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COSTS AND RETURNS TO IRRIGATION UNDER THE CENTRAL ARIZONA PROJECT: ALTERNATIVE FUTURES FOR AGRICULTURE

by

David Bernard Bush

A Thesis Submitted to the Faculty of the

DEPARTMENT OF AGRICULTURAL ECONOMICS

In Partial Fulfillment of the Requirements
For the Degree of

MASTER OF SCIENCE

In the Graduate College

THE UNIVERSITY OF ARIZONA

1984

STATEMENT BY AUTHOR

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APPROVAL BY PROJECT SUPERVISOR

This essay has been approved on the date shown below:

William E. Martin   12 December 1984

WILLIAM E. MARTIN
Professor of Agricultural Economics

Date

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ABSTRACT

Will farmers in Central Arizona be better off or worse off with the Central Arizona Project (CAP)? How much should they be willing to pay for CAP water? These questions are addressed through both long and short term analyses of the potential economic worth of the CAP. In the short term, the marginal cost of groundwater pumping and overdraft is compared to current levels of demand for irrigation water, and to the estimated variable cost of CAP water. In the long term, the potential effect of the CAP on future average total water costs is estimated.

The analytical problem associated with these estimates is in integrating facts and assumptions about the many factors bearing on the present and future costs of alternative water supplies. Among these factors are the costs of energy, taxes, and land subsidence; Colorado River flows; changes in groundwater overdraft and pumping depths to lift; water rights; and the various costs associated with the construction, replacement, operation, and maintenance of water production and distribution facilities.

Evaluating the trends and potential savings in the costs of future water supplies with and without the CAP is the means used to assess the net benefit of the CAP for irrigated agriculture. The net benefit is a measure of the maximum amount that farmers would rationally pay for the CAP.

As compared with other dreams and schemes, the possibility of improving the efficiency of water use by such unromantic devices as elimination of waste or rationalization of pricing procedures may seem drab indeed - the more so as the large gains achievable by merely making better use of supplies in hand may indicate postponement indefinitely of vast new engineering wonders.

Jack Hirschleifer, 1960
<u>Water Supply: Economics, Technology, and Policy</u>

CHAPTER 1

PROBLEM AND METHODOLOGY

> Arizona's principle and also its most fundamental water problem is that of imbalance between supply and use. For years Arizonans have been using water more rapidly than Mother Nature has replenished it. This is possible only through massive borrowing of waters banked as groundwater reserves in past geologic ages . . . Arizona cannot continue its profligate ways forever. Actions to balance supply and use must be taken.
>
> Arizona Water Commission, 1975
> Arizona State Water Plan, Phase I

> A lesson to be learned from a review of groundwater development and costs in Central Arizona is that the problems are not new problems, nor are they of the general crisis proportions which they are often considered to be. Reading the literature on groundwater development in Central Arizona at any point in time since 1930 leaves one with the impression that pump areas in Central Arizona are faced with an immediate crisis of major proportions. The cry "Water shortage is not just idle talk for us - it is grim reality now!" was heard in 1946, as it was in 1966.
>
> Harold M. Stults, 1968
> Unpublished Doctoral Dissertation

This study addresses a simple but controversial question: Will importation of irrigation water via the Central Arizona Project (CAP) leave area farmers economically better off or worse off than before? This chapter discusses the problem setting which gave rise to the movement to build the project. Popular conceptions about the supply and demand for water in Arizona and the need for the CAP are summarized. Objectives and procedures for the research are outlined, and the geographical area of study is described.

The Problem Setting

Recent History of Water Use in Arizona

Economic growth in Arizona, led initially by mining, grazing, and irrigated agriculture but then soon overtaken by the government, manufacturing, and service sectors, was made possible by two major developments in the twentieth century. The first was the development and expansion of the Salt River Project (SRP) over a forty-year period with the financial and managerial assistance of the Bureau of Reclamation. Under this project the surface water flows of the Salt and Verde rivers were captured, stored, and developed. Approximately a quarter of a million acres of land surrounding the city of Phoenix were incorporated into the SRP service area. The second major development was the rapid expansion of groundwater pumping, primarily in the desert lowland province of Central and Southern Arizona.

From the completion of the first works of the SRP shortly before statehood in 1912 until the beginning of World War II, the population and the economy of Arizona grew at a fairly slow pace. Towards the end of this period total diversions of water from all sources averaged about three million acre-feet per year. Agricultural lands were concentrated mostly in areas such as the Salt River Valley or along the Colorado River, where surface water supplies were available or groundwater pumping lifts were shallow.

In the aftermath of the second World War, the economy and population of Arizona began to grow rapidly. Heavy reliance on groundwater pumping allowed vast new areas remote from surface water supplies, especially in Maricopa and Pinal counties of Central Arizona, to be placed under cultivation. Irrigated agricultural lands expanded from 0.5 million to over 1.3 million acres. Total water use more than doubled to 6.5 million acre feet per year, mostly as a result of a roughly four-fold increase in groundwater withdrawals. Accelerating declines in the water table indicated that the rate of groundwater pumping was considerably in excess of the rate of replenishment.

In the 1980's the total quantity of water demanded in Arizona has reached approximately 7.5 million acre feet per year. Surface water diversions, which had for many years fluctuated between about 1.5 and 2.0 million acre feet per year, have increased to about 2.5 million acre feet annually with the development of much of the remaining available surface water sources (Sundie, 1984). The level of groundwater pumping has remained relatively unchanged since the early 1960's, at about 4 to 5 million acre feet per year.

Current Rates of Groundwater Overdraft and Decline

According to the "1970 normalized" estimate of water use in Arizona, each year nearly twice as much groundwater is removed from the aquifers as is returned. The estimated annual rate of groundwater depletion, or overdraft, is 2.2 million acre feet (Arizona Statistics, 1982, p. 58). The high level of groundwater withdrawals and groundwater overdraft has led to concerns that the long term viability of Arizona's water supply is being threatened.

Continued overdraft of the aquifers has caused pumping depths to lift to increase, sometimes by more than 200 feet since the 1940's (Arizona Water Commission, 1975). Groundwater declines in most areas of Central Arizona vary between about one and four feet per year, although in a few isolated hydrologic basins the rate is considerably more than that. The Harquahala valley in western Maricopa County presently experiences an average annual rate of groundwater decline of approximately eight to nine feet per year (US Geological Survey, Unpublished Well Data, 1983).

Popular Concerns About Groundwater Overdraft

Three major concerns sum up the popular image of Arizona's historical water problem, and the impact of groundwater overdraft on the long term cost and availability of water in the state. The first concern is that as the depletion of the groundwater supply continues unabated and demand for water grows, severe shortages will develop which will threaten to ruin the Arizona economy. Unless the overdraft is brought under control, Arizona may literally run out of groundwater.

Agriculture still utilizes approximately 85 to 90 percent of all the water used in Arizona today. Competition for the remaining water supplies is projected to become more intense as the groundwater table falls, population increases, and the nonagricultural economy expands. These changes "have been occuring at relatively rapid rates" during the postwar period and "are expected to continue" (Mack, 1969, p. 1). Kelso, Martin, and Mack (1973, p. 20) noted that a much discussed problem in Arizona for many years has been the degree to which water shortages will be a drag on the state's economy, and what, if anything, can or ought to be done about it. With existing limited supplies already appropriated by an important but heavy-water-using sector, agriculture, and other demands for water increasing rapidly, how are the growing water requirements to be met and economic growth protected?

> All in all, it appeared that limited water supplies in the state might prove to be the number one restraint on continued growth of the Arizona economy . . . Population growth and new uses for water in the state will be stymied unless additional presently unclaimed and unused supplies can be found and developed from either within or outside the state.

The second concern commonly voiced is that the costs of recovering groundwater could grow prohibitive even long before the supplies stored in the aquifers were used up altogether. Groundwater overdraft causes the water table to fall. As the water table falls, more energy is required to lift water to the surface. As a lift deepens well yields frequently tend to decline, reducing pumping efficiency and forcing energy costs up even higher. The chemical quality of the water may deteriorate, and in very deep wells the water may be too hot to use. A receding water table may also require the improvement or replacement of some of the well components with larger and more powerful equipment, increasing well maintenance costs and the level of necessary capital investments.

The final major popular concern about groundwater overdraft is that it causes land subsidence and a related problem, earth fissuring. Land subsidence is caused by declining groundwater levels. Groundwater in the unconsolidated aquifers in a hydrologic basin bears part of the load of overlying sediments. As the aquifers are dewatered, the load overlying the sediments is shifted to the mineral particles which comprise the aquifer. Fine-grained sediments in these strata compact under the weight, causing land surfaces above to subside. Earth fissures appear as long and sometimes deep cracks along the surface of the ground. They may occur whenever land subsides at different rates within different areas of the same subsiding hydrologic basin.

The worst cases of subsidence are reported in western Pinal County. The maximum subsidence measured in the area is 7.5 feet near the town of Eloy for the period 1948 to 1967. Earth fissures as much as eight miles in length have been detected along the edges of this area. Subsidence and earth fissuring in Pinal County have damaged Picacho Reservoir, wells, railroads, streams, highways, and farmland (Arizona Water Commission, 1975.) The compaction of underground strata as a result of subsidence also tends to reduce the storage capacity of the aquifers involved, affecting their ability to recharge to their former volumes (Hirschleifer, 1960).

Active Groundwater Management and the CAP

Much of the research conducted on the "water problem" in Arizona over the past twenty years has attempted to project the possible economic outcomes of a growing water scarcity in Arizona in the face of two great uncertainties. The first was when and if Arizona's last major entitlement to Colorado River water would ever be developed, and what its importation could cost. The second was the ultimate outcome of the pressure for water institution reform in the state. Developments in recent years have rid both considerations of much of their mystery.

In the first instance, the construction of the Bureau of Reclamation's ambitious CAP is nearing completion, a vast, complex, and by any estimate enormously expensive system of pumps, siphons, dams, reservoirs, and acquaducts. The project will transport water from Lake Havasu, on the western border of the state, on a tortuous journey overland for 300 miles and nearly 3,000 feet uphill, through isolated mountains and desert to populated areas in the valleys of Central Arizona. It is designed to deliver over a million acre feet of Colorado River water per year to agricultural, municipal, and industrial users. The CAP will nearly double the annually renewable water supply in Marciopa, Pima, and Pinal counties, where most of the water demand in the state is concentrated and the groundwater overdraft problem is the largest.

Initial water deliveries could arrive in the Phoenix area as early as 1986, and in the Tucson area by the early 1990's. It is now known with a fair measure of certainty who will contract for CAP water, how much they can expect to get, and what it will cost them - at least initially. The Central Arizona Water Conservation District (CAWCD), the state agent for delivering CAP water, has drawn up and is in the process of signing 50-year contracts for water service with the numerous agricultural, municipal, and industrial users interested in the project. Additional contracts to provide federal loans at subsidized interest rates for the construction of local CAP distribution systems have also been drawn up and signed.

In the second instance, the comprehensive Groundwater Management Act of 1980 represents the culmination of many years of struggle for a state-wide consensus on water resources management policy. Groundwater has been declared a public resource which, in the interests of the people of Arizona, should be "stabilized" by restoring a balance between the average annual rate of groundwater withdrawal and the average annual rate of replenishment. The reduction of the groundwater overdraft virtually to zero by the year 2025 is the primary long term objective of Arizona's water resource management policy (Delaration of Policy, Groundwater Management Act of 1980). An integral component of the plan will be the substitution of alternative surface water supplies for groundwater pumping by means of the importation of large new quantities of Colorado River water into Central Arizona.

Most of the planned reduction in groundwater overdraft will be guaranteed by a legal provision that non-Indian agricultural recipients of CAP water, who will consume, on the average, more than half of the total annual supply of CAP water, must reduce groundwater pumping by the amount of project water delivered to them (Master Contract, 1972). As CAP deliveries replace the demand for groundwater pumping, the annual rate of groundwater overdraft in the three-county area will be cut back by two-thirds (Arizona Water Commission, 1975). The remaining one-third of the overdraft will be eliminated through voluntary and mandatory conservation measures imposed on all water users (Arizona Water Commission, 1975).

With the passage of Groundwater Management Act and the creation of the CAP, most of the witnesses to the historic water problems in Arizona believe that a new era of rational management of Arizona's water resources has begun. Agricultural, Indian, commercial, and residential water user interests have met and compromised on the divisive issues which had for so many years prevented a common consensus among them. In the eyes of the public an important and historic set of agreements has been put into effect, enabling Arizona to at last "look to the future with confidence." There is not a major interest group in Arizona which does not think it has an important stake in the newly emerging, state-coordinated water resource management system.

General Description of the Study Area

The study area corresponds to the exterior boundaries of the service area of the Central Arizona Water Conservation District. This special municipal organization was created in 1971 for the purpose of supplying CAP water to agricultural, municipal, and industrial water users in Maricopa, Pima, and Pinal counties of Central Arizona. Five hydrologic basins and fourteen irrigation lie within the study area. The hydrologic basins are, from the southeast to the northwest, Avra Valley, Lower Santa Cruz, Salt River Valley, Lower Hassayampa, and Harquahala. In only two of them, the Salt River Valley and Lower Santa Cruz basins, are their any significant surface water sources. Water users in all five basins are dependent, wholly or partly, on the mining of deep underground acquifers. In most areas the rate of groundwater withdrawal is significantly in excess of the rate of natural and induced replenishment, although the degree of imbalance varies widely.

The fourteen irrigation districts in the study area comprise almost all of the major agricultural irrigation districts which have accepted or are seriously considering accepting CAP water deliveries. Three other major agricultural water users who have expressed a strong interest in contracting for CAP water have been excluded from the analysis. They are the Farmers Investment Company (FICO), the McMicken Irrigation District, and the Salt River Project. FICO and McMicken were not considered because they declined to cooperate in the research project. The Salt River Project was not considered because its potential CAP water allocation is relatively small and will have little effect on the cost or availability of water in that area in the future. All of the major participating and nonparticipating agricultural water service organizations within the general service area of the CAP are illustrated in Figure 1.

Of the irrigation districts included in the study area, eleven depend completely on groundwater for their water supplies, while three use surface water and groundwater conjunctively. The eleven groundwater-only districts are Chandler Heights, Harquahala, Queen Creek, San Tan, and Tonopah in Maricopa County; Avra Valley and Cortaro-Marana in Pima County; and Central Arizona, Hohokam, Maricopa-Stanfield, and New Magma in Pinal County.

The three conjunctive use irrigation districts are Maricopa Municipal Water Conservation District #1 (MCMWCD) and Roosevelt Water Conservation District (RWCD) in Maricopa County, and San Carlos in Pinal County. Farmers in MCMWCD receive about 27 percent of their annual water supply from Lake Pleasant on the Aqua Fria River (Yancy, 1984). Farmers in RWCD receive about 30 percent of their annual water supply from the Salt River Project, which in turn comes largely from diversions

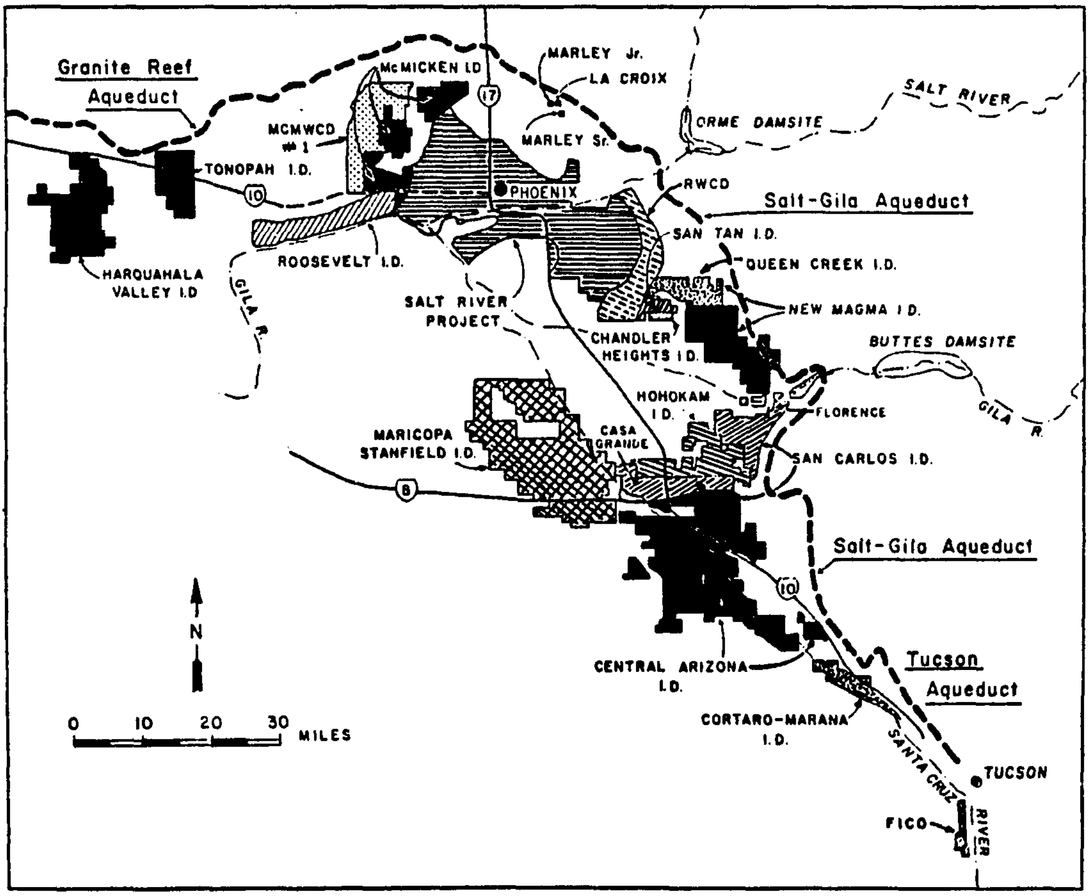


Figure 1. Agricultural Irrigation Districts in the Service Area of the Central Arizona Project.

Source: Bureau of Reclamation. Office of Advanced Planning, 1980.

from the Salt and Verde Rivers (Ward, 1984). Farmers in San Carlos receive approximately 46 percent of their total annual water supply, primarily from the San Carlos Reservoir on the Gila River (San Carlos Project, 1981).

Method of Research

Popular wisdom finds the rational behind the state water resource management policy a self-evident, almost sacred truth: unless vigorous water conservation and supply augmentation measures are put into effect and done so in short order, the people of Arizona will face severe hardship as a shrinking water suppply threatens to ruin the state's economy. From this viewpoint, the CAP is considered an inalienable component of the program for survival.

In spite of, or perhaps because of the conviction that public policymakers express in support of the state water resource management objectives, all may not be as it seems. Economists who study Arizona's water problems argue that there are numerous alternatives for managing its water resources. The array of posssible choices represents far more than only choosing among the CAP, draconian conservation measures, and doomsday.

If Arizona water users want to import Colorado River water via the CAP, then they ought to have sound economic reasons behind this particular preference. The project would have to provide them with better, cheaper, or more water than they would otherwise use at current and projected levels of supply and demand. If water from the CAP appears more expensive than supplies from other sources, and if its price exceeds that which the most marginal user can offer to pay, then the project may be justified only if it offers substantial benefits which would not normally be captured in the traditional pricing framework. Among these potential benefits might be: a reduction in the rate of increase of future groundwater pumping costs, fewer damages caused by land subsidence, and a more reliable water supply. These benefits should be analyzed carefully to determine who will benefit and how, and to what extent they might be willing to pay for the privilege.

Frames of Reference

Under what circumstances would it be economically rational for Arizona to build the CAP? The answer to this question has at least three dimensions. In the most immediate sense, it is worthwhile to develop the CAP only if the returns to the water it delivers meet or exceed its production costs, including any lost opportunity to use alternative and competing groundwater resources. In a broader sense, the CAP would be worthwhile only if, over time, the present value of the net returns to water would be higher with the CAP than without it. In a broader sense still, the project may be judged worthwhile only if no other investment alternative could ultimately leave farmers at least as well off, that is, only if the opportunity cost of capital committed to the CAP is less than the net benefits farmers might enjoy through this particular project.

Clearly, any conclusion about an investigation into the potential worth of the CAP is dependent upon the frame of reference within which the question is posed. In order to clearly define the direction and focus of this particular analysis, therefore, a few key terms are defined first.

The "short run" refers to any arbitrary period during which at least one factor of production is fixed, while all other factors may vary with the level of productive activity. Usually the short run costs on a farm are associated with all inputs that vary with the level of production: among them fertilizer, fuel, day labor, seed, and water.

In the absence of other constraints, and all other factors held constant, the net return to any single factor of production (such as water) is maximized when it is employed in the production of a particular product to the point where the marginal value product of the factor is equal to its marginal unit cost. So long as the gross revenues earned from the product are sufficient to at least meet all of its variable costs of production, it is economically rational to continue production in the short run.

The "long run" refers to any arbitrary period during which <u>no</u> factor of production is fixed. In the long run, the farmer may change the level of any input factor associated with his enterprise, whether or not it varies with the level of production. Among the costs typically considered "fixed" in the short run which then become "variable" in the long run are those associated with the stock of buildings, the inventory of durable equipment, and the size of the landholding.

When the net returns to the production of a given product in the short run are positive, at least some of the long run, "fixed" costs of the enterprise may be met. If gross earnings are sufficient to meet all long run fixed costs and also all short run variable costs, then within that given period of production, the producer earns a profit.

The "short term" is an arbitrary period of time which defines a discrete period of production. In the short run (or short term), a farmer makes production decisions concerning the most appropriate level and mix of economic activities feasible to undertake within the constraints of his enterprise. The entrepreneur's choices may be physically or institutionally constrained by the productive capacity of his "fixed" plant. His choices are economically constrained to the extent that the revenues he earns can cover his variable costs of production.

The "long term" refers to any arbitrary period of time which defines many periods of production, also known as a planning horizon. Over the long term, a producer makes investment decisons concerning the size and scale of his capital plant. These investments will affect the constraint set which in turn defines the types of optimal short term production decisions that he can make.

A given investment will leave a producer better off than otherwise when, over some predetermined planning horizon, the discounted stream of projected net benefits from the investment yields a positive net present value. Among competing investment opportunities, a producer is best off choosing the alternative which yields the greatest potential net present value.

Research Questions and Objectives

This study will attempt to evaluate the worth of the CAP to agriculture by addressing itself to four major sets of questions:

1. What is the nature of the demand for CAP water?
2. What is the cost of groundwater overdraft? (What would be the benefit of controlling it?)
3. What will be the impact of the CAP on controlling groundwater overdraft?
4. What will the CAP cost, and will its potential benefits exceed this cost?

As a means of forming answers to these questions, the study first examines some of the important theoretical economic relationships implied in the issues raised above. Simple economic decision rules and models are devised in order to bring empirical facts about the CAP and the supply and demand for agricultural water in Arizona into a coherant analytical framework. Conclusions about the potential worth of the CAP are then drawn on the basis of the insights gained from the analysis. The specific research objectives are outlined as follows:

1. Describe the current supply and demand for irrigation water in Central Arizona. Describe the standard microeconomic short run decision rules for buying alternative supplies of water such as the CAP. Show why a standard short run microeconomic analysis is inadequate for assessing the potential worth to agriculture of CAP water.

2. Explain how the short run decision rules might be modified to reflect the particular physical, economic and institutional characteristics of the CAP.

3. Describe the costs of groundwater overdraft. Compare the "full" marginal cost of groundwater pumping to the variable cost of CAP water. Identify the key variables affecting the economic cost of groundwater overdraft and the relative competitiveness of CAP water in the short run.

4. Examine the historical trends affecting the supply and demand for irrigation water to determine the sensitivity of net farm income in Arizona to deepening pumping lifts and increasing pumping costs over time.

5. Prepare a long term comparative cost analysis of the CAP by projecting future trends in average water costs with and without project conditions. Identify the key variables affecting the relative worth of the CAP over the long term.

Plan of Study

The potential worth of the CAP to Central Arizona farmers is evaluated in both the short and long term. In the short term, the supply and demand of irrigation water is analyzed to determine the circumstances under which it might be economically rational to use CAP water in production. Both private and social measures of variable water costs are used to develop the decision rules for determining the optimal levels of use of competing sources of water.

In the long term, the focus of the study shall be upon the projected average total costs of water from all sources combined, under alternative project and no-project conditions. The question examined in the long term analysis is whether or not the CAP will make the total cost of producing irrigation water cheaper, and if so how, when, and to what extent. The measurement of the opportunity cost of forgoing alternative investment opportunities for the CAP is beyond the scope of this analysis and is left for subsequent studies.

Chapter 2 offers an economic conceptual framework to describe the water market in Arizona and to pose questions about the CAP's potential worth in that market. Subsections of Chapter 2 review the basic microeconomic theory of profit maximization and marginal cost pricing, and discusses how this theory may be applied to an assessment of the supply and demand for water in Arizona. It then proceeds to identify some of the analytical problems associated with pricing the CAP appropriately for agriculture.

Chapter 3 discusses the economics of water consumption, conservation, and supply augmentation in Arizona. The purpose of the CAP is described in terms of its role in the state's intertemporal water allocation scheme. The potential value of the CAP as a means of controlling groundwater overdraft is discussed. A theoretical framework for modeling the relative costs of groundwater pumping and overdraft is prepared.

Chapter 4 assesses the major external effects of continued groundwater overdraft. Empirical measurements of the various costs of overdraft are brought into the analysis, through the application of decision rules and analytical techniques developed in chapters 2 and 3. The private and social marginal costs of groundwater pumping are compared to the marginal cost of CAP water. The importance of the problem of rising groundwater pumping costs is evaluated in the context of recent historical trends in the supply and demand for irrigation water.

Chapter 5 describes the long-term analytical model used to project the average costs of irrigation water under alternative project and no-project conditions. Eight major Central Arizona agricultural irrigation districts within the planned CAP service area in Maricopa and Pinal counties are chosen for detailed study.

Chapter 6 compares and contrasts the empirical results of the long-term model for each of the irrigation districts studied. A sensitivity analysis on key variables is conducted. Significant trends, factors, and relationships among the variables are discussed.

Chapter 7 summarizes the results of the study and offers some general conclusions about the CAP and water resource management policy.

Some criticism about this study may arise over the simplicity of its approach. The reader who hopes to discover new and complex applications of quantitative analytical techniques will be disappointed. The current body of fact and theory about Arizona's physical water resources is not yet complete enough to allow for very much sophisticated economic analysis, and this study does not attempt to gloss over the high degree of uncertainty that this or any research attempt in this domain has to confront. Yet the potential inacurracy of the projections employed herein ought not to detract from the general significance of their results. Quoting from Kelso, Martin, and Mack (1973 p. xvi),

> We are under no delusions that what we say concerning the Arizona water problem and its solutions is exactly right in all details; but the correct details, whatever they may be, could be different by several orders of magnitude from what we here elucidate without changing their implications for state water policies and programs in the slightest.

CHAPTER 2

SUPPLY AND DEMAND FOR IRRIGATION WATER: A CLASSICAL ECONOMIC EVALUATION OF THE CAP

> The purpose of the CAP is to replace this priceless [groundwater stock] resource with Colorado River water. . .
>
> Clifford Pugh, 1983
> Memorandum to McMicken Irrigation District

> Until and unless it is appreciated that water resources do not in themselves lead to magical growth of wealth, that water is not something "holy" or "sacred," and that water resources are subject to the same economic forces that govern the use of all other economic resources, there may be little progress in the direction of efficiency in the use of water.
>
> Jack Hirschleifer, 1960
> Water Supply: Economics, Technology, and Policy

This chapter formulates decision rules for determining the circumstances under which the CAP would be a worthwhile project for agriculture in the short term. A classical microeconomic analysis of the supply and demand for water is introduced. The basic economic choices faced by the typical farmer concerning the level of use of irrigation water from alternative sources is discussed. The institutional, physical, and economic features of the CAP are reviewed. The basic analytical model is modified and extended in order to reflect these features, and some preliminary conclusions about the potential worth of the CAP are offered.

The classical economic analysis of the CAP suggests that the project is not worthwhile to undertake at the present time. Yet, popular support for the CAP is widely based and enthusiastic. Why is there such a divergence between fact and theory?

A possible explanation is that the classical model is too simple. Several potentially important economic factors concerning the full cost of alternative groundwater sources, which are not amenable to analysis in the ordinary classical economic framework, are ignored. Their inclusion in the study might change the picture of the relative competiveness of the CAP significantly. A more comprehensive study of the problem, which attempts to incorporate these elements into the analytical framework, begins with the modified static economic analysis introduced in the following chapter.

Supply of Water in Arizona

Arizona's Physical Water Resources

About 7.5 half million acre feet of water are diverted for use in the state of Arizona annually. Table 1 shows the breakdown of this water supply into stocks and flows, while Table 2 breaks it down into surface water diversions and groundwater pumping. Roughly 70 percent of all water used in Arizona comes from annually recurring flows, of which about half originates as surface water and half as groundwater recharge. The remaining 30 percent of all the water developed for use in Arizona is recovered from a diminishing stock of groundwater reserves. Two thirds of all water is pumped from underground aquifers, while the remaining one third is diverted from lakes, rivers or streams.

Table 1. Stocks and Flows of Developed Water Resources in Arizona. (Acre feet per year)

FLOWS		
Colorado River	1,100,000	
Salt River Project	883,100	
Gila River	193,200	
Safford Area	96,600	
Duncan Area	19,470	
Agua Fria River	31,500	
Other	176,130	
Subtotal, Surface Water Flows		2,500,000
Natural Recharge	300,000	
Induced Recharge	2,500,000	
Subtotal, Groundwater Flows		2,800,000
Total, All Flows		5,300,000
STOCKS		
Groundwater Overdraft		2,200,000

Sources:

Sundie, Dennis. Department of Water Resources. Personal Communication, 1984.

Valley National Bank. Arizona Statistical Review. Economic Research Department, 1983.

Table 2. Average Annual Production and Use of Water in Arizona. (Acre feet per year)

SUPPLY	
Flows	5,300,000
Stocks	2,200,000
Total Annual Supply	7,500,000
DEMAND	
Pumped Groundwater	5,000,000
Surface Water	2,500,000
Total Annual Demand	7,500,000

Sources:

Sundie, Dennis. Department of Water Resources. Personal Communication, 1984.

Valley National Bank. Arizona Statistical Review. Economic Research Department, 1983.

Four distinct types of stocks and flows of water may therefore be identified in Arizona:

1) Annually renewable flows of surface waters
2) Annually renewable, naturally ocurring groundwater recharge flows
3) Annually renewable, artificially-induced groundwater recharge flows
4) Depletable groundwater stocks.

At the current estimated rate of groundwater recharge, it appears that nearly two million acre feet of groundwater could theoretically be pumped out of the aquifers every year without drawing down the fixed stock supplies. Roughly 10 percent of the recharge comes from natural sources. As much as 90 percent of it is induced by human activities such as sewage effluent releases, seepage from water delivery systems, and agricultural irrigation.

Tables 3 and 4 provide estimates on groundwater reserves and rates of groundwater overdraft in several selected areas of central Arizona. Reserve estimates, to depths up to 700 feet and then from 700 feet to 1,200 feet, are for the amounts of groundwater theoretically recoverable at the current level of technology. Although most of the known groundwater reserves in Arizona are found at depths shallower than 1,000 feet, additional water has been found and exploited at far deeper depths. Wells in Pinal County have successfully pumped water from depths of 2,000 feet and more (Edmond, 1984).

Assuming that no usable groundwater reserves exist below a depth of 1,200 feet, how limited is groundwater in Arizona? Is there a danger

Table 3. Groundwater Reserves and Depletion Rates in Central Arizona. (by Geographical Area)

Area	Rate of Overdraft (af/yr)	Groundwater in Storage to 1,200 feet	Years to Depletion (YTD)
Maricopa County	902,000	291,400,000	323
Pima County	267,000	216,100,000	809
Pinal County	620,000	120,300,000	194
Total, State of Arizona	2,200,000	1,192,808,000	542

Source:

Arizona State Water Plan, Volume I, 1975.

Table 4. Groundwater Reserves and Depletion Rates in Central Arizona. (by Hydrologic Basin)

Area	Rate of Overdraft (af/yr)	Groundwater in Storage to 700 ft	YTD to 700 ft	Groundwater in Storage to 1,200 ft	YTD to 1,200 ft
Avra Valley	119,000	9,800,000	82	6,200,000	52
Harquahala Plains	95,000	16,000,000	168	10,000,000	105
Lower Santa Cruz	520,000	48,800,000	94	42,300,000	81
Tonopah	57,000	26,000,000	456	12,400,000	218
Upper Santa Cruz	133,000	28,000,000	211	28,000,000	211
Salt River Valley	632,000	104,000,000	165	49,600,000	78

Source:

Arizona State Water Plan, Volume I, 1975.

of running out of this resource in the near future? At the current estimated rates of groundwater overdraft, how much time is there left until "doomsday"?

There appears to be no evidence that Arizona will run out of physical water supplies in the foreseeable future. Even if it is assumed that Arizona will continue to mine its groundwater reserves at the current rates, which is highly unlikely, it will not run out of this resource for a long time to come. The most serious case of groundwater depletion appears to be that of the Avra Valley, west of the city of Tucson. Yet, even there it does not appear that at the current rates of overdraft the groundwater stock would be used up until well into the twenty-second century. Pumping lifts would not fall below a depth of 700 feet for 82 years. It would take another 52 years before the groundwater table fell below 1,200 feet. In Pinal County, where some of the worst overdraft conditions are said to persist, and where the cries for supplemental water supplies are the loudest, enough groundwater appears to be recoverable to a depth of 1,200 feet to last nearly two more centuries.

Economic Supply of Water in Arizona

Whether the known physical reserves of groundwater in Arizona are enough to last for twenty years or two hundred years, however, is not in itself a sufficient measure of the quantities of water which will be available for future generations to use. There may always exist circumstances within particular localities where water resources are physically limited or water quality problems prevent exploitation. But these problems will only exist until and unless society either adapts to the limitations imposed or finds the means to overcome them. Given the technology and a willingness to pay to implement that technology, and barring any insurmountable institutional or legal constraints, additional or substitute water supplies are available for Arizona in virtually any quantity desired. The ultimate limitation on water supplies will always be economic, not physical. According to Kelso, Martin, and Mack (1973, p. 34),

> The economic problem of water doesn't rest on the physical quantity of available water alone but on the physical quantities available at particular costs. It isn't enough to know that a million acre-feet of water, for example, are physically available. One must know what quantities, totalling a million acre-feet, are available at what cost for each quantity.

It is only of secondary importance to know that a million acre feet of groundwater stock could be mined every year for two hundred years before the known reserves ran dry. It is more important to know what available quantities of groundwater might be in demand in the future relative to anticipated changes in the cost of supply.

The notion of "availability" in the realm of water resources is subject to much confusion. Beyond the economic constraints on water supply, a complex collection of legal and political institutions governs its exploitation. An available supply of water should therefore be understood as the amount that is economically available within the given set of physical and institutional constraints.

A given water supply may be increased or decreased in the long or short term by altering any of the different factors determining the quantity that is currently "available." Changes in institutions, advancements in the technology of water recovery and development, innovations in methods of transportation, or shifting demand patterns may all affect the volume of available water supplies without altering the physical character of the source's stock or flow characteristics in the slightest.

Economic Supplies of Available Irrigation Water

Many central Arizona farmers use privately pumped groundwater conjunctively with surface water or groundwater supplied by an irrigation district. Through access to cheap electrical power, control over the more productive wells, economies of size, and for other reasons, district water supplies are usually less expensive than most, if not all, of the water supplies that the individual farmer may produce on his own. District water supplies to individual farmers are often divided into discreet water allocations at different unit prices for each. In some cases, as in the Roosevelt Irrigation District in Maricopa County, the district may also price its water according to its chemical quality. During periods of low water demand a farmer will attempt to use only the cheapest combinations of private and district water supplies, while during periods of peak demand more expensive sources may be tapped. The existence of a variety of alternative sources of water at increasing unit costs may be interpreted economically as an increasing marginal cost curve for irrigation water.

Even where only a single source of irrigation water is available, such as in those cases where individual farmers are totally dependent upon their own groundwater supplies, the marginal cost of water still tends to rise over increasing volumes of demand. It not uncommon that some irrigation wells on a farm are significantly cheaper to operate or are more productive than other wells on the same farm. During periods of low water demand, only the most efficient wells are employed and the marginal cost of water is relatively low. At other times, when the demand for water is higher, the less efficient wells are put in service, and the marginal cost of water is driven up.

Demand for Water in Arizona

Requirements Versus Preferences

The daily material requirements that a human being has are relatively small: a minimal amount of food, water, clothing, and shelter would satisfy most basic needs for survival. Few want to live on the barest edge of existence, which for most people would be neither comfortable nor enjoyable. But comfort and enjoyment are relative, not absolute terms for life. Whether a person eats corn or steak, drinks wine or water, wears wool or silk, or lives in an apartment or a house is a matter of personal choice among competing alternative uses for an individual's limited resources.

A preference for a particular kind and amount of one good or service is satisfied to the extent that an individual is willing and able to sacrifice preferences for other goods and services in order to get it. For example, someone who prefers owning a more expensive automobile to a cheaper one may perhaps buy less clothing or spend more potential leisure time working to earn the additional means necessary to buy the car.

The publicly proclaimed interest in having more (or no less) water in the state of Arizona is also an expression of preference. Even the choices concerning the supply and demand for this "lifegiving" substance are relative, not absolute. Water is no more priceless than is clothing, housing, and food. Nobody should want to trade the scarce resources at their disposal for additional water (new, recycled, conserved, recaptured, or otherwise), if the economic value that the water represents to them is less than the value of what they would have to sacrifice in order to have it.

Of course, the motivations behind human behavior need not always be related to the productive or consumptive value of an economic good. National security, community pride, aesthetic tastes, and moral or religious beliefs may all in their own time and place provide suitable justifications for sacrifices which would not otherwise appear to be warranted on the basis of ordinary economic measures of value. Whether or not the purpose and function of the CAP is related to any noneconomic objective is beyond the scope of this study. The interest herein is limited to establishing whether farmers who choose to make large expenditures to build the CAP and to buy CAP water are making the rational economic choice.

Demand for Water in Arizona by User Class

The typical demand curve embodies the principle that most goods of economic value are subject to diminishing marginal utility. The first few units of a good available to a producer or a consumer may be relatively highly valued, and the sacrifice (price) one is willing to make (pay) to obtain the good is correspondingly great. As more and more units of the same good are added to the "market basket," however, all else being held constant, the relative value of the last (marginal) units received must eventually begin to diminish.

In Arizona, the highest use for water is generally represented by certain household applications. Household users are willing to pay handsomly for relatively small amounts of water, but their willingness declines relatively quickly as more water becomes available. Household demands of the highest order include water used for drinking, cooking, and basic sanitation. The demand for some other household uses such as watering lawns or filling swimming pools is much lower.

Commercial and industrial users consume more water than do household users, but their initial marginal willingness to pay is less. That is, industrial demand for water in any production process will probably be less that for the most basic (highest) household uses. Once the first household preferences are satisfied, however, the level of their demand falls off quickly and industry may successfully compete for the remaining water supplies.

Irrigated agriculture has a relatively low willingness to pay for most of its uses of water, but it is also the largest water consumer in the state. Relatively few agricultural uses for water can compete with household or commercial uses at high prices for water. Willing and able to make productive use of water extensively at relatively low prices, however, agriculture can effectively claim water that household and commercial users would employ only marginally. At the present low price of water in Arizona, agriculture still claims large amounts of water for use in relatively marginal productive activities long after most demands in other use classes have been met.

In summary, two general observations may be suggested about demand for water among uses and users:

1) Between classes of users, some classes are "more marginal" than others in the sense that they do not compete strongly for the first small quantities of available water, but they do compete strongly for large quantities of water at low levels of per unit cost.

2) Within each class of users, some uses are more valuable to it than others. That is, there is competition for water by use as well as by user class.

These observations are illustrated in Figures 2 and 3. The example is adapted from Kelso, Martin, and Mack (1973, p. 30).

Figure 2 shows a set of hypothetical aggregate demand curves for the three major classes of water users in the state of Arizona: household, nonagricultural commerce and industry, and irrigated agriculture. At a price of Z dollars there is no competition for water among users classes. Only household users are willing to enter the water market, buying Oa = Q1 units. At a price of Y dollars, water is still too expensive for irrigated agriculture to start bidding for it, but household consumers demand Oa' units and commercial and industrial users demand Ob' units of water, for a total of Q2 units. At the low price of X dollars, household users would be willing to purchase Oa" units, commercial and industrial Ob" units, and agriculture Oc" units, for a total of Q3 units of water.

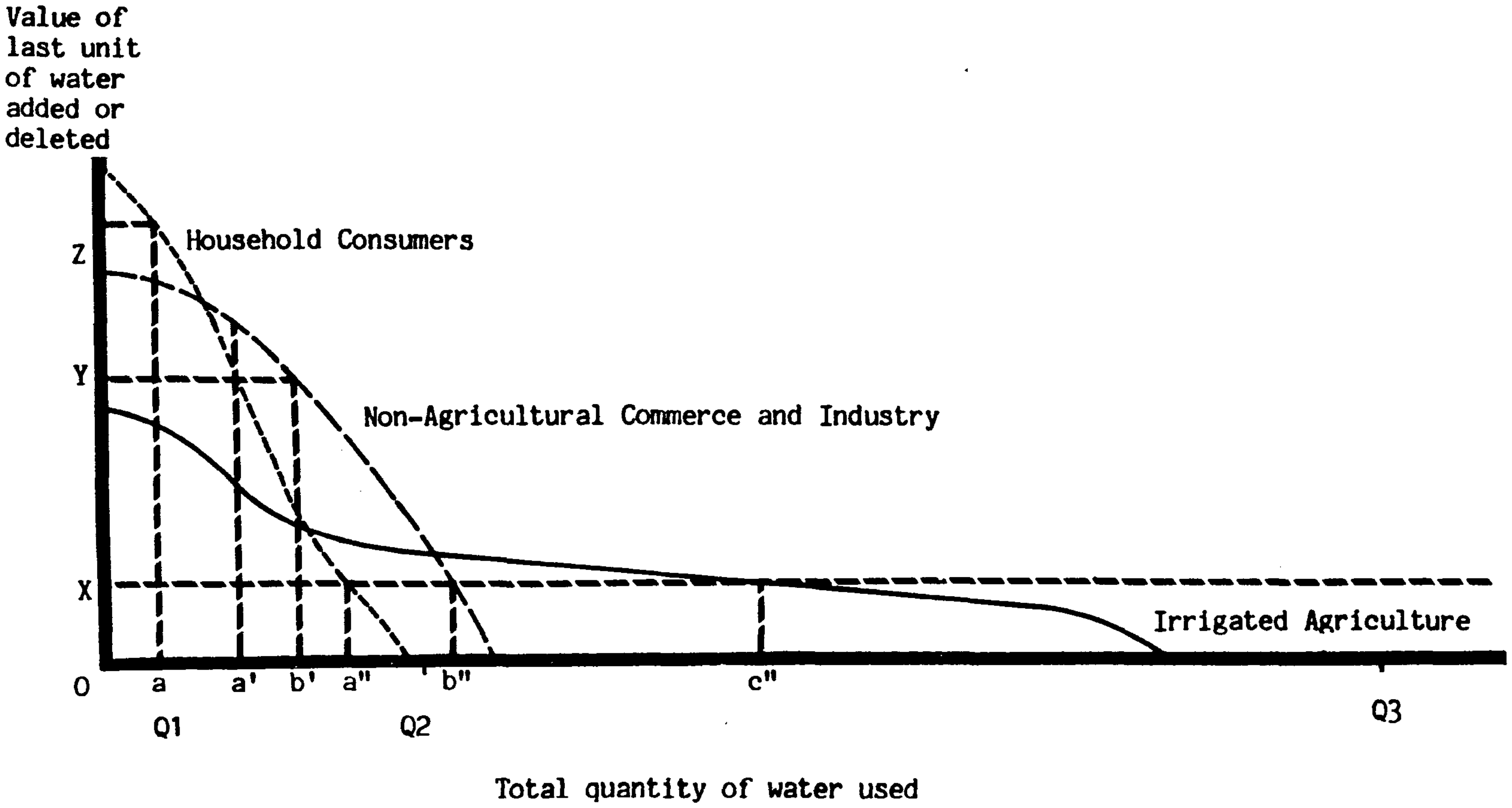


Figure 2. Hypothetical Aggregate Demand for Water in Arizona by Major User Class.

Source: Kelso, Martin, and Mack. Water Supplies and Economic Growth in an Arid Environment. 1973. p. 30.

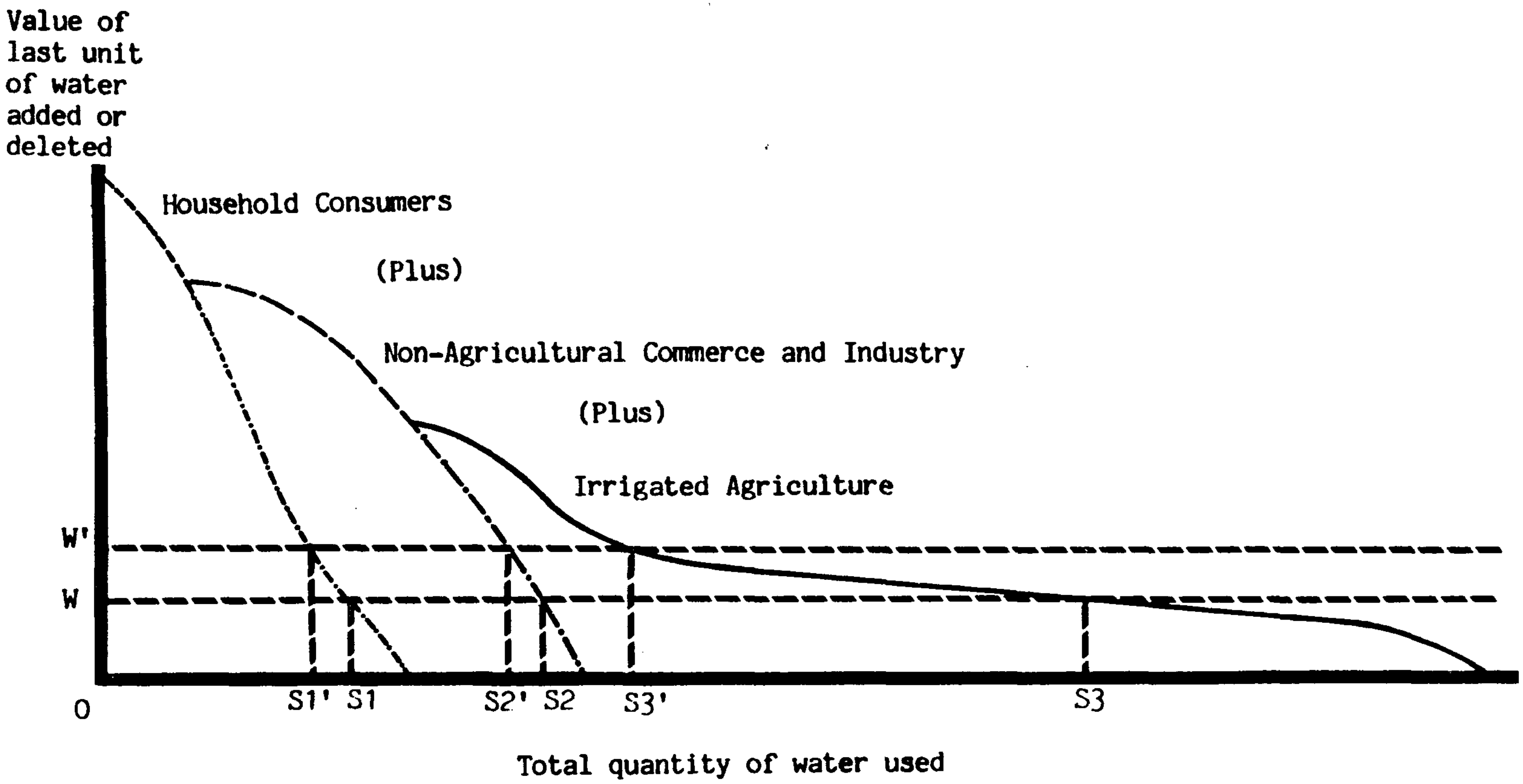


Figure 3. Hypothetical Aggregate Demand for Water in Arizona; Composite of Demand by Major User Classes.

Source: Kelso, Martin, and Mack. Water Supplies and Economic Growth in an Arid Environment. 1973. p. 31.

So long as Q1, Q2, and Q3 units of water are actually available for purchase at the prices of Z, Y, and X dollars respectively, the appropriate levels of demand in each user class are exactly satisfied and there is no "water problem." Water is scarce, since each user would use more if only the price were lower, but it is not in shortage, because the market for water has cleared.

Figure 3 illustrates the hypothetical composite aggregate demand curve for the three major water user classes in Arizona. Total water demand at any given price level for water is equal to the horizontal summation of the aggregate levels of demand by each user class. Letting price W represent the current low cost of water in Arizona today, the total quantity of water in demand by all user classes is equal to OS3 units.

Suppose the price of water in Arizona were raised to W'. Irrigated agriculture would cut back its demand substantially, by the amount S3'S3. Neither nonagricultural and industrial nor household demand would be reduced anywhere near as much, by only the amount S2'S2 and S1'S1, respectively. While household, commercial, and industrial (collectively referred to as municipal and industrial) users would suffer only a fractional cutback in their water consumption as a result of the price increase, agricultural demand would be almost eliminated.

Clearly, a relatively small increase in the cost of water could affect agriculture greatly while affecting all other users only slightly. A change in the price of water in Arizona would impact agriculture to a greater extent than all the other classes of water users combined (Kelso, Martin, and Mack, 1973, p. 32). Griffin (1980) proposed that increasing water costs in the Tucson basin would result in little more than an "inconvenience" outside of agriculture. Stults (1968) in his study of Pinal County estimated that a price increase of $10 an acre foot to all users in central Arizona would put most farmers out of the grain business, while most other agricultural activity would continue although at lower levels of profit. Residential and nonagricultural water use would hardly notice a change in their water costs. The average individual would pay an additional $1.80 per year for water, of which about a penny would account for drinking water consumption.

Allocating Scarce Water Resources Among Competing Uses

Consider a situation in which the total water supply in an economy is for the moment held fixed. Suppose a municipality wishes to obtain additional supplies of water. Let the value for the last unit of water consumed in the municipality be worth at least $100 an acre-foot. Assume that importation costs are not prohibitive, and there are no institutional barriers preventing the transfer of water to this municipality from elsewhere. At a price of $100 per acre-foot, a neighboring farmer whose marginal demand for water is only $40 would be better off selling <u>some</u> of his water to the municipality rather than to use it to irrigate low-valued crops. Both parties could then benefit from a transfer of water.

Suppose now it is the farmer who wants to buy additional water, but at a price not to exceed his demand of $40 per acre-foot. The municipality would not sell him any water for the price he will offer.

In fact, the farmer may not be able to find anyone who will sell him water for only $40. Only if he can find another user to whom the last unit of their water is worth even less to them, say $30, would such a trade be feasible.

In principle, no water user in Arizona other than the most marginal ones should have any serious problem meeting their demand for water, so long as they are willing to pay enough to bid it away from someone else employing it in a lower-valued use. Legally this may be impossible to do, but then the constraint on satisfying water demand is institutional and not economic or physical. If there is a water problem in Arizona, that is, if there is not "enough" water to go around, then the economic problem must be primarily a problem for the marginal user of water in the state. Irrigated agriculture is the most marginal water using class, and certain production activities in agriculture currently represent some of the most marginal uses of water in Arizona. The effect of a supply augmentation scheme such as the CAP should therefore affect agriculture far more than any other class of users. It is for this reason that this study concentrates on the costs and benefits of the CAP for agriculture to the exclusion of every other user class which may be affected.

Demand for Irrigation Water

Demand for irrigation water is derived from the relationship between the demand for agricultural products and their cost of production. If demand for a particular product is high relative to its cost of production, then the demand for irrigation water will be relatively high as well. If the reverse is true, then the demand for irrigation water will tend to be low.

Holding the costs of all other variable factors of production constant, the short run production decision rule for the use of irrigation water on any one crop is as follows. If the cost of an additional unit of water is less than or equal to the returns that it would earn on that crop in production, then it is worthwhile to obtain and use the additional unit of water. The maximum amount that a farmer would pay for the water is simply that sum which would exactly equal the return he could expect to earn through using that water. In other words, the farmer would be indifferent between having or not having an additional unit of water when he would just break even by using it.

Whenever a farmer has the opportunity to pay less than the maximum amount he is willing to pay for water, he would be better off using the water. He would then not only meet all of his variable costs of production, but would also earn additional revenue with which to help cover the fixed costs for the entire farm. If the farmer had to pay more than the maximum amount for his water, all other factors held constant, then he would fail to meet even the variable costs of production. Under those circumstances, the farmer would be better off by not using as much water to produce the crop, or perhaps even by not producing the crop at all.

Figures 4, 5, and 6 illustrate the approximate aggregate demand for irrigation water for use in the production of major crops in Maricopa, Pima, and Pinal Counties. The data are presented in tabular form in Appendix A.

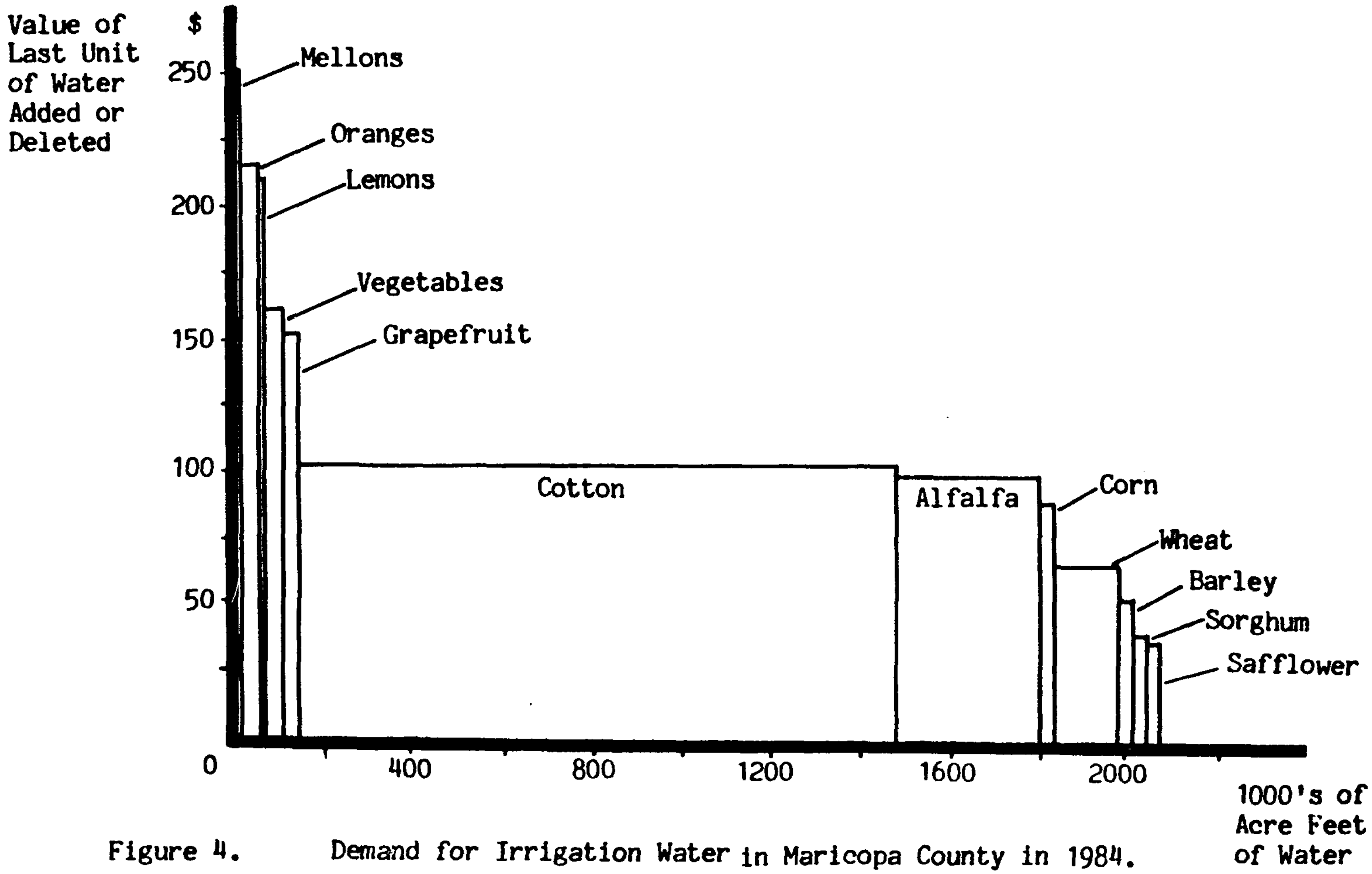


Figure 4. Demand for Irrigation Water in Maricopa County in 1984.

Sources: Hathorn, Scott.
Arizona Citrus Crop Budgets, Maricopa County. 1982.
Arizona Field Crop Budgets, Maricopa County. 1984.
Arizona Pecan Budgets, Maricopa County. 1984.
Cooperative Extension Service, University of Arizona, Tucson, Arizona.

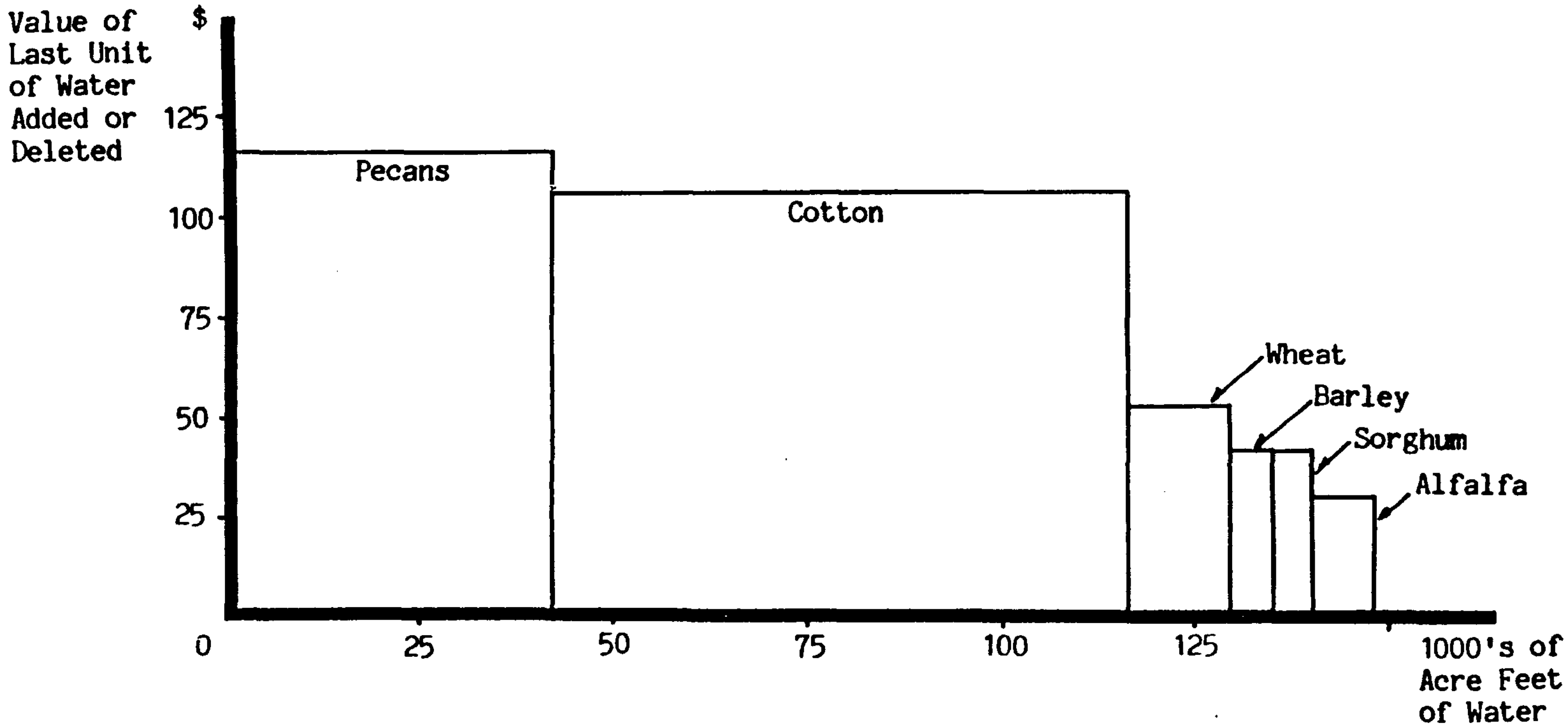


Figure 5. Demand for Irrigation Water in Pima County in 1984.

Sources: Hathorn, Scott.
Arizona Field Crop Budgets, Maricopa County. 1984.
Arizona Pecan Budgets, Maricopa County. 1984.
Cooperative Extension Service, University of Arizona, Tucson, Arizona.

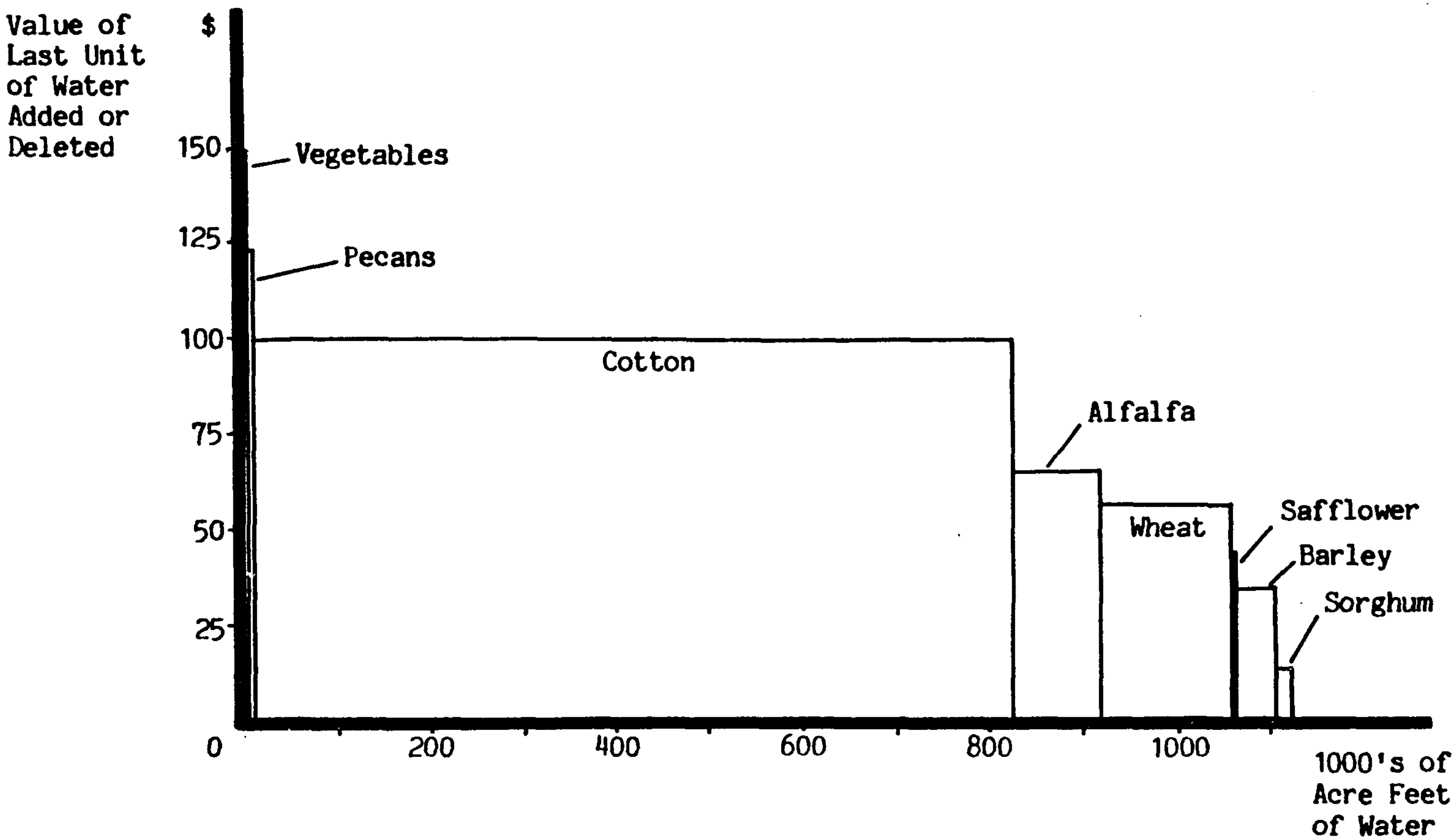


Figure 6. Demand for Irrigation Water in Pinal County in 1984.

Sources: Hathorn, Scott.
<u>Arizona Field Crop Budgets, Maricopa County.</u> 1984.
<u>Arizona Pecan Budgets, Maricopa County.</u> 1984.
Cooperative Extension Service, University of Arizona, Tucson, Arizona.

The demand for water was determined in the following manner. For each crop a gross revenue per acre was calculated on the basis of average yields and unit crop prices. All short run (variable) costs of production except the cost of water were then summed up and subtracted from the gross revenue total. The remainder constituted the maximum amount that the farmer could pay for water and still at least cover his variable costs of production. For the sake of simplicity, it is assumed that production costs and revenues for each crop remain constant over every acre planted. The average maximum willingness to pay for water on the marginal crop is therefore considered a measure of the marginal willingness to pay for water.

Clearly, when all other things are equal, the variable cost of water in central Arizona could approach and even exceed $100 an acre foot in the short run before farmers would choose to remove large acreages from production. In Pima and Pinal Counties, specialized pecan growers may in the short run pay almost $120 per acre foot of water, and in Maricopa County some specialized citrus growers may pay up to $200 per acre foot.

A typical pumping lift for an irrigation well in central Arizona is about 550 feet. A representative electricity rate is about 35 mils. Maintenance costs average about 1.14 cents per acre foot per foot of lift. Using Hathorn's formula (Arizona Field Crop Budgets, 1984), the typical variable pumping cost for water in central Arizona is therefore [(550 feet) * (1.024 Kwh per acre-foot per foot of lift) / 54% efficiency) * ($ 0.035 /Kwh)) + ($ 0.011438 per acre-foot per foot of lift * 550 feet)] = about $43 per acre-foot. It appears then that the typical farmer could pay roughly twice as much as he now is paying for irrigation water in the short run without significantly altering his production choices.

The maximum amount that a farmer is able to pay for water and stay in business, however, is not the same as the maximum amount that he would be willing to pay and maintain his level of profits. The marginal value product of irrigation water on a farmer's most marginal crop, usually a field grain or feed crop such as barley, sorghum, alfalfa, or wheat, currently does not tend to exceed about 35 to 50 dollars per acre foot.

The demand for an additional source of water is generally evaluated in terms of the current marginal marginal demand for water, while a substitute supply is generally evaluated in terms of the current marginal unit cost of water. The typical central Arizona farmer would not rationally pay more than about 35 to 50 dollars (the current marginal value product) for an additional acre foot of irrigation water. He would not rationally seek to replace any amount of water from his current sources at a cost of more than about $43 per acre foot (the current marginal unit cost).

The current estimate for the variable cost of CAP water, as shall be explained in Chapter 4, is about $65 per acre foot. Clearly, most farmers should be willing neither to pay this much for water on the margin in order to grow additional marginal crops, nor to substitute CAP water for an equal quantity of water from their best alternative source. Most farmers, with an average ability to pay as much as $100 per acre foot of water would be able to pay $65 per acre foot for CAP water, but they would reduce their overall net returns if they were to do so. Only farmers who were not growing any crops with a marginal value product of water less than $65 per acre foot or who were paying more than $65 an acre foot for their last units of water from their current sources would want to buy CAP water at this price in the short run.

A Classical Economic Determination of the Supply-Demand Equilibrium for Irrigation Water

Equimarginal Principle of Value in Use

A guiding principle of optimization in microeconomic theory is the principle of equimarginal value in use. It asserts that a resource for production or consumption has been efficiently allocated among all possible uses and users when no further mutually advantageous trade of the good among them is possible. At that point everybody values their last unit of the good equally.

Recall the story about the farmer who valued his last unit of water at $40 per acre foot while the municipality valued its last unit at $100 per acre foot. At some mutually agreed upon price - presumably somewhere between $40 and $100, an acre foot of water could be transfered from the farm to the city and both parties would be better off than before.

Now suppose the municipality wishes to buy still another unit of water. The principle of diminishing marginal utility (embodied in the typical downward sloping demand function) suggests that this next unit will be worth something less to the municipality, perhaps $90.

Meanwhile the farmer, who has fewer units of water than before, now values his marginal unit of water at something more than before, perhaps $50. A trade may still be affected, although the room for bargaining has shrunk. The equimarginal principle implies that trading should continue until such point is reached where the farmer and the municipality both value their respective marginal units of water the same. Then there would no longer be a rational basis for trade and an equilibrium in the allocation of water would be attained.

The process of trade tends to equate the marginal value in use, otherwise known as the marginal willingness to pay for a good, among all uses and users. So long as one individual exists who is willing to pay at the margin more for a unit of a good than would be the opportunity cost to someone else of giving it up, then a basis for mutually beneficial trade exists. This basis for trade is a feasible basis whenever the transactions costs (such as transportation of the good, legal fees, taxes, institutional barriers, and so on) are not prohibitive.

At trade equilibrium, the marginal willingness to pay for the good, excluding transactions costs, should be equal among all economic units. This amount then becomes the market price. At that price the sacrifice involved in producing or giving up the last unit of the good exactly equals the marginal benefit to each and every individual who is in the market for that good. The market price for a freely traded good is a measure of its value not only to the particular individual involved in the trade, but to society as a whole (Hirschleifer, 1960). Unless the development, transfer, and use of a good gives rise to undesirable third party effects, the private decision-making rules which maximize private profit will maximize social welfare simultaneously.

Classical Equilibrium Conditions for the Optimal Level of Use of Irrigation Water

Under normal circumstances a farmer will draw irrigation water for productive use until one of two limitations prevents him from using any more. Either (1) the marginal unit cost of an additional unit of water increases until it equals or exceeds the marginal value product of water on the marginal economic activity, or (2) an intervening constraint or set of constraints prevents production of the marginal crop from expanding up to the point where condition (1) is satisfied. In the first case marginal value product would exactly equal marginal unit cost, while in the second case marginal value product would be greater than marginal unit cost.

In allocating or reallocating the productive resources at his disposal, the farmer maximizes his net revenue (or minimizes his net losses) by making choices to change only the level of the production of his most marginal economic activities. Were it possible within his constraint set to use more irrigation water to grow more of any of his higher-valued crops, he would "bid" irrigation water away from one of his lower-valued activities. At equilibrium, the marginal crop C is using only water that cannot be efficiently devoted to a higher economic use. Since the farmer would never want to grow a crop that could not at least cover its variable costs of production, he would never want to pay more for water on the margin than the marginal value product of that water on crop C.

A Simple Supply-Demand Equilibrium Model for the Optimal Level of Use of Irrigation Water

Consider a hypothetical farm whose marginal unit cost (MUC) and marginal value product (MVP) curves for water are shown in Figure 7. Suppose the farmer grows three crops, A, B, and C. The marginal returns to water on the crops are constant at \$110, \$80, and \$50, respectively. Suppose that currently he can get water from only two sources, a local irrigation district and his own groundwater pumping facilities. The district supplies water in two uniformly priced blocks, one at \$20 per acre-foot and the other at \$30 per acre-foot. These blocks may be purchased separately. The farmer may pump groundwater in any volume he chooses. The marginal unit cost of groundwater pumping begins at \$10 per acre-foot and increases steadily in proportion with the level of extraction.

The marginal cost curve for water is interpreted as follows. The marginal cost of pumping each of the first 200 acre feet of private groundwater is cheaper than any other source of water. At that point, the marginal unit cost of groundwater has risen to \$20 per acre foot, so the first irrigation district allocation of 200 acre feet of water becomes competitive. The next district allocation is also available, but at the higher unit cost of 30 dollars per acre foot, it is worthwhile for the farmer to pump another 200 acre feet of his own groundwater first. When the marginal unit cost of groundwater has risen to \$30 per acre foot, the second allocation of 400 units of district

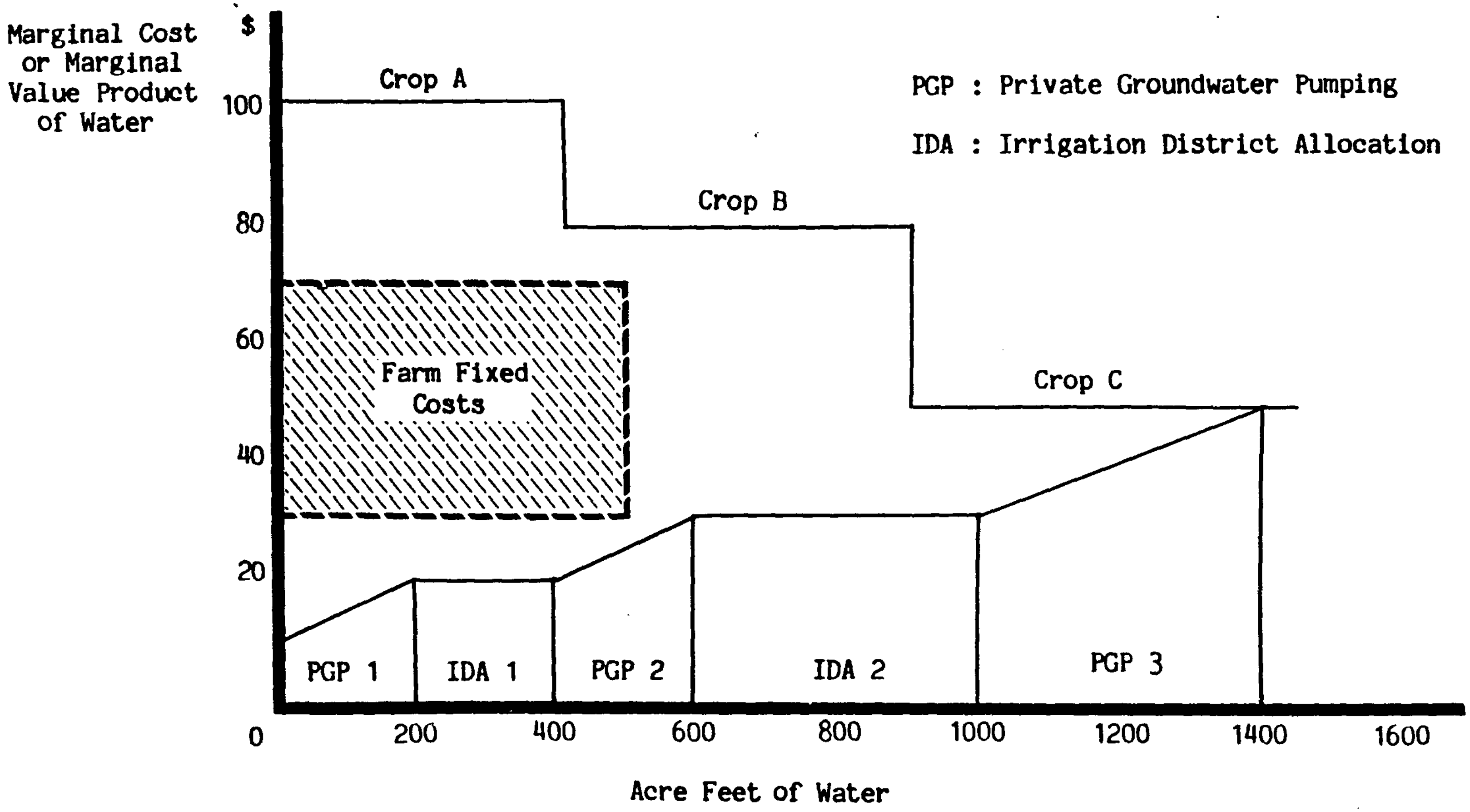


Figure 7. Hypothetical Farm Model of the Optimal Level of Use of Irrigation Water.

Case 1: No CAP Water Available.
No Constraint on Water Use.

water becomes worthwhile to purchase, until it too is exhausted. From then on, all additional units of water must be supplied again from private pumping, at a steadily rising marginal unit cost.

Subject to his physical, economic, and institutional constraints, the farmer will grow as much of his highest-valued crops as possible. The downward-stepping MVP curve represents the diminishing marginal willingness to pay for water as the farmer puts more and more acreage into the production of crops with progressively lower returns to water.

When all 600 acre feet of district water and 800 acre feet of private pumpwater have been drawn, the farmer reaches a competitive state of equilibrium with respect to his use of irrigation water. At that point, the marginal unit cost of irrigation water, $50 per acre foot, is exactly equal to the marginal value product of water on the most marginal product, crop C. The area between the marginal value product curve and the marginal unit cost curve represents the total short run net returns to irrigation water on the farm. The hashed area superimposed upon the graph represents the total fixed cost base for the farm. The farmer must cover all these fixed costs as well as all his variable costs of production in order to earn a profit. Since the size of the fixed cost base never determines the level of economic activity which the farmer chooses, it does not appear in his short run production decision framework. Regardless of the size of his fixed cost obligations, he would want to draw 1,400 acre feet of water and grow crops A, B, and C in exactly the same proportions shown, so long as he decided to remain in business.

Application of the Classical Microeconomic Decision Rules to the Purchase of CAP Water

Unique Features of the CAP

Several unusual circumstances surrounding the importation and use of CAP water make it necessary to modify the usual short run static decision rules for choosing its optimal level of use. First, the CAP will serve as a substitute, not an additional supply of water to central Arizona. All nonIndian agricultural users of CAP water will be legally required to reduce their rate of groundwater pumping equally with the volume of CAP water delivered to them (Master Contract, 1972). Only the San Carlos Irrigation District, which accounts for about 5 percent of the total nonIndian agricultural allocations of CAP water, will be exempted from restrictions against expanding total water use ("CAP Final Allocations," Federal Register, 1983).

Second, the annual fixed costs associated with the CAP system tend to be very large. Some explanation at this point is due concerning what will not constitute a fixed CAP cost for the purposes of this study. Many of the financial obligations of the project are subsidized through tax revenues collected at both the state and federal levels. Generally these costs, while significant in total, are too diffuse to be meaningfully analyzed within the scope of this analysis. Another "fixed cost" that is not considered as such is the repayment obligation by CAP users to the federal government, which will actually be treated as a variable cost within the rate structure for CAP water. Irrigated agriculture will pay a $2 surcharge on every acre foot of water delivered in order to help pay for the construction of the main canal system. All discussions of the variable cost for CAP water in this study assume this surcharge.

The greatest fixed cost obligation associated with the CAP that will be borne directly and exclusively by central Arizona farmers will be those costs associated with the development of their local CAP water distribution systems. Most of the irrigation districts in the study area were formed only recently for the express purpose of contracting for the delivery of CAP water, and currently neither own nor operate any water facilities. They have made or will soon make large capital investments in the development of extensive systems to convey project water from the main acquaduct to their member lands. Other districts, which are already active in providing water service to their members and have a network of canals already in place, may still have to make large investments to improve or expand their facilities to accomodate the CAP. The operation and maintenance of the local water delivery systems will be a significant cost for the farmers on the district lands, even long after the capital debt for construction has been repaid.

Third, farmers who contract for CAP water will have to commit themselves to purchasing and using large quantities over a long period of time, subject to numerous restrictions. Once irrigation districts sign a water service contract, they are obliged to buy CAP water every year for 50 years. In effect, their allocation will have to be purchased "first," every year, regardless of its cost relative to other sources of water.

Fourth, the formation of a market for CAP water will be strongly discouraged, if not prohibited outright. If an irrigation district has more CAP water in a given year than it wants, it may be able to sell the surplus, but for no more than the amount which it paid for the water in the first place. Virtually any incentive to trade CAP water has therefore been removed, since the seller has little or nothing to gain from the transaction.

Fifth, farmers will be limited in their ability to capture the potential benefits of increasing economies of size. According to the Reclamation Reform Act of 1982, farmers will in general not be allowed to farm more than 960 acres of land if their land is serviced by a Bureau of Recalamation project, such as the CAP. In addition to this acreage limitation, the 1980 Groundwater Management Code currently limits farmers to use no more than their average historic volume of irrigation water. Both of these restrictions may reduce the capacity of farmers to adjust over time to changing conditions under the CAP.

Finally, the substitution of CAP water for groundwater and the consequent reduction in groundwater pumping demand may have a significant effect on the rate of groundwater overdraft. The resulting slowdown in the rate of groundwater decline and the rate of increase in future groundwater pumping costs may add greatly to the value of the project.

Alternative Short-Term Static Scenarios for a Competitive Evaluation of the CAP

Consider again the hypothetical farm model introduced earlier. Suppose the farmer now has the option of contracting to buy 400 acre feet of CAP water. Suppose that state law restricts him to the use of no more than his historic average of 1400 acre feet of water, and that he is bound to abstain from pumping an amount of groundwater equal to the amount of CAP water delivered to him.

As a result of the institutional restrictions imposed upon him, the farmer's potential short run gain or loss from the CAP is contingent not upon his marginal willingness to pay for water but upon the relative average cost of the groundwater being replaced. Note that the last 400 acre feet of groundwater pumped range in cost from 30 to 50 dollars an acre foot, averaging $40 an acre foot. As long as the variable cost of CAP water is lower than $40 per acre foot, the farmer would be unambiguously better off in the short run by trading groundwater for the allocation of CAP water.

Assume that CAP water is selling for $30 an acre foot, and consider the outcomes of two possible contractual arrangements. In Figure 8 the farmer is obligated to buy all of the CAP water allocated to him, while in Figure 9 he freely chooses to buy as much or as little of his CAP water allocation as he wishes. Since the average unit cost of the last 400 acre feet of groundwater, $40, exceeds the variable cost of CAP water, he would take his entire CAP allocation whether he had to or not. As shown by the net benefits earned from the project under each alternative scenario, the solutions shown in Figures 8 and 9 are equivalent.

Clearly, the farmer is better off in the short run if he can buy CAP water at a variable unit cost of only $30 per acre foot. He

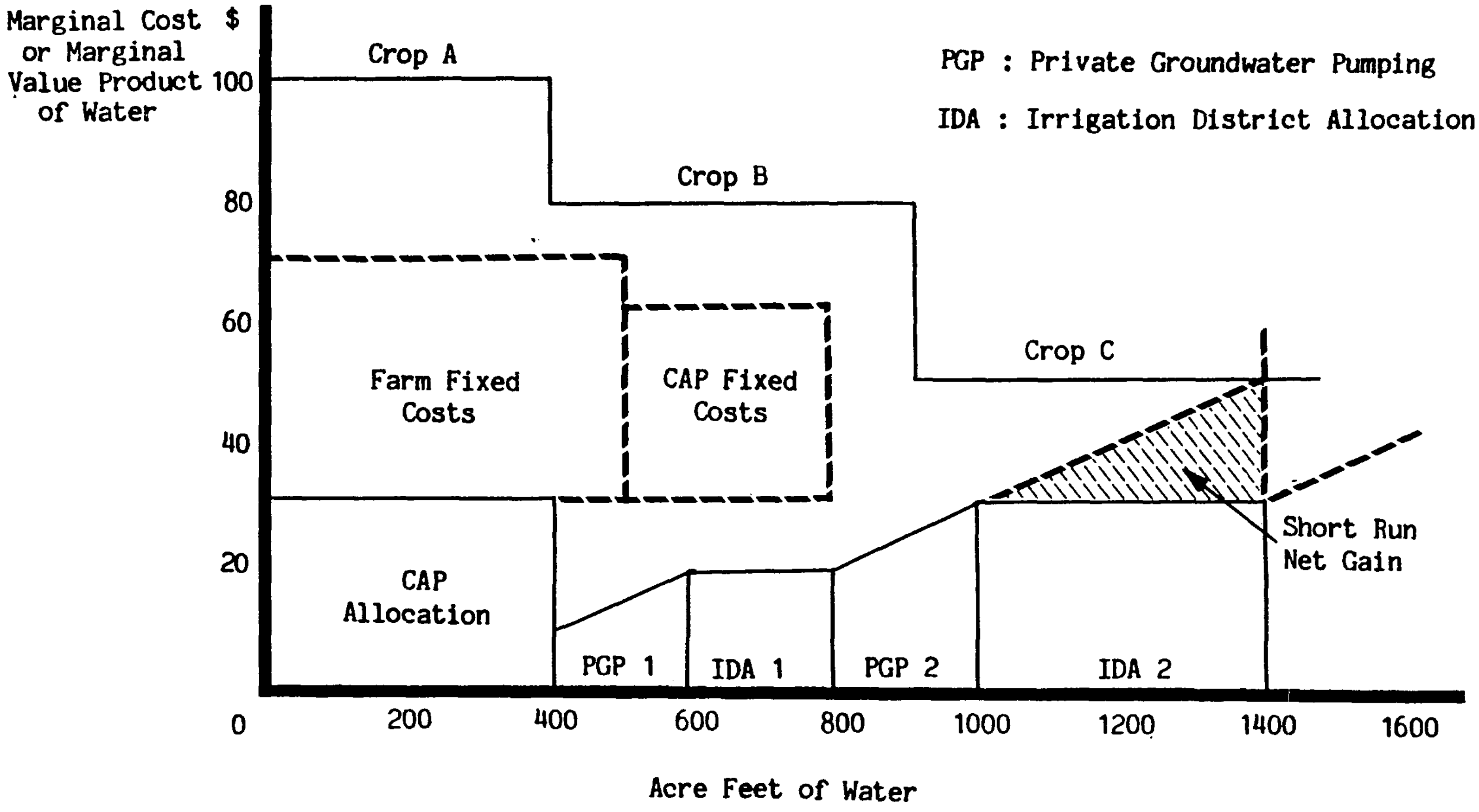


Figure 8. Hypothetical Farm Model of the Optimal Level of Use of Irrigation Water.

Case 2: CAP Allocation Mandatory at $30/af.
Total Water Use Constrained to 1400 af/yr.

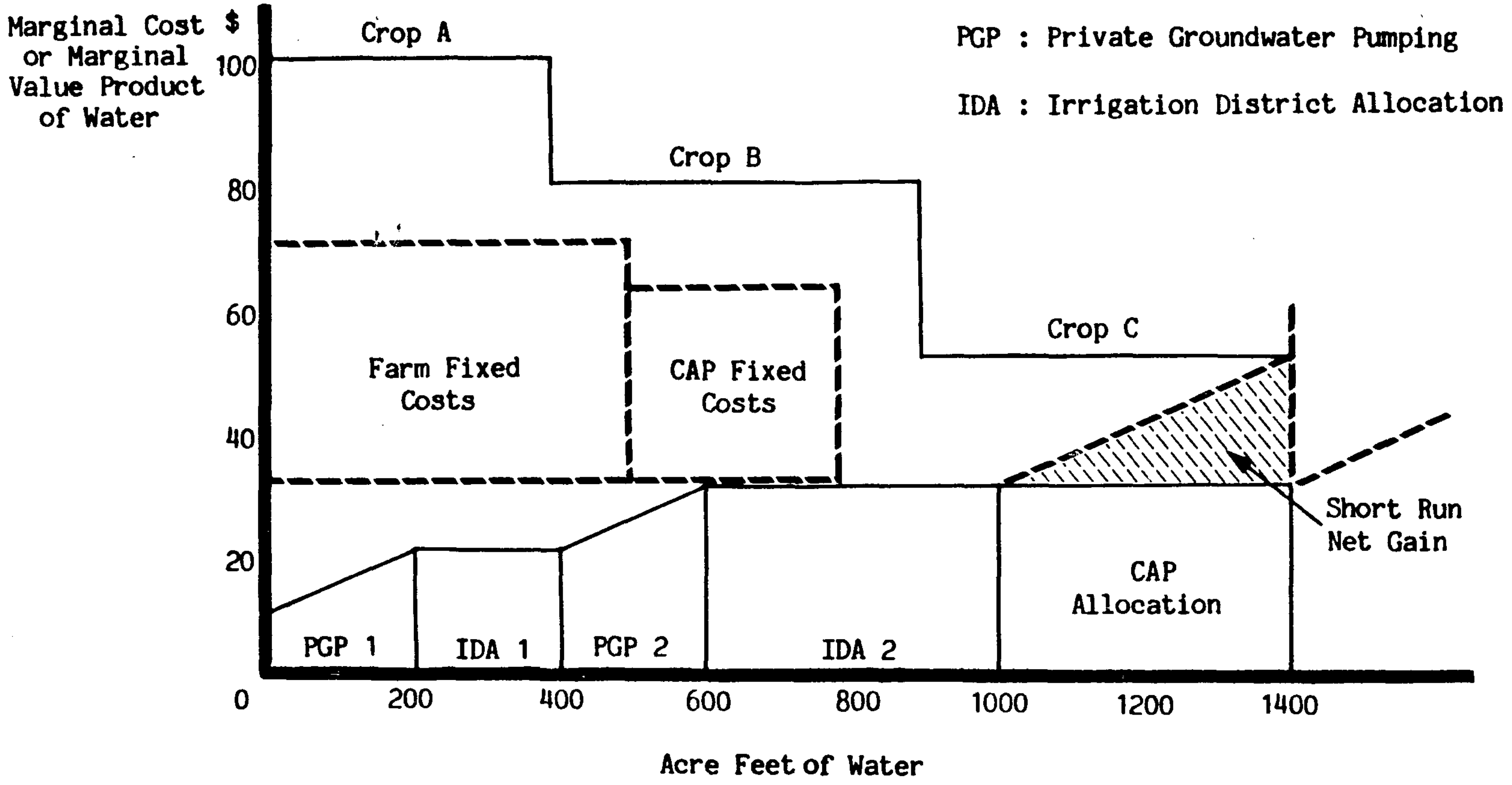


Figure 9. Hypothetical Farm Model of the Optimal Level of Use of Irrigation Water.

Case 3: CAP Allocation Freely Chosen at $30/af.
Total Water Use Constrained to 1400 af/yr.

would also be better off in the long run with CAP water, if the additional short run returns realized from buying CAP water exceeded the annual fixed costs of the project. These additional fixed costs are shown as a second hashed area in each figure, adjacent to the area representing the original farm fixed cost base.

Observe that the farmer could earn even more net return in the short run and increase the likelihood of earning a profit in the long run if he could employ more than 1,400 acre feet of water. Were there no constraints preventing him growing more of crop C or perhaps from introducing a fourth crop, he might conceivably pump at least some additional water and earn some additional short run net return. However, by law he is held to use no more than his historic average of 1,400 acre feet of water per year. Although the farmer is still better off in the short run than before, the legal constraints on his water use may prevent him from increasing his net returns as much as he could otherwise.

Suppose that the cost of CAP is $65 per acre foot. As shown in Figure 10, if the farmer were obligated to buy the full allocation of CAP water, he would lose $25 per acre foot ($65 per acre foot for CAP water, an average of $40 per acre foot for the groundwater replaced). The farmer should never willingly buy CAP water at this price. Were it not for the legal restrictions on the level of water use, and the requirement that groundwater pumping be reduced as CAP water is delivered, the farmer might be able to cut his losses by expanding the production of crop C or by introducing the production of an additional low-valued crop. The marginal cost of groundwater pumping is only $30 per acre foot when he ceases pumping in order to accomodate the CAP deliveries. If he could continue to use at least some of his groundwater pumping capacity and grow any crop with a marginal value product in excess of $30 per acre foot, he could improve the level of his net returns. Since the farmer is obligated to reduce his groundwater pumping by the full 400 acre feet and hold his total water use to 1400 acre feet, however, his short run losses from the CAP cannot be mitigated. The reduction in short run net returns is shown as the shaded area.

A somewhat more complicated possibility, shown in Figure 11, is that the unit cost of CAP could be cheaper on the margin than the most expensive of the water currently used by the farmer, but that the average cost of the entire allocation still exceeds the average cost of his last 400 acre feet. Suppose that the variable cost of CAP were $45 per acre foot. If the farmer could buy only as much of his CAP allocation as he wished, he would pump groundwater just until its marginal unit cost reached $45 per acre foot before he would cease pumping groundwater and switch to buying CAP water. He would pump 300 acre feet of his last 400 acre feet of groundwater and then buy 100 acre feet of CAP water. The net gain from the project would then be represented by the small hatched area. Were he required to take the entire CAP allocation, however, he would realize a net loss. Although he would still gain the amount represented by the small shaded area he would also lose an amount equal to the larger shaded area. Even with CAP water cheaper at the margin, he would be worse off if had to buy the entire block allocated to him.

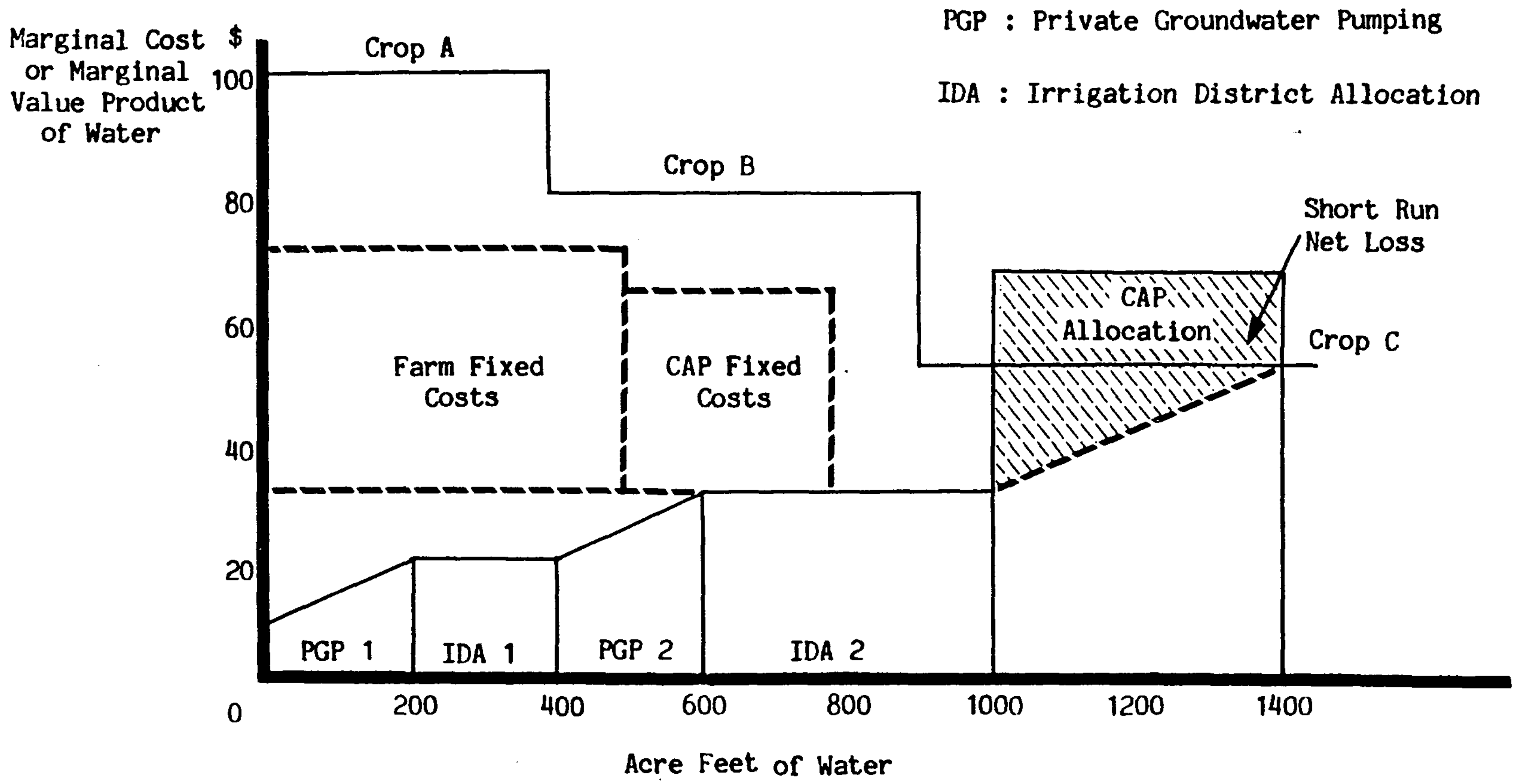


Figure 10. Hypothetical Farm Model of the Optimal Level of Use of Irrigation Water.

Case 4: CAP Allocation Mandatory at $65/af.
Total Water Use Constrained to 1400 af/yr.

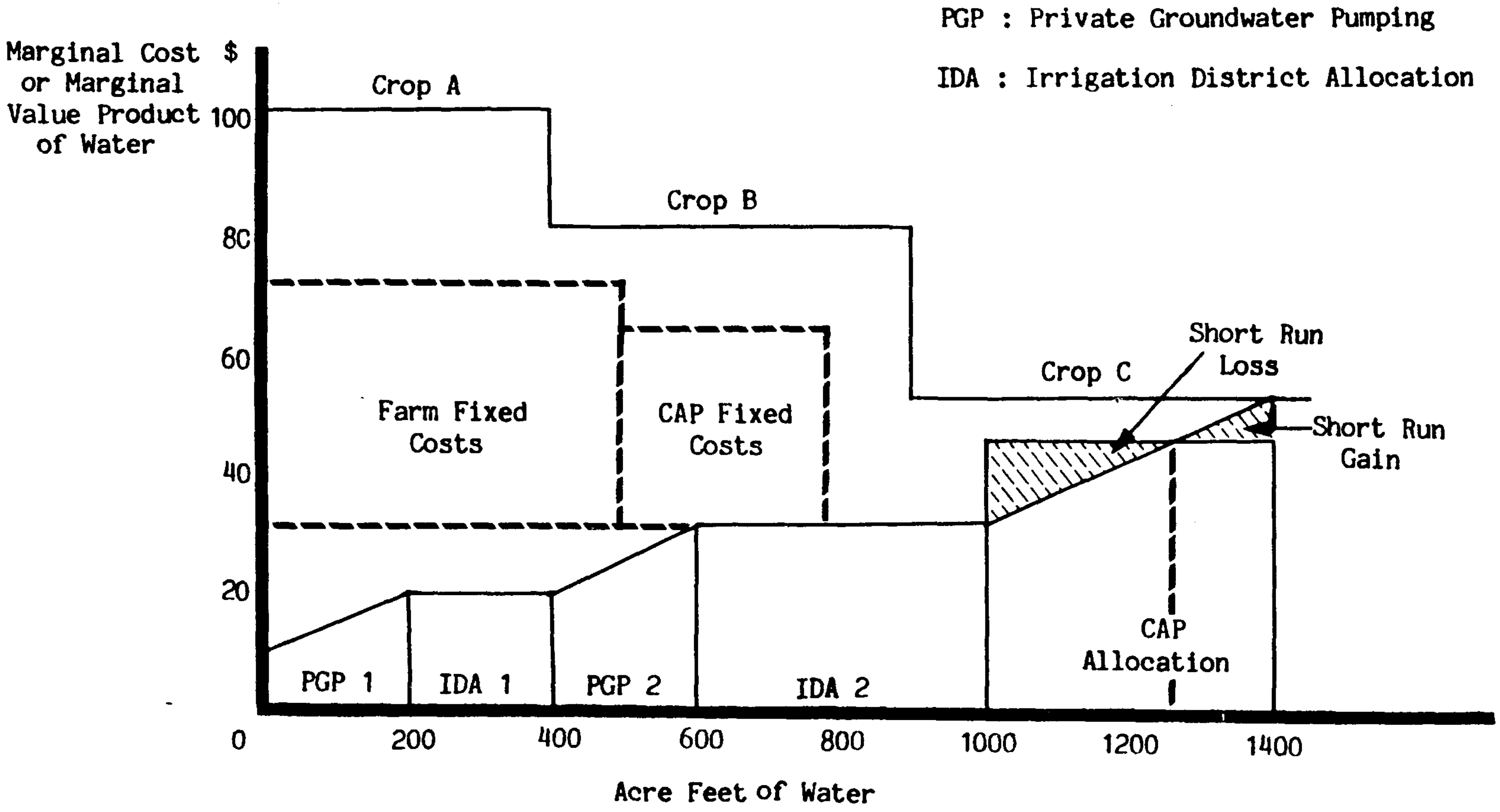


Figure 11. Hypothetical Farm Model of the Optimal Level of Use of Irrigation Water.

Case 5: CAP Allocation Mandatory at $45/af.
Total Water Use Constrained to 1400 af/yr.

Conclusions

The classical economic evaluation of the CAP in light of its special economic and institutional features is integrated and summarized as follows:

1. Marginal pricing decision rules cannot adequately describe the demand for CAP water, because trading will occur elsewhere than only on the margin. Each year the CAP subcontractors will have to commit themselves to buying at a predetermined, fixed unit price large blocks of project water. They must substitute these amounts for an equal amount of groundwater supplies regardless of the relative costs of each. The determining factor in assessing the short run demand for CAP water will therefore be less the willingness of users to pay on the margin for irrigation water, than the respective average unit costs of the blocks of CAP and groundwater being traded. Even if the price for CAP water appeared profitable on the margin, the CAP might still not be competitive once all the mandatory off-marginal trading took place.

2. Significant additional investments will be needed to create or improve and operate the local CAP delivery systems. While these fixed costs will not affect the year-to-year production decisions of the individual farmer whose choices are only a function of variable costs, they will still affect the level of his profits. Even if he were to appear to benefit from the CAP in the short run, a farmer might still not be better off in the long run, once all costs are accounted for. Empirically, it appears that CAP water could rarely if ever be used profitably in the production of marginal crops.

3. The CAP will deliver not only water, but also a host of new constraints on farmers' production and investment decisions. The current state water law grew largely out of the series of agreements and compromises leading to federal sponsorship of the CAP. Under the law, farmers are granted "irrigation rights," which limit the use of irrigation water to specific quantities on certain designated acreages.

Agricultural expansion onto unqualified lands is not permitted. Alternative water supplies may not be developed for the purpose of increasing the overall level of water usage, but only for replacing existing sources of supply. The law is reinforced by federal regulations which mandate the substitution of project water for groundwater, and which limit the acreages of farms in Bureau of Reclamation project service areas. Farmers may not circumvent the restrictions imposed on their use of their land and water resources, regardless of what the additional production potential could be worth to them. Entrepreneurial flexibility on the farm is thereby severely limited, reducing the ability of farmers to adjust as fully and as profitably as possible to changing economic conditions brought on by the CAP.

A classical microeconomic analysis of the CAP indicates that buying CAP water would not be a wise choice for Central Arizona agriculture at the present time. Empirically, however, few agricultural water contractors who have been offered the opportunity to buy CAP water have refused it. The overwhelming majority of farmers appear to favor the project strongly, and are eager to begin accepting deliveries. The analytical tools employed thus far to study the CAP fail to explain this reaction.

The static classical economic analytical framework is useful as a first approximation of the potential value of the CAP to farmers in Central Arizona. However, it does not go far enough. It is inadequate for evaluating the CAP for two principle reasons. First, it does not consider all of the costs of groundwater pumping and overdraft. It is possible that if the full cost of extracting groundwater were assessed, groundwater might no longer appear cheaper than CAP water. Second, it does not consider the beneficial effects that the CAP could have on the future cost of pumping groundwater. Even if groundwater remained cheaper than CAP water, the potential cost savings in lower-than-otherwise future groundwater pumping costs might be significant enough to warrant the development of the CAP. Finally, it does not consider the relative average total costs of all sources of water over time. If the average total cost of irrigation water would not be cheaper with the CAP than without this year or next, it might still become competitive in some year not too long after that. Depending upon the length of the relevent time horizon and the rate of discount employed, the promise of competitive water costs in the future might make the present sacrifices worthwhile. The following chapters address these three considerations to determine the circumstances under which the CAP could in fact become worthwhile for agriculture. These circumstances are defined in the short term with respect to the first consideration, and in the long term with respect to the second and third considerations.

CHAPTER 3

THE ECONOMICS OF OPTIMAL DEPLETION:

MANAGING ARIZONA'S GROUNDWATER OVERDRAFT

> Arizona's water income is its renewable resources, natural recharge and surface supplies. Its savings are the groundwater stock. Arizona is presently living beyond its water income by depleting savings inherited from all its previous generations.
>
> 31st Arizona Town Hall, 1977

> Another reason given to justify the belief that that groundwater should not be depleted is that we who live today should not put the wellbeing of future generations at risk by consuming a supply of something as essential as water. It is argued that if we wish to have a permanent and stable society, we must preserve the supply of water for the future.
>
> But the material welfare of future generations may not be best served by limiting pumping in a basin to the safe yield and so leaving the water in storage forever untouched; in most cases, future generations would be best provided for by consuming the groundwater in a basin in a manner planned to yield the most desirable stream of benefits over time.
>
> Adrian Griffin, 1980
> Unpublished Doctoral Dissertation

This chapter evaluates Arizona's groundwater management strategy in terms of the economic theory of the optimal depletion of exhaustible natural resources. The economic problems of groundwater resource management are discussed. Two alternative models are proposed for analyzing the social cost of groundwater overdraft. One model is chosen as a theoretical framework for estimating this cost on the basis of empirical data presented in the following chapter.

Groundwater Overdraft Management in Arizona and the Role of the CAP

Purpose and Objectives of Active Groundwater Management

An historical water resource management problem in Arizona has been the inability of the state to adequately define the property rights of individual groundwater users, as rights were defined and assigned to claimants for the surface water supplies. Until recently there were no well defined, mutually consistent, and enforceable rules for the allocation and consumption of groundwater resources. Individuals tended to act in their own interests, without regard to the impacts of their extraction activities on other groundwater users. The confusion and the inevitable disputes over groundwater rights led to intense legal battles among water users. The problem continued to grow from after the turn of the century, when groundwater pumping first became significant, until the passage of the Groundwater Management Act of 1980. In the interest of "protecting and stabilizing the general economy" of the state, the Act is meant to "conserve, protect, and allocate the use of groundwater resources of the state and to provide a framework for the comprehensive management and regulation of the withdrawal, transportation, use, conservation, and conveyance of rights to groundwater."

Role of the CAP

The Groundwater Management Act and the CAP were created for the dual purposes of developing and maintaining equitable standards for the allocation of groundwater, while promoting the most efficient possible use of groundwater over time. A need to resolve the complex and politically destabilizing legal disputes over water rights motivated the former purpose. A concern that the continuation of historical patterns of exploitation would endanger the future availability of the groundwater supply and thereby the viability of the Arizona economy motivated the latter purpose.

The construction of the CAP is considered a vital component of Arizona's long term water management strategy. It represents an integral part of the long term objective of eventually eliminating the demand for, and thereby the depletion of, the stock component of the groundwater resource. It effects two transfers of water resources simultaneously. It *trades* the consumption of groundwater stocks for new (CAP) surface water flows, and in doing so it *conserves* (transfers to future generations) indefinitely groundwater stocks that might otherwise be consumed.

Groundwater Resources Management: Fact and Fancy

The public interest in and support of the current water resource management policies in the West is in large part motivated by a set of normative judgements about water that regard it as a unique natural resource. The notion that "water is different" and somehow not subject to the same market forces which are allowed to allocate other scarce water resources has pervaded most water laws and institutions in this country (Kelso, 1967). The historic and chronic imbalance between the supply and demand for water is evidence that the water management policies created in accordance with this philosophy serve only to perpetuate its inefficient use. Two faulty notions about groundwater resources have been especially influential in the currently evolving system of management of groundwater resources in Arizona. These are the "Safe Yield" myth and the "Bank Account" analogy of groundwater overdraft.

The "Safe Yield" Myth

Long term groundwater management objectives in the state of Arizona are generally defined in terms of how and when "safe yield" might be accomplished. Safe yield is most often understood as the average amount of water which can be withdrawn periodically from a groundwater stock without reducing the total amount of water in storage. That is, it is an amount of groundwater withdrawal equal to the average volume of the flow component of a groundwater supply.

Young (1969) observed that safe yield is a vague idea in practice because it is often described in prescriptive and normative instead of descriptive and objective terms. Ven te Chow (1964) called safe yield the "amount of water which can be withdrawn annually from a groundwater basin without producing an undesired result." Young found that Ven te Chow's "undesired result" could take the form of any of a number of prescriptive definitions, of which he specifically identified four. Under these circumstances safe yield may be understood as the result of groundwater management practices which prevent any of the following from occuring:

1. Exceeding the average annual rate of recharge (a hydrologic definition)

2. Lowering the water table below the economic limit determined by the cost of groundwater pumping (an economic definition)
3. Permitting the intrusion of water of undesired quality (a quality definition)
4. Interfering with the rights of other users in the same or adjacent basins (a legal definition).

The objective of achieving hydrologic safe yield in Arizona is in effect a decision to postpone the consumption of valuable groundwater stock resources indefinitely. By reducing groundwater withdrawals to the point where only the annually renewable flows into the aquifers are available for use, the remaining stock component of the resource is left forever untouched. But there is no intuitively obvious reason for believing that the replacement of the depletable groundwater stock resource with annually renewable Colorado River flows via the CAP, and doing so as soon as possible will improve the overall level of welfare in Arizona over time. There is no economic basis for arguing that it is always better to conserve a unit of a stock resource for the future instead of consuming it now, just as in a static analytical framework there is no reason to believe a unit of water will always be valued more highly by user class over another. Moore (1984) warned that the imposition of strict groundwater management controls before they are economically feasible may cause net losses in social welfare. Others (Kelso, Martin, and Mack, 1973, Martin, 1967) proposed that the current rate of groundwater overdraft in Arizona could and probably should be allowed to continue for the next several decades, because the costs of controlling it before that time would probably exceed the potential benefits.

The "Bank Account" Analogy

A popular argument in support of the hydrologic safe yield objective is the "bank account" analogy, which likens groundwater stock reserves to an initial lump sum of capital, or "savings," and the annual rate of renewal of groundwater to "income." Many have suggested on the basis of this analogy that the permissive safe yield from an acquifer ought to be equal to the renewable water "income," just as the long term average rate of withdrawal from a bank account cannot exceed the rate of periodic deposits.

The implicit judgement expressed in the "bank account" argument is that wealth (as opposed to income) spent is wealth wasted, because it shall never be seen again. Yet, as Young (1969, p. 12) replied, this notion "doesn't stand close examination."

> If the initial deposit were invested at interest rather than being left untouched "under the mattress," the present value to the individual would be substantially increased due to the addition of the interest payments to his other current income. So would a groundwater basin produce a larger present value if the water is "invested" in productive use, rather than left idle.

Decision Rules for the Optimal Depletion of Exhaustible Natural Resources

The Logic of Intertemporal Choice

The explicit judgement which has been made in Arizona about the water supply problem is essentially that <u>any</u> degree of groundwater overdraft whatsoever is bad and should be completely avoided. But eliminating the overdraft would not be costless. A vigorous program of groundwater conservation would certainly tend to preserve more physical supplies of groundwater than otherwise for future generations, but is this necessarily desirable? All too easily overlooked is the fact that this future benefit is realized at the expense of the present generation. The burden of lost consumption opportunities is not removed from society, it is only shifted from one generation of consumers to another. The economic principles governing the optimal intertemporal allocation of groundwater resources are essentially the same as those governing the allocation of groundwater resources within a single period. Whether it is among productive uses within a single generation or among different generations, resources are efficiently allocated only when, on the margin, no further "trading" (conservation may be considered a sort of intergenerational transfer, or trade, or resources) could increase social welfare.

Problems in the intertemporal allocation of a scarce and depletable resource such as groundwater occur whenever the unrestricted consumption activities by one generation has an undesirable effect upon the consumption activities of future generations. The purpose of conserving a scarce and exhaustible natural resource is to produce the optimal stream of consumption benefits from that resource over time. Normally the interests of society are best served when the present generation foregoes some measure of their prefered level of consumption of an exhaustible resource in deference to future generations. Only under very unusual circumstances, however, would the objective of optimizing intergeneration welfare ever be realized through a reduction in the level of consumption in the present to zero.

The Theory of Externalities

Economic activity in this country is largely organized in reflection of the ideal that the market process, through such basic economic principles as that of equimarginal value in use, provides a suitable mechanism for allocating resources. Market distortions caused by third party effects, otherwise known as externalites, were traditionally regarded by economists as exceptional cases apart from which the standard competitve model could be judged an adequate norm.

Under the standard competitive economic models, the individual economic unit bases his production and consumption decisions on only those effects which impinge upon him directly. These may be called the "internal" economic effects of his activities. However, economic units are oftentimes interdependent, and the incidence of interdependence is very high in the domain of natural resources. The actions of individual units may then affect the production and welfare possibilities of other units. In such cases, "external," or "third party," or "spillover" effects are said to occur (Young, 1969).

If the supply of a natural resource stock is scarce, then consumption in the present period may come wholly or partly at the expense of future consumption. The lost opportunity for future generations to exploit the resource is an external cost imposed upon them as a result of decisions made by the present generation. Natural resource conservation is thus a means of controlling the externality caused by one generation "robbing" another of valuable consumption benefits. The mere presence of an externality, however, is not sufficient reason to eliminate it altogether. Usually the control of an externality exacts an opportunity cost on somebody. The strategy for achieving an optimal solution to the problem is to strike a balance between the gains realized on the one hand and the losses suffered on the other. That is, the question ought not to be how all externalities ought to be eliminated, but rather to determine the point at which the marginal benefits of creating the externality by the "offender" equal the marginal cost of the externality to the "victim."

The decision rules for determining the optimal economic solution to any intertemporal externality problem are similar to those employed in solving a single-period externality problem. First, the marginal costs and benefits (properly discounted to reflect differences in value over time) of the externality are assessed. The solution to the externality problem is then a matter of following the same equimarginal principle of value in use common to more ordinary microeconomic decisions of resource allocation.

In accordance with the equimarginal principle, intergenerational welfare would not necessarily benefit from the complete abstainance in the current generation of the consumption of a depletable resource stock. A program in Arizona designed to accomplish hydrologic safe yield, or even just a reduced level of groundwater overdraft, is not automatically a wise alternative. Unless it could be demonstrated that the marginal costs of conservation (that is, the marginal net consumption benefits lost) to the present generation would be exceeded by the level of future marginal net consumption benefits gained, the program could not be considered good simply because it saved water.

Common Property Problem of Groundwater

Intertemporal externalities frequently occur in the exploitation of common property resources, such as groundwater. Groundwater does not respect property boundaries. The effect of one user drawing down the acquifer does not stop at the edge of the land to which his water right is appurtenant. As a result, the costs of groundwater depletion by any one individual are spread across all the users, while the benefits are realized only privately. The market, which reflects only private costs and benefits, therefore delivers false price signals to each water user. They consider only their own costs in making consumption decisons, ignoring all the additional costs which their actions impose on every other user.

Attempts by any one individual to significantly influence the quantity or quality of the groundwater stock are frustrated because it is the collective pumping activity of his neighbors that ultimately determines the hydrologic behavior of the common pool. Users are encouraged to effectively manage the groundwater supply as a flow instead of as a stock resource, irrespective of whether they are mining the acquifer or not. Regardless of what each user chooses to conserve or consume, the resource will be available to him at any given depth to lift only during a particular period of time. If he does not extract it during that period, then the opportunity to exploit the services of the water at that particular cost are lost forever.

Consumers of a common groundwater stock resource therefore have no private incentive to conserve water. They would appear to benefit more by applying the traditional static short run optimization rules of profit maximization in deciding the most appropriate volume of water to pump. Their natural tendency is to continue to pump groundwater beyond the point where the true marginal cost of their activity equals the marginal benefit. Groundwater overdraft will tend to be larger than otherwise, and the rate of groundwater decline correspondingly higher. Without some measure of purposeful intervention in the free market choices of groundwater users, they will not tend to act in an economically efficient manner.

Little doubt remains that the groundwater resources in Arizona could be better managed for society's long term benefit. It is not unlikely that, when all the costs of groundwater extraction are considered, the marginal cost of groundwater pumping in many areas of Arizona may exceed its marginal returns. Under these circumstances, an increased rate of groundwater conservation is probably warranted. Yet if a basis for groundwater conservation exists, it is by no means necessarily a justification for achieving hydrologic safe yield at virtually any cost. Only a careful economic analysis of the true marginal costs of groundwater pumping will indicate whether the current rate of groundwater mining reflects a level of activity which differs significantly from that which would be socially optimal, and whether or not the true cost of overdraft is so high that the only rational level of mining is zero. It remains to be seen whether the groundwater management policy objectives, and the stated means of pursuing them, could satisfy the economic criteria for achieving an efficient intertemporal allocation of groundwater resources in Arizona.

A Social Opportunity Cost Model of Groundwater Depletion

McInerney (1976) proposed a simple method of determining the optimal rate of depletion of an exhaustible natural resource through an evaluation of the social opportunity cost of consumption. The opportunity cost of lost marginal consumption benefits for future generations as a result of current consumption activity is estimated and added to the marginal cost of extraction for the present generation. The total cost of extraction in the current period then becomes the full, "social cost" of depletion. Once the marginal social cost of natural resource consumption is quantified and "internalized" into the current resource user's decision framework, a user may proceed to excercise his economic choices as a private profit-maximizing individual. He may consume the depletable resource until such point as the marginal benefits gained just equal the marginal (social) costs.

Let the planning horizon for resource use be condensed into two discrete periods, which may be thought of as the "present" generation and the "future" generation. Although with further elaborations the model may be extended to include any number of additional generations, a simple two period representation is sufficient to capture the essense of the the decision framework while avoiding the need to add unnecessary detail.

Figures 12, 13, and 14 illustrate alternative scenarios for the optimal intertemporal allocation of a depletable stock resource. Consider the situation where the two generations are both using a fixed stock of the resource, OS. Assume that the marginal consumption benefits in the future generation have already been adjusted according to some acceptable discount rate, so that a measure of net benefit in one generation is comparable to an equal measure of net benefit in the other generation. For the sake of simplicity, let it also be assumed that the respective marginal extraction cost functions for the present and the future are constant.

Each generation will try to maximize their own net consumption benefits by extracting and using quantities of the resource until the point is reached where the marginal cost of extraction (MEC) is equal to the marginal social benefit (MSB) of consumption. The current generation will use as much of the resource as it wishes, up to the limit of the stock. Whatever quantities are not consumed by the first generation are left for the future to exploit.

There is no intertemporal resource allocation problem when, as shown in Figure 12, the resource stock is so large that all current demands for the resource can be satisfied without affecting future consumption demand at all. In the present generation, the resource is exploited up to the quantity OQp before MEC begins to exceed MSB and equilibrium is achieved. The future generation will seek to maximize its net consumption benefits by consuming OQf units of the resource. With all demand for the resource satisfied, a surplus stock of QpQf units of the resource still remains unexploited by the end of the future period.

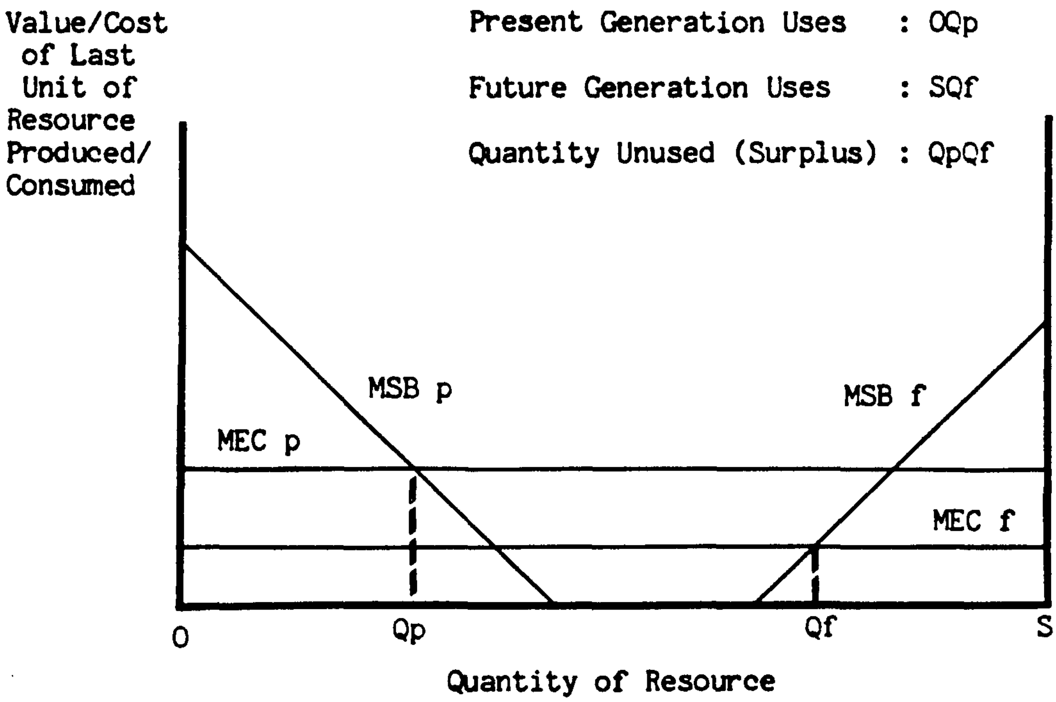


Figure 12. Optimal Intertemporal Allocation of a Depletable Natural Resource, Where Stocks are in Surplus.

Source: McInerney, John. "The Simple Analytics of Natural Resource Economics." <u>Journal of Agricultural Economics</u>, January, 1976. Figure 4a.

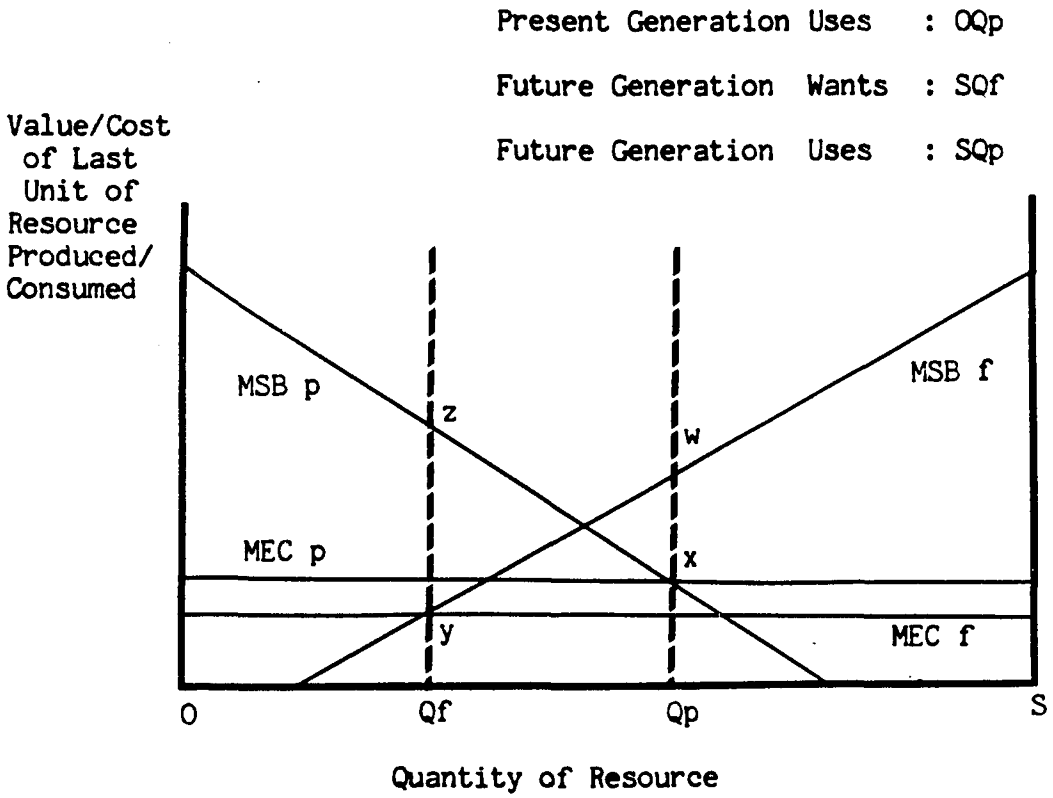


Figure 13. Free-Market Intertemporal Allocation of a Depletable Natural Resource, Where Stocks are Limiting.

Source: McInerney, John. "The Simple Analytics of Natural Resource Economics." *Journal of Agricultural Economics*, January, 1976. Figure 4b.

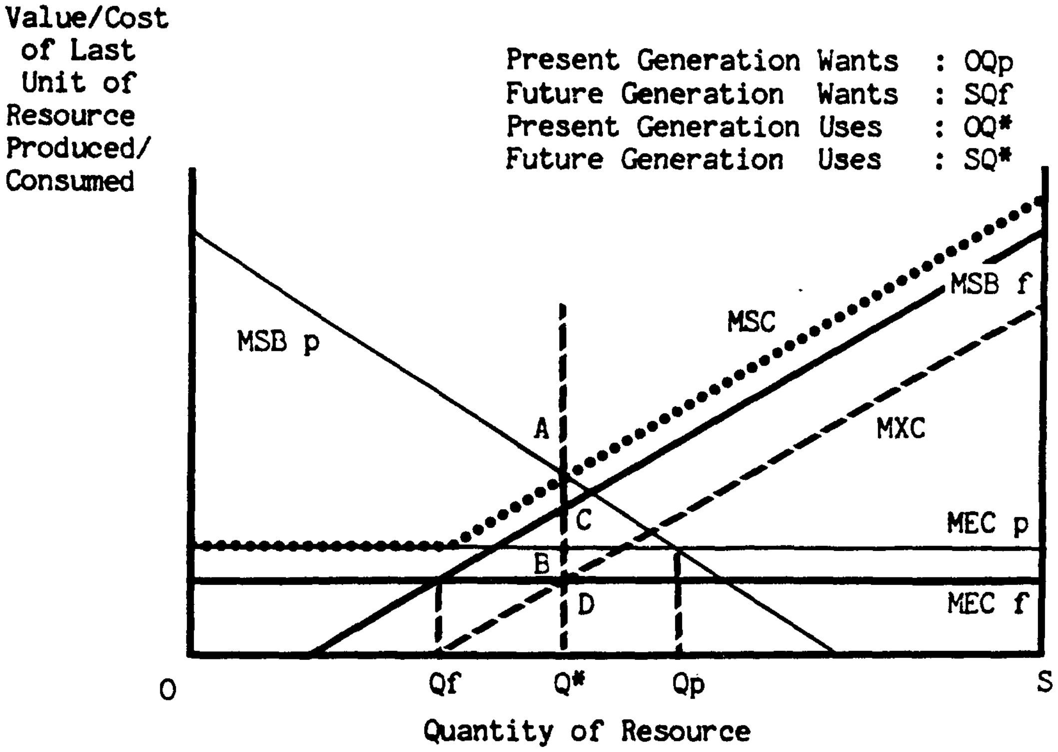


Figure 14. Optimal Intertemporal Allocation of a Depletable Natural Resource, Where Stocks are Limiting.

Source:

McInerney, John. "The Simple Analytics of Natural Resource Economics." <u>Journal of Agricultural Economics,</u> January, 1976. Figure 4b.

The more realistic case is illustrated in Figure 13, where the resource stock is limited and there is "competition" among generations for at least some of the units. The present generation, acting to maximize its own welfare, again chooses to consume 0Qp units of the resource. However, that only leaves SQp units for future consumption when, given its own MEC and MSB functions, it really would have wanted to consume SQf units. The free-market consumption choices by the first generation creates a future shortage of QfQp units of the resource. An opportunity to enjoy the consumption benefits associated with this quantity of the resource is lost to the future generation. This loss, or opportunity cost, is the intertemporal externality, or external cost, that the present generation imposes on the future by virtue of its own welfare-maximizing decision rules.

Suppose that, recognizing the emergence of an intertemporal externality, the government wishes to optimize the intertemporal allocation of this resource. It could, as the state of Arizona wishes to achieve for groundwater within the next forty years, simply forbid the present generation from consuming the resource in any amount over 0Qf units. As a result, the future would not be deprived of any of its consumption benefits. But in eliminating the externality imposed on the future generation, an even greater cost could be exacted upon the present generation.

If 0Qf units of the resource were forcibly conserved by the present generation for the future, then all future demand for the resource would be satisfied. At equilibrium, future marginal extraction costs would equal future marginal social benefits; that is, the future generation would realize zero net benefits from the last unit of the resource consumed and relatively low net returns on each of the last few units consumed. Some of those same units of the resource, if they had been consumed in the first period, would have realized much larger marginal net returns.

At a consumption level of only OQf units, the present generation would be willing to pay on the margin an extra ZY dollars for another unit of the resource, an amount substantially greater than zero. That is, the marginal opportunity cost of conservation at this level is far in excess of its marginal benefits in terms of enhanced future consumption. Apparently, wholesale resource conservation can invoke significant and undesirable social losses, which may even exceed the losses which would be suffered were no conservation practiced at all.

In order to determine the optimal intertemporal allocation of this resource, the government would want to determine the level of conservation in the present generation where the discounted future marginal net benefits of conservation would be equal to the opportunity costs of current net consumption benefits foregone. Assuming that it is possible to determine future levels of demand for the resource and the future marginal extraction cost, then a marginal external cost function (MXC) may be traced as shown in Figure 14. The MXC function is equal at every given level of future resource availability to the corresponding level of future net consumption benefits. Geometrically, this curve is determined by subtracting the future marginal extraction cost function from the marginal social benefit function.

Adding the MXC function to the present generation's MEC function, a marginal social cost (MSC) function may be traced. This function represents the full marginal cost to society of extracting and depleting the resource in the present period. If the government levied a user tax or used some other means of forcing the present generation to realize the full marginal social costs of its own consumption, these users would voluntarily cease consumption of the resource at the level OQ*. Beyond that point, the marginal costs of extraction (and depletion) would exceed their marginal net gains. SQ* units of the resource would then left for future consumption.

If the marginal net benefits of consuming an additional unit of the resource are exactly equal between the two generations when the present consumes OQ* units and the future consumes SQ* units, then by the principle of equimarginal value in use the intertemporal allocation of the resource is optimal. At this point the present generation is willing to pay up to AB dollars for an additional unit of the resource, while the future is willing to pay up to an additional CD dollars for an additional unit. These quantities reflect the difference between their respective marginal extraction costs and marginal social benefits for the resource. If AB equals CD, then social welfare is maximized because no mutually advantageous trade of units of the resource could take place.

Consider the distance AB. It measures the difference between the present generation's marginal social benefit and marginal extraction cost for an additional unit of the resource. It also is a measure of the marginal external cost, since the marginal external cost at this point is just the difference between the marginal social cost AQ* and the marginal extraction cost BQ*. But the marginal external cost is nothing more than the net social benefit to the future generation of consuming an additional unit of the resource at point Q*. Since CD measures the net social benefit at point Q*, CD is equal to AB. The equimarginal principle of value in use is satisfied because at the margin the net benefits of the resource to both generations is exactly the same. The intertemporal allocation of the resource is economically efficient.

The mathmatical proof for the solution found in McInerney's model may be derived with the use of lagrangian calculus. The objective criteria Z for the problem is to maximize the sum of the net benefits over the two periods. The consumption benefits in the present period, BFp, and the current extraction costs, CSp, are a function of the current level of consumption Qp. The consumption benefits in the future period, BFf, and the future extraction costs, CSf, are a function of the future level of consumption, Qf. The total volume of consumption Qp + Qf cannot exceed the level of the fixed resource stock and consumption cannot be negative. The programming problem is then stated in the following manner:

$$\text{Max } Z = BFp(Qp) - CSp(Qp) + BFf(Qf) - CSf(Qf)$$

$$\text{st.} \quad Cp + Cf = S$$

$$Cp > 0$$

$$Cf > 0.$$

Restating the problem as a lagrange, it becomes

$\text{Max } L = BFp(Qp) - CSp(Qp) + BFf(Qf) - CSF(Qf) + t(S - Cp - Cf).$

Assuming an interior solution,

$dL/dQp = 0 = dBFp/dQp - dCSp/dQp - t$

$dL/dQf = 0 = dBFf/dQf - DCSf/dQf - t$

where $dBF/dQ = MSB$, $dCS/dQ = MEC$, and $MSB - MEC$

= net marginal benefit (NMB).

Therefore,

$MSBp - MECp = MNBp = t$

$MSBf - MECf = MNBf = t$ and

$MNBp = MNBf.$

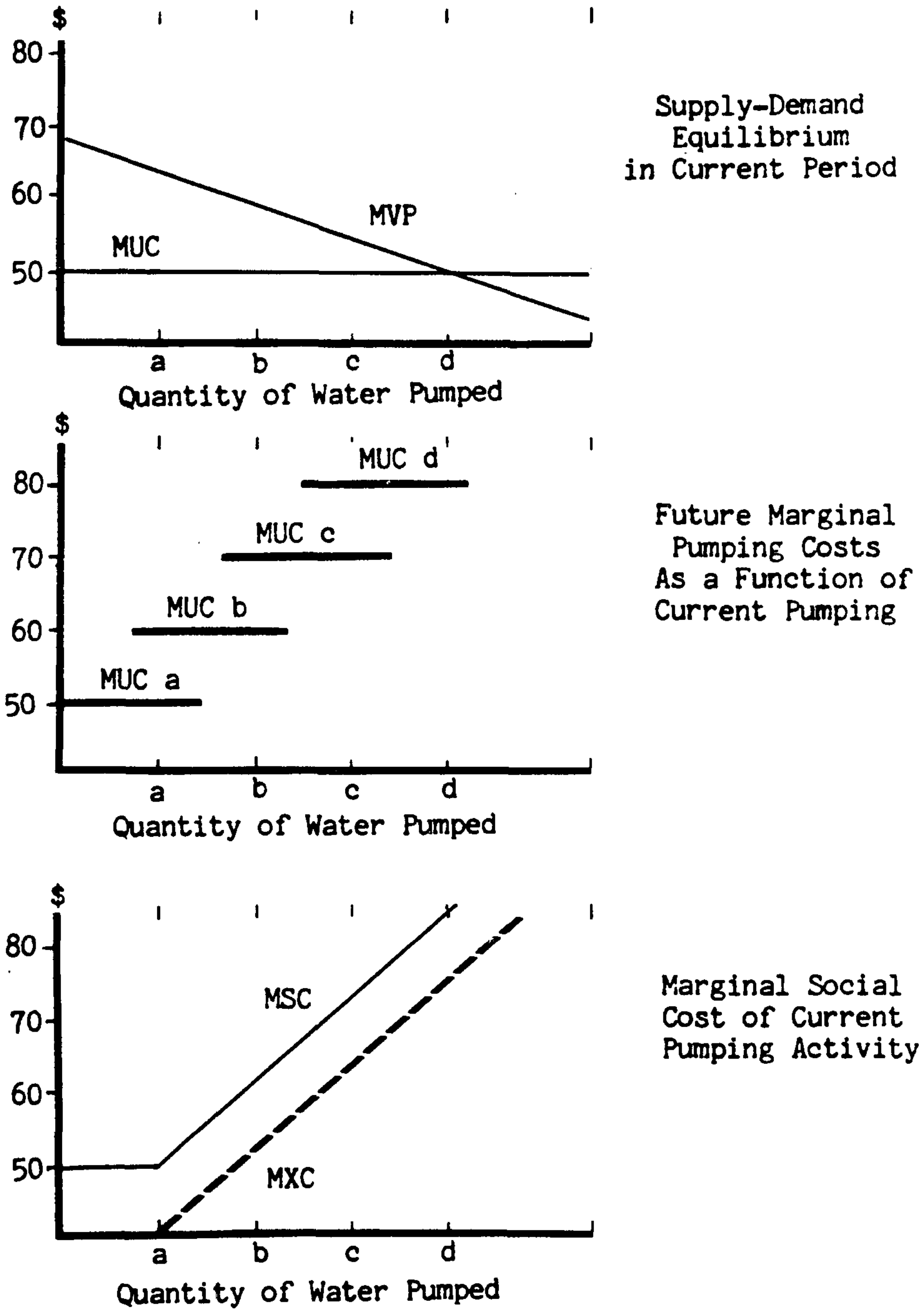
McInerney's social opportunity cost model of the optimal rate of depletion demonstrates how intergenerational welfare might be maximized when a natural resource is <u>physically</u> exhaustible. A physical model of depletion, however, may not be the most effective way to characterize the impacts of alternative decisions about the rate of consumption for limited groundwater resources. It has been argued that the problem of water supply is ultimately never physical, but economic. The significant external effect of groundwater depletion on future generations is less the reduction of physical stocks, which remain large relative to the annual rate consumption, than it is an increase in future pumping costs. Barring any institutional constraints, a future generation can almost always count on being able to pump as much groundwater as it wishes, providing it is willing to pay the cost of extraction.

An alternative analytical framework for modeling the optimal rate of groundwater depletion might therefore trace the effect of overdraft on future marginal pumping costs. The relative size of the marginal pumping costs confronting a future generation will depend upon how much or little groundwater stock the previous generation(s) has withdrawn from the aquifer. The optimal level of groundwater overdraft may be defined as the rate at which the net marginal consumption benefits in the present generation from groundwater mining are exactly equal to the marginal increase in future pumping costs that this overdraft will cause.

Extraction Cost Model for the Optimal Rate of Groundwater Depletion

Consider again a simple two-generation model of resource consumption. The water demand schedule for the present generation is shown at the top of Figure 15. Users in this period would want to pump a total of 0d units water at a marginal unit extraction cost of $50. In the absence of technological progress or the discovery of new, cheaper sources of water, the marginal extraction costs for water should remain the same over time, all other things equal. But all things are not equal; the pumping of 0d units of water would create a severe groundwater overdraft which causes pumping lifts in the future to deepen considerably. Extraction costs for the future would rise from $50 per unit to $110 per unit. The future generation would would therefore lose $110 - $50 = $60 on every unit of water it chose to pump.

If the current generation pumped less water, the intertemporal externality imposed on the future generation would be correspondingly less. Pumping up to the "safe yield" level of only 0a units in the



Supply-Demand Equilibrium in Current Period

Future Marginal Pumping Costs As a Function of Current Pumping

Marginal Social Cost of Current Pumping Activity

Figure 15. Hypothetical Relationship of Groundwater Pumping and Overdraft to Future Marginal Pumping Costs.

present period would prevent any overdraft and groundwater decline. Pumping costs in the future would then stay constant at $50 per unit. Higher current levels of pumping would lead to progressively more overdraft, a faster rate of groundwater decline, and consequently higher and higher future costs for water.

The marginal external cost which corresponds to the level of pumping activity carried out by the current generation is traced at the bottom of Figure 15. Beginning from a zero cost at the "safe yield" pumping rate of Oa units of water per period, the cost rises to $60 per unit when Od units of water are being pumped. Adding this marginal external cost to the present generation's marginal extraction cost function yields the marginal "social" cost of groundwater depletion in the current period.

The optimal solution for the level of depletion is shown in Figure 16. The current generation pumps groundwater at the rate of Ob units, overdrafting the groundwater stock by the amount of AB units of water. This overdraft causes a groundwater decline and a corresponding rise in future marginal extraction costs to the level MUCb. The future generation would then pump OB' units of water, A'B' fewer units than it would have if there no overdraft. This is still B'D' more units than it would have pumped if the current generation had followed the market solution and pumped the full OD units of water.

At the socially optimal level of groundwater pumping and overdraft, the marginal net loss of <u>not</u> pumping an additional unit of water (ignoring the pecuniary effects of any user tax) in the current generation is equal to PbPa dollars. This sum is exactly equal to the

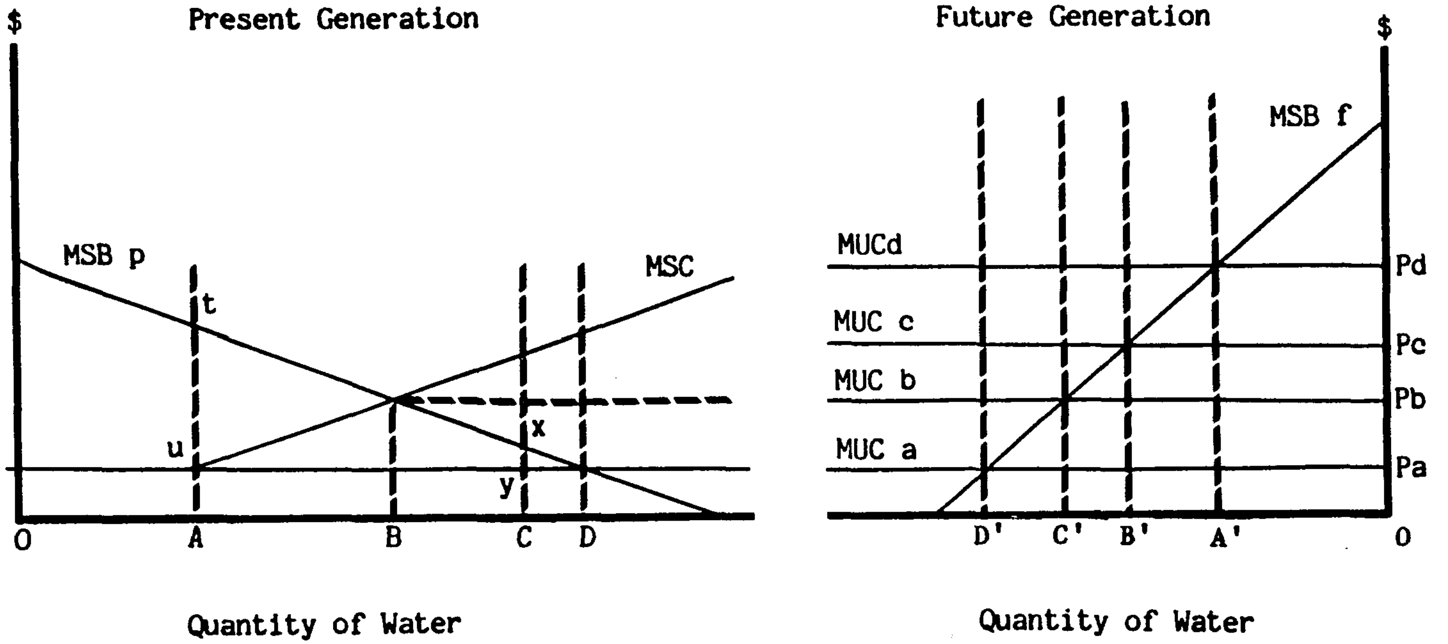


Figure 16. Pumping Cost Externality Model of the Optimal Intertemporal Allocation of Groundwater Resources.

Solution: When the present generation pumps OB units of groundwater, marginal net benefits are equal between generations.

amount of net benefits not realized on the margin by the future generation because extraction costs have risen from MECa to MECb.

The equimarginal principle for optimizing the intertemporal values in use of the groundwater stock would not be honored if the current generation overdrafted either more or less than the amount AB. Suppose the current generation held its groundwater withdrawals to the safe yield level of OA units. Then it would realize a net benefit from its last unit of water of TU dollars. At this rate the future generation would gain zero dollars in net benefits from its last unit of water drawn at the safe yield marginal extraction cost of MECa. If, on the other hand, the current generation pumped as much as OC units of water, its net benefits on the margin would shrink to only XY dollars. This would be far less than the PcPa dollars in marginal net benefits that the future then would have to sacrifice because of higher pumping costs. Intergeneration welfare would improve if the current level of groundwater pumping were adjusted, to a higher level in the first case and to a lower level in the second.

The mathematical proof for the graphical solution to this problem may be derived using lagrangian calculus. It is virtually the same problem as that defined by McInerney's model, with only two differences. The first is that the physical limitation of the resource stock is removed as a constraint. The second is that now the extraction costs of the future generation are dependent upon the levels of both its own consumption and the level of past consumption as well. The problem is defined as follows:

$$\text{Max } Y = BFp(Qp) - CSp(Qp) + BFf(Qf) - CSf(Qf,Qp)$$

$$\text{st.} \quad Qp > 0$$

$$Qf > 0.$$

Since there are no constraints in this program other than the nonnegativity of the consumption variables, the lagrangian expression is the same as the statement above.

Assuming an interior solution,

$$dY/dQp = MSBp - MECp - dCSf/dCp = 0$$

$$dY/dQf = MSBf - MECf = 0 = NMBf$$

where dCSf/dCp is the marginal increase in the extraction cost function experienced in the future as a result of current pumping activity. Then dCSf/dCp is the marginal external cost of pumping, MXC. The sum of the present generation's marginal extraction cost and the marginal external cost equal the marginal social cost of pumping, MSC.

Therefore, NMBf

$$= MSBp - MECp - MXC = 0$$

$$= MSBp - (MECp + MXC) = 0$$

$$= MSBp - MSC = 0 \implies MSBp = MSC.$$

At equilibrium, the socially optimal allocation of groundwater resources then takes place when the current generation continues to pump groundwater until the marginal social benefit of pumping equals the marginal social cost.

The problem with the extraction cost model is that, without a reliable estimate of the future demand for water, it is impossible to predict the magnitude of future losses from higher groundwater pumping costs. Fortunately, a simplifying assumption about the nature of the farmer's marginal demand for water will allow the formulation of a simple and direct measurement of the overdraft-induced external costs imposed as a result of current groundwater overdraft.

Consider the alternative future demand and supply curves for water shown in Figure 17. Assume once again that marginal pumping costs of groundwater extraction remain constant. Let the future demand for water be represented by the sloping (elastic) demand curve. Suppose that when the present generation pumps water at no more than the safe yield rate, future marginal costs will stay unchanged at a constant x dollars per unit. This future cost function is represented by the marginal extraction cost curve MUCx. The farmer in the future will then draw OQ units of the difference between his demand and supply curves, or the area AxC.

Now suppose that the present generation pumps enough groundwater to cause an overdraft situation to develop. Future marginal extraction costs rise to y dollars per unit of groundwater, and the cost curve for groundwater pumping is represented by the function MUCy. The farmer reduces the quantity of groundwater he demands by QQ' units, and consequently earns a lower net return represented by the area AyB. His loss caused by the overdraft is equal to the difference between areas AxC and AyB, or the area xyBC.

If the farmer's demand for water were inelastic, he would lose more net revenues from the imposition of the externality than he would have if his demand were elastic. Since he would not reduce his demand for water at all in the face of rising marginal extraction costs, his

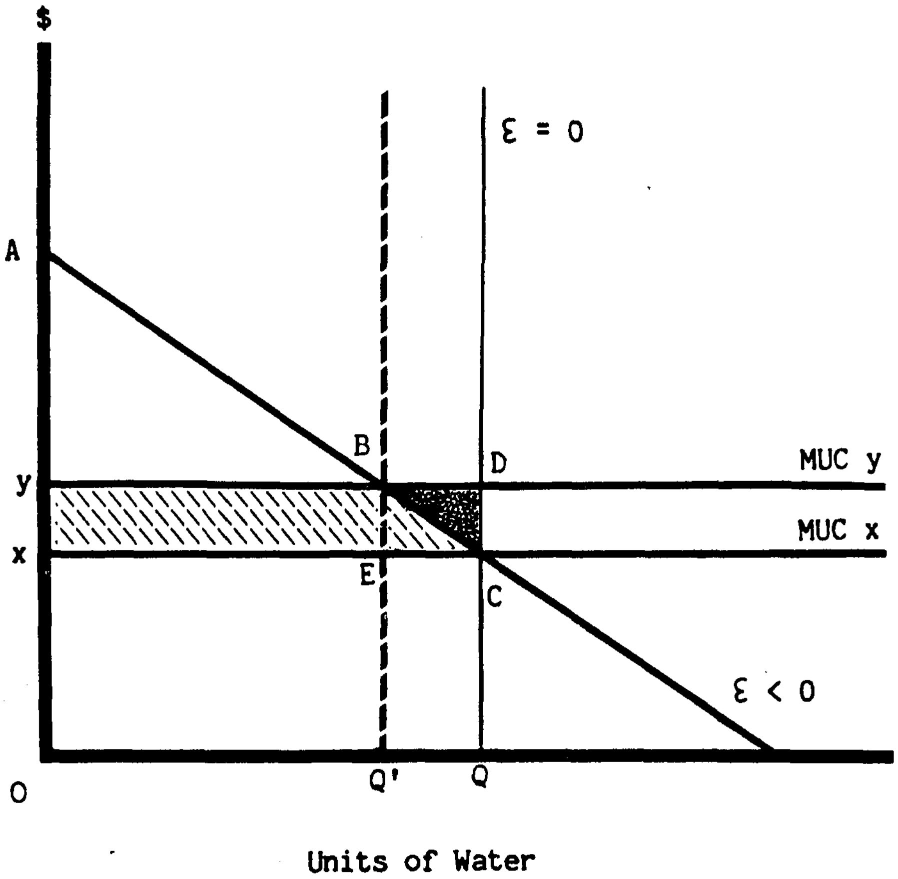


Figure 17. Potential Error of Overestimation of the External Cost of Groundwater Overdraft When Future Demand for Water is Elastic.

loss would be equal to the product of the number of units of water he demands times the unit increase in extraction costs. This loss is represented by the rectangular area xyDC. The difference between the loss experienced under conditions of perfect demand inelasticity and any elastic demand is therefore equal to the the area BCD.

Suppose the simplifying assumption were made that the future farmer's demand curve for water was perfectly inelastic. The calculation of the intertemporal external cost of groundwater overdraft would then be extremely simple to calculate. The marginal external cost which the present generation would impose on the future would then be exactly equal to the marginal increase in the future cost of groundwater pumping. In the event that the elasticity of the demand for water were actually less than zero, the estimation of future losses would be biased upwards. The degree of overestimation would be equal to the amount represented by the triangular area BCD. The assumption of demand inelasticity therefore tends to exagerate the external costs of groundwater overdraft.

If the current level of pumping activity in Central Arizona appeared through this model to exceed the optimal rate, then increased groundwater conservation might be warranted, but probably not to the extent that the model would suggest. But if the model indicated that conservation was not yet necessary at current levels of groundwater demand, this result would be strongly reinforced by the bias in the error of estimation.

CHAPTER 4

EMPIRICAL EVALUATION OF THE COSTS OF GROUNDWATER OVERDRAFT

> A continuing overdraft from the groundwater stock of at least 2.1 million acre-feet appears to be economically rational at least through 2020.
>
> Kelso, Martin, and Mack, 1973

This chapter estimates the full economic costs of groundwater pumping and overdraft in Central Arizona. The potential impact that changes in these costs could have on farmers' demand for groundwater and on the competitiveness of the CAP is evaluated. The relative energy efficiencies of groundwater pumping and the CAP are compared. The sensitivity of the cost of groundwater pumping and overdraft to changes in the rate of energy cost escalation and groundwater decline is tested. Finally, recent historical trends in the factors affecting the supply and demand for groundwater are analyzed in order to draw some conclusions about the relative sensitivity of farm income to increases in groundwater pumping costs.

Overdraft Cost Accounting: Land Subsidence and Water Quality

Subsidence

Subsidence in Central Arizona is commonly assumed to result from the dewatering of deep underground aquifers, which causes the sediment beds to compact and the overlying land to sink and crack.

McCauley (1973) attempted to assess the annual costs of subsidence-related damages in western Pinal County, an area totally dependent upon a heavily overdrafted groundwater supply used almost entirely by irrigated agriculture. Western Pinal County has experienced some of the most severe groundwater overdraft conditions in Arizona, and continues to receive a great deal of publicity in the state over its subsidence-related problems.

McCauley's estimate of the total annual cost of the repairs for subsidence-related damages to land, wells, irrigation ditches, roads and transportation rights of way, and urban and domestic structures, as summarized in Appendix Table T17, equals about fifty cents per acre foot of overdraft per year in constant 1984 dollars. At the time of his research the annual rate of groundwater decline in Western Pinal County averaged about five feet per year. Assuming a simple linear relationship between the rate of groundwater overdraft (decline) and the severity of subsidence damages, it may be inferred that the marginal cost of subsidence equals about ten cents per foot of groundwater decline per year. In any given area the annual cost of subsidence per acre foot is then easily estimated as the product of ten cents times the local rate of groundwater decline.

It is assumed that all potential subsidence associated with a unit of groundwater overdraft and decline occur at one time and that the damages are subject to immediate repair. Subsidence costs are therefore represented as a simple lump sum payment in the year the damage occurs, as opposed to a discounted stream of costs over time.

Water Quality

Water drawn from very deep wells may be affected by thermal activity in the earth which heats the supply to temperatures unsuitable for irrigation. Usually water pumped under thermal conditions poses no problem so long as it can be diluted with water from another source, or else allowed to stand until it can cool. Few farmers in Central Arizona are experiencing thermal groundwater conditions anyway, since the phenomena generally occurs only at well depths several times greater than those from which most water is currently being pumped. No attempt is made to include this problem in the analysis because of its apparent insignificance for Central Arizona agriculture.

A potentially more serious water quality problem is chemical. As a groundwater stock is depleted, the remaining water in storage may come from more compact, finer grained deposits. Water drawn from wells reaching into these strata may have a higher content of disolved salts and minerals than that recovered from the more inert sands above. However, relatively few farmers have suffered any serious water quality problems as their wells have deepened. Nor are those farmers who draw water from aquifers lying relatively close to the surface necessarily guaranteed a clean supply of water. Some of the most saline water used for irrigation is drawn from wells in the Roosevelt Irrigation district west of Phoenix, which are among the shallowest in Central Arizona.

The salinity of irrigation water is projected to rise in coming years, but most if not all of that change is expected to result from the importation of CAP water and not from a deterioration in the quality of the groundwater supplies. Boster (1976, p. 3) reported that the estimated salinity of CAP water will average about 940 parts per million (ppm) when deliveries begin in 1986. Locally the salinity may range from 400 ppm up to 1200 ppm, while the area-weighted average salinity of groundwater in Pinal County is 670 ppm. In his study Boster found that deteriorating water quality should not be cause for concern among Central Arizona farmers. He projected some loss of net income, but on the average it did not amount to any significant sum. The net loss to agriculture averaged about 61 cents ($1.18 in current dollars) per acre per year.

In summary, three points may be observed about water quality problems in Central Arizona. First, there is no simple model which can be used to describe the relationship of water quality to groundwater overdraft. Second, CAP water will probably always be dirtier than most groundwater supplies. Third, even if there were a direct relationship between pumping depth and water quality, and even if groundwater were or would some day be dirtier than CAP water, deteriorating water quality would probably not seriously affect agriculture for a long time to come anyway. In light of these observations, no attempt is made in this analysis to model the effect of groundwater overdraft on water quality.

Overdraft Cost Accounting: Increasing Pumping Lifts

Declining pumping lifts are by far the single greatest cost associated with groundwater overdraft. Not only are the additional costs potentially significant, but the effect is both permanent and cumulative. A change of a single foot in a pumping lift causes the pumping lifts in every subsequent year to be one foot deeper; when the water table falls at a rate of a foot per year, the additional costs mount steadily. Assuming that groundwater pumping technology and the real costs of capital and labor remain constant, and setting aside for the moment the effects of changes in the real price of energy, the additional fixed and variable pumping costs associated with a unit increase in pumping lifts may be represented by a stream of equal payments over time.

Considering the stream of additional costs as a sort of annual annuity, the present worth of the costs of groundwater overdraft may be found in the following manner. Let i represent the rate of discount, and n the length of some finite time horizon. The present value of an annuity A is the product of A and some annuity factor F, where F =

$[(i + 1)^n - 1] / [i * (1 + i)^n)]$.

The time horizon is assumed to be 50 years, and the real rate of discount to be 4 percent. The annuity factor F is then equal to

$[(1.04)^{50} - 1] / [0.04 * (1.04)^{50}]$ = about 21.48.

For any given rate of groundwater decline, the cost of groundwater overdraft per acre foot of overdraft is estimated as the product of the number of feet of decline and the present worth of the stream of additional costs per acre foot per foot of decline. Suppose the additional annual costs associated with one foot of groundwater decline in a given area is estimated to be equal to $0.50 per acre foot. If groundwater levels were falling at the rate of five feet per year, then the present value of all future additional pumping costs caused by this year's groundwater overdraft would be equal to $(0.50 * 21.48 * 5) = $53.70 per acre foot.

Increased Variable Pumping Costs

Changes in variable pumping costs over time are dependent upon two factors, the energy cost of pumping and pump maintenance. Both costs are functions of the depth to lift. An irrigation well operating at 100 percent efficiency would require 1.024 killowatt hours of electricity in order to lift one acre foot of water one foot. Assuming the average irrigation well in Central Arizona operates at 54 percent efficiency, the amount of energy required to lift one acre foot of water one foot is equal to 1.024 divided by 0.54, or about 1.896 kilowatt hours. The product of 1.896 and the cost of electricity per kilowatt hour, multiplied by the pumping depth to lift, will give the energy cost of recovering one acre foot of water.

The pumpwater budget for the Central Arizona Irrigation District in the Eloy area of Pinal County (Hathorn, 1984) is offered as an example. With the price for energy currently at about 25 mils (2.5 cents) per kilowatt hour and with an average pumping lift of about 620 feet, the energy typical pumping cost in the Eloy area is (1.896 * 0.025 * 620 = $29.39 per acre foot. Well maintenance costs are assessed at the rate of $0.011438 dollars per acre foot per foot of lift. In Eloy the maintenance cost for the typical irrigation well is therefore equal to (620 * 0.011438) = $7.09 per acre foot. The total variable cost of pumping is the sum of the energy and maintenance costs, or $29.39 + $7.09 = $36.48 per acre foot.

Suppose groundwater in the Eloy area were overdrafted to the extent that as a result of current pumping activity the water table fell one foot, so that the following year the depth to lift increased from

620 to 621 feet. The additional variable cost of pumping would be evaluated as the sum of the additional energy and maintenance costs for one additional foot of lift, or [(1.024/0.54) * $0.025] + $0.011438 = $0.058845. The present value of the additional variable pumping costs associated with a decline in pumping lifts of one foot in the Eloy area would be equal to the product of the annuity factor 21.48 and the annuity $0.058845, or $1.26 per acre foot of groundwater pumped.

A change in the price of energy would have a significant impact on future variable pumping costs. Suppose that groundwater conditions in the Eloy area remained static, but that the real cost of energy increased by one percent, or $0.00025 per kilowatt hour. A total of (1.024 / 0.54) * 620 = 1176 kilowatt hours are consumed per acre foot. Multiplying this amount by $0.00025, the additional variable pumping costs would be equal to $0.2939 per acre foot. The product of this sum and the annuity factor, 21.48, yields a present value of $6.31 as the cost per acre foot of a permanent increase in the price of electricity of 1 percent.

Central Arizona farmers may normally expect to find that both the cost of electricity and their pumping lifts are changing over time. With the plausible assumption that the rate of groundwater decline is not large relative to the depth to lift, the effect of simultaneous changes in groundwater lifts and energy rates may be approximated by simply adding the separate effects together. The combined effect of a 1 percent increase in the cost of electricity and a three foot groundwater decline in the Eloy area, for example, is found in the following manner.

Multiply the present value of the annual groundwater user cost by three and add it to the present value of the unit energy user cost. The present value of the increased variable pumping costs is then equal to (3 * $1.26) + $6.31 = $10.09 per acre foot.

Increased Fixed Pumping Costs

Four components comprise the total annual fixed cost of groundwater pumping in Hathorn's pumpwater budgets (1975-1984). They are depreciation, interest, taxes, and insurance. For the purposes of this analysis it is assumed that at no time does a farmer "live off his depreciation." When each capital investment in the well is depreciated to zero, another investment of equal or greater value is immediately made to replace the depreciated component. The level of the cost stream associated with depreciation is therefore a constant function of the size of the capital investment, independent of the length of the planning horizon. Interest (the opportunity cost of capital), taxes, and insurance are also assumed to be functions of the size of the well investment. Tax rates vary by region. The only significant departure taken from Hathorn's budgeting system is to substitute his current market interest rate of 13 percent with a long term, real rate of 4 percent.

As pumping lifts increase, more well structure such as piping, tubing, and bowls must be added in order to extend the reach of the pump as it "chases" the receding water table. Eventually the burden of the additional hardware may increase the pump's horsepower requirements to the point where a larger motor is needed. A larger motor may in turn require larger diameter tubes, shafts, and the replacement of other parts. Assuming that well yield does not change over time, the average fixed cost of pumping will increase in proportion to the increase in the size of the capital investment.

In order to trace the rate of increase of average fixed pumping costs as pumping lifts increase, a number of different irrigation wells representing a variety of different groundwater conditions in Central Arizona were "constructed." Well specifications were derived from Hathorn's budgets and from conversations with the managers and engineers of several different irrigation districts in the study area. Once the original well budgets were determined, each well was "rebuilt" several times to reflect the necessary additional investments each well would have to have in order to pump water from successively deeper lifts.

Several dozen fixed cost estimates were thus arrived upon for pumping lifts ranging from 200 to 1000 feet, and well capacities from 800 to 1600 gallons per minute. Appendix Table A1 shows the averaged fixed cost per acre foot of pumped groundwater at various depths to lift. For what be called a "representative" well, fixed costs are projected to increase at a rate of approximately 80 cents per additional fifty feet of pumping lift, or 1.6 cents per additional foot. Multiplying the additional annual fixed pumping cost of 1.6 cents per acre foot per year by the 50 year, 4 percent annuity factor, the present value of the additional fixed pumping costs associated with a single foot of groundwater decline is estimated to be equal to 21.48 * $0.016 = $0.34 per acre foot.

Marginal Social Cost of Groundwater Pumping and Overdraft

Calculation of the Marginal Social Cost of Groundwater Pumping

The full marginal social cost (MSC) of groundwater pumping at any given level of extraction in excess of the hydrologic safe yield is found by adding together the internal and external marginal costs (MEC and MXC) of pumping. Continuing with the example of the Eloy area in Pinal County, the marginal social cost is

MSC = MEC + MXCvp (additional variable pumping costs)

\+ MXCfp (additional fixed pumping costs)

\+ MXCs (subsidence damage repair costs)

= \$36.48 + 1.26 + 0.34 + 0.10

= \$38.19 per acre foot. This amount reflects the estimated real marginal cost of mining groundwater in 1984, assuming that the current rate of overdraft will cause the water table to decline one foot, and real energy rates will not increase next year. If groundwater declined three feet instead of only one foot, while real energy rates remained constant, then the marginal social cost of groundwater pumping would be slightly higher, \$41.61 per acre foot. Should groundwater fall only one foot but real energy costs rise by 3 percent, the marginal social cost of overdraft would increase to \$57.41 per acre foot.

Marginal Social Costs of Groundwater Pumping Compared to CAP Variable Costs

Table 5 shows the estimates for the marginal social cost of groundwater pumping in most of the major agricultural irrigation

Table 5. Estimated Marginal Social Costs of Groundwater Pumping in Central Arizona in 1984.

District	Lift (feet)	Projected Groundwater Decline, 1984-1985 (feet)	Energy Cost (mils/ Kwh)	Projected Real Energy Cost Increase 1984 - 1985 (%)	Estimated Marginal Social Pumping Cost ($/af)
		MARICOPA COUNTY			
Chandler Hts.	600	3	25.00	0	40.44
Harquahala	600	8	52.42	2	114.68
MCMWCD #1	590	3	35.00	0	52.27
Queen Creek	600	3	35.00	1	61.60
RWCD	485	3	35.00	0	33.67
San Tan	600	4	30.00	0	48.64
Tonopah	350	3	52.42	2	62.19
		PIMA COUNTY			
Avra Valley	375	3	79.71	2	97.01
Cortaro-Marana					
(Cortaro)	120	1	17.00	0	6.62
(Marana)	325	2	17.00	0	16.95

Table 5, continued.

District	Lift (feet)	Projected Groundwater Decline, 1984-1985 (feet)	Energy Cost (mils/ Kwh)	Projected Real Energy Cost Increase 1984 - 1985 (%)	Estimated Marginal Social Pumping Cost ($/af)
		PINAL COUNTY			
Central Az	620	3	25.00	0	41.61
Hohokam	410	3	25.00	0	29.26
Maricopa-Stanfield	600	4	36.50	1	61.34
New Magma	600	4	23.00	1	45.17
San Carlos	300	0	25.00	0	17.65

Sources:

Hathorn, Scott. Arizona Pumpwater Budgets. Cooperative Extension Service, University of Arizona, 1975-1984.

Geological Survey. Unpublished Well Data, 1983.

Personal Communications with IndividualIrrigation Districts, 1984.

districts in Central Arizona invited to participate in the CAP. Of the districts listed, only Cortaro-Marana has rejected the offer to contract for CAP water. Projected groundwater declines and real energy cost escalations were derived from examining historical groundwater records and rate histories, and from conversations with irrigation district managers.

Once the full marginal social cost of groundwater pumper has been determined, the relative competitiveness of CAP water is evaluated in the same way as it would be under normal competitive conditions. So long as the marginal cost of CAP water is less than the marginal social cost of groundwater pumping, then farmers are better off buying CAP water. The constant variable (marginal) cost for delivering CAP water to the head of each irrigation district's delivery system, were it delivered today, is about $65 per acre foot. This price is estimated by dividing the official (Bureau of Reclamation) 1984 price of $57 per acre foot by a projected average distribution efficiency factor of about 85 to 95 percent.

CAP water would clearly be competitive with private variable pumping costs in only the Harquahala Irrigation District, and marginally competitive in Avra Valley. With the full assessment of all groundwater pumping user costs, however, both Avra Valley and Harquahala farmers would want to buy CAP water and several other area farmers might be on the verge of finding CAP the cheaper alternative as well. Only a slight deterioration in either energy cost or groundwater lift conditions would make CAP water unambiguously cheaper than groundwater on the margin in

Maricopa County Municipal Water Conservation District (MCMWCD), and in the Queen Creek, Tonopah, and Maricopa-Stanfield irrigation districts.

Comparative Energy Efficiencies of Groundwater Pumping and the CAP

The difference between the marginal private pumping cost and the marginal social pumping cost is significant enough in 1984 to make the CAP begin to appear favorable in some areas where it would not be otherwise. All things being equal, it may appear therefore that at least in the short run, replacing groundwater with CAP water could improve social welfare. Yet all things are not equal; the CAP is generally not as energy efficient a system as is groundwater pumping. The CAP appears competitive with groundwater not only because it is free of groundwater related external costs, but because it is the beneficiary of extremely cheap energy. Although it consumes far more energy per acre foot of water delivered than do almost all groundwater pumps, its energy costs are sometimes lower.

Consumption of Electricity for Groundwater Pumping

Table 6 shows the approximate volumes of pumpage by major irrigation district in the CAP service area, their respective pumping lifts, energy rates, and total kilowatt hour demands. The total average volume of water demanded over all the districts shown is 1,562,100 acre feet per year. Assuming that all of this water is drawn by electric powered pumps, the amount of electricity used totals 1,611,682,000 kilowatt hours annually. The amount of electricity consumed per acre foot of water ranges among the districts from a low of

Table 6. Average Total Water and Electricity Use, and Average Electricity Rates, in Selected Irrigation Districts in Central Arizona in 1984.

District	Total Pumpage (af)	Lift (ft)	Energy Cost (mils)	Total Electricity Consumption (Kwh)
MARICOPA COUNTY				
Chandler Hts	6000	600	25.00	6,827,000
Harquahala	131,300	600	52.42	149,049,000
MCMWCD #1	71,000	590	30.00 @	79,436,000
Queen Crk	84,000	600	35.00	95,573,000
RWCD	80,000	485	35.00	73,576,000
San Tan	10,000	600	30.00	11,378,000
Tonopah	18,800	350	52.42	12,478,000
PIMA COUNTY				
Avra Valley	50,000 *	375	79.71	35,556,000
Cortaro-Marana	41,000	210 #	17.00	16,327,000

* Electric powered wells only
\# Composite of both Cortaro and Marana areas
@ Composite of both public and private facilities

Table 6, continued.

PINAL COUNTY

Central Az	320,000	620	25.00	376,225,000
Hohokam	138,000	410	25.00	107,292,000
Maricopa-Stanfield	400,000	600	36.50	455,111,000
New Magma	110,000	600	23.00	125,156,000
San Carlos	102,000	350 @	25.00	67,698,000

@ Composite of both public and private facilities

Sources:

Hathorn, Scott. *Arizona Pumpwater Budgets.* Cooperative Extension Service, University of Arizona, 1975-1984.

Geological Survey. Unpublished Well Data, 1983.

Personal Communications with Individual Irrigation Districts, 1984.

less than 230 kilowatt hours in the southern end of the Cortaro-Marana Irrigation District, to 1200 kilowatt-hours in some parts of the Central Arizona and Maricopa-Stanfield Irrigation Districts. The average electric power consumption per acre foot is 1032 kilowatt hours. Multiplying 1032 kilowatt hours by the factor (0.54 /1.024) shows that the weighted average pumping lift among the districts is 544 feet. The average electricity rate, weighted by kilowatt hour demand, is 33 mils.

Consumption of Electricity by the CAP

The CAP will deliver between 400,000 and 2,200,000 acre feet annually, consuming between 900,000,000 and 3,500,000,000 kilowatt hours of electricity. The average delivery volume is projected to be about 1,200,000 acre feet per year, with an electric power demand of 2,150,000 kilowatt hours (CAP Information Papers 5A, 1976). On the average, the CAP will use 1792 kilowatt hours of electricity to deliver an acre foot of water. An irrigation well would require an equivalent amount of energy in order to lift groundwater to the surface from a depth of 945 feet. A pumping lift of 600 feet, which is fairly deep, increasing in depth at a rate of 5 feet per year, which is moderately fast, would not begin to consume the same amount of energy per acre foot of water produced as does the CAP for 69 years.

During the "average" year the amount of water delivered by the CAP to agriculture will total about 650,000 acre feet per year. At 1792 kilowatt hours per acre foot, this amount of water will demand 1,164,800,000 kilowatt hours of electric power per year. This much electricity could pump over 72 percent of all the groundwater pumped in the major irrigation districts of the CAP service area. Deliveries of CAP water in the service area will average less than 42 percent of the current level of demand for water.

Relative Energy Costs of Delivering Groundwater versus CAP Water

In spite of the relative energy inefficiency of the CAP water delivery system, its variable production costs are competitive, or almost competitive, with the cost of pumping groundwater in several irrigation districts. It appears so in the short run because the electricity rates from the Navajo power station, the source of energy for the CAP, are significantly lower than the rates paid by almost every other water user in the state for their sources. The estimated rate for electricity from the Navajo station in 1984 is only 20 mils per kilowatt hour (Jackson, 1984). The real rate has remained fairly stable since electric power service began in 1974 (Hine, 1984).

Were the electricity allocated to pumping CAP water instead sold at the same concessionary rate to pump groundwater, the savings would average 33 - 20 = 13 mils per kilowatt hour. Assuming that on the average the CAP consumes 1,164,800,000 kilowatt hours a year delivering water to Central Arizona agriculture, the savings in 1984 alone would amount to 1,164,800,000 * (33 - 20 mils) = $15,500,000. The potential savings that could be realized in groundwater pumping costs should continue to increase every year so long as pumping lifts continue to deepen, the demand for electric energy grows, and the cost of producing commercial energy rises.

Perhaps it might be hypothesized that the cost of using scarce energy resources less efficiently would be outweighed by the benefit of using scarce water resources more efficiently. This possibility may be tested by comparing the variable costs of CAP water and groundwater when all user costs are accounted for and when each alternative source of water uses comparably priced electricity. The distortion caused the by different electricity rates is washed out, and a comparison of the two alternatives may be made purely on the basis of their relative efficiency in allocating scarce water and power resources.

Table 7 shows what the effect on the competitiveness of CAP water would be if the volumes of groundwater subject to trade with the CAP were using a power source as cheap as that allocated for the CAP. No district comes close to finding the CAP an advantageous purchase in the short run anymore. Even the marginal social cost of groundwater pumping in the Harquahala Irrigation District, where lifts are declining at the rate of eight feet a year, is more than twenty dollars an acre foot less expensive than CAP water. Without the CAP's advantage of a concessionary energy rate, the external costs of groundwater overdraft in 1984 would have to be almost unbelievably extreme everywhere before CAP water could begin to compete economically.

Potential Impact of the Marginal Social Cost of Groundwater Pumping on the Demand for Groundwater

Three principle crops are grown in the planned CAP service area of Central Arizona, cotton, alfalfa, and wheat. Other, lower valued and higher valued crops are grown throughout the area, but the acreages devoted to their production are relatively small. Only in the San Tan

Table 7. Potential Impact on the Estimated Marginal Private and Social Costs of Groundwater Pumping if Electricity Rates Were the Same as Those Charged to Pump CAP Water.

District	Current Estimated Marginal Costs of Pumping 1984		Estimated Marginal Costs of Pumping if Electricity Rates Were Stable at 20 Mils, 1984-1985	
	Private	Social	Private	Social
		MARICOPA COUNTY		
Chandler Heights	35.31	40.44	29.62	34.12
Harquahala	66.50	114.68	29.62	41.62
MCMWCD #1	45.91	52.27	29.12	33.62
Queen Creek	46.69	61.60	29.62	34.12
RWCD	28.54	33.67	23.94	28.44
San Tan	41.00	48.64	29.62	34.12
Tonopah	38.79	62.19	17.28	21.78
		PIMA COUNTY		
Avra Valley	60.90	97.01	18.51	23.01
Cortaro-Marana				
(Cortaro)	5.24	6.62	----- *	-----
(Marana)	14.19	15.96	----- *	-----
		PINAL COUNTY		
Central Arizona	36.48	41.61	30.61	35.11
Hohokam	24.13	29.26	20.24	24.74
Maricopa-Stanfld	48.39	61.34	29.62	35.62
New Magma	33.03	43.54	29.62	35.62
San Carlos	17.65	17.65	17.28	17.28

* Current electricity rates are competitive with CAP's rates from the Navajo power plant

and Chandler Heights irrigation districts, where farmers specialize in citrus crops, is the basic cropping pattern markedly different.

Table 8 shows the relative effects on cropping patterns in the CAP service area of individual farmers reacting to marginal pumping costs that reflect first only their own private costs, and then the full social costs of pumping. As may be seen, the assessment of the social marginal pumping costs would influence the production decisions of some but not all farmers, and generally only with respect to their most marginal economic activity. Farmers in three irrigation districts, Harquahala, Avra Valley, and Maricopa-Stanfield, would clearly find that wheat was unprofitable to produce in the short run. Alfalfa would probably see a reduction in acreage in Avra Valley and Harquahala, and even some cotton acreage might be left idle in Harquahala. Farmers in two other irrigation districts, Tonopah, and Queen Creek, would appear to grow their most marginal crops on only the slimmest margin of profit. It is not unlikely that in the short run some wheat acreage might go out of production in these areas.

Apparently, the current rate of groundwater overdraft is economically rational for nearly all but a few marginally productive activities in a few isolated areas. If the full cost of groundwater pumping in 1984 were imposed on all Central Arizona farmers immediately, only a small percentage of the acreage would actually go out of production. Generally those acres are found in areas where the marginal economic activities are already close to the limit of their economic feasibility.

Table 8. Major Field Crops in Central Arizona for Which the Marginal Returns to Water are Insufficient to Cover the Marginal Costs of Pumping in 1984.

District	MUC $/af	MSC $/af	Only Private Costs of Pumping Realized	Full Social Costs of Pumping Realized
		MARICOPA COUNTY		
Chandler Hts	35.31	40.44		
Harquahala	66.50	114.68	Wheat	Wheat, Alfalfa,
MCMWCD #1	45.91	52.27		
Queen Creek	46.69	61.60		Wheat (?)
RWCD	28.54	33.67		
San Tan	41.00	48.64		
Tonopah	38.79	62.19		Wheat (?)
		PIMA COUNTY		
Avra Valley	60.90	97.01	Wheat, Alfalfa	Wheat, Alfalfa
Cortaro-Marana (Marana)	14.19	16.95		
		PINAL COUNTY		
Central Az	36.48	41.61		
Hohokam	24.13	29.26		
Maricopa-St	48.39	61.34		Wheat
New Magma	33.03	45.17		
San Carlos	17.65	17.65		

Marginal Value Product of Water by Crop and by County

County	ORANGES	LEMONS	GRAPEFRUIT	COTTON	ALFALFA	WHEAT
Maricopa	207.72	190.90	137.94	97.60	95.12	63.18
Pima				113.92	34.22	57.31
Pinal				95.22	65.39	55.18

Sources:

Hathorn, Scott.
<u>Arizona Pumpwater Budgets.</u> 1984.
<u>Arizona Field Crop Budgets.</u> 1984.
<u>Arizona Citrus Crop Budgets.</u> 1982.
Cooperative Extension Service, University of Arizona.

Sensitivity of the Marginal Social Cost of Pumping to Alternative Rates of Groundwater Decline and Energy Cost Escalation

Appendix Tables D2 through D16 illustrate, for each of the selected major agricultural irrigation districts in the planned service area of the CAP, the marginal social costs of groundwater pumping in 1984 under 32 alternative scenarios. Each scenario represents a single possible combination of one time, permanent increases in pumping lifts and electricity rates. Under the various alternatives, the discounted present worth (4 percent over 50 years) of the stream of future additional fixed and variable costs of groundwater pumping, and the lump sum payment for subsidence damage repairs, are added to the current private variable cost of groundwater pumping. This sum represents the full, "social" marginal cost of groundwater pumping for the present generation.

The various irrigation districts in Central Arizona which have considered contracting for CAP water experience a wide range of different groundwater and energy cost conditions. Variable pumping costs range from as little as $5.24 per acre foot in the south half (Cortaro area) of the Cortaro-Marana irrigation district, where pumping lifts and and energy rates are among the lowest in the state, to $66.50 in the Harquahala Irrigation District, where pumping lifts and energy rates are among the highest. The relative susceptability of farm income in these areas to incurring short run net losses in the use of irrigation water due to rising energy costs or deepening pumping lifts varies accordingly.

Costs and Returns to Groundwater in Maricopa County

Farmers in two small irrigation districts, Chandler Heights and San Tan, specialize in high-valued citrus crops. The estimated net return to irrigation water is sufficiently high so that any change in groundwater conditions or energy costs that can be reasonably assumed to occur in the course of the following year would leave their production decisions unaffected.

Farms in every other irrigation district in Maricopa County which have considered CAP service grow primarily three crops, cotton, alfalfa, and wheat. The marginal value product of an acre foot of water used on each of the three crops in 1984 is estimated to be $97.60, $95.12, and $63.18, respectively. CAP water, at a variable unit cost of about $65 per acre foot, becomes competitive at approximately the same time that wheat becomes uneconomical to produce.

The production of Durham wheat, the most marginal major crop grown in 1984 in Maricopa County, is very sensitive to the increasing groundwater pumping user costs. Only in the Roosevelt Water Conservation District (RWCD) does it appear that the crop may be grown under any conditions. In contrast, it may not be profitably grown in the Harquahala district even without accounting for any groundwater related externalities, since the <u>private</u> marginal cost of pumping already exceeds the marginal value product of water on Durham wheat. The other districts all appear to be able to grow wheat under almost any reasonable assumption about groundwater decline, so long as energy costs remain fairly stable. Energy escalation rates of 2 percent or more rule out the profitable use of water on wheat in nearly all cases. An exception is found in the Tonopah Irrigation District, where the groundwater decline might exceed three feet before an energy cost increase of 2 percent would make the marginal social cost of groundwater pumping prohibitive.

Alfalfa and cotton, with approximately the same net returns to water, appear considerably more tolerant of increasing marginal pumping costs. Neither are forced out of production in the short run anywhere in Maricopa County under any reasonable set of assumptions except in the Harquahala Irrigation District. Even there, alfalfa and cotton might be grown under half of the scenarios. Elsewhere, in Maricopa County Municipal Water Conservation District (MCMWCD), and in the Queen Creek and Tonopah Irrigation Districts, they approach the limits of profitability only under the most extreme cases. With a groundwater decline of ten feet and an energy cost escalation of 3 percent, they are or are on on the verge of being pushed out of production in every district but the RWCD.

Costs and Returns to Groundwater in Pima County

Groundwater conditions are somewhat similar between the Avra Valley Irrigation District and the Marana area of Cortaro-Marana, but the variable pumping costs are far higher in Avra Valley because its electricity costs are among the highest in Central Arizona.

The marginal value products for an acre foot of water used to grow the principle crops in the two irrigation districts are $113.92 for cotton, $57.31 for wheat, and $34.22 for alfalfa. The variable cost of

CAP water is considerably higher than the marginal value product of water on alfalfa, and about six dollars an acre foot higher than the marginal value product of water on wheat. The CAP thus becomes competitive in Pima County only after irrigation water is already too expensive to be used on both alfalfa and wheat, leaving cotton as the only major field crop worth growing.

Alfalfa, the most marginal of the three crops, cannot be profitably grown in Avra Valley with water drawn from electric-powered wells under any circumstances. It might be grown in Cortaro-Marana under all but the most extreme conditions in the Marana area.

Marginal net returns on wheat just fail to cover marginal pumping costs in Avra Valley under stable groundwater and energy cost conditions. It might be grown profitably under any conditions in Cortaro-Marana.

Cotton has the highest net return to water. It would not be forced out of production anywhere under any conditions unless the groundwater decline and energy cost escalation were relatively extreme, and even then only in the Avra Valley.

Costs and Returns to Groundwater in Pinal County

The marginal value products for an acre foot of water on the principle crops in Pinal County are $95.22 on cotton, $65.39 on alfalfa, and $55.18 on wheat. CAP water therefore becomes competitive well after wheat would be pushed out of production and slightly before alfalfa was threatened.

Two irrigation districts in Pinal County, Hohokam and San Carlos, are currently in the fortunate position of having both low energy costs and moderate groundwater pumping lifts. Neither district would have any incentive to reduce the production of any major crop in the short run under any reasonable assumption about groundwater decline and energy cost escalation.

Durham wheat would become unprofitable in the Maricopa-Stanfield Irrigation District in every case where any decline in the water table were accompanied by an increase in the real cost of energy. Even in the absence of a change in electricity rates, groundwater could not fall much more than three feet before user costs make the production of wheat uneconomical. The situation is less sensitive in the Central Arizona Irrigation District, where lifts might decline over ten feet in the absence of energy cost increases without inhibiting the production of wheat. Moderate energy cost escalations would be within the range of feasible marginal social costs for wheat as long as groundwater declines were also moderate. Pumping costs are currently low enough in the New Magma Irrigation District so that wheat would continue to be grown in the short run unless groundwater levels and energy costs changed dramatically.

Alfalfa would remain relatively unaffected by large changes in either the groundwater level or the cost of energy in every district except Maricopa-Stanfield. Even there, more than half of the possible scenarios appear within the range of feasible conditions for production.

Cotton would not come close to dropping out of production in any district in Pinal County under any reasonable set of conditions. Even in Maricopa-Stanfield, with a decline of ten feet and an energy cost increase of three percent, the residual of the marginal value product of water on cotton over the marginal social cost of groundwater pumping is in excess of eleven dollars per acre foot.

Summary

The present value of the stream of future additional costs caused by current rates of groundwater overdraft does not appear to be large enough to discourage significant changes in agricultural uses for water in the near future. In the short run, CAP water would not become competitive in 1984 in seven of the fourteen districts examined, except under the most extreme groundwater decline and energy cost escalation conditions. These are Chandler Heights and RWCD in Maricopa County, Cortaro-Marana in Pima County, and Central Arizona, Hohokam, New Magma, and San Carlos in Pinal County. Another five districts would find CAP water competitive under several different sets of moderate to extreme conditions. These are MCMWCD, Queen Creek, San Tan, and Tonopah in Maricopa County, and Maricopa-Stanfield in Pinal County. Two districts would find CAP water competitive in the short run under any or almost any conditions. They are Harquahala in Maricopa County and Avra Valley in Pima County.

Of the three major crops examined, only wheat appears susceptible to being taken out of production on a significant scale if groundwater overdraft costs were significant. In several irrigation districts, including RWCD, Cortaro-Marana, Hohokam, New Magma, and San Carlos, groundwater costs are so low, even the production of wheat does not appear to be threatened. The demand for irrigation water would probably not be reduced under any reasonable set of assumptions about groundwater decline and energy cost esalation. Demand for water to irrigate alfalfa would remain virtually unaffected everywhere except under moderate to severe energy cost and groundwater decline conditions in Harquahala, Maricopa-Stanfield, and Avra Valley. Cotton would not be affected at all except under moderate conditions in Harquahala and severe conditions in Avra Valley.

Recent Historical Trends in the Supply and Demand for Irrigation Water in Central Arizona

Estimating the marginal user cost of groundwater pumping and overdraft and comparing it to the marginal value product of water is a useful means of determining the optimal level of groundwater depletion in any given year. However, periodic changes in conditions other than those directly related to groundwater decline and energy cost escalation might alter the level of demand for irrigation water, and hence the optimal level of depletion.

The following discussion examines some recent historical trends affecting the supply and demand for irrigation water in Central Arizona. It is based on Hathorn's crop and Central Arizona pumpwater budgets for the years 1975 to 1984, inclusive, Arizona agricultural statistics published by the Crop and Livestock Reporting Service, and US Geological Survey historic groundwater surveys. All relevent data is recorded in Appendix T. The supply and demand for water in use on three major crops, alfalfa, cotton, and wheat, are studied. Illustrations which summarize these data for three specific areas, Queen Creek in Maricopa County, Avra Valley in Pima County, and Eloy in Pinal County, are found in Figures 18 through 31 at the end of this chapter. All costs are adjusted to reflect equivalent values in 1984 constant dollars.

Variable Groundwater Pumping Costs in Central Arizona, 1975 to 1984

Only in Pima County do current pumping costs appear significantly higher than they were in 1975, primarily because of a single large jump in costs in 1982 to 1983. Costs in Maricopa County are all slightly higher than they were in 1975, the real rate of increase averaging slightly less than 2 percent a year. Costs in Pinal County are actually lower than they were several years ago, although costs appear to have bottomed out in the late 1970's and have risen at various rates since then. Since 1980 real variable pumping costs in Eastern and Central Pinal County have increased at about 3 to 5 percent a year, while those in western Pinal County have increased very rapidly, averaging more than 14 percent a year.

Recent changes in pumping lifts have been so minor that they have had little or no effect on the real cost of recovering groundwater. Lifts in most major areas of Central Arizona have increased only relatively slowly, if at all, since the early 1970's. Apparently, recharge rates have been increasing as the rates of groundwater withdrawal have either stabilized or begun a slow decline. Events in recent years seem to have begun to push Arizona's historic groundwater overdraft towards equilibrium, at least in the agricultural areas of the state.

Electric power rates have in recent years been the most volatile of all the factors affecting the cost of groundwater pumping from one year to the next. Throughout the tricounty area, rates have risen significantly in the few years since 1980 and have been the determining factor causing the recent large increases in the real variable costs of groundwater pumping. The largest increases have been in Pima County and in the Maricopa-Stanfield area of Pinal County, where energy prices have changed the most. An uneven, but rising cost trend is also in evidence in most areas of Maricopa County.

Marginal Value Product of Water in Central Arizona, 1975 to 1984

In Maricopa County the MVP of water on cotton has tended to decline over this period, while trends for wheat and alfalfa have been much less obvious. The MVP of water on wheat eroded dramatically from 1976 to 1978, when it began to recover. Water on aLfalfa experienced a very low MVP in 1982, but by 1984 was enjoying its highest marginal value since 1976.

The marginal value product of water on each crop is a function of three factors, crop prices, crop yields, and the cost of all input factors other than water. Higher crop yields or crop prices would increase the gross returns on a crop, raising the relative value productivity of water. Falling input factor costs would leave relatively more of a residual return to pay for water, also raising its value product.

Cotton prices have fallen significantly, although they did experience a sharp increase in 1975 to 1976, and are higher in the last three years than the low level they reached in 1981. Alfalfa prices have been extremely unstable, rising sharply from 1973 to 1976, then plunging to a low in 1978 which was quickly made up in the following year. Prices dove again from 1979 to 1982, but have been recovering strongly since then. Wheat has shown short upward trends in the periods 1973 to 1976, 1977 to 1981, and 1982 to 1984. Punctuating these rises were large falls in wheat prices in 1975-1976 and 1981-1982. Overall, the trend in wheat prices has been downwards. Currently the unit value of wheat is only slightly more than half of what is was as recently as 1976.

For all three crops, Maricopa County farmers have been the most productive, followed by Pinal and Pima County farmers. Of the three crops studied, cotton appears to have had the most eratic record of yields over the ten-year period. In Maricopa County cotton lint yields rose and fell sharply through the middle and late 1970's, reaching a low in 1978. A steady upward trend was then observed until 1981, after which yields fell slightly to a level which has remained fairly constant since then. Yields reached a low in 1978 in Pima County also. Yields have leveled off in recent years at a level considerabley below that in Maricopa County. Increases in cotton yields in Pinal County have followed basically the same pattern observed in Maricopa County.

Changes in alfalfa yields in Maricopa and Pinal counties have also been similar, exhibiting a fairly steady upward trend broken only by the sharp drop in productivity experienced in 1977 - 1979. Pima County, in contrast, has shown no significant increase in alfalfa yields in more than ten years. Currently Pima County farmers produce only half as much alfalfa per unit acre as do their counterparts in Maricopa and Pinal Counties.

Wheat yields over this period trace a general rise throughout the three county area. All counties show 1978 as the most unproductive year for wheat, while since about 1981 there has been little or no change in yields.

"Factor costs" are understood here to be the cost of all factor inputs except raw water. The historic trends for most factor costs generally exhibit either stability or a gradual decline. Cotton factor costs have fallen steadily everywhere. Those for alfalfa generally fell until the late 1970's, when they leveled off. Wheat factor costs have declined steadily since 1975 everywhere except in Pima County, where costs have remained fairly constant since 1977.

Recent Historical Trends in the Factor Cost-Value Ratio for Water in Central Arizona

How sensitive is farm income to increasing water costs? A means of tracing the trends in the relative cost of water over time is through the analysis of what shall be called the "factor cost-value ratio" of water. The ratio is found by dividing the variable cost of groundwater pumping by the marginal value product of water in some given productive activity. So long as the ratio remains below 100 percent, the short run costs of using water are less than the returns, a positive net revenue is earned, and it is rational to continue production in the short run. The factor cost-value ratio of water on various crops is therefore a relative measure of the changes in net returns to farming with respect to changes in the supply and demand for groundwater.

Three case studies on the recent history of the factor cost-value ratios for irrigation water in Central Arizona are examined: alfalfa in the Eloy area of Pinal County, cotton in the Queen Creek area of Maricopa County, and wheat in the Avra Valley area of Pima County. These areas correspond roughly to the Central Arizona, Queen Creek, and Avra Valley Irrigation Districts, respectively.

Alfalfa in Pinal County: Eloy Area

The input cost-value ratio of water on alfalfa in Pinal County has generally fluccuated between 40 and 70 percent since 1975, with a single large jump to 175 percent in 1978.

From 1977 to 1978 the variable costs of pumping declined moderately in spite of a 1.0 percent deeper lift, because of a drop in energy rates. This benefit was completely washed out by a fall of 77.4 percent in the marginal value product of water. The fall was prompted by simultaneous and large deteriorations in both crop prices and crop yields, of 20.0 percent and 18.5 percent, respectively. From 1978 to 1979 pumping lifts increased insignificantly, but variable pumping costs rose by nearly 10.0 percent as energy rates jumped. The depressing effect of higher pumping costs was canceled out, however, as improving crop prices and crop yields raised the marginal value product of water as dramatically as it had pulled it down before. Consequently the input cost-value ratio returned to almost the same low level it enjoyed in 1977.

Cotton in Maricopa County: Queen Creek Area

Over the period 1975-1984 the marginal variable cost of pumping water in Queen Creek has become more expensive relative to the marginal value product of water on cotton. Consider three periods during these years. The first is the relatively stable ratio from 1977 to 1978. the second is the sharp rise in the ratio between 1980 and 1981. The third is the equally sharp fall in the ratio between 1982 and 1983.

Between 1977 and 1978 the real variable cost of pumping fell 7.7 percent while the marginal value product of water on cotton fell 9.6 percent. As a result of the counteracting movements of these values, the factor cost-value ratio rose only slightly, by 1.8 percent. The decline in variable pumping costs was caused by a decrease in real electric power rates. While pumping lifts increased by 0.9 percent, unit energy costs fell by 8.7 percent. The decline in marginal value product of water on cotton was caused by a fall in cotton prices of 5.0 percent and a rise in input factor costs of 9.3 percent, respectively. Productivity increases of 0.5 percent were not sufficient to offset these losses.

Between 1980 and 1981 variable pumping costs in the Queen Creek area fell again, by 9.2 percent. Outweighing this gain was a fall in the marginal value of product of water on cotton of 45.8 percent. Real variable pumping costs declined because energy costs fell while pumping lifts remained constant. The marginal value product of water fell in spite of a large gain in productivity, because factor prices rose moderately and output prices fell by nearly one third. Even with significantly lower pumping costs, farmers found themselves worse off than in the previous year because their willingness to pay for their water had eroded even more.

Between 1982 and 1983 Queen Creek variable pumping costs declined slightly less than in the previous year, but this time the marginal value product of water on cotton rose dramatically. As a result, the input cost-value ration fell even more than it had risen before. In this year every factor worked in Queen Creek's favor: pumping lifts remained stable, electricity rates fell, crop prices and yields rose, and factor costs fell. Farmers were far better off than the decline in pumping costs alone suggested.

Wheat in Pima County: Avra Valley Area

The input cost-value ratio of water on wheat in the Avra Valley area fell significantly from 1977 to 1981, then rose significantly from 1981 to 1984.

From 1977 to 1981, pumping lifts deepened by 2.7 percent. This negative effect was overcome by an 18.2 percent drop in energy prices. The marginal value product of water rose by more than a third even though factor costs rose slightly, because crop prices jumped over 15 percent while crop yields improved moderately.

From 1981 to 1984, the input cost-value ratio rose in spite of the fact that pumping lifts had stabilized, wheat yields continue to improve, and factor costs fell even more. Higher energy rates rates and a large fall in crop prices both contributed towards a deterioration in the ability of a Pima County farmer to earn a short run net return on wheat.

Conclusions

Relative Impact of Increasing Groundwater Pumping Lifts on the Economic Use of Groundwater

The purpose of the preceding analyses was to put the problem of groundwater overdraft in perspective. Declining groundwater tables have undoubtedly led to higher pumping costs than there would have been in the absence of these declines. That is not the same thing as saying, however, that groundwater overdraft in itself has ever been or is now a serious problem for farmers.

The marginal social costs of groundwater overdraft are generally still too small to justify the conservation measures that the state of Arizona wishes to encourage. The marginal cost of CAP water is still too large relative to the marginal social cost of groundwater pumping to justify its substitution for groundwater. It was shown through the historical analysis that some of the short run production factors which affect the supply and demand for water, primarily crop prices, crop productivity, and energy costs, have been subject to large and sudden changes within relatively short periods of time. In contrast, pumping lifts have changed slowly, progressively, and in a fairly predictable manner. The trend over time in their rate of change is one of continuous moderation, to the point where in most areas groundwater appears to be gradually approaching a long run hydrologic equilibrium.

Policy Implications for Groundwater Overdraft Management in Arizona

This modified short run analysis of the CAP agrees with the basic conclusions reached in the standard short run analysis offered in

Chapter 2. The external benefits of the CAP, when fully assesed, still do not appear to make the project an economically viable alternative to the present sources of water in Central Arizona. The policy implications may be summarized in the following points.

1) The disparity between the private and social costs of groundwater pumping in Central Arizona currently is not sufficient to cause a serious misallocation of scarce groundwater resources. Only under circumstances of unrealistically extreme rates of groundwater decline and energy cost escalation could the net social loss from "excessive" groundwater overdraft become significant in the foreseeable future.

2) As is the case for other depletable natural resources, the timing of groundwater conservation measures is crucial. The welfare of Arizona society with respect to its use of scarce groundwater reserves is maximized over time when the social costs of groundwater depletion are equated on the margin with the marginal social benefits gained from the use of the water.

For farmers in many irrigation districts, the private and marginal costs of groundwater pumping are far below the marginal value product of water. In the absence of other constraints, it appears that increased use, and not conservation, of groundwater would be economically rational. That is, the marginal cost of groundwater is generally not the binding constraint on farm production decisions. Farm income may therefore be improved more effectively by finding means to relax some of the other constraints on their economic activity.

Indiscriminate water conservation in Arizona could be just as costly or even more costly than is the so-called "profligate waste" generated through the current level of overdraft. Eventually, the marginal social costs of groundwater depletion may increase to the point where it would no longer be worthwhile to exploit the aquifers in excess of the hydrologica safe yield. But Arizona does not yet appear to be approaching that limit any time soon. To force water users to behave as if that limit had already been reached could result in significant economic losses.

The ambitious groundwater management program currently being promoted in Arizona, of which the CAP is an integral component, is an attempt to do too much of what could perhaps someday be a good thing, too soon. It is likely that the intertemporal allocation of scarce water resources in the state will be highly inefficient in the coming years, resulting in a lower level of social welfare than would have been enjoyed otherwise.

3) The variable cost of the CAP is so high that it cannot currently compete with groundwater sources in most agricultural areas of Central Arizona, even when the full social costs of groundwater overdraft are assessed. The poor economic performance of the CAP is magnified further when it is realized that the marginal cost of the water is grossly understated. It is priced very cheaply relative to the social opportunity costs of its production, in large part because the delivery system will have the advantage of concessionary electric power rates to pump its water.

A large and growing net social benefit could probably be realized in Arizona by simply reallocating the cheap energy reserved for the CAP to pump groundwater. An unrecognized cost of the CAP will the significant opportunities lost to use these energy resources more effeciently elsewhere.

4) Increasing water scarcity, reflected in increasing pumping depths to lift, does not necessarily mean that net farm income is or will someday soon start declining. It may not even imply that the real cost of groundwater pumping is on the rise. Dramatic changes in many different factors have influenced the cost of water and the marginal willingness of a farmer to pay for it. In contrast, groundwater pumping lifts have tended towards greater and greater stability. Ultimately they have had a relatively minor influence on the historical changes in the variable cost of pumping and on the level of net farm income. Their relative weight will probably continue to diminish over time, as hydrologic equilibrium is approached.

5) The capital outlays for the CAP present a potentially large opportunity cost for Central Arizona farmers. by the time the construction of the CAP is completed, the federal government will have spent at least $2.3 billion on the main canal system alone (Barr and Pingry, 1977). Ostensibly the primary purpose of the project is to help control groundwater overdraft and its associated external costs, which at least for a long time to come should be one of Central Arizona agriculture's least worries.

It is beyond the scope of this study to examine all of the alternative projects for which the resources devoted to building, maintaining, and operating the CAP could have been spent, but a few possibilities might be briefly mentioned without comment. Farm income could probably be improved far more cheaply and easily by investing in, among many others, the following sorts of projects and policies.

1) Developing cheaper sources of energy, or more energy efficient means of producing water.

2) Improving and stabilizing farm output prices.

3) Developing lower cost technologies and cheaper input factors for inputs other than water.

4) Improving irrigation techniques in order to cut efficiency losses and reduce crop irrigation requirements.

5) Introducing higher-valued productive activities which could afford to pay more for water, on the margin.

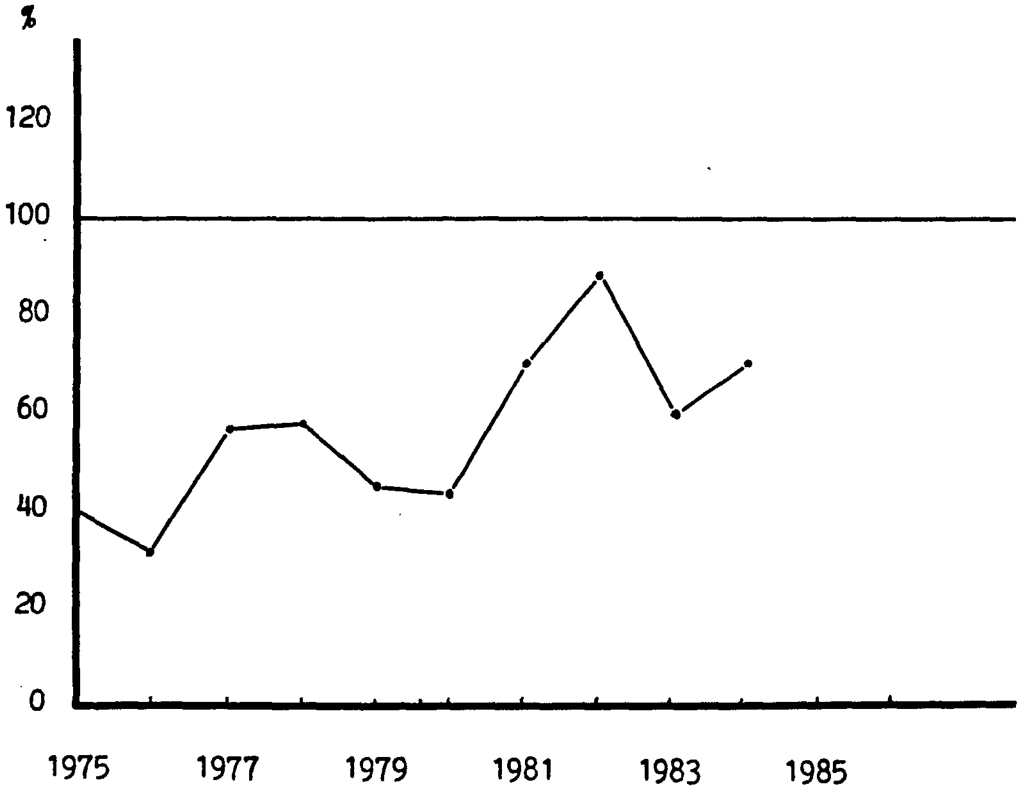


Figure 18. Variable Pumping Costs as a Percentage of the Marginal Value Product of Water on Cotton, 1975 - 1984

Queen Creek Area, Maricopa County

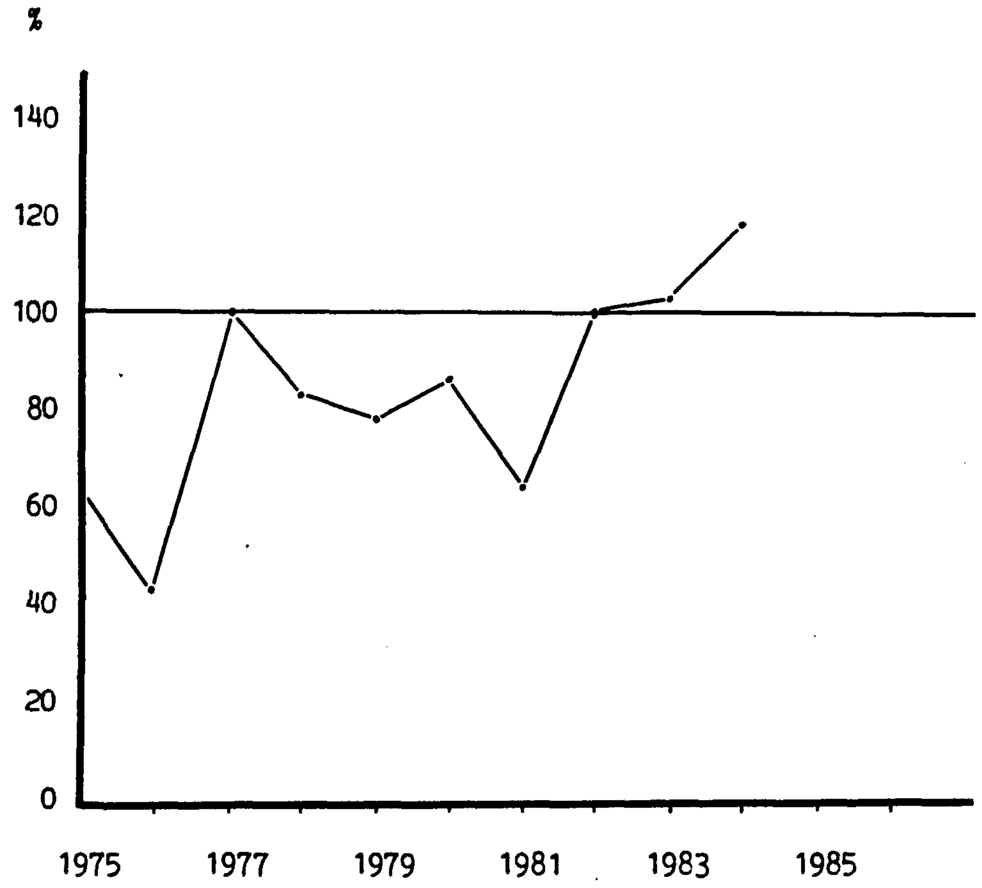


Figure 19. Variable Pumping Costs as a Percentage of the Marginal Value Product of Water on Wheat, 1975 - 1984

Avra Valley Area, Pima County

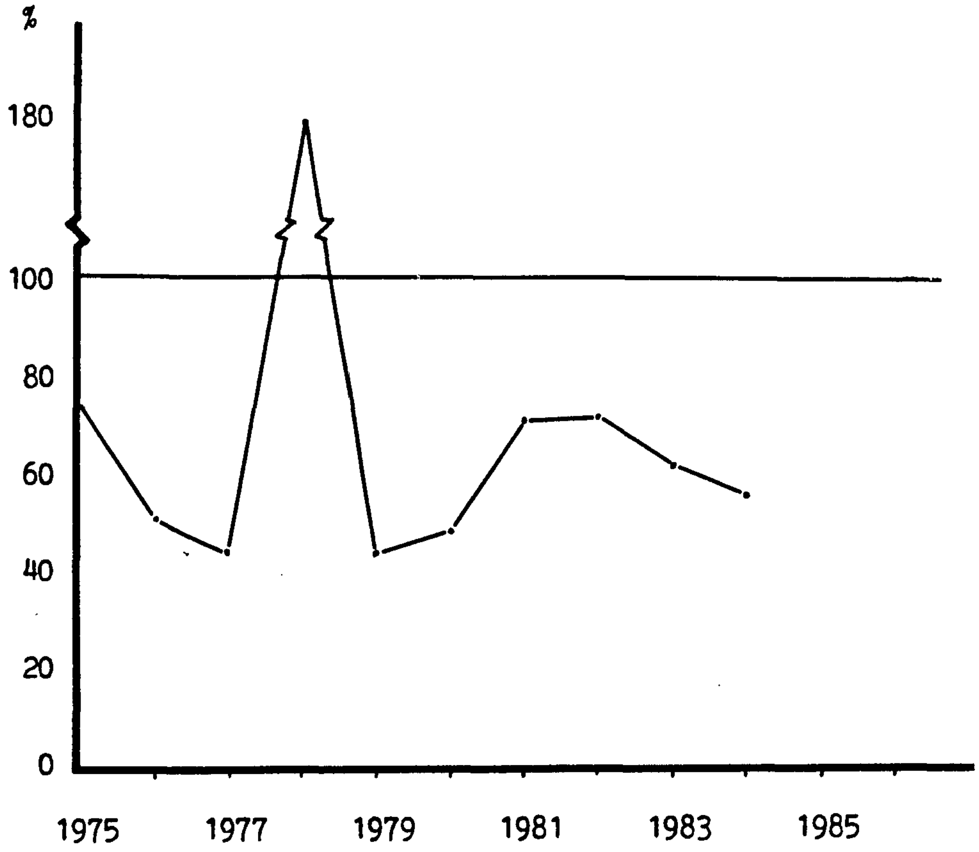


Figure 20. Variable Pumping Costs as a Percentage of the Marginal Value Product of Water on Alfalfa, 1975 - 1984

Eloy Area, Pinal County

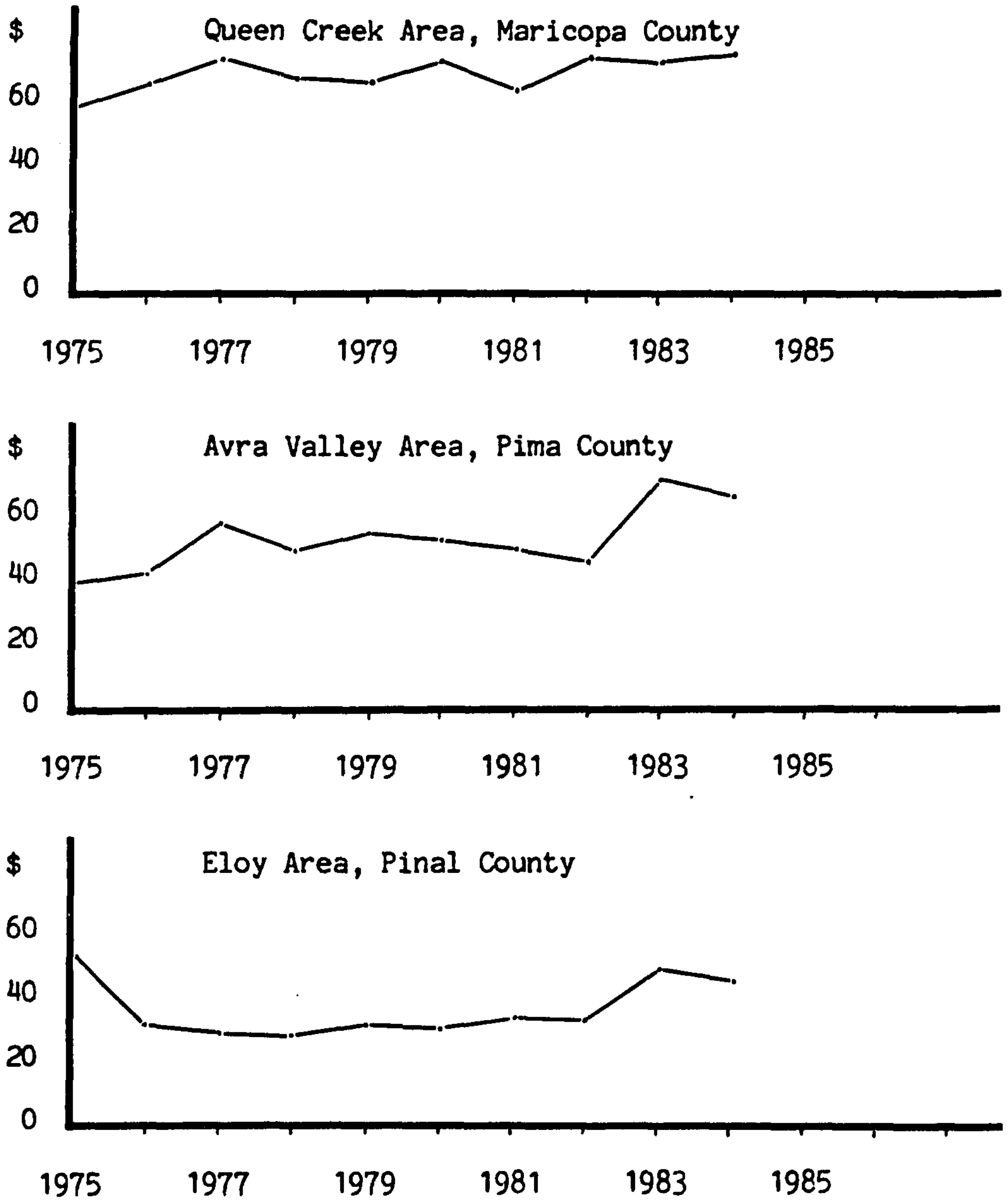


Figure 21. Real ($1984) Variable Pumping Costs, 1975 - 1984.

Source : Hathorn, Scott. Arizona Pumpwater Budgets. Cooperative Extension Service, University of Arizona. 1975 - 1984.

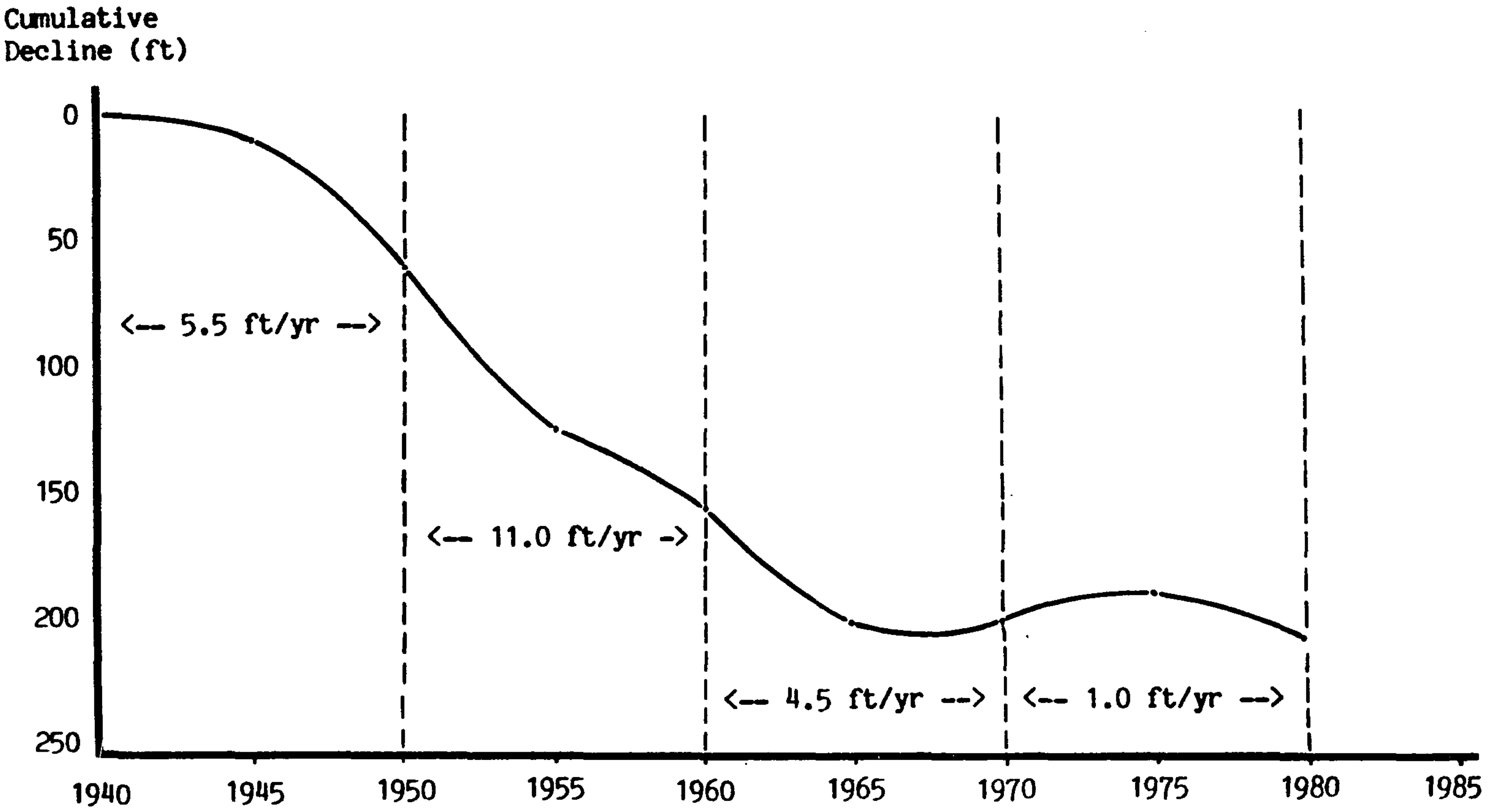


Figure 22. Historic Rates of Groundwater Decline, 1940 - 1980. Queen Creek Area, Maricopa County.

Source: US Geological Survey, "Groundwater Conditions in the Salt River Valley." Well B. 1981.

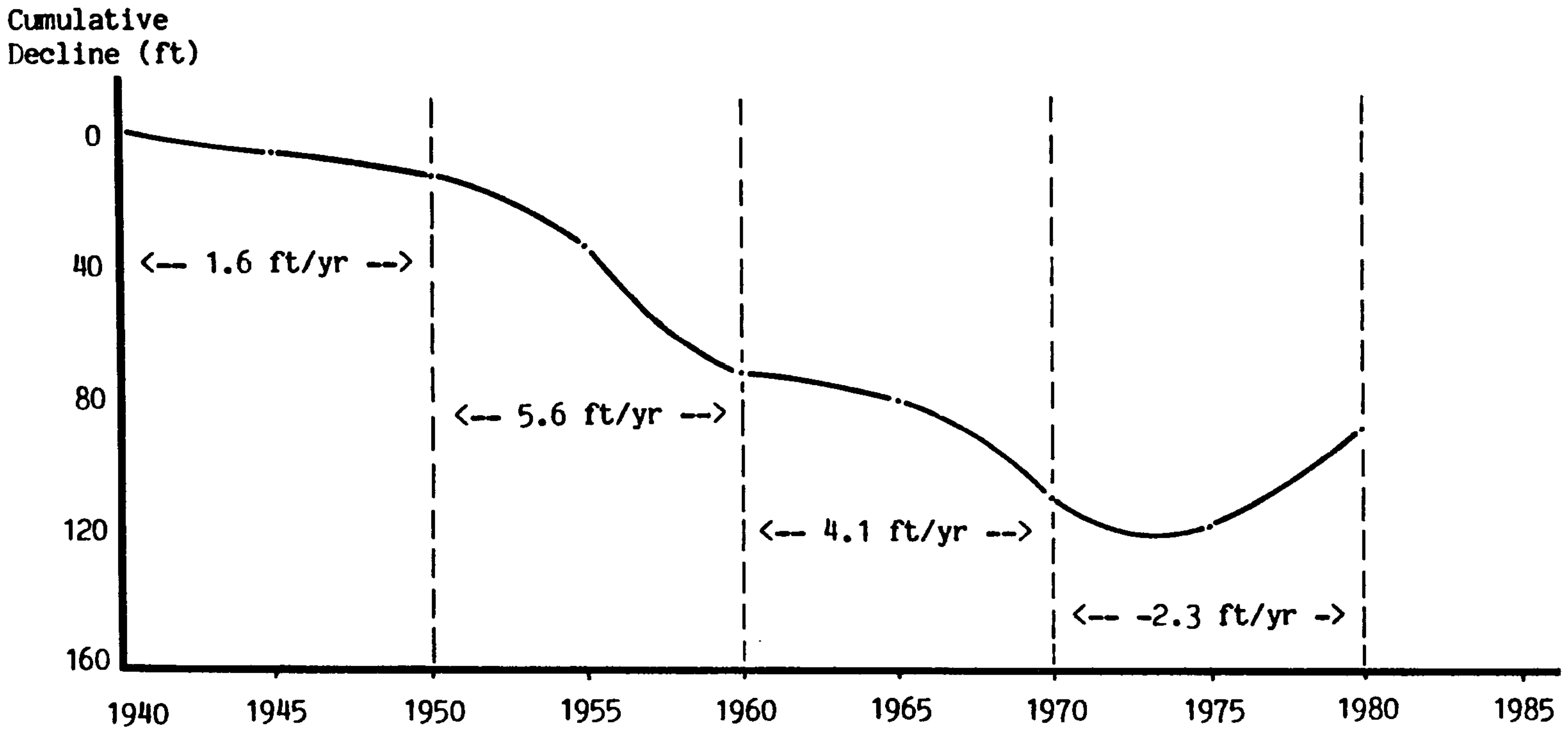


Figure 23. Historic Rates of Groundwater Decline, 1940 - 1980. Avra Valley Area, Pima County.

Source: US Geological Survey, "Groundwater Conditions in the Avra and Altar Valleys." Well D. 1982.

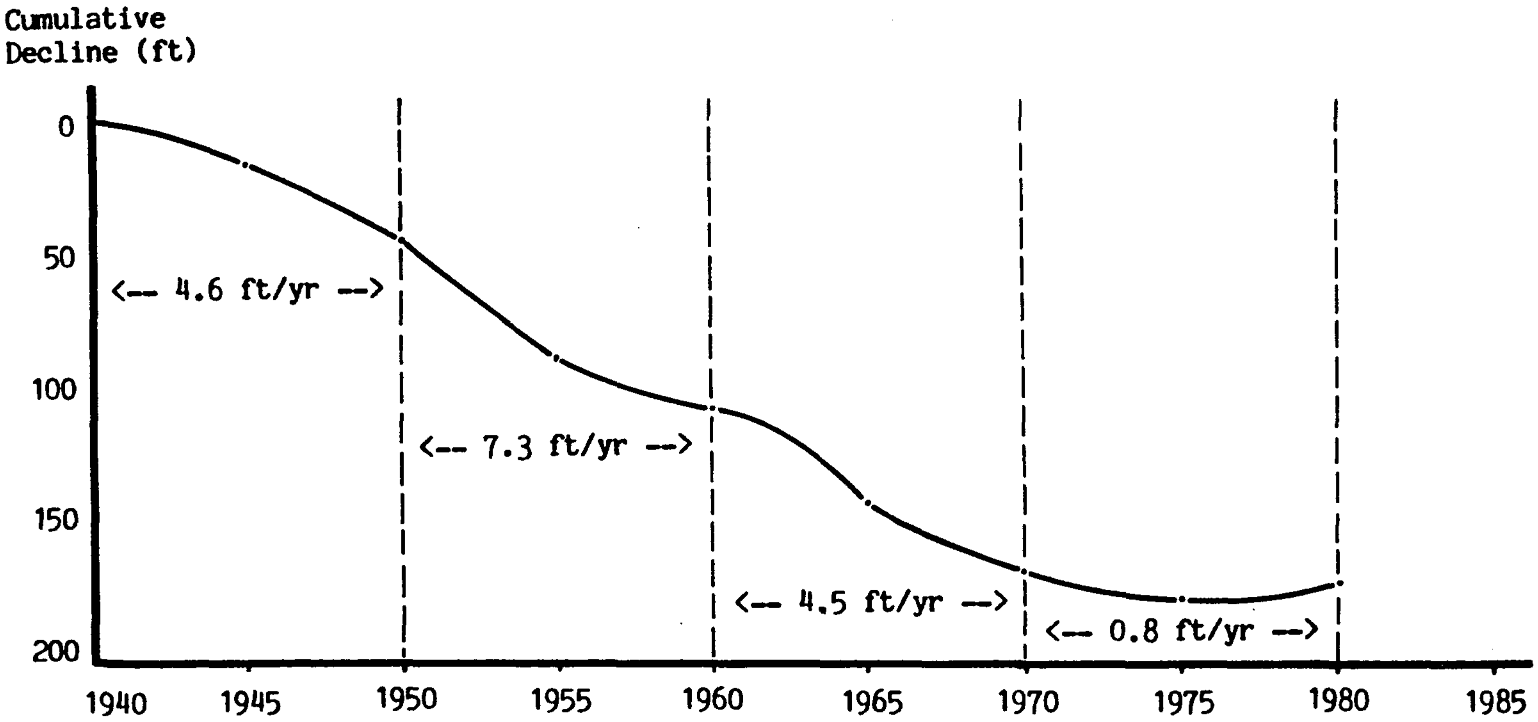


Figure 24. Historic Rates of Groundwater Decline, 1940 - 1980. Eloy Area, Pinal County.

Source: Sanousi, Sanousi Salem. Ground-Water Depletion as an Indicator of Desertification. Unpublished Professional Paper, University of Arizona, 1982.

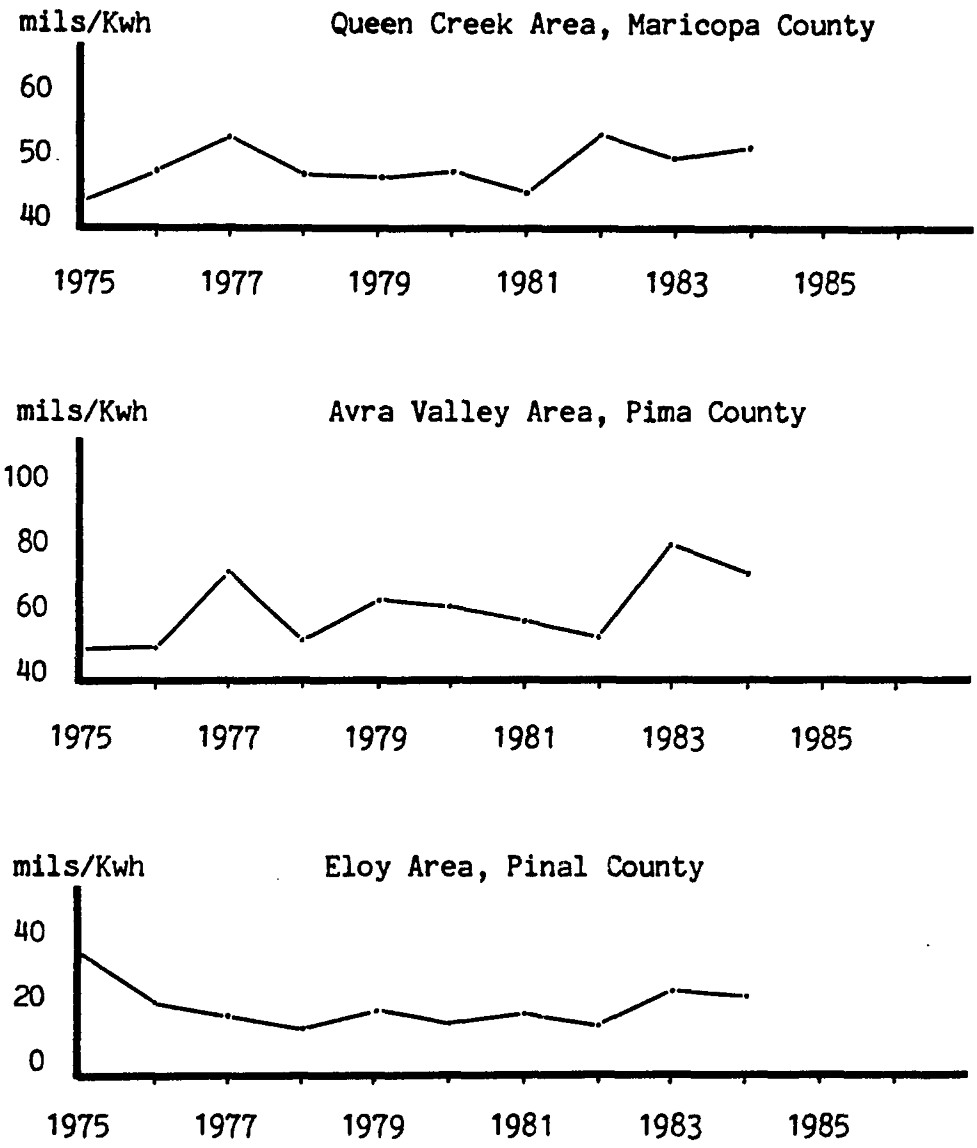
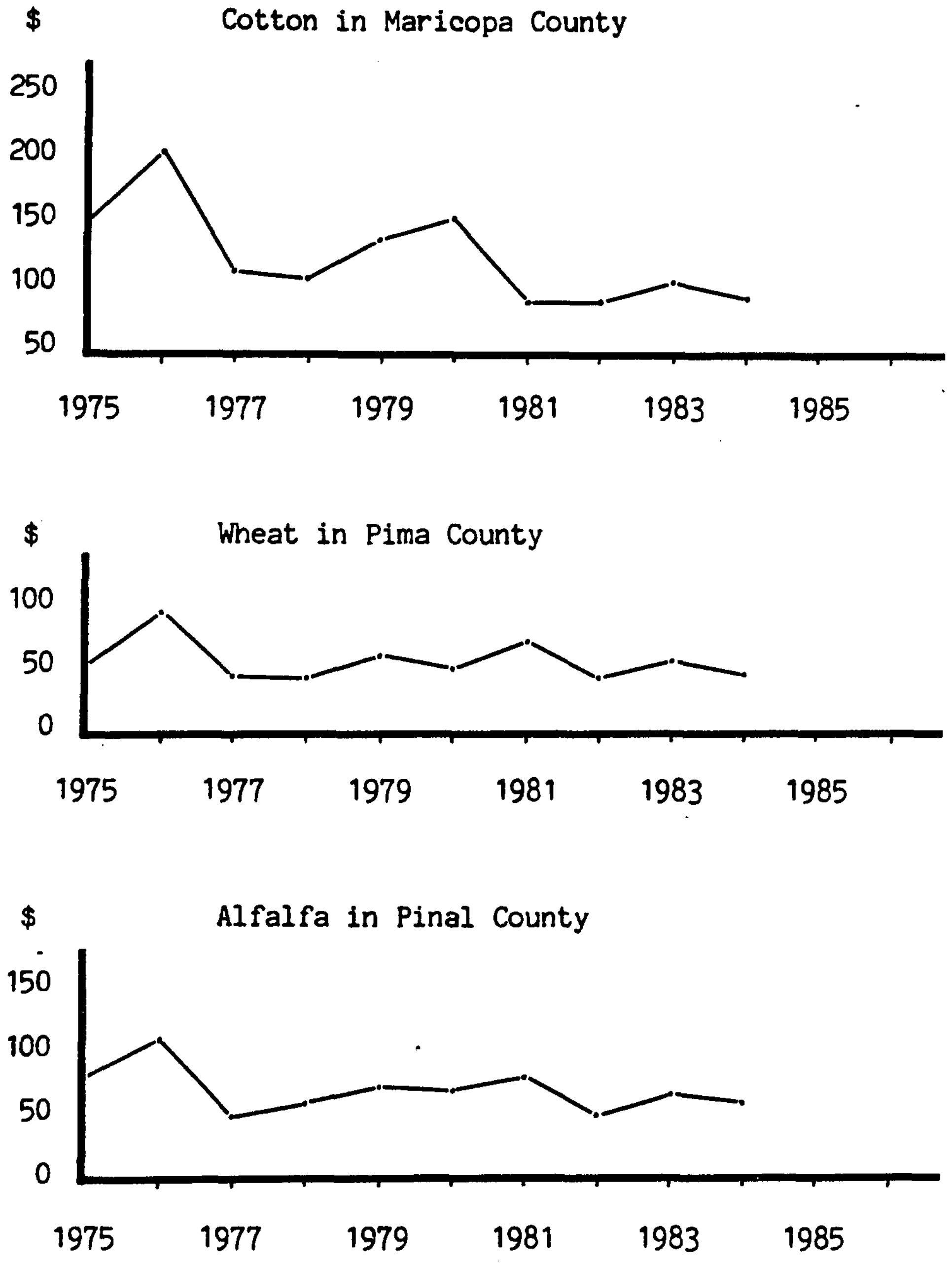


Figure 25. Real ($1984) Electricity Rates, 1975 - 1984.

Source : Hathorn, Scott. Arizona Pumpwater Budgets. Cooperative Extension Service, University of Arizona. 1975 - 1984.



Cotton in Maricopa County

Wheat in Pima County

Alfalfa in Pinal County

Figure 26. Real ($1984) Marginal Value Product of Water on Selected Crops, 1975 - 1984.

Source : Hathorn, Scott. Arizona Field Crop Budgets. Cooperative Extension Service, University of Arizona. 1975 - 1984.

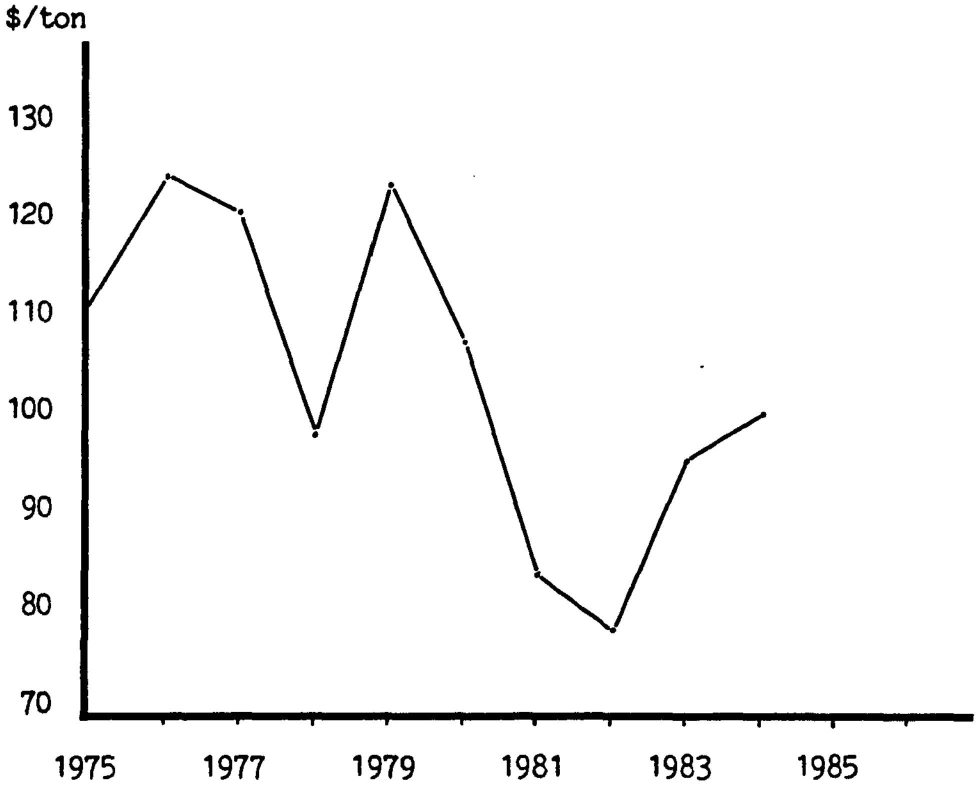


Figure 27.

Real ($1984) Prices Received by Arizona Farmers for Alfalfa, 1975 - 1984.

Sources:

Brantner, Ron. Arizona Agricultural Statistics. Arizona Crop and Livestock Reporting Service, 1979 - 1984.

Valley National Bank. Arizona Statistical Review. Economic Research Department, 1976 - 1983.

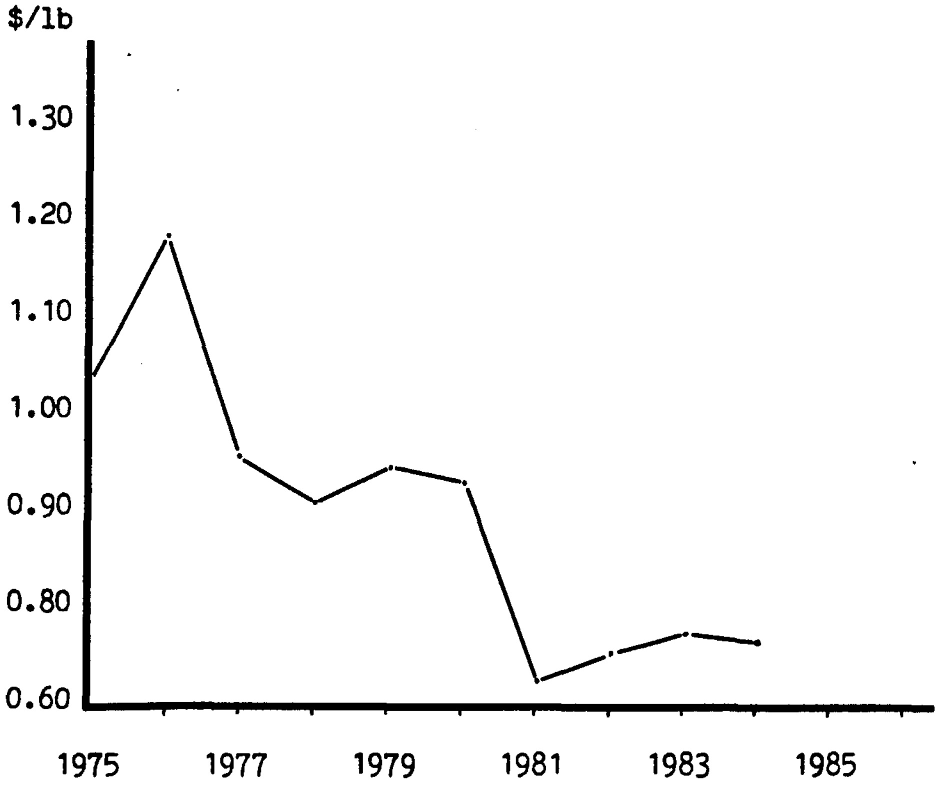


Figure 28.

Real ($1984) Prices Received by Arizona Farmers for Cotton, 1975 - 1984.

Sources:

Brantner, Ron. Arizona Agricultural Statistics. Arizona Crop and Livestock Reporting Service, 1979 - 1984.

Valley National Bank. Arizona Statistical Review. Economic Research Department, 1976 - 1983.

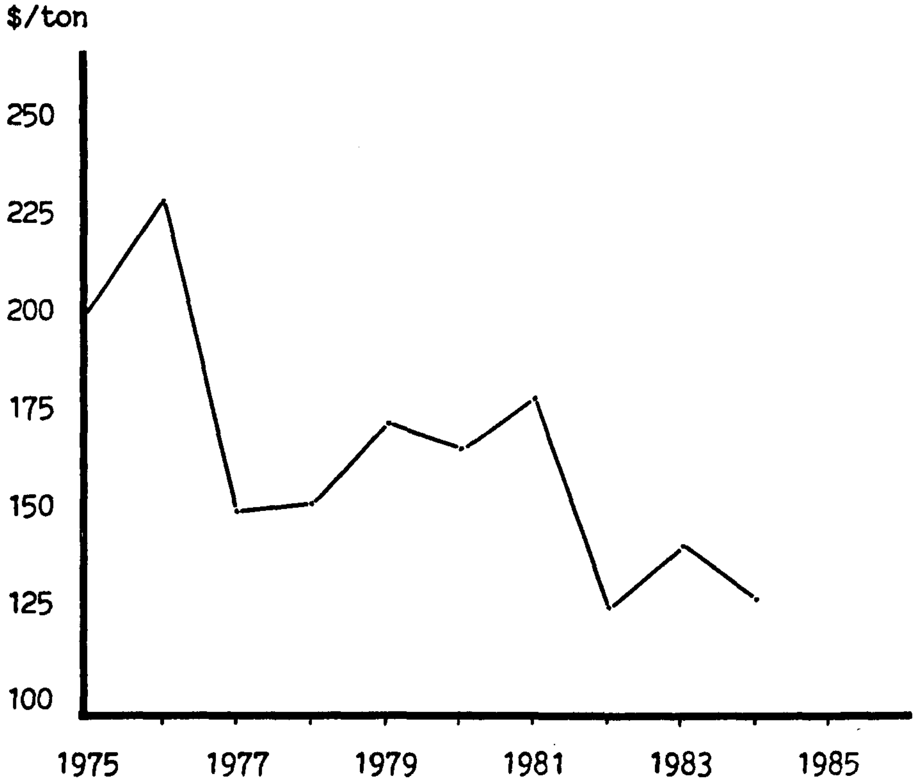


Figure 29.

Real ($1984) Prices Received by Arizona Farmers for Wheat, 1975 - 1984.

Sources:

Brantner, Ron. Arizona Agricultural Statistics. Arizona Crop and Livestock Reporting Service, 1979 - 1984.

Valley National Bank. Arizona Statistical Review. Economic Research Department, 1976 - 1983.

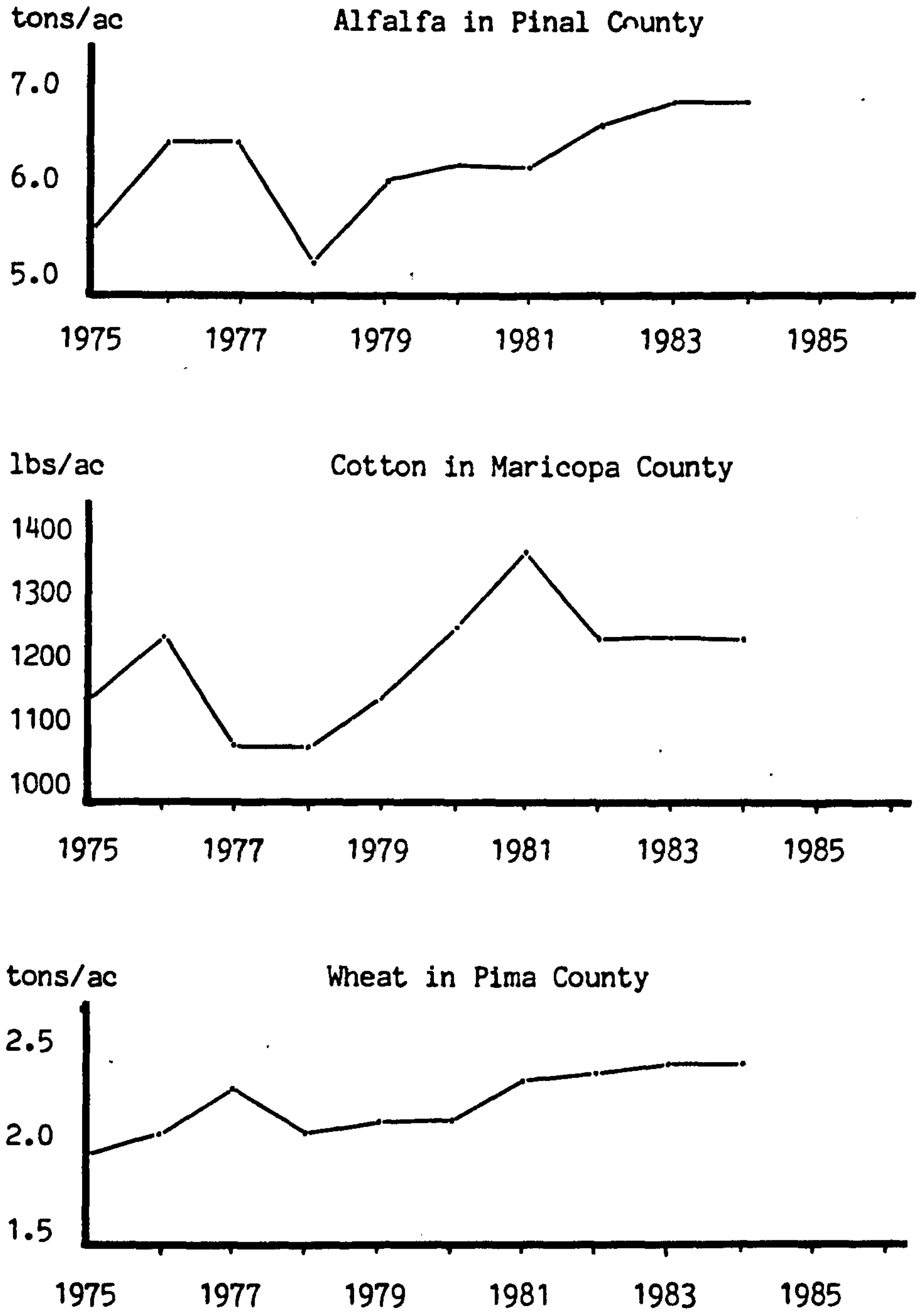


Figure 30. Yields per Acre for Selected Crops, 1975 - 1984.

Source : Brantner, Ron. Arizona Agricultural Statistics. Arizona Crop and Livestock Reporting Service, 1979 - 1984.

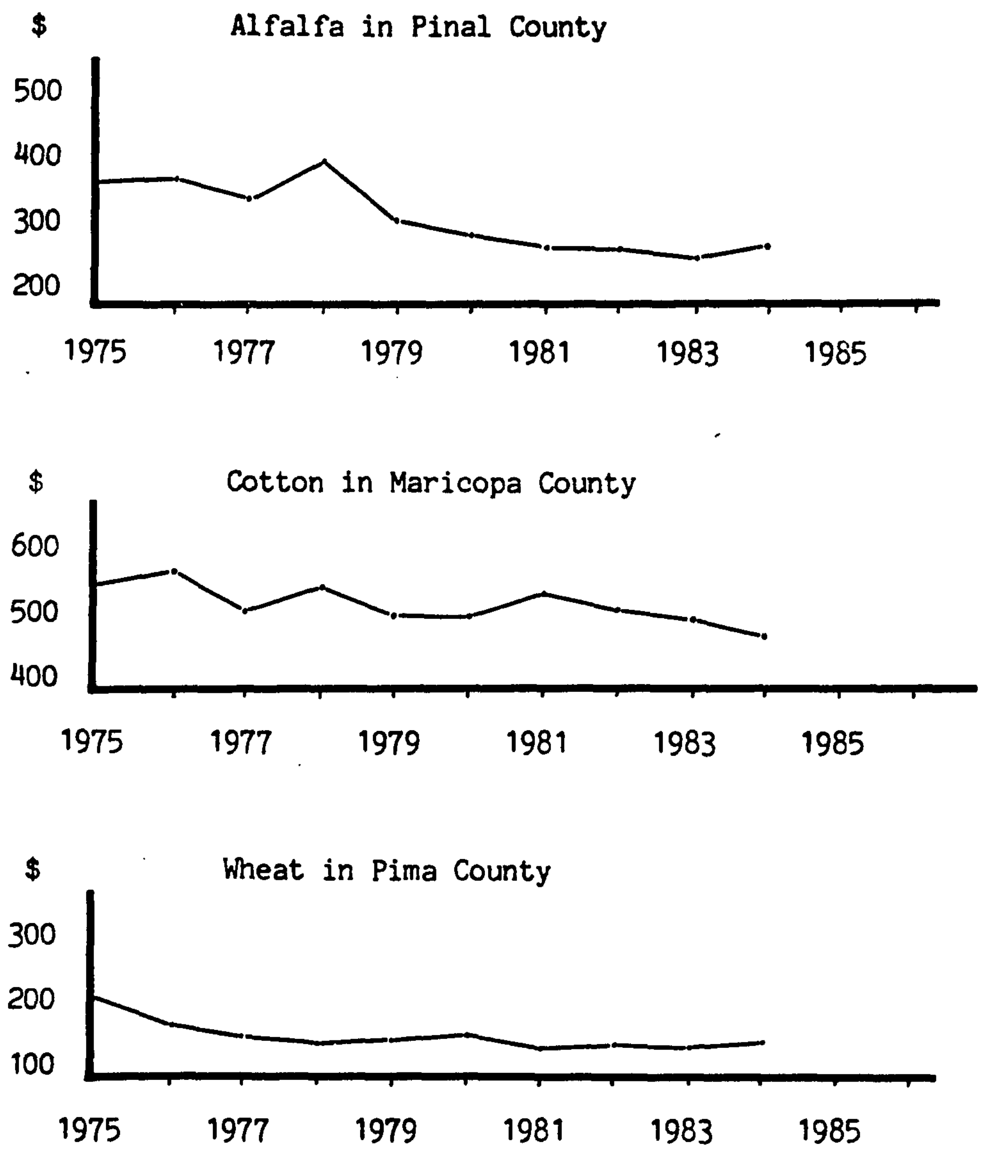


Figure 31. Real ($1984) Variable Production Costs Excluding the Cost of Raw Water on Selected Crops, 1975 - 1984.

Source : Hathorn, Scott. <u>Arizona Field Crop Budgets.</u> Cooperative Extension Service, University of Arizona. 1975 - 1984.

CHAPTER 5

LONG-TERM ANALYSIS OF THE CAP:
ASSUMPTIONS AND PROCEDURES

> The cost per acre foot of water produced by a steam plant pumping from less than 20 feet in 1904 was about the same as that paid by the Pinal County farmer pumping from 600 feet in 1964.
>
> Harold Stults, 1968
> Unpublished Doctoral Dissertation

This chapter introduces and describes a simple, long-term model for projecting the average total costs of irrigation water with and without the CAP. Assumptions and procedures are explained in detail.

Overview of the Model

Comparative projections of irrigation water costs are made under alternative project and no-project conditions for each of eight major irrigation districts planning to receive CAP water. Only a few factors are allowed to vary over time: the cost of electricity, the groundwater depth to lift, the volumes of groundwater production and CAP deliveries, and the fixed cost bases for groundwater and CAP water. In each year from 1984 to 2034 the weighted average total cost of water per acre foot with and without the project are compared. The resulting stream of negative and positive net benefits is discounted back to 1984 in order to determine the present value of the project per acre foot of water.

Description of the Study Area

Selection of Irrigation Districts for Study

Table 9 shows the 23 municipal, federal, and private non-Indian agricultural entities which were offered the opportunity to contract for CAP water. The status of the various allocees as of September, 1984, is as follows.

Nine entities have signed 50 year contracts for CAP service. These are the Central Arizona, Chandler Heights, Harquahala, Hohokam, Maricopa-Stanfield, New Magma, Queen Creek, San Tan, and Tonopah Irrigation Districts.

Four entities have received permission to delay making a decision on their contracts until early in 1985. These are the Avra Valley, Cortaro Marana, and McMicken Irrigation Districts, and the Farmers's Investment Company.

Four entities with existing surface water supplies have not yet been tendered contracts for their consideration. Uncertainties over the details of the negotiations for water exchange agreements between these entities and upstream water users have held up the formulation of an acceptable proposal for CAP delivery. These are the Salt River Project, the Maricopa Municipal and the Roosevelt Water Conservation Districts, and the San Carlos Irrigation District.

One entity, the Arcadia Water Company, will be contracting for CAP service as a municipal and industrial supplier instead of as an irrigation water supplier.

Table 9. Survey of Participating and NonParticipating Irrigation Districts in the CAP Service Area.

(as of September, 1984)

District	Allocation: Percent of Total for NonIndian Agriculture		
	1985	2005	2034
Entities Which Have Signed Contracts for Water Service			
Central Arizona I.D.	18.01	18.73	20.55
Chandler Heights I.D.	0.28	0.28	0.30
Harquahala I.D.	7.67	7.98	8.75
Hohokam I.D.	6.36	6.61	7.25
Maricopa-Stanfield I.D.	20.48	21.30	23.35
New Magma I.D.	4.34	4.52	4.96
Queen Creek I.D.	4.83	4.99	5.42
San Tan I.D.	0.77	0.80	0.86
Tonopah I.D. *	1.98	2.06	2.26
9 Irrigation Districts	64.72	67.27	73.70

A reduced acreage base for the project in the Tonopah Irrigation District will probably reduce Tonopah's allocations according to the following formula suggested by Franzoy, Corey & Associates (March, 1984):

(oldallocation) * ([3600/8150) + 0.20]

= new allocation

= 1.27, 1.32, and 1.45 percent for the years 1985, 2005, and 2034, respectively. These estimates are employed in the projections instead of the original allocations.

Table 9, continued.

	Allocation: Percent of Total for NonIndian Agriculture		
District	1985	2005	2034
Entities Which Have Requested More Time to Consider			
Avra Valley I.D.	3.69	3.84	4.21
Cortaro-Marana I.D.	2.14	2.05	1.99
FICO	1.39	1.44	1.58
McMicken I.D.	7.28	5.60	2.61
3 Irrigation Districts 1 Corporation	14.50	12.93	10.39
Entities Which Have Not Yet Been Tendered Contracts			
MCMWCD #1 (I.D.)	4.66	3.37	2.88
RWCD (I.D.)	5.98	5.92	4.84
Salt River Project	2.97	3.05	0.00
San Carlos I.D.	4.09	4.25	4.66
3 Irrigation Districts 1 Special Water Cons. District	17.70	16.59	12.38
Entities Which Have Changed Their Allocation to M&I			
Arcadia Water Co.	0.13	0.14	0.15
1 Water Company	0.13	0.14	0.15

Table 9, continued.

District	Allocation: Percent of Total for NonIndian Agriculture 1985	2005	2034
Entities Which Have Rejected the Opportunity to Contract			
La Croix	0.04	0.04	0.05
Marley, Kemper Jr.	0.04	0.04	0.05
Rood, W. E.	0.04	0.04	0.05
Roosevelt I.D.	2.61	2.72	2.98
U.S. Forest Service	0.22	0.23	0.25
3 Private Individuals 1 Irrigation District 1 Government Agency	2.95	3.07	3.38
Total	100.00	100.00	100.00

Sources:

Letter dated January 18, 1982, from Arizona Department of Water Resources to the Secretary of the Interior.

Morton, Larry. Personal Communication, September, 1984.

Five entities have declined the opportunity to contract for CAP water. These are La Croix, Kemper Marley Jr., W. E. Rood, the Roosevelt Irrigation District, and the U. S. Forest Service.

Of the nine entities which have already contracted for CAP water service, two small irrigation districts, Chandler Heights and San Tan, are distinct from the rest. Both are in the path of urban development from the city of Phoenix, and both specialize in the production of high-valued citrus crops. They are therefore not considered subject to the types of long term problems that generally face Central Arizona farming, and have been excluded from the analysis.

None of the four entities which have requested additional time to make their decisions have yet released a reasonably complete set of cost estimates on their proposed systems. The lack of data has caused them all to be excluded from the analysis.

Of the three entities who have not yet been tendered contracts, two were excluded from the analysis and one was included. The Salt River Project does not yet have full cost information on its CAP alternative. Furthermore, almost all of the remaining agricultural lands in the Salt River Project service area are expected to undergo urban development within the next few decades. The Marciopa Municipal Water Conservation District does not yet have a complete plan and cost estimate for its system. The San Carlos Irrigation District is the only entity among the three which has developed a comprehensive plan of development with detailed cost data.

Of the twenty-three entities originally offered CAP water allocations by the Bureau of Reclamation, eight were finally selected for inclusion in the long-term comparative cost analysis. These include seven of the nine irrigation districts which have already signed CAP water service subcontracts, plus the San Carlos Irrigation District. Collectively, their CAP allocations constitute more than two thirds of the total amount of project water designated for non-Indian agriculture.

Each of the irrigation districts under study may be classified under one of three distinct categories, according to their plan of development.

Type I Irrigation Districts

The first category includes those irrigation districts which currently have no district facilities for delivering water, and which will develop only specialized facilities for handling CAP water. All supplies currently come from private wells. Under the project the district will assume the responsibility of transporting and delivering all CAP water, while leaving groundwater pumping to the individual landowners. The irrigation districts in this category are Harquahala, Hohokam, Queen Creek, and Tonopah. Harquahala, Hohokam, and Tonopah have had their future systems planned and designed by the consulting engineers of Franzoy, Corey & Associates. Queen Creek has consulted with W. S. Gooking & Associates for its design.

Type II Irrigation Districts

The second category includes those irrigation districts which currently have no district facilities for delivering water, but which intend to develop general facilities for handling <u>all</u> irrigation water demands by their member lands. Private irrigation wells will be acquired by the district and integrated with the local CAP delivery system. Irrigation districts in this category are Central Arizona, Maricopa Stanfield, and New Magma. All three districts have had their future systems planned and designed by Bookman-Edmonston Engineering, Inc.

San Carlos Irrigation District

The third category includes only the San Carlos Irrigation District, which is part of the federally created and managed San Carlos Project. The district controls all water rights within its service area, and deliveries water to the landowners conjunctively from groundwater pumps and from its facilities on the Gila River. Private groundwater is pumped by some of the farmers from lands adjacent to the district, which is then tranported to their lands in San Carlos.

The district will use CAP water conjunctively with its existing groundwater and surface water supplies, while leaving the private pumping facilities unaffected. Although relatively few additional canals will have to be constructed in order to allow the present distribution network to handle CAP water, the system will have to be cement-lined in order to meet Bureau of Reclamation project specifications. The consulting engineers for the district are Franzoy, Corey & Associates.

Supply and Demand for Irrigation Water

As the historical analysis in Chapter 4 revealed, rising water costs in Arizona have not lead to diminished levels of use, because the demand for water has generally remained sufficiently high. Previous studies (Kelso, Martin, and Mack, 1973) proposed that rising water costs in excess of demand would sharply reduce water use among the marginal user classes in the future. However, it is assumed in this analysis that the historical pattern will continue, that is, that the overall level of demand will always keep pace with rising supply costs.

It is also assumed that the state water conservation laws will maintain a binding constraint on supply, but that this constraint will remain constant over time. Since it is the explicit policy of Arizona water planners to systematically tighten the regulations on water use in an attempt to eliminate groundwater overdraft, this assumption conservatively overestimates the likely level of groundwater demand and groundwater overdraft in the future.

The two simplifying assumptions are illustrated in Figure 32. Consider three years, 1, 2, and 3, which are in chronological sequence. In Year 1, the state-imposed water conservation requirements restrict the level of water use to OQ units. By Year 2, both the supply (marginal cost) and demand for water have shifted, but demand has kept apace with supply and it is only the maintenance of the conservation requirement that constrains water use to OQ units again. By Year 3, demand still exceeds the cost of supply and the supply constraint still operates to maintain the use of water at no more that OQ units.

The effect of this simple view of the future progression of the supply, demand, and level of use of irrigation water over time is that it exagerates the future strain on groundwater reserves and thereby puts the CAP "rescue" program in the best possible light.

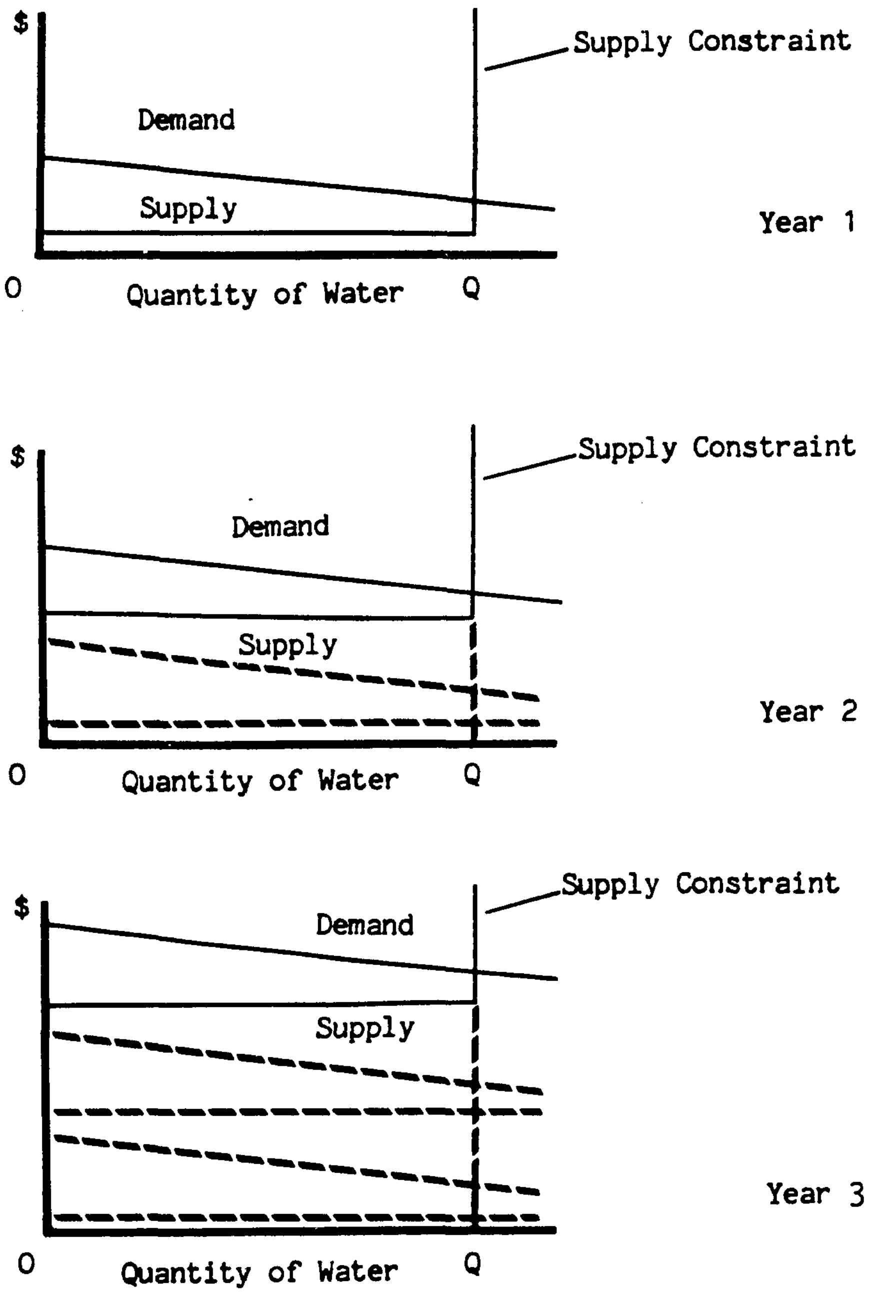


Figure 32. Hypothetical Progression of Supply, Demand, and the Level of Use of Irrigation Water Over Time.

CAP Water Deliveries

Colorado River Flows

The Bureau of Reclamation has created a series of Colorado River flow simulation models to project the amounts of water which will be available for the CAP in future years. The results of the New Waddell Sizing Study, Option 2 (Max Winter), developed in March, 1982, is used in the projection described in this chapter. New Waddell uses modified historic hydrologic data on Colorado River flows, from the years 1906 to 1981, inclusive, arranged into 15 ordered traces of several decades each. The 15 sequences are 58 years in length, projecting volumes of Colorado River water available for the CAP from 1983 to 2040.

Sequence 1 assumes that the year 1983 is similar to historic year 1906, 1984 similar to 1907, and so on. Each of the subsequent traces 2 through 15 is the result of a 5-year displacement in the positioning of the historic record. In Sequence 2, for example, 1983 is assumed to have the same flow as occured in 1911, 1984 the same as 1912, etc. Whenever the entire set of historic years is run through to the end, the next future year begins with the historical 1906 record again. In Sequence 8, for example, the year 2023 is assumed to experience the same level of flow as occured in 1981. The following year, 2024, then follows the 1906 record, 2025 is the same as 1907, etc.

If these sequences are assumed to represent a random distribution of possible levels of Colorado River flows, then each of the 15 "observations" has an equal likelihood of ocurring. The "expected" Colorado River flow level is then determined as the arithmetic mean of the set. Figure 33 shows the average projected volumes of water available for delivery through the CAP system over the period 1989 to 2034. The declining trend in available water is the result of the expectation by the Bureau that other water users outside of Arizona with higher priority rights to the Colorado River than the CAP will develop the rest of their claims.

Diminishing Colorado River water availability will affect some CAP users more than others, as shown in Appendix Table E1, and in Figure 34. Municipal and industrial (M&I) users will increase their share of CAP water over time, while the apportionment to Indians will diminish gradually. The quantity of CAP water reserved for nonIndian irrigated agriculture is expected to fall dramatically in the first 20 years of the project and then continue to decline but at a reduced rate thereafter. By the end of the project planning horizon, nonIndian agriculture can expect on the average to draw as little as 20 percent of the volume of CAP water that they could at the beginning of the project. A much discussed problem has been if and how additional water sources could be developed to supplement the overextended resources of the Colorado River.

CAP Allocations and Deliveries to Individual Irrigation Districts

Agricultural claimants to CAP water will receive their allocations as a percentage of the volume of CAP water available in any given year for irrigation. Appendix Table E2 shows the breakdown of the proportional allocations among the various agricultural entities that were originally offered the opportunity to contract for CAP deliveries,

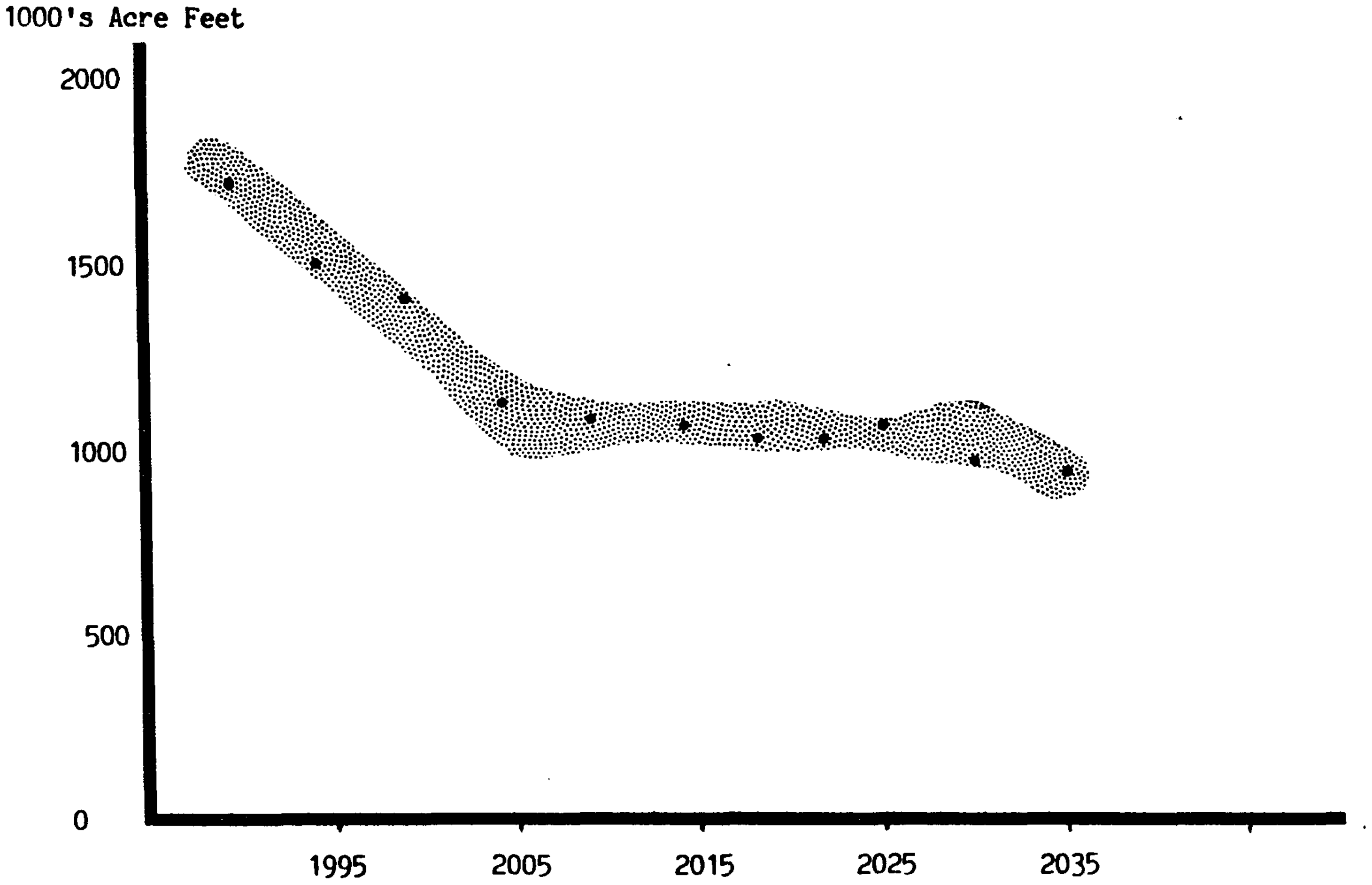


Figure 33. Projected Supplies of Colorado River Water Available for Delivery via the CAP, 1989 - 2034.

Source: Bureau of Reclamation. Central Arizona Project, New Waddell Sizing Studies Option 2 (Max Winter), March 22, 1982.

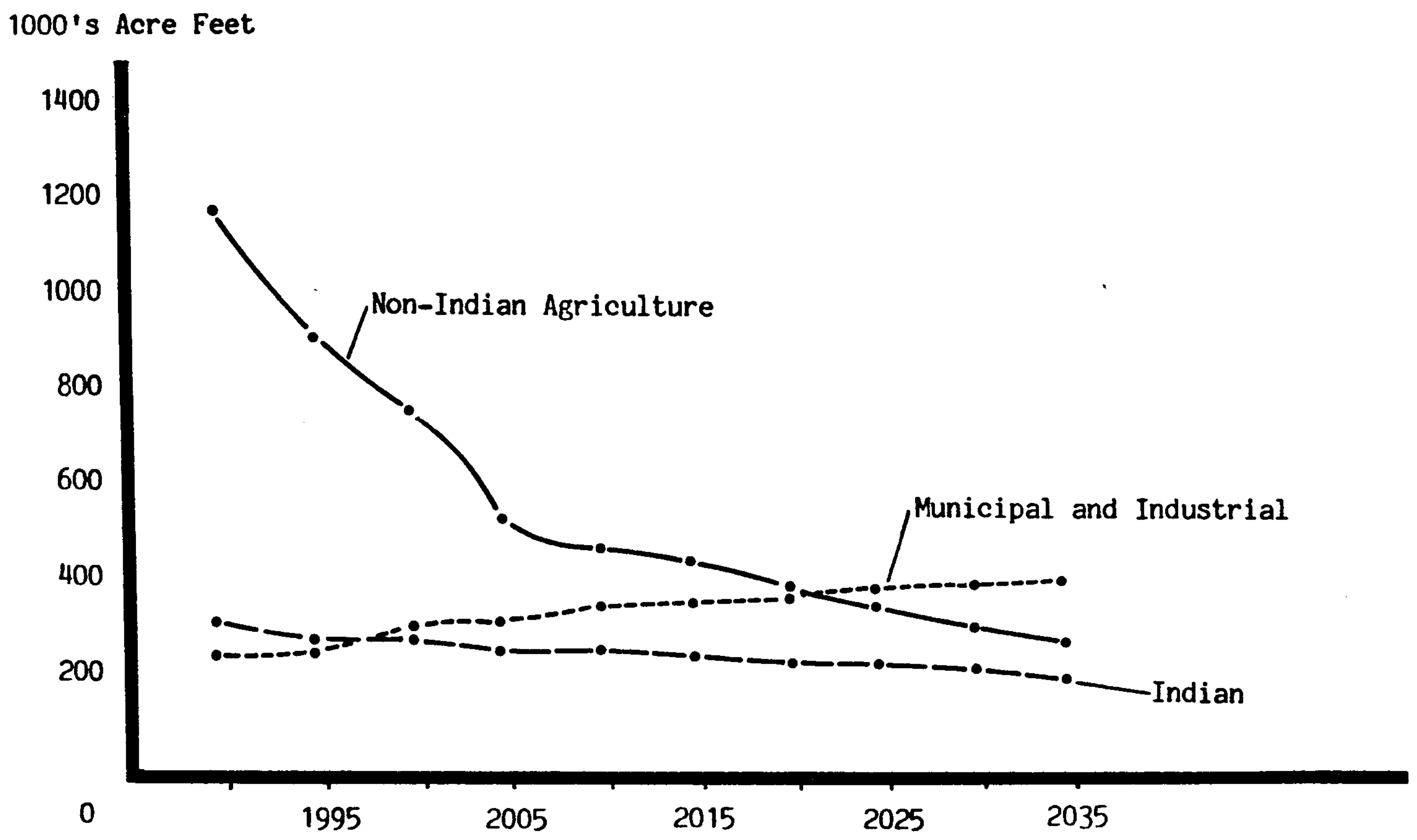


Figure 34. Projected Supplies of Colorado River Water Available for Urban, Indian, and Agricultural Users in Arizona, 1989 - 2034.

Source: Bureau of Reclamation. Central Arizona Project, New Waddell Sizing Studies Option 2 (Max Winter), March 22, 1982.

as proposed by the Arizona Department of Water Resources in 1982. The following year, the federal government tenatively approved the first round of allocations only (Federal Register, March 1983). For the purposes of this study study, it is assumed that the original allocation figures proposed by the state are reasonable approximations of what they will actually be. Proportions for the years in between 1985 and 2005, and between 2005 and 2034, are found by linearly interpolating from the known values. The only change made in the allocations is that suggested by Franzoy, Corey, & Associates (March 1984) for the Tonopah Irrigation District, which recently excluded substantial acreages from its planned service area.

Table 10 shows the projected volumes of CAP water which will be delivered to each of the eight irrigation districts in the study area over the sample project years 1989, 2009, and 2034. In each year the amount of CAP committed to each district is determined as the product of the total quantity of CAP water available to agriculture and the irrigation district's allocation precentage.

The volume of CAP water actually reaching the individual farm headgates will be somewhat less than the total quantity delivered to the district turnout, due to system losses. Losses between the turnout and the farm headgate are generally attributable to canal water seepage, evaporation, and human and mechanical failure. Generally, delivery efficiency is assumed to be either 85 or 90 percent of the district's CAP allocation. The particular efficiency estimate depends upon the size of the district's local distribution system and the distance that

Table 10. Projected Deliveries of CAP Water to Selected Irrigation Districts in the Years 1989, 2005, and 2034.

Irrigation District	District Allocation (percent)	District Allocation (acre feet)
1989 Agricultural Allocation: 1,146,100 acre feet		
Central Arizona	18.15	208,063
Harquahala	7.73	88,616
Hohokam	6.41	73,465
Maricopa Stanfield	20.64	236,601
New Magma	4.38	50,153
Queen Creek	4.86	55,723
San Carlos	4.12	47,242
Tonopah	1.28	14,670
2009 Agricultural Allocation: 470,100 acre feet		
Central Arizona	18.98	89,230
Harquahala	8.09	38,013
Hohokam	6.70	31,489
Maricopa Stanfield	21.58	101,461
New Magma	4.58	21,534
Queen Creek	5.05	23,737
San Carlos	4.31	20,245
Tonopah	1.34	6,290

Table 10, continued.

Irrigation District	District Allocation (percent)	District Allocation (acre feet)
2034 Agricultural Allocation: 263,900 acre feet		
Central Arizona	20.55	54,231
Harquahala	8.75	23,091
Hohokam	7.25	19,133
Maricopa Stanfield	23.35	61,621
New Magma	4.96	13,089
Queen Creek	5.42	14,303
San Carlos	4.66	12,298
Tonopah	1.45	3,827

Sources:

Arizona Department of Water Resources, letter to the Secretary of the Interior of January 18, 1982.

Bureau of Reclamation, New Waddell Sizing Studies Option 2 (Max Winter), March 22, 1982.

the water must be transported to it from the district turnout at the CAP's main aquaduct.

CAP Delivery Security

As decreed by the Secretary of the Interior (Federal Register, March 1983), irrigated nonIndian agriculture is the lowest priority user class for CAP water, only having claim to whatever supplies are left over once all other allocations to higher user classes are fulfilled. Water shortages will be managed by first using up all the supplies that would normally have gone to agriculture. Agricultural water supplies must be completely exhausted before turning to Indian and M&I users, who in the event of an extreme shortage would have to resort to reducing their allocations on a pro rata basis.

Large historic variations in Colorado River flows and the low priority of nonIndian agricultural water claims combine to make the CAP an extremely unreliable water source for Central Arizona farmers. Throughout the life of the project the probability of the occurence of severe shortage conditions which could reduce agriculture's share of CAP water to zero steadily increases. Table 11 shows the average delivery volumes, the first year of zero deliveries, and the total number of zero delivery years of CAP water for agriculture for each of the 15 sequences plus a composite summary.

In four of the sequences it is expected that agriculture will actually get no CAP water at all for more than half of the years between 1989 and 2034. In four more sequences the number of zero allocation years totals more than a third of the years over the planning horizon.

Table 11. Expected Volume of CAP Deliveries and Zero Delivery Years to NonIndian Agriculture, 1989 - 2034.

Sequence	Average Volume of Deliveries (1000's af)	First Year of Zero Deliveries	Number of Years of Zero Deliveries (out of 46)
1	644	2015	17
2	508	2010	22
3	384	2006	25
4	292	2001	30
5	224	2001	30
6	254	1997	26
7	431	2004	21
8	523	2001	19
9	633	1998	15
10	672	1994	12
11	821	1996	5
12	938	2034	1
13	939	2029	4
14	863	2026	7
15	747	2021	11
Average	592	2009	16

Source:

Bureau of Reclamation. Central Arizona Project, New Waddell Sizing Studies Option 2 (Max Winter), March 22, 1982.

Only five of the fifteen sequences project the occurrence of zero allocation years less than 25 percent of the time. On the average, Central Arizona farmers may expect to experience a zero allocation year by 2009 and endure another 15 years of zero allocations before the year 2035.

Groundwater Pumping

Groundwater as a Residual Supply

Groundwater pumping is expected to serve as a residual supply of water after the CAP. Assuming that total water consumption remains constant, declining CAP deliveries will be matched with rising levels of groundwater pumping. Figure 35 shows in idealized form the relationships between CAP deliveries, groundwater pumping, and total water consumption over time. Groundwater facilities must also function as a complete backup system in the years that the CAP fails to deliver any water at all.

Investment in Conjunctive Water Delivery Facilities

Bredehoeft and Young (1983), in a study of the conjunctive use of groundwater and surface water, found that groundwater was generally more expensive but also more reliable than surface water supplies. The more of the total water demand that can be supplied from groundwater pumping facilities, the less variance in income a farmer will tend to experience as the risk of a short-term water shortage is reduced. At first the objectives of reducing income variance and increases the expected level of income might be complementary goals and there is no

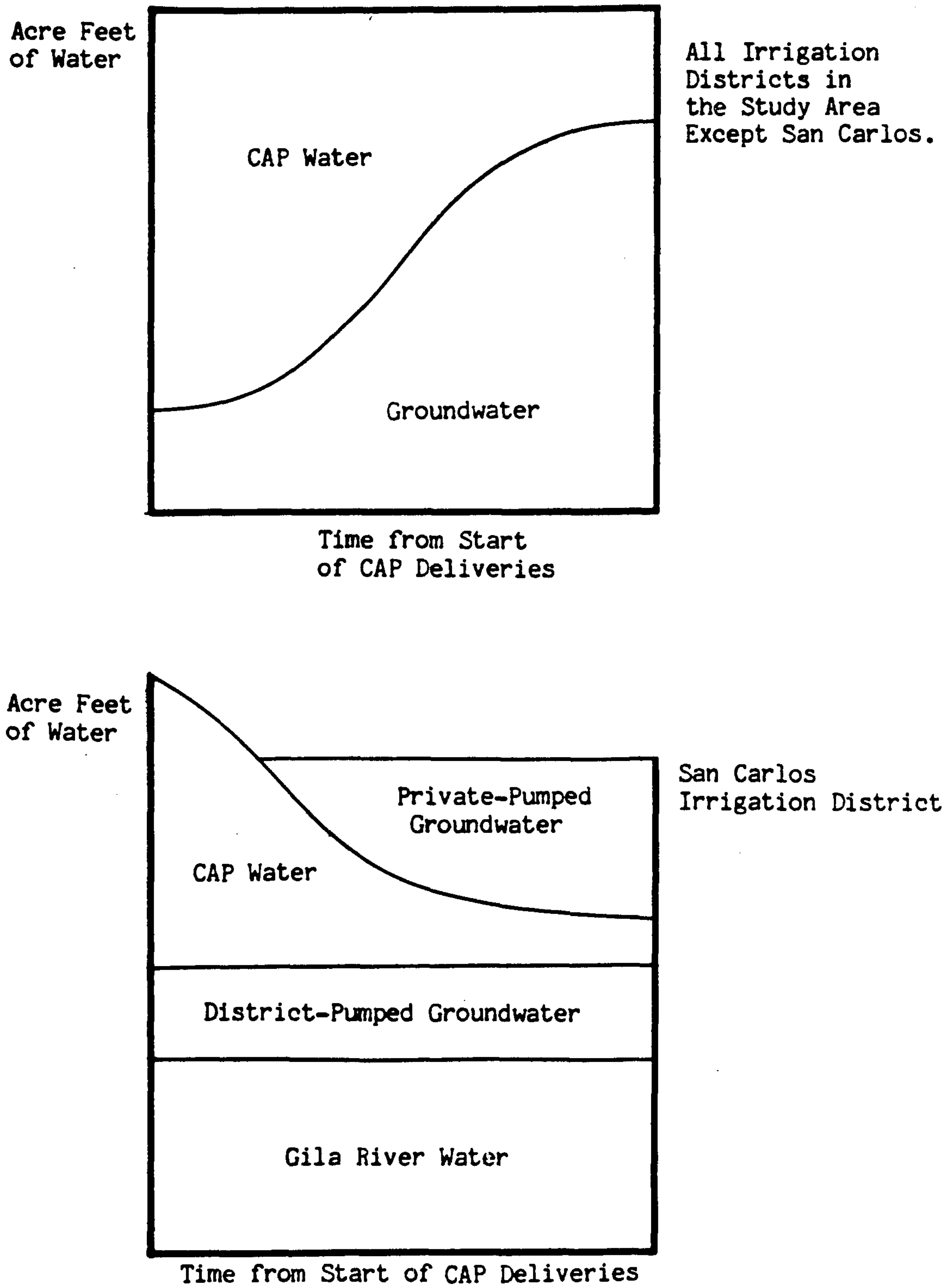


Figure 35. Idealized Representation of CAP Water Deliveries Over Time, and Water Production from Existing Sources of Supply.

conflict in investing in additional groundwater pumping facilities. But as well capacity begins to become highly redundant with respect to the surface water delivery facilities, the two objectives become antagonistic as reductions in income variance come at the expense of reduced income expectations.

Bredehoeft and Young noted that farmers generally tend to be highly risk averse, and observed evidence of that behavior by the manner in which they made investment decisions with respect to their conjunctive groundwater and surface water facilities. Farmers appear to invest in groundwater facilities to a much greater extent than that which would maximize their expected income. That is, they implicitly pay a substantial "risk premium" by building more well capacity than they theoretically need in order to reduce their income variance.

Consider the hypothetical relationships described in Figure 36 between the level of investment in groundwater pumping facilities and the levels of expected income and income variance. Farmers would maximize the expected value of their incomes with respect to irrigation water at the level b if they invested in pumping facilities up to the level x. But at this maximum level of expected income, income variance may be at an unacceptably high level d. Then farmers may choose to invest in additional well capacity up to level y in order to reduce their income variance down to c. In doing so, they reduce their expected level of income from b to a, and the amount ba constitutes their water shortage risk premium.

The model in this study employs the conservative assumption that so long as farmers face a substantial risk of not getting their expected

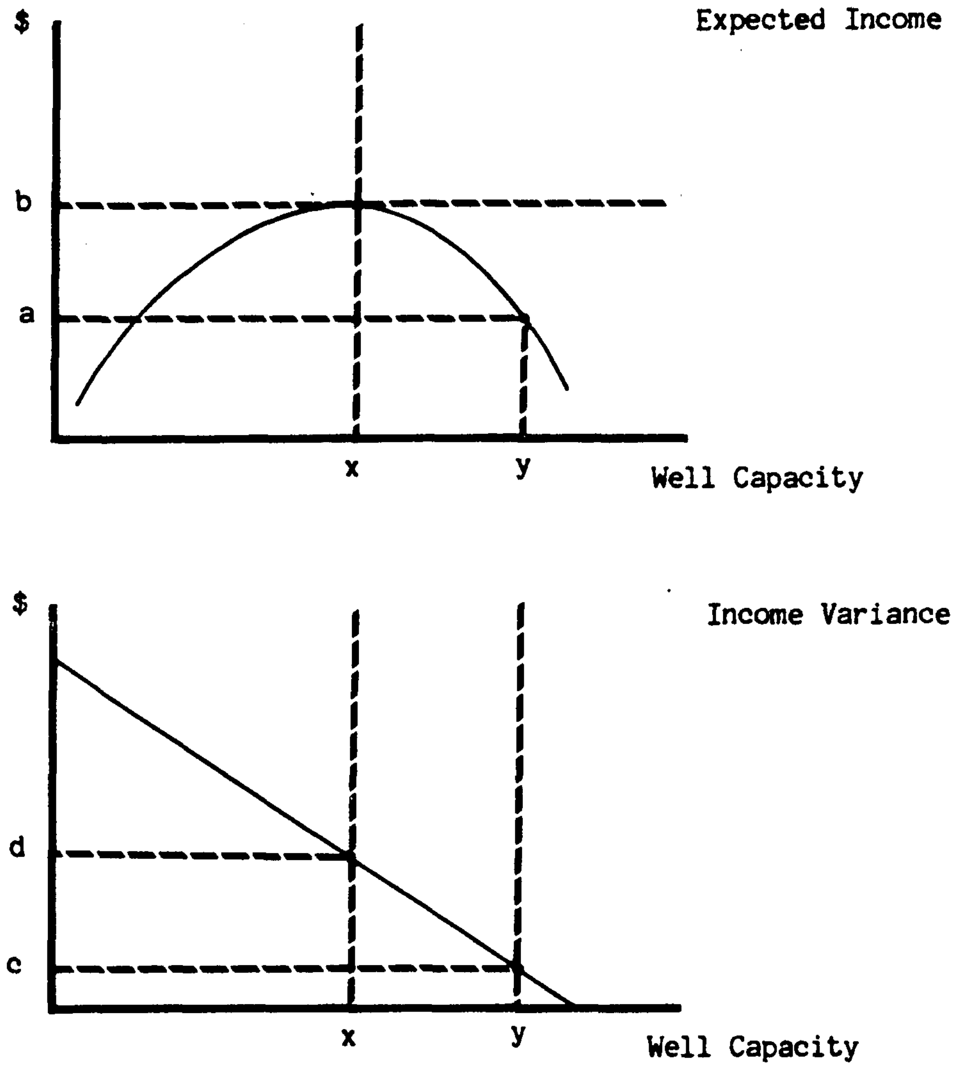


Figure 36. Hypothetical Relationships Between the Level of Investment in Groundwater Pumping Capacity in a Conjunctive Surface/Ground Water Supply System and Expected Farm Income and Income Variance.

Source: Bredehoeft and Young, 1983.

allocations of CAP water, they will maintain their entire groundwater pumping facility intact. Since the CAP is a substitute and not a supplemental source of water, the more CAP capacity is used the less groundwater capacity is used at the same time, and vice versa. The more water that is delivered from one supply source, the less unused capacity is wasted in that system. Meanwhile the alternative supply system is being underused and may be operating less efficiently and at a higher average unit fixed cost.

Since private groundwater pumps are already on the farm and are thus "below" the farm headgate, the distance over which groundwater must be tranported once it is pumped out of the ground is assumed to be zero. The delivery efficiency of groundwater is therefore held constant at 100 percent.

Water Supplies for San Carlos

The water delivery situation San Carlos Irrigation District differs in four principle ways from that of each of the other seven districts in the study area. The first difference is that San Carlos has an existing surface water supply, the Gila River. As it is delivered entirely through gravity flow, the cost of this source is by far the cheapest alternative. The marginal cost to the district of supplying additional quantities of Gila River water, should they become available, is assumed to be zero.

The second difference is that groundwater is supplied from two sources, district-operated pumps within the district service area, and private pumps located on adjacent lands.

The third difference is that San Carlos is not strictly bound to reduce groundwater pumping by an amount equal to the volume of CAP water delivered (Federal Register, March 1983). Water consumption may therefore rise somewhat with the advent of the CAP.

The fourth difference is that the canals in the current district distribution system are unlined and therefore cause considerable efficiency losses through seepage. The historic average delivery efficiency is about 68 percent (San Carlos Project annual report, 1981). Private groundwater pumps are assumed to be close but not on district lands; an arbitrary delivery efficiency of 90 percent is assigned to these facilities. The construction of the CAP system will require lining of the district canals, increasing their delivery efficiency to about 85 percent (Franzoy, Corey, & Associates, 1984). Deliveries of district groundwater and Gila River water to member lands will increase by 85 percent divided by 68 percent or 131 percent, without changing the overall level of production at all. The relative delivery efficiency of private groundwater facilities should remain unaffected.

Estimates show that the sum of CAP deliveries in the early years of the project, plus the new levels of district groundwater and Gila River deliveries, will slightly exceed the current average total water consumption in the district. Assuming that the district has no incentive to reduce production, it is projected that the additional water will be used on expanding marginal cropping activities.

The argument has been advanced on numerous occasions in the past that overall water use in the San Carlos district will increase permanently with the addition of CAP water. However, this study rejects that theory on the grounds that if water demand in the district were sufficiently high to warrent a higher rate of consumption, then additional low-cost water supplies could have been developed in the past. The district could have drilled more wells or lined its canals to reduce delivery losses, and individual farmers could have either pumped water from their own private wells or else bought water from someone else with private pumping facilities. It is assumed that, with the exception of the first few project years, the total level of water use in San Carlos will remain unchanged. Private groundwater production, traditionally the residual source of supply, will temporarily fall to zero. As CAP deliveries begin to decline in subsequent years and public supplies are no longer adequate to meet all demands for water, private groundwater production for the district will resume. The idealized form of the relationships between CAP deliveries, Gila River deliveries, district groundwater pumping, private groundwater pumping, and total water consumption over time are illustrated in Figure 35.

Groundwater Dynamics

Groundwater Pumping, Overdraft, and Decline

Two major simplifying hydrologic assumptions are made in the model. The first is that 30 percent of all the water used for irrigation from whatever source eventually percolates down to the aquifer. In areas where groundwater is the sole source of water supply, therefore, the rate of overdraft is estimated as 70 percent of withdrawals.

Since (except in the San Carlos district) the use of CAP water will not increase the overall level of water use by farmers, it is assumed that the recharge rate will remain constant regardless of whether the project comes on line or not. The only factor which will change is the rate at which groundwater is pumped. All others things equal, a reduction in groundwater pumping will therefore lead to a reduction in the rate of overdraft. The second major hydrologic assumption is that the rate of groundwater decline is linearly proportional to the rate of overdraft. Cutting the rate of overdraft in half will also halve the rate of groundwater decline, and so on.

CAP Deliveries and Their Effect on Rates of Groundwater Overdraft and Decline

All the irrigation districts included in the study, with the exception of San Carlos, currently rely totally on groundwater pumping to meet their demands for irrigation water. Suppose one of these districts pumps 54,000 acre feet of groundwater per year. Of this quantity, 30 percent is assumed to represent all natural recharge, plus that portion of the pumped water which recycles back to the aquifer in the course of its use (as incidental recharge). The remaining 70 percent, or the portion of the water "consumed" by the crops, never returns to the aquifer and constitutes the groundwater overdraft. The total annual overdraft is therefore estimated to equal 0.70 * 54,000 = 37,800 acre feet.

If the current rate of groundwater decline is 4 feet per year, then the ratio of groundwater overdraft to groundwater decline is 37,800 / 4 = 9,450 acre feet to 1 foot. That is, 9,450 feet of groundwater drawn from the aquifer in excess of hydrologic safe yield will cause a 1 foot decline in the water table. Conversely, for each 9,450 acre foot reduction in groundwater pumping, the rate of groundwater decline will slow by 1 foot. As water delivered via the CAP will replace an equal volume of groundwater, the effect of the importation of CAP water will be to slow the rate of overdraft and groundwater decline.

The larger the assumed rate of groundwater overdraft, the less effect the CAP would have in slowing the rate of groundwater decline. It may be argued that the rates of groundwater recharge in many areas of Central Arizona are far less than 30 percent. Suppose it were only 10 percent. Then the annual rate of overdraft would be 48,600 acre feet instead of 37,800 acre feet, and the ratio of overdraft to decline would be 12,150 acre feet per foot instead of only 9,450 acre feet per foot. A considerably greater amount of CAP water would therefore be required in order to achieve a reduction in the rate of groundwater decline.

The faster the rate of groundwater decline relative to the rate of groundwater overdraft, the more effective the CAP would be in slowing it down. Certain areas in Central Arizona may experience faster rates of decline than those suggested in the model. If the rate of groundwater decline were six feet per year instead of only four, as in the example cited above, then a groundwater overdraft of 37,800 acre feet per year would result in an overdraft-to-decline ratio of only 6,300 acre feet to 1 foot instead of 9,450 to 1. Clearly, under these circumstances the CAP would appear to be far more effective in controlling the rate of groundwater decline.

Popular opinion generally favors the CAP because of pessimistic reports about <u>both</u> the high rate of groundwater overdraft and also the high rate of groundwater decline. But it is the relationship between the two, and not their respective absolute values, that will ultimately determine whether the CAP can be an effective tool for controlling the groundwater "problem." All other things being equal, revising the projections of groundwater decline upwards will tend to favor the CAP more, while increasing the estimated rates of groundwater overdraft will only make the CAP appear worse. The model probably tends to underestimate the rate of groundwater overdraft while overestimating the rate of groundwater decline. The baseline results are therefore probably somewhat biased in favor of the CAP because they will tend to exaggerate its potential effects.

Special Assumptions for the San Carlos Irrigation District

An examination of well records in the San Carlos Irrigation District suggests that there have been no significant changes in most pumping depths to lift over at least the past 10 or 15 years (San Carlos Project, annual report, 1981). This may be an indication that groundwater pumping activity is more or less in long term equilibrium with the rate of natural and induced recharge. Groundwater pumping lifts within the San Carlos Irrigation District are projected to remain static at all times, under all possible conditions. This is not unreasonable to imagine, so long as the plausible assumption is made that the district's long term average rate of groundwater withdrawals and the long-term average volume of water used remain constant.

Outside of the district service area, private groundwater pumping for transportation to San Carlos lands will rise and fall in accord with the level of district water production. Under normal circumstances, the changes in groundwater withdrawals would affect the rate of groundwater overdraft and thereby the rate of groundwater decline. In this case, however, no such assumption can be made. Since the private wells used to deliver water to San Carlos district lands are scattered around the perimeter of the district, their collective hydrologic impact is probably too diluted to have a significant impact anywhere. As a result, it is conservatively assumed that the rate of groundwater overdraft and decline outside of the San Carlos lands will remain the same regardless of the level of pumping activity.

Water Costs

CAP Costs

The fixed costs of the CAP are those costs associated with the operation, maintenance, and debt service on the local distribution systems. Operation, maintenance, and repair (OM&R) costs are reported by the consultants as real values, which in this study are assumed to increase at the rate of inflation. The total OM&R cost therefore appears constant over the length of the planning horizon. Acreage assessments (charges imposed on individual farmers to pay for project costs in the years before water service actually begins), operational contingency fund contributions, and debt service are all reported by the consultants as nominal monetary amounts which must be deflated to their real dollar value in each year.

The consultants' data were used in their original form as much as possible. Occasionally, OM&R costs had to be revised to reflect equivalent 1984 prices for the given figures, which were at times as much as three years old. Elsewhere, preservice assessments of approximately ten dollars per acre were added to the district's fixed cost total in the few cases where no figure was quoted.

Over time, the total fixed cost base for the CAP will decline as the capital debt is repaid, and only the obligations of operation, maintenance, and repair will be left. No cost estimates for capital depreciation have been made. This produces a bias favoring the CAP over groundwater, since well capital depreciation is accounted for and can be a significant cost component of pumping groundwater.

Determination of the average fixed CAP costs were handled differently depending upon the type of irrigation district. The simplist case was for the Type I districts, which will develop specialized facilities for the delivery of CAP water. Each year the total fixed CAP costs was divided by the number of acre feet of CAP water delivered.

The type II districts present a special problem because they are planning to deliver their CAP water conjunctively with groundwater through a single, centralized distribution system. The consultants for these districts did not attempt to separate the costs attributable to the CAP and to groundwater, making it difficult to compare the relative costs of water from each source.

Although offering no estimates to back up their claims, the consultants suggested that the future costs of groundwater would be lower in the district system even before the hydrologic benefits of the CAP were considered. With all the wells under central control, they claimed that the districts could concentrate on extracting water from only their best pumps, thus producing groundwater more efficiently than before. No attempt is made in this study to model a change in groundwater pumping efficiency, however. No meaningful data on this potential savings are available, and in any case high administrative costs and significant system losses, especially through evaporation and seepage, could more than overcome any gains so made.

It is conservatively assumed that the cost and availability of groundwater is unaffected by the development of the district system. All capital and operating contingency costs, and all pre-service acreage assessments, are thus attributed to CAP water only. System operation, maintenance, and repair costs in the Type II districts are reduced by the amount corresponding to running the irrigation wells.

"Well credits," or the sum credited to individuals in compensation for the transfer of ownership and control of their wells to the district, are ignored altogether. Since the irrigation districts function as user cooperatives, it is assumed that the wells are worth exactly as much whether in private or public possession. The well credit system is simply the means by which the members reimburse themselves for giving up some of their capital wealth to the district.

As a result employing the assumptions mentioned above, groundwater costs in Type II districts are treated "as if" the pumps were still operated by private individuals. Analytically, Type II districts therefore lose their distinctiveness and may be modeled in exactly the same manner as the Type I districts.

The San Carlos Irrigation District has always handled all sources of water within its service area. The CAP will make the costs of both of the existing groundwater and surface water sources less expensive by improving their delivery efficiency. All current and projected fixed costs in the system are therefore spread equally over CAP, Gila River, and district groundwater supplies. Only the private groundwater source does not include system costs in its unit totals.

The $57 per acre foot variable cost of CAP water is composed of three cost components. In 1984 these are estimated as $46.20 for the energy cost of pumping, $8.80 for operation, maintenance, and repair, and $2 for capital repayment for the construction of the main canal (Gookin and Associates, 1984). This cost is adjusted up to either $67.06 or $63.33, depending upon whether the particular district being examined will carry the water with a delivery efficiency of 85 percent or 90 percent. As established by the Bureau of Reclamation, the unit variable cost for CAP water is constant regardless of the quantity delivered.

The real average variable costs and the real marginal costs of CAP water are assumed to remain constant over time. The capital repayment charge on CAP water is not expected to change in the foreseeable future, although in theory there is nothing to prevent the federal government from raising it. Operation, maintenance, and repair costs are assumed to increase at the rate of inflation. Making the rather strong assumption that both the energy consumed to lift Colorado River water and the real unit cost of energy will not change over time, the pumping energy cost component will also increase at just the rate of inflation.

A hypothetical representation of the average total cost curve for CAP water is given in Figure 37. Given some arbitrary fixed cost base and a constant delivery quantity OQ, the average fixed cost per acre foot of CAP water is equal to OA. The marginal unit cost is OB, and the average total cost is equal to the sum of OA and OB, or OC.

Electricity Costs for Groundwater Pumping

Unit energy costs are generally the single most important factor determining the cost of groundwater in Central Arizona. Electrical power is the predominant source of energy in the irrigation districts under study, and can be obtained from three major types of sources. These are federally subsidized "preferential" hydropower, regional water and power projects, and private utility companies.

The primary suppliers of federal preferential hydropower in the study area are the Arizona Power Authority, which is the state contractor for Hoover Dam power, and the Colorado River Storage Project, which operates the Parker/Davis complex. The regional water and power projects are the Salt River Project in Maricopa County and the San Carlos Project in Pinal County, both of which began by generating energy from surface water flows but have since diversified and expanded their sources to fossil fuels and the Palo Verde nuclear generating station. These entities also contract for federal hydropower. The major private utility company in the study area is Arizona Public Service.

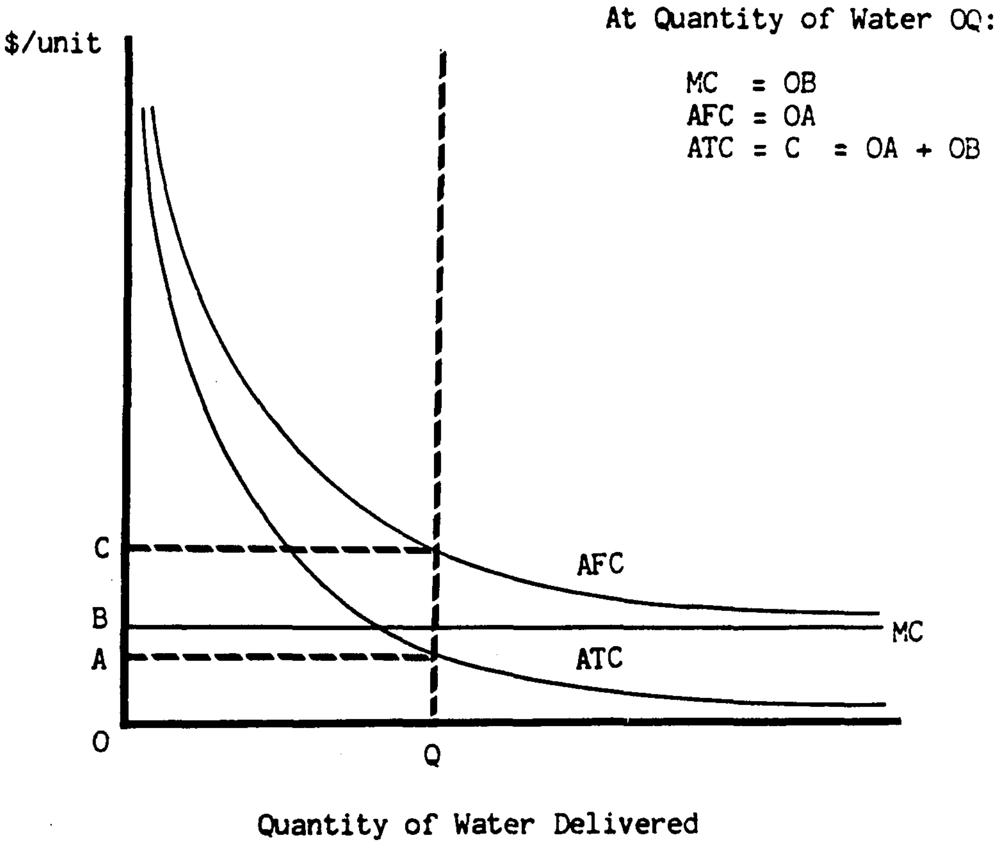


Figure 37. Hypothetical Marginal, Average Fixed, and Average Total Cost Curves for CAP Water

Rural Electrical Districts (ED's) act as energy distributors between the primary power suppliers and the irrigation districts. Most of the ED's hold contracts with the federal government to receive specified amount of inexpensive federal hydropower. Usually the contracted amount is not sufficient to meet the demands of the district's service area. In such cases, power from auxiliary sources such as private utility companies is used to supplement the supply.

All preferential contracts with the federal government come up for renewal in 1988. At that time the allocation of preferential rights may change, due to litigation concerning the apportionment of federal power among the lower Colorado basin states and pressures to alter the federal power marketing criteria. These changes could affect both the amounts of power delivered to the irrigation districts and the rate structure.

Table 12 outlines the primary power sources and the distributors for the various irrigation districts in the study area. The districts using predominantly federal hydropower are currently paying the lowest electricity rates, between 23 and 25 mils per kilowatt hour. The cost electricity is projected to increase at the rate of 1.0 percent per year over the rate of inflation. With the renewal of federal power contracts in 1988, its is projected that the real cost of electricity will jump to 35 mils per kilowatt hour before continuing its real rate of increase of 1 percent per year.

Districts using a mixture of federal hydropower and commercial power pay the next highest rates for electricity, between about 35 and 36.5 mils per kilowatt hour. It is projected that the real annual rate

Table 12. Sources of Electrical Power for Groundwater Pumping.

Irrigation District	Electric Power Distributors	Primary Electric Power Producers
Districts Using Primarily Hydropower		
Central Arizona	ED 2, ED 4, ED 5	APA, SRP
Hohokam	ED 2	APA, SRP
New Magma	ED 6	APA, CRSP
San Carlos	ED 2, SCP	APA, SCP, SRP
Districts Using a Mixture of Hydropower and Commercial Power		
Maricopa Stanfield	ED 1, ED 3	APA, SRP, CRSP, APS
Queen Creek	ED 6, QCED	APA, SRP, CRSP, APS
Districts Using Primarily Commercial Power		
Harquahala	---------	APS
Tonopah	---------	APS

ED : Electrical District, Pinal County
SRP : Salt River Project
APS : Arizona Public Service Company
APA : Arizona Power Authority (Hoover Dam)
CRSP : Colorado River Storage Project (Parker/Davis Dams)
SCP : San Carlos Project
QCED : Queen Creek Electrical District

Sources:

Bookman-Edmonston Engineering.
Franzoy, Corey, & Associates.
O'Neil, Patricia. Personal Communications, 1983.
Personal Communications with ID's and ED's, 1984.
W. S. Gookin & Associates.

of increase over the project planning horizon will be 1.5 percent per year. Districts using primarily commercial power sources pay the highest electricity rates and have endured some of the most rapidly increasing costs in recent years. It is projected that the real annual rate of increase over the project planning horizon will be 2.0 percent per year.

Groundwater Pumping Costs

Unless a farmer opts to abandon an irrigation well, the total fixed costs of its operation should continue at a constant real level for as long as the well is in use and so long as no investments are made in additional pumping capacity. The average annual fixed cost of a well is a function of the volume of water pumped, in exactly the same way as the average fixed cost of CAP water in any given year is a function of the number of acre feet delivered.

Hathorn's (1984) estimate for well operation, maintenance, and repair costs of $0.011438 per acre foot per foot of lift is assumed to increase at the rate of inflation. The state pumping tax is currently 50 cents per acre foot and will be allowed by law to increase to as much as five dollars per acre foot by the year 2025. A constant real pumping tax of one dollar per acre foot is used in the model.

Regardless of what happens to pumping lifts, real energy costs are assumed to rise significantly over time. In accordance with the specifications for the long term rates of energy escalation given above, electricity rates will double or even triple over the planning horizon. Since the energy cost of pumping CAP water is projected to remain constant during the same period, which is probably a dubious assumption, the model produces a rather strong bias in favor of the CAP.

Groundwater Pumping Costs in the San Carlos District

Historically in the San Carlos Irrigation District, acreage assessments on district lands paid for all administrative expenses, canal maintenance, salaries, equipment, and pump maintenance and fixed pumping costs. Only recently has an additional assessment begun to be levied to reflect the energy cost of pumping, which before was subsidized by the San Carlos Project (Justice, 1984).

A representative acreage assessment equalling about $17.97 per acre foot was determined by dividing the district's current estimated total annual operating costs less the energy cost of groundwater pumping of $1.8 million (Franzoy, Corey & Associates) by the average district delivery volume of 100,160 acre feet (San Carlos Project annual report, 1981). It is assumed that the total annual fixed cost figure of $1.8 million maintains a constant real value over the planning horizon for the model. No analytical problem was presented by considering the maintenance and repair costs of pumping, which are included in that amount, as invariant over time, because it was assumed that pumping lifts and the volume of district groundwater pumping would also remain stable.

Energy pumping costs were evaluated somewhat differently in the district than elsewhere. An examination of historic pumping records showed that the efficiency of the district pumps averaged closer to 64 percent as opposed to the 54 percent figure that Hathorn used in his budgets for private wells. It is therefore estimated that the representative irrigation well in the San Carlos Irrigation District uses 1.59 kilowatt hours to pump an acre foot up one foot, instead of the typical 1.896 kilowatt hours.

Effect of the CAP on Fixed and Variable Groundwater Costs

Static Effects

The short-term, static effects of the CAP on groundwater costs are those which occur within a single time period, which in this study is assumed to be an individual year or growing season. Within a single time period, the groundwater pumping lift, the electricity rate, the total fixed cost base, and the volumes of water obtained from each alternative source of water are constant.

Normally the marginal cost of groundwater pumping within any given period of time would be expected to increase with respect to the volume of water produced. Two principle factors are behind this relationship. The first is that the more water is pumped in a the short term, the more pronounced the "coning" effect of the water table tends to become. This phenomena is the result of the pumping action of a well punching of a "hole" in the groundwater table, forcing pumping lifts in the immediate vicinity of the well to be temporarily lower than elsewhere. Although the degree of coning in a well does not necessarily effect the long-term rate of groundwater decline, which is assumed to be zero within any given period, it will affect the depth of the pumping lift. The greater the volume of water pumped, the deeper the coning, and the higher the marginal pumping costs. The second is that a farmer will tend to use his most efficient pumping facilities first, using the less efficient only as his water demands approach the capacity of his system. Less efficient wells may be older, less fuel efficient, and may be drawing from a deeper lift.

The pumping cost data obtained from Hathorne's budgets (1984) and elsewhere is generally derived from the bowl settings in the wells. Since the bowls are adjusted to recover water from the deepest depth to which it is expected to fall during the given year, it may be assumed that the pumping cost data represent the marginal (highest) unit costs in each area. It is also assumed that the data are slightly conservative in that it tends to report the status of the deeper wells rather than the shallower ones.

Figure 38 shows the hypothetical shapes of the marginal, average fixed, and average total cost curves for groundwater pumping in Central Arizona under alternative assumptions of constant and rising marginal pumping costs. The average total cost curve ATC1 appears U-shaped, falling over lower volumes of water and then rising over larger ones as the increasing marginal cost of pumping comes to dominate the falling average fixed cost. At the pumping volume OQ, where the marginal pumping cost is equal to OA, the averge total cost of groundwater pumping is at a minimum. But at this point the marginal cost of pumping might still fall short of the marginal value product of water, so a farmer would choose to continue to draw water up to some higher level OQ', where his marginal pumping cost would equal OB.

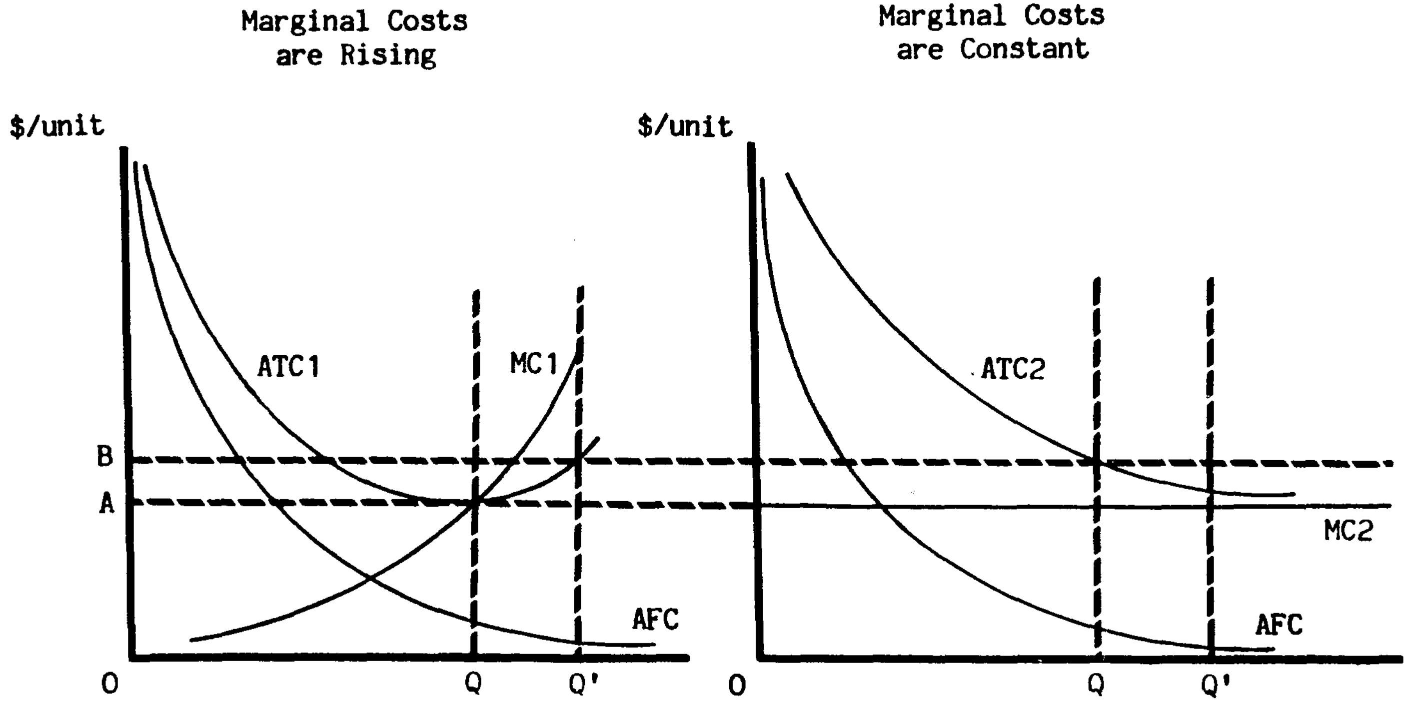
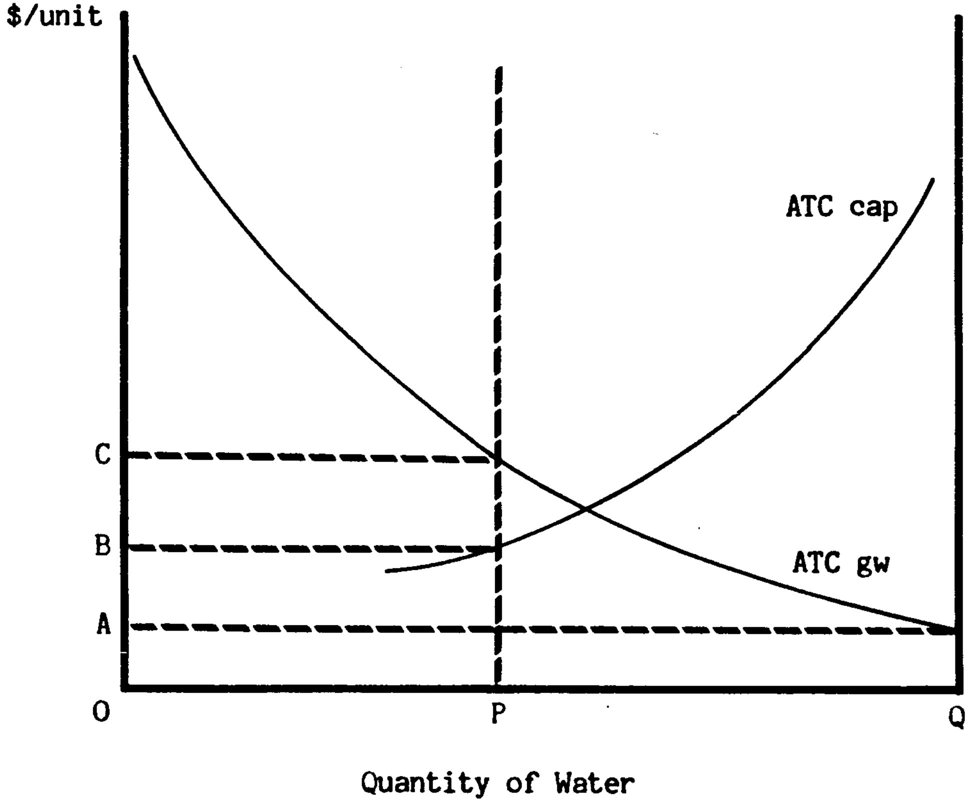


Figure 38. Hypothetical Average Total Cost Curves for Groundwater Pumping Under Alternative Conditions of Constant and Rising Marginal Pumping Costs.

No data are currently available which can be used to trace the typical marginal pumping cost curves for the irrigation areas in Central Arizona. It is not known if the marginal cost rises fairly rapidly and over what volumes of water. In the consideration of this lack of knowledge about true marginal costs and for the sake of analytic simplicity, it is assumed in the model that the marginal cost for groundwater over the volume of water up for trade with the CAP is constant. Under these conditions, the average total cost of groundwater may be represented in Figure 38 by the monotonically decreasing function ATC2. At the current rate of groundwater consumption 0Q, the marginal cost of pumping B is assumed to be the average variable cost of pumping throughout the entire volume of water being considered.

Given the assumption that the marginal cost for groundwater pumping over the relevent range of production is constant, the static effect of trading CAP for groundwater on the cost of water may be illustrated in Figure 39. Suppose that an irrigation district consumes the constant quantity of groundwater 0Q per period. Let the district decide to buy PQ units of CAP water, which it must use to substitute an equal amount of groundwater. Note that when 0Q units of groundwater were used, the average total cost was A dollars per unit. With the importation of PQ units of CAP water and the subsequent reduction in groundwater pumping volumes, the average cost of groundwater rises to 0C dollars per unit. This increase in average total costs results from the assumption that farmers wish to maintain their groundwater pumping facility at its original capacity. They have to bear higher average



Unit Cost of Groundwater only = OA

Weighted Average Unit Cost of Groundwater and CAP Water, Blended =

$$\frac{(OC * OP) + (OB * QP)}{OQ}$$

Figure 39. Hypothetical Static Effect on the Weighted Average Total Cost of Irrigation Water When Groundwater is Partially Substituted with CAP Water.

fixed costs as the constant total fixed cost base is spread over a smaller volume of groundwater.

So long as the average total cost of CAP is not significantly less than the average total cost of groundwater, then the weighted average total cost of all irrigation water under project conditions will tend to be higher than otherwise, in any one year. That is, the static effect of the CAP will be, at least in the early years of the project unless or until CAP water becomes cost competitive, to increase overall water costs.

Comparative Static Effects

Whether or not the particular allocation of CAP water in a given year is at or close to this minimum cost mix, and whether or not the weighted average cost of water under project conditions is lower than it would be in the absence of project conditions, are questions which only have significant meaning when examined over the long term. Consider the relative effects of project and no-project conditions on the relative weighted average costs of water. Figure 40 shows the evolution of the costs of water in some hypothetical irrigation district over two arbitrary years 1 and 2, where Year 2 is subsequent to Year 1. In Year 1 the average fixed cost of water at quantity OQ is A dollars, and the marginal cost of water is X dollars. In the absence of project conditions, deepening pumping lifts and rising electricity rates will shift the marginal cost function for groundwater up to Y dollars. Meanwhile, the average fixed cost function for groundwater shifts out and at the quantity OQ has risen from A to B dollars.

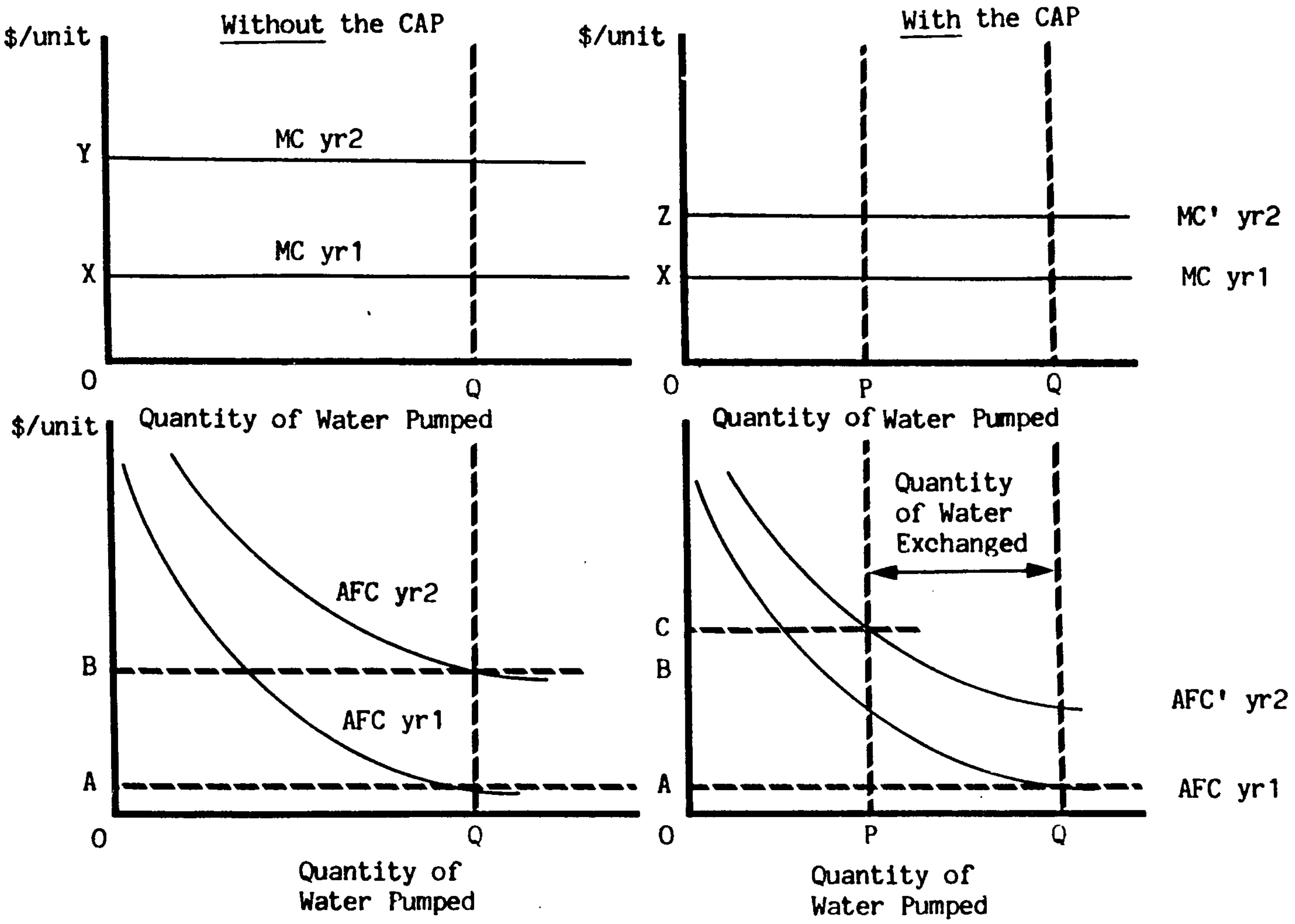


Figure 40. Hypothetical Static and Comparative Static Effects on the Cost of Irrigation Water When Groundwater is Partially Substituted With CAP Water.

Under project conditions, neither the marginal cost nor the average cost curves for groundwater would shift as much. If 0Q units of groundwater were pumped in Year 2, then as a result of groundwater savings realized in Year 1, the average total cost of groundwater would be lower than otherwise. But the result of trading groundwater for CAP pushes the average fixed cost of groundwater pumping higher than it would have ever been without the project, to C dollars per unit.

Three different cost effects may therefore be observed as a result of importing CAP water, and their interaction will determine whether the average total cost of groundwater under project conditions will tend to be higher than, lower than, or the same as otherwise. The marginal cost of groundwater pumping is unambiguously lower under project conditions, but the average fixed cost of pumping may rise or fall. Moderated groundwater declines under project conditions reduce the need for additional well investments, tending to hold the average fixed costs of pumping down. But at the same time the inefficient use of the pumping facility from cutting back on groundwater production tends to push the average fixed cost up.

An additional complicating factor is that even after groundwater pumping costs are determined to rise or fall under project conditions, the cost of CAP water may change the weighted average costs enough to reverse the result. Suppose that the average total cost of groundwater pumping under project conditions is higher than otherwise. What happens if the average total cost of CAP is considerably lower than both? Then in that particular year the weighted average cost of water under project conditions may still be lower than otherwise. Conversely, if CAP is considerably more expensive than groundwater, then any savings in average total pumping costs may be wiped out by the costliness of the CAP.

The progression of the average total costs of irrigation water over time under project and no-project conditions, as shown in Figure 41, is hypothesized to be as follows. In the early years of the project, CAP water will be expensive relative to groundwater, the hydrologic benefits of the CAP will not yet have been realized to any significant extent, and the groundwater pumping facility will be used the most inefficiently. Average total water costs will therefore tend to be considerably higher under project conditions than otherwise. As time goes on, CAP unit costs may change somewhat but not significantly, the hydrologic benefits of the CAP will become important in the relative pumping costs of groundwater, and the groundwater pumping facility will be used more and more efficiently as the volume of pumpage increases back towards the capacity of the system. In some future Year X, it is likely that the average total water costs under project conditions will begin to become less expensive than under no-project conditions. Whether or not the turnaround occurs soon enough and significantly enough to generate a net benefit stream with a positive present value, is an empirical question which the model attempts to answer.

Comparative Water Cost Projections

Format

The model is run several times for each irrigation district to investigate the relative impact on the results of alternative discount

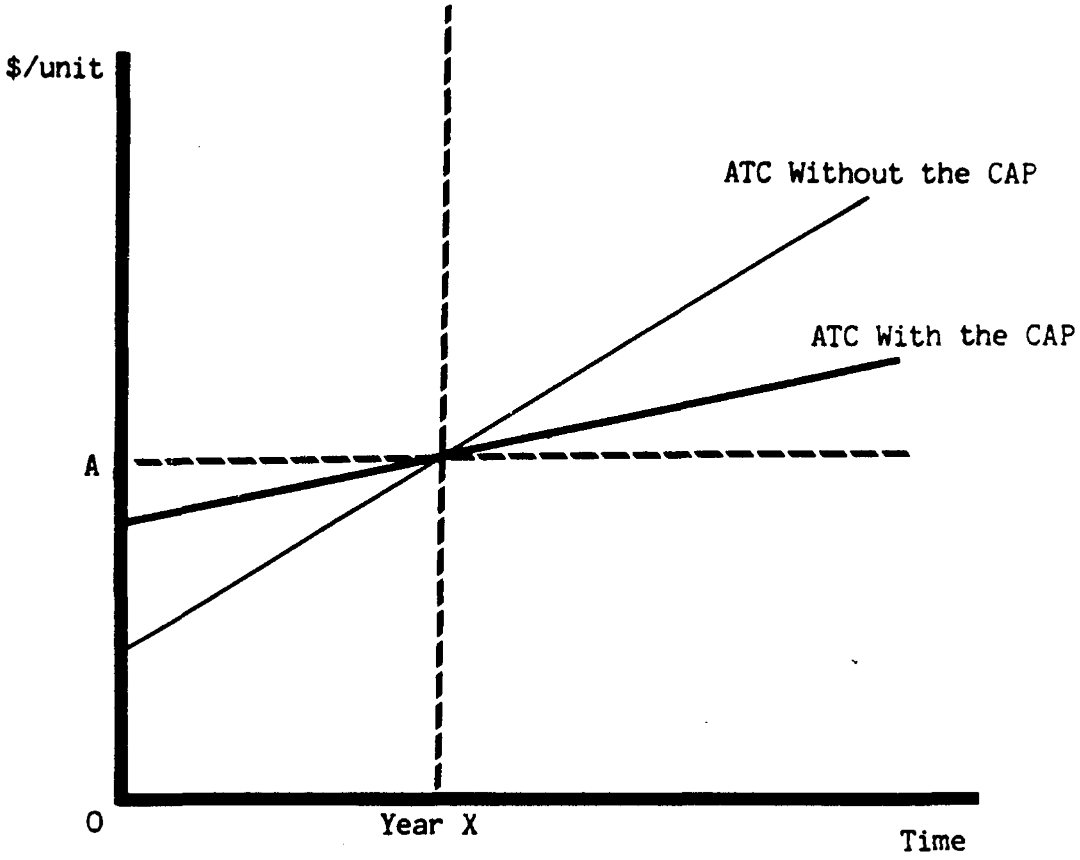


Figure 41. Hypothetical Progression Over Time of the Weighted Average Total Costs of Irrigation Water Under Alternative Project and No-Project Conditions.

rates, energy cost escalation rates, groundwater decline rates, and CAP delivery schedules. The weighted average total water costs under project and no-project conditions are compared each year for the fifty years from 1984 to 2034.

If water under project conditions is cheaper, then in that year the project produces a positive net benefit per acre foot of water. The benefit is exactly equal to the difference between the weighted total average water costs of the two alternatives. If instead project water is more expensive, then the difference between the two weighted average costs is assessed as a negative net benefit. The positive or negative net benefits are discounted back to 1984, and a present worth for the project is determined per acre foot of water. The baseline energy cost escalation and groundwater decline assumptions for each of the eight study areas are summarized in Table 13.

Each baseline projection is modified in order to test the sensitivity of the results to changes in the rate of groundwater decline, the rate of energy cost escalation, and alternative rates of discount. The purpose of the sensitivity analysis is to determine the degree to which assumptions about key variables in the model would have to be in error before the outcome of the model would change. Within the context of the three alternative CAP allocation scenarios, three variables are tested. These are the rate of discount, the rate of groundwater decline, and the energy cost escalation rate. In each case the magnitude of the variable is increased or diminished as much as possible until the present worth of the CAP is found to be close to zero.

Table 13. Summary of Baseline Assumptions About Rates of Groundwater Decline and Energy Cost Escalation.

District	Rate of Groundwater Decline	Rate of Energy Cost Escalation
Central Arizona	3	1.0 *
Harquahala	8	2.0
Hohokam	3	1.0 *
Maricopa Stanfield	4	1.5
New Magma	4	1.0 *
Queen Creek	3	1.5
San Carlos	0	1.0
Tonopah	3	2.0

Inflation rate for adjusting CAP capital repayments is six percent.

Real discount rate is four percent.

Starred (*) energy escalation rates will increase at the rate of one percent per year through 1987, then jump to 35 mils per Kwh in 1988 before resuming one percent growth trend.

The sensitivity analysis of the rate of groundwater decline in San Carlos is conducted somewhat differently from the way that it is in the other districts. The assumption that groundwater levels within the district service area remain stable at all times is maintained, while the rate of decline of groundwater pumped from private facilities outside the district are allowed to vary. It is also still assumed that neither the groundwater levels inside or outside the district are affected by the volume of CAP water delivered.

Description of the Scenarios

Two alternative CAP allocation schedules are used in the model for all eight irrigation districts, "standard" and "sustained maximum". Under the standard allocations, the declining average annual Colorado River flows projected by the Bureau of Reclamation are used as an estimate of the CAP supply for agriculture. The water is apportioned to the districts according to the the percentage allocations recommended by the Arizona Department of Water Resources. An inflation rate of 6 percent is used to adjust the nominal money debt service and contingency fund obligations of the irrigation districts to constant 1984 dollar values.

Under the sustained maximum allocation schedule, a constant 1,100,000 acre feet of CAP is assumed to be available for agriculture every year, with no uncertainty over delivery. Only the 1985 percentages are used to distribute the supply among the various districts throughout the 50 year horizon, so CAP deliveries are held absolutely constant. Average fixed costs for groundwater pumping will only vary with the depth to lift and not the volume of pumpage, because well owners may divest themselves of redundant well capacity without any risk of income loss from insufficient water supplies.

A third, "zero" alternative CAP allocation schedule is applied to the San Carlos Irrigation District. Under this scenario, it is assumed that the district constructs all of the CAP-related facilities but receives no project water at all throughout the planning horizon.

A total of six different projections are run for the Type I and Type II irrigation districts, while those six plus an additional three projections are run for the San Carlos Irrigation District. Projection 1 is the baseline projection. Standard CAP allocations and assumptions about groundwater declines and energy costs were employed. The projection was run ten times, with discount rates varying from 0 to 9 percent. Projection 2 keeps all baseline assumptions but allowed the magnitude of the rate of groundwater decline to vary. Projection 3 keeps all baseline assumptions but allowed the magnitude of the rate of energy cost escalation to vary.

Projection 4 modifies the baseline projection by introducing sustained maximum CAP allocations. The projection is run ten times, with discount rates varying from 0 to 9 percent. Projection 5 follows the modified baseline projection, but allows the magnitude of the rate of groundwater decline to vary. Projection 6 follows the modified baseline projection, but allows the magnitude of the rate of energy cost escalation to vary.

Projections 7, 8, and 9 are run only on the San Carlos Irrigation District. Their purpose is to isolate the benefit of the canal system improvement component of the CAP program in the district from whatever cost or benefit the importation of the project water itself would cause. Projection 7 modifies the baseline projection by eliminating the CAP allocation altogether. The projection is run ten times, with discount rates varying from 0 to 9 percent. Projection 8 follows Projection 7, but allows the magnitude of the rate of private groundwater decline to vary. Projection 9 follows Projection 7, but allows the magnitude of the rate of energy cost escalation to vary.

CHAPTER 6

RESULTS OF THE LONG-TERM ANALYSIS

> . . . it should be recognized that the Central Arizona Project (CAP) was not authorized for the purposes of providing lower cost water to central Arizona. The basic objective of the CAP is to provide a Colorado River water supply for use in substitution for groundwater pumping. Its purpose is to conserve and extend the life of the local groundwater resources rather than to produce economic benefits as is the case for more conventional United States Bureau of Reclamation programs.
>
> Clifford Pugh, 1983
> Memorandum to McMicken Irrigation District

This chapter compares and contrasts the results of the long-term projections of the costs of irrigation water with and without the CAP in each of the eight irrigation districts in the study area. A sensitivity analysis on key variables is conducted. Significant trends, factors, and relationships among the variables are discussed.

Standard CAP Allocations: Baseline Results

Results of the model for the standard CAP allocations scenario are summarized in Appendices G through K.

Variable Groundwater Pumping Costs

In most areas the initial slowdown in the rate of groundwater decline is quite dramatic. Reductions in groundwater withdrawals are sometimes significant enough to temporarily eliminate the overdraft entirely. As CAP deliveries fall off in later years, however, the rates of overdraft and groundwater decline return begin to rise again.

Since the effects of groundwater decline are cumulative, the effects of the hydrologic benefits of the CAP should be most evident at the end of the project planning horizon. By 2034, the difference in pumping lifts in all the districts except San Carlos (where the CAP is assumed to have no net hydrologic effect) between project and no-project conditions is significant. However, pumping lifts are already so deep in most areas, the absolute savings in future pumping lifts is not proportionately large.

The greatest savings in pumping lifts and variable pumping costs is found in the Harquahala Irrigation District, where the rate of groundwater decline is the fastest and the overdraft the most sensitive to the rate of groundwater withdrawals. Yet the pumping depth to lift and the variable cost of pumping in Harquahala under project conditions by 2034 is still 83 percent of what they would have been if no project were undertaken. Project pumping lifts in the Tonopah District are 84 percent of no-project lifts. Elsewhere, the proportions are higher, ranging from 90 to 94 percent.

Rapidly increasing electricity rates cause variable pumping costs to increase tremendously regardless of whether CAP water is imported or not. In no district are the hydrologic benefits of the CAP sufficient to prevent the variable cost of groundwater pumping from doubling, tripling, or growing by even more. In Harquahala, for example, the variable cost of groundwater pumping per acre foot increases from $67.51 in 1984 to $231.72 and $279.99 under project and no-project conditions, respectively.

If pumping lifts in Harquahala had remained stable at the level recorded in 1984, then the variable cost of pumping would still have risen to $168.39 per acre foot. If the unit cost of energy had remained unchanged but the pumping lift increased at the rate projected under no-project conditions, then the variable cost of pumping would have risen to only $111.84. Even in Harquahala, where the projected rate of groundwater decline is at least twice as great as any other district in the study area, most of the projected increase in the variable cost of pumping between 1984 and 2034 is due to energy escalation, not groundwater decline.

Variable pumping costs in the San Carlos district increase roughly 1.5 times under project conditions but more than double without project conditions. The cost savings under the project is realized even though the pumping depth to lift remains the same throughout the planning horizon with or without the CAP, and energy rates increase uniformly. The substantial net benefit is gained from the improvement in delivery efficiency of the system as a result of lining the canals.

Fixed Groundwater Pumping Costs

Inefficient use of the groundwater pumping facilities causes the fixed cost of groundwater pumping to be much higher under project than no-project conditions, even when the savings from reduced capital investment is accounted for. Most of the districts use CAP water to meet more than half and sometimes as much as two thirds of their total water demand in the early years of the project.

The more an irrigation district substitutes large quantities of groundwater for CAP, the higher are the average fixed pumping costs. In the Queen Creek Irrigation District, which achieves one of the highest ratios of CAP water to groundwater, groundwater pumping in 1989 is projected to be cut back to 33 percent of its preproject level. Since the average fixed cost is $14.69 per acre foot when Queen Creek farmers operate their pumping plants at normal capacity, in 1989 the adjusted average fixed cost is estimated by dividing $14.69 by 33 percent. As a result of using their facilities inefficiently, they effectively pay $44.34 per acre foot for the fixed cost of groundwater pumping alone.

The only district which does not experience higher fixed groundwater pumping costs in the initial years of the project is San Carlos, where the fixed costs for groundwater pumping are blended with other charges. Average total fixed costs in the district are determined by dividing the total fixed costs base by the total amount of water delivered from all sources by the district. The total amount of water delivered by the district declines over time as CAP supplies diminish, tending to push up the average fixed cost per acre foot of water. At the same time, however, the fixed cost base is shrinking as its capital debt for the canal reconstruction and lining program is paid off. Overall, the average fixed cost of water under project conditions remains fairly stable throughout the planning horizon.

CAP Costs

The variable cost of CAP water is assumed constant over the planning horizon. All of the movement recorded in the average total cost of CAP water is therefore due only to variations in its average fixed cost.

As the debt service for the construction of the local CAP distribution system is retired over time, and as inflation systematically reduces the real dollar value of the annual payments, the fixed cost base for each district progressively shrinks. Assuming no charges for capital depreciation, ultimately a point is reached where all capital debts are paid and the only remaining annual obligation of the district is its OM&R costs, which are assumed to be maintained at a constant real cost.

If the volume of CAP deliveries remained constant, the average fixed cost of CAP water would then tend to decline gradually over time. But CAP deliveries are projected to diminish, steadily reducing the number of units of water over which the fixed cost base may be spread. There is therefore an opposing tendency at work to push the average fixed costs of the CAP up. Depending upon which trend dominates, the decline in the total fixed average fixed cost or the decline in CAP delivery volumes, average fixed CAP costs may rise, fall, or remain roughly constant over time.

The general trend observed in the model is that the average fixed cost and therefore the average total cost of CAP water increases slightly over time, but usually not to a very significant degree when compared to the increases in groundwater pumping costs. In Harquahala the average total cost of CAP water is $80.36 per acre foot in 1989, and $88.46 per acre foot in 2034. In Queen Creek, the average total cost of the CAP per acre foot rises from $80.22 in 1984 to $95.95 in 2014 to

$102.17 in 2034. The greatest increase in average total CAP costs is in the New Magma district, where it rises from $101.61 per acre foot in 1989 to $127.73 in 2034.

Average total CAP costs in the San Carlos Irrigation District remains almost constant throughout the planning horizon. Neither the changes in the total fixed cost base nor in the total amount of water delivered by the district are very significant. Neither factor manages to dominate the other enough to cause any significant increase or decrease in average fixed CAP costs over time.

Weighted Average Total Water Costs

The savings realized through lower variable groundwater pumping costs under project conditions is no guarantee that the average total cost of groundwater will be lower than otherwise, at least initially. Average fixed pumping costs are high enough to offset the relative groundwater savings in every district except San Carlos for more than ten years before average total pumping costs under project conditions finally begin to appear cheaper than under no-project conditions.

Even in the Harquahala district, which is the area the most affected hydrologically by the CAP, the average total cost of groundwater pumping under project conditions does not become competitive with average total groundwater costs in the absence of project conditions until after the year 1994. The cost reversal does not take place in Maricopa Stanfield and New Magma until after the year 2004, after 2009 in Hohokam and Queen Creek, and 2019 in Central Arizona.

In San Carlos, average total groundwater costs are less expensive under project conditions from the first year the CAP system is operational. This is because of the assumption that neither the district's nor the private groundpumping facilities are ever underused. Average fixed costs in the district actually go down because more water is supplied by the district for only a slightly higher total fixed cost. The savings in variable pumping costs is therefore never initially offset by higher average fixed costs as it is elsewhere.

In two districts, Harquahala and San Carlos, the weighted average total cost of all water under project conditions would be cheaper than without the project from very early in the projection. In four of the districts, Queen Creek, Tonopah, Central Arizona, and Maricopa Stanfield, it is found that the average total cost of water with the project would become competitive with no-project water at about the time that CAP water costs become competitive with both project and no-project groundwater costs.

In the year 2009 in Maricopa Stanfield, for example, the average total costs for no-CAP water and groundwater under project conditions are $95.07 and $96.27 per acre foot, respectively. The weighted average total costs of project water in 2009 are $95.98, while the cost of groundwater under no-project conditions is $96.74.

For two districts, Hohokam and New Magma, the average total cost of CAP water is so high that it causes the weighted average total cost for all water to be greater under project than no-project conditions, even long after groundwater pumping costs become relatively less expensive with the CAP than without. In Hohokam, the average total cost of groundwater under project conditions becomes competitive with no-project conditions in the year 2014, when their costs per acre foot are $60.47 and $60.90, respectively. But in 2014 the average total cost of CAP water is $101.23, considerably more than the cost of groundwater under either circumstance. As a result, the weighted average total water cost under project conditions is $67.68 per acre foot, while without the project the cost is only $60.90.

The relatively high cost of CAP water in Hohokam persists in keeping the average total cost of water under project conditions higher than otherwise until after the year 2029, at nearly the end of the project planning horizon. A similar set of circumstances in New Magma prevents project water from becoming competitive until after the year 2019, a decade and a half beyond the point at which project groundwater costs has become less expensive than no-project groundwater.

Present Worth Analysis

The 50-year present worth analysis shows that only farmers in the Harquahala and San Carlos Irrigation Districts can expect to realize a net benefit from the CAP. San Carlos realizes a positive gain amounting to $97.62 per acre foot, while the present worth of the project in Harquahala is $440.96 per acre foot. Elsewhere, the net present worth of the project per acre foot is negative. Net losses per acre foot range from $46.70 in Tonopah to $215.86 in New Magma.

Sustained Maximum CAP Allocations: Baseline Results

Three factors contribute to the generally positive effect that a large and constant flow of CAP water has on the competitiveness of average total water costs under project conditions. First of all, a high volume of CAP water means that the facilities devoted to the CAP are being used at or close to capacity, so the efficiency of the CAP delivery system is increased. Average fixed CAP costs, and therefore average total CAP costs, are lower than otherwise. Second, complete delivery security means that farmers need no longer be concerned about significant variations in project water supplies. They will not have to invest in a larger pumping facility than necessary to handle the expected volumes of groundwater demanded. Average fixed well costs are no longer driven up as a result of inefficient use of the groundwater production facilities. Finally, the larger volume of CAP water delivered will cause a lower rate of groundwater overdraft and less groundwater decline than there would be otherwise.

In sum, the long term effect of sustained maximum CAP allocations is to maintain average total CAP and groundwater costs at lower levels than they would have been without the project. This does not necessarily mean that farmers in a district will actually find themselves better off with the CAP than without, but their chances for enjoying improved conditions are generally better under this scenario.

Results of the sustained maximum allocation scenario for the eight irrigation districts are summarized in Appendices L through P. Three districts, Central Arizona, Hohokam, and San Carlos, representing three different reactions to the implementation of this scenario, are selected for discussion. Both the Central Arizona and Hohokam districts formerly realized a substantial net loss under project conditions, and both find the present worth of the CAP improves with sustained maximum allocations. However, while the project changes from an unfavorable to a favorable alternative for Central Arizona, Hohokam is still worse off with the CAP, although by not much as it would have been under the standard CAP allocation scenario. The San Carlos district finds that it is still better off under project conditions than under no-project conditions, but it is not quite as well off as it was under the standard allocation scenario. Farmers in this area appear to be better off with less CAP water rather than more.

Variable Groundwater Pumping Costs

Assumptions about the progression in the unit cost of energy are the same as before. The variable cost of pumping therefore differs from the results of the standard CAP allocation scenario in direct proportion with the relative changes in pumping lifts. CAP deliveries are constant in the Central Arizona district at 178,299 acre feet per year. As a result, the rate of groundwater decline slows dramatically to only 0.61 feet per year throughout the years the project is in operation. By 2034 the pumping depth to lift is 663 feet, approximately 86 percent of the 770 foot depth to which pumping lifts would have fallen if there were no project at all. If the standard assumption about CAP allocations had held, the final depth to lift would have been 711 feet, or 92 percent of the pumping depth under the no-project alternative. The savings in the pumping lift by the year 2034 which is realized through the project nearly doubles, from only 59 feet to 107 feet.

CAP deliveries in the Hohokam district are constant at 59,466 acre feet per year. Hohokam's pumping lift in 2034 under project conditions is 477 feet, 37 feet shallower than the lift would have been under project conditions with standard CAP allocations. The final pumping lift is 83 feet shallower than it would have been in the absence of project conditions. Expressed as percentages, the pumping depth to lift in 2034 is 85 percent of the lift under the no-project alternative. This compares to 92 percent realized under the standard CAP allocation scenario.

Private and district groundwater depths to lift and the variable costs of pumping in the San Carlos district are still assumed to be unaffected by the volume of CAP water delivered.

Fixed Groundwater Pumping Costs

Farmers are assumed to divest themselves of unneeded groundwater pumping capacity when CAP deliveries begin. In Central Arizona, the average fixed cost of groundwater pumping in 1989 is only $19.47 per acre foot, less than half of the $46.94 that would have been spent if there were no CAP delivery security, as is assumed under the standard allocation projections. In Hohokam, the average fixed pumping cost in 1989 is $10.40 per acre foot, as compared to $18.96 in the absence of delivery security. In later years, as groundwater pumping capacity under the standard CAP allocation scenario is more efficiently used, the difference between the average fixed pumping costs under project conditions diminished. At the same time, however, faster groundwater declines under the former scenario lead to higher rates of investment in well capacity than when CAP allocations are at a sustained maximum. This difference in investments prevents the two average cost figures from converging completely.

Average private groundwater pumping fixed costs in San Carlos are assumed to be unaffected by the volume of CAP water delivered. Average fixed costs in the district are lower because the overall volume of water delivered remains higher than otherwise. With CAP deliveries of 38,242 acre feet, Gila River supplies of 90,525 acre feet, and groundwater supplies of 34,676 acre feet, the annual amount of water produced in or imported by the district total 163,443 acre feet per year. Dividing this quantity of water into the the district's total annual fixed cost obligation gives the average annual fixed cost for delivering district water. The abundant supply of district water means that the importation of privately pumped groundwater into the district service area ceases. Assuming that these wells are either shut down or else that the supplies are sent elsewhere, private groundwater pumping is no longer considered a cost for San Carlos farmers.

CAP Costs

The costs for CAP water are uniformly lower over all three districts because more acre feet of water are delivered while the fixed cost base remains unchanged. As capital debts are paid off, the annual fixed cost obligation in each district shrinks until it is composed of nothing but the system's basic OM&R costs. As a result, the average fixed cost of CAP water exhibits a downward trend over time.

Weighted Average Total Water Costs

Average total groundwater pumping costs in Central Arizona and in Hohokam are relatively lower under project conditions than no-project conditions from the first year after CAP deliveries begin. The relatively high cost of CAP water still forces the weighted average total cost of water under project conditions to be initially higher than under the no-project alternative, but the turning point in the relative costs comes sooner.

In Central Arizona, the weighted average total cost of water under project conditions becomes cheaper than without project conditions sometime after the year 1994, and in Hohokam, after the year 2019. Under the standard CAP allocation scenario, the turning point years are for the two districts are after 2014 and 2029, respectively.

In San Carlos the weighted average total cost of water is still lower under project conditions than no-project conditions almost from the beginning of CAP deliveries, but the annual savings per acre foot is slightly less than that observed under the standard CAP allocation scenario. The reason is because the average total cost of CAP water is consistently higher than the weighted average total cost for the rest of the district's water supplies. The delivery of additional amounts of CAP water therefore tends to raise the weighted average total cost instead of lowering it as is the case, at least eventually, in all the other districts.

Present Worth Analysis

The present worth of the project improves for both Central Arizona and Hohokam, but the character of the respective outcomes are different. In Central Arizona the net present worth increases enough to become significantly positive, from a net loss of $130.72 per acre foot to a net gain of $87.92 per acre foot. Meanwhile farmers in Hohokam only find themselves losing less than they would have under the standard allocation scenario. They can still expect to lose a discounted sum of $170.04 per acre foot over the 50 years between 1984 and 2034. This is certainly an improvement over the $206.26 per acre foot loss they would have suffered otherwise, but nevertheless that is no incentive for them to have the CAP.

Farmers in San Carlos still find themselves better off, but not as well off as they would have been with standard CAP allocations Two opposing effects influence the cost of water in San Carlos as a result of the project. One is the high cost of CAP water, and the other is the benefit of improved delivery efficiency. Although farmers would still be better off because of the significant gains they would realize under the latter, the former tends to reduce the magnitude of that gain. From a net present worth of $97.62 per acre foot of water under the standard CAP allocation scenario, the value of the project falls to $74.66 per acre foot when CAP deliveries are large and sustained.

Zero CAP Allocations: Baseline Results

The zero allocation scenario was developed for the model in order to test the hypothesis that farmers in the San Carlos Irrigation

District would benefit from the CAP only because of the reconstruction of their canal system, and not from the delivery of project water. The assumption in this scenario is that all of the planned improvements in the district's water distribution system are carried out, but no CAP water is ever delivered. In this manner the full measure of the benefits attributable to improved delivery efficiency may be isolated from those which would be associated with the importation of Colorado River water. Results of the analysis are summarized in appendix Q.

Weighted Average Total Water Costs

With a constant district water delivery volume of 125,201 acre feet per year, the average fixed cost of district water is lower than it would be in the absence of project conditions, but higher than if any volume of CAP water were delivered. The 125,201 acre feet of groundwater and surface water would be delivered under any allocation scenario for CAP water, so long as the planned improvements in the water delivery system were made.

Average total fixed costs for water are higher under project conditions in this allocation scenario than in the other two because, without any CAP water at all, the volume of district water over which to spread the fixed cost base is the least. However, this loss is more than outweighed by the gain realized from the resulting lower average variable costs of water. Since surface water has a variable cost of zero and the variable cost of district groundwater is only $43.87 per acre foot as late as the year 2034, CAP water at a variable cost of $67.06 per acre foot could never compete with these sources. Rising electricity rates would finally cause the variable cost of privately pumped groundwater to become more expensive than CAP water after the year 2024, but the effect would be much too little too late to make any difference.

Present Worth Analysis

The option of building the CAP infrastructure but refusing CAP water deliveries altogether is clearly superior to either the standard or the sustained maximum allocation options for the San Carlos Irrigation District. The present worth of the project to San Carlos farmers stands at $132.64 per acre foot under the zero CAP allocation scenario. This compares to only $97.62 per acre foot when CAP water was delivered under the standard allocation scenario.

Sensitivity Analysis: Standard CAP Allocations Scenario

Only two irrigation districts, Harquahala and San Carlos, appear better off with the CAP than without it under the baseline assumptions. The six other districts appear to be worse off with the CAP.

Discount Rate

Normally, the present worth of a project where the costs are "front-loaded" and the benefits "back-loaded" increases in inverse proportion to the size of the discount rate. The larger the discount rate, the more weight is placed on the stream of early net costs. As the discount rate becomes smaller, relatively more weight is placed on the stream of future net benefits.

Within the range of real discount rates employed in the analysis, the only irrigation districts which showed any potential for alternative results at all were Maricopa-Stanfield and Tonopah. In the former the present worth of the CAP is negative but becomes marginally positive at a real discount rate of 1 percent. The present worth of the project in Tonopah is also negative but appears significantly positive at any discount rate between 0 and 2 percent. The present worth of the project in Harquahala, Hohokam, and San Carlos is completely unaffected by variations in the discount rate. In Harquahala and San Carlos the net present worth of the CAP remains positive, while in Hohokam the net present worth remains negative.

Rate of Groundwater Decline

The faster the rate of groundwater decline, the more quickly would groundwater pumping costs become prohibitively expensive and the sooner would the CAP become a competive alternative. A more rapid deterioration of pumping lifts would also mean that the ratio of overdraft to decline is smaller than otherwise assumed, so the rate of decline would be much more sensitive to the importation of CAP water.

The two irrigation districts which would be better off under project conditions in the standard CAP allocation scenario, Harquahala and San Carlos, would continue to benefit from the project even if their rates of no-project groundwater decline were zero. In Harquahala, CAP water would still be competitive with groundwater because the great and growing difference in energy costs between the two alternative sources persists. In San Carlos, the enormous project-induced benefit of improved system delivery efficiency is still the dominant factor.

In each of the other six districts, which are all worse off under the project with standard CAP allocations, farmers could not expect to even break even with the CAP unless the rate of groundwater decline were significantly higher than is assumed under the baseline projection. Rates of groundwater decline in most of these areas must at least gain the historically high rates experienced in the 1960's in order to cause that the CAP to appear favorable. Rates of 6.81 feet per year in Maricopa Stanfield, 7.06 in Queen Creek, and only 3.78 in Tonopah would be enough to at least leave farmers in these areas indifferent between having and not having the CAP. Elsewhere, rates of groundwater decline would have to exceed even the historically high rates in order to make the project with standard CAP allocations appear favorable. Rates would have to approach 8.94 feet per year in Central Arizona, 13.62 in Hohokam, and 14.62 in New Magma before the break-even point would be reached.

Rate of Energy Cost Escalation

It is assumed throughout the model that the demand for energy and the unit cost of energy for pumping CAP water remains constant. Any changes in the assumptions about trends in real electricity rates will therefore affect only the cost of groundwater pumping. As it is plausible (although probably not realistic) to project that the rate of energy cost escalation will increase at a rate less than that of the general rate of inflation, negative escalation rates are permitted in the analysis.

In Harquahala and San Carlos, the average annual rates of energy cost escalation would have to reach a negative 1.25 percent and 3.00 percent, respectively, before farmers would become indifferent between having nor not having the CAP. Four other districts must have energy escalation rates of between 2 and 3 percent before the break-even point for the CAP is reached. These are Central Arizona with 2.88 percent, Maricopa Stanfield with 2.25, Queen Creek with 2.69, and Tonopah with 2.94. Two other districts would not break even without energy escalation rates greater than 4 percent. These are Hohokam with 4.75 percent, and New Magma with 4.12 percent.

Sensitivity Analysis: Sustained Maximum CAP Allocations

Only two irrigation districts, Hohokam and New Magma, would still find themselves worse off with the project under the assumptions of this scenario. Central Arizona, Maricopa Stanfield, Queen Creek, and Tonopah all find that they are now better off under project conditions, whereas they were worse off before. Harquahala's formerly favorable position is strengthened further. The net benefit enjoyed by San Carlos is still positive, but less positive than it was under the assumptions of standard CAP allocations.

Discount Rate

The outcomes in a few of the districts exhibit some sensitivity to the rate of discount under the sustained maximum CAP allocation scenario. Farmers in Central Arizona would generally find the project a very favorable alternative under this scenario, but at high rates of discount, from about 8 or 9 percent on, they would begin to see their losses dominating their gains. In Queen Creek and Tonopah, similar trends are evident. They would also enjoy a net gain from the project unless discount rates rose to 7 or 8 percent or higher. In the New Magma district, where even under sustained maximum CAP allocations, the project generally appears unfavorable, the present value of the project would not become positive unless the discount rate approached zero. The present worth of the project in Harquahala, Hohokam, and San Carlos would be completely unaffected by variations in the discount rate. In Harquahala and San Carlos the net present worth of the CAP would remain positive, while in Hohokam the net present worth would remain negative.

Rate of Groundwater Decline

Even groundwater declines of zero would be insufficient to reduce the net present worth of the project in Harquahala and San Carlos below zero. Of the four irrigation districts which would have suffered net losses from the CAP under the standard allocation scenario and would now enjoy net benefits, a not unreasonable change in hydrologic assumptions may again make the project appear questionable. Groundwater decline rates need only fall to 0.75 feet per year in Central Arizona, 0.25 in Maricopa Stanfield, 0.56 in Queen Creek, and 1.59 in Tonopah to make the CAP a break-even proposition. None of those rates of decline would necessarily be an unrealistic reflection of recent trends in groundwater pumping lifts in these areas.

Neither Hohokam nor New Magma would enjoy a positive net benefit from the project even under this generous scenario for CAP allocations, although their loss would not be as great as otherwise. The break-even rates of groundwater decline in these two districts would be correspondingly lower, 8.62 feet per year in Hohokam and 7.75 feet per year in New Magma. Although some farmers in these areas may have once experienced rates of decline of these magnitudes, few if any still do.

Rate of Energy Cost Escalation

Energy escalation rates below a negative 2.38 percent and 0.75 per year in Harquahala and San Carlos, respectively, would cease to make farmers in those areas better off with the CAP than without it. Energy escalation rates would have to fall to a positive 0.19 percent in Central Arizona, 0.38 percent in Maricopa Stanfield, 0.88 percent in Queen Creek, and 1.44 percent in Tonopah before the CAP no longer appeared favorable. The CAP would not begin to appear favorable in Hohokam and New Magma until escalation rates rose to a positive 3.00 and 2.12 percent, respectively.

Sensitivity Analysis: Zero CAP Allocations

The present value of the project in the San Carlos irrigation district would be too large to be affected by any feasible rate of discount. Groundwater declines in San Carlos of zero feet per year could not succeed in eliminating the positive present worth of the project. Energy rates would have to decline at the rate of 7 percent below inflation every year in San Carlos in order for the CAP to no longer appear favorable.

Conclusions

Baseline Results

Six of the eight irrigation districts studied would find themselves worse off with the CAP than without under the assumption of standard CAP allocations. Two districts out of eight would still find themselves worse off even if their deliveries of CAP water remained high and delivery security absolute throughout the planning horizon. One of these two districts, San Carlos, would be better off after the project was built under either allocation scenario, but would actually find it in its best interest to buy less, not more, CAP water. Farmers in San Carlos appear to benefit the most under the project when their district takes no CAP deliveries at all.

Several reasons may be offered to explain why most of the districts would fail to benefit from the CAP under the standard allocation assumptions. First, the variable cost of CAP water would exceed the variable cost of groundwater pumping in every district but two throughout all, or nearly all, of the project planning horizon. Only in the Harquahala and Tonopah districts would the variable cost of CAP effectively compete with groundwater over a substantial part of the 50-year period.

Another important reason is that the hydrologic effects of the CAP would not create a large savings in groundwater pumping costs early enough in the project to make much of a difference. Groundwater pumping costs would rise dramtically everywhere, regardless of whether the CAP was in operation or not. In every area except San Carlos the CAP would cause the rate of groundwater decline to slow, moderating pumping costs somewhat, but the savings would be no match for the steadily increasing costs of energy. Even in the Harquahala district, where the groundwater savings would be the greatest, the rising cost of energy dominates the trends in the variable cost of pumping.

Reinforcing the argument that the principle factor behind the increasing cost of groundwater pumping would be the cost of energy and not the rate of groundwater decline, is to note which two districts would find the variable cost of CAP water competitive with the variable cost of pumping relatively early in the project. The two were Harquahala and Tonopah, which shared the highest, fastest-growing electricity rate among those of all the districts studied. While Harquahala also has deep pumping lifts and rapid rates of groundwater decline, Tonopah actually has the second <u>shallowest</u> pumping lift (only after the district pumps in San Carlos) in the study area and only a moderate rate of groundwater decline. Clearly, the depth to lift is not the determining factor in projecting the economic feasiblity of groundwater pumping in the future.

The last major factor which tends to make the CAP appear unfavorable is the high level of fixed costs which the irrigation districts would have to assume, especially with respect to their groundwater pumping facilities. They would have to maintain their pumps at twice and sometimes three times their average demand capacity for many years before CAP deliveries dropped off enough to allow groundwater pumping to return to a more efficient level of activity. But while the groundwater facility would eventually resume operating at normal capacity, the CAP facility would at the same time tend to be used at a progressively lower capacity, with correspondingly less cost efficiency. As the average fixed costs of groundwater pumping moderated, those of the CAP would rise steadily.

Two key assumptions governing the behavior of the model under the sustained maximum CAP allocation scenario are worth criticizing. The first is that it is doubtful that the delivery security of CAP water could ever be sufficient to enable a wholescale divestment of the redundant groundwater pumping capacity. The second problem, also in the form of a rather strong bias in favor of the CAP, is the assumption that allocations of CAP could be sustained at a continuously high level without increasing its real variable costs over time. The alternatives for increasing the flow of Colorado River water to agriculture via the CAP are limited. Among the possiblities are buying out other claims (both within and outside of Arizona) to the water, increasing mountain runoff, and diverting supplies from other distant water sources, such as icebergs and entire river systems, into the Colorado. Probably without exception, these solutions are all either politically impossible, detrimental to the environment, or, where not otherwise constrained, extremely costly to develop.

Sensitivity Analysis

The results of the sensitivity analysis are mixed. The rate of discount generally has little or no effect on the relative favor or disfavor which alternative scenarios cast upon the CAP in each irrigation district. Sometimes moderate changes in the rate of groundwater decline would effect the outcome of the model, but usually these rates would have to be unrealistically high or low relative to the baseline estimates in order to change the evaluation of the CAP. The conclusion about the rate of energy cost escalation is similar.

In most districts, a high rate of real energy cost escalation, between about 2.5 and 4.5 percent, is sufficient to make the CAP appear favorable under either allocation scenario. Usually a low rate of energy cost escalation, between about -1.0 and 1.0 percent, is sufficient to make the CAP appear unfavorable under either allocation scenario. Generally, therefore, it may be suggested that if the cost of energy for groundwater pumping over the next 50 years rises below, at, or only slightly above the rate of inflation, then the CAP could never be justified. If, on the other hand, the cost of energy for groundwater pumping rose at a rate significantly above that of inflation, then the CAP could almost always be justified. Ultimately, it will be the cost of energy and not the purported hydrologic benefits of the CAP that will determine its relative economic worth.

Credibility of the Estimated Rates of Groundwater Decline and Energy Cost Escalation

Groundwater declines in Central Arizona in the past have been observed at rates of 5 feet per year, 10 feet per year, and sometimes even more. However, such rates are now almost unheard of. An examination of well records published by the Geological Survey indicates that since the early and mid 1970's the rate of groundwater decline is the slowest it has been in several decades. Typical rates of groundwater decline in the agricultural areas of central Arizona now rarely exceed 4 or 5 feet per year, and usually amount to far less. In several areas where historic declines had once been large and where the CAP is considered a top priority, the average rate over the last 10 years has been less than 2 feet. From the peak of groundwater withdrawals and overdraft in the 1950's and 1960's, the hydrological balance in central Arizona has slowly begun to move towards a rough equilibrium.

It therefore seems extremely unlikely that irrigation districts in central Arizona will ever experience the high rates of groundwater decline indicated by the sensitivity analysis as those which would be necessary to change the unfavorable outcomes of the projections. On the other hand, the low rates that would be necessary to change most of the favorable outcomes do not seem so far-fetched. Large areas of rural central Arizona already experience rates of groundwater decline of less than 2 feet per year. It may not take much more of a reduction in water use (or an increase in the levels of incidental recharge) before that rate could fall to zero. At that point, even with the unrealistic assumption that the real variable cost of the CAP would remain constant, the CAP probably could not pay for itself.

Whether or not the unit cost of energy will continue to rise faster than the rate of inflation for an extended period of time, and if so how much, are matters of conjecture beyond the scope of this study. However, the specific rate at which the cost of energy increases faster or slower than the rate of inflation is really not the issue. The point which does come to bear on this study is to what extent, if any, the cost of energy for groundwater pumping will move up or down relative to the cost of the energy used to move CAP water.

The energy escalation rate for the CAP is naively held constant at zero, while the rates for groundwater pumping are varied up to over 4 percent and down below -2 percent. Over time, this method of projection creates fantastic differences between the mil rate for electricity used to move water via the CAP the projected mil rate for groundwater pumping. Consider the baseline analysis of the Central Arizona, Hohokam, New Magma, and San Carlos Irrigation districts. The electricity rate rises from only slightly higher than the CAP's current mil rate of 20 per kilowatt hour to 35 in 1988, 45 in 2014, and over 55 in 2034, more than double the assumed charge from the Navajo power station. In Queen Creek and Maricopa Stanfield, the rate rises from about 35 per kilowatt hour in 1984 to 65 in 2024 to almost 77 mils per kilowatt hour in 2034, nearly four times the Navajo rate. In the worst case, that represented in Harquahala and Tonopah, the mil rate starts at nearly three times the Navajo power station rate in 1984, and rises to more than seven times that rate by 2034. It is no wonder that the CAP soon appears enormously less expensive than groundwater in these areas.

The baseline projections in themselves already suggest a rather unrealistic disparity between the power rates for CAP water and groundwater. The "extreme" energy cost escalation scenarios of the sensitivity analysis may therefore do nothing but push the respective energy costs for groundwater and the CAP back towards some rough equality. In Harquahala, for example, an energy cost escalation factor of 1.25 percent below the rate of inflation will turn the CAP into an undesireable project. Yet, the mil rate for groundwater pumping is still consistently higher than the mil rate for pumping CAP water. By 2034, after 50 years of steadily declining real energy prices for groundwater pumping, the mil rate in Harquahala is still estimated to be almost eight mils higher than Navajo's rate.

Perhaps it would be more realistic to assume that over the long term the respective unit energy costs for pumping CAP water and for pumping groundwater should trend in the same general direction. Some power users may continue to enjoy subsidized energy prices, but not to the extent so generously assumed in the model. The "extreme" energy cost escalation scenarios on the low side may actually tell a more credible story of what could happen to the relative costs of CAP water and groundwater than their baseline counterparts. If so, then the potential net losses to agriculture from the CAP could be even greater than the results suggest.

CHAPTER 7

CONCLUSIONS

> My observations of a number of federal water projects suggest that to identify lesser-cost alternatives involving other than federal construction are seldom pursued with any reasonable vigor and are never successful. Of course, the least cost alternative may mean no public action at all, a course of action that gets insufficient attention.
>
> - Robert Young, 1978

Water policy in the arid Southwest has traditionally been one of increasing supply. Water officials and layman alike view additional water and economic growth as synonymous. Contrary to the admonitions of most economists, water is considered an absolute necessity, a good with few substitutes (Miller and Underwood, 1983). Much analytical attention has been devoted to the question of how to develop additional or substitute water supplies rather than in determining whether existing supplies are being well utilized (Hirschleifer, 1960).

Water authorities in Arizona have steadfastly adhered to the belief that the long-run supply of water in the state, and consequently the health of the regional economy, is threatened by the progressive depletion of the groundwater stocks. Water, the "scarcest and most precious" resource in the desert, has been shamelessly "wasted" by Arizona's "profligate ways" at an "alarming rate." The CAP is widely regarded as an admittedly expensive, but necessary means of achieving the objective of controlling the overdraft and eventually eliminating it.

A major thrust of this thesis has been to put the problem of groundwater overdraft into its proper economic perspective. When groundwater stocks are depleted, there is no destruction of a scenic amenity. The public health is not threatened, the world is not thrown into a state of godless immorality, and the sanctity of our nation's constitution is violated by no enemy, neither foreign nor domestic. All that does happen is that one resource, groundwater, tends to become more scarce relative to other sources of water, and to other resources in general.

Young (1969) argued that the exploitation of relatively inexpensive groundwater supplies is a rational means of fueling the initial economic development of a local economy. Once developed, the economy might then be willing to pay, if groundwater supplies proved inadequate, for the development of water from other more expensive sources, such as the CAP. Kelso, Martin, and Mack (1973) noted that the economy of Arizona is now highly developed, but it has not yet reached the point where water is scarce enough to warrant the development of the CAP. Water has and continues to be a relatively cheap and abundant resource. Large quantities are still being used today for the production of only marginal profitable economic goods. There is no evidence that water is becoming a limiting factor on economic growth in Arizona, nor that it may become one in the foreseeable future.

Kelso, Martin, and Mack (1973) suggested that Arizona could more effectively manage its water resources for economic growth by facilitating the transfer of existing water from lower to higher economic uses, rather than by investing in the development of costly new supplies. Martin and Young (1969) argued that higher (generally, municipal and industrial) user classes of water should not suffer any serious economic consequences from increasing water scarcity. Since their demand for water is high relative to agriculture, they should, in the absence of intitutional constraints, always be able to obtain adequate supplies of relatively inexpensive water by bidding supplies away from its traditional uses in irrigation. Martin and Young observed that regional growth in Arizona and elsewhere had already been successfully achieved through this process, the most notable example being the process of urbanization in the Salt River Project. The first economic sector to face decline in the face of increasing water scarcity, and the one the most interested in finding cheap and abundant sources of water, is therefore irrigated agriculture.

Since agricultural users of water are the marginal users, any additional (or substitute) water must be evaluated at its incremental value in agriculture. It is at this margin where alternative water supplies must be competitive. Farmers would benefit from importing water via the CAP only to the extent that this supply contributed to their net income by reducing their water costs or by allowing the profitable production of additional low-valued crops.

Several conclusions about the worth of the CAP for irrigated agriculture in Central Arizona may be noted. The first is that agriculture as a whole should expect to suffer a significant net loss as a result of contracting for CAP water. Even under fairly pessimistic assumptions about the future of groundwater conditions and the real cost of energy for groundwater pumping, assumptions which tend to make the CAP appear more favorable than it really would be, choosing the project over the no-project alternative would cause a net loss to nearly all of the agricultural areas studied over the next 50 years.

A second conclusion is that the blame for the rising cost of groundwater pumping in Central Arizona appears to be misplaced. The most fundamental cause of the problem of increasing real pumping costs is not the growing depths from which groundwater must be recovered, but rather the rising real cost of energy.

The CAP will have to lift water from 1,000 to 2,700 feet from the Colorado River up to the various agricultural users. Few irrigators are currently pumping groundwater from depths much in excess of 600 feet, and, at current rate of overdraft, fewer still are likely to reach a depth of as much as 1,000 feet in the foreseeable future. Under certain very limited circumstances CAP water does in fact appear to be competitive with groundwater, but only because it enjoys the advantage of having an extremely cheap source of energy from which to draw. Were the unit cost of the energy consumed by the CAP the same as that typically charged in Central Arizona, the project could virtually never deliver water at a competitive price to agriculture anywhere along its line of supply.

The evidence clearly suggests that the CAP is a "solution" to the wrong problem. It wastes energy in order to conserve groundwater, even though energy is economically far more "scarce" than groundwater. In the logic of economics, scarce resources should be used sparingly while more abundant ones are exploited more heavily, and not the other way around. Far greater social benefit could probably be enjoyed in Arizona by simply releasing the cheap energy supply reserved for the CAP and using that supply to pump groundwater instead of wasting it on moving the Colorado River. In the distant future, should groundwater pumping lifts increase to levels of 1,000 or 2,000 feet, or well yields deteriorate to the point where the energy requirement for lifting a unit of water grows prohibitively expensive relative to the alternatives, then perhaps it may become worthwhile to pump Colorado River water uphill 2,700 feet and overland 300 miles. In the meantime, investment resources are probably better employed elsewhere.

A third conclusion which may be inferred from the course of the analysis is that the CAP may not be a wise choice even though it appears to leave some farmers better off than before, because the opportunity cost of investing in the CAP may exceed the returns to the project. New technological developments in irrigation techniques designed to increase irrigation efficiency, such as lasar leveling and drip irrigation, have the potential of reducing the costs of irrigation water far more than will the CAP, and of reducing the costs immediately (Wilson, Ayer, and Snyder, 1984). Not only would the effects of such investments sharply reduce the demand for groundwater, but they would do so consistently, progressively, and indefinitely, not in the eratic and unpredictable manner characteristic of the CAP.

These alternative investments, like the CAP, are expensive. They may be so expensive that they will compete for capital funds which have already been allocated to the CAP. It is possible that farmers may not be able to afford to pay for the importation of Colorado River water <u>and also</u> make other timely and important investments which might benefit them considerably more. The CAP will divert a large amount of scarce investment resources into a costly and lengthy program of questionable value. In doing so it may destroy the entreprenurial flexibility that farmers will need to survive. Ultimately it may cut short the future of Central Arizona agriculture instead of providing it with a new one.

The positive benefits of overdrafting Arizona'a groundwater stocks have and continue to outweight the negative effects produced as a result of that activity. Mining these reserves does not constitute irresponsible or shortsighted exploitation so long as all the present and future costs of extraction are accounted for. It has been argued in this thesis, as it has in previous studies, that the groundwater stock may continue to be reduced and pumping lifts allowed to deepen for quite some time to come before serious economic adjustments will have to be made.

Water supply problems should and are receiving increasing attention, because water is becoming less abundant relative to a number of other resources. It is in transition from an almost free, or at least a very cheap good, to a more expensive commodity (Hirschleifer, 1960). Indications are that a more comprehensive and active management of water resources is becoming necessary. However, there is no effective case yet to be made in Arizona for the implementation of any water rescue mission on the scale of the CAP, nor is there any need in the foresseable future to attempt to "balance the water budget."

It has been shown that none of the potential economic benefits associated with the CAP would be significant enough to make the project cost-effective for a long time to come. Any justification for building the CAP today must therefore be found outside the sphere of economics; typically in such cases the next place one ought to look is somewhere in the middle of the political arena.

APPENDIX A

GROUNDWATER PUMPING COSTS

Table A1. Relationship of Average Fixed Groundwater Pumping Costs in 1984 to Pumping Depth to Lift.

Pump Lift (ft)	Various Estimated Fixed Pumping Costs ($/af)	Average Fixed Cost ($/af)	"Fitted" Average Fixed Cost ($/af)
200	5.56	5.56	6.0
250	6.64	6.64	6.8
300	8.96	8.96	7.6
350	8.03, 9.35	8.69	8.4
400	9.08, 9.82, 10.40	9.77	9.2
450	9.32, 10.62, 10.76	10.23	10.0
500	8.61, 9.94, 11.13, 8.31	9.50	10.8
550	9.10, 10.26, 11.69, 9.09	10.04	11.6
600	14.69, 14.11, 12.85, 10.63 12.08, 11.59, 15.42, 12.05 15.83, 9.20	12.85	12.4
650	10.38, 15.86, 13.19, 15.87 16.38	14.34	13.2
700	15.93, 13.62, 13.31, 12.13 16.68, 16.88, 10.38	14.13	14.0
750	11.63, 16.78, 13.97, 13.85 13.72, 17.13, 17.77, 11.46	14.54	14.8
800	16.80, 14.40, 17.60, 18.33 11.90	15.81	15.6
850	17.45, 16.06, 14.41, 14.33 18.02, 18.62	16.48	16.4
900	18.14, 19.94, 19.11	19.06	17.2
950	16.86	16.86	18.0
1000	19.01	19.01	18.8
1050	17.50	17.50	19.6

Overall, average fixed pumping costs appear to increase at a rate of approximately 80 cents per acre-foot per 50 feet of increased lift.

Sources: Hathorn, Scott. Arizona Pumpwater Budgets. Cooperative Extension Service, 1984.

Johnston Pump Company. Johnston Engineering Data Book, # 753.

Personal Communications, Dr. Scott Hathorn, 1984.

Table A2. Variable Pumping Costs in Central Arizona, 1975 - 1984.

Maricopa County

Year	Gila Bend ($/af)	Aguila ($/af)	Rainbow Valley ($/af)	Harquahala ($/af)	Queen Creek ($/af)
1975	29.83	49.71	47.22	57.17	57.17
1976	32.11	53.08	50.52	60.97	60.93
1977	35.35	58.96	55.34	66.87	66.84
1978	32.44	56.17	51.35	61.44	61.67
1979	31.15	55.24	49.90	60.08	60.16
1980	32.80	58.07	52.49	63.26	63.34
1981	29.78	52.76	47.67	57.43	57.50
1982	36.10	63.96	57.79	69.64	69.73
1983	33.27	58.95	53.25	64.14	64.23
1984	34.53	61.32	55.32	66.50	66.65

Pima County

	Avra Valley ($/af)	Marana ($/af)
1975	37.46	32.10
1976	39.93	34.02
1977	56.99	48.92
1978	42.86	37.31
1979	52.10	46.07
1980	49.87	43.97
1981	48.18	42.49
1982	45.83	40.41
1983	63.98	54.98
1984	60.90	52.34

Table A2, continued.

Pinal County

Year	Coolidge ($/af)	Casa Grande ($/af)	Eloy ($/af)	Maricopa ($/af)	Stanfield ($/af)
1975	32.56	50.16	50.12	39.67	64.43
1976	21.96	30.84	32.57	29.16	64.29
1977	19.00	26.57	29.94	27.82	70.81
1978	24.62	34.55	28.08	29.09	38.17
1979	22.66	31.77	30.87	26.68	35.62
1980	20.95	29.38	29.45	22.92	30.56
1981	19.86	27.84	30.02	29.90	38.66
1982	22.52	31.57	28.95	39.08	30.23
1983	26.12	36.64	39.49	37.63	48.65
1984	24.13	33.84	36.48	39.92	51.62

All values are expressed in terms of constant 1984 dollars.

Source: Hathorn, Scott. Arizona Pumpwater Budgets. Cooperative Extension Service, 1975 - 1984.

APPENDIX B

MARGINAL VALUE PRODUCT OF IRRIGATION WATER ON SELECTED CROPS

Table B1. Marginal Value Product of Irrigation Water on Selected Crops in Maricopa County in 1984

Crop	Gross Receipts ($/acre)	Variable Costs, Less Water ($/af)	Net Returns to Water ($/acre)	Water Used (af/acre)	Marginal Value Product ($/af)
Melons	1500	464	1036	3.00	345
Oranges	1547	503	1044	5.15	203
Lemons	2616	1633	983	5.15	191
Vegetables and Specialty Crops					150
Grapefruit	1300	590	710	5.15	138
Pima Cotton	1123	486	637	6.00	106
Upland Cotton	1021	485	537	5.50	98
Alfalfa	785	215	571	6.00	95
Corn	595	302	293	3.50	84
Milling Wheat	360	150	210	2.83	74
Durham Wheat	330	150	179	2.83	63
Barley	263	141	122	2.67	46
Sorghum	235	121	115	3.00	38
Safflower	273	111	162	4.50	36

Sources:

Brantner, Ron. Arizona Agricultural Statistics. Arizona Crop and Livestock Reporting Service, 1979 - 1984.

Hathorn, Scott. Arizona Field Crop Budgets. 1984.
Arizona Citrus Crop Budgets. 1982.
Cooperative Extension Service, University of Arizona.

Table B2. Marginal Value Product of Irrigation Water on Selected Crops in Pima County in 1984.

Crop	Gross Receipts ($/acre)	Variable Costs, Less Water ($/af)	Net Returns to Water ($/acre)	Water Used (af/acre)	Marginal Value Product ($/af)
Vegetables and Specialty Crops					150
Pecans	1530	703	827	6.92	120
Pima Cotton	889	412	477	4.00	119
Upland Cotton	736	337	399	3.50	114
Durham Wheat	350	159	191	3.33	57
Milling Wheat	327	159	168	3.33	50
Barley	280	155	124	3.00	41
Sorghum	281	150	131	3.17	41
Alfalfa	322	117	205	6.00	34

Sources:

Brantner, Ron. Arizona Agricultural Statistics. Arizona Crop and Livestock Reporting Service, 1979 - 1984.

Hathorn, Scott. Arizona Field Crop Budgets. Arizona Pecan Budgets. Cooperative Extension Service, 1984.

Table B3. Marginal Value Product of Irrigation Water on Selected Crops in Pinal County in 1984.

Crop	Gross Receipts ($/acre)	Variable Costs, Less Water ($/af)	Net Returns to Water ($/acre)	Water Used (af/acre)	Marginal Value Product ($/af)
Vegetables and Specialty Crops					150
Pecans	1530	703	827	6.92	120
Upland Cotton	900	424	476	5.00	95
Pima Cotton	845	411	433	5.00	87
Alfalfa	705	296	409	6.25	65
Milling Wheat	320	156	164	2.96	56
Durham Wheat	319	156	163	2.96	55
Safflower	324	134	190	4.42	43
Barley	248	148	92	2.67	34
Sorghum	193	145	48	3.67	13

Sources:

Brantner, Ron. Arizona Agricultural Statistics. Arizona Crop and Livestock Reporting Service, 1979 - 1984.

Hathorn, Scott. Arizona Field Crop Budgets.
Arizona Pecan Budgets.
Cooperative Extension Service, 1984.

Table B4. Marginal Value Product of Irrigation Water on Selected Crops, 1975 - 1984.

Year	Upland Cotton ($/af)	Alfalfa ($/af)	Wheat ($/af)
	Maricopa County		
1975	149.42	68.04	70.93
1976	204.22	94.38	111.51
1977	119.02	88.22	41.06
1978	107.56	44.21	38.73
1979	144.59	75.15	67.78
1980	154.61	72.38	86.53
1981	83.80	51.22	92.80
1982	80.24	37.77	60.51
1983	111.12	87.26	82.14
1984	97.60	95.12	74.30
	Pima County		
1975	191.63	30.21	58.66
1976	224.69	51.35	94.27
1977	106.21	33.18	57.22
1978	83.73	32.66	52.31
1979	151.87	46.80	67.38
1980	154.81	46.46	58.92
1981	59.73	67.73	77.82
1982	89.41	42.74	46.27
1983	129.68	57.76	60.58
1984	113.92	50.31	50.31

Table B4, continued.

Year	Upland Cotton ($/af)	Alfalfa ($/af)	Wheat ($/af)
		Pinal County	
1975	96.21	67.96	70.64
1976	198.09	67.56	111.07
1977	132.32	70.86	48.92
1978	98.91	16.02	52.62
1979	141.00	72.36	72.66
1980	160.30	62.07	76.09
1981	107.87	41.88	82.62
1982	79.67	40.06	49.94
1983	108.41	64.14	63.01
1984	95.22	65.39	55.56

All values are expressed in terms of constant 1984 dollars.

Sources:

Brantner, Ron. Arizona Agricultural Statistics. Arizona Crop and Livestock Reporting Service, 1979 - 1984.

Hathorn, Scott. Arizona Field Crop Budgets. Cooperative Extension Service, 1975 - 1984.

APPENDIX C

FACTOR COST-VALUE RATIO OF WATER ON SELECTED CROPS

Table C1. Factor Cost-Value Ratio of Water on Alfalfa, 1975 - 1984.

Year	Variable Pumping Cost ($/af)	Marginal Value Product of Water ($/af)	Variable Pumping Cost as a Percentage of Marginal Value Product (Factor Cost-Value Ratio)
	Queen Creek Area - Maricopa County		
1975	57.17	68.04	84
1976	60.93	94.38	65
1977	66.84	88.22	76
1978	61.67	44.21	139
1979	60.16	75.15	80
1980	63.34	72.38	88
1981	57.50	51.22	112
1982	69.73	37.77	185
1983	64.23	87.26	74
1984	66.65	95.12	70
	Avra Valley Area - Pima County		
1975	37.46	30.21	124
1976	39.93	51.35	78
1977	56.99	33.18	172
1978	42.86	32.66	131
1979	52.10	46.80	111
1980	49.87	46.46	107
1981	48.18	67.73	71
1982	45.83	42.74	107
1983	63.91	57.76	111
1984	60.90	50.31	121

Table C1, continued.

Year	Variable Pumping Cost ($/af)	Marginal Value Product of Water ($/af)	Variable Pumping Cost as a Percentage of Marginal Value Product (Factor Cost-Value Ratio)
	Eloy Area - Pinal County		
1975	50.12	67.96	74
1976	32.57	67.56	48
1977	29.94	70.86	42
1978	28.08	16.02	175
1979	30.87	72.36	43
1980	29.45	62.07	47
1981	30.02	41.88	72
1982	28.95	40.06	72
1983	39.49	64.14	62
1984	36.48	65.39	56

All values are expressed in terms of constant 1984 dollars.

Sources:

Brantner, Ron. Arizona Agricultural Statistics. Arizona Crop and Livestock Reporting Service, 1979 - 1984.

Hathorn, Scott. Arizona Pumpwater Budgets. Arizona Field Crop Budgets. Cooperative Extension Service, 1975 - 1984.

Table C2. Factor Cost-Value Ratio of Water on Cotton, 1975 - 1984.

Year	Variable Pumping Cost ($/af)	Marginal Value Product of Water ($/af)	Variable Pumping Cost as a Percentage of Marginal Value Product (Factor Cost-Value Ratio)
	Queen Creek Area - Maricopa County		
1975	57.17	149.42	38
1976	60.93	204.22	30
1977	66.84	119.02	56
1978	61.67	107.56	57
1979	60.16	144.59	42
1980	63.34	154.61	41
1981	57.50	83.80	69
1982	69.73	80.24	87
1983	64.23	111.12	58
1984	66.65	97.60	68
	Avra Valley Area - Pima County		
1975	37.46	191.63	20
1976	39.93	224.69	18
1977	56.99	106.21	54
1978	42.86	83.73	51
1979	52.10	151.87	34
1980	49.87	154.81	32
1981	48.18	59.73	81
1982	45.83	89.41	51
1983	63.91	129.68	49
1984	60.90	113.92	53

Table C2, continued.

Year	Variable Pumping Cost ($/af)	Marginal Value Product of Water ($/af)	Variable Pumping Cost as a Percentage of Marginal Value Product (Factor Cost-Value Ratio)
		Eloy Area - Pinal County	
1975	50.12	96.21	52
1976	32.57	198.09	16
1977	29.94	132.32	23
1978	28.08	98.91	28
1979	30.87	141.00	22
1980	29.45	160.30	18
1981	30.02	107.87	28
1982	28.95	79.67	36
1983	39.49	108.41	36
1984	36.48	95.22	38

Table C3. Factor Cost-Value Ratio of Water on Wheat,1975- 1984.

Year	Variable Pumping Cost ($/af)	Marginal Value Product of Water ($/af)	Variable Pumping Cost as a Percentage of Marginal Value Product (Factor Cost-Value Ratio)
	Queen Creek Area - Maricopa County		
1975	57.17	70.93	81
1976	60.93	111.51	55
1977	66.84	41.06	163
1978	61.67	38.73	159
1979	60.16	67.78	89
1980	63.34	86.53	73
1981	57.50	92.80	62
1982	69.73	60.51	115
1983	64.23	82.14	78
1984	66.65	74.30	90
	Avra Valley Area - Pima County		
1975	37.46	58.66	64
1976	39.93	94.27	42
1977	56.99	57.22	100
1978	42.86	52.31	82
1979	52.10	67.38	77
1980	49.87	58.92	85
1981	48.18	77.82	62
1982	45.83	46.27	99
1983	63.91	60.58	105
1984	60.90	50.31	121

Table C3, continued.

Year	Variable Pumping Cost ($/af)	Marginal Value Product of Water ($/af)	Variable Pumping Cost as a Percentage of Marginal Value Product (Factor Cost-Value Ratio)
		Eloy Area - Pinal County	
1975	50.12	70.64	71
1976	32.57	111.07	29
1977	29.94	48.92	61
1978	28.08	52.62	53
1979	30.87	72.66	42
1980	29.45	76.09	39
1981	30.02	82.62	36
1982	28.95	49.94	58
1983	39.49	63.01	63
1984	36.48	55.56	66

All values are expressed in terms of real 1984 dollars.

Sources:

Brantner, Ron. Arizona Agricultural Statistics. Arizona Crop and Livestock Reporting Service, 1979 - 1984.

Hathorn, Scott. Arizona Pumpwater Budgets.
Arizona Field Crop Budgets.
Cooperative Extension Service, 1975 - 1984.

APPENDIX D

MARGINAL SOCIAL COST OF GROUNDWATER PUMPING AND OVERDRAFT

Table D1. Derivation of the Marginal Social Cost of Groundwater Pumping in 1984.

District	MEC ($/af)	MXC, Fixed ($/af)	MXC, Variable ($/af)	SUB ($/af)	MXC, Total ($/af)	MSC ($/af)
Irrigation Districts in Maricopa County						
Chandler Hts	35.31	1.03	3.79	0.30	5.12	40.43
Harquahala	66.50	2.75	19.05	0.80	22.60	89.10
MCMWCD #1	45.91	1.03	5.01	0.30	6.34	52.25
Queen Creek	46.69	1.03	5.01	0.30	6.34	53.03
RWCD	28.54	1.03	5.01	0.30	6.34	34.88
San Tan	41.00	1.37	5.87	0.40	7.64	48.64
Tonopah	52.42	1.03	7.14	0.30	8.47	60.89
Irrigation Districts in Pima County						
Avra Valley	60.90	1.03	10.47	0.30	11.80	72.70
Cortaro	5.24	0.69	0.94	0.10	1.73	6.97
Marara	14.19	0.69	1.88	0.20	2.77	16.96
Irrigation Districts in Pinal County						
Central Az	36.48	1.03	3.79	0.30	5.12	41.60
Hohokam	24.13	1.03	3.79	0.30	5.12	65.73
Mar-Stanfld	48.39	1.29	6.93	0.40	8.62	57.01
New Magma	33.03	1.29	4.73	0.40	6.42	39.45
San Carlos	24.13	1.03	3.79	0.30	5.12	29.25

MEC: Marginal Unit Cost (Private).
MXC: Marginal External Cost.
SUB: Subsidence Cost.
MSC: Marginal Social Cost.

Sources:

Hathorn, Scott.
Arizona Field Crop Budgets.
Arizona Pumpwater Budgets.
Cooperative Extension Service, 1984.

McCauley, Charles. Unpublished Doctoral Dissertation, 1973.

Personal Communications with Irrigation Districts, 1984.

Table D2. Marginal Social Cost of groundwater pumping per acre foot in 1984, under alternative energy cost escalation and groundwater decline scenarios.

Chandler Heights Citrus Irrigation District - Maricopa County

Depth to lift		=	600 feet
Cost of electricity		=	25.00 mils/Kwh
Marginal Private Pumping Cost		=	35.31 $/af
Marginal Value Product of Water on	Oranges	=	207.72 $/af
	Lemons	=	190.90 $/af
	Grapefruit	=	137.94 $/af
Discount rate		=	4 percent
Planning horizon		=	50 years

Groundwater Decline (ft)	Energy Escalation Rate (percent increase over inflation) 0	1	2	3
0	35.31	41.42	47.53	53.64
1	37.02	43.13	49.24	55.35
2	38.73	44.84	50.95	57.06
3	40.44	46.55	52.66	58.77
4	42.15	48.26	54.37	60.48
5	43.86	49.97	56.08	62.19
8	48.99	55.10	61.21	67.32
10	52.41	58.52	64.63	70.74

Table D3. Marginal Social Cost of groundwater pumping per acre foot in 1984, under alternative energy cost escalation and groundwater decline scenarios.

Harquahala Irrigation District - Maricopa County

Depth to lift = 600 feet
Cost of electricity = 52.42 mils/Kwh
Marginal Private Pumping Cost = 66.50 $/af
Marginal Value Product
of Water on Upland Cotton = 97.60 $/af
Alfalfa = 95.12 $/af
Durham Wheat = 63.18 $/af
Discount rate = 4 percent
Planning horizon = 50 years

	Energy Escalation Rate (percent increase over inflation)			
Groundwater Decline (ft)	0	1	2	3
0	66.50	79.31	92.12	104.93
1	69.32	82.13	94.94	107.75
2	72.14	84.95	97.76	110.57
3	74.96	87.77	100.58	113.39
4	77.78	90.59	103.40	116.21
5	80.60	93.41	106.22	119.03
8	89.06	101.87	114.68	127.49
10	94.70	107.51	120.32	133.13

Table D4. Marginal Social Cost of groundwater pumping per acre foot in 1984, under alternative energy cost escalation and groundwater decline scenarios.

Maricopa County Municipal Water Conservation District #1 -
Maricopa County

Depth to lift = 590 feet
Cost of electricity = 35.00 mils/Kwh
Marginal Private Pumping Cost = 45.91 $/af
Marginal Value Product
of Water on Upland Cotton = 97.60 $/af
Alfalfa = 95.12 $/af
Durham Wheat = 63.18 $/af
Discount rate = 4 percent
Planning horizon = 50 years

	Energy Escalation Rate (percent increase over inflation)			
Groundwater Decline (ft)	0	1	2	3
0	45.91	54.32	62.73	71.14
1	48.03	56.44	64.85	73.26
2	50.15	58.56	66.97	75.38
3	52.27	69.68	69.09	77.50
4	54.39	62.80	71.21	79.62
5	56.51	64.92	73.33	81.74
8	62.87	71.28	79.69	88.10
10	67.11	75.52	83.93	92.34

Table D5. Marginal Social Cost of groundwater pumping per acre foot in 1984, under alternative energy cost escalation and groundwater decline scenarios.

Queen Creek Irrigation District - Maricopa County

Depth to lift		=	600	feet
Cost of electricity		=	35.00	mils/Kwh
Marginal Private Pumping Cost		=	46.69	$/af
Marginal Value Product of Water on	Upland Cotton	=	97.60	$/af
	Alfalfa	=	95.12	$/af
	Durham Wheat	=	63.18	$/af
Discount rate		=	4	percent
Planning horizon		=	50	years

Groundwater Decline (ft)	Energy Escalation Rate (percent increase over inflation) 0	1	2	3
0	46.69	55.24	63.80	72.35
1	48.81	57.36	65.92	74.47
2	50.93	59.48	68.04	76.59
3	53.05	61.60	70.16	78.71
4	55.17	63.72	72.28	80.83
5	57.27	65.82	74.38	82.93
8	63.65	72.20	80.76	89.31
10	67.89	76.44	85.00	93.55

Table D6. Marginal Social Cost of groundwater pumping per acre foot in 1984, under alternative energy cost escalation and groundwater decline scenarios.

Roosevelt Water Conservation District - Maricopa County

Depth to lift		=	485	feet
Cost of electricity		=	25.00	mils/Kwh
Marginal Private Pumping Cost		=	28.54	$/af
Marginal Value Product of Water on	Upland Cotton	=	97.60	$/af
	Alfalfa	=	95.12	$/af
	Durham Wheat	=	63.18	$/af
Discount rate		=	4	percent
Planning horizon		=	50	years

Groundwater Decline (ft)	Energy Escalation Rate (percent increase over inflation) 0	1	2	3
0	28.54	33.48	38.42	43.36
1	30.25	35.19	40.13	45.07
2	31.96	36.90	41.84	46.78
3	33.67	38.61	43.55	48.49
4	35.38	40.32	45.26	50.20
5	37.09	42.03	46.97	51.91
8	42.22	47.16	52.10	57.04
10	45.64	50.58	55.52	60.46

Table D7. Marginal Social Cost of groundwater pumping per acre foot in 1984, under alternative energy cost escalation and groundwater decline scenarios.

San Tan Irrigation District - Maricopa County

Depth to lift = 600 feet
Cost of electricity = 30.00 mils/Kwh
Marginal Private Pumping Cost = 41.00 $/af
Marginal Value Product
of Water on Oranges = 207.72 $/af
Lemons = 190.90 $/af
Grapefruit = 137.94 $/af
Discount rate = 4 percent
Planning horizon = 50 years

Groundwater Decline (ft)	Energy Escalation (percent increase over inflation) 0	1	2	3
0	41.00	48.33	55.66	62.99
1	42.91	50.24	57.57	64.90
2	44.82	52.15	59.48	66.81
3	46.73	54.06	61.39	68.72
4	48.64	55.97	63.30	29.63
5	50.55	57.88	65.21	72.54
8	56.28	63.61	70.94	78.27
10	60.10	67.43	74.76	82.09

Table D8. Marginal Social Cost of groundwater pumping per acre foot in 1984, under alternative energy cost escalation and groundwater decline scenarios.

Tonopah Irrigation District - Maricopa County

Depth to Lift		=	350	feet
Cost of electricity		=	52.42	mils/Kwh
Marginal Private Pumping Cost		=	38.79	$/af
Marginal Value Product of Water on	Upland Cotton	=	97.60	$/af
	Alfalfa	=	95.12	$/af
	Durham Wheat	=	63.18	$/af
Discount rate		=	4	percent
Planning horizon		=	50	years

Groundwater Decline (ft)	Energy Escalation Rate (percent increase over inflation) 0	1	2	3
0	38.79	46.26	53.73	61.20
1	41.61	49.08	56.55	64.02
2	44.43	51.90	59.37	66.84
3	47.25	54.72	62.19	69.66
4	50.07	57.54	65.01	72.48
5	52.89	60.36	67.83	75.30
8	61.35	68.82	76.29	83.76
10	66.99	74.46	81.93	89.40

Table D9. Marginal Social Cost of groundwater pumping per acre foot in 1984, under alternative energy cost escalation and groundwater decline scenarios.

Avra Valley Irrigation District - Pima County

Depth to lift		=	375	feet
Cost of electricity		=	79.61	mils/Kwh
Marginal Private Pumping Cost		=	60.90	$/af
Marginal Value Product of Water on	Upland Cotton	=	113.92	$/af
	Alfalfa	=	34.22	$/af
	Durham Wheat	=	57.31	$/af
Discount rate		=	4	percent
Planning horizon		=	50	years

Groundwater Decline (ft)	Energy Escalation Rate (percent increase over inflation) 0	1	2	3
0	60.90	73.06	85.22	97.38
1	64.83	76.99	89.15	101.31
2	68.76	80.92	93.08	105.24
3	72.69	84.85	97.01	109.17
4	76.62	88.78	100.94	113.10
5	80.55	92.71	104.87	117.03
8	92.34	104.50	116.66	128.82
10	100.20	112.36	124.52	136.68

Table D10. Marginal Social Cost of groundwater pumping per acre foot in 1984, under alternative energy cost escalation and groundwater decline scenarios.

Cortaro-Marana Irrigation District (Marana) - Pima County

Depth to lift		= 325	feet
Cost of electricity		= 17.00	mils/Kwh
Marginal Private Pumping Cost		= 14.19	$/af
Marginal Value Product of Water on	Upland Cotton	= 113.92	$/af
	Alfalfa	= 34.22	$/af
	Durham Wheat	= 57.31	$/af
Discount rate		= 4	percent
Planning horizon		= 50	years

Groundwater Decline (ft)	Energy Escalation Rate (percent increase over inflation)			
	0	1	2	3
0	14.19	16.44	19.69	21.94
1	15.57	17.82	21.07	23.32
2	16.95	19.20	22.45	24.70
3	18.33	20.58	23.83	26.08
4	19.71	21.96	25.21	27.46
5	21.09	23.34	26.59	28.84
8	25.23	27.48	30.73	32.98
10	27.99	30.24	33.49	35.74

Table D11. Marginal Social Cost of groundwater pumping per acre foot in 1984, under alternative energy cost escalation and groundwater decline scenarios.

Cortaro-Marana Irrigation District (Cortaro) - Pima County

Depth to lift		=	120	feet
Cost of electricity		=	17.00	mils/Kwh
Marginal Private Pumping Cost		=	5.24	$/af
Marginal Value Product of Water on	Upland Cotton	=	113.92	$/af
	Alfalfa	=	34.22	$/af
	Durham Wheat	=	57.31	$/af
Discount rate		=	4	percent
Planning horizon		=	50	years

Groundwater Decline (ft)	Energy Escalation Rate (percent increase over inflation) 0	1	2	3
0	5.24	6.07	6.90	7.73
1	6.62	7.45	8.28	9.11
2	8.00	8.83	9.66	10.49
3	9.38	10.21	11.04	11.87
4	10.76	11.59	12.42	13.25
5	12.14	12.97	13.80	14.63
8	16.28	17.11	17.94	18.77
10	19.04	19.87	20.70	21.53

Table D12. Marginal Social Cost of groundwater pumping per acre foot in 1984, under alternative energy cost escalation and groundwater decline scenarios.

Central Arizona Irrigation District - Pinal County

Depth to lift		=	620	feet
Cost of electricity		=	25.00	mils/Kwh
Marginal Private Pumping Cost		=	36.48	$/af
Marginal Value Product of Water on	Upland Cotton	=	95.22	$/af
	Alfalfa	=	65.39	$/af
	Durham Wheat	=	55.18	$/af
Discount rate		=	4	percent
Planning horizon		=	50	years

Groundwater Decline (ft)	Energy Escalation Rate (percent increase over inflation) 0	1	2	3
0	36.48	42.79	49.10	55.41
1	38.19	44.50	50.81	57.12
2	39.90	46.21	52.52	58.83
3	41.61	47.92	54.23	60.54
4	43.32	49.63	55.94	62.25
5	45.03	51.34	57.65	63.96
8	50.32	56.63	62.94	69.25
10	53.58	59.89	66.20	72.51

Table D13. Marginal Social Cost of groundwater pumping per acre foot in 1984, under alternative energy cost escalation and groundwater decline scenarios.

Hohokam Irrigation District - Pinal County

Depth to lift		=	410	feet
Cost of electricity		=	25.00	mils/Kwh
Marginal Private Pumping Cost		=	24.13	$/af
Marginal Value Product				
of Water on	Upland Cotton	=	95.22	$/af
	Alfalfa	=	65.39	$/af
	Durham Wheat	=	55.18	$/af
Discount rate		=	4	percent
Planning horizon		=	50	years

Groundwater Decline (ft)	Energy Escalation Rate (percent increase over inflation) 0	1	2	3
0	24.13	28.31	32.49	36.67
1	25.84	30.02	34.20	38.38
2	27.55	31.73	35.91	40.09
3	29.26	33.44	37.62	41.80
4	30.97	35.15	39.33	43.51
5	32.68	36.86	41.04	45.22
8	37.81	41.99	46.17	50.35
10	41.23	45.41	49.59	53.77

Table D14. Marginal Social Cost of groundwater pumping per acre foot in 1984, under alternative energy cost escalation and groundwater decline scenarios.

Maricopa-Stanfield Irrigation District - Pinal County

Depth to lift = 600 feet
Cost of electricity = 36.50 mils/Kwh
Marginal Private Pumping Cost = 48.39 $/af
Marginal Value Product
of Water on Upland Cotton = 95.22 $/af
Alfalfa = 65.39 $/af
Durham Wheat = 55.18 $/af
Discount rate = 4 percent
Planning horizon = 50 years

Groundwater Decline (ft)	Energy Escalation Rate (percent increase over inflation)			
	0	1	2	3
0	48.39	54.50	60.61	66.72
1	50.10	56.21	62.32	68.43
2	51.81	57.92	64.03	70.14
3	53.52	59.63	65.74	71.85
4	55.23	61.34	67.45	25.17
5	56.94	63.05	69.16	75.27
8	62.07	68.18	74.29	80.40
10	65.49	71.60	77.71	83.82

Table D15. Marginal Social Cost of groundwater pumping per acre foot in 1984, under alternative energy cost escalation and groundwater decline scenarios.

New Magma Irrigation District - Pinal County

Depth to lift		=	600	feet
Cost of electricity		=	23.00	mils/Kwh
Marginal Private Pumping Cost		=	33.03	$/af
Marginal Value Product of Water on	Upland Cotton	=	95.22	$/af
	Alfalfa	=	65.39	$/af
	Durham Wheat	=	55.18	$/af
Discount rate		=	4	percent
Planning horizon		=	50	years

Groundwater Decline (ft)	Energy Escalation Rate (percent increase over inflation) 0	1	2	3
0	33.03	38.65	44.27	49.89
1	34.66	40.28	45.90	51.52
2	36.29	41.91	47.53	53.15
3	37.92	43.54	49.16	54.78
4	39.55	45.17	50.79	56.41
5	41.18	46.80	52.42	58.04
8	46.07	51.69	57.31	62.93
10	49.33	54.95	60.57	66.19

Table D16. Marginal Social Cost of groundwater pumping per acre foot in 1984, under alternative energy cost escalation and groundwater decline scenarios.

San Carlos Irrigation District - Pinal County

Depth to lift		=	300	feet
Cost of electricity		=	25.00	mils/Kwh
Marginal Private Pumping Cost		=	17.65	$/af
Marginal Value Product of Water on	Upland Cotton	=	95.22	$/af
	Alfalfa	=	65.39	$/af
	Durham Wheat	=	55.18	$/af
Discount rate		=	4	percent
Planning horizon		=	50	years

Groundwater Decline (ft)	Energy Escalation Rate (percent increase over inflation) 0	1	2	3
0	17.65	20.70	23.75	26.80
1	19.36	22.41	25.46	28.51
2	21.07	24.12	27.17	30.22
3	22.78	25.83	28.88	31.93
4	24.49	27.54	30.59	33.64
5	26.20	29.25	32.30	35.35
8	31.33	34.38	37.43	40.48
10	34.75	37.80	40.85	43.90

APPENDIX E

PROJECTED CAP SUPPLIES AND DELIVERIES

Table E1. Projected CAP Supplies and Deliveries to all Users, 1986 - 2034.

Year	Delivery Supply	Indian	Municipal & Industrial	New Mexico	Non-Indian Agriculture
1986	1564.8	309.8	201.4	18.0	1035.5
1987	1633.3	309.8	211.1	18.0	1094.4
1988	1686.9	309.8	220.8	18.0	1138.2
1989	1704.5	309.8	230.6	18.0	1146.1
1990	1690.8	309.8	240.3	18.0	1122.7
1991	1636.9	309.8	250.0	18.0	1059.0
1992	1651.8	309.8	259.7	18.0	1064.3
1993	1555.9	309.8	269.5	18.0	958.6
1994	1496.9	298.7	270.9	18.0	909.3
1995	1503.8	297.9	279.4	18.0	908.4
1996	1438.2	286.5	279.7	18.0	854.0
1997	1402.9	282.1	287.3	18.0	815.4
1998	1307.0	264.8	279.7	18.0	744.5
1999	1358.2	284.5	304.4	18.0	751.3
2000	1362.8	297.4	325.8	18.0	721.6
2001	1286.0	249.3	289.1	18.0	729.6
2002	1247.3	265.8	314.7	18.0	648.7
2003	1151.3	248.7	304.3	18.0	580.3
2004	1115.3	247.9	315.3	18.0	534.1
2005	1091.9	236.6	307.5	18.0	529.7
2006	1130.4	234.1	310.6	18.0	567.8
2007	1105.7	251.5	338.9	18.0	497.2
2008	989.3	219.1	305.8	18.0	446.4
2009	1089.3	250.1	351.1	18.0	470.1
2010	1118.0	253.9	362.0	18.0	484.1
2011	1065.6	217.4	322.5	18.0	507.7
2012	1066.4	220.8	334.3	18.0	493.2
2013	1056.0	215.6	332.1	18.0	490.3
2014	1052.3	236.8	374.7	18.0	422.8
2015	1059.6	227.4	366.3	18.0	447.8
2016	1076.9	214.4	348.7	18.0	495.8
2017	1022.3	217.6	360.8	18.0	425.9
2018	1028.1	212.7	358.1	18.0	439.3
2019	1011.7	222.3	382.2	18.0	389.2
2020	1003.2	214.3	372.6	18.0	398.3
2021	1017.8	197.5	349.8	18.0	452.5
2022	1022.9	214.3	384.2	18.0	406.5
2023	1012.3	212.7	383.4	18.0	398.2
2024	1002.1	216.7	394.6	18.0	372.8
2025	1067.0	233.9	431.1	18.0	384.0

Table E1, continued.

Year	Delivery Supply	Indian	Municipal & Industrial	New Mexico	Non-Indian Agriculture
2026	1037.5	211.9	395.6	18.0	412.0
2027	991.4	212.1	406.3	18.0	355.0
2028	963.7	212.6	406.5	18.0	326.6
2029	911.6	206.1	398.2	18.0	289.2
2030	967.2	205.9	407.6	18.0	335.7
2031	1044.9	217.7	430.2	18.0	378.9
2032	1110.0	228.6	460.3	18.0	403.1
2033	968.1	212.6	429.5	18.0	308.0
2034	880.7	198.0	400.7	18.0	263.9

All units are expressed in thousands of acre-feet.

Source:

Bureau of Reclamation. Central Arizona Project, New Waddell Sizing Studies Option 2 (Max Winter) March 22, 1982.

Table E2. State of Arizona Recommended Allocation of Central Arizona Project Water for Non-Indian Irrigation (Percent of Available Water)

Water User	1985	2005	2034
	Allocation Year		
Avra Valley	3.69	3.84	4.21
Central Arizona	18.01	18.73	20.55
Chandler Heights	0.28	0.28	0.30
Cortaro-Marana	2.14	2.05	1.99
Fico	1.39	1.44	1.58
Harquahala	7.67	7.98	8.75
Hohokam	6.36	6.61	7.25
Maricopa-Stanfield	20.48	21.30	23.35
McMicken	7.28	5.60	2.61
MCMWCD #1	4.66	3.37	2.88
New Magma	4.34	4.52	4.96
Queen Creek	4.83	4.99	5.42
Roosevelt	2.61	2.72	2.98
RWCD	5.98	5.92	4.84
Salt River Project	2.97	3.05	0.00
San Carlos	4.09	4.25	4.66
San Tan	0.77	0.80	0.86
Tonopah	1.98	2.06	2.26
Other	0.47	0.49	0.55
Total	100.00	100.00	100.00

Source:

Letter dated January 18, 1982, from Arizona Department of Water Resources to the Secretary of the Interior.

APPENDIX F

IRRIGATION DISTRICT FACT SHEETS

Fact Sheet F1.

Central Arizona Irrigation District

Formation

In 1964, for the express purpose of forming a public entity to contract for the delivery of Colorado River water via the CAP.

Location

West-central Pinal County around the town of Eloy, roughly midway between Tucson and Phoenix.

Land Area

144,000 acres, of which approximately 88,000 acres are eligible under state and federal regulations for irrigation and for participation in the CAP. All eligible acreage will be included in the district's project service area.

Water Production and Use in the Project Service Area

320,000 acre feet per year from private irrigation wells.

Major Crops

Cotton (64%), small grains (24%), citrus and pecans(2%), and specialty crops (10%).

Plan of Development

The facilities will consist of a system of canals extending through the district from three turnouts from the Tucson segment of the

CAP Acquaduct. Laterals will convey water from the main canals to individual farm units.

The district's North Main Canal is planned as a multiple-user facility, referred to by the Bureau of Reclamation as the "Santa Rosa Canal." Capacity will be provided in this canal to serve the Maricopa-Stanfield Irrigation District and the Ak Chin and Chiuchu Indian communities. Capacity may also be included for the cities of Casa Grande, Eloy, and Arizona City. All entities will share in the costs of the North Main Canal's construction and maintenance.

The district will acquire all registered and operable irrigation wells, along with all groundwater pumping rights for irrigation, within its service area. The wells will be integrated into the system to permit the conjunctive use of CAP water and groundwater.

Construction will be completed in 1989, at a total cost of about $83.6 million. System OM&R costs, excluding well costs, will amount to about $1.4 million annually.

Initial CAP deliveries may arrive as early as 1987, while full service to all areas of the district should begin by 1989. The volume of CAP deliveries is expected to range from a high of over 200,000 acre feet per year early in the project to as little as 55,000 acre feet by 2034.

Sources

Bookman-Edmonston Engineering, Inc.
Arizona Department of Water Resources.
Bureau of Reclamation.

Fact Sheet F2.

Harquahala Irrigation District

Formation

In 1964, to permit unified action in the application for CAP water and in the solution of common problems such as flood hazard.

Location

Western Maricopa County, about 60 miles from Phoenix.

Land Area

60,500 acres, of which approximately 32,000 acres are eligible under state and federal regulations for irrigation and for participation in the CAP. All eligible acreage will be included in the district's project service area.

Water Production and Consumption in the Service Area

131,300 acre feet per year from private irrigation wells.

Major Crops

Cotton (46%), grains (34%), alfalfa (9%), fruits, vegetables, and specialty crops (11%).

Plan of Development

The facilities will consist of a system of canals extending through the district from turnouts from the Granite Reef section of the CAP acquaduct. Three main canals and two laterals will convey the water to the individual farm units. The system is designed to transport only

CAP water. Landowners will retain ownership and control of their wells, pumps, and other on-farm irrigation facilities. Upon delivery, the CAP supply will be used conjunctively with groundwater.

Construction will be completed by 1986 at a total cost of about $27.6 million. System OM&R costs will amount to about $420,000 annually.

Full CAP service should begin by 1986. The volume of CAP deliveries is expected to range from a high of over 88,000 acre feet per year early in the project, to as little as 23,000 acre feet by 2034.

Sources

Franzoy, Corey, & Associates Consulting Engineers.
Arizona Department of Water Resources.
Bureau of Reclamation.

Fact Sheet F3.

Hohokam Irrigation District

Formation

In 1972, for the express purpose of forming a public entity to contract for the delivery of Colorado River water via the CAP.

Location

West-central Pinal County, near the towns of Coolidge, Florence, and Casa Grande.

Land Area

38,000 acres of which about 32,400 acres are eligible under under state and federal regulations for irrigation and for participation in the CAP. All eligible acreage will be included in the district's project service area.

Water Production and Use in the Project Service Area

138,000 acre feet per year from private irrigation wells.

Major Crops

Cotton (60%), small grains (30%), and vegetables and specialty crops (10%).

Plan of Development

The facilities will consist of a system of canals extending through the district from turnouts from the CAP acquaduct in the vicinity of the Picacho Reservoir. One main canal and three laterals will convey the water to the individual farm units. The system is designed to transport only CAP water. Landowners will retain ownership and control of their wells, pumps, and other on-farm irrigation facilities. Upon delivery, the CAP supply will be used conjunctively with groundwater.

Construction will be completed in 1988 at a total cost of $25.6 million. System OM&R costs will amount to about $638,000 annually.

Full CAP service should begin by 1989. The volume of CAP deliveries is expected to range from a high of over 73,000 acre feet per year early in the project to as little as 19,000 acre feet by 2034.

Sources

Franzoy, Corey, & Associates.
Arizona Department of Water Resources.
Bureau of Reclamation.

Fact Sheet F4.

Maricopa-Stanfield Irrigation District

Formation

In 1962, for the express purpose of forming a public entity to contract for the delivery of Colorado River water via the CAP.

Location

Northwestern Pinal County, north of the Central Arizona Irrigation District and south of the Gila River Indian Reservation.

Land Area

148,000 acres, of which approximately 89,000 acres are eligible under state and federal regulations for irrigation and for participation in the CAP. All eligible acreage will be included in the district's project service area.

Water Production and Use in the Project Service Area

375,000 acre feet per year from private irrigation wells.

Major Crops

Cotton (64%), grains (24%), Pecans (2%), and specialty crops (10%).

Plan of Development

The facilities will consist of a system of canals extending throughout the district from a turnout on the Tucson segment of the CAP acquaduct. Laterals will convey water from the main canal to the individual farm units.

Approximately 55 miles of the main canal are planned as a multiple use facility, referred to by the Bureau of Reclamation as the "Santa Rosa Canal." Capacity in this canal will also serve the Central Arizona Irrigation District and the Ak Chin and Chiuchu Indian communities. Capacity may also be included for the cities of Casa Grande, Eloy, and Arizona City. All entities will share in the costs of the construction and maintenance of the joint system.

The district will acquire all registered and operable irrigation wells, along with all groundwater pumping rights for irrigation, within its service area. The wells will be integrated into the system to permit the conjunctive use of CAP water and groundwater.

Construction will be completed in 1989, at a total cost of about $97.5 million. System OM&R costs, excluding well costs, will amount to about $1.9 million annually.

Initial CAP deliveries may arrive as early as 1987, while full service to all areas in the district should begin by 1989. The volume of CAP deliveries is expected to range from a high of over 230,000 acre feet per year early in the project to less than 62,000 acre feet by 2034.

Sources

Bookman-Edmonston Engineering, Inc.
Arizona Department of Water Resources.
Bureau of Reclamation.

Fact Sheet F5.

New Magma Irrigation District

Formation

In 1965, upon the dissolution of the smaller Magma Irrigation District, which had been organized in 1945. The new district was formed for the purpose of contracting for CAP water.

Location

Northern Pinal County north of the town of Florence, with a small portion of the district extending into southeastern Maricopa County.

Land Area

Originally 36,000 acres, of which approximately 25,000 acres were eligible under state and federal regulations for irrigation and for participation in the CAP. Recently, an additional 2,000 eligible acres were annexed from the neighboring Queen Creek District in a move to consolidate service areas and to improve the efficiency of their respective systems. All 27,000 acres are included in New Magma's project service area.

Water Production and Use in the Project Service Area

100,000 acre feet per year from private irrigation wells.

Major Crops

Cotton (61%), small grains (13%), safflower and sorghum (6%) and specialty crops (20%).

Plan of Development

The facilities will consist of a system of canals and pipelines extending throughout the district from four turnouts on the Salt-Gila Acquaduct segment of the CAP. Laterals will convey water from the main canals to the individual farm units.

The district will acquire all registered and operable irrigation wells, along with all groundwater pumping rights for irrigation, within its service area. The wells will be integrated into the system to permit the conjunctive use of CAP water and groundwater.

Construction will be completed by 1987, at a total cost of about $21.9 million. System OM&R costs, excluding well costs, will amount to about $675,000 annually.

Initial CAP deliveries may arrive as early as 1986, while full service to all areas should begin by 1987. The volume of CAP deliveries is expected to range from a high of over 50,000 acre feet per year early in the project, to as little as 13,000 acre feet by 2034.

Sources

Bookman-Edmonston Engineering, Inc.
Arizona Department of Water Resources.
Bureau of Reclamation.

Fact Sheet F6.

Queen Creek Irrigation District

Formation

In 1923, for the purpose of contracting for low cost electrical power to operate private irrigation pumps on member lands.

Location

Southeastern Maricopa County, just north of the New Magma Irrigation District and about 20 miles outside of the Phoenix metropolitan area.

Land Area

Included approximately 23,000 acres, of which slightly over 21,000 have been under cultivation. Recently, 2,000 acres were withdrawn from the district and annexed by New Magma. The remaining acres eligible for irrigation and included within the Queen Creek Service area therefore total about 19,000.

Water Production and Use in the Project Service Area

Adjusting for the withdrawal of the 2.000 acres, approximately 70,000 acre feet per year from private irrigation wells.

Major Crops

Cotton (54%), grains (23%), corn (10%), vegetables (13%).

Plan of Development

The facilities will consist of a joint distribution system with the San Tan and Chandler Heights Irrigation Districts.

The system design has been reworked extensively since the original plan published in 1981. Descriptions of the new design have not yet been released.

Only CAP water will be delivered to the Queen Creek district. Landowners will retain ownership and control of their wells, pumps, and other on-farm irrigation facilities. Upon delivery, the CAP supply will be used conjunctively with groundwater.

Preliminary estimates of the updated construction costs indicate that the nominal sum is similar to that proposed in 1981. Construction will be completed by 1987 at a total cost of $10.1 million. System OM&R costs will amount to about $500,000 annually.

Full CAP service should begin by 1987. The volume of CAP deliveries is expected to range from a high of over 55,000 acre feet per year early in the project to as little as 14,000 acre feet by 2034.

Sources

W. S. Gookin & Associates.
Arizona Department of Water Resources.
Bureau of Reclamation.

Fact Sheet F7.

San Carlos Irrigation District

Formation

In 1924, as part of the San Carlos Project to develop the water and power resources of the Gila River for agricultural development.

Location

Central Pinal County, near the towns of Coolidge, Casa Grande, and Florence.

Land Area

Includes 50,000 acres, of which about 38,000 acres are under cultivation and eligible under state and federal regulations for irrigation and for participation in the CAP. Due to the special status of the San Carlos Irrigation District as a component of the San Carlos Project, somewhat more than 38,000 acres may be irrigated early in the project for a short time.

Water Production and Use in the Project Service Area

A total of 156,000 acre feet per year from district and private sources:

27,740	acre feet from district groundwater pumps.
72,420	acre feet from the Gila River.
55,840	acre feet from private groundwater pumps on lands outside of the district service area.

Major Crops

Cotton (47%), grains (42%), and alfalfa (11%).

Plan of Development

Presently the San Carlos district transports its water via unlined canals. The present system is in continual need of maintenance due to siltation, weed growth and bank erosion.

The physical plan is to rehabilitate and concrete line the existing canals and laterals. The lined system will be used to convey CAP water comingled with San Carlos Project surface water and groundwater to district lands. The sizing of the system would be the same with or without the availability of CAP water.

Rehabilitation will be completed by 1989 at at total cost of $31.1 million. System OM&R costs, which include the maintenance and capitalization of district groundwater pumps, will remain unchanged at about $1,800,000 annually.

Full CAP service should begin by 1989. The volume of CAP deliveries is expected to vary from a high of over 47,000 acre feet per year early in the project to as little as 12,000 acre feet by 2034.

Sources

Franzoy, Corey, & Associates.
San Carlos Project.
Arizona Department of Water Resources.
Bureau of Reclamation.

Fact Sheet F.8

Tonopah Irrigation District

Formation

In 1977, for the express purpose of forming a public entity to contract for the delivery of Colorado River water via the CAP.

Location

Western Maricopa County, about 40 miles west of Phoenix.

Land Area

Includes over 40,000 acres, of which about 9,000 are under cultivation and eligible under state and federal regulations for irrigation and for participation in the CAP.

The original CAP service area was to include about 8150 of these acres, but the costliness of delivering water to some of the areas and the withdrawal of one large landholding from the district led to a scaling down of the proposed system. Currently plans call for a CAP service area of 3600 acres.

Water Production and Use in the Project Service Area

18,800 acre feet per year from private irrigation wells.

Major Crops

Cotton (53%), grains (14%), alfalfa (33%).

Plan of Development

The facilities will consist of a system of canals extending through the district from a turnout in the Granite Reef section of the CAP acquaduct. One main canal and five laterals will convey the water the the individual farm units. The system is designed to transport only CAP water. Landowners will retain ownership and control of their wells, pumps, and other on-farm irrigation facilities. Upon delivery, the CAP supply will be used conjunctively with groundwater.

Construction will be completed in 1985 at a total cost of about $2.8 million. System OM&R costs will amount to about $83,800 annually.

Full CAP service should begin by 1986. The volume of CAP deliveries is expected to range from a high of over 14,000 acre feet per year early in the project, to less than 4,000 acre feet by 2034.

Sources

Franzoy, Corey & Associates.
Arizona Department of Water Resources.
Bureau of Reclamation.

APPENDIX G

PROJECTED FUTURE VARIABLE GROUNDWATER PUMPING COSTS: STANDARD CAP ALLOCATIONS, BASELINE PROJECTION

Table G1. Standard CAP Allocations, Baseline Projection,
VARIABLE GROUNDWATER PUMPING COSTS:
Central Arizona Irrigation District

Year	Pumping Lift (ft)		Rate of Increase in Lift (ft/yr)		Energy Cost (mils/ Kwh)	Variable Cost of Pumping ($/af)	
	CAP	No CAP	CAP	No CAP		CAP	No CAP
1984	620	620	3.00	3.00	25.00	37.48	37.48
1989	635	635	0.49	3.00	35.35	50.83	50.83
1994	638	650	0.99	3.00	37.15	53.27	54.23
1999	644	665	1.32	3.00	39.05	56.04	57.85
2004	651	680	1.80	3.00	41.04	59.13	61.70
2009	660	695	1.92	3.00	43.13	62.57	65.80
2014	670	710	2.02	3.00	45.33	66.23	70.16
2019	679	725	2.08	3.00	47.65	70.16	74.80
2024	690	740	2.10	3.00	50.08	74.37	79.73
2029	700	755	2.29	3.00	52.63	78.89	84.99
2034	711	770	2.35	3.00	55.32	83.71	90.58

Table G2. Standard CAP Allocations, Baseline Projection,
VARIABLE GROUNDWATER PUMPING COSTS:
Harquahala Irrigation District

Year	Pumping Lift (ft)		Rate of Increase inLift (ft/yr)		Energy Cost (mils/ Kwh)	Variable Cost of Pumping ($/af)	
	CAP	No CAP	CAP	No CAP		CAP	No CAP
1984	600	600	8.00	8.00	52.42	67.51	67.51
1989	621	640	1.44	8.00	57.88	76.30	78.56
1994	631	680	2.75	8.00	63.90	84.63	91.18
1999	646	720	3.62	8.00	70.55	94.83	105.56
2004	666	760	4.85	8.00	77.89	106.99	121.95
2009	691	800	5.19	8.00	86.00	121.55	140.62
2014	716	840	5.43	8.00	94.95	138.12	161.86
2019	742	880	5.60	8.00	104.83	157.07	186.01
2024	770	920	5.66	8.00	115.75	178.73	213.45
2029	798	960	6.16	8.00	127.79	203.50	244.62
2034	827	1000	6.29	8.00	141.09	231.72	279.99

Table G3. Standard CAP Allocations, Baseline Projection,
VARIABLE GROUNDWATER PUMPING COSTS:
Hohokam Irrigation District

Year	Pumping Lift (ft)		Rate of Increase inLift (ft/yr)		Energy Cost (mils/ Kwh)	Variable Cost of Pumping ($/af)	
	CAP	No CAP	CAP	No CAP		CAP	No CAP
1984	410	410	3.00	3.00	25.00	25.13	25.13
1989	425	425	1.07	3.00	35.35	34.35	34.35
1994	431	440	1.45	3.00	37.15	36.29	37.03
1999	439	455	1.71	3.00	39.05	38.50	39.90
2004	448	470	2.07	3.00	41.04	40.97	42.95
2009	458	485	2.17	3.00	43.13	43.73	46.22
2014	469	500	2.24	3.00	45.33	46.68	49.70
2019	480	515	2.29	3.00	47.65	49.85	53.42
2024	491	530	2.31	3.00	50.08	53.26	57.39
2029	503	545	2.46	3.00	52.63	56.92	61.63
2034	514	560	2.50	3.00	55.32	60.85	66.15

Table G4. Standard CAP Allocations, Baseline Projection,
VARIABLE GROUNDWATER PUMPING COSTS:
Maricopa-Stanfield Irrigation District

Year	Pumping Lift (ft)		Rate of Increase inLift (ft/yr)		Energy Cost (mils/ Kwh)	Variable Cost of Pumping ($/af)	
	CAP	No CAP	CAP	No CAP		CAP	No CAP
1984	600	600	4.00	4.00	36.50	49.39	49.39
1989	620	620	0.76	4.00	39.32	54.32	54.32
1994	625	640	1.40	4.00	42.36	58.33	59.73
1999	633	660	1.83	4.00	45.63	62.98	65.66
2004	643	680	2.44	4.00	49.16	68.27	72.17
2009	655	700	2.61	4.00	52.96	74.29	79.31
2014	668	720	2.73	4.00	57.05	80.89	87.13
2019	681	740	2.81	4.00	61.46	88.17	95.71
2024	695	760	2.84	4.00	66.21	96.19	105.12
2029	709	780	3.09	4.00	71.33	105.02	115.42
2034	724	800	3.15	4.00	76.84	114.72	126.72

Table G5. Standard CAP Allocations, Baseline Projection,
VARIABLE GROUNDWATER PUMPING COSTS:
New Magma Irrigation District

Year	Pumping Lift (ft)		Rate of Increase inLift (ft/yr)		Energy Cost (mils/ Kwh)	Variable Cost of Pumping ($/af)	
	CAP	No CAP	CAP	No CAP		CAP	No CAP
1984	600	600	4.00	4.00	23.00	34.03	34.03
1989	615	620	1.56	4.00	35.35	49.28	49.65
1994	624	640	2.05	4.00	37.15	52.09	53.41
1999	635	660	2.37	4.00	39.05	55.26	57.42
2004	647	680	2.83	4.00	41.04	58.78	61.70
2009	662	700	2.95	4.00	43.13	62.68	66.26
2014	676	720	3.04	4.00	45.33	66.86	71.13
2019	691	740	3.11	4.00	47.65	71.34	76.32
2024	706	760	3.13	4.00	50.08	76.15	81.86
2029	722	780	3.31	4.00	52.63	81.31	87.77
2034	738	800	3.36	4.00	55.32	86.84	94.07

Table G6. Standard CAP Allocations, Baseline Projection,
VARIABLE GROUNDWATER PUMPING COSTS:
Queen Creek Irrigation District

Year	Pumping Lift (ft)		Rate of Increase inLift (ft/yr)		Energy Cost (mils/ Kwh)	Variable Cost of Pumping ($/af)	
	CAP	No CAP	CAP	No CAP		CAP	No CAP
1984	600	600	3.00	3.00	35.00	47.69	47.69
1989	609	615	0.13	3.00	37.70	51.54	52.01
1994	611	630	0.71	3.00	40.62	55.05	56.73
1999	615	645	1.09	3.00	43.76	59.10	61.90
2004	622	660	1.63	3.00	47.14	63.67	67.55
2009	630	675	1.78	3.00	50.78	68.87	67.55
2014	639	690	1.89	3.00	54.71	74.55	80.47
2019	648	705	1.96	3.00	58.94	80.79	87.85
2024	657	720	1.99	3.00	63.49	87.63	95.92
2029	667	735	2.20	3.00	68.40	95.15	104.74
2034	677	750	2.26	3.00	73.68	103.39	114.37

Table G7. Standard CAP Allocations, Baseline Projection,
VARIABLE GROUNDWATER PUMPING COSTS:
San Carlos Irrigation District (Private)

Year	PumpingLift (ft)	Rate of Increase in Lift (ft/yr)	Energy Cost (mils/ Kwh)	Variable Cost of Pumping (90% efficient) ($/af)
1984	410	3 *	25.00	27.92
1989	425	3	35.35	38.17
1994	440	3	37.15	41.14
1999	455	3	39.05	44.33
2004	470	3	41.04	47.72
2009	485	3	43.13	51.36
2014	500	3	45.33	55.22
2019	515	3	47.65	59.36
2024	530	3	50.08	63.77
2029	545	3	52.63	68.48
2034	560	3	55.32	73.50

* Pumping lifts, rates of groundwater decline, and variable pumping costs are unaffected by the operation of the CAP.

Table G8. Standard CAP Allocations, Baseline Projection,
VARIABLE PUMPING COSTS:
San Carlos Irrigation District (District)

		Variable Cost of Pumping *	
Year	Energy Cost (mils/Kwh)	No CAP (68% efficient) ($/af)	CAP (85% efficient from 1989) ($/af)
1984	25.00	19.01	19.01
1989	35.35	26.27	21.01
1994	37.15	27.53	22.02
1999	39.05	28.86	23.09
2004	41.04	30.26	24.21
2009	43.13	31.73	25.38
2014	45.33	33.27	26.61
2019	47.65	34.90	27.92
2024	50.08	36.60	29.28
2029	52.63	38.39	30.71
2034	55.32	40.28	32.22

* Pumping lifts are assumed constant at 300 feet. Variable costs include only the energy cost of pumping. Maintenance costs are subsumed in the fixed acreage assessment. Pump efficiency is about 64% instead of the usual 54%.

Table G9. Standard CAP Allocations, Baseline Projection,
VARIABLE PUMPING COSTS:
Tonopah Irrigation District

Year	Pumping Lift (ft)		Rate of Increase inLift (ft/yr)		Energy Cost (mils/ Kwh)	Variable Cost of Pumping ($/af)	
	CAP	No CAP	CAP	No CAP		CAP	No CAP
1984	350	350	3.00	3.00	52.42	39.79	39.79
1989	356	365	0.00	3.00	57.88	44.20	45.23
1994	357	380	0.59	3.00	63.90	48.39	51.39
1999	361	395	0.99	3.00	70.55	53.44	58.36
2004	367	410	1.56	3.00	77.89	59.39	66.25
2009	375	425	1.71	3.00	86.00	66.42	75.17
2014	383	440	1.82	3.00	94.95	74.36	85.26
2019	392	455	1.90	3.00	104.83	83.33	96.66
2024	401	470	1.93	3.00	115.75	93.60	109.53
2029	411	485	2.15	3.00	127.79	105.21	127.20
2034	421	500	2.21	3.00	141.09	118.34	140.50

APPENDIX H

PROJECTED FUTURE FIXED GROUNDWATER PUMPING COSTS: STANDARD CAP ALLOCATIONS, BASELINE PROJECTION

Table H1. Standard CAP Allocations, Baseline Projection,
FIXED PUMPING COSTS:
Central Arizona Irrigation District

	NO CAP	CAP		
Year	Average Cost ($/af)	Rate ($/af)	Well Capacity Factor	Average Cost ($/af)
1984	19.47	19.47	1.00	19.47
1989	19.47	19.47	0.41	46.94
1994	19.47	19.47	0.53	36.66
1999	20.75	19.47	0.61	31.98
2004	20.75	20.75	0.72	28.85
2009	20.75	20.75	0.75	27.70
2014	20.75	20.75	0.77	26.93
2019	20.75	20.75	0.79	26.42
2024	22.03	20.75	0.79	26.23
2029	22.03	20.75	0.84	24.84
2034	22.03	20.75	0.85	24.48

Table H2. Standard CAP Allocations, Baseline Projection,
FIXED PUMPING COSTS:
Harquahala Irrigation District

	NO CAP	CAP		
Year	Average Cost ($/af)	Rate ($/af)	Well Capacity Factor	Average Cost ($/af)
1984	12.08	12.08	1.00	6.35
1989	12.08	12.08	0.43	28.34
1994	12.08	12.08	0.54	22.36
1999	13.36	12.08	0.62	19.60
2004	13.36	12.08	0.72	16.67
2009	14.64	12.08	0.75	16.02
2014	14.64	13.36	0.78	17.24
2019	15.92	13.36	0.79	16.92
2024	15.92	13.36	0.80	16.80
2029	17.20	14.64	0.84	17.46
2034	17.20	14.64	0.85	17.21

Table H3. Standard CAP Allocations, Baseline Projection,
FIXED PUMPING COSTS:
Hohokam Irrigation District

	NO CAP	CAP		
Year	Average Cost ($/af)	Rate ($/af)	Well Capacity Factor	Average Cost ($/af)
1984	10.40	10.40	1.00	10.40
1989	10.40	10.40	0.55	18.96
1994	10.40	10.40	0.64	16.29
1999	11.20	10.40	0.70	14.89
2004	11.20	10.40	0.78	13.27
2009	11.20	11.20	0.81	13.89
2014	11.20	11.20	0.82	13.61
2019	12.00	11.20	0.83	13.42
2024	12.00	11.20	0.84	13.35
2029	12.00	12.00	0.87	13.74
2034	12.80	12.00	0.88	13.60

Table H4. Standard CAP Allocations, Baseline Projection,
FIXED PUMPING COSTS:
Maricopa-Stanfield Irrigation District

	NO CAP	CAP		
Year	Average Cost ($/af)	Rate ($/af)	Well Capacity Factor	Average Cost ($/af)
1984	15.83	15.83	1.00	15.83
1989	15.83	15.83	0.43	36.63
1994	16.63	15.83	0.54	29.05
1999	16.63	16.63	0.62	26.81
2004	16.63	16.63	0.73	22.86
2009	17.43	16.63	0.76	21.98
2014	17.43	16.63	0.78	21.39
2019	18.23	17.43	0.79	22.01
2024	18.23	17.43	0.80	21.86
2029	18.23	17.43	0.84	20.74
2034	19.03	17.43	0.85	20.46

Table H5. Standard CAP Allocations, Baseline Projection, FIXED PUMPING COSTS: New Magma Irrigation District

	NO CAP	CAP		
Year	Average Cost ($/af)	Rate ($/af)	Well Capacity Factor	Average Cost ($/af)
1984	11.59	11.59	1.00	11.59
1989	11.59	11.59	0.57	20.20
1994	11.59	11.59	0.66	17.61
1999	11.59	11.59	0.71	16.21
2004	11.59	11.59	0.80	14.57
2009	12.87	11.59	0.82	14.19
2014	12.87	11.59	0.83	13.92
2019	12.87	12.87	0.84	15.26
2024	12.87	12.87	0.85	15.18
2029	14.15	12.87	0.88	14.63
2034	14.15	12.87	0.89	14.48

Table H6. Standard CAP Allocations, Baseline Projection, FIXED PUMPING COSTS: Queen Creek Irrigation District

	NO CAP	CAP		
Year	Average Cost ($/af)	Rate ($/af)	Well Capacity Factor	Average Cost ($/af)
1984	14.69	14.69	1.00	14.69
1989	14.69	14.69	0.33	44.34
1994	14.69	14.69	0.47	31.58
1999	14.69	14.69	0.55	26.49
2004	14.69	14.69	0.68	21.58
2009	14.69	14.69	0.72	20.54
2014	14.69	14.69	0.74	19.85
2019	16.29	14.69	0.76	19.40
2024	16.29	14.69	0.76	19.22
2029	16.29	14.69	0.81	18.04
2034	16.29	14.69	0.83	17.73

Table H7. Standard CAP Allocations, Baseline Projection, FIXED PUMPING COSTS: San Carlos Irrigation District (Private)

Year	Rate	Average Cost (90% efficiency)
1984	7.88	8.76
1989	7.88	8.76
1994	7.88	8.76
1999	8.68	9.64
2004	8.68	9.64
2009	8.68	9.64
2014	8.68	9.64
2019	9.48	10.53
2024	9.48	10.53
2029	9.48	10.53
2034	10.28	11.42

It is assumed that the reduction in private groundwater deliveries to San Carlos district lands as a result of CAP deliveries to the district does not affect the overall level of use of the private groundwater facilities.

Therefore, the average fixed cost of <u>private</u> pumping is not multiplied by a "capacity factor" as it is in the other districts.

Table H8. Standard CAP Allocations, Baseline Projection, FIXED PUMPING COSTS: San Carlos Irrigation District (District)

Year	NO CAP (68%efficient)			CAP (85% efficient from 1989)		
	Total OM&R ($)	Delivery Volume (af)	Avg. Cost ($/af)	Total OM&R, Capital ($) *	Delivery Volume (af **)	Avg Cost ($/af)
1984	1800000	100160	17.97	1800000	100160	17.97
1989	1800000	100160	17.97	2231000	165357	13.49
1994	1800000	100160	17.97	2247660	157369	14.28
1999	1800000	100160	17.97	2132510	152035	14.03
2004	1800000	100160	17.97	2005900	144459	13.89
2009	1800000	100160	17.97	1980630	142409	13.91
2014	1800000	100160	17.97	1931420	140932	13.70
2019	1800000	100160	17.97	1909190	139916	13.65
2024	1800000	100160	17.97	1883710	139520	13.50
2029	1800000	100160	17.97	1867110	136482	13.68
2034	1800000	100160	17.97	1800000	135654	13.27

* Cost includes capital repayment and OM&R for the entire water delivery system, including that which was already in place before construction of the CAP facilities.

** Before 1989, total district deliveries average about 100,160 acre feet per year. CAP deliveries begin in 1989. In addition to the CAP water, district deliveries from traditional sources rise to a constant level of 125,201 acre feet per year. This amount includes 34,676 acre feet of groundwater and 90,525 acre feet of Gila River water. Total district deliveries rise to a maximum of over 165,000 acre feet per year before the diminishing availability of CAP water causes district deliveries to decrease.

Table H9. Standard CAP Allocations, Baseline Projection,
FIXED PUMPING COSTS:
Tonopah Irrigation District

	NO CAP	CAP		
Year	Average Cost ($/af)	Rate ($/af)	Well Capacity Factor	Average Cost ($/af)
1984	6.35	6.35	1.00	6.35
1989	6.35	6.35	0.30	21.33
1994	6.35	6.35	0.44	14.52
1999	7.63	6.35	0.53	11.97
2004	7.63	6.35	0.66	9.58
2009	7.63	6.35	0.77	9.09
2014	7.63	7.63	0.72	10.53
2019	7.63	7.63	0.74	10.28
2024	8.91	7.63	0.75	10.18
2029	8.91	7.63	0.80	9.51
2034	8.91	7.63	0.82	9.34

APPENDIX I

PROJECTED FUTURE CAP COSTS:
STANDARD CAP ALLOCATIONS, BASELINE PROJECTION

Table I1. Standard CAP Allocations, Baseline Projection,
CAP COSTS:
Central Arizona Irrigation District

Year	Variable Cost ($/af)	Fixed Costs Total Capital, OM&R, and Contingency ($)	Delivery Volume (af)	Avg Total ($/af)	Average Total Cost ($/af)
1984	-----	880,000	0	2.75	00.00
1989	63.33	4,171,580	187,257	22.28	85.61
1994	63.33	3,471,090	150,040	23.13	86.47
1999	63.33	2,947,640	125,186	23.55	86.88
2004	63.33	2,556,490	89,860	28.45	91.78
2009	63.33	2,264,190	80,307	28.19	91.53
2014	63.33	1,968,470	73,421	26.81	90.14
2019	63.33	1,400,000	68,685	20.38	83.72
2024	63.33	1,400,000	66,844	20.94	84.28
2029	63.33	1,400,000	52,671	26.58	89.91
2034	63.33	1,400,000	48,808	28.68	92.02

Table I2. Standard CAP Allocations, Baseline Projection,
CAP COSTS:
Harquahala Irrigation District

Year	Variable Cost ($/af)	Fixed Costs Total Capital, OM&R, and Contingency ($)	Delivery Volume (af)	Avg Total ($/af)	Average Total Cost ($/af)
1984	-----	100,000	0	00.76	00.00
1989	67.06	1,002,110	75,324	13.30	80.36
1994	67.06	854,990	60,360	14.16	81.22
1999	67.06	791,366	50,367	15.71	82.77
2004	67.06	723,698	36,158	20.01	87.07
2009	67.06	649,271	32,311	20.09	87.15
2014	67.06	594,807	29,537	20.14	87.20
2019	67.06	551,276	27,629	19.95	87.01
2024	67.06	518,389	26,886	19.28	86.34
2029	67.06	492,650	21,183	23.26	90.32
2034	67.06	420,000	19,628	21.40	88.46

Table I3. Standard CAP Allocations, Baseline Projection,
CAP COSTS:
Hohokam Irrigation District

Year	Variable Cost ($/af)	Fixed Costs			Average Total Cost ($/af)
		Total Capital, OM&R, and Contingency ($)	Delivery Volume (af)	Avg Total ($/af)	
1984	-----	0	0	0.00	0.00
1989	67.06	899,730	62,445	14.41	81.47
1994	67.06	905,915	50,026	18.11	85.17
1999	67.06	941,988	41,733	22.57	89.63
2004	67.06	954,417	29,952	31.86	98.92
2009	67.06	909,476	26,765	33.98	101.04
2014	67.06	836,183	24,469	34.17	101.23
2019	67.06	800,502	22,889	34.97	102.03
2024	67.06	638,000	22,274	28.64	95.70
2029	67.06	638,000	17,551	36.35	103.41
2034	67.06	638,000	16,263	39.23	106.29

Table I4. Standard CAP Allocations, Baseline Projection,
CAP COSTS:
Maricopa-Stanfield Irrigation District

Year	Variable Cost ($/af)	Fixed Costs			Average Total Cost ($/af)
		Total Capital, OM&R, and Contingency ($)	Delivery Volume (af)	Avg Total ($/af)	
1984	-----	940,000	0	2.51	0.00
1989	63.33	5,101,260	212,941	23.96	87.29
1994	63.33	4,292,160	170,622	25.16	88.49
1999	63.33	3,687,570	142,361	25.90	89.24
2004	63.33	3,235,770	102,190	31.66	95.00
2009	63.33	2,898,170	91,314	31.74	95.07
2014	63.33	1,900,000	83,472	22.76	86.10
2019	63.33	1,900,000	78,076	24.34	87.67
2024	63.33	1,900,000	75,972	25.01	88.34
2029	63.33	1,900,000	59,855	31.74	95.08
2034	63.33	1,900,000	55,459	34.26	97.59

Table I5. Standard CAP Allocations, Baseline Projection,
CAP COSTS:
New Magma Irrigation District

Year	Variable Cost ($/af)	Fixed Costs			Average Total Cost ($/af)
		Total Capital, OM&R, and Contingency ($)	Delivery Volume (af)	Avg Total ($/af)	
1984	-----	174,300	0	1.74	0.00
1989	67.06	1,473,070	42,630	34.55	101.61
1994	67.06	1,271,370	34,170	37.21	104.27
1999	67.06	1,120,640	28,520	39.29	106.35
2004	67.06	1,008,010	20,479	49.22	116.28
2009	67.06	675,000	18,304	36.88	103.94
2014	67.06	675,000	16,735	40.33	107.39
2019	67.06	675,000	15,656	43.11	110.17
2024	67.06	675,000	15,236	44.30	111.36
2029	67.06	675,000	12,006	56.22	123.28
2034	67.06	675,000	11,126	60.67	127.73

Table I6. Standard CAP Allocations, Baseline Projection,
CAP COSTS:
Queen Creek Irrigation District

Year	Variable Cost ($/af)	Fixed Costs			Average Total Cost ($/af)
		Total Capital, OM&R, and Contingency ($)	Delivery Volume (af)	Avg Total ($/af)	
1984	63.33	20,000	0	0.27	0.00
1989	63.33	846,937	50,151	16.89	80.22
1994	63.33	817,945	40,116	20.39	83.72
1999	63.33	772,528	33,416	23.12	86.45
2004	63.33	729,135	23,948	30.45	93.78
2009	63.33	682,081	21,363	31.93	95.26
2014	63.33	635,876	19,496	32.62	95.95
2019	63.33	500,000	18,206	27.46	90.80
2024	63.33	500,000	17,688	28.27	91.60
2029	63.33	500,000	13,914	35.94	99.27
2034	63.33	500,000	12,873	38.84	102.17

Table I7. Standard CAP Allocations, Baseline Projection,
CAP COSTS:
San Carlos Irrigation District

Year	Variable Cost ($/af)	Fixed Costs: Total Capital, OM&R, and Contingency ($)	Fixed Costs: Delivery Volume (af)	Fixed Costs: Avg Total ($/af)	Average Total Cost ($/af)
1984	-----	1,800,000	0	17.97	0.00
1989	67.06	2,231,000	40,156	13.49	80.55
1994	67.06	2,247,660	32,168	14.28	81.34
1999	67.06	2,132,510	26,834	14.03	81.09
2004	67.06	2,005,900	19,258	13.89	80.94
2009	67.06	1,980,630	17,208	13.91	80.97
2014	67.06	1,931,420	15,731	13.70	80.76
2019	67.06	1,909,190	14,715	13.65	80.70
2024	67.06	1,883,710	14,319	13.50	80.56
2029	67.06	1,867,110	11,281	13.68	80.74
2034	63.33	1,800,000	10,453	13.27	80.33

* Cost includes capital repayment, and OM&R for entire water delivery system, including that which was already in place before construction of the the CAP facilities.

** Before 1989, total district deliveries average about 100,160 acre feet per year. CAP deliveries begin in 1989.

In addition to the CAP water, San Carlos delivers 34,676 acre feet of groundwater and 90,525 acre feet of surface water. A residual supply of privately pumped groundwater fills whatever demand is unmet by the district.

The average fixed cost of CAP water is found by dividing the total annual fixed costs for the district by the total volume of water delivered by the district.

Table I8. Standard CAP Allocations, Baseline Projection, CAP COSTS: Tonopah Irrigation District

Year	VARIABLE COST ($/af)	FIXED COSTS Total Capital, OM&R, and Contingency ($)	Delivery Volume (af)	Avg Total ($/af)	AVERAGE TOTAL COST ($/af)
1984	-----	2,100	0	00.11	00.00
1989	63.33	124,630	13,203	9.44	72.77
1994	63.33	113,914	10,577	10.77	74.10
1999	63.33	105,560	8,824	11.96	75.30
2004	63.33	98,516	6,333	15.56	78.89
2009	63.33	100,097	5,661	17.68	81.02
2014	63.33	95,295	5,176	18.41	81.74
2019	63.33	93,216	4,844	19.24	82.58
2024	63.33	92,210	4,715	19.56	82.89
2029	63.33	83,800	3,716	22.55	85.88
2034	63.33	83,800	3,444	24.33	87.67

APPENDIX J

PROJECTED AVERAGE TOTAL WATER COSTS: STANDARD CAP ALLOCATIONS, BASELINE PROJECTION

Table J1. Standard CAP Allocations, Baseline Projection,
AVERAGE TOTAL WATER COSTS:
Central Arizona Irrigation District

	NO CAP	CAP				
Year	Groundwater ($/af)	Groundwater ($/af)	%	CAP ($/af)	%	Weighted Average ($/af)
1984	56.95	59.70	100	2.75	0	59.70
1989	70.30	97.77	41	85.61	59	90.26
1994	73.70	89.93	53	86.47	47	87.72
1999	78.60	88.02	61	86.88	39	86.94
2004	82.45	87.98	72	91.78	28	88.43
2009	86.55	90.27	75	91.53	25	90.02
2014	90.91	93.16	77	90.14	23	92.03
2019	95.55	96.59	79	83.72	21	93.82
2024	101.76	100.60	79	84.28	21	97.19
2029	107.02	103.72	84	89.91	16	101.45
2034	112.61	108.19	85	92.02	15	105.72

Table J2. Standard CAP Allocations, Baseline Projection,
AVERAGE TOTAL WATER COSTS:
Harquahala Irrigation District

	NO CAP	CAP				
Year	Groundwater ($/af)	Groundwater ($/af)	%	CAP ($/af)	%	Weighted Average ($/af)
1984	79.59	80.35	100	0.76	0	80.35
1989	90.64	104.64	43	80.36	57	90.71
1994	103.26	106.99	54	81.22	46	95.14
1999	118.92	114.43	62	82.77	38	102.28
2004	135.31	123.66	72	87.07	28	113.59
2009	155.26	137.57	75	87.15	25	125.17
2014	176.50	155.35	78	87.20	22	140.02
2019	201.93	173.99	79	87.01	21	155.69
2024	229.37	195.53	80	86.34	20	173.17
2029	261.82	220.96	84	90.32	16	199.98
2034	297.19	248.93	85	88.46	15	224.94

Table J3. Standard CAP Allocations, Baseline Projection,
AVERAGE TOTAL WATER COSTS:
Hohokam Irrigation District

	NO CAP	CAP				
Year	Groundwater ($/af)	Groundwater ($/af)	%	CAP ($/af)	%	Weighted Average ($/af)
1984	35.53	35.53	100	0.00	0	35.53
1989	44.75	53.31	55	81.47	45	66.02
1994	47.43	52.58	64	85.17	36	64.36
1999	51.10	53.39	70	89.63	30	64.32
2004	54.15	54.24	78	98.92	22	63.92
2009	57.42	57.61	81	101.04	19	66.01
2014	60.90	60.28	82	101.23	18	67.53
2019	65.42	63.27	83	102.03	17	69.68
2024	69.39	66.61	84	95.70	16	71.29
2029	73.63	70.67	87	103.41	13	74.82
2034	78.95	74.45	88	106.29	12	78.19

Table J4. Standard CAP Allocations, Baseline Projection,
AVERAGE TOTAL WATER COSTS:
Maricopa Stanfield Irrigation District

	NO CAP	CAP				
Year	Groundwater ($/af)	Groundwater ($/af)	%	CAP ($/af)	%	Weighted Average ($/af)
1984	65.22	67.73	100	2.51	0	67.73
1989	70.15	90.95	43	87.29	57	88.87
1994	76.36	87.38	54	88.49	46	87.88
1999	82.29	89.79	62	89.24	38	89.58
2004	88.80	91.12	73	95.00	27	92.18
2009	96.74	96.27	76	95.07	24	95.98
2014	104.56	102.29	78	86.10	22	98.68
2019	113.94	110.19	79	87.67	21	105.50
2024	123.35	118.05	80	88.34	20	112.03
2029	133.65	125.76	84	95.08	16	120.86
2034	145.75	135.17	85	97.59	15	129.61

Table J5. Standard CAP Allocations, Baseline Projection,
AVERAGE TOTAL WATER COSTS:
New Magma Irrigation District

	NO CAP	CAP				
Year	Groundwater ($/af)	Groundwater ($/af)	%	CAP ($/af)	%	Weighted Average ($/af)
1984	45.62	47.36	100	1.74	0	47.36
1989	61.24	69.48	57	101.61	43	83.18
1994	65.00	69.69	66	104.27	34	81.51
1999	69.01	71.47	71	106.35	29	81.42
2004	73.29	73.35	80	116.28	20	82.14
2009	79.13	76.87	82	103.94	18	81.82
2014	84.00	80.78	83	107.39	17	85.23
2019	89.19	86.60	84	110.17	16	90.29
2024	94.73	91.33	85	111.36	15	94.38
2029	101.92	95.94	88	123.28	12	99.22
2034	108.22	101.32	89	127.73	11	104.26

Table J6. Standard CAP Allocations, Baseline Projection,
AVERAGE TOTAL WATER COSTS:
Queen Creek Irrigation District

	NO CAP	CAP				
Year	Groundwater ($/af)	Groundwater ($/af)	%	CAP ($/af)	%	Weighted Average ($/af)
1984	62.38	62.64	100	0.00	0	62.64
1989	66.70	95.88	33	80.22	77	85.41
1994	71.42	86.64	47	83.72	53	85.08
1999	76.59	85.59	55	86.45	45	85.97
2004	82.24	85.25	68	93.78	32	87.98
2009	88.41	89.41	72	95.26	28	91.08
2014	95.16	94.40	74	95.95	26	94.80
2019	104.14	100.19	76	90.80	24	97.91
2024	112.21	106.86	76	91.60	24	103.26
2029	121.03	113.19	81	99.27	19	110.61
2034	130.66	121.12	83	102.17	17	117.87

Table J7. Standard CAP Allocations, Baseline Projection, AVERAGE TOTAL WATER COSTS: San Carlos Irrigation District (Without the CAP)

Year	Private Ground-Water ($/af)	%	District Gila River ($/af)	%	District Ground-Water ($/af)	%	Weighted Average ($/af)
1984	36.67	36	17.97	46	36.98	18	28.05
1989	46.92	36	17.97	46	44.23	18	33.01
1994	49.90	36	17.97	46	45.50	18	34.30
1999	53.97	36	17.97	46	46.84	18	35.99
2004	57.37	36	17.97	46	48.23	18	30.54
2009	61.00	36	17.97	46	49.69	18	39.01
2014	64.87	36	17.97	46	51.23	18	40.67
2019	69.89	36	17.97	46	52.87	18	42.76
2024	74.30	36	17.97	46	54.57	18	44.64
2029	79.01	36	17.97	46	56.37	18	46.65
2034	84.92	36	17.97	46	58.25	18	49.10

Table J8. Standard CAP Allocations, Baseline Projection,
AVERAGE TOTAL WATER COSTS:
San Carlos Irrigation District (With the CAP)

Year	Private Ground-Water ($/af)	%	District Gila River ($/af)	%	District Ground-Water ($/af)	%
1984	36.67	36	17.97	46	36.98	18
1989	46.92	0	13.49	55	44.23	21
1994	49.90	0	14.28	58	45.50	22
1999	53.97	3	14.03	58	46.84	22
2004	57.37	7	13.89	58	48.23	22
2009	61.00	9	13.91	58	49.69	22
2014	64.87	10	13.70	58	51.23	22
2019	69.89	10	13.65	58	52.87	22
2024	74.30	11	13.50	58	54.57	22
2029	79.01	13	13.68	58	56.37	22
2034	84.92	13	13.27	58	58.25	22

Year	CAP ($/af)	%	Weighted Average ($/af)
1984	0.00	0	28.05
1989	80.55	24	34.06
1994	81.34	20	32.59
1999	81.09	17	31.43
2004	80.94	13	30.54
2009	80.97	11	30.81
2014	80.76	10	31.12
2019	80.70	10	31.78
2024	80.56	9	32.42
2029	80.74	7	33.38
2034	80.33	7	34.27

Table J9. Standard CAP Allocations, Baseline Projection, AVERAGE TOTAL WATER COSTS: Tonopah Irrigation District

		PROJECT				
Year	NO PROJECT ($/af)	Groundwater ($/af)	%	CAP ($/af)	%	Weighted Average ($/af)
1984	46.14	46.26	100	0.11	0	46.26
1989	51.58	65.53	30	72.77	70	70.62
1994	57.74	62.91	44	74.10	56	69.21
1999	65.99	65.40	53	75.30	47	70.05
2004	73.88	68.96	66	78.89	34	72.31
2009	82.80	75.51	70	81.02	30	77.17
2014	92.89	84.89	72	81.74	28	84.03
2019	104.29	93.66	74	82.58	26	90.80
2024	118.44	103.79	75	82.89	25	98.54
2029	132.99	114.72	80	85.88	20	109.02
2034	149.41	127.68	82	87.67	18	120.35

APPENDIX K

PRESENT WORTH ANALYSIS:

STANDARD CAP ALLOCATIONS, BASELINE PROJECTION

Table K1. Standard CAP Allocations, Baseline Projection,
PRESENT WORTH ANALYSIS:
Central Arizona Irrigation District

Year	Average Total Water Costs		Net Benefit From CAP ($/af)	Cumulative Present Worth ($/af)
	NO CAP ($/af)	CAP ($/af)		
1984	56.95	59.70	- 2.75	- 2.75
1989	70.30	90.26	- 19.96	- 27.63
1994	73.70	87.72	- 14.02	- 88.00
1999	78.60	86.94	- 8.34	- 118.39
2004	82.45	88.43	- 5.98	- 134.29
2009	86.55	90.02	- 3.47	- 143.42
2014	90.91	92.03	- 1.13	- 146.97
2019	95.55	93.82	1.72	- 145.33
2024	101.76	97.19	4.57	- 141.08
2029	107.02	101.45	5.57	- 136.06
2034	112.61	105.72	6.88	- 130.72

Table K2. Standard CAP Allocations, Baseline Projection,
PRESENT WORTH ANALYSIS:
Harquahala Irrigation District

Year	Average Total Water Costs		Net Benefit From CAP ($/af)	Cumulative Present Worth ($/af)
	NO CAP ($/af)	CAP ($/af)		
1984	79.59	80.35	- 0.76	- 0.76
1989	90.64	90.71	- 0.07	- 12.52
1994	103.26	95.14	8.11	5.59
1999	118.92	102.28	16.64	45.25
2004	135.31	113.59	21.72	95.00
2009	155.26	125.17	30.09	149.39
2014	176.50	140.02	36.47	207.53
2019	201.93	155.69	46.24	267.57
2024	229.37	173.17	56.20	327.86
2029	261.82	199.88	61.94	384.92
2034	297.19	224.94	72.25	440.96

Table K3. Standard CAP Allocations, Baseline Projection,
PRESENT WORTH ANALYSIS:
Hohokam Irrigation District

Year	Average Total Water Costs		Net Benefit	Cumulative Present Worth
	NO CAP ($/af)	CAP ($/af)	($/af)	($/af)
1984	35.53	35.53	0.00	0.00
1989	44.75	66.02	- 21.27	- 17.96
1994	47.43	64.36	- 16.93	- 86.47
1999	51.10	64.32	- 13.23	- 131.82
2004	54.15	63.92	- 9.76	- 161.04
2009	57.42	66.01	- 8.60	- 180.45
2014	60.90	67.53	- 6.62	- 193.87
2019	65.42	69.68	- 4.26	- 201.32
2024	69.39	71.29	- 1.90	- 204.79
2029	73.63	74.82	- 1.19	- 206.15
2034	78.95	78.19	0.76	- 206.26

Table K4. Standard CAP Allocations, Baseline Projection,
PRESENT WORTH ANALYSIS:
Maricopa-Stanfield Irrigation District

Year	Average Total Water Costs		Net Benefit	Cumulative Present Worth
	NO CAP ($/af)	CAP ($/af)	($/af)	($/af)
1984	65.22	67.73	- 2.51	- 2.51
1989	70.15	88.87	- 18.72	- 36.17
1994	76.36	87.88	- 11.53	- 89.17
1999	82.29	89.58	- 7.29	- 115.67
2004	88.80	92.18	- 3.38	- 127.71
2009	96.74	95.98	0.76	- 128.88
2014	104.56	98.68	5.88	- 123.51
2019	113.94	105.50	8.44	- 112.39
2024	123.35	112.03	11.32	- 100.52
2029	133.65	120.86	12.80	- 88.59
2034	145.75	129.61	16.14	- 75.83

Table K5. Standard CAP Allocations, Baseline Projection,
PRESENT WORTH ANALYSIS:
New Magma Irrigation District

Year	Average Total Water Costs		Net Benefit	Cumulative Present Worth
	NO CAP ($/af)	CAP ($/af)	($/af)	($/af)
1984	45.62	47.36	- 1.74	- 1.74
1989	61.24	83.18	- 21.94	- 67.59
1994	65.00	81.51	- 16.51	- 136.39
1999	69.01	81.42	- 12.41	- 178.68
2004	73.29	82.14	- 8.85	- 204.25
2009	79.13	81.82	- 2.69	- 215.85
2014	84.00	85.23	- 1.23	- 218.97
2019	89.19	90.29	- 1.09	- 220.86
2024	94.73	94.38	0.35	- 221.07
2029	101.92	99.22	2.70	- 218.82
2034	108.22	104.26	3.96	- 215.86

Table K6. Standard CAP Allocations, Baseline Projection,
PRESENT WORTH ANALYSIS:
Queen Creek Irrigation District

Year	Average Total Water Costs		Net Benefit	Cumulative Present Worth
	NO CAP ($/af)	CAP ($/af)	($/af)	($/af)
1984	62.38	62.64	- 0.27	- 0.27
1989	66.70	85.41	- 18.71	- 50.23
1994	71.42	85.08	- 13.66	- 107.51
1999	76.59	85.97	- 9.39	- 141.15
2004	82.24	87.98	- 5.74	- 159.42
2009	88.41	91.08	- 2.66	- 167.62
2014	95.16	94.80	0.36	- 168.97
2019	104.14	97.91	1.58	- 163.08
2024	112.21	103.26	8.95	- 153.87
2029	121.03	110.61	10.42	- 144.22
2034	130.66	117.87	12.79	- 134.08

Table K7. Standard CAP Allocations, Baseline Projection,
PRESENT WORTH ANALYSIS:
San Carlos Irrigation District

Year	Average Total Water Costs		Net Benefit	Cumulative Present Worth
	NO CAP ($/af)	CAP ($/af)	($/af)	($/af)
1984	28.05	28.05	0.00	0.00
1989	33.01	34.18	- 1.18	- 3.96
1994	34.30	32.84	1.45	- 4.29
1999	35.99	31.71	4.28	5.04
2004	37.45	30.76	6.69	18.82
2009	39.01	31.05	7.96	33.56
2014	40.67	31.33	9.35	47.87
2019	42.76	31.97	10.79	61.80
2024	44.64	32.59	12.05	74.74
2029	46.65	33.53	13.12	86.50
2034	49.10	34.27	14.83	97.62

Table K8. Standard CAP Allocations, Baseline Projection,
PRESENT WORTH ANALYSIS:
Tonopah Irrigation District

Year	Average Total Water Costs		Net Benefit	Cumulative Present Worth
	NO CAP ($/af)	CAP ($/af)	($/af)	($/af)
1984	46.14	46.26	- 0.11	- 0.11
1989	51.58	70.62	- 19.03	- 70.06
1994	57.74	69.21	- 11.46	- 124.06
1999	65.99	70.05	- 4.05	- 144.19
2004	73.88	72.31	1.57	- 146.59
2009	82.80	77.17	5.64	- 139.16
2014	92.89	84.03	8.86	- 126.36
2019	104.29	90.80	13.49	- 110.37
2024	118.44	98.54	19.90	- 90.38
2029	132.99	109.02	23.97	- 68.85
2034	149.41	120.35	29.06	- 46.70

APPENDIX L

PROJECTED FUTURE VARIABLE GROUNDWATER PUMPING COSTS: SUSTAINED MAXIMUM CAP ALLOCATIONS, BASELINE PROJECTION

Table L1. Maximum Sustained CAP Allocations, Baseline Projection
VARIABLE GROUNDWATER PUMPING COSTS:
Central Arizona Irrigation District

Year	Pumping Lift (ft)		Rate of Increase in Lift (ft/yr)		Energy Cost, (mils/ Kwh)	Variable Cost of Pumping ($/af)	
	CAP	No CAP	CAP	No CAP		CAP	No CAP
1984	620	620	3.00	3.00	25.00	37.48	37.48
1989	635	635	0.61	3.00	35.35	50.83	50.83
1994	638	650	0.61	3.00	37.15	53.25	54.23
1999	641	665	0.61	3.00	39.05	55.81	57.85
2004	644	680	0.61	3.00	41.04	58.50	61.70
2009	647	695	0.61	3.00	43.13	61.34	65.80
2014	650	710	0.61	3.00	45.33	64.34	70.16
2019	653	725	0.61	3.00	47.65	67.51	74.80
2024	656	740	0.61	3.00	50.08	70.84	79.73
2029	659	755	0.61	3.00	52.63	74.36	84.99
2034	663	770	0.61	3.00	55.32	78.08	90.58

Table L2. Maximum Sustained CAP Allocations, Baseline Projection
VARIABLE GROUNDWATER PUMPING COSTS:
Harquahala Irrigation District

Year	Pumping Lift (ft)		Rate of Increase in Lift (ft/yr)		Energy Cost, (mils/ Kwh)	Variable Cost of Pumping ($/af)	
	CAP	No CAP	CAP	No CAP		CAP	No CAP
1984	600	600	8.00	8.00	52.42	67.51	67.51
1989	621	640	1.80	8.00	57.88	76.29	78.56
1994	630	680	1.80	8.00	63.90	84.55	91.18
1999	639	720	1.80	8.00	70.55	93.78	105.56
2004	648	760	1.80	8.00	77.89	104.07	121.95
2009	656	800	1.80	8.00	86.00	115.56	140.62
2014	665	840	1.80	8.00	94.95	128.39	161.86
2019	674	880	1.80	8.00	104.83	142.70	186.01
2024	683	920	1.80	8.00	115.75	158.68	213.45
2029	692	960	1.80	8.00	127.79	176.50	244.62
2034	700	1000	1.80	8.00	141.09	196.40	279.99

Table L3. Maximum Sustained CAP Allocations, Baseline Projection
VARIABLE GROUNDWATER PUMPING COSTS:
Hohokam Irrigation District

Year	Pumping Lift (ft)		Rate of Increase in Lift (ft/yr)		Energy Cost, (mils/Kwh)	Variable Cost of Pumping ($/af)	
	CAP	No CAP	CAP	No CAP		CAP	No CAP
1984	410	410	3.00	3.00	25.00	25.13	25.13
1989	425	425	1.16	3.00	35.35	34.35	34.35
1994	431	440	1.16	3.00	37.15	36.28	37.03
1999	437	455	1.16	3.00	39.05	38.32	39.90
2004	442	470	1.16	3.00	41.04	40.49	42.95
2009	448	485	1.16	3.00	43.13	42.78	46.22
2014	454	500	1.16	3.00	45.33	45.22	49.70
2019	460	515	1.16	3.00	47.65	47.80	53.42
2024	466	530	1.16	3.00	50.08	50.53	57.39
2029	471	545	1.16	3.00	52.63	53.43	61.63
2034	477	560	1.16	3.00	55.32	56.50	66.15

Table L4. Maximum Sustained CAP Allocations, Baseline Projection
VARIABLE GROUNDWATER PUMPING COSTS:
Maricopa-Stanfield Irrigation District

Year	Pumping Lift (ft)		Rate of Increase in Lift (ft/yr)		Energy Cost, (mils/Kwh)	Variable Cost of Pumping ($/af)	
	CAP	No CAP	CAP	No CAP		CAP	No CAP
1984	600	600	4.00	4.00	36.50	49.39	49.39
1989	620	620	0.91	4.00	39.32	54.32	54.32
1994	625	640	0.91	4.00	42.36	58.31	59.73
1999	629	660	0.91	4.00	45.63	62.63	65.66
2004	634	680	0.91	4.00	49.16	67.32	72.17
2009	638	700	0.91	4.00	52.96	72.39	79.31
2014	643	720	0.91	4.00	57.05	77.89	87.13
2019	647	740	0.91	4.00	61.46	83.85	95.71
2024	652	760	0.91	4.00	66.21	90.30	105.12
2029	656	780	0.91	4.00	71.33	97.30	115.42
2034	661	800	0.91	4.00	76.84	104.87	126.72

Table L5. Maximum Sustained CAP Allocations, Baseline Projection
VARIABLE GROUNDWATER PUMPING COSTS:
New Magma Irrigation District

Year	Pumping Lift (ft)		Rate of Increase in Lift (ft/yr)		Energy Cost, (mils/ Kwh)	Variable Cost of Pumping ($/af)	
	CAP	No CAP	CAP	No CAP		CAP	No CAP
1984	600	600	4.00	4.00	23.00	34.03	34.03
1989	615	620	1.68	4.00	35.35	49.29	49.65
1994	624	640	1.68	4.00	37.15	52.08	53.41
1999	632	660	1.68	4.00	39.05	55.04	57.42
2004	641	680	1.68	4.00	41.04	58.18	61.70
2009	649	700	1.68	4.00	43.13	61.51	66.26
2014	657	720	1.68	4.00	45.33	65.03	71.13
2019	666	740	1.68	4.00	47.65	68.77	76.32
2024	674	760	1.68	4.00	50.08	72.73	81.86
2029	683	780	1.68	4.00	52.63	76.94	87.77
2034	691	800	1.68	4.00	55.32	81.39	94.07

Table L6. Maximum Sustained CAP Allocations, Baseline Projection
VARIABLE GROUNDWATER PUMPING COSTS:
Queen Creek Irrigation District

Year	Pumping Lift (ft)		Rate of Increase in Lift (ft/yr)		Energy Cost, (mils/ Kwh)	Variable Cost of Pumping ($/af)	
	CAP	No CAP	CAP	No CAP		CAP	No CAP
1984	600	600	3.00	3.00	35.00	47.69	47.69
1989	610	615	0.27	3.00	37.70	51.55	52.01
1994	611	630	0.27	3.00	40.62	55.04	56.73
1999	612	645	0.27	3.00	43.76	58.80	61.90
2004	614	660	0.27	3.00	47.14	62.86	67.55
2009	615	675	0.27	3.00	50.78	67.25	73.72
2014	616	690	0.27	3.00	54.71	71.98	80.47
2019	618	705	0.27	3.00	58.94	77.08	87.85
2024	619	720	0.27	3.00	63.49	82.59	95.92
2029	620	735	0.27	3.00	68.40	88.54	104.74
2034	622	750	0.27	3.00	73.68	94.96	114.37

Table L7. Maximum Sustained CAP Allocations, Baseline Projection
VARIABLE GROUNDWATER PUMPING COSTS:
San Carlos Irrigation District (Private)

Year	PumpingLift (ft) *	Rate of Increase in Lift (ft/yr)	Energy Cost, (mils/ Kwh)	Variable Cost of Pumping (90% efficient) ($/af)
1984	410	3	25.00	27.92
1989	425	3	35.35	38.17
1994	440	3	37.15	41.14
1999	455	3	39.05	44.33
2004	470	3	41.04	47.72
2009	485	3	43.13	51.36
2014	500	3	45.33	55.22
2019	515	3	47.65	59.36
2024	530	3	50.08	63.77
2029	545	3	52.63	68.48
2034	560	3	55.32	73.50

* Pumping lifts, rates of groundwater decline, and variable pumping costs are unaffected by the operation of the CAP.

Table L8. Maximum Sustained CAP Allocations, Baseline Projection
VARIABLE GROUNDWATER PUMPING COSTS:
San Carlos Irrigation District (District)

		Variable Cost of Pumping *	
Year	Energy Cost (mils/Kwh)	NO PROJECT (68% efficient) ($/af)	PROJECT (85% efficient from 1989) ($/af)
1984	25.00	19.01	19.01
1989	35.35	26.27	21.01
1994	37.15	27.53	22.02
1999	39.05	28.86	23.09
2004	41.04	30.26	24.21
2009	43.13	31.73	25.38
2014	45.33	33.27	26.61
2019	47.65	34.90	27.92
2024	50.08	36.60	29.28
2029	52.63	38.39	30.71
2034	55.32	40.28	32.22

* Pumping lifts are assumed constant at 300 feet. Variable costs include only the energy cost of pumping. Maintenance costs are subsumed in the fixed acreage assessment. Pump efficiency is about 64% instead of the usual 54%.

Table L9. Maximum Sustained CAP Allocations, Baseline Projection
VARIABLE GROUNDWATER PUMPING COSTS:
Tonopah Irrigation District

Year	Pumping Lift (ft)		Rate of Increase in Lift (ft/yr)		Energy Cost, (mils/ Kwh)	Variable Cost of Pumping ($/af)	
	CAP	No CAP	CAP	No CAP		CAP	No CAP
1984	350	350	3.00	3.00	52.42	39.79	39.79
1989	356	365	0.13	3.00	57.88	44.19	45.23
1994	357	380	0.13	3.00	63.90	48.35	51.39
1999	358	395	0.13	3.00	70.55	52.95	58.36
2004	358	410	0.13	3.00	77.89	58.04	66.25
2009	359	425	0.13	3.00	86.00	63.67	75.17
2014	360	440	0.13	3.00	94.95	69.89	85.26
2019	360	455	0.13	3.00	104.83	76.77	96.66
2024	361	470	0.13	3.00	115.75	84.38	109.53
2029	362	485	0.13	3.00	127.79	92.80	124.08
2034	362	500	0.13	3.00	141.09	102.11	140.50

APPENDIX M

PROJECTED FUTURE FIXED GROUNDWATER PUMPING COSTS: SUSTAINED MAXIMUM CAP ALLOCATIONS, BASELINE PROJECTION

Table M1. Maximum Sustained CAP Allocations, Baseline Projection
FIXED GROUNDWATER PUMPING COSTS:
Central Arizona Irrigation District

	NO CAP	CAP		
Year	Average Cost ($/af)	Rate ($/af)	Well Capacity Factor	Average Cost ($/af)
1984	19.47	19.47	1.00	19.47
1989	19.47	19.47	1.00	19.47
1994	19.47	19.47	1.00	19.47
1999	20.75	19.47	1.00	19.47
2004	20.75	19.47	1.00	19.47
2009	20.75	19.47	1.00	19.47
2014	20.75	20.75	1.00	20.75
2019	20.75	20.75	1.00	20.75
2024	22.03	20.75	1.00	20.75
2029	22.03	20.75	1.00	20.75
2034	22.03	20.75	1.00	20.75

Table M2. Maximum Sustained CAP Allocations, Baseline Projection
FIXED GROUNDWATER PUMPING COSTS:
Harquahala Irrigation District

	NO CAP	CAP		
Year	Average Cost ($/af)	Rate ($/af)	Well Capacity Factor	Average Cost ($/af)
1984	12.08	12.08	1.00	12.08
1989	12.08	12.08	1.00	12.08
1994	12.08	12.08	1.00	12.08
1999	13.36	12.08	1.00	12.08
2004	13.36	12.08	1.00	12.08
2009	14.64	12.08	1.00	12.08
2014	14.64	12.08	1.00	12.08
2019	15.92	12.08	1.00	12.08
2024	15.92	12.08	1.00	12.08
2029	17.20	12.08	1.00	12.08
2034	17.20	12.08	1.00	12.08

Table M3. Maximum Sustained CAP Allocations, Baseline Projection
FIXED GROUNDWATER PUMPING COSTS:
Hohokam Irrigation District

	NO CAP	CAP		
Year	Average Cost ($/af)	Rate ($/af)	Well Capacity Factor	Average Cost ($/af)
1984	10.40	10.40	1.00	10.40
1989	10.40	10.40	1.00	10.40
1994	10.40	10.40	1.00	10.40
1999	11.20	10.40	1.00	10.40
2004	11.20	10.40	1.00	10.40
2009	11.20	10.40	1.00	10.40
2014	11.20	11.20	1.00	11.20
2019	12.00	11.20	1.00	11.20
2024	12.00	11.20	1.00	11.20
2029	12.00	11.20	1.00	11.20
2034	12.80	11.20	1.00	11.20

Table M4. Maximum Sustained CAP Allocations, Baseline Projection
FIXED GROUNDWATER PUMPING COSTS:
Maricopa-Stanfield Irrigation District

	NO CAP	CAP		
Year	Average Cost ($/af)	Rate ($/af)	Well Capacity Factor	Average Cost ($/af)
1984	15.83	15.83	1.00	15.83
1989	15.83	15.83	1.00	15.83
1994	16.63	15.83	1.00	15.83
1999	16.63	15.83	1.00	15.83
2004	16.63	16.63	1.00	16.63
2009	17.43	16.63	1.00	16.63
2014	17.43	16.63	1.00	16.63
2019	18.23	16.63	1.00	16.63
2024	18.23	16.63	1.00	16.63
2029	18.23	16.63	1.00	16.63
2034	19.03	16.63	1.00	16.63

Table M5. Maximum Sustained CAP Allocations, Baseline Projection
FIXED GROUNDWATER PUMPING COSTS:
New Magma Irrigation District

	NO CAP	CAP		
Year	Average Cost ($/af)	Rate ($/af)	Well Capacity Factor	Average Cost ($/af)
1984	11.59	11.59	1.00	11.59
1989	11.59	11.59	1.00	11.59
1994	11.59	11.59	1.00	11.59
1999	11.59	11.59	1.00	11.59
2004	11.59	11.59	1.00	11.59
2009	12.87	11.59	1.00	11.59
2014	12.87	11.59	1.00	11.59
2019	12.87	11.59	1.00	11.59
2024	12.87	11.59	1.00	11.59
2029	14.15	12.87	1.00	12.87
2034	14.15	12.87	1.00	12.87

Table M6. Maximum Sustained CAP Allocations, Baseline Projection
FIXED GROUNDWATER PUMPING COSTS:
Queen Creek Irrigation District

	NO CAP	CAP		
Year	Average Cost ($/af)	Rate ($/af)	Well Capacity Factor	Average Cost ($/af)
1984	14.69	14.69	1.00	14.69
1989	14.69	14.69	1.00	14.69
1994	14.69	14.69	1.00	14.69
1999	14.69	14.69	1.00	14.69
2004	14.69	14.69	1.00	14.69
2009	14.69	14.69	1.00	14.69
2014	14.69	14.69	1.00	14.69
2019	16.29	14.69	1.00	14.69
2024	16.29	14.69	1.00	14.69
2029	16.29	14.69	1.00	14.69
2034	16.29	14.69	1.00	14.69

Table M7. Maximum Sustained CAP Allocations, Baseline Projection
FIXED GROUNDWATER PUMPING COSTS:
San Carlos Irrigation District (Private)

Year	Rate	Average Cost (90% efficiency)
1984	7.88	8.76
1989	7.88	8.76
1994	7.88	8.76
1999	8.68	9.64
2004	8.68	9.64
2009	8.68	9.64
2014	8.68	9.64
2019	9.48	10.53
2024	9.48	10.53
2029	9.48	10.53
2034	10.28	11.42

It is assumed that the reduction in private groundwater deliveries to San Carlos district lands as a result of CAP deliveries to the district does not affect the overall level of use of the private groundwater facilities.

Therefore, the average fixed cost of <u>private</u> pumping is not multiplied by a "capacity factor" as it is in the other districts.

Table M8. Maximum Sustained CAP Allocations, Baseline Projection
FIXED GROUNDWATER PUMPING COSTS:
San Carlos Irrigation District (District)

Year	NO CAP (68%efficient)			CAP (85% efficient from 1989)		
	Total OM&R $	Delivery Volume af	Avg. Cost $/af	Total OM&R, Capital $ *	Delivery Volume af **	Avg Cost $/af
1984	1800000	100160	17.97	1800000	100160	17.97
1989	1800000	100160	17.97	2231000	163443	13.65
1994	1800000	100160	17.97	2247660	163443	13.75
1999	1800000	100160	17.97	2132510	163443	13.05
2004	1800000	100160	17.97	2005900	163443	12.27
2009	1800000	100160	17.97	1980630	163443	12.12
2014	1800000	100160	17.97	1931420	163443	11.82
2019	1800000	100160	17.97	1909190	163443	11.68
2024	1800000	100160	17.97	1883710	163443	11.53
2029	1800000	100160	17.97	1867110	163443	11.42
2034	1800000	100160	17.97	1800000	163443	11.01

* Cost includes capital repayment, and OM&R for entire water delivery system, including that which was already in place before construction of the the CAP facilities.

** Before 1989, total district deliveries average about 100,160 acre feet per year. CAP deliveries begin in 1989.

In addition to the CAP water, 34,676 acre feet of groundwater and 90,525 acre feet of surface water are delivered by San Carlos, for a constant average total district supply of 163,443 acre feet of water per year. No additional demand exists for private groundwater.

The average fixed cost of CAP water is found by dividing the total fixed costs for the district by the total volume of water delivered by the district.

Table M9. Maximum Sustained CAP Allocations, Baseline Projection
FIXED GROUNDWATER PUMPING COSTS:
Tonopah Irrigation District

	NO CAP	CAP		
Year	Average Cost ($/af)	Rate ($/af)	Well Capacity Factor	Average Cost ($/af)
1984	6.35	6.35	1.00	6.35
1989	6.35	6.35	1.00	6.35
1994	6.35	6.35	1.00	6.35
1999	7.63	6.35	1.00	6.35
2004	7.63	6.35	1.00	6.35
2009	7.63	6.35	1.00	6.35
2014	7.63	6.35	1.00	6.35
2019	7.63	6.35	1.00	6.35
2024	8.91	6.35	1.00	6.35
2029	8.91	6.35	1.00	6.35
2034	8.91	6.35	1.00	6.35

APPENDIX N

PROJECTED FUTURE CAP COSTS:

SUSTAINED MAXIMUM CAP ALLOCATIONS, BASELINE PROJECTION

Table N1. Maximum Sustained CAP Allocations, Baseline Projection
CAP COSTS:
Central Arizona Irrigation District

Year	Variable Cost ($/af)	Fixed Costs			Average Total Cost ($/af)
		Total Capital, OM&R, and Contingency ($)	Delivery Volume (af)	Avg Fixed ($/af)	
1984	-----	880,000	0	2.75	00.00
1989	63.33	4,171,580	178,299	23.40	86.73
1994	63.33	3,471,090	178,299	19.47	82.80
1999	63.33	2,947,640	178,299	16.53	79.87
2004	63.33	2,556,490	178,299	14.34	77.67
2009	63.33	2,264,190	178,299	12.70	76.03
2014	63.33	1,968,470	178,299	11.04	74.37
2019	63.33	1,400,000	178,299	7.85	71.19
2024	63.33	1,400,000	178,299	7.85	71.19
2029	63.33	1,400,000	178,299	7.85	71.19
2034	63.33	1,400,000	178,299	7.85	71.19

Table N2. Maximum Sustained CAP Allocations, Baseline Projection
CAP COSTS:
Harquahala Irrigation District

Year	Variable Cost ($/af)	Fixed Costs			Average Total Cost ($/af)
		Total Capital, OM&R, and Contingency ($)	Delivery Volume (af)	Avg Fixed ($/af)	
1984	-----	100,000	0	0.76	00.00
1989	67.06	1,002,110	71,714	13.97	81.03
1994	67.06	854,990	71,714	11.92	78.98
1999	67.06	791,366	71,714	11.03	78.09
2004	67.06	723,698	71,714	10.09	77.15
2009	67.06	649,271	71,714	9.05	76.11
2014	67.06	594,807	71,714	8.29	75.35
2019	67.06	551,276	71,714	7.69	74.75
2024	67.06	518,389	71,714	7.23	74.29
2029	67.06	492,650	71,714	6.87	73.93
2034	67.06	420,000	71,714	5.86	72.92

Table N3. Maximum Sustained CAP Allocations, Baseline Projection
CAP COSTS:
Hohokam Irrigation District

		Fixed Costs			
Year	Variable Cost ($/af)	Total Capital, OM&R, and Contingency ($)	Delivery Volume (af)	Avg Fixed ($/af)	Average Total Cost ($/af)
1984	-----	0	0	0.00	0.00
1989	67.06	899,730	59.466	15.13	82.19
1994	67.06	905,915	59,466	15.23	82.29
1999	67.06	941,988	59,466	15.84	82.90
2004	67.06	954,417	59,466	16.05	83.11
2009	67.06	909,476	59,466	15.29	82.35
2014	67.06	836,183	59,466	14.06	81.12
2019	67.06	800,502	59,466	13.46	80.52
2024	67.06	638,000	59,466	10.73	77.79
2029	67.06	638,000	59,466	10.73	77.79
2034	67.06	638,000	59,466	10.73	77.79

Table N4. Maximum Sustained CAP Allocations, Baseline Projection
CAP COSTS:
Maricopa-Stanfield Irrigation District

		Fixed Costs			
Year	Variable Cost ($/af)	Total Capital, OM&R, and Contingency ($)	Delivery Volume (af)	Avg Fixed ($/af)	Average Total Cost ($/af)
1984	-----	940,000	0	2.51	00.00
1989	63.33	5.101,260	202,752	25.16	88.49
1994	63.33	4,292,160	202,752	21.17	84.50
1999	63.33	3,687,570	202,752	18.19	81.52
2004	63.33	3,235,770	202,752	15.96	79.29
2009	63.33	2,898,170	202,752	14.29	77.63
2014	63.33	1.900,000	202,752	9.37	72.70
2019	63.33	1,900,000	202,752	9.37	72.70
2024	63.33	1,900,000	202,752	9.37	72.70
2029	63.33	1,900,000	202,752	9.37	72.70
2034	63.33	1,900,000	202,752	9.37	72.70

Table N5. Maximum Sustained CAP Allocations, Baseline Projection
CAP COSTS:
New Magma Irrigation District

Year	Variable Cost ($/af)	Fixed Costs			Average Total Cost ($/af)
		Total Capital, OM&R, and Contingency ($)	Delivery Volume (af)	Avg Fixed ($/af)	
1984	-----	174,300	0	1.74	00.00
1989	67.06	1,473,370	40,579	36.30	103.36
1994	67.06	1,271,370	40,579	31.33	98.39
1999	67.06	1,120,640	40,579	27.62	94.68
2004	67.06	1,008,010	40,579	24.84	91.90
2009	67.06	675,000	40,579	16.63	83.69
2014	67.06	675,000	40,579	16.63	83.69
2019	67.06	675,000	40,579	16.63	83.69
2024	67.06	675,000	40,579	16.63	83.69
2029	67.06	675,000	40,579	16.63	83.69
2034	67.06	675,000	40,579	16.63	83.69

Table N6. Maximum Sustained CAP Allocations, Baseline Projection
CAP COSTS:
Queen Creek Irrigation District

Year	Variable Cost ($/af)	Fixed Costs			Average Total Cost ($/af)
		Total Capital, OM&R, and Contingency ($)	Delivery Volume (af)	Avg Fixed ($/af)	
1984	-----	20,000	0	0.27	00.00
1989	63.33	846,937	47,817	17.71	81.05
1994	63.33	817,945	47,817	17.11	80.44
1999	63.33	772,528	47,817	16.16	79.49
2004	63.33	729,135	47,817	15.25	78.58
2009	63.33	682,081	47,817	14.26	77.60
2014	63.33	635,876	47,718	13.30	76.63
2019	63.33	500,000	47,718	10.46	73.79
2024	63.33	500,000	47,718	10.46	73.79
2029	63.33	500,000	47,718	10.46	73.79
2034	63.33	500,000	47,718	10.46	73.79

Table N7. Maximum Sustained CAP Allocations, Baseline Projection
CAP COSTS:
San Carlos Irrigation District

Year	Variable Cost ($/af)	Fixed Costs: Total Capital, OM&R, and Contingency ($)	Fixed Costs: Delivery Volume (af)	Fixed Costs: Avg Fixed ($/af)	Average Total Cost ($/af)
1984	-----	1,800,000	0	17.97	0.00
1989	67.06	2,231,000	38,242	13.65	80.71
1994	67.06	2,247,660	38,242	13.75	80.81
1999	67.06	2,132,510	38,242	13.05	80.11
2004	67.06	2,005,900	38,242	12.27	79.33
2009	67.06	1,980,630	38,242	12.12	79.18
2014	67.06	1,931,420	38,242	11.82	78.88
2019	67.06	1,909,190	38,242	11.68	78.74
2024	67.06	1,883,710	38,242	11.53	78.58
2029	67.06	1,867,110	38,242	11.42	78.48
2034	63.33	1,800,000	38,242	11.01	78.07

* Cost includes capital repayment, and OM&R for entire water delivery system, including that which was already in place before construction of the the CAP facilities.

** Before 1989, total district deliveries average about 100,160 acre feet per year. CAP deliveries begin in 1989.

In addition to the CAP water, 34,676 acre feet of groundwater and 90,525 acre feet of surface water are delivered by San Carlos, for a constant average total district supply of 163,443 acre feet of water per year. No additional demand exists for private groundwater.

The average fixed cost of CAP water is found by dividing the total fixed costs for the district by the total volume of water delivered by the district.

Table N8. Maximum Sustained CAP Allocations, Baseline Projection
CAP COSTS:
Tonopah Irrigation District

Year	Variable Cost ($/af)	Fixed Costs: Total Capital, OM&R, and Contingency ($)	Fixed Costs: Delivery Volume (af)	Fixed Costs: Avg Fixed ($/af)	Average Total Cost ($/af)
1984	-----	2,100	0	0.11	00.00
1989	63.33	124,630	12,573	9.91	73.25
1994	63.33	113,914	12,573	9.06	72.39
1999	63.33	105,560	12,573	9.06	71.73
2004	63.33	98,516	12,573	7.84	71.17
2009	63.33	100,097	12,573	7.96	71.29
2014	63.33	95,294	12,573	7.58	70.91
2019	63.33	93,216	12,573	7.41	70.75
2024	63.33	92,210	12,573	7.33	70.67
2029	63.33	83,800	12,573	6.67	70.00
2034	63.33	83,800	12,573	6.67	70.00

APPENDIX O

PROJECTED FUTURE AVERAGE TOTAL WATER COSTS: SUSTAINED MAXIMUM CAP ALLOCATIONS, BASELINE PROJECTION

Table 01. Maximum Sustained CAP Allocations, Baseline Projection
AVERAGE TOTAL WATER COSTS:
Central Arizona Irrigation District

	NO CAP	CAP				
Year	Groundwater ($/af)	Groundwater ($/af)	%	CAP ($/af)	%	Weighted Average ($/af)
1984	56.95	59.70	100	2.75	0	59.70
1989	70.30	70.30	44	86.73	56	79.06
1994	73.70	72.72	44	82.80	56	77.76
1999	78.60	75.28	44	79.87	56	77.20
2004	82.45	77.97	44	77.67	56	77.19
2009	86.55	80.81	44	76.03	56	77.58
2014	90.91	85.09	44	74.37	56	78.68
2019	95.55	88.26	44	71.19	56	78.74
2024	101.76	91.59	44	71.19	56	80.22
2029	107.02	95.11	44	71.19	56	81.78
2034	112.61	98.83	44	71.19	56	83.43

Table 02. Maximum Sustained CAP Allocations, Baseline Projection
AVERAGE TOTAL WATER COSTS:
Harquahala Irrigation District

	NO CAP	CAP				
Year	Groundwater ($/af)	Groundwater ($/af)	%	CAP ($/af)	%	Weighted Average ($/af)
1984	79.59	80.35	100	0.76	0	80.35
1989	90.64	88.37	45	86.73	55	84.36
1994	103.26	96.63	45	82.80	55	86.99
1999	118.92	105.86	45	79.87	55	90.69
2004	135.31	116.65	45	77.67	55	94.85
2009	155.26	127.64	45	76.03	55	99.50
2014	176.50	140.47	45	74.37	55	104.90
2019	201.93	154.78	45	71.19	55	111.07
2024	229.37	170.76	45	71.19	55	118.07
2029	261.82	188.58	45	71.19	55	125.96
2034	297.19	209.76	45	71.19	55	135.02

Table 03. Maximum Sustained CAP Allocations, Baseline Projection
AVERAGE TOTAL WATER COSTS:
Hohokam Irrigation District

	NO CAP	CAP				
Year	Groundwater ($/af)	Groundwater ($/af)	%	CAP ($/af)	%	Weighted Average ($/af)
1984	35.53	35.53	100	0.00	0	35.53
1989	44.75	44.75	57	82.19	43	60.84
1994	47.43	46.68	57	82.29	43	61.99
1999	51.10	48.72	57	82.90	43	63.41
2004	54.15	50.89	57	83.11	43	64.74
2009	57.42	53.18	57	82.35	43	65.72
2014	60.90	56.42	57	81.12	43	67.03
2019	65.42	59.00	57	80.52	43	68.25
2024	69.39	61.73	57	77.79	43	68.63
2029	73.63	64.63	57	77.79	43	70.29
2034	78.95	67.70	57	77.79	43	72.04

Table 04. Maximum Sustained CAP Allocations, Baseline Projection
AVERAGE TOTAL WATER COSTS:
Maricopa-Stanfield Irrigation District

	NO CAP	CAP				
Year	Groundwater ($/af)	Groundwater ($/af)	%	CAP ($/af)	%	Weighted Average ($/af)
1984	65.22	67.73	100	2.51	0	67.73
1989	70.15	70.15	46	88.49	54	80.07
1994	76.36	74.14	46	84.50	54	79.74
1999	82.29	78.46	46	81.52	54	80.12
2004	88.80	83.95	46	79.29	54	81.43
2009	96.74	89.02	46	77.63	54	82.86
2014	104.56	94.52	46	72.70	54	82.73
2019	113.94	100.48	46	72.70	54	85.46
2024	123.35	106.93	46	72.70	54	88.43
2029	133.65	113.93	46	72.70	54	91.64
2034	145.75	121.50	46	72.70	54	95.12

Table 05. Maximum Sustained CAP Allocations, Baseline Projection
AVERAGE TOTAL WATER COSTS:
New Magma Irrigation District

	NO CAP	CAP				
Year	Groundwater ($/af)	Groundwater ($/af)	%	CAP ($/af)	%	Weighted Average ($/af)
1984	45.62	47.36	100	2.75	0	47.36
1989	61.24	60.88	59	103.36	41	78.12
1994	65.00	63.67	59	98.39	41	77.76
1999	69.01	66.63	59	94.68	41	78.01
2004	73.29	69.77	59	91.90	41	78.75
2009	79.13	73.10	59	83.69	41	77.40
2014	84.00	76.62	59	83.69	41	79.49
2019	89.19	80.36	59	83.69	41	81.71
2024	94.73	84.32	59	83.69	41	84.07
2029	101.92	89.91	59	83.69	41	87.33
2034	108.22	94.26	59	83.69	41	89.97

Table 06. Maximum Sustained CAP Allocations, Baseline Projection
AVERAGE TOTAL WATER COSTS:
Queen Creek Irrigation District

	NO CAP	CAP				
Year	Groundwater ($/af)	Groundwater ($/af)	%	CAP ($/af)	%	Weighted Average ($/af)
1984	62.38	62.64	100	0.27	0	62.64
1989	66.70	66.24	36	81.05	64	75.68
1994	71.42	69.73	36	80.44	64	76.56
1999	76.59	73.49	36	79.49	64	77.32
2004	82.24	77.55	36	78.58	64	78.21
2009	88.41	81.94	36	77.60	64	79.17
2014	95.16	86.67	36	76.63	64	80.27
2019	104.14	91.77	36	73.79	64	80.31
2024	112.21	97.28	36	73.79	64	82.30
2029	121.03	103.23	36	73.79	64	84.46
2034	130.66	109.65	36	73.79	64	86.79

Table 07. Maximum Sustained CAP Allocations, Baseline Projection
AVERAGE TOTAL WATER COSTS:
San Carlos Irrigation District

Year	Private Ground-Water With CAP ($/af)	%	District Gila River With CAP ($/af)	%	District Ground-Water With CAP ($/af)	%
1984	36.67	36	0.00	46	36.98	18
1989	46.92	0	13.65	55	34.66	21
1994	49.90	0	13.75	55	35.77	21
1999	53.97	0	13.05	55	36.14	21
2004	57.37	0	12.27	55	36.48	21
2009	61.00	0	12.12	55	37.50	21
2014	64.87	0	11.82	55	38.43	21
2019	69.89	0	11.68	55	39.60	21
2024	74.30	0	11.53	55	40.81	21
2029	79.01	0	11.42	55	42.14	21
2034	84.92	0	11.01	55	43.23	21

Year	CAP ($/af)	%	Weighted Total Average Cost With CAP ($/af)	Weighted Total Average Cost Without CAP * ($/af)
1984	0.00	0	28.05	28.05
1989	80.71	24	33.80	33.01
1994	80.81	20	34.12	34.30
1999	80.11	17	33.64	35.99
2004	79.33	13	33.10	30.54
2009	79.18	11	33.19	39.01
2014	78.88	10	33.15	40.67
2019	78.74	10	33.29	42.76
2024	78.58	9	33.43	44.64
2029	78.48	7	33.63	45.65
2034	78.07	7	33.54	49.10

* See Table J7.

Table 08. Maximum Sustained CAP Allocations, Baseline Projection
AVERAGE TOTAL WATER COSTS:
Tonopah Irrigation District

	NO CAP	CAP				
Year	Groundwater ($/af)	Groundwater ($/af)	%	CAP ($/af)	%	Weighted Average ($/af)
1984	46.14	46.26	100	0.11	0	46.26
1989	51.58	50.54	33	73.25	67	65.73
1994	57.74	54.70	33	72.39	67	66.53
1999	65.99	59.30	33	71.73	67	67.61
2004	73.88	64.39	33	71.17	67	68.92
2009	82.80	70.02	33	71.29	67	70.87
2014	92.89	76.24	33	70.91	67	72.68
2019	104.29	83.12	33	70.75	67	74.85
2024	118.44	90.73	33	70.67	67	77.31
2029	132.99	99.15	33	70.00	67	79.65
2034	149.41	108.46	33	70.00	67	82.74

APPENDIX P

PRESENT WORTH ANALYSIS:

SUSTAINED MAXIMUM CAP ALLOCATIONS, BASELINE PROJECTION

Table P1. Maximum Sustained CAP Allocations, Baseline Projection
PRESENT WORTH ANALYSIS:
Central Arizona Irrigation District

Year	Weighted Average Total Water Costs		Net Benefit	Cumulative Present Worth
	NO CAP ($/af)	CAP ($/af)	($/af)	($/af)
1984	56.95	59.70	- 2.75	- 2.75
1989	70.30	79.06	- 8.76	- 18.43
1994	73.70	77.76	- 4.06	- 40.23
1999	78.60	77.20	1.40	- 41.15
2004	82.45	77.19	5.26	- 32.06
2009	86.55	77.58	8.96	- 16.96
2014	90.91	78.68	12.22	1.45
2019	95.55	78.74	16.80	22.64
2024	101.76	80.22	21.54	44.99
2029	107.02	81.78	25.24	66.95
2034	112.61	83.43	29.18	87.92

Table P2. Maximum Sustained CAP Allocations, Baseline Projection
PRESENT WORTH ANALYSIS:
Harquahala Irrigation District

Year	Weighted Average Total Water Costs		Net Benefit	Cumulative Present Worth
	NO CAP ($/af)	CAP ($/af)	($/af)	($/af)
1984	79.59	80.35	- 0.76	- 0.76
1989	90.64	84.36	6.28	10.32
1994	103.26	86.99	16.26	54.37
1999	118.92	90.69	28.23	124.06
2004	135.31	94.85	40.46	211.10
2009	155.26	99.50	55.76	311.17
2014	176.50	104.90	71.59	419.47
2019	201.93	111.07	90.86	532.94
2024	229.37	118.07	111.31	648.69
2029	261.82	125.96	135.86	764.97
2034	297.19	135.02	162.17	880.33

Table P3. Maximum Sustained CAP Allocations, Baseline Projection
PRESENT WORTH ANALYSIS:
Hohokam Irrigation District

Year	Weighted Average Total Water Costs		Net Benefit	Cumulative Present Worth
	NO CAP ($/af)	CAP ($/af)	($/af)	($/af)
1984	35.53	35.53	0.00	0.00
1989	44.75	60.84	- 16.09	- 13.71
1994	47.43	61.99	- 14.55	- 68.49
1999	51.10	63.41	- 12.32	- 109.30
2004	54.15	64.74	- 10.58	- 138.25
2009	57.42	65.72	- 8.30	- 157.57
2014	60.90	67.03	- 6.13	- 169.91
2019	65.42	68.25	- 2.83	- 175.52
2024	69.39	68.63	0.76	- 176.38
2029	73.63	70.29	3.34	- 174.29
2034	78.95	72.04	6.91	- 170.04

Table P4. Maximum Sustained CAP Allocations, Baseline Projection
PRESENT WORTH ANALYSIS:
Maricopa-Stanfield Irrigation District

Year	Weighted Average Total Water Costs		Net Benefit	Cumulative Present Worth
	NO CAP ($/af)	CAP ($/af)	($/af)	($/af)
1984	65.22	67.73	- 2.51	- 2.51
1989	70.15	80.07	- 9.92	- 28.93
1994	76.36	79.74	- 3.38	- 51.19
1999	82.29	80.12	2.17	- 51.58
2004	88.80	81.43	7.37	- 39.10
2009	96.74	82.86	13.87	- 15.76
2014	104.56	82.73	21.84	13.73
2019	113.94	85.46	28.48	48.96
2024	123.35	88.43	34.92	85.28
2029	133.65	91.64	42.02	121.45
2034	145.75	95.12	50.63	157.52

Table P5. Maximum Sustained CAP Allocations, Baseline Projection
PRESENT WORTH ANALYSIS:
New Magma Irrigation District

Year	Weighted Average Total Water Costs		Net Benefit	Cumulative Present Worth
	NO CAP ($/af)	CAP ($/af)	($/af)	($/af)
1984	45.62	47.36	- 1.74	- 1.74
1989	61.24	78.12	- 16.87	- 54.98
1994	65.00	77.76	- 12.76	- 107.80
1999	69.01	78.01	- 9.00	- 139.49
2004	73.29	78.75	- 5.46	- 156.60
2009	79.13	77.40	1.74	- 160.08
2014	84.00	79.49	4.51	- 154.50
2019	89.19	81.71	7.48	- 145.95
2024	94.73	84.07	10.66	- 135.44
2029	101.92	87.33	14.59	- 122.80
2034	108.22	89.97	18.25	- 110.06

Table P6. Maximum Sustained CAP Allocations, Baseline Projection
PRESENT WORTH ANALYSIS:
Queen Creek Irrigation District

Year	Weighted Average Total Water Costs		Net Benefit	Cumulative Present Worth
	NO CAP ($/af)	CAP ($/af)	($/af)	($/af)
1984	62.38	62.64	- 0.27	- 0.27
1989	66.70	75.68	- 8.98	- 25.64
1994	71.42	76.56	- 5.14	- 49.79
1999	76.59	77.32	- 0.73	- 57.75
2004	82.24	78.21	4.03	- 53.22
2009	88.41	79.17	9.24	- 39.15
2014	95.16	80.27	14.90	- 18.46
2019	104.14	80.31	23.84	9.35
2024	112.21	82.30	29.91	40.19
2029	121.03	84.46	36.57	71.48
2034	130.66	86.79	43.88	102.56

Table P7. Maximum Sustained CAP Allocations, Baseline Projection
PRESENT WORTH ANALYSIS:
San Carlos Irrigation District

	Weighted Average Total Water Costs		Net Benefit	Cumulative Present Worth
Year	NO CAP ($/af)	CAP ($/af)	($/af)	($/af)
1984	28.05	28.05	0.00	0.00
1989	33.01	33.80	- 0.79	- 3.65
1994	34.30	34.12	0.18	- 5.55
1999	35.99	33.64	2.35	- 1.33
2004	37.45	33.10	4.36	7.19
2009	39.01	33.19	5.82	17.44
2014	40.67	33.15	7.52	28.54
2019	42.76	33.29	9.47	40.40
2024	44.64	33.43	11.21	52.14
2029	46.65	33.63	13.02	63.44
2034	49.10	33.54	15.56	74.66

Table P8. Maximum Sustained CAP Allocations, Baseline Projection
PRESENT WORTH ANALYSIS:
Tonopah Irrigation District

	Weighted Average Total Water Costs		Net Benefit	Cumulative Present Worth
Year	NO CAP ($/af)	CAP ($/af)	($/af)	($/af)
1984	46.14	46.26	- 0.11	- 0.11
1989	51.58	65.73	- 14.14	- 55.00
1994	57.74	66.53	- 8.79	- 95.48
1999	65.99	67.61	- 1.62	- 108.23
2004	73.88	68.92	4.96	- 103.39
2009	82.80	70.87	11.93	- 85.76
2014	92.89	72.68	20.21	- 58.37
2019	104.29	74.85	29.44	- 23.73
2024	118.44	77.31	41.13	17.17
2029	132.99	79.65	53.33	61.94
2034	149.41	82.74	66.67	108.42

APPENDIX Q

PROJECTED FUTURE GROUNDWATER AND CAP WATER COSTS:

ZERO CAP ALLOCATIONS, BASELINE PROJECTION

Table Q1. Zero CAP Allocations, Baseline Projection
FIXED WATER COSTS:
San Carlos Irrigation District

	NO CAP (68%efficient)			CAP (85% efficient from 1989)		
Year	Total OM&R ($)	Delivery Volume (af)	Avg. Cost ($/af)	Total OM&R, Capital ($)	Delivery Volume * (af)	Avg Cost ($/af)
1984	1800000	100160	17.97	1800000	100160	17.97
1989	1800000	100160	17.97	2231000	125201	17.82
1994	1800000	100160	17.97	2247660	125201	17.95
1999	1800000	100160	17.97	2132510	125201	17.03
2004	1800000	100160	17.97	2005900	125201	16.02
2009	1800000	100160	17.97	1980630	125201	15.82
2014	1800000	100160	17.97	1931420	125201	15.43
2019	1800000	100160	17.97	1909190	125201	15.25
2024	1800000	100160	17.97	1883710	125201	15.05
2029	1800000	100160	17.97	1867110	125201	14.91
2034	1800000	100160	17.97	1800000	125201	14.38

* Cost includes capital repayment, and OM&R for entire water delivery system, including that which was already in place before construction of the the CAP facilities.

** Before 1989, total district deliveries average about 100,160 acre feet per year. From 1989 on, the increased level of delivery efficiency raises district deliveries from groundwater and Gila River sources to 34,676 and 90,525 acre feet per year, respectively, for a total of 125,201 acre feet per year.

The average fixed cost of CAP water is found by dividing the total fixed costs for the district by the total volume of water delivered by the district.

Table Q2. Zero CAP Allocations, Baseline Projection
AVERAGE TOTAL WATER COSTS:
San Carlos Irrigation District

Year	Private Groundwater With CAP ($/af)	%	District Gila River With CAP ($/af)	%	District Groundwater With CAP ($/af)	%
1984	36.67	36	17.97	46	36.98	18
1989	46.92	20	17.82	58	44.23	22
1994	49.90	20	17.95	58	45.50	22
1999	53.97	20	17.03	58	46.84	22
2004	57.37	20	16.02	58	48.23	22
2009	61.00	20	15.82	58	49.69	22
2014	64.87	20	15.43	58	51.23	22
2019	69.89	20	15.25	58	52.87	22
2024	74.30	20	15.05	58	54.57	22
2029	79.01	20	14.91	58	56.37	22
2034	84.92	20	14.38	58	58.25	22

Year	CAP ($/af)	%	Weighted Total Average Cost With CAP ($/af)	Weighted Total Average Cost Without CAP * ($/af)
1984	---	0	28.05	28.05
1989	---	0	28.24	33.01
1994	---	0	29.16	34.30
1999	---	0	29.46	35.99
2004	---	0	29.57	30.54
2009	---	0	30.38	39.01
2014	---	0	31.10	40.67
2019	---	0	32.24	42.76
2024	---	0	33.25	44.64
2029	---	0	34.39	45.65
2034	---	0	35.47	49.10

* See Table J7.

Table Q3. Zero CAP Allocations, Baseline Projection
PRESENT WORTH ANALYSIS:
San Carlos Irrigation District

Year	Weighted Average Total Water Costs NO CAP ($/af)	Weighted Average Total Water Costs CAP ($/af)	Net Benefit ($/af)	Cumulative Present Worth ($/af)
1984	28.05	28.05	0.00	0.00
1989	33.01	28.24	4.77	0.92
1994	34.30	29.16	5.14	18.05
1999	35.99	29.46	6.53	35.93
2004	37.45	29.57	7.89	53.85
2009	39.01	30.38	8.63	70.42
2014	40.67	31.10	9.57	85.46
2019	42.76	32.24	10.52	99.23
2024	44.64	33.25	11.39	111.58
2029	46.65	34.39	12.25	122.54
2034	49.10	35.47	13.63	132.64

APPENDIX R

SENSITIVITY ANALYSIS: DISCOUNT RATES

Table R1. Sensitivity Analysis of the Discount Rate:
Central Arizona Irrigation District

	CAP Allocation Scenario	
Discount Rate (%)	STANDARD Present Worth Over 50 Years ($/af)	SUSTAINED MAXIMUM Present Worth Over 50 Years ($/af)
0	-142	494
1	-147	325
2	-144	213
3	-138	138
4	-131	88
5	-122	54
6	-114	30
7	-106	14
8	-97	3
9	-91	-5

Table R2. Sensitivity Analysis of the Discount Rate:
Harquahala Irrigation District

	CAP Allocation Scenario	
Discount Rate (%)	STANDARD Present Worth Over 50 Years ($/af)	SUSTAINED MAXIMUM Present Worth Over 50 Years ($/af)
0	1651	3258
1	1162	2292
2	829	1639
3	600	1191
4	441	880
5	328	662
6	248	505
7	189	392
8	146	309
9	114	248

Table R3. Sensitivity Analysis of the Discount Rate: Hohokam Irrigation District

	CAP Allocation Scenario	
Discount Rate (%)	STANDARD Present Worth Over 50 Years ($/af)	SUSTAINED MAXIMUM Present Worth Over 50 Years ($/af)
0	- 386	- 286
1	- 325	- 251
2	- 277	- 220
3	- 238	- 193
4	- 206	- 170
5	- 180	- 150
6	- 159	- 133
7	- 140	- 118
8	- 125	- 105
9	- 112	- 94

Table R4. Sensitivity Analysis of the Discount Rate: Maricopa-Stanfield Irrigation District

	CAP Allocation Scenario	
Discount Rate (%)	STANDARD Present Worth Over 50 Years ($/af)	SUSTAINED MAXIMUM Present Worth Over 50 Years ($/af)
0	74	832
1	4	552
2	- 38	366
3	- 62	242
4	- 76	158
5	- 82	100
6	- 84	61
7	- 84	34
8	- 82	15
9	- 79	3

Table R5. Sensitivity Analysis of the Discount Rate: New Magma Irrigation District

Discount Rate (%)	CAP Allocation Scenario STANDARD Present Worth Over 50 Years ($/af)	SUSTAINED MAXIMUM Present Worth Over 50 Years ($/af)
0	- 306	17
1	- 281	- 45
2	- 258	- 81
3	- 236	- 101
4	- 216	- 110
5	- 198	- 113
6	- 182	- 113
7	- 168	- 110
8	- 155	- 106
9	- 144	- 101

Table R6. Sensitivity Analysis of the Discount Rate: Queen Creek Irrigation District

Discount Rate (%)	CAP Allocation Scenario STANDARD Present Worth Over 50 Years ($/af)	SUSTAINED MAXIMUM Present Worth Over 50 Years ($/af)
0	- 71	644
1	- 108	417
2	- 126	267
3	- 133	168
4	- 134	103
5	- 131	59
6	- 126	29
7	- 119	10
8	- 113	- 3
9	- 106	- 12

Table R7. Sensitivity Analysis of the Discount Rate: San Carlos Irrigation District

	CAP Allocation Scenario		
Discount Rate (%)	STANDARD PresentWorth Over 50 Years ($/af)	SUSTAINED MAXIMUM Present Worth Over 50 Years ($/af)	ZERO Present Worth Over 50 Years ($/af)
0	363	307	408
1	257	212	300
2	184	148	224
3	133	105	171
4	98	75	133
5	72	54	105
6	54	39	84
7	41	28	68
8	31	21	56
9	24	15	47

Table R8. Sensitivity Analysis of the Discount Rate: Tonopah Irrigation District

	CAP Allocation Scenario	
Discount Rate (%)	STANDARD Present Worth Over 50 Years ($/af)	SUSTAINED MAXIMUM Present Worth Over 50 Years ($/af)
0	276	856
1	135	539
2	45	333
3	- 11	198
4	- 47	108
5	- 68	50
6	- 81	11
7	- 88	- 15
8	- 91	- 31
9	- 92	- 42

APPENDIX S

SENSITIVITY ANALYSIS:

RATES OF GROUNDWATER DECLINE AND ENERGY COST ESCALATION

Table S1. Sensitivity Analysis of the Rates of Groundwater Decline and Energy Cost Escalation: Central Arizona Irrigation District

Condition *	Rate of Increase of Pumping Lifts (ft / yr)	Energy Escalation Rate (% / yr)	Present Worth Over 50 years ($ / af) **
1	3.00	1.00	- 130.72
2	8.94	1.00	---
3	3.00	2.88	---
4	3.00	1.00	87.92
5	0.75	1.00	---
6	3.00	0.19	---

Table S2. Sensitivity Analysis of the Rates of Groundwater Decline and Energy Cost Escalation: Harquahala Irrigation District

Condition *	Rate of Increase of Pumping Lifts (ft / yr)	Energy Escalation Rate (% / yr)	Present Worth Over 50 years ($ / af) **
1	8.00	2.00	440.96
2	0.00	2.00	49.73
3	8.00	- 1.25	---
4	8.00	2.00	880.33
5	0.00	2.00	349.41
6	8.00	- 2.38	---

* See explanatory notes.

** Where no present worth is given, the value is zero, plus or minus five dollars.

Table S3. Sensitivity Analysis of the Rates of Groundwater Decline and Energy Cost Escalation: Hohokam Irrigation District

Condition *	Rate of Increase of Pumping Lifts (ft / yr)	Energy Escalation Rate (% / yr)	Present Worth Over 50 years ($ / af) **
1	3.00	1.00	- 206.26
2	13.62	1.00	---
3	3.00	4.75	---
4	3.00	1.00	- 170.04
5	8.62	1.00	---
6	3.00	3.00	---

Table S4. Sensitivity Analysis of the Rates of Groundwater Decline and Energy Cost Escalation: Maricopa-Stanfield Irrigation District

Condition *	Rate of Increase of Pumping Lifts (ft / yr)	Energy Escalation Rate (% / yr)	Present Worth Over 50 years ($ / af) **
1	4.00	1.50	- 75.83
2	6.81	1.50	---
3	4.00	2.25	---
4	4.00	1.50	157.52
5	0.25	1.50	---
6	4.00	0.38	---

* See explanatory notes.

** Where no present worth is given, the value is zero, plus or minus five dollars.

Table S5. Sensitivity Analysis of the Rates of Groundwater Decline and Energy Cost Escalation: New Magma Irrigation District

Condition *	Rate of Increase of Pumping Lifts (ft / yr)	Energy Escalation Rate (% / yr)	Present Worth Over 50 years ($ / af) **
1	4.00	1.00	- 215.86
2	14.62	1.00	---
3	4.00	4.12	---
4	4.00	1.00	- 110.06
5	7.75	1.00	---
6	4.00	2.12	---

Table S6. Sensitivity Analysis of the Rates of Groundwater Decline and Energy Cost Escalation: Queen Creek Irrigation District

Condition *	Rate of Increase of Pumping Lifts (ft / yr)	Energy Escalation Rate (% / yr)	Present Worth Over 50 years ($ / af) **
1	3.00	1.50	- 134.08
2	7.06	1.50	---
3	3.00	2.69	---
4	3.00	1.50	102.56
5	0.56	1.50	---
6	3.00	0.88	---

* See explanatory notes.

** Where no present worth is given, the value is zero, plus or minus five dollars.

Table S7. Sensitivity Analysis of the Rates of Groundwater Decline and Energy Cost Escalation: San Carlos Irrigation District

Condition *	Rate of Increase of Private Pumping Lifts (ft / yr)	District & Private Energy Escalation Rate (% / yr)	Present Worth Over 50 years ($ / af) **
1	3.00	1.00	97.62
2	0.00	1.00	59.81
3	3.00	- 3.00	---
4	3.00	1.00	74.66
5	0.00	1.00	26.46
6	3.00	- 0.75	---
7	3.00	1.00	132.64
8	0.00	1.00	111.03
9	3.00	- 7.00	50.54

Table S8. Sensitivity Analysis of the Rates of Groundwater Decline and Energy Cost Escalation: Tonopah Irrigation District

Condition *	Rate of Increase of Pumping Lifts (ft / yr)	Energy Escalation Rate (% / yr)	Present Worth Over 50 years ($ / af) **
1	3.00	2.00	- 46.70
2	3.78	2.00	---
3	3.00	2.94	---
4	3.00	2.00	108.42
5	1.59	2.00	---
6	3.00	1.44	---

* See explanatory notes.

** Where no present worth is given, the value is zero, plus or minus five dollars.

S9. Explanatory Notes

1: Standard CAP allocations.
Standard rate of groundwater decline.
Standard rate of energy cost escalation.

2: Standard CAP allocations.
Extreme rate of groundwater decline.
Standard rate of energy cost escalation.

3: Standard CAP allocations.
Standard rate of groundwater decline.
Extreme rate of energy cost escalation.

4: Sustained maximum CAP allocations.
Standard rate of groundwater decline.
Standard rate of energy cost escalation.

5: Sustained maximum CAP allocations.
Extreme rate of groundwater decline.
Standard rate of energy cost escalation.

6: Sustained maximum CAP allocations.
Standard rate of groundwater decline.
Extreme rate of energy cost escalation.

7: Zero CAP allocations.
Standard rate of groundwater decline.
Standard rate of energy cost escalation.

8: Zero CAP allocations.
Extreme rate of groundwater decline.
Standard rate of energy cost escalation.

9: Zero CAP allocations.
Standard rate of groundwater decline.
Extreme rate of energy cost escalation.

APPENDIX T

MISCELLANEOUS DATA

Table T1. Price Index Multipliers

Year	Index	Base Year 1975	Base Year 1984
1975	161.2	100.00	51.50
1976	170.5	105.77	54.47
1977	181.5	112.59	57.99
1978	195.4	121.22	62.43
1979	217.4	134.86	69.46
1980	246.8	153.10	78.85
1981	272.4	168.98	87.03
1982	289.1	179.34	92.37
1983	298.4	184.93	95.34
1984 (est)	313.0	194.17	100.00

Source:

Valley National Bank. Arizona Statistical Review. Sept. 1983. (US City Average, US Department of Labor, Bureau of Labor Statistics)

Table T2. Average Total Annual Water and Electricity Use in Selected Irrigation Districts in Central Arizona

District	Total Pumpage (af)	Lift (ft)	Energy Cost (mils)	Total Electricity Consumption (Kwh/yr)
		Maricopa County		
Chandler Hts	6000	600	25.00	6,827,000
Harquahala	131,300	600	52.42	149,049,000
MCMWCD #1	71,000	590	30.00 @	79,436,000
Queen Creek	84,000	600	35.00	95,573,000
RWCD	80,000	485	35.00	73,576,000
San Tan	10,000	600	30.00	11,378,000
Tonopah	18,800	350	52.42	12,478,000
		Pima County		
Avra Valley	50,000 *	375	79.71	35,556,000
Cort-Marana	41,000	210 #	17.00	16,327,000
		Pinal County		
Central Az	320,000	620	25.00	376,225,000
Hohokam	138,000	410	25.00	107,292,000
Mar-Stanfld	400,000	600	36.50	455,111,000
New Magma	110,000	600	23.00	125,156,000
San Carlos	102,000	350 @	25.00	67,698,000

* Electric powered wells only
# Composite of both Cortaro and Marana areas
@ Composite of both public and private facilities

Sources:

Department of Water Resources, <u>Water Service Organizations in Arizona</u>. 1983.

Bookman-Edmonston Consulting Engineers, Inc.
Franzoy, Corey, & Associates.
W. S. Gookin & Associates.

Personalcommunicationswithindividualirrigation districts, 1984.

Table T3. Electric Groundwater Pump Maintenance Costs, 1975 - 1984.

Year	Nominal Cost ($/af/ft)	Cost in Constant 1984 Dollars ($/af/ft)
1975	0.007512	0.0145864
1976	0.007512	0.0137911
1977	0.007512	0.012954
1978	0.007512	0.0120327
1979	0.008038	0.0115721
1980	0.009003	0.0114179
1981	0.009903	0.0113788
1982	0.010893	0.0117928
1983	0.013322	0.0139731
1984	0.011438	0.011438

Source:

Hathorn, Scott. Arizona Pumpwater Budgets. Cooperative Extension Service, 1975 - 1984.

Table T4. Rates of Groundwater Decline in Central Arizona, 1940 - 1980

Year	Change in Pumping Lift Since Last Period (ft)	Cumulative Change in Pumping Lift (ft)	Average Annual Rate of Decline (ft/yr)
	Queen Creek Area - Maricopa County		
1940	0	0	--.-
1945	- 5	- 5	1.0
1950	- 50	- 55	10.0
1955	- 75	- 125	15.0
1960	- 35	- 160	7.0
1965	- 45	- 205	9.0
1970	0	- 205	0.0
1975	+ 25	- 180	- 5.0
1980	- 35	- 215	7.0
	Avra Valley Area - Pima County		
1940	0	0	--.-
1945	- 5	- 5	1.0
1950	- 11	- 16	2.2
1955	- 19	- 35	3.8
1960	- 37	- 72	7.4
1965	- 13	- 85	2.6
1970	- 28	- 113	5.6
1975	- 14	- 127	2.8
1980	+ 37	- 90	- 7.4

Table T4, continued.

Year	Cumulative Change in Pumping Lift (ft)	Annual Rate of Decline (ft/yr)
	Eloy Area - Pinal County	
1940	0.00	--.--
1941	- 1.33	- 1.33
1942	- 5.76	- 4.33
1943	- 10.27	- 4.51
1944	- 14.58	- 4.31
1945	- 19.36	- 4.78
1946	- 24.30	- 4.97
1947	- 28.64	- 4.31
1948	- 33.64	- 5.00
1949	- 39.02	- 5.38
1950	- 46.10	- 7.08
1951	- 51.83	- 5.73
1952	- 59.62	- 7.79
1953	- 68.79	- 9.17
1954	- 79.16	- 10.37
1955	- 85.90	- 6.70
1956	- 96.60	- 10.70
1957	- 103.10	- 6.50
1958	- 107.90	- 4.80
1959	- 117.40	- 9.50
1960	- 118.80	- 1.40
1961	- 126.90	- 8.10
1962	- 130.50	- 3.60
1963	- 135.80	- 5.30
1964	- 142.60	- 6.80
1965	- 144.00	- 6.60
1966	- 159.50	- 15.50
1967	- 160.80	- 1.30
1968	- 160.70	+ 0.10
1969	- 164.10	- 3.40
1970	- 165.90	- 1.80
1971	- 166.50	- 0.60
1972	- 166.00	+ 0.50
1973	- 170.40	- 4.40
1974	- 174.90	- 4.50
1975	- 171.60	+ 3.30

Table T4, continued.

Year	Cumulative Change in Pumping Lift (ft)	Annual Rate of Decline (ft/yr)
	Eloy Area - Pinal County	
1976	- 174.00	- 2.40
1977	- 172.40	+ 1.60
1978	- 164.40	+ 8.00
1979	- 171.00	- 6.60
1980	- 172.40	- 1.40

Sources:

US Geological Survey. Map of Groundwater Conditions in the Salt River Valley, 1981. Well B.

US Geological Survey. Map of Groundwater Conditions in the Avra and Altar Valleys, 1982. Well B.

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Table T5. Electricity Rates for Groundwater Pumping in Central Arizona, 1975 - 1984.

	AREA				
Year	Gila Bend ($/Kwh)	Aguila ($/Kwh)	Rainbow Valley ($/Kwh)	Harquahala ($/Kwh)	Queen Creek ($/Kwh)
1975	0.04474	0.04474	0.04474	0.04474	0.04474
1976	0.04823	0.04815	0.04825	0.04815	0.04814
1977	0.05332	0.05330	0.05334	0.05325	0.05322
1978	0.04882	0.04903	0.04893	0.04857	0.04858
1979	0.04690	0.04735	0.04705	0.04670	0.04678
1980	0.04977	0.05017	0.04990	0.04958	0.04964
1981	0.04465	0.04505	0.04479	0.04448	0.04454
1982	0.05520	0.05567	0.05535	0.05499	0.05506
1983	0.05020	0.05065	0.05035	0.04999	0.05006
1984	0.05270	0.05331	0.05291	0.05242	0.05255

Pima County

	Area	
	Avra Valley ($/Kwh)	Marana ($/Kwh)
1975	0.04874	0.04874
1976	0.05155	0.05155
1977	0.07550	0.07584
1978	0.05475	0.05593
1979	0.06718	0.06982
1980	0.06410	0.06644
1981	0.06176	0.06402
1982	0.05823	0.06037
1983	0.08353	0.08418
1984	0.07961	0.08022

Table T5, continued.

Pinal County

Year	Coolidge ($/Kwh)	Casa Grande ($/Kwh)	Eloy ($/Kwh)	Maricopa ($/Kwh)	Stanfield ($/Kwh)
	Area				
1975	0.03635	0.04039	0.03635	0.03635	0.04847
1976	0.02203	0.02203	0.02111	0.02478	0.04832
1977	0.01811	0.01811	0.01897	0.02328	0.05341
1978	0.02563	0.02563	0.01762	0.02483	0.02587
1979	0.02303	0.02303	0.02016	0.02325	0.02232
1980	0.02093	0.02093	0.01902	0.01839	0.01916
1981	0.01953	0.01953	0.01953	0.02585	0.02585
1982	0.02273	0.02273	0.01840	0.02598	0.02598
1983	0.02622	0.02622	0.02622	0.03252	0.03252
1984	0.02500	0.02500	0.02500	0.03650	0.03650

Source:

Hathorn, Scott. Arizona Pumpwater Budgets. Cooperative Extension Service, 1975 - 1984.

Table T6. Prices Received by Arizona Farmers on Selected Field Crops, 1975 - 1984

Year	Upland Cotton ($/pound)	Alfalfa ($/ton)	Wheat ($/ton)
1975	1.031	111.65	205.24
1976	1.179	125.76	239.21
1977	0.967	122.43	153.47
1978	0.919	97.92	156.98
1979	0.980	125.08	175.64
1980	0.941	108.17	171.59
1981	0.643	84.83	176.61
1982	0.704	79.39	128.83
1983	0.741	96.50	141.28
1984 (est)	0.715	100.67	130.60

All prices are expressed in terms of 1984 contant dollars.

Source:

Brantner, Ron. Arizona Agricultural Statistics. Arizona Crop and Livestock Reporting Service, 1979 - 1984.

Valley National Bank. Arizona Statistical Review. Economic Research Department, 1976 - 1983.

Table T7. Yields on Selected Arizona Field Crops, 1975 - 1984

Year	Alfalfa (tons/acre)	Cotton (lbs/acre)	Wheat (tons/acre)
	Maricopa County		
1975	6.6	1154	2.16
1976	7.1	1268	2.34
1977	7.5	1078	2.16
1978	6.3	1083	2.13
1979	6.4	1170	2.22
1980	7.4	1275	2.44
1981	7.5	1390	2.69
1982	7.8	1248	2.78
1983	7.8	1250	2.88
1984 (est)	7.8	1250	2.76
	Pima County		
1975	2.9	885	1.95
1976	3.3	874	2.09
1977	3.5	711	2.28
1978	3.0	700	2.08
1979	3.0	798	2.14
1980	3.5	847	2.14
1981	3.2	812	2.41
1982	3.0	911	2.45
1983	3.2	900	2.50
1984 (est)	3.2	900	2.50

Table T7, continued.

Year	Alfalfa (tons/acre)	Cotton (lbs/acre)	Wheat (tons/acre)
		Pinal County	
1975	5.6	839	2.10
1976	6.5	1101	2.22
1977	6.5	1049	2.10
1978	5.3	902	2.09
1979	6.2	1056	2.21
1980	6.4	1186	2.30
1981	6.4	1372	2.36
1982	6.8	1112	2.49
1983	7.0	1100	2.45
1984 (est)	7.0	1100	2.45

Source:

Brantner, Ron. Arizona Agricultural Statistics. Crop and Livestock Reporting Service, 1979 - 1984.

Table T8. Variable Costs of All Factor Inputs Expect Water for Selected Arizona Field Crops, 1975 - 1984

Year	Alfalfa ($/acre)	Upland Cotton ($/acre)	Wheat ($/acre)
		Maricopa County	
1975	560.21	311.63	218.47
1976	579.49	302.96	206.30
1977	507.24	275.13	201.36
1978	554.44	240.27	211.56
1979	508.64	212.12	175.05
1980	516.56	215.03	144.39
1981	546.03	220.11	180.91
1982	533.29	217.68	166.35
1983	514.58	214.53	151.51
1984	484.55	214.50	150.20
		Pima County	
1975	135.79	388.85	204.87
1976	141.66	386.32	186.07
1977	126.63	393.71	159.41
1978	115.30	414.94	152.30
1979	114.87	358.54	151.50
1980	121.94	366.59	171.01
1981	121.82	379.24	166.46
1982	121.59	398.15	161.54
1983	115.97	346.30	151.47
1984	116.81	337.46	158.96

Table T8, continued.

Year	Alfalfa ($/acre)	Upland Cotton ($/acre)	Wheat ($/acre)
		Pinal County	
1975	388.37	510.99	221.92
1976	395.15	488.43	202.29
1977	352.99	468.30	177.50
1978	418.82	454.00	171.54
1979	323.28	472.85	173.11
1980	304.34	471.44	168.57
1981	281.19	455.04	172.26
1982	289.51	470.54	172.97
1983	275.03	435.75	159.85
1984	296.02	423.51	155.51

Source:

Hathorn, Scott. Arizona Field Crop Budgets. Cooperative Extension Service, 1975 - 1984.

Table T9. Estimated Total Annual Cost of Subsidence in Western Pinal County

Agriculture		
Land Leveling	$60,000	
Crack Repair	60,000	
Well Repair	57,250	
Ditch Repair	10,000	
	$187,250	$187,250
Transportation		
Highways	15,500	
All Other	4,300	
	$19,800	19,800
Domestic and Urban Structures	0	0
Total, $1970		$207,050

$207,050/yr divided by: 1,100,00 acre feet of groundwater used annually in Pinal County in 1970

= $0.1882 /af/yr in 1970

Table T9, continued.

Annual rate of groundwater decline western Pinal County in 1970	=	5 ft/yr
Annual cost of subsidence per acre foot per foot of groundwater decline	=	$0.1882 / af / 5 ft
	=	$0.0376 / af / ft ($1970)
$1984 Price Index Multiplier	=	2.5632
$1984 Annual Cost per acre foot	=	($0.0376) * (2.5632)
	=	$0.0965 / af / ft ($1984)

ANNUAL COST OF SUBSIDENCE =

About 10 cents per acre foot per foot of the current rate of groundwater decline.

Source:

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