income distribution and property rights, as well as economic impacts. Therefore, the adoption of a project will depend upon how it impacts the community. Water harvesting, like the introduction of any new technology, will have an impact upon the social structure and the success or failure will depend upon how the community views the feasibility of the technology as well as its impact upon the social structure.

Nabhan, et al (1980) studied the use of floodwater farming for tepary bean production on the Papago Indian Reservation in Arizona. The tepary bean, a historical food source of the Papago Indian, has been produced on small plots irrigated by floodwater from intermittent rains in the arid southwest. Bean production on the traditional plots are 250kg./ha. to 900kg./ha. Though the incidence of floodwater farming is in a decline, the authors conclude that the system is viable if given the appropriate economic and social incentives though no examples of possible incentives were given.

Bentley (1982) discussed the social impacts of water harvesting for village water supply, stabilizing subsistence farming systems, and promoting cash crop production in areas with adequate land resources but inadequate water resources. Bentley states, "The acceptance or rejection [of the three possible water harvesting applications] will in many cases be a direct result of the attention paid to social issues from the very conception of the development process."

The author outlines problems that present applications of water harvesting have encountered. In particular since water harvesting systems require more maintenance than wells or other sources, deterioration of the system is a chronic problem. He states: "At present, especially on Indian reservations in Arizona, there are more abandoned than functioning water harvesters."

Bentley recommends that a water harvesting projects should incorporate into project design, social constraints that may affect the outcome of the project. Goals should be made with an adequate knowledge of what the community goals are. The importance the community places on the expected net benefits should be ascertained since this will have a direct bearing on the their willingness to maintain the system. The effects on work roles within the community and appropriate technology for the local situation must be ascertained. Finally, if supporting sectors are needed, e.g. markets, supplies, etc., are they available?

Finally Bentley recommends a systematic outline of criteria for high quality social analysis and the need for ex-post evaluations on functioning projects.

CHAPTER FOUR

ANALYTICAL FRAMEWORK

Comparative Statics

The farm as an economic enterprise will optimize inputs and outputs with the assumed objective of maximizing the present value of net returns. Relationships between inputs and outputs can be represented by a long run production function where output (y) is a function of all the set of inputs required to produce "y", or:

(1) $$y = Y(t,w,x1,\ldots,xn)$$

where t is the amount of land required, w is the quantity of water applied and x1 through xn are the other inputs required. A restricted total product function (2) which relates output to land (t) and water (w) will can be used to describe the technology. Perfect competition in all input markets and holding all other inputs constant is assumed.

(2) $$y = Y(t,w)$$

The optimal mix of inputs at any given output is the level of inputs where the ratio of marginal products of the inputs are equal to the ratio of the input prices:

(3) $$MPP_t / MPP_w = MUC_t / MUC_w$$

Maximization of profits requires an optimal mix of inputs and outputs occur where the marginal product of an input equals the ratio of it's marginal unit cost to the price of the output:

(4) $$MPP_t = MUC_t / P_y$$

and

(5) $$MPP_w = MUC_w / P_y$$

Rearranging (4) and (5), the factor product conditions for the operation are:

(6) $$MVP_t = MUC_t$$

and

(7) $$MVP_w = MUC_w$$

If the MUC_t increases, the optimal quantity of land decreases.

For a standard vineyard, the relationship between land and water is strictly economically determined (3). However, under a water harvesting system, water is a function of the catchment area and therefore, a function of land area. A simple estimation of water collection as a function of land area[9] is that the quantity of water

[9]Personal communication with Dr. Gordon Dutt, Dept. of Soils and Water Engineering, University of Arizona, Tucson, March, 1985.

collected is a function of the catchment area and precipitation:

(8) $$w = P * e * Ca$$

where w is water in inches per unit area, P is yearly precipitation rate, and Ca is catchment area. Precipitation rate is multiplied by an efficiency factor "e", where e is the product of the catchment efficiency e_r and the storage efficiency e_s.

The catchment area needed for supplemental irrigation can be approximated modifying (9). For a given consumptive use requirement of the cultivar (cu) and cultivation area (V), precipitation rate (P), and efficiency factor (e), the catchment area needed is:

(9) $$Ca = (cu-P)/e * V$$

Like the conventional system, the total product for water harvesting is a function of land and water (11).

(10) $$y_{wh} = Y(t,w)$$

As in the conventional system (2), (t) is the total land area used and (w) is water used water w = P*e*Ca as defined above in equation (9) and the input "t" only relates to the area under cultivation. Land and water inputs under water harvesting however,have a distinctly different relationship than under conventional technology. Since water is a function of land area in water harvesting, the two inputs are much more complementary in nature. If more water is required, then more catchment area is needed.

The catchment design also increases the soil moisture storage ability. Since the catchments are similar to conservation bench terraces, it follows that since there is increased soil moisture storage with CBT's then there should be increased soil moisture storage with water harvesting (contrasting water harvesting with a conventional system without terraces.)

The total cost of water becomes a function of three factors: the price of pumping water from the reservoir, the cost of constructing the catchment and reservoir, and the market value of the extra land. The construction and development costs of the water harvesting system is a problem of optimal sizing. The size of the system has to account for the inherent variability of rainfall as well as possible future changes in crops grown, and therefore, different water requirements.

The total cost of the system given two inputs is a function of the variable cost which is a function of the crop-water relationship and pumping cost and the fixed cost of the system (11).

(11) $TC_{wh} = c*W(y) + k*((cu-P)/e)*V + r*Ca + r*t$

where c equals the pumping cost and W(y) is the water used for a given output level. The remainder of (11) is the fixed cost which is comprised of development costs and land costs for the water harvesting system. Construction costs of the catchment and storage system are based on the size needed to provide consumptive requirements of the cultivar. Sizing is estimated by dividing the difference between the consumptive use (cu) of the crop and precipitation rate (P), (cu-P), by the system efficiency and multiplying by the size of cultivation area (V). The last factor "r" is the market price of the land. Assuming that the infrastructure costs are fixed, the marginal unit cost of water is simply pumping cost, (12).

$$(12) \qquad MUC_w = d(c*W(y) + k*((cu-P)/e)*V + r*Ca)/dw$$
$$= d(c*W(y))/dw$$

For simplicity, input markets are assumed to be perfectly competitive. However, since crop water requirements can make the catchment area to cultivation area range as high as fifteen to one, it is conceivable that in an area where farmers cluster around each other the market for land may become imperfect if widespread adoption of the technology occurs. Then the MUC of water under water harvesting will be:

$$MUC_w = d(c*W(y) + k*((c-P)/e)*t + r(t))/dw$$
$$(13) \qquad = d(c*W(y) + D(r))/dw,$$

where (t), total land area is a function of cultivation area and catchment area. For simplicity though the analysis will assume perfectly competitive land markets. The factor product conditions for water become:

(14) $$MVP_W = d(c*W(y))/dw$$

Because of the increase in land required for a water harvesting system, the effect on the optimal quantity of water for a water harvesting system will be distinctly different. The increased soil moisture storage will shift the value product curves to the left (assuming ceteris paribus conditions,) in figure 4 when comparing water harvesting system with a conventional system with no water conserving technology. The reduction in water use however, is more than compensated for by the increase in the quantity of land used.

Precipitation rates will have an impact on not only the MVP of water in the water harvesting system, but also on the marginal unit cost of water. Given a total product function, shifting the same hypothetical function froma proecipitation regime of a lower yearly rate to a higher yearly rate, the marginal value of supplemental irrigation should to shift to the left. The same operation at a different precipitation regime would necessarily require a different fixed as well as variable input mix. Therefore viewing the operation from a total product function, the higher the annual precipitation rate the less supplemental irrigation required. In the shortrun the operator would move along the MVP curve but in the long run would adjust

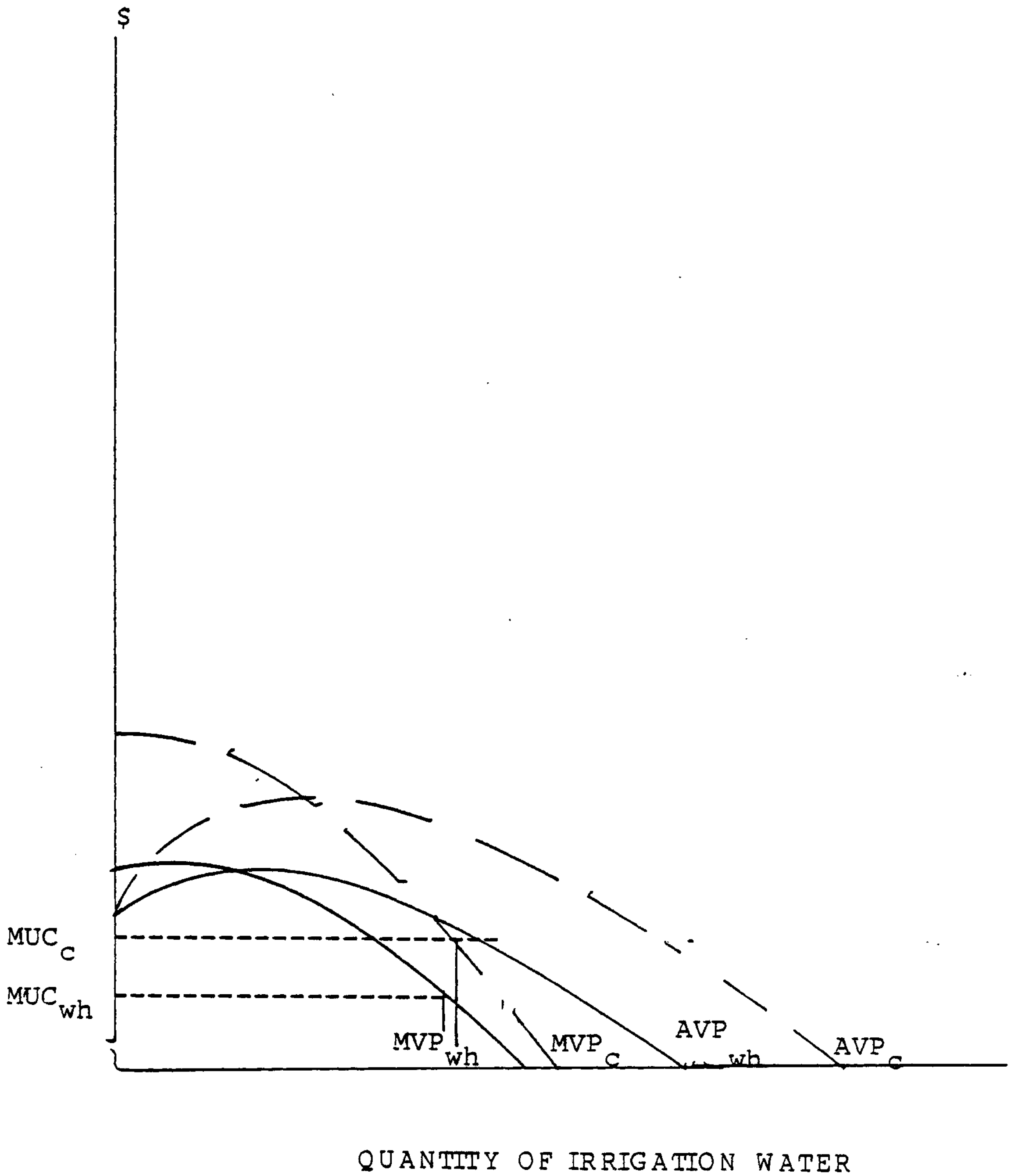
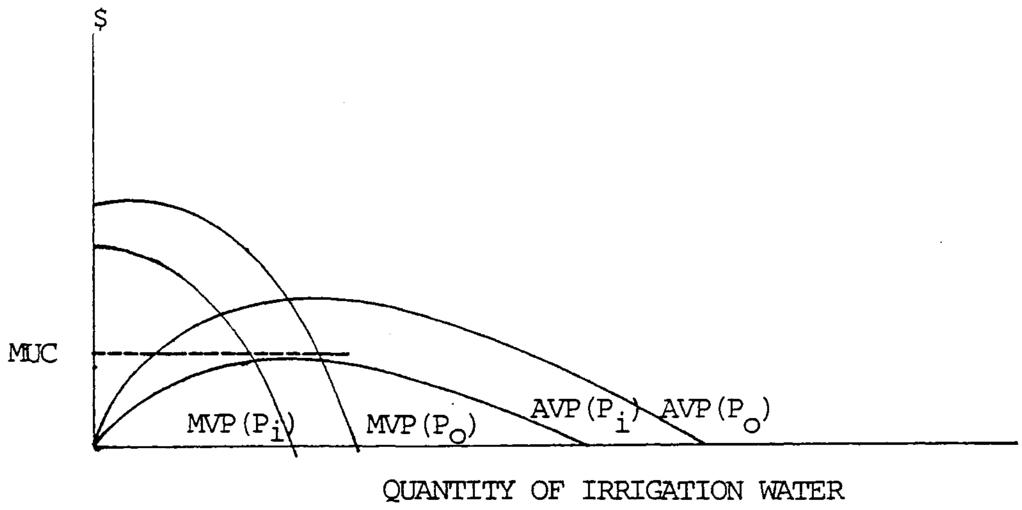


Figure 4. MVP of Supplemental Irrigation.

The impact of water harvesting technology on the value product function of water. The subtitles "wh" correspond to adoption of water harvesting.



Optimal quantity of inputs for a conventional system

Figure

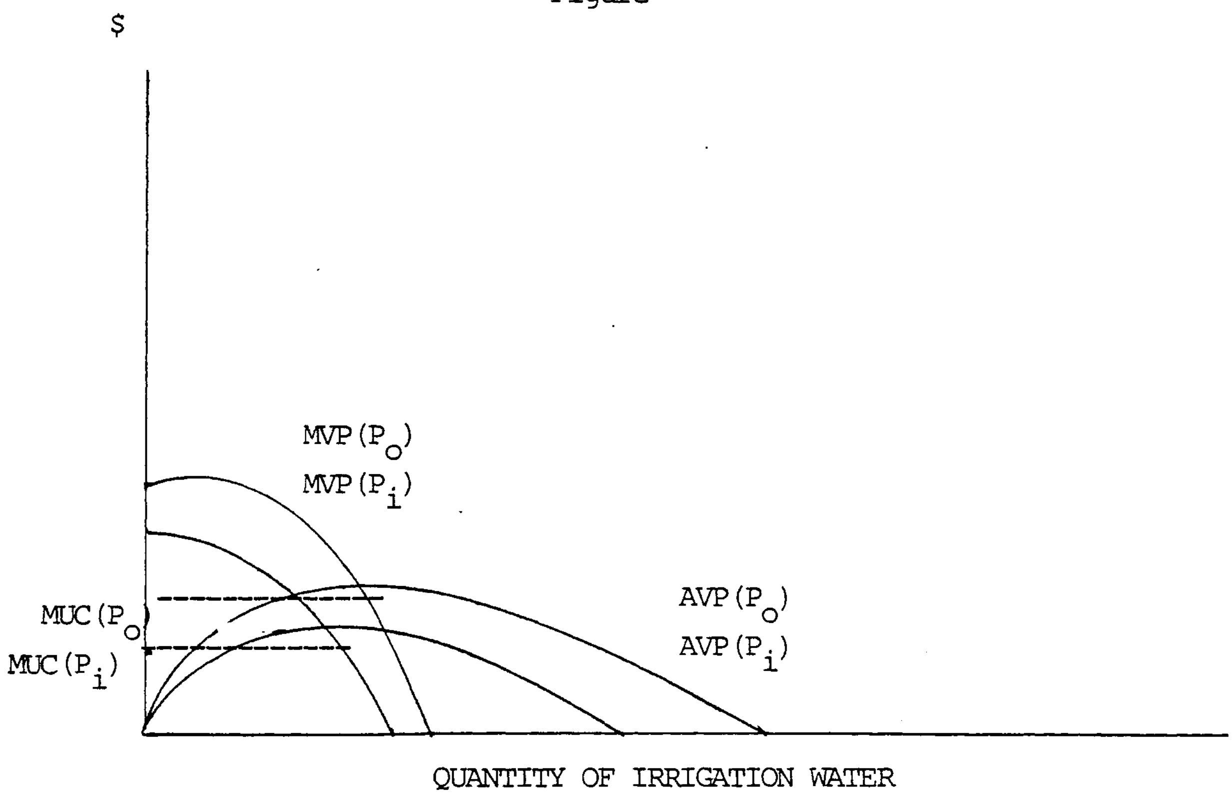


Figure 5. Optimal Quantity of Irrigation Water with Varying Precipitation Regimes.

Factor product relationships for water harvesting and conventional technologies with varying mean annual precipitation rates (P.) $P_i > P^o$

capital and other inputs that are fixed in the short run view, causing the the total product curve to shift. In the case of an increase in mean annual precipitation, the total product curve should shift left since less supplemental irrigation is required.

The impact of an increase in the annual precipitation rate (P) is illustrated in figure 5. The increased precipitation P_o to P_i causes the marginal product of irrigation water to shift to the left in the conventional system. The optimal quantity of water in the conventional system, that quantity where MUC = MPP shifts to the left. The MUC of water is in this analysis a function of depth of lift so remains the same.

The mean annual precipitation rate affects the MVP curve of the water harvesting system in the same manner as conventional systems. The marginal unit cost of water under the water harvesting system would stay the same since MUC reflects primarily energy and labor costs associated with irrigation.

The economic impact of water harvesting can be viewed more clearly in a cost analysis. The significant amount of land movement required to construct the system implies that a trade-off between variable costs and fixed costs occurs between the two technologies. Pumping lift (and therefore costs) for a water harvesting system are obviously lower than all but the most shallow wells. However, due to extensive design of a water harvesting system, the infrastructure costs would be significantly higher. Since irrigation infrastructure costs are generally one-time costs, these costs would be part of the fixed costs of the operation.

Figure 6 shows a comparision of the cost curves for a new technologies with a typical set of cost curves belonging to a conventional operation. High infrastructure costs coupled with the low energy costs shift the average fixed cost curve up while shifting the average variable cost curve down.

Input and output price relationships are arbitrary in Figure 6 so no real a priori conclusion can be made from the analysis. Economic theory states that a firm will exit the market when average revenue can no longer cover average variable costs so adoption of technology that "substitutes" fixed costs for variable costs would seem to benefit the farmer and help "insulate" the operation from unanticipated reductions in output price because in the long run average fixed costs continue to decrease. This apparent benefit in adoption of technology however, only illustrates shortcomings of static analysis. Higher fixed costs translates to higher debt loads in the real world.

Financial Analysis

Most technological innovations can be considered an investment, i.e. an expenditure now for the specific purpose

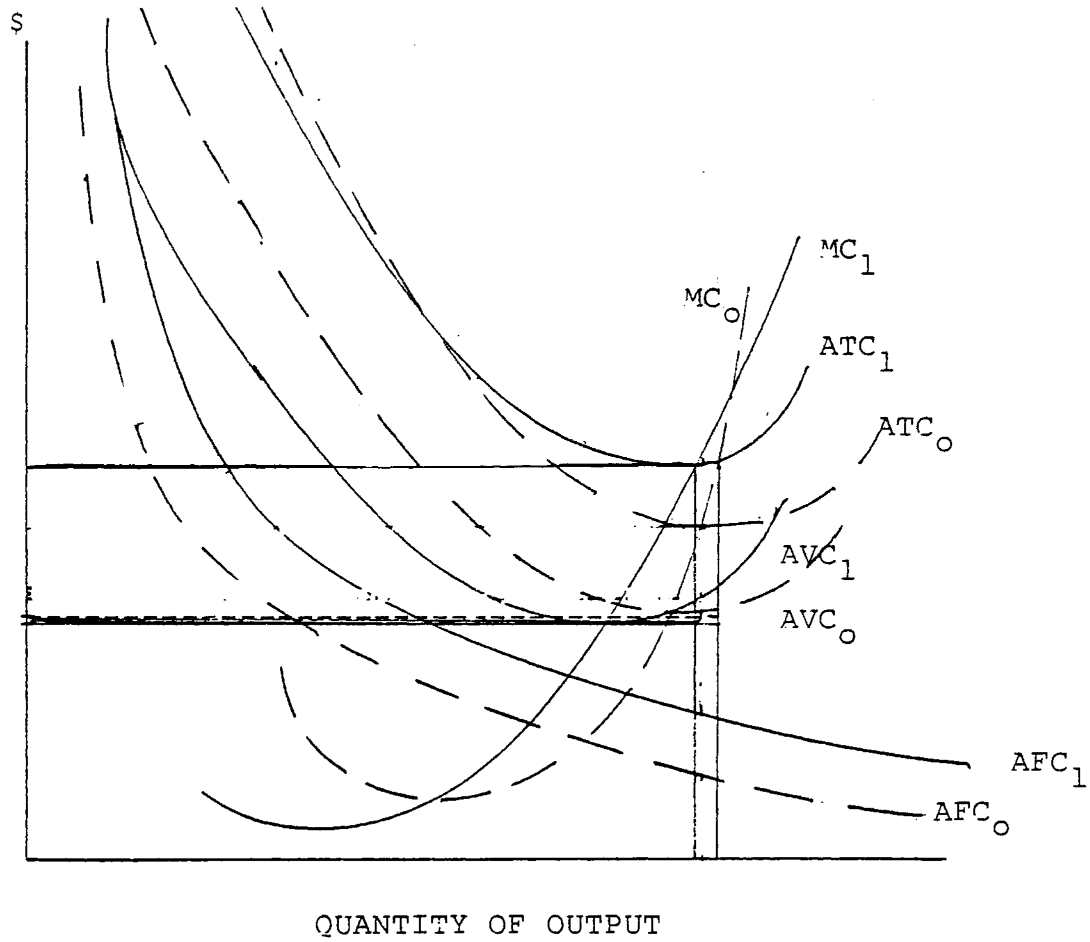


Figure 6. Cost Theory Implications to Water Harvesting.

The impact of a technology like water harvesting increases quasi-rent. Cost curves subtitled with "o" represent an operation without the technology while "1" represent an operation with the technology.

of receiving benefits in the future. The farmer considering a water harvesting agrisystem will have a set of different opportunities from which to choose. Since an investment expenditure means a reduced consumption for the first period the farmer if he chooses to invest, will expect a net benefit to result from the investment greater than that of a decision to not invest or invest in another alternative. Graphically, this can be seen figure 7 below. In period one the individual has an income of Y_1 and a first period consumption of C_1. The budget line is represented by MM´ with a slope equal to -(1+i) where "i" equals the intertemporal cost of money. The individuals utility function is shown by U and is tangent to the budget line at Y_1Y_2.

Individuals will choose an investment on the production possibilities curve PP´ such that the marginal rate of substitution MRS is equal to the cost of capital. The individual borrows $C_1 - Y_1$ for period two income and pays back the loan equal to the difference multiplied by (1+i). An inferior alternative investment would produce an income combination to the left of the PP´ curve. At point Y the individual maximizes the present value of the stream of income over time.

Mathematically, present value can be represented as the following equation:

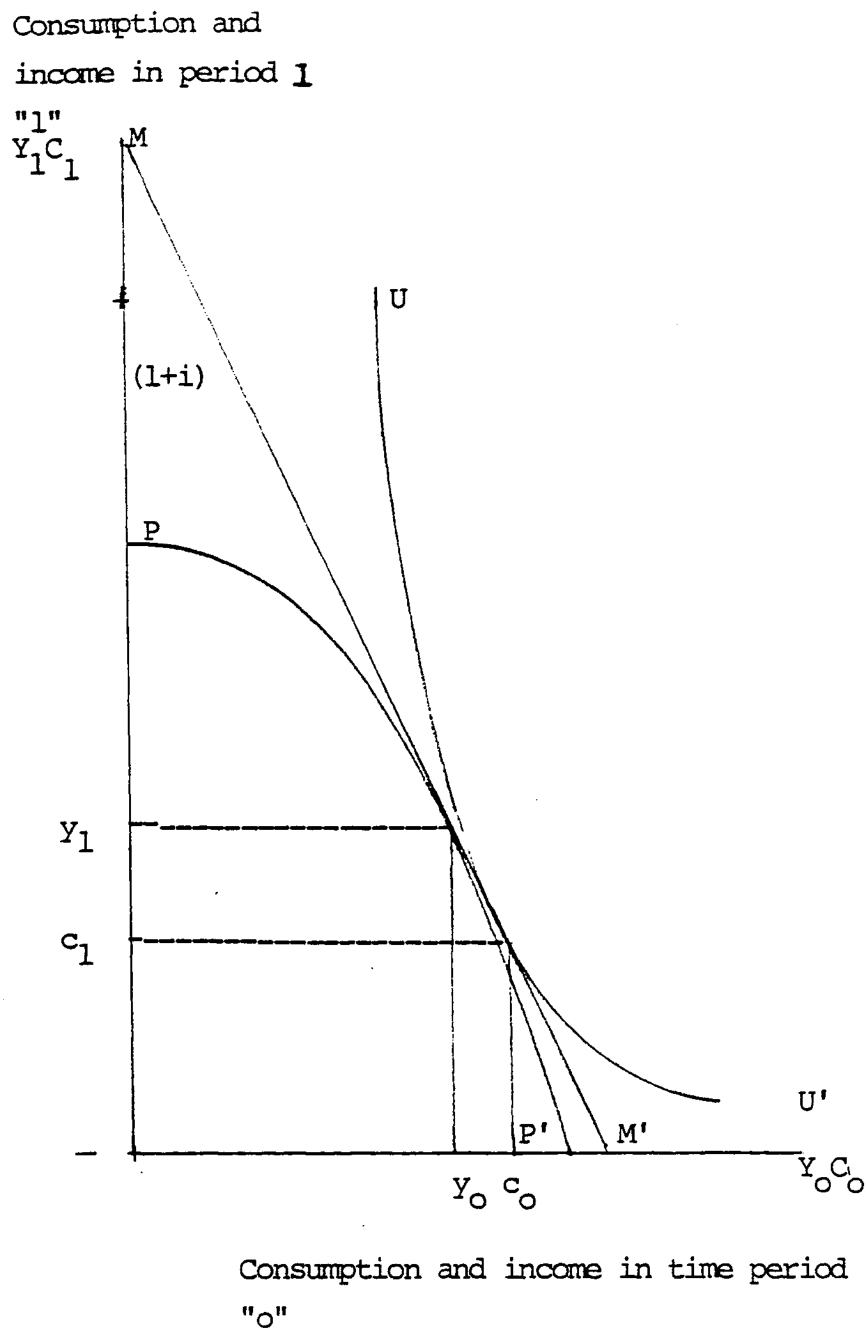


Figure 7. Investment Theory[10]

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[10]Randall, Alan, Resource Economics, An Economic Approach to Natural Resource and Environmental Policy, [Gid Publishing: Columbus, Ohio] 1981, p.203.

$$NPV = -I + R /(1+i) + R /(1+i)^2 + ...R /(1+i)^n$$

or

$$NPV = R_t/(1+i)^t$$

where NPV = net present value

I = initial investment

R = maximized net returns during time period i.

i = discount rate

n = number of time periods

A more complex model will be used to compare the investment of water harvesting with a conventional drip irrigation system. The NPV will be calculated as follows:

$$NPV = [nr_d - (MTR(nr_d - D - I) - IC) - LP - DP] (1 + i)^{-t}$$

where NPV is the after-tax net present value of the difference in revenue,

nr_d is the net revenue difference between the two alternatives,

MTR is the marginal tax rate,

D is the depreciation difference,

I is the interest difference,

IC is the investment tax credit difference,

LP is the loan payment,

and DP is the down payment.

The model can be separated into three different effects: The discounted value of the before tax net returns, the discounted value of the income tax rate, and the discounted cost of the loan.

$$PV_{nr} = R/(1+i)^t,$$

$$PV_{tx} = Mtr(nr - d - i)/(1+i)^t,$$

$$PV_{lp} = LP/(1+i)^t.$$

In most investments taxes have a negative affect on the net present value. However, because of depreciation and interest deductions from a firm's tax liability , it is conceivable that given an investment large enough, the depreciation and interest could have a negative effect upon the operation's taxa liability, (assuming that a positve tax liability is subtracted from income), making the net present value of the income increase with increasing tax rates.

An expenditure on the construction on a water harvesting system is to a large extent irreversible. Such a system cannot practically be used for other purposes. An investment in the development of the system precludes the choice of other alternate consumption and investment opportunities.

The choice of the correct discount rate is another important subject of discussion in present value analysis and a source of much controversy especially for public projects and projects in traditional communities of the developing world. In general discount rates are specified by what the decision-maker perceives as a typical rate of return around him or as in public projects, a legislated decision. For this analysis the discount rate will be chosen that either is comparable to what the individual can earn in the bank or at the level of what the individual can borrow at a lending institution. In either case the discount rate will be varied and a sensitivity analysis conducted. If the water harvesting project is a public project or development project, then the social rate of discount should be used. Since the costs and benefits are shared the discount rate is necessarily lower. Generally water harvesting is a private decision since it is a system to distribute water to one operation so the private discount rate is more appropriate. However, it is conceivable that water harvesting technology can be designed to serve a group of individuals so a social discount rate in this situation would be more appropriate. The forthcoming analysis in chapter five and six however, will be an evaluation based upon private decision making.

An important underlying assumption of water harvesting is that it is a technology for individuals with a reduced opportunity set. For legal or social reasons the individual cannot move out of the area or sell the property devoid of traditional water resources and must make the best with what the individual has. Economics assumes as an aspect of utility maximization that an individual always has a choice to buy or not to buy. Since such a situation is not likely for capital intensive arid land agriculture, water harvesting will most likely be appropriate if at all, for small farming systems and traditional agriculture. Whether or not an individual or group of individuals are actually constrained depends to a large extent upon the local situation surrounding them. If the location is an important part of an individual´s social identity or the costs of more conventional agricultural methods are prohibitively expensive, an individual may be more inclined to stay and utilize the technology than move to another location.

Water harvesting technology gives the individual the opportunity to produce where once there was no production (because of the lack of water resources,) but is this the maximum social benefit that the individual could receive. Afterall, it may benefit the individual more to move somewhere else.

Water harvesting technology was developed for individuals who derive a special benefit from a particular location and since standard economic analysis can only measure cash benefits as they accrue, economic evaluations may be limited when non-cash benefits accrue from either the operation or from something only incidentally associated with the operation such as location or cultural characteristics.

A value of such a non-monetary benefit can be conceptualized in terms of the opportunity cost of the decision to remain on a piece of land accepting a lower income than one could have gotten elsewhere. How much is forgone if for some non-monetary reason, an indvidual prefers to stay on that particular piece of land devoid of water resources. An individual then will attach a premium to the off-locale alternative in very much the same manner that an investor attaches a risk premium to different investments. The result is a different discount rate for different projects The investor chooses that alternative that maximizes his the discounted net returns of his investment.

The following analysis only evaluates cash net benefits accruing from water harvesting. Therefore conclusions drawn from this analysis are only relevant for modern agriculture in the United States. Feasiblity of water harvesting in less developed countries will depend upon a unique set of institutional relationships specific to each situation and country and thus will be a site specific judgement.

CHAPTER FIVE

THE PAGE RANCH WATER HARVESTING SYSTEM: AN ECONOMIC CASE STUDY

The Page Ranch water harvesting system is a series of linear microcatchments with a four foot strip at the bottom used for growing crops. The canal serves the dual purpose of cultivation and channeling excess rain water to a storage reservoir. The catchment areas are treated with NaCl at a rate of five tons to the acre. Water harvesting is the only source of irrigation water available to the crops grown on it in the area.

The following is an economic "description" of a prototypical water harvesting agrisystem at Page Ranch. Page Ranch consists of 16 acres of which 8.212 acres are in linear catchments and of those, 3.5 acres are in wine grape production. The budget, however, is made as if the whole 8.212 acres are in wine grape production so as to ignore differences in equipment purchases for different crops. The ratio of catchment area to cultivation area is 9.72:1 or in terms of the number of vines, 239 sq. ft. per vine.

Agronomic studies have shown that wine grapes can be grown successfully on the Page Ranch water harvesting system (Meilke and Dutt, 1981.) Therefore the evaluation of the technology will be with respect to wine grape production.

Labor is assumed to be completely owner labor except for harvesting which is contracted out at $60 per ton. Yearly rainfall is 14 inches and variability is not considered[10]. Only one variety of grape was produced and yields begin during the third year of operation and reach a maximum during the sixth year.

Construction costs (table 2) for the vineyard and water harvesting system are estimated on the rental cost of the equipment and the rate at which an individual that knows how to build the system could construct each portion. The time taken for shaping and smoothing is four days per acre with another four days per acre for the chemical treatment and compaction. Materials prices were assumed to be near wholesale since the operation will be expanded to 110 acres in the next chapter.

Operation costs for the vineyard were estimated from actual applications at the Page Ranch, standard vineyard budgets compiled by the Arid Lands Institute, and previous work by Luben and Angus (1983). The quantity of inputs and outputs per year for the first four years are shown in Table 3. Variable costs for standard operational inputs not directly related with the water harvesting system, are

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[11]Precipitation variability can be compensated for by design. Two studies indicate that variability for the Page Ranch system is not an important factor. Variability becomes a problem only when the yearly requirement for the cultivar is over 50% of the annual runoff for the area and the reservoir capacity is 36% ov mean annual rainfall (Dietterick, B.,C. 1982.) Mielke and Dutt (1981) estimated that the grapes at Page Ranch used only 18% of the water collected in the water harvesting system.

LAND PREPARATION	
SITE SURVEY	$200.00
SITE PREPARATION	
SITE CLEARING($40/ACRE)	$640.00
SOIL PREPARATION	
SHAPING(2 acres/day for 8.9 acres)	$150.00
SMOOTHING	$334.50
4.1 days * $45.00/day	
CHEMICAL SPREADERS	$175.00
4.1 days * $50.00/day +tractor rental at $150.00/4 days	
ROLLER COMPACTOR	$205.00
LABOR $5.00/HR	$62.50
SALT (74,000 lbs. @ $0.0375/lb)	$2775.00
TOTAL CATCHMENT CONSTRUCTION	$4542.00
STORAGE SYSTEM	
GROUND EXCAVATION	
EQUIPMENT	$289.68
LABOR	$86.40
SEEPAGE CONTROL	
CHEMICAL	$765.00
TOTAL STORAGE COST	$1141.08
MISC. COSTS	
FENCING	
MATERIALS	$200.00
LABOR	$50.00
SULFUR(8 lbs./vine * 1355 vines * $206/ton)	$1116.52
TOTAL MISC. COSTS	$1366.52
TOTAL WATER HARVESTING CONSTR. COSTS	$7049.60
DRIP IRRIGATION SYSTEM	
MATERIALS	$2922.75
LABOR	$5845.50
INJECTION EQUIPMENT	
50 GAL TANK	
INJECTOR	
TOTAL	$900.00
TOTAL IRRIGATION COSTS	$9668.45
PUMP	$1350.00

Table 2. Water Harvesting and Vineyard Construction Budget. All costs are in 1983 dollars. Labor costs shown for construction and development are capitalized into the cost of the investment.

YEAR ONE

Operational Inputs	Quantity	unit	Cost/unit	Cost
Water	3	a-i	$14.74	$40.98
Fertilizer (N)	70.81	lbs	$.50	$35.23
Pesticides				
Malathion	0			
Treflan	0			
Fungicide				
Benlate	0	lbs	$12.25	
Sulfur dust	0	lbs	$.18	
Paraquat				$927.00
Property Tax				$79.50
Total Cost				1082.71

YEAR TWO

Operational Inputs	Quantity	unit	Cost/unit	Cost
Water	6	a-i	$14.74	$81.97
Fertilizer (N)	116.52	lbs	$.50	$58.26
Pesticides				
Malathion	63.51	ou	$.37	$23.50
Treflan				
Fungicide				
Benlate	13.02	lbs	$12.25	$159.50
Sulfur dust	6.74	lbs	$.18	$1.21
Paraquat				$927.00
roperty tax				$79.49

Table 3b. Operational Costs during Vineyard Development. Third and fourth year operational costs for an eight acre vineyard incorporating water harvesting technology.

YEAR THREE

Operational Inputs	Quantity	unit	Cost/unit	Cost
Water	6	a-i	$14.74	$81.97
Fertilizer (N)	176.69	lbs	$.50	$88.35
Pesticides				
Malathion	63.51	ou	$.37	$23.50
Treflan	4.23	gal	$27.00	$114.21
Fungicide				
Benlate	13.02	lbs	$12.25	$159.50
Sulfur dust	6.74	lbs	$.18	$1.21
Paraquat				$927.00
Property tax				$79.49
Total costs				1475.219

YEAR FOUR

Operational Inputs	Quantity	unit	Cost/unit	Cost
Water	6	a-i	$14.74	$88.44
Fertilizer (N)	176.69	lbs	$.50	$88.35
Pesticides				
Malathion	63.51	ou	$.37	$23.50
Treflan	4.23	gal	$27.00	$114.21
Fungicide				
Benlate	13.02	lbs	$12.25	$159.50
Sulfur dust	6.74	lbs	$.18	$1.21
Paraquat				$927.00
Property Tax				$79.50

Table 3a. Operational Costs during Vineyard Development. Operational costs for an eight acre vineyard incorporating water harvesting technology.

assumed to be more or less the same on a per vine basis with standard vineyards in the area with vine densities of 400 to 450 vines to the acre. However,the impact of different variable costs will be considered later in this section.

Water requirements for wine grapes on a drip irrigation system range from 22 to 30 inches consumptive use depending upon the local soil characteristics and evapotranspiration rate. Water use at Page Ranch has been about six inches on top of a yearly annual rainfall of 14 inches to 15.5 inches. Total consumptive use then is less than 22 inches.

Lack of rainfall became a serious problem two years out of twelve. During those periods the number vines irrigated were cut in half, pushing the others into dormancy. Those vines that received little water survived but did not produce a significant yield. Though the effect of the variable input, water, is an important aspect of water harvesting, there was not enough data available to measure the effect on net return precisely. However, the quantity of water used for irrigation compared to the quantity of water collected was about eighteen percent (Meilke and Dutt, 1981), indicating that only the most severe droughts during the winter months have a serious effect on production.

Table 4 gives a fifteen year cashflow summary for the vineyard operation. The price per ton for grapes is assumed to be $500 and the yearly precipitation rate was assumed to 14.5 inches. Labor costs for construction and development of the water harvesting system are included as part of the initial investment and not in operation costs.

An enterprise budget (Figure 8) for an average annual net return support the assertion that the fixed cost is the most significant cost factor. The budget assumes an opportunity cost of capital of twelve percent. Mean annual cost and revenue figures were derived by calculating the present value of revenue and cost flows and then annualizing the present value at a discount rate of twelve percent. The yearly net returns to risk, management and land are -$3453.80 for 8.212 acres.

To test the impact of operating costs, a sensitivity analysis was conducted. A reduction in operating costs by as much as 50% will elicit a change in yearly net return of only 5.6%. Operating costs for the water harvesting system are only 25% of total yearly costs.

The economic feasibility of the technology will also vary depending upon annual precipitation rates because the size of the water harvesting system is related to the expected annual precipitation. Figure 9 gives the net returns pe. year of the operation evaluated for different annual precipitation rates. The quantity of catchment area is inversely related to the precipitation rate for a given yearly requirement of irrigation water. Given a runoff

YEAR	1	2	3	4	5
YIELD	0	0	8.8075	11.739	14.677
ferti	35.22948	58.26414	88.34470	88.34470	88.34470
water	40.98362	81.96724	81.96724	81.96724	81.96724
pest	0	184.2069	298.4169	298.4169	298.4169
paraq"	927	927	927	927	927
Tot. Op Csts	1003.213	1251.438	1395.729	1395.729	1395.729
harvco"	0	0	528.45	704.34	880.62
ptax"	79.49216	79.49216	79.49216	79.49216	79.49216
tocst"	1082.705	1330.930	2003.671	2179.561	2355.841
GR"	0	0	4403.75	5869.5	7338.5
NR"	-1082.71	-1330.93	2400.079	3689.939	4982.659

YEAR	6	7	8	9	10
YIELD	17.615	17.615	17.615	17.615	17.615
ferti	88.34470	88.34470	88.34470	88.34470	88.34470
water	81.96724	81.96724	81.96724	81.96724	81.96724
pest	298.4169	298.4169	298.4169	298.4169	298.4169
paraq"	927	927	927	927	927
Tot. Op Csts	1395.729	1395.729	1395.729	1395.729	1395.729
harvco"	1056.9	1056.9	1056.9	1056.9	1056.9
ptax"	79.49216	79.49216	79.49216	79.49216	79.49216
tocst"	2532.121	2532.121	2532.121	2532.121	2532.121
GR"	8807.5	8807.5	8807.5	8807.5	8807.5
NR"	6275.379	6275.379	6275.379	6275.379	6275.379

YEAR	11	12	13	14	15
YIELD	17.615	17.615	17.615	17.615	17.615
ferti	88.34470	88.34470	88.34470	88.34470	88.34470
water	81.96724	81.96724	81.96724	81.96724	81.96724
pest	298.4169	298.4169	298.4169	298.4169	298.4169
paraq"	927	927	927	927	927
Tot. Op Csts	1395.729	1395.729	1395.729	1395.729	1395.729
harvco"	1056.9	1056.9	1056.9	1056.9	1056.9
ptax"	79.49216	79.49216	79.49216	79.49216	79.49216
tocst"	2532.121	2532.121	2532.121	2532.121	2532.121
GR"	8807.5	8807.5	8807.5	8807.5	8807.5
NR"	6275.379	6275.379	6275.379	6275.379	6275.379

Table 4. Cost and Returns to Land and Management for an Eight Acre Vineyard.

efficiency of 65% and a storage efficiency of 30%, the acres of catchment area needed (CA) are related inversely to the yearly annual precipitation:

$$CA = 12/(P * a * b) * AF$$

where CA is the acres of catchment area needed, "P" is the expected annual precipitation in inches, "a" is the runoff efficiency, and "Af" is the yearly acre feet requirement.

From Figure 13, it can be seen that within a range of eight to twenty inches of yearly annual rainfall and a range of discount rates of ten percent, net returns remain significantly below zero. However, overall profitability of the prototype is negative with or without the water harvesting system. The small size of the system causes the fixed costs excluding the water harvesting system to be too high.

A simple net present value of the net cashflows can show more information as to whether the negative net returns in the earlier periods are worth the positive net returns in the later periods. Present value analysis assumes that an individual does not have to borrow funds to construct the system. At an opportunity cost of capital of 12% and a net cashflow ranging from -$1212.63 in year zero to $6205.32 in year six, the net present value of the income stream is -$23766.80.

The internal rate of return at an annual precipitation rate of fourteen inches is just above two

YEARLY GROSS REV	5979.066	
YEARLY OPERATING CSTS	2130.113	
NR minus opco		3848.953
ANNUALIZED INVEST.	6303.011	
Returns to risk, mgt., & land		-2454.06

Figure 8. Enterprize Budget.

Enterprize budget for an eight acre vineyard using water harvesting technology. Costs and revenues are annualized over a fifteen year period at an interest rate of 10%.

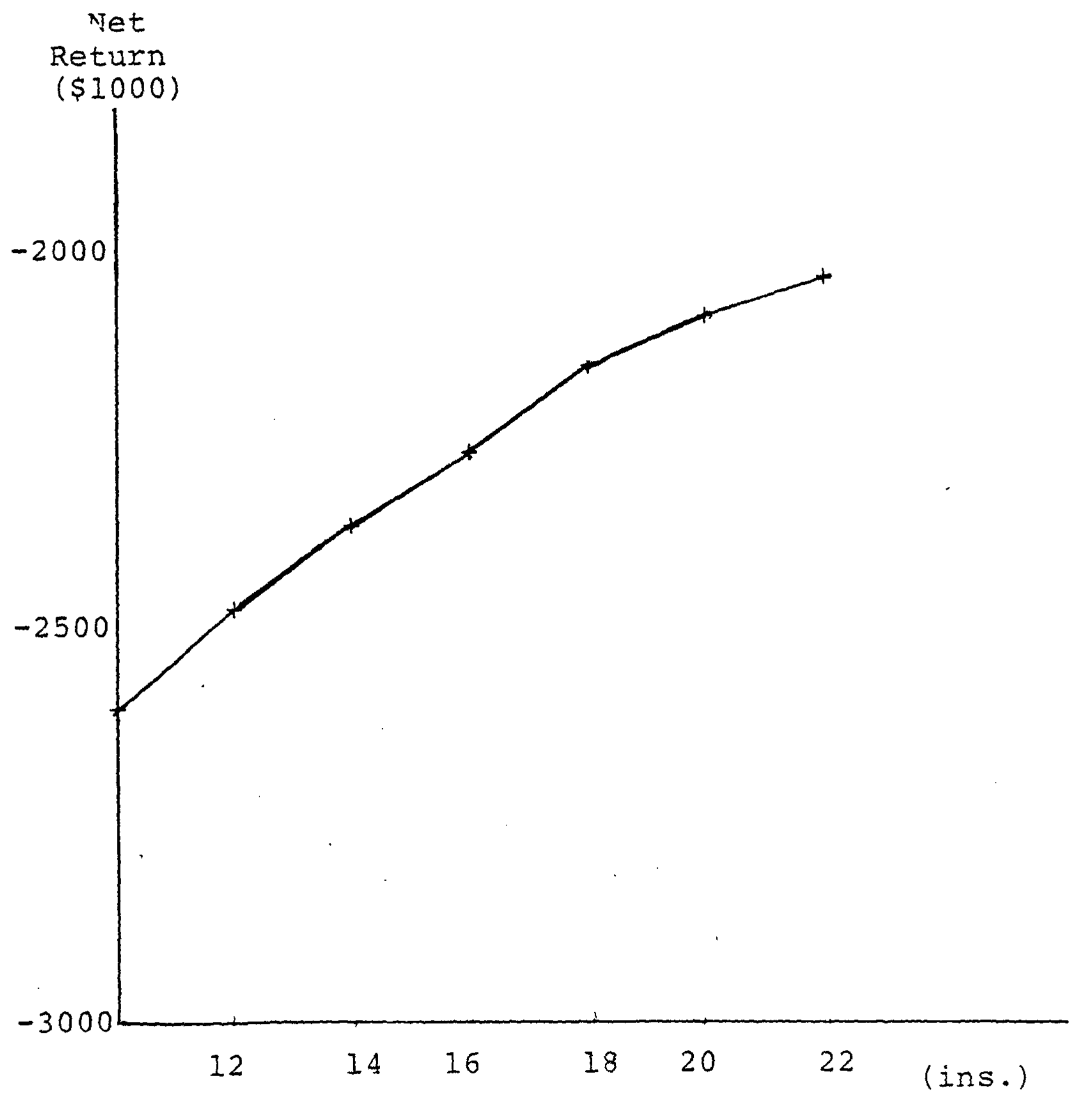

Figure 9. Net Return At Varying Precipitation Regimes.

Net return from an eight acre vineyard varying precipitation regimes.

percent. The internal rate of return drops below zero with eight inches of rain or less because of the increasing capital expenditures for supplemental irrigation.

From the above analysis, a water harvesting design for small farms requires a large amount of initial capital and expertise to construct and maintain. Since the size of the water harvesting system increases geometrically with decrease in mean rainfall, this would imply that cost increases nonlinearly with a decrease in precipitation. At a precipitation rate of eight inches, the need for supplemental water is drastic, the area of land necessary, however, to collect enough irrigation water in a water harvesting system such as Page Ranch becomes too large to be economically feasible regardless of the opportunity cost of capital chosen by the operator.

CHAPTER SIX

GENERAL ANALYSIS - A COMPARATIVE EVALUATION OF THE ECONOMIC AND FINANCIAL PROFITABILITY OF WATER HARVESTING TECHNOLOGY

Economic Evaluation

This chapter will investigate a hypothetical water harvesting system producing 240 tons of grapes and compare the system with a conventional vineyard of the same size. An operation of the size in the previous chapter cannot really be considered anything more than part-time in the United States. The first budget is a model of a water harvesting agrisystem producing about 240 tons of grapes. The second budget is a vineyard using conventional drip irrigation technology producing about the same quantity but instead of the 165 vines to the acre in the water harvesting system there are 454 vines to the acre.

The water harvesting system is constructed on 110 acres with a little larger machinery inventory and one half-time labor. The rest of the labor required is owner labor. As in the Page Ranch prototype, labor used for construction and development of the system is capitalized into the cost of the investment.

Operation costs are given in tables 5 through 7. Tables 5 and 6 give water costs for both the conventional system and the water harvesting system. Each year of

YEAR	ACRES PLANTED	A - F CONS.	TOTAL COST
1	13.83	1.402484	92.28345
2	27.65	4.207729	276.8686
3	41.48	7.012973	461.4537
4	55.30	9.818218	646.0388
5	69.13	12.62346	830.6239
6	82.95	15.42871	1015.209
7	96.78	18.23395	1199.794
8	110.61	21.03920	1384.379
9	110.61	22.44196	1476.681
10	110.61	22.44196	1476.681
11	110.61	22.44196	1476.681
12	110.61	22.44196	1476.681
13	110.61	22.44196	1476.681
14	110.61	22.44196	1476.681
15	110.61	22.44196	1476.681

Table 5. Water Requirements for a 110 acre Vineyard.

Acre-inch requirements for a 110 acre vineyard using water harvesting technology.

YEAR	ACRES PLANTED	A - F CONS.	TOTAL COST
1	5.00	2.22	146.86
2	10.00	6.65	440.61
3	15.00	11.09	734.36
4	20.00	15.52	1028.10
5	25.00	19.95	1321.85
6	30.00	24.39	1615.60
7	35.00	28.82	1909.35
8	40.00	33.26	2203.10
9	40.00	33.26	2203.10
10	40.00	33.26	2203.10
11	40.00	33.26	2203.10
12	40.00	33.26	2203.10
13	40.00	33.26	2203.10
14	40.00	33.26	2203.10
15	40.00	33.26	2203.10

Table 6. Water Requirements for a Forty acre Vineyard.

Acre-inch requirements for a forty acre vineyard using conventionalirrigation water sources.

	WATER HARV.	CONVENT.	QUANTITY CONSUMED	COST
YEAR	ACRES PLANTED	ACRES PLANTED		
1	13.83	5.00	118.41	59.20
2	27.65	10.00	311.28	155.64
3	41.48	15.00	607.32	303.66
4	55.30	20.00	903.36	451.68
5	69.13	25.00	1199.40	599.70
6	82.95	30.00	1495.44	747.72
7	96.78	35.00	1791.48	895.74
8	110.61	40.00	2087.51	1043.76
9	110.61	40.00	2265.15	1132.57
10	110.61	40.00	2368.31	1184.15
11	110.61	40.00	2368.31	1184.15
12	110.61	40.00	2368.31	1184.15
13	110.61	40.00	2368.31	1184.15
14	110.61	40.00	2368.31	1184.15
15	110.61	40.00	2368.31	1184.15

Table 7. Fertilizer Consumption.

Fertilizer consumption for water harvesting and conventional vineyards.

development corresponds to the same number of vines in production. Table 7 gives fertilizer quantities and costs for both systems. Fertilzer is assumed to not change. Pesticide costs were simply taken from budgets produced by Wright, Selley, and Kilby (1984.) An important difference of cultural practices between the two systems is the use of paraquat to eradicate plant growth on the catchment surfaces. This however can be substituted with labor. Other costs harvest costs and miscallaneous costs are simply taken from budgets by Luben and Angus (1983.)

Both the water harvesting model and the conventional model assume that construction and development occur over a period of years. For this analysis, development was assumed to occur over a period of eight years, with the complete system not reaching yield maturity until after year eleven. For simplicity the operation was funded completely through borrowed funds.

The total investment cost for the water harvesting system was $289,037.00 excluding the cost of land which was valued at $312 per acre. The fifteen year cashflow budget for the water harvesting system is presented in Table 8. The conventional system on the other hand, required a cumulative expenditure of $91000. The money was borrowed at a rate of twelve percent for ten years each year beginning the year the particular expense occurred. Water harvesting expenditures were scaled up to 110 acres assuming no economies of scale in construction of the system between an eight acre system and the 110 acre system. Though economies of scale of construction were assumed in some of the technical studies, (e.g.,Cluff and Frobel, 1976) no real economies of scale could be found in this analysis. Economies of scale however, do exist from the machinery component of the investment expenditure.

The water source for the conventional system is an eight inch diameter well producing 50 gallons a minute on an electrical pump. The fifteen year cashflow budget (Table 9) assumed 500 feet of head and a trivial installation fee for electrical lines.

Enterprise budgets for the two technologies are summarized in figure 10. Average annual costs and revenues were calculated by taking the net present value of the stream cashflows and annualizing them to obtain a yearly average. The net returns to land, mgt. and risk are below zero for the water harvesting system. The major reason for negative net returns is high fixed costs for development. In contrast, the annual net returns for the conventional system are almost $20,000 higher. Fixed costs for the water harvesting system and the conventional system are 73% and 30% respectively of gross revenues. A sensitivity analysis shows that the break-even price per ton for grapes for the water harvesting system is $550. In contrast, the break-even price for the conventional system is under $300 per ton.

The objective of this analysis is to describe conditions necessary for water harvesting to be economically feasible. Since the stated objective of water harvesting is to substitute for other sources of irrigation water, the relevant question then is how expensive can the more conventional sources of irrigation water be before water harvesting becomes an economically relevant alternative?

The first consideration is the energy cost resulting from different water tables. Figure 11 shows the yearly net returns with varying depth to lift levels and different opportunity costs of capital. From the graph it can be seen that vineyards are not very sensitive to variable pumping costs. A tenfold increase in pumping depth reduces average yearly net returns by only 33%.

The second component of the cost of water is the fixed cost. Since a pump run on electrical energy requires an installation cost for an electrical line, the cost can become a significant factor if electrical lines a large distance away. (The question of natural gas pumps is ignored. Natural gas affords lower energy costs but higher installation costs so for low producing well, electricity would more likely be the preferred choice.) Assuming the cost for installation of three dollars per linear foot with the first five hundred feet free, the fixed cost for water was calculated corresponding to electrical lines varying from less than 500 feet to 60,000 feet (11.36 miles.) The

year"	1	2	3	4	5	6
yield"	0	0	14.87836	34.71616	57.71616	87.36616
OPERATING COSTS						
	0	0	0	0	0	0
labor"	5200	5200	5200	5200	5200	5200
water"	92.2834	461.4537	646.0388	830.6239	1015.209	1199.794
pesticide	0	313.6605	936.0726	1558.485	2180.897	2803.309
paraquat	312.14	624.28	936.42	1248.56	1560.7	1872.84
fert"	59.2	155.64	303.66	451.68	599.7	747.72
harcost"	0	0	892.7018	2082.970	3462.970	5241.970
misc"	71.19	71.19	71.19	71.19	71.19	71.19
TVC"	5734.813	6826.224	8986.083	11443.51	14090.67	17136.82
INSURANCE	1000	1000	1000	1000	1000	1000
PROPER. TAX"	48.35	96.7	145.05	193.4	241.75	290.1
TFC"	1048.35	1096.7	1145.05	1193.4	1241.75	1290.1
TC"	6783.163	7922.924	10131.13	12636.91	15332.42	18426.92
GR"	0	0	7439.182	17358.08	28858.08	43683.08
CF-OP & OH	-6783.16	-7922.92	-2691.95	4721.173	13525.67	25256.16

LAND ACQ	5873.634	5873.634	5873.634	5873.634	5873.634	5873.634
MACH	24509					
PREP"	26220.36	26220.36	26220.36	26220.36	26220.36	26220.36
PLANT+LAB"	3033.432	3033.432	3033.432	3033.432	3033.432	3033.432
STAKING"		2282	2282	2282	2282	2282
TRELLIS CONSTR"		1993.386	1993.386	1993.386	1993.386	1993.386
TOTAL"	53762.79	33529.18	33529.18	33529.18	33529.18	33529.18
BEGINNING BAL	53762.79	84228.30	112783.2	139427.4	164160.9	186983.8
MORT. PYMTS (30 YEAR)	729.1730	1458.346	2187.519	2916.692	3645.865	4375.038
CAP. LOAN PYMTS	9515.201	15449.36	21383.52	27317.67	33251.83	39185.99
CAP. INT	6451.535	10475.04	14498.54	18522.04	22545.54	26569.04
CAP. PRINC	3063.666	4974.323	6884.979	8795.635	10706.29	12616.95
END LOAN BAL"	50699.12	79253.98	105898.2	130631.7	153454.6	174366.8
investment credit			12082.11	3352.918	3352.918	3352.918
Fixed csts & lp	11292.72	18004.40	24716.08	31427.77	38139.45	44851.13
btx-NCF minus lp	-17027.5	-24830.6	-26263.0	-25513.2	-23372.0	-18304.9
DEPRECIATION						
machinery (15 years)	1633.933	1633.933	1633.933	1633.933	1633.933	1633.933
vineyard & w-h system	1170.152	2511.319	3852.486	5193.653	6534.820	7875.987
TOTAL DEPR.	2804.085	4145.252	5486.419	6827.586	8168.753	9509.920
mtr(nr-d-i)	-7884.95	-11835.3	-25956.5	-18611.8	-19578.8	-19668.1
AFT TX NCF	-9142.59	-12995.4	-306.489	-6901.43	-3793.22	1363.199

Table 8. Cashflow Budget for a 240 Ton Vineyard Using Water Harvesting Technology.

Years one through six are shown above. Vineyard development takes place through a period of eight years.

7	8	9	10	11	12	13	14	15
117.0162	146.6662	176.3162	205.9662	220.7387	230.55	240	240	240
0	0	0	0	0	0	0	0	0
5200	5200	5200	5200	5200	5200	5200	5200	5200
1384.379	1476.681	1476.681	1476.681	1476.681	1476.681	1476.681	1476.681	1476.681
3425.721	4039.133	4660.546	4971.297	4971.297	4971.297	4971.297	4971.297	4971.297
2184.98	2497.12	2809.26	3121.4	3433.54	3745.68	4057.82	4369.96	4682.1
895.74	1043.76	1132.57	1184.15	1184.15	1184.15	1184.15	1184.15	1184.15
7020.970	8799.970	10578.97	12357.97	13244.32	13833	14400	14400	14400
71.19	71.19	71.19	71.19	71.19	71.19	71.19	71.19	71.19
20182.98	23127.85	25929.22	28382.69	29581.18	30482.00	31361.14	31673.28	31985.42
1000	1000	1000	1000	1000	1000	1000	1000	1000
338.45	386.8	386.8	386.8	386.8	386.8	386.8	386.8	386.8
1338.45	1386.8	1386.8	1386.8	1386.8	1386.8	1386.8	1386.8	1386.8
21521.43	24514.65	27316.02	29769.49	30967.98	31868.80	32747.94	33060.08	33372.22
58508.08	73333.08	88158.08	102983.1	110369.4	115275	120000	120000	120000
36986.65	48818.43	60842.07	73213.59	79401.37	83406.20	87252.06	86939.92	86627.78
5873.634	5873.634	0	0	0	0	0		
26220.36	26220.36							
3033.432	3033.432							
2282	2282	2282	0	0	0	0	0	
1993.386	1993.386	1993.386	1184	1184	1184	1184	1184	
33529.18	33529.18	4275.386	1184	1184	1184	1184	1184	0
207896.0	226897.6	214734.7	199236.8	193186.6	193003.2	192234.9	193309.7	195043.8
5104.211	5833.384	5833.384	5833.384	5833.384	5833.384	5833.384	5833.384	5833.384
45120.15	51054.30	51810.98	42505.33	36780.72	31056.12	25331.51	19606.90	13672.74
30592.54	34616.04	35129.09	35271.17	35413.25	29103.79	25222.37	21340.95	17317.45
14527.60	16438.26	16681.89	7234.162	1367.474	1952.322	109.1356	-1734.05	-3644.71
193368.4	210459.3	198052.8	192002.6	191819.2	191050.9	192125.7	195043.8	198688.5
3352.918	3352.918	427.5386	118.4	118.4	118.4	118.4	118.4	0
51562.81	58274.49	59031.17	49725.51	44000.91	38276.30	32551.69	26827.09	20892.93
-13237.7	-8069.26	3197.700	24874.88	36787.26	46516.70	56087.17	61499.64	67121.65
1633.933	1633.933	1633.933	1633.933	1633.933	1633.933	1633.933	1633.933	1633.933
9217.154	10558.32	10729.34	10776.70	10824.06	10871.42	10918.78	10966.14	10966.14
10851.09	12192.25	12363.27	12410.63	12457.99	12505.35	12552.71	12600.07	12600.07
-19757.3	-19816.2	-13715.9	-6960.48	-3443.59	1353.867	5375.226	8149.184	11161.24
6519.613	11746.93	16913.64	31835.36	40230.86	45162.83	50711.94	53350.45	55960.41

Table 8. Cashflow Budget for a 240 Ton Vineyard Using Water Harvesting Technology.

Years seven through fifteen are shown above.

year"	1	2	3	4	5	6
yield"	0	0	14.625	34.112	58.487	87.711
variable cost"						
labor"	5200	5200	5200	5200	5200	5200
water"	146.8740	440.6219	734.3699	1028.118	1321.866	1615.614
pest"	0	309.1286	927.5674	1546.006	2164.445	2782.884
fert"	59.2016	157.765	305.769	453.773	601.777	749.781
har-cost"	0	0	877.5	2046.72	3509.22	5262.66
misc"	71.19	71.19	71.19	71.19	71.19	71.19
TVC"	5477.266	6178.706	8116.396	10345.81	12868.50	15682.13
OVERHEAD						
INSURANCE	1000	1000	1000	1000	1000	1000
OWNER INCOME	0	0	0	0	0	0
PROPER. TAX"	48.35	96.7	145.05	193.4	241.75	290.1
TOTAL OVERHED	1048.35	1096.7	1145.05	1193.4	1241.75	1290.1
GR"	0	0	7312.5	17056	29243.5	43855.5
NR - Opco	-5477.27	-6178.71	-803.896	6710.193	16375.00	28173.37
LAND"	3120	1560	1560	1560	1560	1560
MACHINERY"	24509	0	0	0	0	
PREP"	5083.17	8000.57	8341.27	8341.27	8341.27	8341.27
WELL & EQUIP.	6877	0	0	0		500
INVESTMENT"	36469.17	8000.57	8341.27	8341.27	8341.27	8841.27
DEBT SCHEDULE ON BORROWED FUNDS						
MORT PYMNT	387.3274	580.9912	774.6549	968.3186	1161.982	1355.646
CAP. PYMT		6454.492	7870.472	9346.751	10823.03	12299.31
CUM CAP INV	36469.17	44469.74	52811.01	61152.28	69493.55	78334.82
investment credit			0	0	0	0
fixed cst + lp	1435.677	8132.183	9790.177	11508.47	13226.76	14945.05
btx NR minus lp	-6912.94	-14310.9	-10594.1	-4798.28	3148.241	13228.32
DEPRECIATION SCHEDULE						
machinery (15 years)	2092.4	2092.4	2092.4	2092.4	2092.4	2125.733
vineyard (25 years)	203.3268	523.3496	857.0004	1190.651	1524.302	1857.953
total depr.			7860.877	3283.051	3616.702	3983.686
mtr(nr-d-i)	-1643.18	-1853.61	-241.169	2013.058	4912.501	8452.011
AFT-TX NR	-5269.76	-12457.3	-10352.9	-6811.33	-1764.26	4776.306

Table 9. Cashflow Budget for a 240 Ton Vineyard Using Conventional Water Sources..

As in table 8, this operation was developed over an eight year period. Years one through six are shown above.

7	8	9	10	11	12	13	14	15
116.987	146.237	175.487	204.737	219.362	229.125	234	234	234
5200	5200	5200	5200	5200	5200	5200	5200	5200
1909.362	2203.110	2349.984	2349.984	2349.984	2349.984	2349.984	2349.984	2349.984
3401.323	4019.761	4638.200	4947.510	4947.510	4947.510	4947.510	4947.510	4947.510
897.785	1045.789	1134.591	1184.032	1184.032	1184.032	1184.032	1184.032	1184.032
7019.22	8774.22	10529.22	12284.22	13161.72	13747.5	14040	14040	14040
71.19	71.19	71.19	71.19	71.19	71.19	71.19	71.19	71.19
18498.88	21314.07	23923.19	26036.94	26914.44	27500.22	27792.72	27792.72	27792.72
1000	1000	1000	1000	1000	1000	1000	1000	1000
0	0	0	0	0	0	0	0	0
338.45	386.8	386.8	386.8	386.8	386.8	386.8	386.8	386.8
1338.45	1386.8	1386.8	1386.8	1386.8	1386.8	1386.8	1386.8	1386.8
58493.5	73118.5	87743.5	102368.5	109681	114562.5	117000	117000	117000
39994.62	51804.43	63820.31	76331.56	82766.56	87062.28	89207.28	89207.28	89207.28
1560	1560	0	0	0	0	0	0	0
8341.27	8341.27	3258.1	404.7	0	0	0	0	0
				500				
8341.27	8341.27	3258.1	404.7	500	0	0	0	0
1549.310	1742.973	1742.973	1742.973	1742.973	1742.973	1742.973	1742.973	1742.973
13864.08	15340.36	16816.64	17393.27	11010.40	9682.917	8206.639	6730.360	5254.081
86676.09	95017.36	98275.46	98680.16	99180.16	99180.16	99180.16	99180.16	99180.16
0	0	0	0	0	0	0	0	0
16751.84	18470.13	19946.41	20523.04	14140.18	12812.69	11336.41	9860.133	8383.855
23242.78	33334.30	43873.90	55808.52	68626.39	74249.59	77870.87	79347.15	80823.43
2125.733	2125.733	2125.733	2125.733	2159.067	2159.067	2159.067	2159.067	2159.067
2191.604	2525.254	2655.578	2671.766	2671.766	2671.766	2671.766	2671.766	2671.766
4317.337	4650.988	4781.312	4797.500	4830.833	4830.833	4830.833	4830.833	4830.833
11998.39	15541.33	19146.09	22899.47	24829.97	26118.69	26762.19	26762.19	26762.19
11244.40	17792.97	24727.81	32909.05	43796.42	48130.91	51108.69	52584.97	54061.24

Table 9. Cashflow Budget for a 240 Ton Vineyard Using Conventional Water Sources.

Years seven through fifteen are shown above.

ENTERPRIZE BUDGET FOR A
110 ACRE WATER HARVESTING TECHNOLOGY

(All costs annualized over fifteen years)

Gross returns	45685.69	
Operating Costs	16694.92	
Returns over operating costs		28990.77
Fixed Costs	33734.70	
Returns to land, mgt., and risk		-4743.93

FORTY ACRE CONVENTIONAL TECHNOLOGY
ENTERPRIZE BUDGET

Gross returns	45297.05	
Operating csts	15171.47	
Returns over operating costs		30125.58
Fixed Costs	11667.05	
Returns to Land, Mgt., and risk		18458.51

Figure 10. Enterprize Budgets for Water Harvesting and Conventional Vineyards.

Costs and revenues for both operations are annualized over a fifteen year period at an interest rate of 12%.

average net return per year varied from $16,000 to $5300. The length of electrical line required for water harvesting to be feasible then is 55,000 feet (over ten miles.)

In general the net returns with different costs of water are presented in figure 12. Water harvesting does not become feasible until the total cost of water (fixed plus variable) reaches $360 per acre foot.

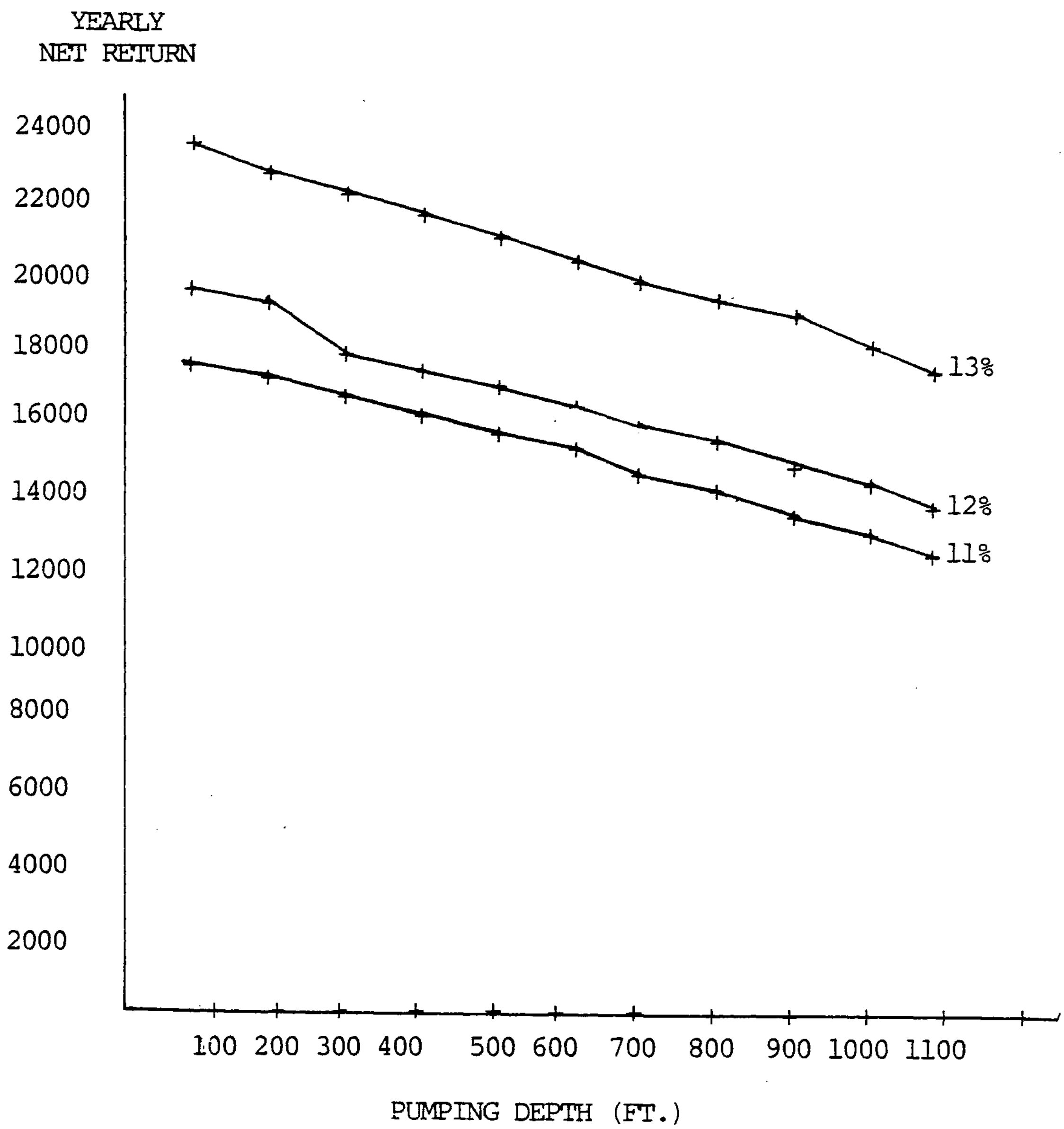

Figure 11. Net Return Versus Pumping Depth and Capitalization Rate.

Net returns to a conventional forty acre vineyard three different opportunity costs of capital varying pumping depth.

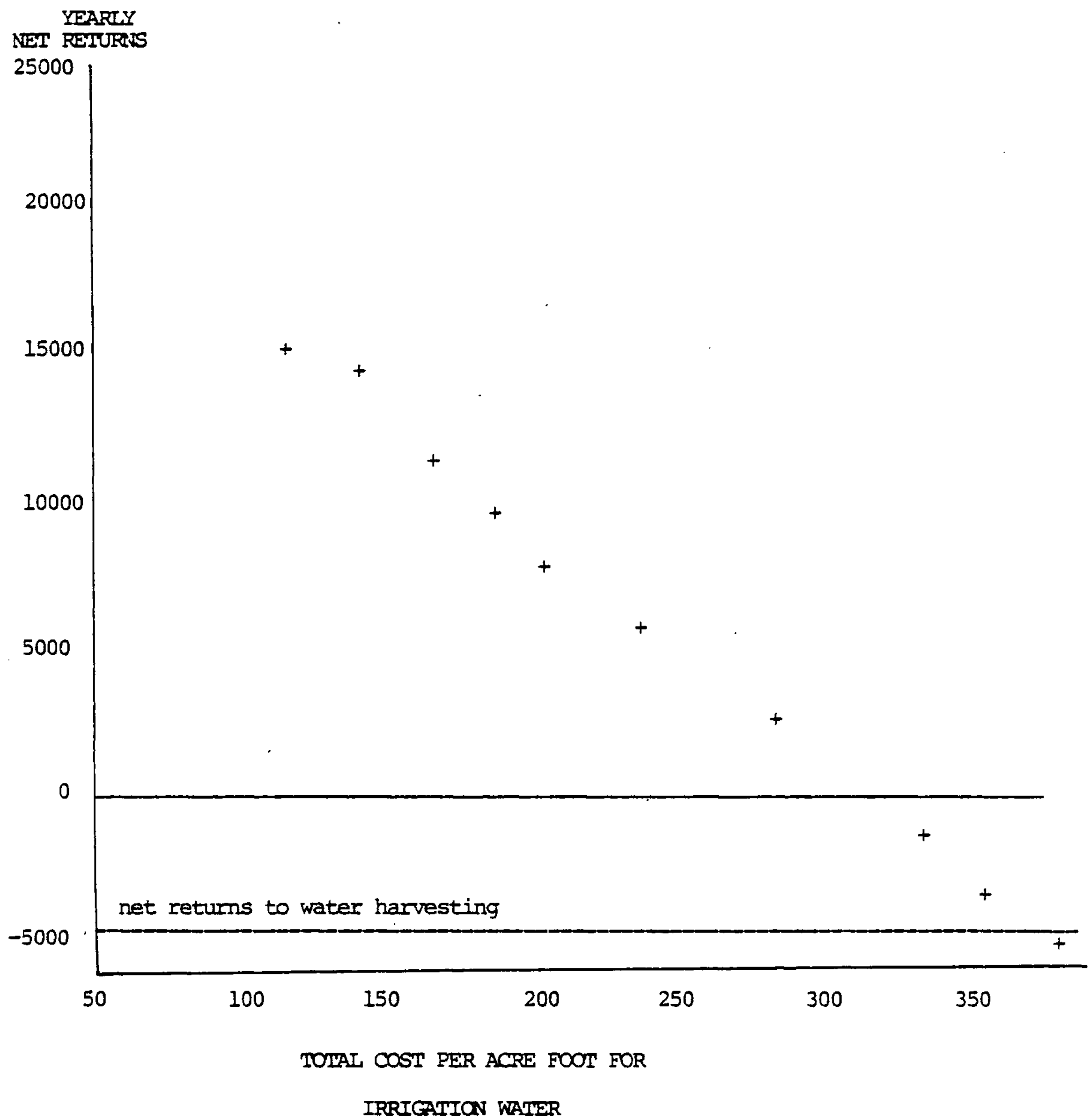

Figure 12. Net Returns Versus Total Cost per Acre-foot of Irrigation Water.

Net returns to risk, land, and mgt. varying the total cost of water per acre-foot for a conventional vineyard. The dotted line represents the annualized net returns to a vineyard adopting water harvesting.

Financial Evaluation

The final analysis will be a comparative financial evaluation. A static evaluation such as enterprise budgets can only produce limited conclusions. Net cashflows increased from a negative value in the early years to a positive value in the latter years so the decision-maker has to choose an investment that maximizes net returns over a planning horizon, in this case fifteen years.

The financial models developed from the fifteen year cashflow statement in figures 8 and 9 have several important characteristics and assumptions. First, all investment funds used were borrowed at a twelve percent loan rate. Funds used for the capital expenditures were borrowed for ten years while land expenditure was borrowed for thirty years. For simplicity, no down payment was demanded.

The organizational structure of the operation is assumed to be a partnership or sub-chapter S corporation and income to all shareholders are taxed at thirty percent for reasons that will be discussed later. The net cashflows in this analysis are to be interpreted as returns to management or operation for simplicity. Depreciation followed the IRS rules for orchards and vineyards using straight line depreciation. The vineyard was depreciated over 25 years and the water harvesting system, well and irrigation equipment, and machinery were depreciated over 15 years.

The present value model can be divided into two components: the present value of the net returns and the present value of the tax liability. The model is specified as follows:

pvNR = pv{nr - lp} = the present value of the net returns minus the loan payment;

pvTX = pv{mtr(nr - i - d) - IC} = the present value of the tax liability,

Af-tx NPV = pvNR - pvTX.

The present value of the tax liability flow is meaningful as stated above, only if all the shareholders are taxed at the same rate. A negative present value is equal to the present value of the extra income flow resulting from lower taxes owed. A negative value is a tax shelter while a positive value is a tax loss.

After tax net present value of the water harvesting vineyard is $49,416 with a discount rate of 13 percent and a price per ton for grapes of $500, figure 13a. However, it is important to notice that the positive value is because of the tax structure. The present value of the net returns are negative but the present value of the tax liability is a significantly larger negative number. Therefore, the net result is a positive net present value. This assumes however, that more than one owner will be enjoying the benefit of this tax shelter. For a single proprietorship, negative tax liabilities are impossible and are simply

NPV ANALYSIS (A)

(1) pv{nr - lp}	-36494.6
(2) pv{mtr(nr-d-i) - ic}	-84423.6
(1)-(2) af-tx npv	47929.02

NPV ANALYSIS (B)

(1) pv{nr - lp}	-36494.6
(2) pv{mtr(nr-d-i) - ic}	-10948.4
(1)-(2) af-tx npv	-25546.2

Figure 13. Net Present Value of a 240 Ton Water Harvesting Vineyard.

Figure 13a presents the NPV assuming the usual deductions while 13b presents the NPV assuming no depreciation, interest credits, and investment credit. The discount rate is 13% and price per ton is $500. The loan rate is 12% and income tax rate is 30%.

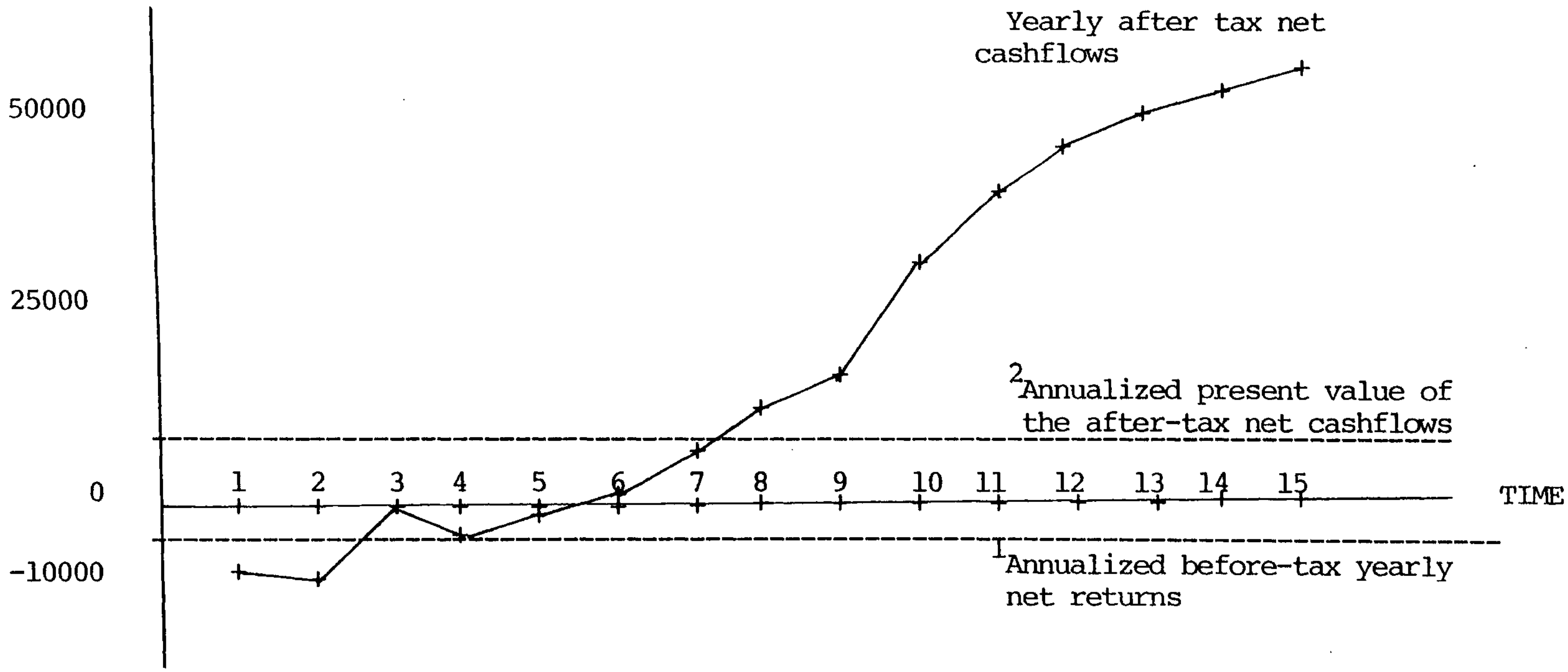

Figure 14. Tax impacts on the economics of water harvesting.

With a fifteen year cashflow beginning negative and ending positive, the annualized value of before tax net returns (1) and annualized value of of after tax net cash flows (2) are shown.

carried back as much as three years or carried forward up to fifteen years[11]. To illustrate the impact of the tax structure, the net present value of the cashflow is calculated by simply excluding the investment credit and interest and depreciation deductions, figure 13b. Predictably the net present values become negative.

This tax shelter can be illustrated another way. The before tax enterprise budgets show the average annual return to be negative. However, annualizing the after tax net present value at the same opportunity cost of capital result in a positive annualized net cash flow (figure 14.)

Under present economic conditions the net present value is positive. However, compared with the conventional technology, water harvesting is still inferior to conventional irrigation technology. The objective of the next section is compare and contrast water harvesting with conventional technology and to identify conditions necessary for water harvesting to be the preferred alternative.

At a thirteen percent discount rate and a price per ton of $500 the net present value of a 240 ton operation using conventional irrigation is given in Figure 15. At a range of discount rates and prices per ton the net present value of the operation is consistently higher than the water harvesting system. (See Appendix one.)

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[12] United States Internal Revenue Service, Farmers Tax Guide, Publication 225, page 21.

NET PRESENT VALUE ANALYSIS

(A)

(1) pv{nr-lp}	112094.5
(2) pv{mtr(nr-d-i)	31037.86
(1) - (2)	81056.64

(B)

NET PRESENT VALUE ANALYSIS

(1) pv{nr-lp}	112094.5
(2) pv{mtr(nr-d-i)	56030.17
(1) - (2)	56064.33

Figure 15. Net Present Value of a conventional Vineyard.

As in figure 13, the net present values are calculated with and without the standard deductions and credits. The discount rate is 13%, price per ton is $500, and the loan rate is 12%. Depth of lift was assumed to be 400 feet with no significant electrical installation cost.

TOTAL HEAD (FT)		DISCOUNT RATE 10%	12%	14%	16%
	pv{nr-lp}	158185.6	115021	99937.12	79360.75
400	tax liab.	45427.95	32288.86	27253.11	20863.82
	af-tx npv	112757.65	82732.14	72684.01	58496.93
	pv{nr-lp}	154317.2	122336.2	96959.13	76723.24
500	tax liab.	44081.52	34095.7	26193.65	19914.32
	af-tx npv	110235.68	88240.5	70765.48	56808.92
	pv{nr-lp}	150637.6	119115.2	94121.27	74207.7
600	tax liab.	42790.96	32953.54	25175.51	55206.96
	af-tx npv	107846.64	86161.66	68945.76	19000.74
	pv{nr-lp}	145884	114926.54	90407.33	70895.59
700	tax liab.	41032.32	31383.54	23764.24	17723.99
	af-tx npv	104851.68	83543	66643.09	53171.6
	pv{nr-lp}	141868.9	111372.2	87242.51	68062.04
800	tax liab.	39494.83	30003.67	22517.53	16590.64
	af-tx npv	102374.07	81368.53	64724.98	51471.4
	pv{nr-lp}	137315.9	107360.9	83686.6	64891.52
900	tax liab.	37813.31	28502.94	21168.85	15370.85
	af-tx npv	99502.59	78857.96	62517.75	49520.67
	pv{nr-lp}	132699.9	103292.3	80078.46	61673.2
1000	tax liab.	36102.81	26975.54	19795.5	14128.14
	af-tx npv	96597.09	76316.76	60282.96	47545.06
	pv{nr-lp}	128829.2	99901.17	77088.22	59020.48
1100	tax liab.	34735.64	25764.16	18714.47	13157.03
	af-tx npv	94093.56	74137.01	58373.75	45863.45

Table. 10. NPV of a Conventional Vineyard Varying Discount Rate and Total Head

The next question to consider is the how expensive must conventional sources of irrigation water must before water harvesting becomes financially profitable. Since the cost of water is comprised of two costs, the energy cost plus the fixed cost or infrastructure cost, both will be evaluated as to their impact on the conventional vineyard investment.

The variable cost of water for this analysis is derived from pumping at different depths. Total lift was varied from 100 feet to 1100 feet. Table 10 presents different aftertax net present values at different pumping depths. Given a net present value for the water harvesting investment for a common grape price of $500 per ton, the conventional drip irrigation system is preferable at all discount rates evaluated.

The next component of the cost of water is the fixed cost. This cost can come from several sources, the annualized cost of the well and pump, and the annualized cost of the infrastructure, i.e., the electrical lines canals, or gas pipes. For this analysis, as in the previous static analysis, the cost results from the installation of electrical lines. From the installation and pumping costs a fixed cost per acre foot can be derived and then the impact on the net present value analyzed (Appendix two.) Figure 26 presents the net present values given different discount rates and different fixed costs of water. Water harvesting

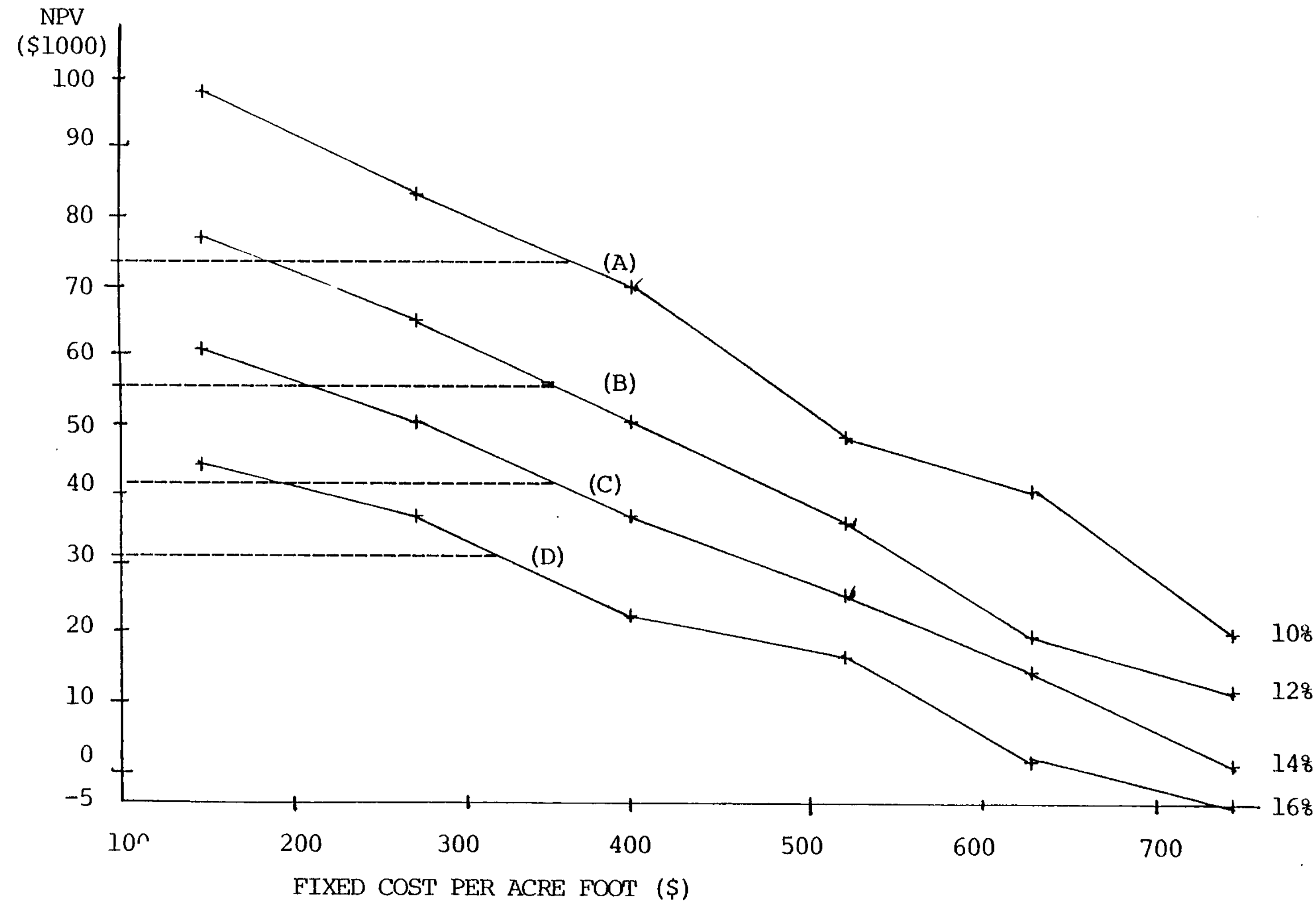

Figure 16. NPV Varying Fixed Cost per Acre-foot of Water.

Net present values of a conventional irrigation system varying fixed cost per acre-foot and discount rate. The variable cost per acre-foot of water is assumed to be $66. The dashed lines (A) - (B) are the net present values of water harvesting at each discount rate. The price per ton for grapes is $500.

becomes the financially preferred technology after the fixed cost of water increases to $394 per acre foot per year.

The last analysis will explore the impact of the tax structure. Tables 11 and 12 give the net present values of water harvesting and the conventional system respectively with varying discount rates and tax rates. From the schedule for the water harvesting system, it can be seen that the high negative tax liabilities of the water harvesting system have a more positive impact on the net present values as the tax rates increase.

At tax rates of around 40% or more water harvesting becomes the preferred choice. Table 13 gives a comparision of net present values at different discount rates and tax rates. For each combination of tax rate and discount rate, the after tax NPV of the water harvesting vineyard is subtracted from the corresponding NPV of the conventional vineyard. Negative values for the after tax net present value in this schedule indicate those combinations of factors that make water harvesting preferable and negative values occur at a tax rate of 40% or greater.

income tx rate		DISCOUNT RATE 10%	12%	14%	16%
30%	pv{nr-lp}	(21389.1)	(32310.4)	(39982.6)	(45240.6)
	tax liab.	(94706.2)	(87684.4)	(81320.0)	(75554.6)
	af-tx npv	73317.1	55374.0	41337.4	30314.0
35%	pv{nr-lp}	(21389.1)	(32310.4)	(39982.6)	(45240.6)
	tax liab.	(107324.0)	(99380.0)	(92176.4)	(85649.0)
	af-tx npv	85934.9	67069.6	52193.8	40408.4
40%	pv{nr-lp}	(21389.1)	(32310.4)	(39982.6)	(45240.6)
	tax liab.	(119942.0)	(111076.0)	(103033.0)	(95743.4)
	af-tx npv	98552.9	78765.6	63050.4	50502.8
45%	pv{nr-lp}	(21389.1)	(32310.4)	(39982.6)	(45240.6)
	tax liab.	(132560.0)	(122771.0)	(113889.0)	(105838.0)
	af-tx npv	111170.9	90460.6	73906.4	60597.4
50%	pv{nr-lp}	(21389.1)	(32310.4)	(39982.6)	(45240.6)
	tax liab.	(145178.0)	(134167.0)	(124746.0)	(115932.0)
	af-tx npv	123788.9	101856.6	84763.4	70691.4

Table 11. Income Tax Impacts to NPV of a 240 Ton Vineyard incorporating Water Harvesting Technology.

		DISCOUNT RATE			
		10%	12%	14%	16%
income tx rate					
	pv{nr-lp}	158185.6	115021.0	99937.1	79360.8
30%	tax liab.	45428.0	32288.9	27253.1	20863.8
	af-tx npv	112757.6	82732.1	72684.0	58497.0
	pv{nr-lp}	158185.6	115021.0	99937.1	79360.8
35%	tax liab.	54089.8	42178.3	32735.8	25217.5
	af-tx npv	104095.8	72842.7	67201.3	54143.3
	pv{nr-lp}	158185.6	115021.0	99937.1	79360.8
40%	tax liab.	62751.6	49070.9	38218.5	29571.2
	af-tx npv	95434.0	65950.2	61718.6	49789.6
	pv{nr-lp}	158185.6	115021.0	99937.1	79360.8
45%	tax liab.	71413.4	55963.4	43701.3	33924.9
	af-tx npv	86772.2	59057.6	56235.8	45435.9
	pv{nr-lp}	158185.6	115021.0	99937.1	79360.8
50%	tax liab.	80075.2	62855.9	49184.0	38278.6
	af-tx npv	78110.4	52165.1	50753.1	41082.3

Table 12. Income Tax Impacts on NPV of a 240 Ton Vineyard incorporating Conventional Water Sources.

income tx rate		DISCOUNT RATE 10%	12%	14%	16%
	pv{nr-lp}	179574.7	147331.4	139919.7	124601.4
30%	tax liab.	140134.2	119973.3	108573.1	96418.4
	af-tx npv	39440.5	27358.1	31346.6	28183.0
	pv{nr-lp}	179574.7	147331.4	139919.7	124601.4
35%	tax liab.	161413.8	141558.3	124912.2	110866.5
	af-tx npv	18160.9	5773.1	15007.5	13734.9
	pv{nr-lp}	179574.7	147331.4	139919.7	124601.4
40	tax liab.	182693.6	160146.9	141251.5	125314.6
	af-tx npv	(3118.9)	(12815.5)	(1331.8)	(713.2)
	pv{nr-lp}	179574.7	147331.4	139919.7	124601.4
45%	tax liab.	203973.4	178734.4	157590.3	139762.9
	af-tx npv	(24398.7)	(31403.0)	(17670.6)	(15161.5)
	pv{nr-lp}	179574.7	147331.4	139919.7	124601.4
50%	tax liab.	225253.2	197022.9	173930.0	154210.6
	af-tx npv	(45678.5)	(49691.5)	(34010.3)	(29609.2)

Table 13. NPV Difference Varying the Income Tax Rate and Discount Rate.

NPV of the water harvesting operation is subtracted from the NPV of the conventional operation for each combination of discount rate and income tax rate.

CHAPTER SEVEN

CONCLUSIONS

Water harvesting is a technology for extraordinary circumstances, i.e., for extraordinary high water costs. Tax shelter effect makes the net present values positive, however, the higher debt load leads to a higher risk operation. It is doubtful that water costs of the magnitude needed to make water harvesting the preferred technology exist in the U.S.

The above discussion, however, does not consider the ultimate choice of the individual, which is to not develop at all. Though this technology may make a particular piece of land productive that may not have been productive before, it does not address the question of whether it may be more prudent for the individual to simply leave a location devoid of conventional irrigation resources. The old platitude "you can´t squeeze water out of a rock" may be particularly appropriate in these circumstances. The question of what the social value is of remaining on the afore-mentioned piece of land and earning a living confronts the decision-maker.

Given a situation where the nature of the operation or location is such that the producer receives non-monetary benefits from the operation as well as cash income, a simple economic evaluation of the cash income flows may not necessarily the actions of the decision-maker. In such a case the farmer will choose water harvesting rather than conventional irrigation, if the utility derived from the discounted value of the streams of income from water harvesting is greater than the utility of the discounted value of the stream of income from the conventional system.

While the tax shelter effects do make water harvesting financially feasible, changes in the tax laws can change the feasibility drastically. For instance, a change to a flat tax with no deductions turns the net present value negative.

The above analysis shows that there certainly are situations where water harvesting may be appropriate since a positive internal rate of return exists. However, the question remains that there may be other areas where an individual might invest his capital that may produce a larger net benefit. In areas where water availability is extremely costly water harvesting should be considered as an alternative to other sources of irrigation water.

From the above analysis water harvesting has potential in certain restricted conditions where the cost of water is prohibitively expensive because of high fixed costs. Though it is doubtful that water harvesting as modeled in Page Ranch could be useful for modern agriculture in the desert southwest, aspects of the technology are promising. In particular technology designed to increase water storage potential in the soil that reduce runoff and erosion such as micro basins should continue to be investigated. Urban rainwater harvesting is in this authors opinion a subject of great potential. Economic studies on benefits of "retro-fitting" communities with water harvesting and planning new communities incorporating water harvesting would be very valuable.

APPENDIX A

The following schedules (Table 14) present the net present values for different price levels and discount rates. The sensitivities to prices and discount rates a very close between the two technologies. The water harvesting system is slightly less sensitive to the discount rate because of the positive change in the tax liability. The sensitivity of the water harvesting system is 16% at a price, discount rate combination of $500 and 10%, while the conventional system is 18%.

Price changes have the opposite effect however. The conventional system is a little less sensitive to price changes. A one dollar change in price for the conventional system elicits a $515 change in the net present value while in the water harvesting system a $520 change will occur.

AFTER TAX NET PRESENT VALUES FOR A 240 TON VINEYARD USING CONVENTIONAL DRIP IRRIGATION TECHNOLOGY

PRICE/TON		DISCOUNT RATE 10%	12%	14%	16%
	pv{nr-lp}	10778.5	2313.8	(4029.5)	(8761.4)
$300	tax liab.	1205.8	(3724.6)	(3936.9)	(5572.8)
	af-tx npv	9572.7	6038.4	(92.6)	(3188.6)
	pv{nr-lp}	84482.0	64016.5	47953.8	35299.7
$400	tax liab.	23316.9	16775.0	11658.1	7645.5
	af-tx npv	61165.1	47241.5	36295.7	27654.2
	pv{nr-lp}	158185.6	115021.0	99937.1	79360.8
$500	tax liab.	45428.0	32288.9	27253.1	20863.8
	af-tx npv	112757.7	82732.1	72684.0	58496.9
	pv{nr-lp}	231898.1	187422.0	151920.4	123421.8
$600	tax liab.	67559.0	53796.4	42848.1	34082.0
	af-tx npv	164339.1	133625.6	109072.3	89339.8

AFTER TAX NET PRESENT VALUE OF A 240 TON VINEYARD INCORPORATING WATER HARVESTING TECHNOLOGY

PRICE/TON		DISCOUNT RATE 10%	12%	14%	16%
	pv{nr-lp}	(170128.0)	(156775.0)	(144796.0)	(134044.0)
$300	tax liab.	(129328.0)	(125024.0)	(112764.0)	(102196.0)
	af-tx npv	(40800.0)	(31751.0)	(32032.0)	(31848.0)
	pv{nr-lp}	(95758.8)	(94542.6)	(92389.9)	(89642.1)
$400	tax liab.	(117017.0)	(106354.0)	(97041.9)	(88875.1)
	af-tx npv	21258.2	11811.4	4652.0	(767.0)
	pv{nr-lp}	(21389.1)	(32310.4)	(39982.6)	(45240.6)
$500	tax liab.	(94706.2)	(87684.4)	(71310.0)	(75554.6)
	af-tx npv	73317.1	55374.0	31327.4	30314.0
	pv{nr-lp}	52980.5	29921.7	12424.0	(839.1)
$600	tax liab.	(72395.8)	(69014.7)	(65598.0)	(62234.2)
	af-tx npv	125376.3	98936.4	78022.0	61395.1

Table 14. Grape price and Discount Rate Sensitivity of NPV. Paranthetical figures represent negative values.

APPENDIX B

The following schedule (Table 15) presents the net present values and corresponding fixed costs per acre foot for different infrastructure costs. The variable costs are assumed to be $66 per acre foot. The infrastucture costs were generated by varying the cost of electrical installation charged by the Tucson Power Co. which are $3 per foot after the first five hundred feet.

INFRASTRUCTURE COST ($1000)		DISCOUNT RATE 10%	12%	14%	16%	FIXED CST /AC-FT
	pv{nr-lp}	131777.5	101722.8	78051.3	59330.0	146.417
25.50	tax liab.	33276.5	24102.8	16910.2	15129.6	
	af-tx npv	98501.0	77620.1	61141.1	44200.4	
	pv{nr-lp}	103979.5	76463.3	55013.6	38244.7	270.577
55.50	tax liab.	20485.5	12331.1	6022.8	1140.7	
	af-tx npv	83494.0	64132.2	48990.7	37104.0	
	pv{nr-lp}	76181.5	51203.9	31975.9	17159.9	394.7429
85.50	tax liab.	7694.5	559.5	(4864.5)	(4895.3)	
	af-tx npv	68487.0	50644.3	36840.3	22055.1	
	pv{nr-lp}	48383.5	25944.4	8938.2	(3925.2)	518.9058
115.50	tax liab.	(24.7)	(11212.1)	(15751.8)	(19088.1)	
	af-tx npv	48408.2	37156.5	24690.0	15162.9	
	pv{nr-lp}	23365.3	(3210.9)	(11795.8)	(22901.8)	630.6524
148.50	tax liab.	(16608.5)	(21806.6)	(25550.4)	(24520.5)	
	af-tx npv	39973.8	18595.7	13754.6	1618.7	
	pv{nr-lp}	(4432.8)	(22048.6)	(34833.5)	(43986.8)	754.817
175.50	tax liab.	(24327.6)	(33578.2)	(36437.7)	(38305.4)	
	af-tx npv	19894.8	11529.6	1604.2	(5681.4)	

Table 15. NPV of a Conventional Vineyard and Water Cost Relationships.

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