Agricultural groundwater conservation programs in the Phoenix Active Management Area: An economic assessment

Order Number 1341489

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The University of Arizona, 1990

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AGRICULTURAL GROUNDWATER CONSERVATION PROGRAMS IN THE PHOENIX ACTIVE MANAGEMENT AREA: AN ECONOMIC ASSESSMENT

by

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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

1990

STATEMENT BY AUTHOR

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ACKNOWLEDGEMENTS

This project was funded by the Agricultural Economics Department and the Water Resource Research Center of the University of Arizona. Thanks are extended to all those who helped in the research process. Generous amounts of data and time were provided by Sterling Stipe, Howard Stapleton, and Dennis Kimberlin at the Arizona Department of Water Resources, and Richard Segal at the Salt River Project.

Thanks to the entire faculty and staff at the University of Arizona Agricultural Economics Department, especially Gary Thompson, James Wade, Harry Ayer, Annie Hudecek, and Jane Wershay.

Regards to my fellow researchers, Dennis Cory, Bruce Peacock, David Boggs, Than Van Cao, and Robert Hinks; the most rewarding part of this project has been getting to know you. Most important have been the contributions of Dennis Cory, who made this all possible and mostly enjoyable.

For Sheila and Riley.

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ABSTRACT

The Arizona Groundwater Management Act (GMA) restricts the quantity of groundwater which farmers may use annually. The act also requires that a withdrawal fee be paid for each acre-foot of groundwater used. The impact of these policies on agricultural income and groundwater use in the Phoenix Active Management Area is estimated.

A linear programming model is used to simulate the typical farm's response to GMA policy over the period from 1990 to 2025.

The impacts of two possible revisions of GMA policy are also considered. One simulation estimates the impacts resulting from the elimination of urban conservation programs. A second scenario considers elimination of agricultural conservation measures. Results indicate that the GMA agricultural conservation program will generate only small changes in income and groundwater use.

SECTION ONE: MODELING FARMER RESPONSE TO GROUNDWATER CONSERVATION POLICY

"*This writing has always been on the wall. It is not a revelation to learn that cheap energy makes societies boom, that groundwater in arid regions has negligible recharge, that humans tend to use as much of anything as they can lay hands on. We can ignore these facts and mine and combust with abandon, or we can recognize these facts and attempt to construct a sustainable society. There will be no painless answers, nor were there any in the past.*" - Chuck Bowden, 1977

"*The positive benefits of overdrafting Arizona's groundwater stocks have and continue to outweigh 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.*" - David Bush, 1984

Section one is comprised of chapters one and two. Chapter one presents a summary of the Arizona Groundwater Management Act (GMA) and its provisions for groundwater conservation by agriculture. Chapter two presents the fundamental research tool, a linear programming model, and explains how this tool is used to simulate farmer response to GMA conservation requirements.

CHAPTER ONE

THE ARIZONA GROUNDWATER ACT AND ITS POTENTIAL IMPACT ON AGRICULTURE

Problem Statement

The purpose of this research is to evaluate the role of agriculture in meeting the legislated goals of the Arizona Groundwater Management Act (GMA) in the Phoenix Active Management Area (AMA). The goal of the GMA, as established in 1980, is that safe yield levels of water use be obtained by the year 2025. To obtain this goal, significant changes in the current patterns of supply and demand of water will have to occur.

Agricultural water users will be required to obtain maximum feasible irrigation efficiencies by the turn of the century, as determined by the Arizona Department of Water Resources (ADWR).[1] This requirement is implemented through restrictions on the amount of water a farm may use annually for irrigation. The total volume of water allowed the farm is known as the farm's **water allotment** (or, on a per acre basis

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[1] Specifically, Arizona Revised Statute 45-565 states in part that, "The irrigation water duty ... shall be calculated as the quantity of water reasonably required to irrigate the crops historically grown in the farm unit and shall assume the maximum conservation consistent with prudent long-term farm management practices ... considering the time required to amortize conservation investments and financing costs." A more complete discussion of this topic is found in chapter six.

as the farm's water duty). Also, all groundwater pumpers must pay a **withdrawal fee** on each acre foot of water pumped from underground. In addition to these two conservation measures, ADWR has the authority to retire agricultural land, after 2006, in the interest of conserving water.

Obtaining an estimate of the amount of lost income attributable to the GMA's agricultural conservation measures is the intent of this research. The impacts of the water allotment and pump tax are given primary attention.

Layout of Chapter One

A brief background of the history of Arizona groundwater law and legislation is provided in the next two sections of this chapter. This is followed by general information on the GMA and ADWR. The last two sections clarify the specific objectives of this research.

A Brief History of Arizona's Water Problem

The common perception of the water problem in Arizona is relatively simple: groundwater is being used at a faster rate than it is being replenished. To make up for this deficit, the high water use areas of the State rely largely on mined groundwater. Groundwater mining occurs when more water is removed from an underground aquifer than is replaced by incidental, artificial, and natural recharge. It is also referred to as groundwater overdraft. Although the water problem facing Arizona appears simple at first glance, a review of the scholarly literature reveals that no definitive consensus exists regarding the severity of the problem or the best solution to the problem. A more in-depth analysis of the water 'issue' will be developed throughout the body of this text. First, however, it is useful to examine the basic details of water supply and demand in Arizona, especially for those readers not familiar with the history of Arizona's water law.

The Sonoran desert covers most of the southern half of the state of Arizona. Annual rainfall ranges from three to twelve inches on the basins, with the isolated mountain ranges receiving up to twice as much. Large underground aquifers are bounded by these ranges, and it is this water which provides a dependable supply in a geography where rainfall is spatially and temporally sparse. Pieces of this desert which are farmed intensively and/or support large urban populations, such as in Phoenix or Tucson, are where groundwater controversies ferment.

From the mid-nineteen thirties to the nineteen fifties the volume of groundwater pumped in Arizona increased dramatically. A prolonged drought, combined with good cotton prices and the introduction of deep-well turbine pumps led to increased cotton acreage and increased dependence on groundwater. Recently, the unprecedented growth of the Tucson and Phoenix metropolitan areas has exacerbated the overdraft problem.

Leaders in Arizona have long recognized the discrepancy between water supply and demand in the state, and efforts to reduce overdraft date back at least as far as the 1930s [Pontius 1980]. The most dramatic result of this concern is the Central Arizona Project (CAP), an enormously expensive collection of canals and pumping stations which moves water from the Colorado River to the thirsty regions of south-central Arizona.

Attempts to change the nature of groundwater demand in Arizona prior to 1980 were largely unsuccessful, as vested interests of water users and the independent spirit typical of the western U.S. stifled all substantive legislation [Dunbar 1977]. Historically, the impetus behind successful groundwater legislation in Arizona has been more the threat of lost federal CAP funding than a serious desire to conserve water.

Water Law in Arizona

In Arizona, as elsewhere in the United States, groundwater law evolved as the science of geo-hydrology brought forth greater knowledge of the nature of underground water.[2] Key changes in the law before 1980 took shape in court decisions which resolved conflicts between competing pumpers. For most of Arizona's history, the English rule of absolute ownership applied, which allowed the overlying landowner to pump as much water from an aquifer as desired. The right to pump water remained guaranteed with land ownership until 1948, when the Critical Groundwater Code was passed. This code, implemented under the threat of a loss of federal funding for the CAP, outlawed expansion of irrigated acreage in those areas which the state deemed 'critical'. There remained no limit to the amount which an established water user could pump, and groundwater mining continued to escalate in the fast growing Phoenix and Tucson urban areas.

The need for further groundwater legislation became an agenda for Arizona cities and mines when the Arizona Supreme Court's decision in *FICO vs. Bettwy* [1976] limited the amount

[2] Leshy and Belanger [1988] present a thorough account of how water law in Arizona has evolved in response to hydrological understanding of the relationship between groundwater and surface water supplies. The rationality and the irrationality of various court decisions regarding Arizona water law is unveiled.

of water which could be transferred away from appurtenant land (i.e. the land overlying the aquifer from which the well is pumping). Urban and mining interests felt that this decision threatened their future growth and operations. The motivation for a comprehensive groundwater code increased when Arizona was threatened with the cut-off of federal CAP funding. This time, Secretary of Interior Cecil Andrus provided the catalyst which would eventually lead to the Groundwater Management Act of 1980.

On June 12, 1980 a remarkable piece of legislation known as the Arizona Groundwater Management Act (GMA) was signed into law by Governor Bruce Babbitt. The GMA was the result of intense negotiation and compromise between the three major user groups of the state: the cities, the mines, and agriculture. Generally, the cities and mines teamed up against agricultural interests in settling disputes. Despite being the 'loser' in many of the GMA compromises, agriculture remained in the negotiations because no group wanted to be singled out as the culprit which caused CAP funding to be lost.[3] Unresolved disputes were often left to the discretion of the

[3] Connall [1982] details the legal events and main actors involved in the negotiations leading up to the passage of the Groundwater Management Act. According to Connall, Governor Babbitt played a crucial role in keeping antagonists together long enough to achieve the final compromise.

director of the newly formed Arizona Department of Water Resources (ADWR). Much of the law reflects the fact that it was born out of compromise among vested interests. No group suffered immediate damage, as the GMA conservation requirements do not become severe until the mid 1990s. Some observers feel that the law has already served its major purpose of insuring the completion of the CAP, and that the GMA will be discarded before the teeth of the law bite down on groundwater users.

If it is true that the law may soon be discarded, it brings into question the relevance of this research. Tarlock [1985] argues that the basic choices faced by society with respect to renewable groundwater resources "are to decide how the resource is to be shared among competing claimants and the appropriate time period to balance the rate of extraction with the rate of recharge." The GMA establishes a framework for resolving both of these issues. If this law is abolished or modified, it is likely to be replaced by a law with similar tools of conservation. Even if the institutional framework is entirely made over, the sector which will no doubt be most affected will be agriculture. Assuming that the state will continue to hold safe-yield as a desireable goal, it remains interesting to analyze the social costs of getting there, and the efficacy of the conservation tools utilized to balance the state's water budget.

The Arizona Groundwater Management Act

The GMA brought substantive change to the rules of the water game in Arizona. The Act abandoned the common law tradition and put in its place a comprehensive state-administrated regulatory program. The code is designed not only to conserve groundwater, but also to shift groundwater away from agriculture to other uses [Tarlock 1985]. Increasingly restrictive conservation plans are stipulated to be implemented in five successive management periods. The final goal in the most important regions of the state is to reach safe yield levels of water use by 2025. Safe yield is defined as a long term balance between groundwater withdrawals and recharge [ADWR 1988].

ADWR defined the most critical areas of the state according to groundwater basins and political regions. These are called Active Management Areas (AMAs) (see figure 1.1). Each AMA contains one or more complete groundwater sub-basins. Safe Yield by 2025 is the management goal for the Phoenix, Tucson, and Prescott AMA's. The goal for the Pinal AMA is to maintain the current agricultural-based economy for as long as possible, while maintaining a minimal stock of underground water for future non-irrigation needs.

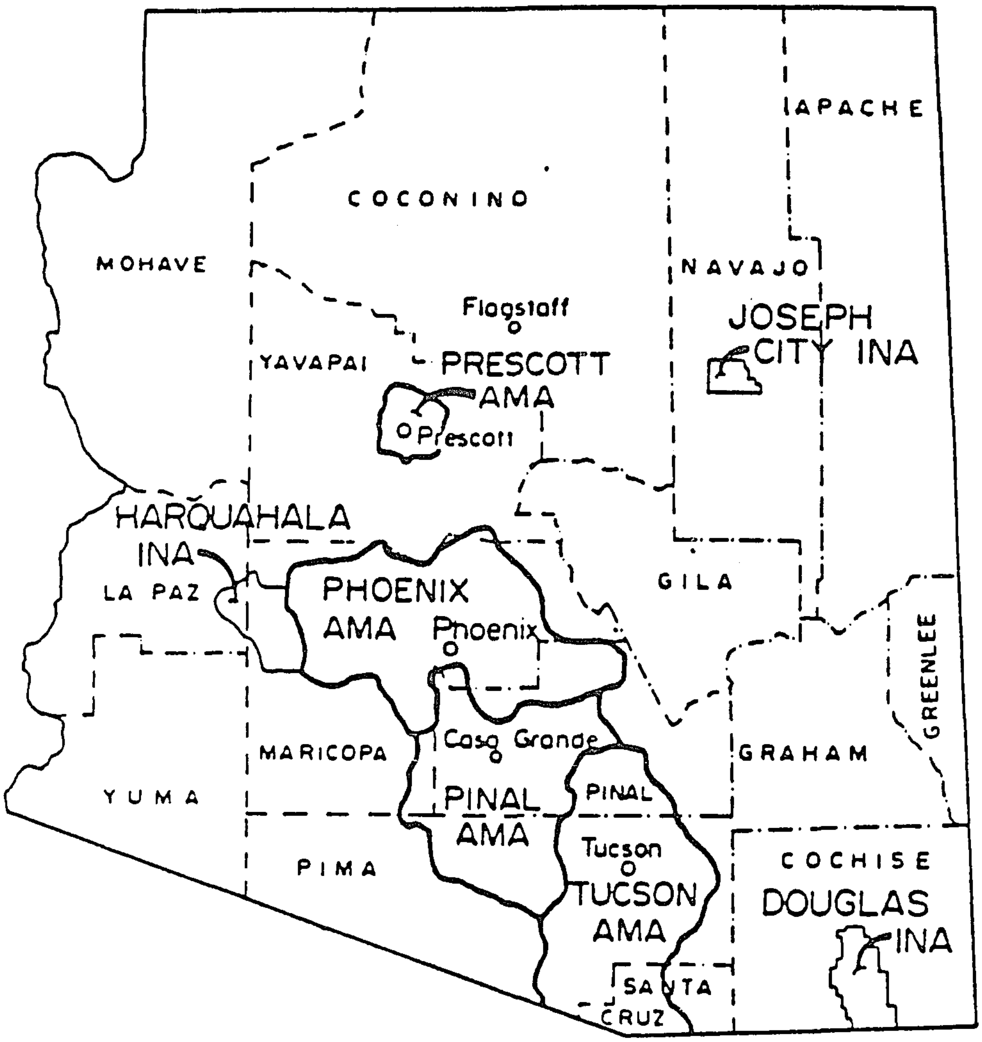

FIGURE 1.1

ACTIVE MANAGEMENT AREAS AND IRRIGATION NON-EXPANSION AREAS IN ARIZONA

source: Arizona Department of Water Resources, 1988.

The most important change instituted by the code is the establishment of a system of grandfathered rights and state issued permits which are now required to pump groundwater in an AMA. Only limited pumping for domestic needs is exempt from regulation within an AMA. The Act protected those interests which were using groundwater as of 1980 by issuing grandfathered rights to individuals who could demonstrate groundwater use between 1975 and 1980. Quantities which right-holders are allowed to pump are based on their historical use between 1975-80.

ADWR is responsible for the regulation of the withdrawal, transportation, use, conservation, and conveyance of groundwater. Regulation is decentralized through branch offices located in each AMA. ADWR has developed a complete registry of groundwater rights, and recorded water use in the AMA's since 1984. At the time of this writing, ADWR is nearing completion of the Management Plan for the Second Management Period (SMP), which will detail the conservation programs to be enforced from 1990-2000. The draft of this management plan is in print and is the source of the most current ADWR information.

The conservation measures stipulated by the GMA require all groundwater user groups to become more efficient in their water use over time. For industrial users, this most often means using the best available technology, as defined by ADWR, in production activities. Urban areas are required to obtain decreasing rates of per-capita water use. Agricultural users face water allotments which will decrease through the second management period until maximum efficiency levels are required in 2000. (The concept of irrigation efficiency is discussed in detail in chapter 3). All rights holders are required to pay a withdrawal fee, the proceeds of which are used to fund administrative, water supply augmentation, and land purchasing activities undertaken by ADWR.

GMA Agricultural Conservation Measures

Agriculture has always been the primary water user in Arizona, and at present accounts for approximately 83% of total state use. In the Phoenix AMA, agricultural use is now about 65% of the total. The authors of the GMA seemed to have felt that if substantial reductions in water demand were necessary, agriculture would have to be the biggest loser. The law reflects this belief in a number of ways.

ADWR has made projections of likely trends in the agricultural sector in the Phoenix AMA. According to the Draft Second Management Plan estimates, there are approximately 350,000 acres of non-Indian farm land now eligible for irrigation in the AMA. It is projected that non-Indian farmland will be converted to urban uses over the next 35 years while land devoted to Indian agriculture is likely to increase. Overall, the total acreage devoted to farming is projected to decrease by 150,000 acres by 2025. In spite of this substantial reduction in irrigated acreage, ADWR projects AMA overdraft to be 422,346 acre-feet (ac-ft) annually in the year 2025. This projection assumes full compliance with the conservation requirements to be implemented in the second management period. The implication is that even more draconian water saving measures or more extravagant water augmentation programs will be needed to balance the Phoenix AMA water budget by 2025.

The GMA provides three primary tools which can be used to reduce agricultural demand for water: the water duty, the withdrawal fee, and farmland retirement. The water duty is the amount of water per acre per annum which a farm is allowed to use for irrigating crops. The water duty times the number of duty acres on a farm equals the farm's total water allotment. The allotment is the total volume of water the farm may use in a year. The allotments are computed for each farm in an AMA based on the farm's cropping history between 1975-1980. The allotments in the Phoenix AMA will be reduced throughout the 1990s, until maximum irrigation efficiency is obtained.

The second conservation tool affecting agriculture is the water withdrawal fee. The withdrawal fee is an indirect conservation tool; the primary purpose for its implementation is to cover the costs of ADWR activities. The fee will likely lead to some reduction in water use, and will certainly affect farm income. The fee is limited to a maximum of five dollars per acre-foot (ac-ft), with one dollar to cover ADWR administration costs, and two dollars each allocated to water augmentation and farm land retirement. Fees for the latter two programs can only be charged when specific plans for these programs are developed.

After the year 2006, ADWR can begin to retire farm land in order to reduce water consumption. Given SMP projections, at least 100,000 acres of farm land, in addition to that land which is urbanized, will have to be retired in the Phoenix AMA in order to reach safe yield by 2025. The combined impacts of agricultural land conversion, decreasing water duties, withdrawal fees, and the retirement of irrigated acreage could be reasonably expected to result in a non-Indian agricultural sector in the Phoenix AMA which will be less than a quarter of what it is today.

Study Area

The diverse combination of water users and water supplies in the Phoenix Active Management Area makes it the interesting and important AMA in Arizona. The AMA lies mostly in Maricopa County, with a southeast portion of it extending into Pinal county. Some of the western and south-western parts of Maricopa County are not included in the Phoenix AMA. Several major rivers converge and join the Gila River in the AMA. In recent decades, surface water has provided approximately 35% of all water consumed. The Salt River Project (SRP), the first major project federally funded under the Reclamation Act of 1902, is the major supplier of water in the region.

The Phoenix metro area includes over half of Arizona's population, and has been one of the country's fastest growing urban areas for the last two decades. The AMA also contains extensive agricultural land, primarily found in the East and West Salt River sub-basins (figure 1.2). About one third of the total value of Arizona's crops are harvested here, which equates, on average, to over $300 million of annual marketings. Approximately 273,000 acres, or 80% of total AMA farmland, are accounted for in this study.

ADWR [1988] estimates that about 2.4 million ac-ft of water from was consumed in the AMA in 1985. Of this total, non-Indian agricultural water use accounted for about 1.4

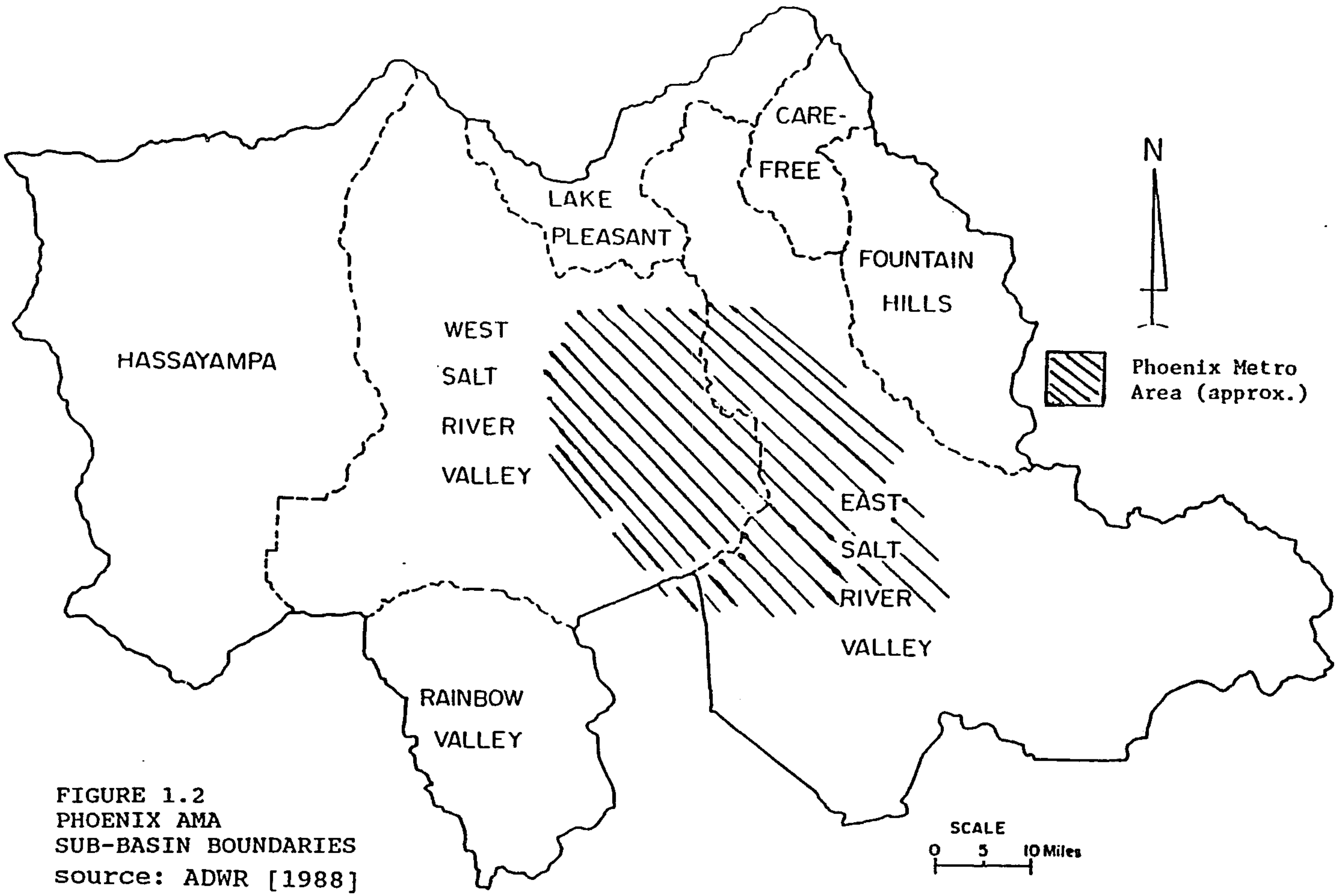

FIGURE 1.2
PHOENIX AMA
SUB-BASIN BOUNDARIES
source: ADWR [1988]

million ac-ft, or 61%. The major sources of this (total AMA) water were surface (39%), renewable groundwater (designated as either natural or incidental recharge) (31%), and mined groundwater (29%). The arrival of CAP water is estimated to increase renewable AMA water supplies by about .5 million ac-ft per year, which will significantly reduce overdraft in the next decade. However, ADWR projects that overdraft will begin to increase after the year 2000, in spite of SMP conservation measures and the CAP.

Study Objective

This thesis represents a portion of a larger research project titled "Enforcing The Groundwater Management Act:Implications For Agriculture and Industrial Development. "Arizona Revised Statute 45-401, which is the Act's statement of policy, reads in part that,

> "...in many basins and sub-basins withdrawal of groundwater is greatly in excess of the safe annual yield and that this is threatening to destroy the economy of certain areas of this state... The legislature further finds that it is in the best interest of the general economy and welfare of this state and its citizens that the legislature invoke

its police power to prescribe which uses of groundwater are most beneficial and economically effective."

Whether or not sound economic reasoning was used in formulating this policy is now a moot point; the authors of the GMA considered safe yield to be an appropriate AMA management goal, and the conservation measures of the GMA are the only ones which have been agreed upon up to this time. The question of interest then becomes, given the goal of safe yield and the means available to achieve this goal, what is the optimal route to get there? At what time, and to what extent, should conservation measures be implemented? Answering this question is the goal of the larger research effort.

This thesis serves to support the larger project by evaluating the effectiveness of the GMA agricultural conservation program in achieving reductions in water use. Specifically, the goal of this thesis is to estimate the costs which enforcement of the GMA will impose on the agricultural sector of the Phoenix AMA, and the water savings which will result. The time horizon considered is from 1990 to 2025. The primary effects estimated are:

1) The potential loss of agricultural income in the AMA attributable to the irrigation water duties;

2) The potential loss of income due to the withdrawal fee paid by irrigators;

3) The potential water savings due to implementation of the above policy tools.

A linear programming (LP) model is utilized to estimate representative farm income in the AMA under different policy and macroeconomic scenarios. A benchmark is given by a scenario which assumes that no GMA measures are imposed In the AMA. The LP model is re-solved with constraints and objective function parameters adjusted to reflect the impacts of the GMA. Solutions are compared to assess the impact of the law on representative farms.

CHAPTER TWO

THE LINEAR PROGRAMMING MODEL

I. Introduction

The Department of Water Resources (ADWR) has divided the Phoenix Active Management Area (AMA) into 12 Areas of Similar Farming Condition (ASFC). Each ASFC is modeled by a representative farm which typifies farming conditions in the ASFC. (The details of the ASFCs and the representative farms are found in chapter three). A linear programming (LP) model is utilized to determine the profit maximizing mix of crops, water use, and irrigation technology over each representative farm's planning horizon. By varying such parameters as the withdrawal fee and the water duty, the LP model can capture the effects that conservation measures of the Arizona Groundwater Management Act (GMA) will have on the representative farm. Scenarios which consider the effect of different levels of future farm profitability will also be analyzed by LP model runs.

Conservation Measures Of The GMA

The **withdrawal fee** is a charge levied on all groundwater users in the AMA. The fee is charged in units of dollars per acre-foot of groundwater withdrawn. The GMA specifies limits to how high a withdrawal fee may be charged by ADWR.[1]

The **water duty** is the amount of water, in acre-feet per acre per year, which a farm is allowed to use for irrigation. The **water allotment** is calculated by multiplying the water duty times the farm's total duty acres (e.g. the total acres used for growing crops). The allotment, then, is the total volume of water which a farm may use for irrigation in a year. The terms allotment and water duty are often used interchangeably here, as they both refer to the annual water constraint imposed on the farm by the GMA.

Water allotments will decrease in 1995 and again in 2000, when ADWR will set the allotments at levels reflecting 'maximum irrigation efficiency' (chapter 6). The mechanics of the water allotments in the LP model are discussed in this chapter under the heading, 'water use constraints'. A thorough examination of irrigation efficiencies and their relationship to the water duty is found in chapter six.

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[1] Withdrawal fee proceeds are designated for three purposes. One dollar of the fee is to be spent for DWR administrative costs. Two dollars of the fee is allocated to augmentation, and can only be assessed when DWR has developed an augmentation plan. (DWR currently is trying to amend the law to allow this two dollar component of the fee to be spent on a conservation program). The remaining two dollars, which are to be spent on farmland retirement, can only be charged after 2005, and after the department has produced a detailed land retirement plan.

The LP Model, Descriptive

The linear programming (LP) model maximizes the discounted value of gross revenue less variable cost and irrigation technology investment costs over the representative farm's planning horizon. For the most part, fixed costs are not included in the LP model because of the difficulty of allocating fixed costs appropriately among crop activities. Also, once the decision is made by a farm to operate, annual profit-maximizing production choices would be made on the basis of variable costs only.

Revenues for the LP model are generated by four crop activities: upland cotton, Pima cotton, alfalfa, and wheat. These four crops account for about 80% of all field crops grown in Maricopa County in a typical year, as demonstrated by figure 2.1. Irrigation, and investment in irrigation technology are the other activities in the LP model. (The cost of investing in irrigation technology is the one fixed cost which **is** included in the LP model).

The LP model is constrained by typical resource and production constraints such as a total farm acreage limit, crop rotational requirements, farm endowments of irrigation technologies, and limits to investment per year. Annual water use constraints are included in those models which are used to estimate the impact of the water duty on farm income. The

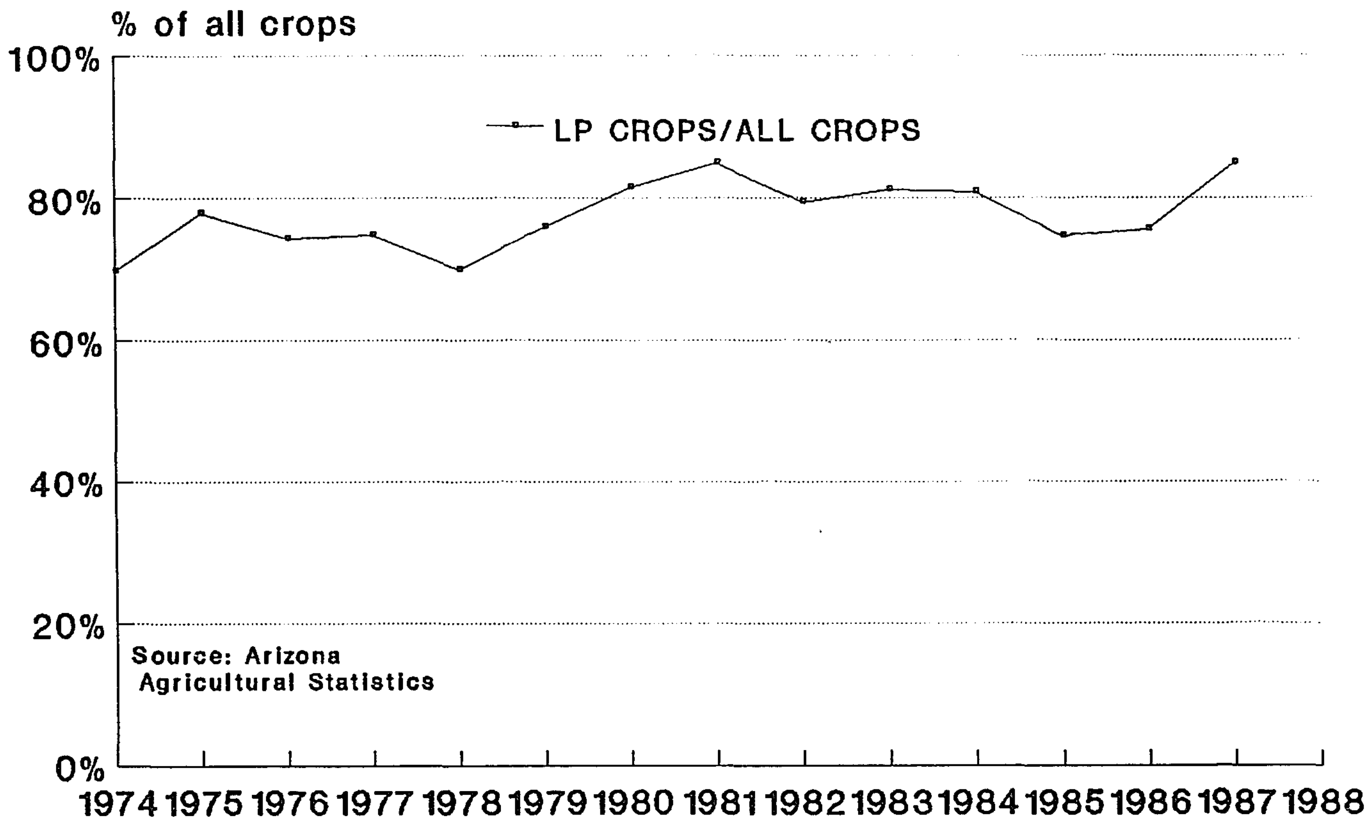

FIGURE 2.1
ACRES PLANTED: COTTON, ALFALFA, & WHEAT
As A % Of All Crops, Maricopa County

impact of the withdrawal fee is modeled by adding the amount of the fee to the variable cost of irrigation water.

In the set of runs denoted as the base case, one LP run for each representative farm assumes a world where the GMA does not exist. The objective function value from this 'no policy' run is compared to models which account for the impacts of Second Management Plan (SMP) water duties and withdrawal fees. The difference in these objective function values is the estimate of the GMA's impacts on representative farm discounted income.

A number of different policy and profit scenarios are then considered. Two potential revisions in GMA conservation policy are modeled. Estimates are obtained of the impacts of eliminating either urban or agricultural conservation policy. LP solutions resulting from these changes in policy are measured against the SMP policy scenario. Profit scenarios are used to see how the impacts of GMA measures change as farm sector profits change.

The discussion in this chapter focusses on the base case, which is the analysis of the changes in farm income and groundwater use resulting when going from the no policy scenario to the SMP policy scenario. The emphasis here is to show how the LP model can be used to assess policy impacts.

II. The LP Model, Mathematical Specification

Objective Function

The objective function of the LP model has the following form:

$$\max \sum_{t=1}^{T} \{ d_t [(\sum_{i=1}^{3} \sum_{j=1}^{4} C_{ijt} X_{ijt}) - \sum_{n=1}^{N} (W_{nt} IR_{nt}) - I1_t T1_t - I2_t T2_t - I3_t T3_t] \}. \tag{2.1}$$

where subscripts:

i = irrigation technology = (it1, it2, it3).

t = year = (1990,1991,...,T). T = 2025.

j = crop = (upland, Pima, wheat, alfalfa).

n = water source = (Salt River Project, Central Arizona (Project, Groundwater, other Irrigation District).

and:

X_{ijt} = acres of crop activity
C_{ijt} = net revenue over variable cost in $/acre

IR_{nt} = annual irrigation activity in acre-feet (ac-ft)
W_{nt} = cost of irrigation water in $/ac-ft

$I1_t$ = irrigation tech. investment activity 1 in acres
$I2_t$ = irrigation tech. investment activity 2 in acres
$I3_t$ = irrigation tech. investment activity 3 in acres
$T1_t$ = cost of irrigation investment 1 in $/acre
$T2_t$ = cost of irrigation investment 2 in $/acre
$T3_t$ = cost of irrigation investment 3 in $/acre

d_t = discount factor = $1/(1+.03)^t$

The impact of the withdrawal fee is modeled in the objective function (eq.2.1) by increasing the W_{nt} parameter to include the fee. Farm profit scenarios are created by variations in the C_{ijt} parameter. Profit scenarios are specified and discussed in chapter four. All revenues and costs in the model are stated in real 1987 dollars.

The cost of irrigation investment is entered as a one time cost only. This cost is calculated as the discounted value of the stream of payments assuming a loan borrowed at a 10% interest rate, and paid back in seven equal annual installments. The choice of these parameter values is based on an ADWR [1986] study. Though not entirely robust, this model of investment costs avoids the need for a parametric programming model. Also, sensitivity analysis is accomplished by considering a fairly wide range of investment costs for each investment activity. Extensive detail about the cost and benefits of irrigation technology assumed in the LP models can be found in chapter six.

Water Use Constraints

Constraints in the LP model can be characterized as falling into four categories: water use (volume) constraints, cropping constraints, land use constraints, and investment constraints. There are four water use constraints:

$$\sum_{i=1}^{3}\sum_{j=1}^{4} R_{ijt}\, X_{ijt} \leqslant \sum_{n=1}^{N} IR_{nt}\;; \qquad (t = 1990, 1991, \ldots, T) \qquad (2.2)$$

$$F_t = A_t/2 \qquad ; \qquad (t = 1990) \qquad (2.3)$$

$$F_t = A_{t-1} + F_{t-1} - \sum_{n=1}^{N} IR_{n,t-1} \; ; \quad (t = 1991, 1992, \ldots, T) \qquad (2.4)$$

$$A_t/2 + F_t \geqslant 0 \; ; \quad (t = 1991, 1992, \ldots, T+1) \qquad (2.5)$$

where:

R_{ijt} = water requirements for crop j on land with irrigation technology i in year t, in ac-ft/acre.

IR_{nt} = farm irrigation water use in year t, from source n, in ac-ft.

F_t = flex account balance in year t, in ac-ft.

A_t = farm's total water allotment in year t, in ac-ft.

Equations 2.2 are crop water use constraints which insure that crops selected by the LP model will be irrigated with the amount of water necessary in an average year. Note that for each crop (subscript j) and for each irrigation technology (subscript i) there is a unique annual water requirement. The implied crop to water relationship is a fixed proportion production function. The water quantity necessary for the LP crops (parameter R_{ijt}) is determined by crop consumptive needs [ADWR 1988], and the farm's irrigation efficiency. Investment in irrigation technology also leads to an increase in revenues (C_{ijt}). Irrigation technology and efficiency is discussed in greater detail in chapter six.

Equation 2.3 initialize the farm's flexibility account balance at 50% of the 1990 allotment. The flexibility, or flex, account was designed by ADWR to allow farmers to manage their water use through time as required by weather and other conditions. The essence of the flex account is this: any portion of a farm's water allotment which goes unused in a calendar year is credited to the flex account and becomes available for use in future years. Likewise, a farmer may borrow from the flex account in years when the farm's water needs exceed the annual allotment.

When the farmer's flex account goes into debt greater than an amount equal to 1/2 of his current allotment, the farm is in violation. Violations can lead to fines and\or cease and desist orders imposed by ADWR. The LP model assumes that the representative farm will comply with its conservation requirements, as required by equations 2.5.

Equations 2.4 are balancing constraints which carry the flex account balance forward from year to year. Any amount of groundwater use beyond the allotment is subtracted from the subsequent year's flex balance. Any portion of the allotment not used is credited to the next year's account (endnote 3.1).

In the no-policy scenario, the LP model does not include equations 2.3, 2.4, or 2.5. In this case the farm is not limited in the amount of water which it may use. These constraints are then incorporated in the LP model to assess the potential impacts of the water duty. Different magnitudes of the allotment are evaluated by changing the allotment parameter, A_t.

Crop Rotation Constraints

Crop rotations are included in the LP model which reflect historical cropping patterns in the AMA. There are two rotational constraints:

$$X_{iwt} \geqslant (X_{iut} + X_{ipt}) * RW \tag{2.6}$$
(i = it1, it2, it3)
(t = 1990,1991,...,T)

and,

$$X_{iwt} + X_{iat} \geqslant (X_{iut} + X_{ipt}) * RA \tag{2.7}$$
(i = it1, it2, it3)
(t = 1990,1991,...,T)

where the subscripts are defined:

u = upland cotton.

p = Pima cotton.

a = alfalfa.

w = wheat.

and:

X_{ijt} = acres planted of crop j on technology i in year t.

RW = ratio of wheat to cotton.

RA = ratio of wheat plus alfalfa to cotton.

Cotton is the principal crop grown in Maricopa County, generally accounting for about half of all acreage planted. Though cotton generally is Arizona's most profitable field crop, there are a number of reasons why farmers will also plant less profitable crops such as wheat or alfalfa. Among these reasons are the following: 1) Alfalfa restores nitrogen to the soil, and wheat is a good source of organic matter; 2) Rotating crops helps to control pests; 3) Since wheat requires water during non-peak seasons, it may be planted by those farms which do not have the weekly water delivery capacity to meet peak season needs if 100% alfalfa and\or cotton are planted; 4) Some crop mixing probably reflects risk aversion to crop or market failure.

Crop rotation practices generally follow some sequential cropping pattern, such as cotton-alfalfa-cotton-wheat. Rather than explicitly model these patterns or the four incentives listed above, the LP model uses proportional rotational requirements based on average county crop mixes over the 10 year period of 1978-1987. Figure 2.2 shows the relative quantities of the LP crops planted in Maricopa County since 1961. The percentages shown represent the ratio of acres planted of each crop over the sum of the acres planted of all four crops.

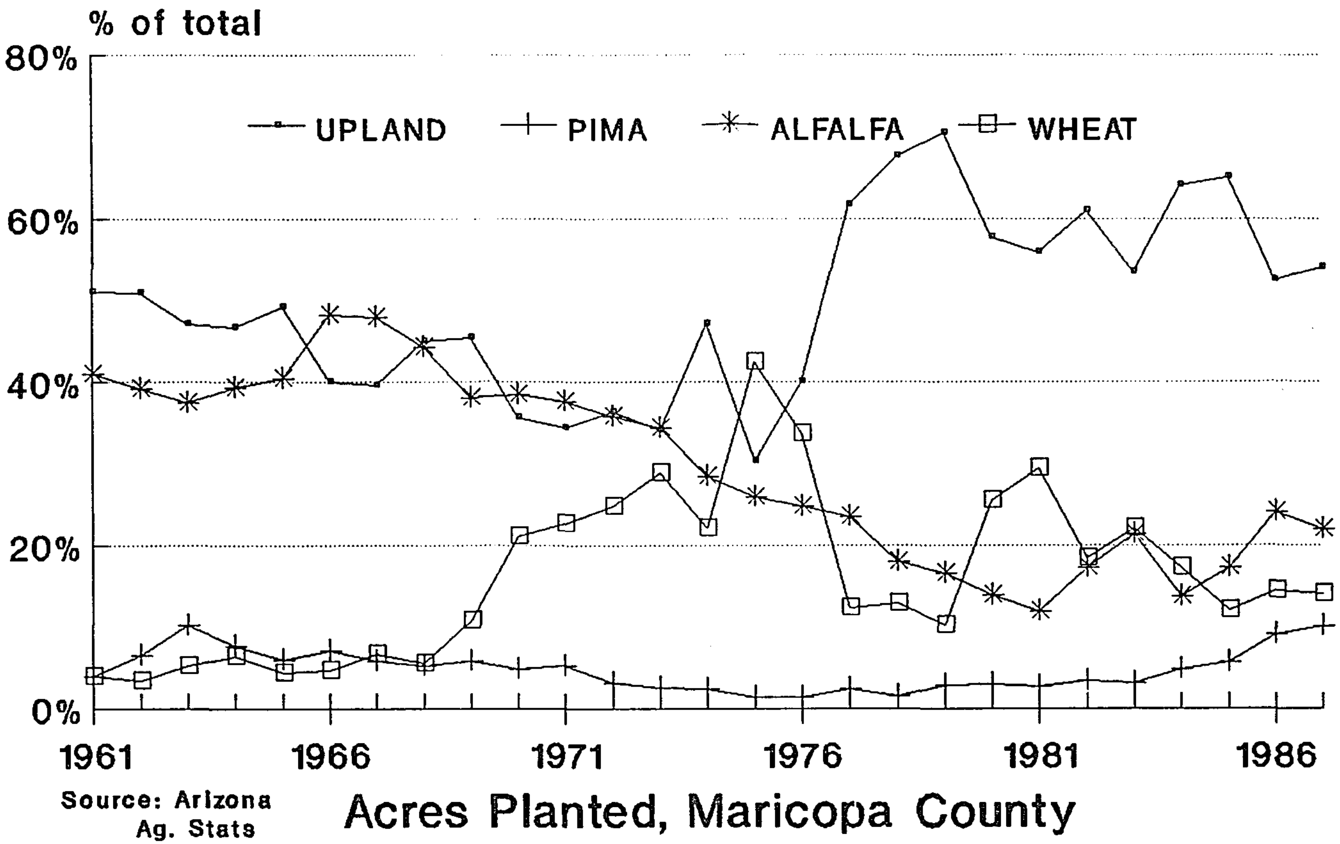

FIGURE 2.2
ACRES PLANTED OF LP MODEL CROPS:
As A Percent Of Total LP Crops

Trends in crop mix have been relatively stable since 1977, with the notable exception of increased Pima cotton production in recent years. During this time, planted acres of alfalfa and wheat averaged 54% of total cotton acreage. Accordingly, parameter RA in equation 2.7 is fixed at .54. Thus, constraint 2.7 insures that for every acre of Pima or upland cotton activity, wheat and alfalfa activities will sum to at least .54 acres.

Price and yield data shows that alfalfa has been a more profitable crop than wheat in the AMA, especially in areas with relatively cheap water. Thus, the LP model will "want" to rotate only alfalfa with wheat if it has this option. There are a number of reasons why this is unlikely, one of which is that the alfalfa market is somewhat localized, and large increases in AMA production will likely lead to reduced prices, which would in turn lead to reduced production. For these reasons, equations 2.6 are included. Parameter RW is set at .14, which is the lowest value of acres planted of wheat over acres planted of cotton in Maricopa County between 1978 and 1987.

The LP model does have the flexibility of substituting wheat, a low water use crop, for alfalfa.

Land Use Constraints

This category of constraints includes equations which account for the quantity of land available for planting and the type of land in terms of irrigation technology (it#). There are three irrigation technologies included, all of which are varieties of surface irrigation systems. Technology it3 is the most advanced and costly irrigation system and it1 is the least. Irrigation technology is examined in detail in chapter six.

The representative farm begins in 1990 with a certain endowment of irrigation technologies. This endowment is based on a survey of AMA farms completed by ADWR [1986]. The following constraints initialize the representative farm's endowment of irrigation technology:

$$[\sum_{j=1}^{4} X_{ijt}] + S_{it} \leqslant K1 \; ; \qquad (t = 1990) \quad (i = it1) \qquad (2.8)$$

$$[\sum_{j=1}^{4} X_{ijt}] + S_{it} \leqslant K2 \; ; \qquad (t = 1990) \quad (i = it2) \qquad (2.9)$$

$$[\sum_{j=1}^{4} X_{ijt}] + S_{it} \leqslant K3 \; ; \qquad (t = 1990) \quad (i = it3) \qquad (2.10)$$

where:

it# = irrigation technology (subscript i).

it1 = traditional row and furrow irrigation.

it2 = land laser-graded smooth to its existing slope.

it3 = land which is dead level.

X_{ijt} = acres planted of crop j, on land with technology i, in year t.

S_{it} = land with it i left fallow in year t.

K1, K2, K3 = endowment of it1, it2, and it3, in acres.

The LP model will determine an investment strategy which results in some optimal mix of irrigation technology. The following transfer equations are needed to account for farm acreage when it is shifted from lower to higher irrigation technology by investment activity:

$$[\sum_{j=1}^{4} X_{ijt}] + S_{it} \leqslant [\sum_{j=1}^{4} X_{ij,t-1}] - I1_{t-1} - I2_{t-1} + S_{i,t-1} \qquad (2.11)$$
$$(i = it1) \qquad (t = 1991, 1992, \ldots T)$$

$$[\sum_{j=1}^{4} X_{ijt}] + S_{it} \leqslant [\sum_{j=1}^{4} X_{ij,t-1}] - I3_{t-1} + I1_{t-1} + S_{i,t-1} \qquad (2.12)$$
$$(i = it2) \qquad (t = 1991, 1992, \ldots T)$$

$$[\sum_{j=1}^{4} X_{ijt}] + S_{it} \leqslant [\sum_{j=1}^{4} X_{ij,t-1}] + I2_{t-1} + I3_{t-1} + S_{i,t-1} \qquad (2.13)$$
$$(i = it3) \qquad (t = 1991, 1992, \ldots T)$$

where:

$I1_t$ = investment moving land from it1 to it2, in acres.

$I2_t$ = investment moving land from it1 to it3, in acres.

$I3_t$ = investment moving land from it2 to it3, in acres.

Equations 2.11 through 2.13 are land transfer constraints which restrict crop activity by irrigation technology according to the farm's 1990 endowment and subsequent investments (activities I1, I2, and I3). A fallow land activity, S_{it}, is included to insure that the farm is not forced to grow non-profitable crops in year t for the sole purpose of insuring land availability in year t+1. This unusual strategy could arise given the structure of constraints 2.11-2.13.

Finally, the farm is limited by its total acreage:

$$\sum_{i=1}^{3}[(\sum_{j=1}^{4} X_{ijt}) + S_{it}] \leqslant DA \;; \quad (t = 1990, 1991, \ldots T) \qquad (2.14)$$

where DA is the average farm's duty acres, or total acres available for planting.

Investment Constraints

If not otherwise constrained, the LP model generates solutions in which the optimal investment strategy is implemented in the first year of the farm's planning horizon. For instance, if level basin irrigation (it3) is the profit maximizing technology, the LP solution will dictate that all farmland be leveled flat in the first year. This is an unrealistic scenario for at least two reasons: 1) Farm operators will have a limited amount of capital to invest;

2) Only a few months of the year will be available for treating land (i.e. the period of time when the land is fallow).

These behavioral modeling problems are again dealt with by using empirical-based constraints; equations 2.15 limit the number of acres treated annually based on information about typical land treatment practices in the AMA.

$$.5*I1_t + I2_t + I3_t \leqslant .25*DA \quad ; (t = 1990,1991,...T) \quad (2.15)$$

where:

$I1_t$ = investment moving land from it1 to it2.

$I2_t$ = investment moving land from it1 to it3.

$I3_t$ = investment moving land from it2 to it3.

DA = duty acres = the farm's total cropping acres.

it1 = traditional row and furrow irrigation.

it2 = land laser-graded smooth to its existing slope.

it3 = land which is dead level.

As explained in chapter six, it is assumed that farmers grade land when it is fallow, and thus do not incur the opportunity cost of a lost crop. There are a number of ways which farmers can do this. Farmers who participate in the cotton program often level acreage which must be set aside for the agricultural conservation reserve (ACR). In four of the five years since 1985, participation in the cotton subsidy program has required that the farm set aside 25% of its cotton 'base' land for conservation. Assuming that half of a farm's land is for the cotton program base land, this means that 12.5% of its acreage was typically in the ACR, and could be leveled without the loss of a crop. According to Shearer [1990], farms are also able to level land between alfalfa and wheat rotations. This opportunity is available to those farms which use a cotton-alfalfa-wheat rotation.

Wilson's [1990] research experience indicates that farms in Pinal County (which is adjacent to Maricopa County) generally laser-grade to level at least 40, but not more than 120, acres of land a year, depending on farm size. The LP model assumes that the representative farm can laser-grade to level (activities I2 and I3 in eq. 2.15) up to 25% of its total acreage a year. Laser-grading to existing slope (it1) requires much less dirt moving and no ditch replacement, so the representative farm is allowed to treat up to half of its acreage with this technology in any year. Since representative farms in the AMA range from 161 to 495 acres, constraints 2.15 imply that the AMA farms will be able to dead level from 40 to 123 acres per year, and grade to slope twice those amounts.

III. Capturing The Impacts Of The GMA Conservation Measures

The Withdrawal Fee

The withdrawal fee affects irrigation water users by increasing water costs by the amount of the fee times the amount of groundwater used annually. The groundwater code placed strict limits on the withdrawal fee, with the maximum charge being $5 per acre-foot, and this only after the year 2005. Nowhere in the code is there a provision for indexing the fee to keep pace with inflation, but the Auditor General has implicitly recommended this change.[2] It is assumed that the withdrawal fee is limited to the maximums specified in the code, but that these limits will be constant in real, rather than nominal, terms.

The Water Duty

The income effect of the water duty is more difficult to capture than that of the withdrawal fee. This is because the representative farm has a number of options in response to a binding water allotment (see equations 2.3 - 2.5). A binding allotment is generally evidenced in the LP solution in one of the following two ways:

[2] Actually, the Auditor General [1989] recommended that the withdrawal fee be adjusted each year so as to insure that enough funds are collected to cover one half of DWR's operating expenses. This, in effect, would index withdrawal fees to match the rate of inflation of DWR operating costs.

1) an investment strategy different from the investment strategy in the no policy scenario is selected by the LP model;

2) a crop mix, different than the no policy scenario crop mix, is selected by the LP model.

Chapter six explains in some detail how the allotment can potentially affect the representative farm. This result hinges on the farm's ability to adopt irrigation technologies which obtain irrigation efficiencies as high as those implied by the water duty. The model farm can also adapt to water duties by building up positive flex account balances before the year 2000, which is when water duties are reduced to minimum levels. Then the model farm may use this water as a supplement to the annual allotment.

On Model Complexity

A guiding principle of science is that desired results be obtained using the simplest method possible. The LP model described herein is a comparatively simple one; constraints have been specified on the basis of empirical data, rather than behavioral models. If the emphasis of this study were to determine optimal farmer responses to the GMA conservation programs, a dynamic or quadratic programming model incorporating a wider range of activities and constraints would certainly be warranted.

Conversely, as simple as the LP model is, much of the same task could be accomplished with a spreadsheet. The LP model was chosen as the proper tool for our objectives for the following reasons: 1) A spreadsheet, while useful for static analysis, is difficult to utilize in the temporal setting modeled here. The LP model selects optimal activities, while a spreadsheet only responds to activities selected for it; 2) A dynamic programming model, especially one which considers risk aversion, requires substantial data collection. While very useful for modeling a specific farm's behavior, a dynamic model would not significantly improve the LP model's estimate of average behaviors, especially in light of the high cost of specifying, solving, and collecting data for numerous large and complex models.

As will become clear to those readers who examine chapters four, five, and six, great care has been taken to consider a full range of possible futures in terms of the LP model data inputs. It is in this attention to detail that a substantial payoff is expected.

IV. Endnotes

3.1. The actual workings of the flex account are quite a bit more complicated than the LP constraints indicate. Special accounting practices are used for various water sources such as spill water, effluent, and tailwater. If a farm uses only surface water, the GMA conservation measures do not apply. However, if even a very small proportion of the water a farm uses is groundwater, the farm is subject to regulation.

For example, suppose a farm has an annual water allotment of 1000 ac-ft. If the farm uses 1100 ac-ft, but uses only surface water, no debit to the farm's flex account is made. If 100 ac-ft of the 1100 was groundwater, the farm's flex account will be debited this amount.

Credits to flex accounts work in the same way; when a farm uses less than its allotment, its flex account goes up by only the amount of **groundwater** not used.

PART TWO: SPECIFICATION OF THE MODEL

Section two is comprised of chapters three, four, five, and six. These chapters discuss, in detail, the analysis and generation of 4 data sets used as inputs to the linear programming (LP) models. Many readers may wish to skip this section altogether, as the material can become somewhat tedious. Others may wish to go directly to some aspect of the data which particularly interests them. This introduction is meant to serve as a concise reference which describes the contents of these four data chapters.

Chapter three delineates the division of the Phoenix Active Management Area (AMA) into Areas Of Similar Farming Condition (ASFC). Each ASFC is represented by an average, or typical, farm which in turn implies a unique LP model. Farms within an ASFC are assumed to be homogeneous in size, slope of land, water cost, and certain policy parameters. The basic stratification of the AMA into ASFCs, and the specification of the representative farms, was originally done by the Arizona Department of Water Resources [1986].

Chapter four documents the projection of the gross returns and variable production costs of crop production. The four crops used in the LP models are upland cotton, pima cotton, wheat, and alfalfa. Data on prices and yields of these crops are from Arizona Agricultural Statistics [Bloyd et al. 1965-89]. Data on crop production costs are from the Arizona Field Crop Budgets [Hathorn, Wade et al. 1975-89].

Standard time series methods are used to project future gross revenue and production costs for an acre of crop activity. For each parameter, two projections are made. One projection is based on the trend in cost or gross revenue from 1950-1988. The other projection is the mean parameter value from 1984-1988. Projections of variable cost and gross revenue are then combined in a way to create three gross margin scenarios for each crop, where gross margin is defined as gross revenue minus variable production cost. The three gross margin projections are designated as being high, average, and low profit scenarios. Appendix I is an extension of chapter four.

Chapter five explains the projection of water cost for the various AMA water sources. An ASFC by ASFC breakdown of projected water cost is found in appendix II. Groundwater cost estimates require projections of future lifts and energy costs. Lift projections are made using data from ADWR's Draft Second Management Plan (SMP) [1988]. Two different projections of lift are made, based on overdraft projections from the SMP. One of these projections assumes overdraft levels for a no-conservation scenario, the other projection assumes full compliance with SMP conservation policy. Energy data comes directly from the major electrical suppliers in the area, or from irrigation districts. Time series analysis is used to project future energy costs.

A number of surface water suppliers are also important in the AMA. Primary among these are the Salt River Project (SRP) and the Central Arizona Project (CAP). Time series analysis and/or structural models are used to project water cost for these suppliers, as documented in chapter five and appendix II.

Chapter six documents data used in the LP models for the cost and benefit of adopting irrigation technology. Much of the analysis follows guidelines from Daubert and Ayer [1982]. Other data has been taken from the work of ADWR [1986] or from conversations with local irrigation experts. Two technologies are available in the model. One is to laser level fields to less than 2% slope (level basin). A less intensive technology alternative is to laser fields smooth at the existing slope (laser-to-slope). Chapter six also delves into the intricacies of the water duties, and how they could impact farmers in the AMA.

CHAPTER THREE

AREAS OF SIMILAR FARMING CONDITION

I. The Need For Representative Farms

The conservation measures of the Groundwater Management Act (GMA) will not have an equal effect on all farms in the Phoenix Active Management Area (AMA). Significant differences may arise due to dissimilar production attributes among farms. In order to account for these differences, the AMA is stratified into Areas Of Similar Farming Condition (ASFCs). Each ASFC is modeled by a representative farm, which is based on averages of key production parameters in the ASFC. The parameters defining each representative farm are inputs to an individual Linear Programming (LP) model.

The ASFC's and representative farms utilized in the LP analysis were developed by ADWR [1986]. ADWR defined the ASFC's in order to determine per acre water duties which met the following mandate of Arizona Revised Statute 45-565:

> "... The irrigation water duty and any intermediate water duties shall be calculated as the quantity of water reasonably required to irrigate the crops historically grown in the farm unit and shall assume the maximum conservation consistent with prudent long-term farm management practices within *areas of similar farming conditions,...*"

According to the ASFC Manual [ADWR 1986], "Grouping was done based on terrain, water costs, water quality, potential for subdivision development, CAP deliveries, water logging study, soils, availability of surface water, and crop and irrigation system potential." Supply of water is a strong delineating factor, as many of the ASFC's are centered around, and named after, irrigation districts. In all, twelve ASFC's were defined. Figure 3.1 is a map of the AMA showing the ASFC's. Two of the ASFC's, 'Problem Soils' and 'Citrus', are not geographically contiguous and are not shown.

Once the ASFC's were defined, ADWR analyzed its data on irrigation grandfathered groundwater rights to determine average values of key production parameters characterizing the representative farm in each ASFC. These are the same representative farms analyzed via the LP analysis. ADWR's stratification of the AMA is extended here by also considering farms with different planning horizons as separate cases within each ASFC.

The primary factors which differentiate the representative farms are farm size, irrigation technology, slope of cropland, water cost, water supply, water quality, and the per acre water duty assigned by ADWR.

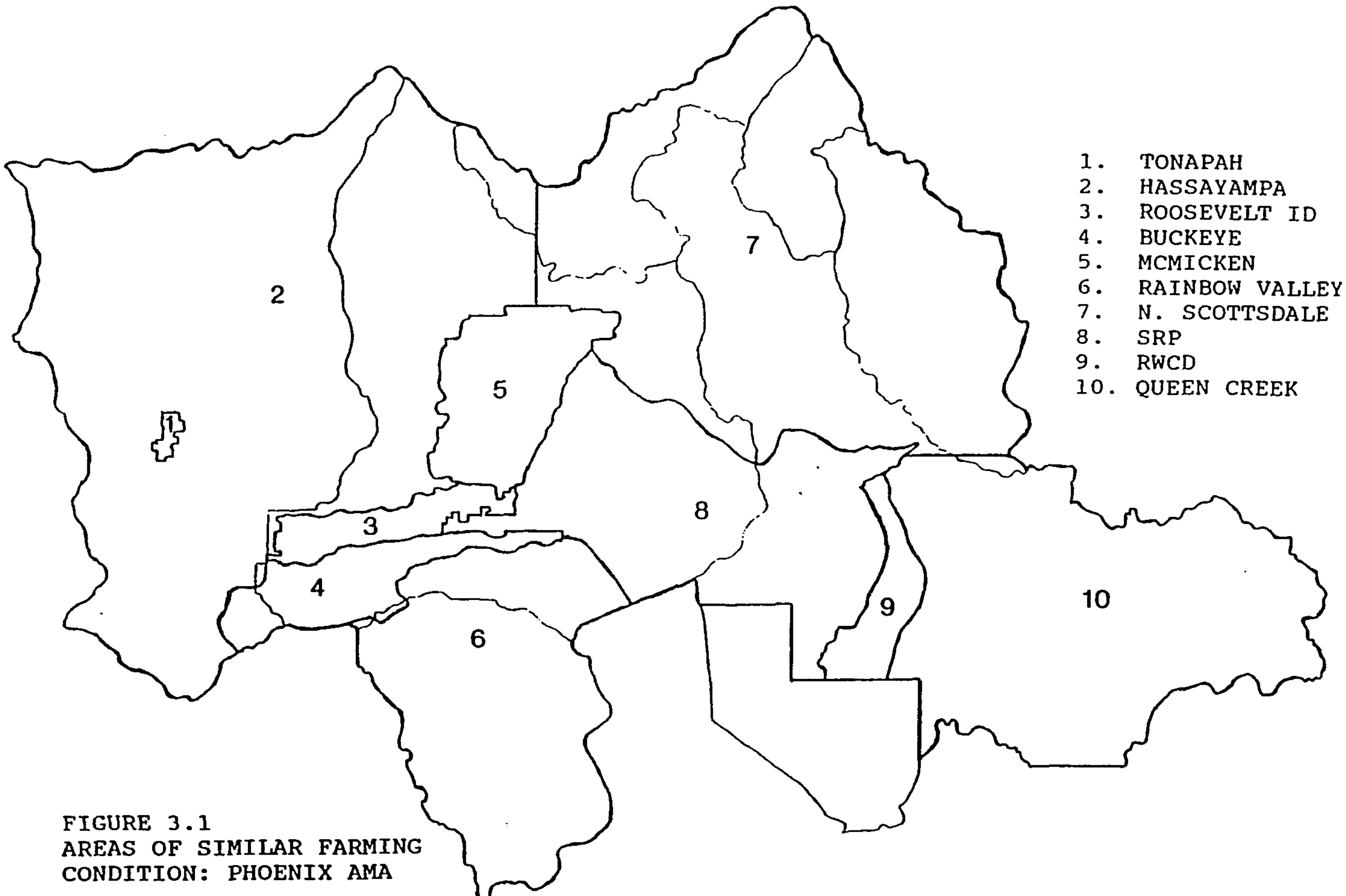

FIGURE 3.1
AREAS OF SIMILAR FARMING
CONDITION: PHOENIX AMA

source: ADWR [1988]

II. AMA Stratification

Distinguishing Factors: Overview

Figure 3.2 shows diagrammatically the stratification of the AMA which determines the number of LP runs necessary to account for the entire AMA. There are three tiers of differentiation portrayed in figure 3.2; from top to bottom these are the AMA, the ASFC, and sub-ASFC levels of analysis. At each level, parameters listed are generally applicable to all farms at and below that level. Thus, figure 3.2 indicates that the withdrawal fee will be the same for all farms in the AMA.[1] Likewise, the second tier of figure 3.2 demonstrates that water costs will be different for different ASFC's, but equal for all farms within an ASFC. The focus of this chapter is on the second tier of analysis, or those parameters which distinguish between the ASFC's. The reader may find it useful to refer back to figure 3.2 while reading this chapter.

Factors distinguishing the representative farms can conveniently be divided into three categories: water factors, policy factors, and land factors. The policy factors relate to water, and can be considered a subset of the water factors. Table 3.1 specifies the values of these parameters for the 12

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[1] Some irrigators in the west part of the AMA are only required to pay a minimal ($.25/ac-ft) withdrawal fee, because they are experiencing rising groundwater tables. These areas, which include the Arlington, Buckeye, and St. Johns irrigation districts, have also been exempted from the water duty.

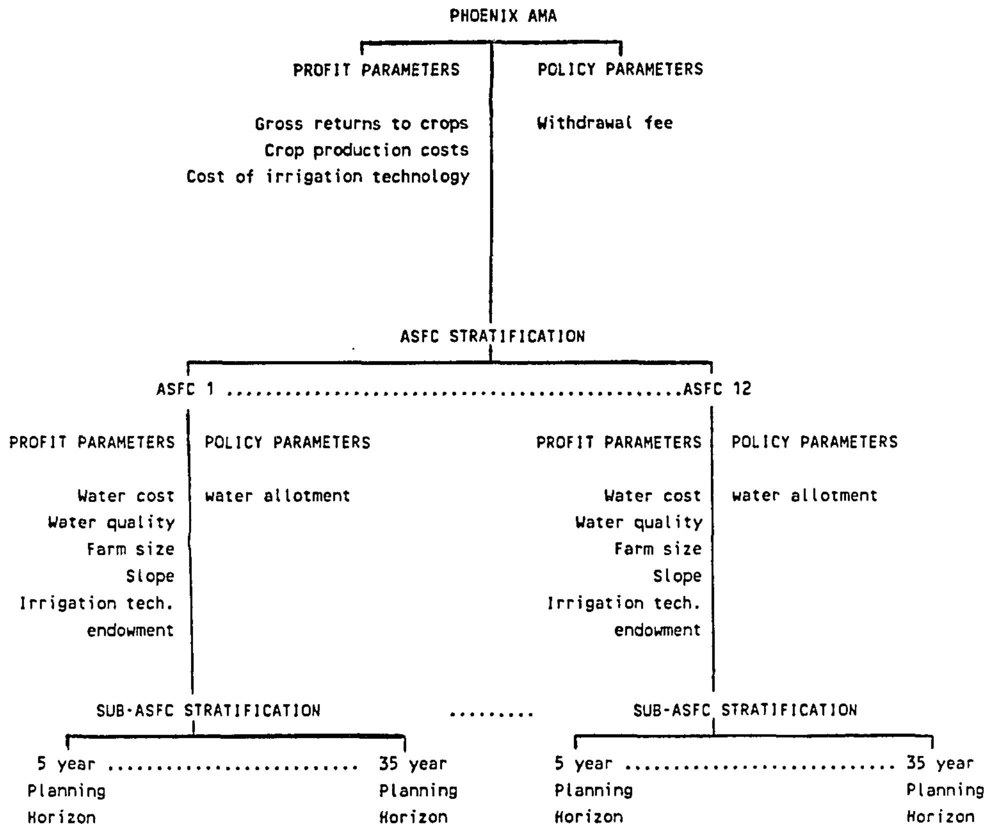

FIGURE 3.2: PHOENIX AMA STRATIFICATION

representative farms. Note that the parameters in table 3.1 are found at the middle level of figure 3.2, and that these are the factors which stratify the AMA into ASFC's.

Distinguishing Factors: Water

1) Water Cost: Data in table 3.1 comes from ADWR's ASFC analysis. The values for water cost are the average cost per acre-foot paid in 1986 in each ASFC. Water costs in the AMA in 1986 ranged from \$15.88/ac-ft to \$70.00/ac-ft. Projections of future water costs and supplies, by ASFC, are documented in chapter five, and appendix II.

2) Water quality: Water quality is given in total dissolved solids per liter, and in 1986 ranged from 361 TDS/l to 2757 TDS/l. Generally, water quality in the AMA is good for use in crop production.

3) Water Source: The next two columns in table 3.1 regard the future availability of surface water in each ASFC. A 'Y' indicates that surface water will be available. The row labeled 'Surface Water' accounts for sources other than the Central Arizona Project (CAP). Availability of CAP water is noted in the next column. ASFC 5, the McMicken area, is divided up further for the LP runs due to a distinct cleavage in water supply sources. Surface water is supplied to approximately half of the acreage in this area by the Maricopa

TABLE 3.1: REPRESENTATIVE FARM PARAMETERS

ASFC #, NAME	WATER PARAMETERS: 1986 COST ($/acft)	WATER PARAMETERS: 1986 QUALITY (TDS/l)	WATER PARAMETERS: << SUPPLY >> SURFACE?	WATER PARAMETERS: << SUPPLY >> CAP?	POLICY PARAMETERS: TARGET EFFICIENCY '2000	POLICY PARAMETERS: << WATER DUTY >> 1990	POLICY PARAMETERS: << WATER DUTY >> 1995	POLICY PARAMETERS: << WATER DUTY >> 2000	LAND FACTORS: AVERAGE SLOPE	LAND FACTORS: IRRIGATION EFF. '1986	LAND FACTORS: TOTAL ACRES
1 TONOPAH	48.03	1000	N	Y	85%	6.42	5.37	4.32	.3 X.3	57%	477
2 HASSAYAMPA	40	634	N	N	85%	6.48	5.56	4.63	.3 X.3	61%	303
3 R.I.D.	26	1552	N	N	70%	5.93	5.45	4.97	.7 X.2	59%	269
4 BUCKEYE	28	2757	Y	Y	N.A.	N.A.	N.A.	N.A.	.4 X.2	60%	170
5 McMICKEN	51.71	361	Y	Y	85%	5.53	4.71	3.88	.3 X.3	60%	626
6 RAINBOW VAL	60	1184	N	N	85%	5.93	4.95	3.96	.4 X.3	57%	303
7 N SCOTTSDALE	50	345	N	N	85%	7.2	6.71	6.21	.3 X.3	73%	89
8 S.R.P.	15.88	747	Y	N	85%	5.96	5.16	4.35	.3 X.3	62%	153
9 R.W.C.D.	34.13	805	Y	Y	85%	5.1	4.72	4.33	.2 X.2	72%	191
10 QUEEN CREEK	70	737	N	Y	85%	5.35	4.82	4.29	.4 X.3	68%	405
11 POOR SOILS	38.85	957	N	Y	70%	5.74	5.40	5.06	.4 X.2	62%	196
12 CITRUS	50.43	634	Y	Y	65%	5.54	5.56	5.58	.5 X.3	66%	123

source: ADWR [1986]

County Water Conservation District #1 (MCWCD #1). The majority of the other farms in ASFC 5 belong to the McMicken ID, and rely on self pumped groundwater. The differences between these two areas are discussed in appendix II. MCWCD #1 is designated as ASFC 5A and McMicken as ASFC 5B. All characteristics other than water cost and source are assumed to be the same for these two areas.

Distinguishing Factors: Policy

1) Target Irrigation Efficiency: The middle of table 3.1 is devoted to what may be called policy parameters pertaining to water. The ADWR analysis determined maximum irrigation efficiencies achievable in the ASFC's. Irrigation efficiency is defined by the following equation:

$$\text{Irrigation Efficiency} = \frac{\text{Crop Water Consumptive Needs}}{\text{Irrigation Water Applied}} \qquad (2.1)$$

Once the target irrigation efficiency is determined, the water duty is calculated considering historical planting between 1975 and 1980:[2]

$$\text{Water Duty} = \frac{\text{Water Needs/acre (based on historical crop mix)}}{\text{Target Irrigation Efficiency}} \qquad (2.2)$$

[2] A more detailed discussion of irrigation efficiencies is found in chapter 5, which explores the relationship of the water duties to irrigation technology.

In general, ADWR came to the conclusion that laser leveling is a feasible irrigation technology in the AMA (in this case, feasible implies a benefit-cost ratio of greater than 1). According to ADWR, this technology achieves a potential irrigation efficiency level of 85%. Water duties after the year 2000 will be based on 85% irrigation efficiency. As revealed in table 3.1, the Roosevelt Irrigation District (RID), Buckeye, Problem Soils, and Citrus, ASFCs are exceptions to the 85% target efficiency.

2) Water Duty: Movement towards requiring the maximum level of irrigation efficiency (minimum water duty) will take place in steps as water duties are curtailed in 1995. In 1992, some adjustment up or down in the water duty will occur based on ADWR's assessment of current data on farm water needs. By the year 2000, water duties will equal the amount of water necessary to grow an acre of the crop mix grown between 1975-1980, assuming the ASFC's target efficiency.

3) Withdrawal Fee: The withdrawal fee is assumed to be generally homogeneous throughout the AMA and therefore is found at the top tier of figure 3.2. It is not listed on table 3.1. A 'maximum' scenario has the withdrawal fee going from the current $1.00/ac-ft to $3.00/ac-ft in 1991, to $5.00/ac-ft in 2006. These levels of the fee are based on the limits written into the GMA.

Distinguishing Factors: Land

1) Average Slope: The first of the land factors considered in table 3.1 is the average slope of the typical farm's fields. Slope is measured in ft-drop per 100-ft horizontal run. Slope is of importance in this model because it affects the cost of leveling fields. The steeper the slope, the greater will be the amount of soil moved and thus the cost of laser leveling per acre will be higher. Slopes in the AMA range from .2 to .7. Average slope across two directions is shown for all ASFCs.

2) Irrigation Technology Endowment: The next column exhibits the average farm irrigation efficiency existing in the ASFCs in 1986. These efficiencies were determined by an ADWR survey done for the original ASFC analysis.

3) Total Farm Crop Acreage: Known also as water duty acres, this is the total number of acres on a representative farm available for planting, and does not include land devoted to roads, ditches and fences. The total farm acreage in the AMA representative farms varies from 89 (North Scottsdale ASFC) to 626 (McMicken ASFC) acres.

Sub-ASFC Stratification

Investment in an improved irrigation system can require a substantial initial cost. The benefits of this investment will be realized incrementally over an extended number of years. The length of the planning horizon of a farmer will impact his decision to invest in irrigation technology, and in turn change the impacts of conservation policy. In some of the ASFCs a large percentage of the farmland will likely be urbanized before 2025, and therefore it is necessary to have estimates of the number of farms in each ASFC with planning horizons less than the 35 year study-period. Estimates of ASFC acreage with 5, 10, 15, 20, 25, and 30 year planning horizons (as determined by urbanization) have been obtained from ADWR and SRP. This data allows for a meaningful aggregation of results from models of representative farms with different length of planning horizon.

Another sub-ASFC stratification is based on the cost and benefits which a farm will realize from laser leveling its fields. As documented in chapter six, there is some dispute about the true value of maximum feasible irrigation efficiency. This stratification considers the impact of the water duties if the average farm's soil characteristics and water delivery systems will not allow them to obtain the efficiency required by ADWR.

These sub-ASFC stratifications extend ADWR's original ASFC analysis by considering different behavioral strategies and feasible technologies.

Summary

Not all of the ASFCs are included in this analysis. ASFC 4, Buckeye, is not included because irrigators in this area have been relieved of the water duty due to local rising water tables. The withdrawal fee in this area is only a quarter of the general AMA withdrawal fee. ASFCs 7, 11, and 12 are not included because of their relative insignificance and/or the special modeling requirements which these areas would require.

As discussed in appendix II, ASFC 5 is further sub-divided into ASFC 5A and ASFC 5B. This sub-division is based on two distinct sources of water used in the area. The areas which are included in the analysis account for about 273,000 out of a total 340,000 acres of non-Indian agriculture. This means that 80% of the total acreage is accounted for in this study.

CHAPTER FOUR

FARM PROFIT SCENARIOS

I. Introduction

Overview of Analysis

The stated goal of the GMA designates 2025 as the date when Active Management Areas (AMA's) should reach safe-yield levels of water use. Accordingly, the change in farm profits between 1990 to 2025 will be estimated. It is likely that different levels of general profitability in the AMA farming will result in different estimates of the GMA's social cost. Since no one can say with certainty what typical farm profits will be in the AMA from 1990-2025, it is necessary to put reasonable bounds on the future profitability of crop production in the AMA. Pessimistic and optimistic scenarios of future returns to farming, developed for use in the LP model, are presented in this chapter.

Profit scenarios for each of the crop activities in the LP model are created by combining three independently projected parameters. These parameters are gross revenue per acre of crop activity, variable cost per acre of crop activity, and water cost per acre foot. The first part of this chapter details the projection of gross revenue and variable cost. The chapter ends with a discussion of water cost projections.

Scenario Modeling: Theory

Ayres [1969 p.xiv] defines scenario as "... a time ordered, episodic sequence of events bearing a logical relationship to one another and designed to illumine a hypothetical future situation... A scenario is not and is not intended to be either a prediction or a forecast." This definition highlights an important point; in creating scenarios of future farming profitability in Arizona we attempt not to say 'this is the likely future', but rather 'it is likely that the future will fall within these extremes'. The final measurement which we attempt to encapsulate with these scenarios is the potential income loss in the Phoenix AMA agricultural sector attributable to GMA conservation measures. Scenarios are developed with this end product in mind; assumptions about farming conditions and policy measures which yield maximum and minimum estimates are evaluated. Also considered is a 'no change' case where it is assumed that farm profits will remain at 1984-1988 mean levels.

II. Parameters Needed For The LP Model And Data Sources

Three profit scenarios are developed for each crop for the time period 1990 to 2025. These three reflect a high-low-average framework, where the average scenario is simply an extension of mean profit from 1984-1988. The extreme scenarios are more difficult to determine, and are also based on historical data trends. In the case of alfalfa and wheat, the low-profit scenario is the same as the average scenario (i.e. mean profit from 1984-1988), reflecting historical upward profit trends for these two crops.

Parameters

The LP model determines the revenue maximizing crop mix over the period 1990-2025. The net crop mix solution results directly from the combination of resource constraints and crop profit parameters included in the model. Gross revenue and variable production cost parameters are assumed to be invariant across the AMA. Thus, the revenue/cost scenarios developed in this chapter will be applied to all of the representative farms describing the AMA.

For each crop, and in every year, the profit parameter is partitioned into the following components:

$$PP = TR - TVC \qquad (4.1)$$

$$= TR - (C + WC) \qquad (4.2)$$

$$= TR - C - (W \times AF) \qquad (4.3)$$

where:

PP = profit per acre of a crop planted, **not including fixed costs.**

TR = gross revenue per acre of crop planted.

TVC = total variable cost per acre of crop planted = C + WC.

C = variable production costs per acre planted excluding water cost.

WC = variable water costs per acre crop activity.

W = variable water cost per acre-foot of water.

AF = acre-feet of water required per acre of crop activity.

The above disaggregation of the crop-profit parameter is the minimal division feasible for our purposes. The water cost parameter must be separate in order to allow for manipulation of future water costs reflecting the withdrawal fee. Also, water cost varies extensively between the ASFC's, while the other components of the profit parameter (PP) are assumed to be homogeneous throughout the AMA.

Forecasting a single aggregated gross revenue (TR) parameter does present the following problem. One of the benefits of laser leveling farmland is an increase in yield per acre due to better distribution of irrigation water across fields. The exact size of this yield improvement is unknown, with recent literature putting the increase at somewhere between 0-30% [Daubert & Ayer 1982].[1] If the farm's decision to laser level or not changes within this range of yield

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[1] Recent discussion with agricultural researchers [Wilson, 1989. Shearer, 1990] indicates that some of the improvement in yields previously attributed to laser leveling may actually be more a function of better management of water application, where management relates to the timing and quantity of water applied.

improvements, there are implications regarding the impact of water duties on farm profits.

Percent improvements in yield due to laser leveling can be modeled by increasing gross revenue by an equal percent. This is correct assuming that the percentage improvement in yields due to leveling is not functionally related to the nominal value of yield per acre. (See endnote 4.1)

Data Sources

Price and yield data for the years 1950-1988 are collected for five primary Arizona crops from Arizona Agricultural Statistics [Bloyd *et al.* 1965-1989]. Nominal prices are converted to real 1987 prices using the parity index. The primary source for production costs are the Arizona Field Crop Budgets, [Hathorn, Wade *et al.* 1975-1989]. Production cost data is available over the period 1974-1988.

Water cost data come from a number of different sources. The Arizona Pump Water Budgets [Hathorn 1975-1984], are used to analyze trends in groundwater cost. Irrigation district water costs were collected by the Department of Water Resources (ADWR) [Stipe, 1989], the Crop Budgets, or directly from the providers. A complete discussion of water cost projections is included in chapter five.

Total Revenue Data

An examination of yield and price data from 1950 to 1988 shows interesting and consistent trends for the 4 crops used in the LP model (see figures 4.1A-4.1D).[2] Yields increased dramatically over this period, while real prices steadily declined. The decade following World War II exhibited the highest real prices, while current prices are near historical lows. Trends in total revenue (i.e. yield times real price) are less defined. Alfalfa and wheat indicate general upward trends in gross revenue per acre planted. Upland cotton and Pima cotton revenues have been declining, even when subsidies are taken into account.

Cost Data

Costs of production per acre planted of each crop are projected based on data from the Arizona Crop Budgets. Omitted from what is heretofore called the production cost parameter are water cost and fixed costs. Fixed costs should not affect a farmer's yearly production choices, given a decision to remain in business. Fixed costs become of import when annual returns over variable costs fall short of annual

[2] Data for crop prices and yields is actually available at least as far back as 1933. By using 1950-1988 we are presuming that parameter changes over the next 35 years will mirror changes of the past 36 years.

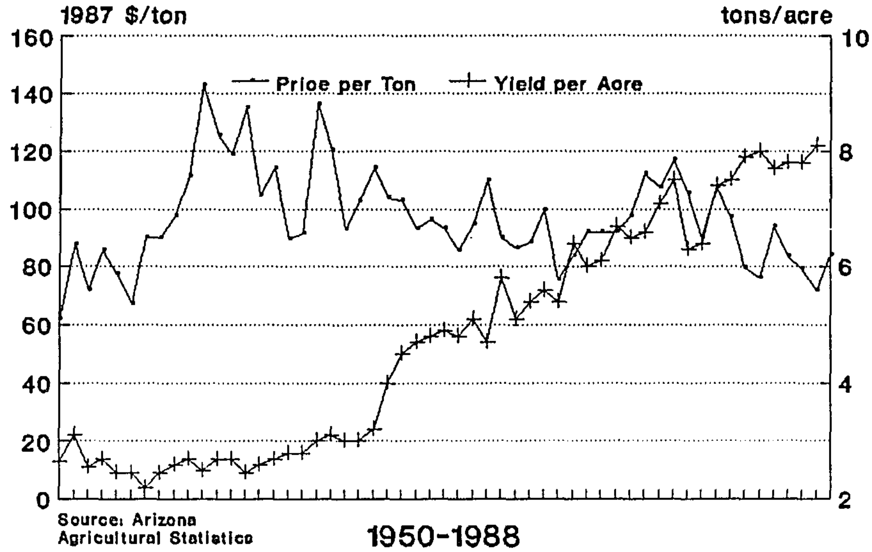

FIGURE 4.1A
ALFALFA YIELD AND PRICE

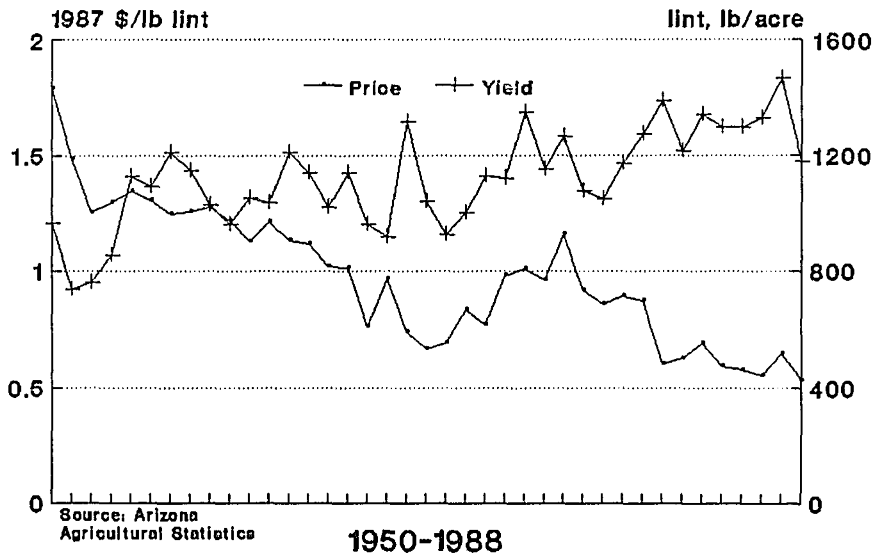

FIGURE 4.1B
UPLAND COTTON YIELD AND PRICE

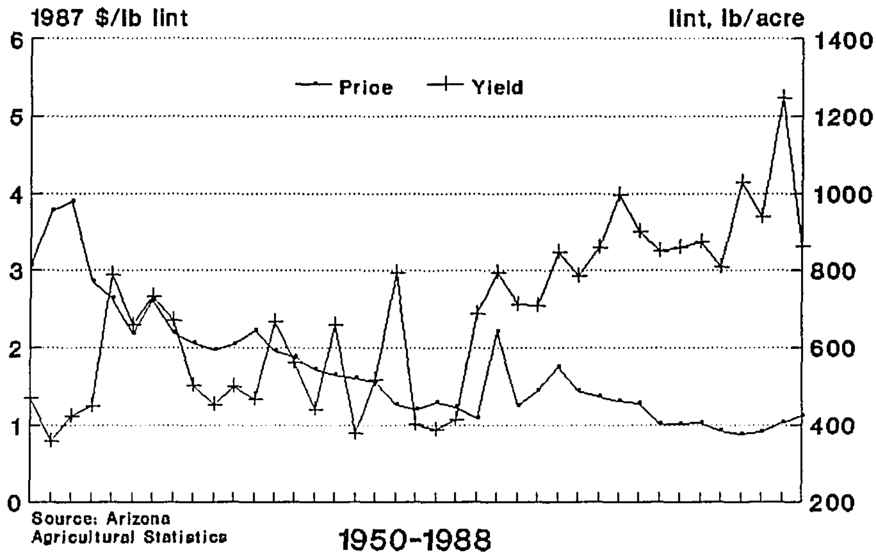

FIGURE 4.1C
PIMA COTTON YIELD AND PRICE

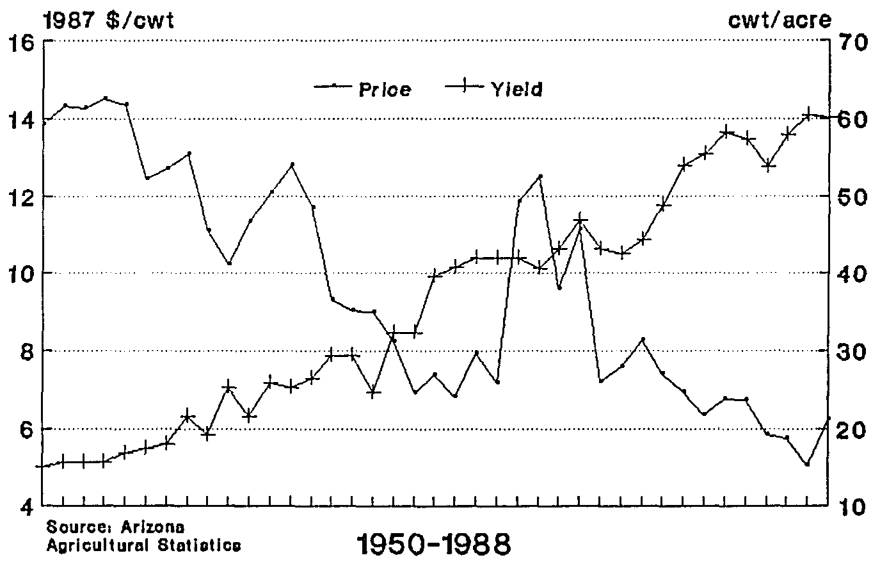

FIGURE 4.1D
WHEAT YIELD AND PRICE

fixed costs over an extended number of years. This situation will eventually drive the farmer out of business. Fixed costs are evaluated exogenous of the LP model, and are considered **separately from** the assessment of the allotment's and withdrawal fee's impact on farms which remain in operation. The exclusion of fixed costs should not significantly effect the estimates of the **change** in net revenue given by the LP model.

One fixed cost which is considered in the LP model is the cost of irrigation technology investment. Irrigation investment cost is included in the LP model objective function as a cost required to obtain an improved irrigation technology. These costs are discussed in greater detail in chapter six.

An examination of data for real production costs indicates downward trends for all crops. (see figure 4.2A, table 4.2, and appendix I). Most dramatic are the cost decreases in wheat, and the two cotton crops. Alfalfa production costs have also declined since 1974, but appear to have leveled off over the last 10 years.

III. Projections: Crop Profit Scenarios

Time Series Analysis

Data for real gross revenue and real cost of production have been examined for trends. At least two scenarios for each parameter are generated, one forecasting high future values and another projecting low future values for these parameters. The 1984-1988 mean serves as one of the scenarios. For example, if a parameter suggests a downward trend, the 1984-1988 mean is used as the high-level scenario. This feature of the projections is best observed by noting the cost/revenue projections presented in figure 4.2A and in appendix 1.

Ordinary Least Squares (OLS) and Box-Jenkins (ARIMA) analysis are used to generate parameter projections. Generally, a linear or one-term-auto-regressive model provides the most reasonable projection. The linear (OLS) model is of the form,

$$Y_t = a + bT \qquad (4.4)$$

where Y is either cost or revenue and T is time, in annual units from 1950-1988. The parameter b is the annual change in parameter Y, or the slope of the projection line with respect to T. An autoregressive model is of the form:

$$Yt = a + bY_{t-1} + cY_{t-2} + dY_{t-3} \quad \ldots \qquad (4.5)$$

AR(1) is used as an abbreviation for a one-term-autoregressive model, which is to say that

$$Y_t = a + bY_{t-1} \qquad (4.6)$$

If the data to be fit has a definite upward or downward trend, it is necessary to transform the data to a differenced form, where the new data Y' is:

$$Y'_t = Y_t - Y_{t-1} \qquad (4.7)$$

An AR(1) model based on differenced data has the form:

$$Y'_t = a + bY'_{t-1} \qquad (4.8)$$

or, converting back to original data form:

$$Y_t - Y_{t-1} = a + b(Y_{t-1}-Y_{t-2}) \qquad (4.9)$$

and,

$$Y_t = a + (1+b)Y_{t-1} - bY_{t-2} \qquad (4.10)$$

The AR(1)-differenced model implies that Y_t is a function of Y_{t-1} and Y_{t-2}. In all cases documented in this chapter, the autoregressive models are based on first order differencing of the data.

Model Selection, Gross Revenue

In selection of 'best' parameter projections for use in the LP model, the overriding criteria is that the projections are reasonable considering historical data trends. It is very possible that these projections will not enclose all true future parameter values. However, when synthesized to create minimum/maximum profit scenarios, these projections do include a very wide range of possible futures.

In the case of gross revenue, two primary criteria are used to choose between mathematical forms. Reasonableness of a projection is judged on how closely the projected change in gross revenue from 1990-2025 reflects the historic change in that parameter over an equal time period. Change in projected gross revenue from 1990 to 2025 is measured against the change in gross revenue realized between 1950 and 1988. The change in gross revenue between 1950 and 1988 is calculated as the difference between the mean from 1948-1952 and the mean from 1984-1988. Thus, the difference between 1990-2025, a 35 year projection period, is effectively weighed against the change between 1950-1986, a 36-year historical period.

The second criteria utilized in model selection is the goodness of fit, or the R-squared, of the regression equation. When making projections so far outside the data, and given the high variance in the gross revenue data, statistical selection criteria lose much of their relevance. Therefore the R-square is used only to select between models otherwise judged to be equally 'reasonable'.

Model Selection, Variable Cost

It is difficult to establish a selection criteria for cost projections that is as intuitive as the 'absolute change' yardstick applied to gross revenue projections. Consistent cost data is available only from 1974 to 1988, which means that projections extending to 2025 cover a time period 2.4 times longer than that of the data. Real production costs fell rapidly for all 5 crops during the past 15 years, and utilizing an absolute change criteria implies that projected costs for all of the LP crops will go negative before 2025! Such radical declines in production costs are probably implied due to the lack of an extended data series for this parameter.

In general, it appears that the downward trends in production cost have leveled off in the most recent 5 years (note figure 4.2A and appendix I). Theory would hold that the decreasing production cost data reflects technological improvements overcoming any increase in production costs due to resource scarcity. Fisher's [1981 ch.4] review of resource scarcity measures indicates that, worldwide, real production costs have been declining in agriculture. This appears to be the case in Arizona as well. The key question in projecting future costs is, "will this trend continue, or are we near a turning point?" The final 'low-cost' projections are consistent with a hypothesis that the downward trend in real cost will continue, but at a slower rate somewhat than that realized over the past 15 years. The maximum cost projections assume that real production costs will maintain 1984-1988 mean levels.

Auto-regressive models of cost produce similar R-squares as linear fits, while having the desired effect of dampening the rate of projected decline. Since model selection criteria for cost is less than robust, consistency among the crops is protected by using AR projections for all LP crops. As a measure by which to compare projections of cost, the following, somewhat ad-hoc, yardstick is calculated for each crop in the following manner:

1) The % decrease in variable cost from 1976 to 1986 is calculated, based on the mean costs from 1974-1978 and 1984-1988.

2) The yardstick is calculated by assuming that every 10 years costs will decrease by the same percent as that realized over 1976-1986. This yardstick imposes a structure of costs which decrease, but at a decreasing rate.

Results of this yardstick, compared with actual cost projections are given for each crop in the sections which follow. This yardstick is used to make the point that our estimates of declining costs are relatively conservative, considering the data. In every case, projected costs decline much less than the yardstick would imply.

Results: Cost, Revenue, and Gross Margin Projections

The basic philosophy used to analyze the gross revenue and production cost data is this: one projection assumes that the data reflects a long run trend, the other projection holds that the most likely future values for these parameters are the mean values over the past five years (1984-1988).

Figure 4.2B shows data and projections for cost, gross revenue, and net returns not including water cost for upland cotton.[3] Similar projections for the other LP crops are found in appendix I. At this point it is convenient to define a new term, Gross Margin, which is defined here as the net returns to an acre of production not including fixed cost or water cost. Gross margin scenarios are generated by subtracting cost projections from gross revenue projections. Figure 4.2B shows projections of the upland cotton gross margin parameter.

[3] Due to software limitations, plots of cost and gross revenue do not show data points prior to 1956 or after 2015. This data was included in the time series analysis, and do not in any case weaken the trends shown.

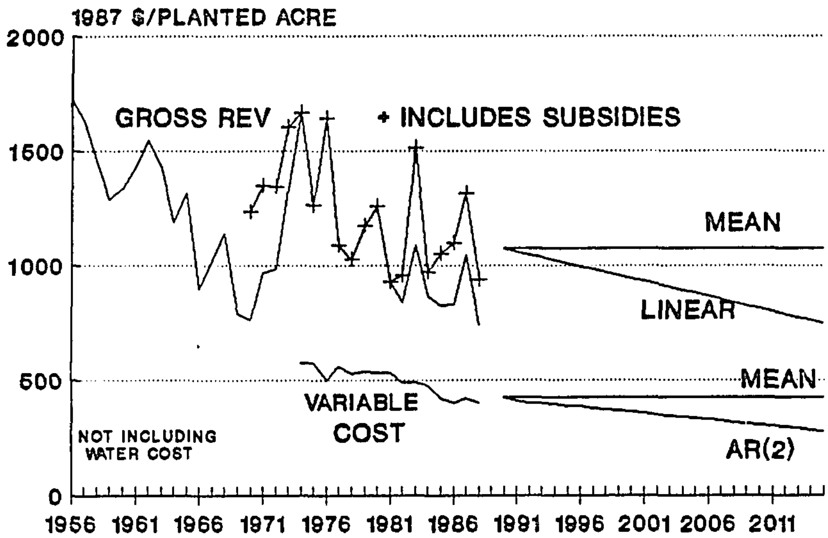

FIGURE 4.2A
UPLAND COTTON REVENUE & COST PROJECTIONS

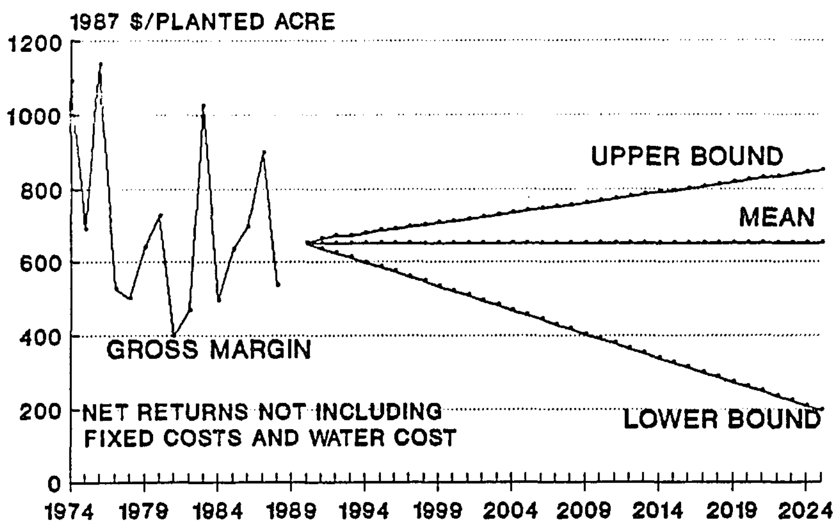

FIGURE 4.2B
UPLAND COTTON GROSS MARGIN PROJECTIONS

Upland Cotton Gross Margin Scenarios

Upland cotton has long been the most important crop to Arizona agriculture. (Trends indicate that upland's prominence could soon give way to Pima cotton and alfalfa). Figure 4.2A shows upland cotton gross revenues per acre in Arizona. This data includes seed and lint revenues. Also pictured in figure 4.2A is gross revenue per acre including government subsidies. Government subsidies per acre is calculated as the ratio of all government payments to Arizona farmers (not including disaster payments) divided by acres of upland cotton planted in Arizona. Unfortunately, consistent subsidy data is available only back to 1970. A regression of the gross revenue-with subsidy data on time yields even stronger downward trends than the data not including subsidies (1950-1988). The trend (slope) of projected upland gross revenues is taken from an AR(1) fit of the gross revenue data **not** including subsidies. The initial (1990) value is set as the average gross revenue **including** subsidies. Figure 4.2A and table 4.1 demonstrate the end results. Gross revenue for upland cotton is projected to at best hold steady over the next 35 years, and in the lower bound scenario to decline by about 50% ($576/acre) from 1990 to 2025 (table 4.1, figure 4.2A).

TABLE 4.1

SUMMARY OF GROSS REVENUE PROJECTIONS

GROSS REVENUE/ACRE, IN 1987 DOLLARS						
CROP		PARAMETER	GROSS REVENUE	ABSOLUTE CHANGE	MODEL	ADJUSTED R-SQUARE
	DATA:	1948-52 MEAN:	1289	-428		
UPLAND ^^ COTTON		1984-88 MEAN:	861			
		1990 VALUE:	1074	-498	AR(1)	0.4291
	PROJECTION:	2025 VALUE:	576			
	DATA:	1948-52 MEAN:	1324	-281		
PIMA COTTON		1984-88 MEAN:	1043			
		1990 VALUE:	1043	-239	AR(1)	0.2209
	PROJECTION:	2025 VALUE:	804			
	DATA:	1948-52 MEAN:	307	334		
		1984-88 MEAN:	641			
ALFALFA						
		1990 VALUE:	641	173	AR(1)	0.6984
	PROJECTION:	2025 VALUE:	814			
	DATA:	1948-52 MEAN:	219	124		
		1984-88 MEAN:	343			
WHEAT^^						
		1990 VALUE:	386	140	LINEAR	0.6875
	PROJECTION:	2025 VALUE:	526			

SOURCE: BLOYD et. al., 1965-1989

^^ data shown does not include subsidy payments, but projections take subsidies into account.

Mitigating the loss in gross margin suffered over the recent years has been a strong downward trend in the real cost of growing upland cotton. As detailed in table 4.2, the mean cost per acre of upland cotton declined by nearly 25% between 1976 and 1986. The AR(1) model projects this trend to continue, with real production costs being only half of what they are now by the year 2025. The gross margin projections resulting from combinations of cost and gross revenue scenarios are shown in figure 4.2B.

Gross Margin Scenarios: Other LP Crops

Projections of gross revenue, variable production cost, and gross margin for the other LP model crops are found in appendix I. The methodology used is identical for all the LP crops. The results are that alfalfa has the strongest upward trend in gross margin, wheat is upward tending also, and Pima cotton gross margin is downward tending, although not as sharply as upland cotton. In spite of these trends, upland and Pima cotton remain the most profitable crops in most scenarios and over the entire 35 year planning horizon.

TABLE 4.2

SUMMARY OF VARIABLE PRODUCTION COST PROJECTIONS

		VARIABLE COST/ACRE, IN 1987 DOLLARS					
CROP	PARAMETER		VARIABLE COST	YARDSTICK, PROJECTED CHANGE		MODEL	ADJUSTED R-SQUARE
	DATA:	1974-78 MEAN:	548	YARDSTICK:	-319		
UPLAND COTTON		1984-88 MEAN:	423				
		1990 VALUE:	423	PROJECTED:	-198	AR(1)	0.7916
	PROJECTION:	2025 VALUE:	225	CHANGE:			
	DATA:	1975-79 MEAN:	531	YARDSTICK:	-270		
PIMA ^ COTTON		1984-88 MEAN:	438				
		1990 VALUE:	438	PROJECTED:	-137	AR(1)	0.6336
	PROJECTION:	2025 VALUE:	301	CHANGE:			
	DATA:	1978-82 MEAN:	220	YARDSTICK:	-57		
		1984-88 MEAN:	210				
ALFALFA^^							
		1990 VALUE:	210	PROJECTED:	-22	AR(1)	0.0965
	PROJECTION:	2025 VALUE:	188	CHANGE:			
	DATA:	1978-82 MEAN:	165	YARDSTICK:	-86		
		1984-88 MEAN:	148				
WHEAT^^							
		1990 VALUE:	148	PROJECTED:	-55	AR(1)	0.205
	PROJECTION:	2025 VALUE:	93	CHANGE:			

SOURCE: BLOYD et. al., 1965-1989

^^ wheat and alfalfa yardsticks are calculated based on '78-'82 mean.
^ pima cotton data only available beginning in 1975

IV. ENDNOTES

4.1. Going back to our original formulation, consider the following crop-on-laser-leveled-land activities, which differ only in yield improvement per acre, which is expressed as a percent of yield on non-lasered land:

$$PP_t = TR_t - TC_t$$

$$= (P_t \times Y_t) - (C_t + WC_t)$$

$$PP_t{}' = TR_t' - TC_t$$

$$= (P_t \times 1.\alpha(Y_t)) - C_t - WC_t \qquad 0 < \alpha < .10$$

$$= 1.\alpha(P_t \times Y_t) - C_t - WC_t$$

$$= 1.\alpha(TR_t) - C_t - WC_t = TR_t - TC_t$$

where:

no superscript refers to an assumption of $\alpha = 0$

superscript ' refers to an assumption of $\alpha > 0$

and other parameters are the same as previously defined.

The above equations show that, if we assume α is not functionally related to Y, a percentage increase in yield of can be accounted for in the LP model by simply multiplying the total revenue parameter by $(1 + \alpha)$. Therefore, it was not necessary to make separate projections for yield and price given the assumption that the improvement in yield will not be a function of total yield.

CHAPTER FIVE

THE LP WATER SUPPLY FUNCTION

I. Introduction

Overview

Irrigation water in the Phoenix AMA (AMA) comes from a number of different sources. Primary among these are two surface water suppliers, the Salt River Project (SRP) and the Central Arizona Project (CAP). The Maricopa County Municipal Water District #1 (MCWCD#1) also supplies surface water, from the Agua Fria river. Groundwater in the AMA is either pumped on site, or pumped by an irrigation district (ID) and delivered to member farms.

The Areas of Similar Farming Condition (ASFC) are largely stratified on the basis of water supply. Each representative farm is faced with a unique water supply function,[1] which results from some combination of the general sources mentioned above.

Water Cost In The LP Model

The LP model maximizes discounted farm revenues over

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[1] By water supply function we mean certain quantities of water available at a certain price in each year t. The LP model uses average water prices rather than marginal, therefore the supply curve will be a step function. The price paid for water in year t will change only when the representative farm switches supply source.

variable cost for some planning horizon. In the LP objective function (equation 2.1), water cost is defined as parameter w_{nt}. The representative farm's total water bill in any year is given by the following:

$$\sum_{n=1}^{N} W_{nt}\ IR_{nt} \qquad (5.1)$$

where:

subscript t = year (1990, 1991, ... 2025).
subscript n = water source (GW, CAP, ID, SRP)

IR_{nt} = water from source n applied in year t.
W_{nt} = average variable cost of water/acre-foot from source n in year t.

The concern of this chapter is parameter w_{nt}. Projections of average variable water cost for various AMA water suppliers are found here and in appendix II.

II. Cost Projections For Farm Pumped Groundwater

Data

Data and methodology for the cost of pumping groundwater is largely compiled from the Arizona Pump Water Budgets [Hathorn 1975-1984]. The average variable cost of groundwater per acre-foot is given by the following formula:

$$GW = (L * a)/e * EC + R*L + P \qquad (5.2)$$

where:

GW = average variable groundwater cost in $/ac-ft.
L = lift (the depth of the water underground) in feet.
a = Kwh required to lift 1 ac-ft of water 1 foot.

e = efficiency of the well.
EC = average annual energy cost in $/kwh.
R = repair costs in $/ac-ft-ft.
P = the withdrawal fee, or pump tax, in $/ac-ft.

Following the precedent of the Arizona Pump Budgets, parameters a and e are set as constants of value 1.024 and .54 respectively. Expression 5.2 then reduces to,

$$GW = 1.896*L*EC + R*L + P \qquad (5.3)$$

The first term (1.896*L*EC) in equation 5.3 is the energy cost per acre-foot of pump water, which is the most important component of groundwater cost.

In this framework, projections of groundwater cost require separate projections of lift (L), energy cost (EC), repair costs (R), and the withdrawal fee (P). The following sections present the data and projections for the first three of these four parameters.

Lift: Initial Depths

Projections of lift require 2 components, the depth to lift in the base year (1990) and the rate of decline over the projection period.

Boggs [1989] has generated depth to groundwater maps based on studies done in 1982 [Long *et al.* 1982, Long 1983]. A hand drawn approximation of Boggs' map is shown by figure

5.1. The depths shown represent average static lifts, and do not take into consideration cones of depression in the water table which will develop in regions of high pumping. Groundwater depth contours at 100 foot intervals are shown as they existed in 1982.

For purposes of the LP model, the average depth to groundwater (lift) is needed for each ASFC. To calculate these averages, the lift map (fig. 5.1) is laid over the ASFC boundary map. A planimeter is then used to find the percent of each ASFC falling into each category of lift. The weighted average of the lifts in each ASFC is the estimate of the average ASFC lift in 1982. The results of this calculation are summarized by table 5.1.

TABLE 5.1: STATIC DEPTHS TO WATER IN 1982

ASFC	Name	Average Lift in 1982
1	Tonopah	250 feet
2	Hassayampa	170 feet
3	Roosevelt ID	119 feet
4	Buckeye	50 feet
5	McMicken	398 feet
6	Rainbow Valley	319 feet
7	N. Scottsdale	300 feet
8	SRP	119 feet
9	Roosevelt WCD	278 feet
10	Queen Creek	342 feet

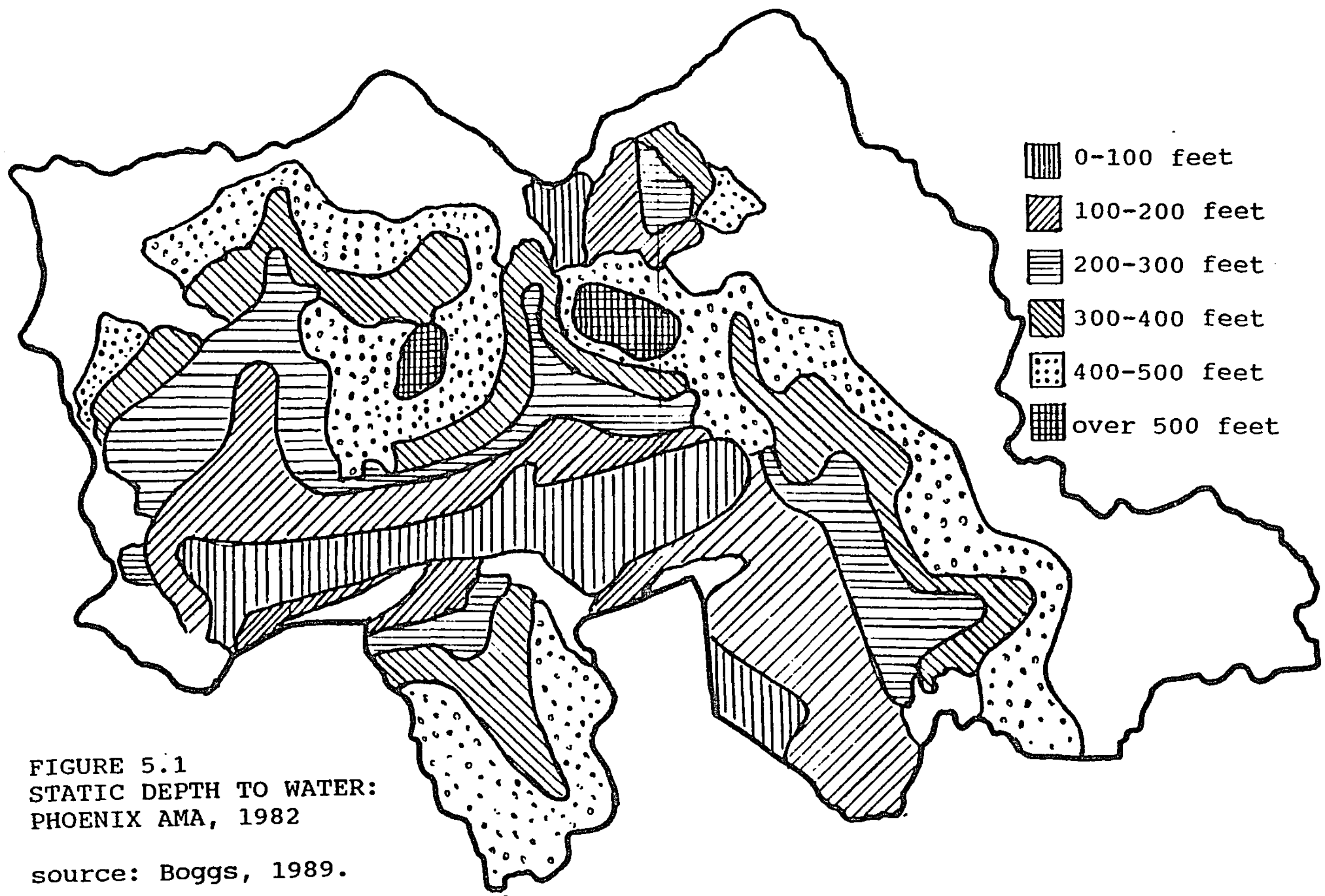

FIGURE 5.1
STATIC DEPTH TO WATER:
PHOENIX AMA, 1982

source: Boggs, 1989.

To generate the average ASFC lift in 1990, 1982 lifts are increased based on average rates of annual water table decline from 1982 to 1990. This calculation is discussed in the next section.

Actual pumping lifts at a well-site depend on aquifer parameters which define the velocity of groundwater movement, and on the rate of pumping. Pumping lifts will always be deeper than the static rest levels presented in table 5.1 and figure 5.1 due to water table depressions which develop around wells. Some difference in lifts from the average will also results from the fact that farms are not evenly distributed throughout an ASFC. Depending on the ASFC, farms may be located in areas where water tables are generally deeper, or shallower, than the average.

Rather than attempt to calculate the actual pumping lifts in each ASFC by use of a hydrological model or detailed survey, pumping lifts are imputed from the average variable cost of water used in ADWR's whole farm analysis [1986]. This is done by rearranging equation 5.3 to get the following form:

$$L = GW / (1.896*EC + R) \tag{5.4}$$

The result is that typical ASFC pumping lifts differ from average static water depths by as much as 35% (table 5.2).

TABLE 5.2: PUMPING DEPTHS TO WATER IN 1990
(for areas relying primarily on self-pumped groundwater)

ASFC	Name	Average Lift in 1990
1	Tonopah	313 feet
2	Hassayampa	281 feet
5	McMicken	550 feet
6	Rainbow Valley	448 feet
10	Queen Creek	526 feet

sources: calculation from equation 5.4 based on ADWR estimates of average variable water cost [ADWR 1986].

Rates of Decline

The rate of water table decline in an ASFC is a function of the relative rate of pumping to recharge. This is not an easy calculation to make for geographic areas as small as the ASFC. Data on recharge and underground water movements, by ASFC, are sketchy at best. Therefore, a somewhat crude method is used to estimate the rate of decline in each ASFC.

Over the past 50 years, the water table in the Phoenix AMA has been dropping at a rate of about 2.7 feet per year. Over this same period, AMA overdraft (groundwater use minus recharge) has averaged about 621,000 ac-ft per year. This yields the following relationship:

AMA Annual Decline = Annual AMA Overdraft / 230,000 (5.5)

Equation 5.5 allows calculation of the average decline in AMA water tables given some projected level of AMA overdraft. The Department of Water Resources [ADWR 1988] projected rates of AMA overdraft assuming various conservation policies. Ordinary Least Squares fits of these overdraft (OD) projections are displayed in figure 5.2A. The upper line is projected overdraft assuming no conservation in the AMA. The lower path is projected overdraft assuming full compliance with Second Management Plan (SMP) conservation measures.

The values of overdraft displayed in figure 5.2A are inserted into equation 5.5, resulting in projected rates of water decline, in feet per year, for 1990 to 2025. These projections are shown in figure 5.2B. Again, these are the **average** annual declines for the **entire AMA**. Historical rates of decline in the ASFC's have deviated from the AMA average by as much as a factor of four times, with those ASFC's bordering the Gila and Salt rivers experiencing the slowest rates of decline.

The same method as that used to calculate ASFC lifts is used to calculate ASFC average historical rates of decline. An ADWR map of areas of equal average annual decline rates is laid over the ASFC boundary map [ADWR, Draft Second Management Plan, p.19, 1988]. Weighted averages of equal-decline-rate areas are used to estimate the average rate of decline for

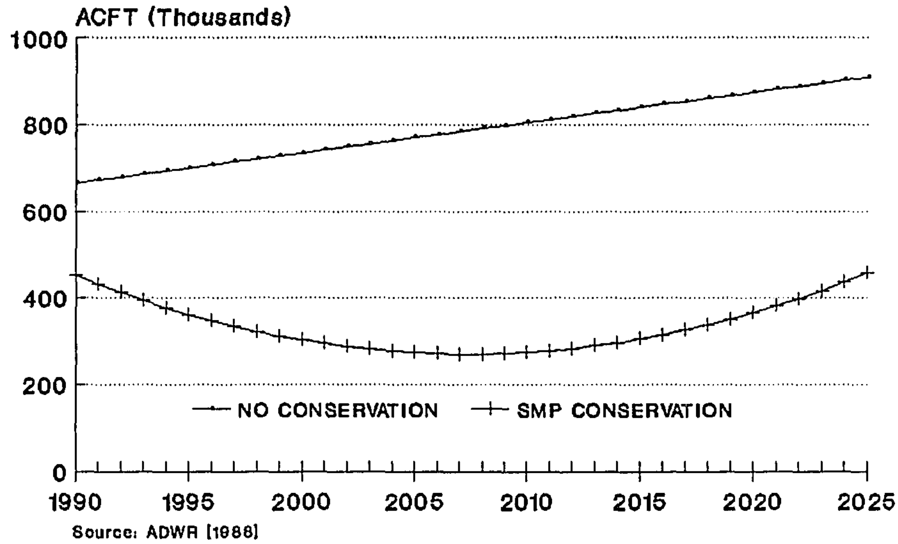

FIGURE 5.2A
PROJECTED OVERDRAFT, PHOENIX AMA

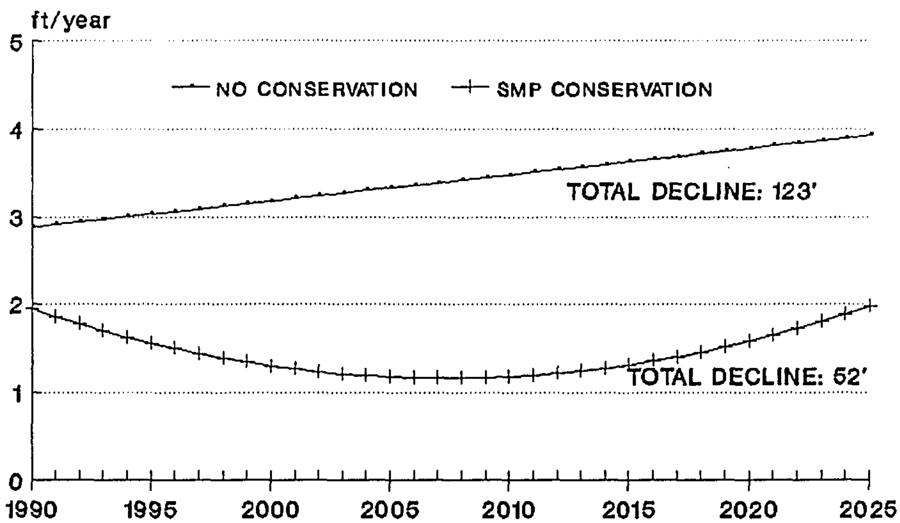

FIGURE 5.2B
PROJECTED RATES OF WATER TABLE DECLINE:
PHOENIX AMA

each ASFC. In order to project future rates of decline, the following ratio is assumed to remain constant through time:

$$\text{ASFC Rate of Decline} / \text{AMA Rate of Decline} = K \qquad (5.6)$$

Once the AMA rate of decline is projected using equation 5.5, the ASFC's rate of decline is estimated as a simple ratio of the AMA's, as given by equation 5.6. The resulting rates of decline, according to the two overdraft scenarios are shown in figures 5.3A, and 5.3B.

Energy

The other principal factor contributing to groundwater cost is the price of the energy used to draw irrigation water above ground. Electricity in Maricopa County primarily comes from three sources, SRP, Arizona Public Service Co. (APS), and Hoover Dam (ED7)[2]. The monthly energy bill includes hook-up charges, a charge based on the power requirement (Kilowatt capacity) of the pump, and a charge per Kilowatt-hour (Kwh). In the case of APS, the charge per Kwh is a block rate structure, with a lower rate being charged once the monthly energy usage is greater than 275 kwh per month.

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[2] Groundwater pumpers may also use natural gas, gasoline, or diesel fuel driven pumps. Energy costs for these sources have generally escalated at similar rates, and so these alternatives are not considered.

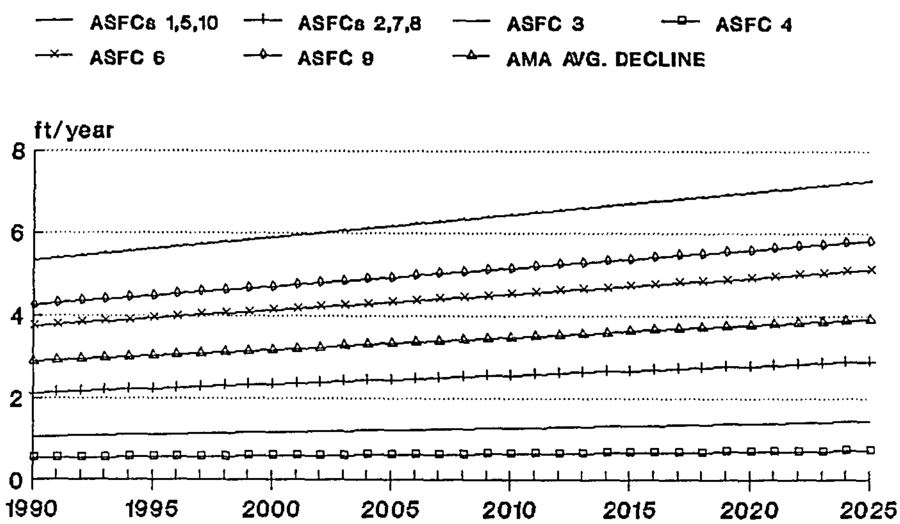

FIGURE 5.3A
ASFC RATES OF WATER TABLE DECLINE
ASSUMING NO CONSERVATION

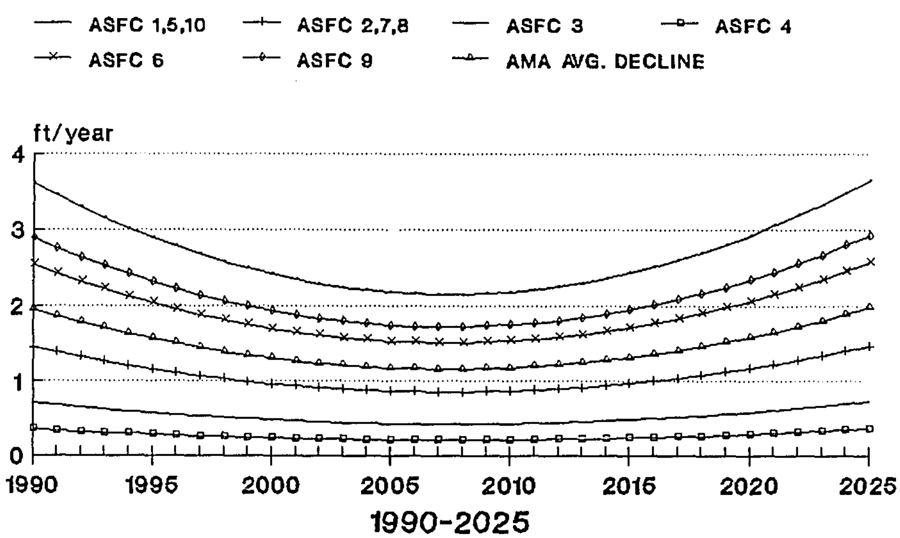

FIGURE 5.3B
ASFC RATES OF WATER TABLE DECLINE
ASSUMMING SMP CONSERVATION

For the calculation of groundwater cost, an estimate of the average cost per Kwh, paid by the representative farm for irrigation during the year, is required. The most exact way to do this would be to calculate the average monthly rates for the representative farm and then use the weighted average of all 12 months' rates. This calculation requires a substantial knowledge of the timing of the farm's energy demand. As an approximation, the same formula is used here as used by the Arizona Pump Budget's calculation of average energy cost [Wade 1990].

Average annual energy cost data is generated based on a peak summer month's rates and energy demand. Since rates are higher in the summer than the winter, the use of a summer month biases the estimate upwards. However, the larger energy requirement at this time of year means that more Kwh are purchased at the lower block rate. It is presumed that the net result is close to the true average annual energy cost per Kwh. Rates and charges from SRP and APS are used to generate energy cost data based on assumptions of monthly Kwh demand and the KW capacity of the pump. These two parameters are calculated as averages of the 5 Maricopa County wells found in Hathorn [1975-1984]:

Monthly Kwh demand = 220,081

Pump Power Requirement (capacity) = 317KW.

The energy cost data and projections are shown in figure 5.4. Data from 1950 to 1988 is used in the projections, but due to software limitations, data for 1950 to 1965 is not shown. The projections in figure 5.4 come from an OLS model of the form,

$$EC_t = b + b1*t1_t + b2*t2_t \tag{5.7}$$

where:

EC_t = average annual energy cost in $/Kwh
$t1_t$ = 1, 2, ...T for 1950, 1951, ... 2025
$t2_t$ = 0..0 for 1950...1972 and 1,2 ...T for 1973, 1974,..2025

Many irrigation districts in the AMA establish contracts with energy providers which allow for energy to be purchased at rates lower than the standard irrigation rate. Rather than project energy costs for each district separately, it is assumed that the ratio of an irrigation district's energy rates to SRP rates will remain constant over time. Thus, if an irrigation district's energy rates are currently 75% of the SRP rate, it is assumed that future energy costs in the ID will remain at 75% of SRP's rate. These energy costs are incorporated into the projections of pump water cost found in appendix II.

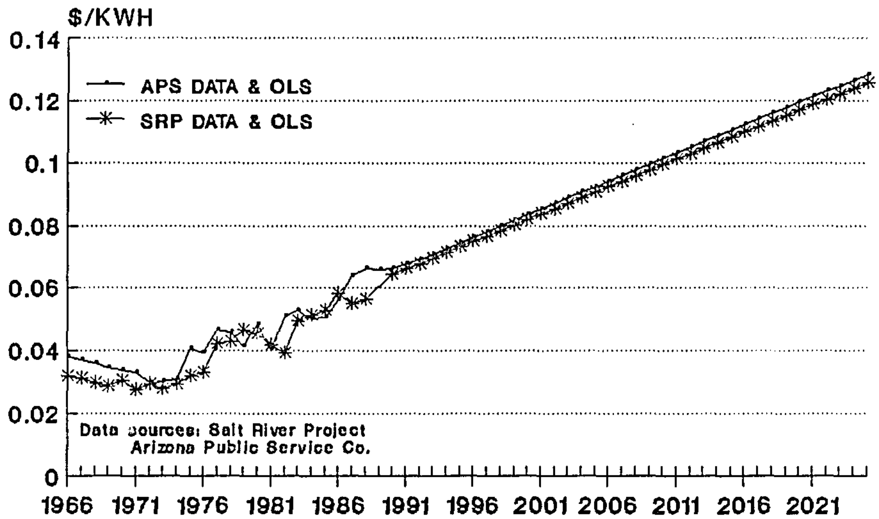

FIGURE 5.4
APS AND SRP ENERGY COST PROJECTIONS:
AVERAGE WELL USE AND POWER REQUIREMENTS

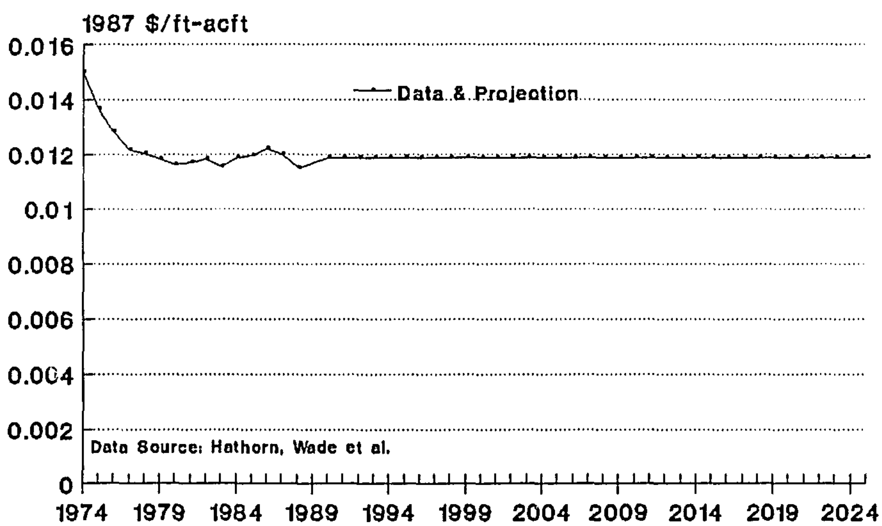

FIGURE 5.5
WELL REPAIR COST FACTOR:
DATA AND PROJECTION

Other Groundwater Cost Components

The repair factor (R, in equation 5.2) is plotted with its projection in figure 5.5. In real terms, the parameter has been very stable since 1977, so the mean value from 1984 to 1988 is used as the likely future value.

Synthesis: Projections of Groundwater Cost

When projected lifts, energy costs, fixed costs, and repair costs are inserted in equation 5.3, results are obtained such as that shown in figure 5.6. Figure 5.6 is the projection of variable water cost assuming a lift of 310 feet in 1990, SRP energy costs, and AMA average rates of decline. For a well characterized by these assumptions, the projected cost of groundwater in 2025 ranges from about $87 to $106 per ac-ft for the two pumping lift scenarios. Projections of groundwater cost for each ASFC are found in appendix II.

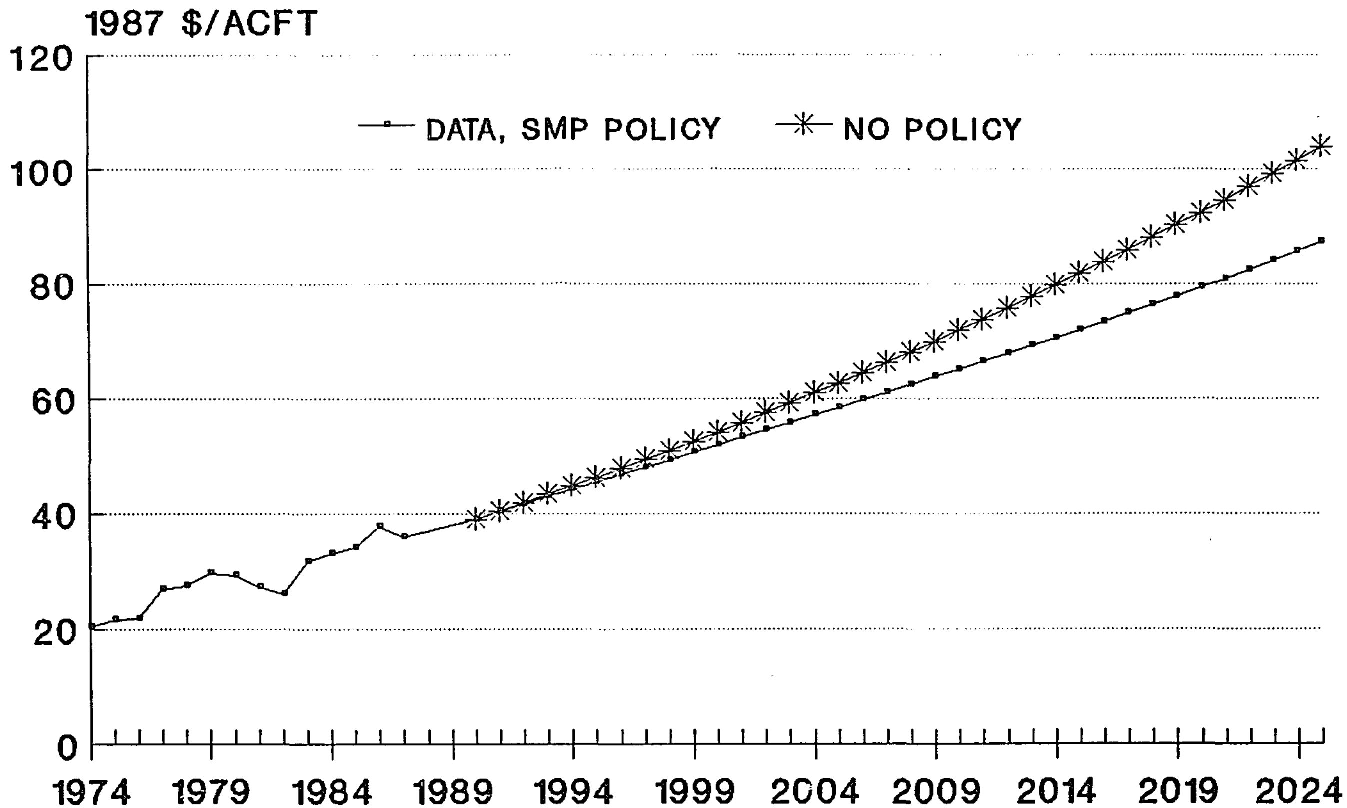

FIGURE 5.6
GROUNDWATER COST PROJECTIONS:
AMA AVERAGE DECLINES, 310' LIFT IN '90

III. SALT RIVER PROJECT WATER COSTS

SRP is the most important water provider in the AMA. The cost of irrigation water provided by SRP is institutionally determined, but it is influenced by energy rates, lifts, and the repair costs of delivery facilities. The calculations required to compute the average variable cost of SRP irrigation water in any year follows:

$$SW = A/2 + S$$
$$GW = G \qquad (5.8)$$

where:

SW = average variable cost of SRP surface water.
GW = average variable cost of SRP groundwater.
A = assessment charge in $/acre.
S = surface water charge in $/ac-ft.
2 = 2 ac-ft/acre of water which comes with assessment.
G = groundwater charge in $/ac-ft.

Missing from equations 5.8 are two delivery charges. One is a charge levied per account and the other is a fee that is charged per acre. Both of these costs are considered here to be fixed charges, and contribute little to the farm's total water bill. The components of equations 5.8 are best considered individually:

1) A/2 : the total assessment fee which the farm must pay to maintain its right to SRP surface water. Although the assessment is in many ways a fixed cost, it

must be included in projections because payment of this charge compensates delivery of two ac-ft of surface water;

2) S: S is the unit cost of surface water. Surface water is classified by SRP as being either 'stored and delivered', or 'normal flow'. Since the charges for these two types have generally been equal, it suffices to put them under one general heading. Historically, the third acre-foot of water which a farm receives, regardless of its source, is charged at the SW rate [Farence 1990];

3) G: Assuming that the representative farm has a 'pump right' to groundwater delivered by SRP, any use beyond 3 ac-ft per acre will be charged at the pump water, or G, rate.

Projections of SRP Water Cost Components

Ordinary least squares (OLS) models are used to project the three SRP water cost components. The projection of SRP water cost parameters are based on an OLS regression on time, identical in structure to equation 5.6, where,

$$A_t = a + a1*t1_t + a2*t2_t$$

$$S_t = b + b1*t1_t + b2*t2_t$$

$$G_t = c + c1*t1_t + c2*t2_t$$

t1 = 1,2,...21 for 1958, 1959...1988

t2 = 0...0 for 1958...1973, t2 = 1,2,...15 for 1974...1988.

Projection of the assessment, groundwater, and surface water fees are shown in figure 5.7.

IV. Other Water Suppliers

Central Arizona Project

The Central Arizona Project (CAP) is a system of canals and pumping stations which bring Colorado River water to South-Central Arizona. There is quite a bit of uncertainty about future quantities and costs of CAP water. Future CAP water quantities will depend upon weather as well as future appropriation of river water by other states. Cost of CAP water will depend on future energy and maintenance costs.

CAP Water Costs

Because deliveries of CAP only recently commenced, there is no useable time series data for Central Arizona Project (CAP) water costs. There are two components of variable CAP water cost, an energy charge, and an operation and maintenance charge, both of which the farm pays per acre-foot of water delivered. In some IDs, CAP users also must pay tax assessments which pay for the infrastructure built to

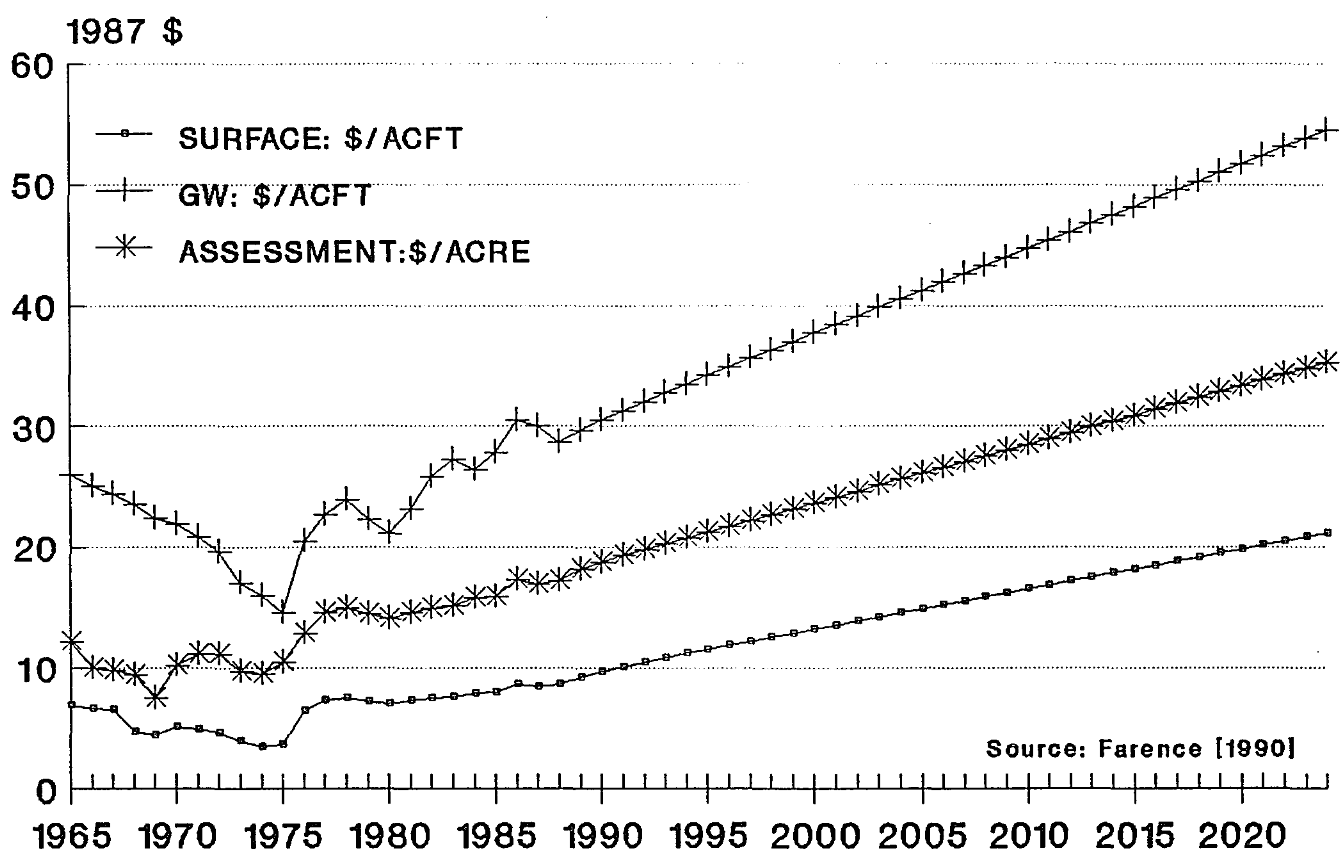

FIGURE 5.7
PROJECTIONS OF SRP FEES

receive CAP water. These fixed costs are not considered here.

Currently, the variable cost of CAP water in the Phoenix AMA is $48.45 per ac-ft [Gould 1990]. Of the $48.45, $36 is for energy, and the remainder is for other operation and maintenance of CAP canals and pumps. As with other sources, CAP water costs will largely depend on the cost of energy. CAP average variable water costs are projected by assuming that they will increase at the same rate as SRP surface water costs. It is assumed that the ratio of CAP water costs to SRP surface water costs will be constant through time. This projection is shown
in figure 5.8.

Significant amounts of CAP water will be available in ASFC 1 (Tonopah ID), ASFC 9 (Roosevelt Water Conservation District or RWCD), and ASFC 10 (Queen Creek and New Magma IDs). However, given that projected variable groundwater costs in some areas are lower than CAP costs, there is some doubt that all allocated water will actually be taken by these IDs. If irrigation districts are able to market their allotted CAP water to other users, they are relieved of all variable CAP water costs [Dozier 1990]. The base case LP runs assume the following: In ASFC 1, where groundwater is projected to be considerably cheaper than CAP, the model is allowed to select the cheapest supply for irrigation; In ASFC 10, where

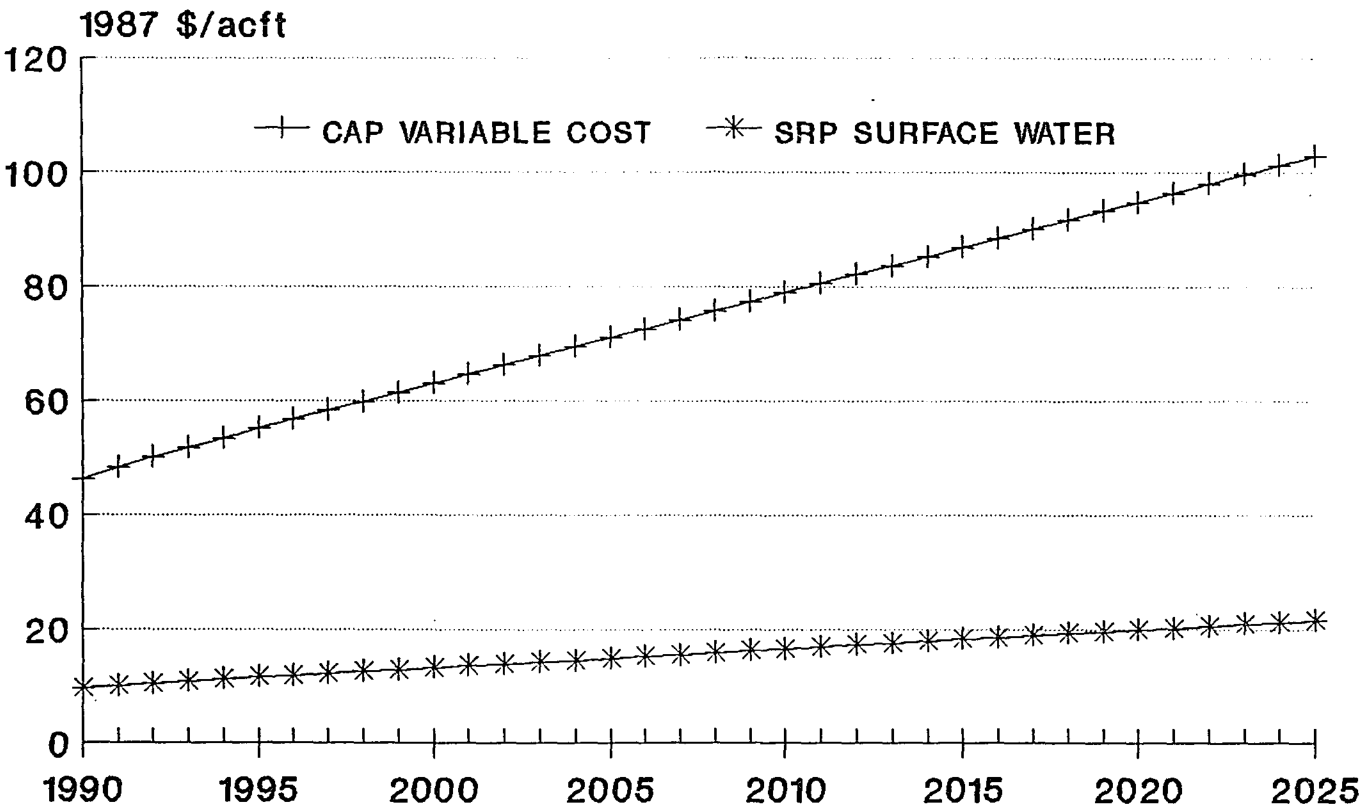

FIGURE 5.8
PROJECTIONS OF CAP VARIABLE WATER COST

CAP water costs are projected to be cheaper than groundwater, it is assumed that the full CAP allotment will be used; In ASFC 9, where projections of groundwater and CAP costs are very similar, it is assumed that the full allotment of CAP water will be utilized. For ASFC 9, a second set of runs is made which allows the model farm to select the cheapest source of supply; ironically, in this case more groundwater is used in the policy scenario than in the no-policy scenario. This is because the price escalation of groundwater is slowed down by conservation in the policy case.

CAP Water Quantities

The U.S. Bureau of Reclamation [1982] has projected the amount of CAP water which will be available to non-Indian agriculture in Arizona. (A description of the Bureau's methodology can be found in Bush [1986]). Available CAP water will be allocated to irrigation districts based on long term contracts in which districts contract for a percentage of the total CAP water available in each year. The quantities of total non-Indian CAP water and CAP water by ASFC which are assumed in LP model runs are shown in table 5.3.

The total volume of CAP water per ASFC is converted to an amount per acre available to the representative farm by dividing the total quantity by the number of acres available

TABLE 5.3
CAP ALLOCATIONS BY ASFC (1000 ac-ft)

YEAR	TOTAL AG. SUPPLY (100%)	ASFC (% ALLOCATION) #10 (10.22%)	#9 (5.98%)	#1 (1.98%)
1990	1,122.70	114.74	67.14	22.23
1991	1,059.00	108.23	63.33	20.97
1992	1,064.30	108.77	63.65	21.07
1993	958.60	97.97	57.32	18.98
1994	909.30	92.93	54.38	18.00
1995	908.40	92.84	54.32	17.99
1996	854.00	87.28	51.07	16.91
1997	815.40	83.33	48.76	16.14
1998	744.50	76.09	44.52	14.74
1999	751.30	76.78	44.93	14.88
2000	721.60	73.75	43.15	14.29
2001	729.60	74.57	43.63	14.45
2002	648.70	66.30	38.79	12.84
2003	580.30	59.31	34.70	11.49
2004	534.10	54.59	31.94	10.58
2005	529.70	54.14	31.68	10.49
2006	567.80	58.03	33.95	11.24
2007	497.20	50.81	29.73	9.84
2008	446.40	45.62	26.69	8.84
2009	470.10	48.04	28.11	9.31
2010	484.10	49.48	28.95	9.59
2011	507.70	51.89	30.36	10.05
2012	493.20	50.41	29.49	9.77
2013	490.30	50.11	29.32	9.71
2014	422.80	43.21	25.28	8.37
2015	447.80	45.77	26.78	8.87
2016	495.80	50.67	29.65	9.82
2017	425.90	43.53	25.47	8.43
2018	439.30	44.90	26.27	8.70
2019	389.20	39.78	23.27	7.71
2020	398.30	40.71	23.82	7.89
2021	452.50	46.25	27.06	8.96
2022	406.50	41.54	24.31	8.05
2023	398.20	40.70	23.81	7.88
2024	372.80	38.10	22.29	7.38
2025	384.00	39.24	22.96	7.60

sources: Bureau of Reclamation. Central Arizona Project, New Waddell Sizing Studies Option 2 (Max Winter).
Central Arizona Water Conservation District, CAP Subcontracting Status Report, 10/2/89.

to take CAP water in future years in each ASFC. This is accomplished using ADWR projections of future ASFC acreage, which are described in appendix III.

Other Irrigation Districts

A number of irrigation districts in the Phoenix AMA provide surface water, groundwater, or both to member farms. Data on ID water costs is compiled from the Arizona Crop Budgets, and from personal interviews with the IDs. ARIMA (AR(1)) models are used to project ID water cost. Benefits of conservation are included in these water costs by adjusting the projected ID water costs by the method discussed in the next section.

The Benefits of Conservation

The impacts of conservation policy on future lifts in the AMA are internalized in the LP model by adjusting projected water costs to reflect reductions in lift due to conservation (reduced overdraft). This feature of the model is of critical importance to eventual results, since it allows for the possibility of farm profits actually going up as a result of the Groundwater Management Act (GMA) conservation measures.

For those areas in which the representative farm pumps its own groundwater, the benefits of conservation are incorporated directly into the policy scenario by using lift projections which assume SMP rates of overdraft as discussed earlier in this chapter. The cost of water from irrigation districts (ID) which deliver only surface water is assumed to be unaffected by conservation.

For those districts which deliver groundwater conjunctively with surface water, the following methodology is used to incorporate the benefits of conservation into water costs:

1) Two projections of ASFC pump water cost, using equation 5.3, are made. One projection is based on lifts which assume no conservation. The other projection assumes SMP conservation;

2) The percent reduction in groundwater cost due to conservation is calculated, for each year;

3) If the ID charges for groundwater are separable, such as with SRP, econometric projections of groundwater cost are reduced by the percentage calculated above. This becomes the estimate of ID groundwater costs in the SMP policy scenario;

4) If an ID, such as MCWCD#1, delivers groundwater conjunctively with surface water at a fee which is not separable, the projected cost of

water is reduced by a percentage of the savings calculated in step 2), above. This percentage is the historic average ratio of groundwater to surface water delivered by the ID;

Conclusion

The temptation was strong to create water cost scenarios in a manner similar to the profit scenarios discussed in chapter four. For a number of reasons this was not done. Primary among these is the fact that water costs vary significantly across the AMA. Thus, comparing model results across ASFCs will yield an indication of how water costs affect the impacts of policy. Unlike gross revenue and variable cost data, energy and water cost data exhibit very strong upward trends. An adjusted R-square of .92 with a Durban-Watson statistic of 1.88 was obtained for the projection of SRP energy rates (equation 5.7). Lift data is somewhat less robust, but all data indicate that lifts, too, are definitely upward tending. An attempt is made to be consistent in the use of lift data, so that although results may be off in magnitude, they will not be off in sign.

Projected water supply functions for each ASFC are discussed in detail in appendix II.

CHAPTER SIX

IRRIGATION TECHNOLOGY AND THE WATER DUTY

I. Introduction

Background

"The irrigation water duty ... shall be calculated as the quantity of water reasonably required to irrigate the crops historically grown in the farm unit and shall assume the maximum conservation consistent with prudent long-term farm management practices..."

[Arizona Revised Statute 45-565]

" Prudent long-term farm management practices were determined by the Department to be management practices commonly used on Central Arizona Farms that have proven economically feasible."

[ADWR 1988]

GMA water duties could have an adverse effect on a farm's income if the irrigation efficiency required by the water duty is higher than the farm's optimal irrigation efficiency.[1] The farm's optimal irrigation efficiency will largely be a function of the farm's soil characteristics and slope of

[1] Optimal irrigation efficiency is defined here to be the efficiency associated with the profit maximizing irrigation technology for which the farm has the resources necessary to implement.

fields. Of particular importance are the uniformity and magnitudes of soil intake rates and soil water holding capacities. Farm water delivery systems will also affect the efficiency of flood irrigation systems, as large flows of water are especially well suited to level basin technology. Also, if a farmer is unable or unwilling to make the investment expenditure necessary to obtain the required irrigation efficiency, the water duty could cause some income loss.[2]

It is worthwhile to note that nowhere in the groundwater code is it stated that farmers must be able to maximize profits. The only requirement, as inferred from ADWR's definition of prudent (see beginning of this section), is that the irrigation technology be economically feasible for some farms in his Area of Similar Farming Condition (ASFC), and in common use in central Arizona[3].

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[2] Mitigating this potential for income loss is the fact that there are two process whereby a farmer may seek to get his water duties relaxed. The administrative review process allows the farmer to apply to ADWR for an increase in water duty. The farmer may also seek a variance which allows for a five year delay in the reduction of water duties, provided that the farmer can demonstrate financial hardship.

[3] Random House defines feasible as "capable of being done or accomplished. A similar definition is assumed here; the technology is feasible if the farm can adopt it and service the associated investment costs.

Methodology

ADWR [1986] based most of the second management plan (SMP) water duties on its analysis of dead level surface irrigation systems. ADWR has asserted that dead level irrigation systems will allow a farm to operate at an annual irrigation efficiency of 85%, and that in 7 of the 12 ASFCs, dead level systems can be adopted by typical farms at a net gain (i.e., a farm benefit-cost ratio greater than 1). Halderman [1989] has challenged the validity of ADWR's results, arguing that ADWR overstated the benefits, and underestimated the costs of level basin irrigation. The magnitude of the difference between ADWR's and Halderman's analysis is depicted in figure 6.1. ADWR asserted that the

```
           Benefit-cost Ratio: Linear Scale

|----------------+-------|-----------+-----------|
0               .68      1         1.55          2
           (Halderman)             (ADWR)
```

FIGURE 6.1

Different Ideas About The Benefits And Costs Of Level Basin Irrigation Systems

Benefit-cost (B/C) ratio of adopting 100% level basin irrigation systems in the Salt River Project ASFC would be as high as 1.55. Halderman calculated this same ratio to be .68.

This uncertainty in the true mean benefit-cost ratio for dead level fields is managed in the LP analysis by creating two representative farms for each ASFC. These representative farms are distinct only in that the costs and benefits of adopting a level basin irrigation system are different for each. Assumptions are made about the benefits and costs of irrigation systems which in one case are somewhat less optimistic than ADWR's, and in the other case somewhat more optimistic than Halderman's.

Since data on irrigation technology most often is given in ranges (e.g., the cost of ditch replacement will be between $0 and $250 per acre) the two model farms are easily created by selecting data which falls near one end of the likely range. The implications of this methodology become more apparent as the two models are specified at the end of this chapter.

II. The Irrigation Water Duty

The water duties are based on target irrigation efficiencies which are defined by the following ratio, which is calculated over a years time:

$$\text{IRRIGATION EFFICIENCY } (\times 100 = \%) = \frac{\text{Total Irrigation Requirement}}{\text{Total Volume of Water Applied}} \quad (6.1)$$

The total irrigation requirement (numerator in eq. 6.1) is the amount of water needed annually to satisfy consumptive use, leaching requirements, and all other needs of crops grown by the farm unit from 1975-1980 [ADWR 1988]. 'Other needs' generally refers to the additional needs of farms with poor quality water, as defined by high salinity content.[4] The total volume of water applied (the denominator in eq. 6.1) equals the sum of all water used by the farm in crop production, including that lost to seepage and evaporation.

The Department of Water Resources has specified target water duties for every farm unit for the SMP, which covers the years 1990 to 2000. The irrigation water duty is defined by the following ratio:

$$\text{IRRIGATION WATER DUTY (ac-ft/acre)} = \frac{\text{Total Irrigation Requirement/Acre}}{\text{Assigned Irrigation Efficiency}} \quad (6.2)$$

The total irrigation requirement is as defined in equation 6.1. For most farms in the AMA, the water duties will be reduced to levels in 1999 based on an 85% irrigation

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[4] Due to the minimal amount of rainfall in the Phoenix AMA, DWR did not factor precipitation into the calculation of crop water needs. Thus in a year of favorable precipitation, a farm could obtain efficiencies of greater than 100%.

efficiency. Water duties will differ among farms depending on historical crop mix from 1975-1980. Those farms which planted high water use crops during that period will be allotted a greater quantity of water than those planting a less water intensive crop mix.

On Efficiency

Wade [1986] points out that whole farm water use efficiencies such as that used by ADWR to calculate the water duties can be decomposed into at least two more specific efficiencies commonly considered in irrigation literature. **Field efficiency** is the percent of water applied to the field which is consumed by crop evapotranspiration. **Conveyance efficiency** is the percent of water introduced to the farms delivery system which makes it to the fields. Total irrigation efficiency will be the product of conveyance and field efficiencies. Irrigation efficiency as defined by ADWR includes a dynamic element: the irrigation efficiency over a year is a weighted average of the efficiencies realized for each irrigation during that year.

Typically, the irrigation efficiency for a water application made early in a crop's life cycle will be relatively low. The crop has a shallow root zone at this time, and it is likely that some water will be lost to deep percolation [Shearer 1990]. (This is especially true for surface irrigation systems). As the crop reaches maturity, higher field application efficiencies will be realized. The irrigation efficiency measure used by ADWR to set water duties is an annual, weighted average which considers all water used and all crops grown by a farm.

III. Irrigation Technologies

Technologies In The LP Model

ADWR [1986] defined 14 unique surface irrigation technologies on the basis of field slope, length of run, degree of management, and the use of a pumpback (tailwater recovery) system. Table 6.1 catalogues these technologies, and the water use efficiency which ADWR assigned to each.

For all but three of the ASFC's, Irrigation Technology (ITA, or Irrigation Technology Applied) 10 was selected by ADWR to be the basis for future water duties (i.e., water duties will be based on 85% target irrigation efficiency in 1999).

Daubert and Ayer [1982] contrast the benefits and costs of 3 distinct irrigation technologies. The most primitive of the three analyzed is the traditional row and furrow system common in Arizona. The most advanced system considered is a dead level system. As an intermediate technology, the authors

TABLE 6.1

IRRIGATION TECHNOLOGIES AND EFFICIENCIES
(Phoenix, Pinal, and Tucson AMAs)

SLOPE	ITA	RUN	MANAGEMENT	PUMPBACK	EFFICIENCY
SLOPED	1	1280'	Unmanaged	No	50%
FIELDS	2	1280'	Managed	No	60%
	3	1280'	U	Yes	60%
	4	1280'	M	Yes	70%
MODIFIED					
SLOPE	5	1280'	U	No	65%
	6	1280'	M	No	75%
	7	840'	U	No	65%
	8	840'	M	No	75%
LEVEL					
BASIN ^	9	1280'	U	No	75%
	10	1280'	M	No	85%
	11	840'	U	No	75%
	12	840'	M	No	85%
	13	620'	U	No	75%
	14	620'	M	No	85%

^Level basin systems are not considered feasible for soil with an intake rate greater than 1 in/hr [ADWR 1986].

source: ADWR, unpublished report by Duncan Galusha, 1986

consider fields which are planed smooth at the existing slope, or 'lasered-to-slope'. The LP model farms have three irrigation technologies to select from, which are heretofore labeled IT1, IT2, and IT3. These three technologies are based on Daubert and Ayer; IT1 is traditional row and furrow, IT2 is lasered to slope, and IT3 is a dead level system. It is assumed that profit maximizing water application management is applied regardless of which irrigation technology is used by the model farm.[5]

The representative farms for each ASFC are endowed with a certain mix of irrigation technologies based on survey work done by ADWR in 1986. ADWR ITAs 1-4 are equated to LP model IT1, ITAs 5-8 are considered equivalent to IT2, and ITAs 9-14 are grouped as IT3. Substantial investment in irrigation technology has no doubt occurred in the AMA since 1986. Rather than collect investment data for the 1986-1990 period, irrigation system improvements are roughly accounted for in the 1990 model endowment by considering all irrigation systems to be well managed (i.e., many farms in the 1986 survey were considered unmanaged). This simplification allows future investments to be modeled in concrete terms of physical land improvements.

The LP representative farm is subdivided into two model farms which are distinct only in the benefits and costs of irrigation investment. These two farms are called Farm H and Farm L, with the first farm realizing a high (> 1) B/C ratio of leveling, and Farm L obtaining a relatively low B/C. These two farms help to account for two uncertainties in the data:

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[5] Irrigation water management involves monitoring soil moisture and water application to insure that crops get the quantity of water needed at the optimal time.

1) Most importantly there is dispute over what the true average farm, in terms of the benefits and costs of dead level irrigation systems, is;

2) There is general agreement that benefits and costs of laser leveling will vary across the AMA, especially due to soil geography. Thus, having two representative farms allows for assessment of those farms whose production possibilities (i.e. obtainable irrigation efficiency) fall above or below the average.

Other Conceptual Issues

The LP model is rigid concerning future changes in technologies. It is likely that irrigation efficiencies will increase over time, due to the development and diffusion of technology. However, our results will not be as sensitive to the absolute level of irrigation efficiency as to any discrepancy between obtainable irrigation efficiencies and the target efficiencies implied by the water duty. By law, ADWR is required to set water duties which reflect improvements in irrigation technology, so it is anticipated that water duties will be reduced as irrigation technology improves.[6]

---

[6] See Arizona Revised Statutes 45-566, 45-567, and 45-568.

The LP model could also be criticized for not including irrigation technologies such as sprinkler or drip systems, which often are optimal for farms with sandy soils. These technologies are not in wide use in the state, and were deemed by ADWR to still be experimental [ADWR 1986]. It is important to recognize that the goal of this research is not to develop individual farm strategies for responding to the GMA, but rather to estimate what effect the GMA will have, on average, on typical AMA farms.

IV. LP Model Irrigation Technologies: Specification

Overview

Data for the benefits and costs of irrigation technology investment is generally given as a range which is dependent on farm field and ditch conditions. The remainder of this chapter details the data used in the LP models. The representative Farm H will realize higher benefits and lower costs for irrigation investment than the representative Farm L.

Data On Irrigation Investment: Benefits

The two benefits attributed to leveling fields are increased yields and reduced water use. Going from a sloping system (IT1) to dead level (IT3) can increase yields anywhere from 0 to 30% [Daubert and Ayer 1982]. Going from a sloping system to a lasered-to-slope field (IT2) can increase yields up to 10% [Ibid]. A range of yield improvements so wide as 0 to 30% introduces a large degree of uncertainty into the analysis. In 1988, for example, a 10% increase in Pima Cotton yield would have resulted in approximately $100/acre more profit! The benefit of leveling fields is generally more sensitive to yield increases than to water savings.

Farm H assumes that yields on IT3 are 10% greater than yields on IT1. IT2 shows a 5% increase in yields for farm H. For Farm L, yield increases of only 2.5% for IT3, and 1.25% for IT2 are assumed.

Water savings is the other key benefit of leveling fields. Table 6.1 shows the water use efficiency which ADWR has assigned to each ITA. For Farm H, IT1 in the LP model is assigned an efficiency equal to ADWR's ITA 1, or 60%. IT2 is assigned an efficiency of 70%, a 10% improvement over IT1. Dead level fields (IT3) are assigned an efficiency of 85%, which corresponds to ADWR's figure.

For Farm L, IT1 is again assigned an irrigation efficiency of 60%. The water savings accorded to investment is less for Farm L, with IT2 being 65% and IT3 75% efficient.

The implication of improvements in irrigation efficiency can be demonstrated by the following manipulation of equation 6.1.

$$\text{Total Volume Water Used} = \frac{\text{Total Irrigation Requirement}}{\text{Irrigation Efficiency}} \quad (6.3)$$

further manipulation provides the following:

$$\text{Change In Water Used} = \frac{\text{Change In Irrigation Efficiency}}{\text{Final Irrigation Efficiency}} \quad (6.4)$$

By (6.4), an increase in irrigation efficiency from 60% to 85% will result in a 29% reduction in the total volume of water applied ((.60-.85)/.85). Farm H, which realizes a 10% increase in yields in addition to the 29% water savings on IT3, realizes substantial benefits from implementing dead level irrigation systems. Farm L on the other hand, realizes increases in yields of only 2.5%, and reduces water use 20% when utilizing a level basin system.

Data On Irrigation Investment: Costs

Grading: The main cost of adopting ITs 2 or 3 is the cost of moving dirt. Currently, the average cost of grading is about $.45/yard, or $50/acre, whichever is higher [Echols 1989]. The amount of dirt to be moved depends on the initial slope of the field before grading and the final slope of the field after grading. The Soil Conservation Service (SCS) defines level basin as a field with a total grade change of less than .2'/100'. The SCS also has generated matrices which show how much dirt will have to be moved to obtain a finished grade of .1'/100', given the initial slope of the field. ADWR's survey of the ASFCs included documentation of the typical slope conditions for each ASFC. The SCS dirt moving requirements, coupled with ADWR's typical ASFC slopes, result in a cost of grading estimate for each ASFC. It is assumed that the final field slope is .1'/100' in one direction and flat in the other.

The resulting level-basin-grading-cost typical in the AMA is about $431/acre (1987 dollars). Included in the grading costs for Farm L is $70/acre not incurred by Farm H. This cost covers potential post grading soil ripping ($20/acre) and manure application ($5/ton * 10 ton/acre) [Halderman 1989]. The cost of grading for a lasered-to-slope system is set at 1/3 the cost of dead leveling. This roughly corresponds to the work of Daubert and Ayer. The cost of dead leveling a field which is already lasered to slope (from IT2 to IT3) is set equal to the cost of dead leveling an IT1 field.

Ditching: The other primary cost of investment in IT3 is the removal and replacement of irrigation ditches. Depending on the length, location, and elevation of old ditches, the farm may have to replace 0 to 100% of its ditches. The average cost of removing ditches is $1.25/ft, and the cost of new ditches is about $4.67/ft [SCS 1989]. It is assumed that Farm H replaces 1/3 of its ditches. Given a row length of 840', this means that 17.3 feet of ditches are replaced per acre leveled, at a cost of $5.92/ft. Farm L is required to replace 75% of its ditches, which means its ditching costs are 2.25 times greater than Farm H ($230/acre vs. $102/acre). The model assumes adoption of IT2 from existing IT1 has no associated ditching costs.

Operation and Maintenance Costs: Lasered irrigation systems such as ITs 2 and 3 require special touch up about every 5 years at a cost of approximately $50/acre. To accommodate this in the LP model, $10/acre is added to the variable costs of crops grown on ITs 2 and 3. The cost of machinery operations on level basin systems generally increases due to extra turning time, but the cost of irrigation labor and management is expected to decrease [Shearer 1990]. In the LP model, it is assumed that the net result of these two effects will be zero, and thus variable production costs for ITs 2 and 3 change only by the $10/acre resulting from the 5 year touch up.

Loss of Yields: Often, in the first two years after leveling, a farm realizes reduced yields due to disruption of topsoil. The yield losses run from 0 to 15% of potential yield. Farm L realizes a 10% loss of yield in the first year. In the second year, Farm L yield losses are set at 5%. In the third year Farm L yields reach full potential. This loss of yield is modeled by making the following addition to the investment cost of IT3:

$$IC_t' = IC_t + .1GR_{t+1} + .05GR_{t+1} \qquad (6.4)$$

where,

IC_t' = total investment cost, including lost future yields ($/acre).

IC_t = total investment cost, all factors but lost yields ($/acre).

GR_t = upland cotton gross revenue per acre, in year t. ($/acre).

t = year of investment.

Upland cotton is used in this calculation because it is the most profitable crop in the early years of the analysis, and is the crop most likely to be allocated to a limited amount of leveled land. (Given the yield improvements of dead level irrigation systems, the LP model will allocate crops with highest gross returns to a limited amount of IT3). Farm H does not face losses in yield when dead leveling fields.

Revenue Foregone: Depending on a farm's rotation process, a crop may be lost while fields are leveled. This cost depends on the crop lost (usually wheat), and depends on price and expected yield. On the other hand, farms participating in conservation subsidy programs may be able to schedule leveling on acres which are not planted anyway. It is assumed that AMA farms will be able to 'squeeze' some amount of leveling activity into the rotation/conservation process. The amount of acreage which a farm is 'allowed' to level in a year is constrained according to subsidy programs and rotational practices typical of each ASFC.

In 4 of the last 5 years, participation in the cotton program required a 25% set-aside. Therefore the model farms are constrained to dead level only up to 25% of their farmland. Half of the model's farmland may be lasered to slope, and the combination of dead leveling and lasering to slope activities is not allowed to exceed 50% of the farm's total acreage. This system of constraints is detailed in the "Investment Constraint" sub-section of chapter 2.

Lost Acreage: Depending on the farm, some acreage loss may result due to extra canal and roads necessary for level basin farming. No consideration of this potential cost is included in the model.

Subsidies: The Agricultural Stabilization and Conservation Service (ASCS) has a cost sharing program in effect which encourages farmers to laser level their fields. This program will pay either $.40/yd for grading, or 65% of the total investment cost, whichever is less. There is a $3,500/year limit on payments a farmer may receive from ASCS. Daubert and Ayer [1982] point out that this subsidy program will encourage laser leveling, but will slow the optimal rate of leveling for participating farms. This subsidy program is not modeled in the LP analysis. The assumptions of adoption cost and benefits for Farms H and L cover a range wide enough to make it unnecessary to complicate the LP model by modeling this program.

Summary: Key Differences Between Farms H and L

Table 6.2 summarizes the benefits and costs of adopting ITs 2 and 3, for Farms H and L. The costs of lasering to slope (adopting IT2) are identical for the two model farms, but Farm L obtains substantially less benefits than Farm H from this investment.

In the case of dead leveling (adoption of IT3), both the costs and benefits are different for the two model farms. Farm L faces higher ditching costs, as well as a loss in yields the

TABLE 6.2
BENEFITS AND COSTS OF IRRIGATION TECHNOLOGIES

	IT 1 (Traditional Row and Furrow)		IT 2 (Lasered-to-Slope)		IT 3 (Level Basin)	
BENEFITS/COSTS	FARM H	FARM L	FARM H	FARM L	FARM H	FARM L
BENEFITS						
Irrigation Efficiency:	60%	60%	70%	65%	85%	75%
Yield Improvement:	0%	0%	5%	1.25%	10%	2.5%
COSTS						
Grading Cost:	0	0	\$.45/yd	\$.45/yd	\$.45/yd	\$.45/yd
Ditch Replacement:	0	0	\$5.92/ft	\$5.92/ft	\$5.92/ft	\$5.92/ft
Ditch Replaced/acre:	0	0	0	0	17'/ac	39'/ac
Change in Variable Cost:	0	0	+\$10/ac	+\$10/ac	+\$10/ac	+\$10/ac
Yield Loss, 1st 2 Years:	0	0	0	0	0	10%, 5%
Total Investment Cost:^ (AMA average)	0	0	\$147/ac	\$147/ac	\$642/ac	\$930/ac

^ does not include interest cost, or the cost of yield losses, 1987 dollars first two years of leveling.

Not included in table 6.2 is the interest cost of investment. Following the example set by ADWR [1986], it is assumed that investment funds are borrowed at 10% interest and paid back in equal installments amortized over a seven year period. Future payments are discounted at 3%, and summed to create a single cost parameter for irrigation investment in each year. Also, future costs due to yield losses are discounted and added into this one lump sum. This model of investment cost ignores some key matters such as depreciation and tax impacts. However, it allows for a more concise model, and, given the Farm H-Farm L stratification, considers an extended range of investment impacts.

The bottom line as far as investment costs is that the average cost of adopting IT3 in the AMA, including interest cost, is $829/acre for Farm H and $1192/acre for Farm L. Farm L will incur an additional cost of lost yields the first two years after treatment, which is not included in the $1192 figure.

The net result is that adopting a level basin system is significantly less profitable for model Farm L than it is for model Farm H. Neither model farm makes unreasonable assumptions, or is designed to be an extreme case. Rather they represent two potential averages, which according to this research, seem to be plausible.

PART THREE: SCENARIO RESULTS AND POLICY IMPLICATIONS

Part three is comprised of chapters seven and eight, which detail the results of model simulations. Four policy scenarios are considered. One is a no policy scenario which is used as a benchmark. The Second Management Plan (SMP) policy scenario is used to evaluate the impacts of the Arizona Groundwater Management Act (GMA) on agriculture, as the law currently stands. Two policy revision scenarios are then considered. One scenario estimates the impact of removing urban conservation policy. The other policy revision scenario considers the removal of agricultural conservation measures.

Chapter seven presents detailed results from the model simulations. This chapter is somewhat lengthy, as it explains many of the assumptions that go into each scenario. Chapter eight is more concise, and concentrates on the policy implications of the most important results.

CHAPTER SEVEN

AN EFFICIENCY EVALUATION OF THE ARIZONA GROUNDWATER MANAGEMENT ACT: A PARTIAL APPRAISAL

I. Introduction

There is a high degree of uncertainty about the future values of many of the parameters used as inputs to this analysis. This uncertainty is exacerbated by the relatively long (36 year) planning horizon over which policy impacts are evaluated. An attempt is made to estimate the potential effect of these uncertainties through the use of scenarios. These evaluations are found in the section of this chapter entitled Sensitivity Analysis.

Another set of scenarios evaluates two potential revisions to the Arizona Groundwater Management Act (GMA). Resulting changes in income and groundwater use in these revised policy scenarios are measured against a base case policy scenario. The base case policy scenario is introduced in section II.

In depth analysis of the full policy implications of the model results is reserved for chapter eight. In chapter seven, the emphasis is on presenting the outputs in as clear a manner as possible.

II. Benefit-Cost Impacts Of The GMA, Base Case Results

Specification Of The Base Case

The future impacts of the GMA's conservation measures on the agricultural sector in the Phoenix Active Management Area (AMA) will depend on a number of factors, some of them outside of the policy maker's control. Scenarios tested are based on combinations of the following factors, which are used either to create policy scenarios, or to test the sensitivity of the model to a change in the factor:

1) **Future profit levels in the agricultural sector.** These will depend on prices of inputs and outputs, as well as crop yields. Scenarios of high, low, and average gross revenue and variable cost are documented in chapter four;

2) **Future aquifer depth.** As explained in chapter five, future reductions in pumping costs due to GMA conservation measures are incorporated directly into the LP models via the groundwater cost parameter. Two different time-paths of lifts are used in the creation of four different policy scenarios. Arizona Department of Water Resources (ADWR) projections of overdraft, coupled with historical relationships of overdraft to water table declines in the AMA, are used to adjust

projected lifts;

3) **The typical farm's ability to adopt technology which obtains required irrigation efficiencies.** Chapter six describes this issue in detail. There is genuine dispute over whether or not the efficiencies implied by Second Management Plan (SMP) water duties are, on average, achievable. Two different model farms, Farm H and Farm L, which are differentiated on the basis of the benefit-cost ratio of leveling fields, are used to analyze this factor;

4) **The future rate, or intensity, of farming.** ADWR data indicates that much of the available farmland in the Phoenix Active Management Area (AMA) has not been planted over the past 5 years. In some areas, the ratio of planted to total available farmland has been less than 40%;

5) **The rate of urbanization in the Phoenix AMA.** Population forecasts put Maricopa County at over five million by 2025. Urban growth is expected to remove approximately half of the AMA's farms from production. As discussed later in this chapter and in appendix III, a land conversion model, coupled with different projections of population,

is used to assess the effect of different rates of urban growth on policy impacts;

6) **The rate of incidental recharge of water used by agriculture.** Reducing groundwater use by an acre foot does not necessarily reduce overdraft by an acre foot. Some of the water saved would have found its way back to the aquifer anyway. Conservative estimates of the rate of incidental recharge for agricultural water users are used to adjust estimates of reduced overdraft.

Of these 6 factors, three are treated endogenously within the LP model. These are factors 1, 2, and 3. Factor 1, future profit levels, is built into the gross margin (C_{ijt}) parameter in the LP model; high, average, and low profit scenarios are considered. Factor 2, future AMA pumping lifts, is utilized to create different policy scenarios. Different assumptions about factor 2 translate directly into different future groundwater costs. Factor 3, obtainable irrigation efficiencies, is analyzed by the division of representative farms into Farm H and Farm L as described in chapter six; Farm H assumes a relatively high benefit-cost ratio for laser leveling, Farm L a relatively low one.

Factors 4, 5, and 6 above are treated as exogenous to the LP model. All of the exogenous factors are described in the body of this chapter, and are applied to LP model results after solutions are obtained.

The Base Case: Endogenous Factors

The base case is a combination of factors 1-6 selected to create a scenario which is the most plausible of all potential combinations. Farm L was chosen for factor 3 not only on the basis of plausibility, but also because initial results indicated that this choice would maximize the impacts of conservation policy on the agricultural sector. Some support for this choice is found in the fact that approximately 1700 irrigation groundwater users have applied for an increase in water duties through the administrative review process.[1]

To summarize, the base case LP model assumes the following combinations of factors 1, 2, and 3 above:

1) The average gross margin scenario is used;

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[1] According to Arizona Revised Statute 45-575, "Any aggrieved party may request an administrative review of the irrigation water duty or any conservation requirement not later than ninety days from the date of notice of such duty or requirement given thirty days after the adoption of the management plan." The administrative review process allows a groundwater user to get a hearing before DWR and, if desired, to appeal to the superior court in the county where the user's land is located.

2) It is assumed that future lifts will be reduced by GMA conservation policies as calculated in chapter five;

3) Farm L, which assumes a relatively low benefit-cost ratio of leveling fields, is used (chapter six).

Figure 7.1 diagrams the potential combinations of endogenous factors which create unique LP models.

The Base Case: Exogenous Factors

The base case results are aggregated assuming that 80% of all farmland, which is defined to be that land with an irrigation grandfathered right, in each ASFC will be planted. According to ADWR data, this rate is higher than the rate realized in any ASFC between 1984-1988 [ADWR ROGR database]. However, it is intuitive to believe that use rates may increase over time because the farms which will remain in the AMA will be those which are more active in the industry. Use rates are calculated from ADWR data assuming the following relationship:

$$\text{Land Use Rate} = \frac{\text{Total Groundwater Use}}{\text{Total Groundwater Allotment}} \qquad (7.1)$$

This methodology implicitly assumes that allotments from 1984 to 1988 were on average equal to irrigators' actual water needs. If the allotments during this time were not binding, this method underestimates the actual land use rate.

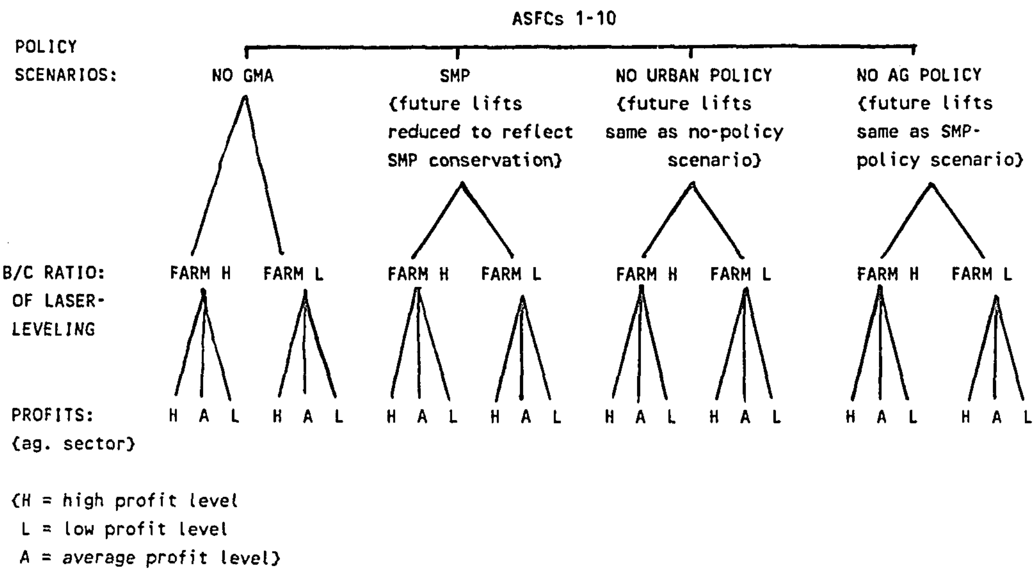


FIGURE 7.1: SCENARIO DIAGRAM, Factors Endogenous to the LP model

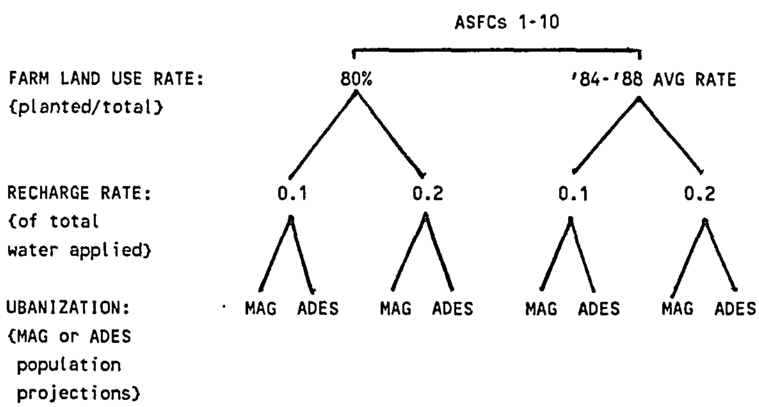


FIGURE 7.2: SCENARIO DIAGRAM, Factors Exogenous to the LP model

Rates of farmland urbanization are taken from a land conversion model developed by ADWR, which is documented in appendix III. ADWR's projections of land conversion are based on population forecasts used by the Mountain West company in a study done for the Maricopa Association of Governments (MAG) [1987]. An alternative to the ADWR projections is generated by calibrating the land conversion model to a more conservative projection of county population, which was made by the Arizona Department of Economic Security (ADES).

The rate of incidental recharge is defined here as the ratio of irrigation water lost to deep percolation to all groundwater used for irrigation. In the Draft Second Management Plan, ADWR estimates this rate to be between .12 and .35, with the rate decreasing as farms become more efficient. A recharge rate of .1 is used for the base case, and a rate .2 to establish an upper bound for this impact, although even a higher rate might be justified. Figure 7.2 diagrams the factors which are considered exogenous of the LP model.

Aggregation Methodology

All of the results documented in this chapter are stated in terms of the **change** in groundwater use and the **change** in farm income in a particular policy scenario as measured against some other scenario. The base case scenario compares results when SMP conservation measures are assumed with the results when a 'no-policy' scenario is assumed. In the SMP scenario the farm is constrained in groundwater use by the water duty, and must pay a withdrawal fee on each acre foot of groundwater used; future groundwater costs are reduced to reflect reductions in lift due to water conservation by urban and agricultural sectors.

Planning horizons of 5, 10, 15, 20, 25, 30, and 36 years are evaluated for each ASFC. Farms with a planning horizon of 1-5 years are represented by the 5 year model, those with a 6-10 year planning horizon by the 10 year model, and so on. Table 7.1 is a partial sample of the results from ASFC 8 used here to demonstrate how the aggregation process works.

Step one in the aggregation process is to calculate the number of agricultural acres in the ASFC which will be urbanized in each year. The results of these calculations are found in the column labeled 'CHANGE' in the upper half of table 7.1. In each year from 1990 to 1994, 4,099 acres are expected to be urbanized. Thus, there are 20,493 (4,099*5) acres of land which are expected to be urbanized between 1990 and 1994. The column labeled 'ACRES TALLIED' shows the total number of acres in each year to which the 5-year model results are applied.

Model results stating the change in income and the change in water use per acre are multiplied by the 'ACRES TALLIED' column to get the total policy impact in each year on all farms with planning horizons of five years or less. In a similar fashion, the 10 year model accounts for farms with a planning horizon between 6-10 years, and so on. Total impacts are summed across all planning horizons, for each year from 1990-2025, to get the net policy impact in an ASFC.

TABLE 7.1: METHOD OF AGGREGATING RESULTS
(Partial base case results for ASFC 8)

Step 1: Calculation of the number of acres represented by the 5-year model in each year from 1990-1994.

YEAR	PROJECTED DUTY ACRES	CHANGE	ACRES TALLIED	
1990	84,600	4,099	20,493	(=16394+4099)
1991	80,501	4,099	16,394	(=12296+4099)
1992	76,403	4,099	12,296	(=8197+4099)
1993	72,304	4,099	8,197	(=4099+4099)
1994	68,206	4,099	4,099	

Step 2: aggregation of results for entire ASFC 8.

YEAR	CHANGE IN Y/ACRE	CHANGE IN GW/ACRE	DUTYAC	TOTAL Y-CHANGE	TOTAL GW-CHANGE
1990	-3.07	0.00	20,493	-62,817	0
1991	-8.51	0.00	16,394	-139,510	0
1992	-7.80	0.00	12,296	-95,873	0
1993	-7.01	-0.08	8,197	-57,486	-660
1994	-6.23	-0.08	4,099	-25,529	-330

Base Case Results: Overview

The most significant result from the simulations is that Second Management Plan conservation measures will have little impact on either agricultural water use or agricultural income. Total income loss in the AMA is expected to be less than 3% of gross revenue over variable cost. Groundwater savings are estimated to amount to 527,218 acre feet. Inserting this number into equation 5.5 indicates that on average, the AMA water table will be 2.29 feet higher in 2025 than if no conservation policy were in place:

$$\frac{527{,}218 \text{ acft}}{230{,}000 \text{ ft/acft}} = 2.29 \text{ ft} \qquad (7.2)$$

The discounted cost of this water savings in lost agricultural income is estimated to be $2,998,917. This, and all other figures unless otherwise noted, is stated in 1987 dollars, and does not include any multiplier effects.

Table 7.2 furnishes the results of the base case scenario. Column 1 of table 7.2 is the estimated total change in agricultural income in each ASFC. All dollar figures in this chapter are stated in 1987 dollars, and discounted at a rate of 3%. Most striking is the result that agricultural income actually goes up in 6 of the 9 ASFC's. This occurs when savings in groundwater costs due to reduced overdraft outweigh the negative impacts of the withdrawal fee and water duties.

TABLE 7.2: RESULTS OF THE BASE CASE

ASFC #	CHANGE IN INCOME	CHANGE IN GW USE	RATIO $/ac-ft	ACRE-YRS	WEIGHT
1:	1,207,996 3.6%	1,825 0.2%	661.91	220,150	0.04
2:	-347,445 -0.6%	-10,600 -0.6%	32.78	435,432	0.07
3:	-4,491,442 -3.5%	-259,065 -7.8%	17.34	633,690	0.11
5A:	496,495 0.8%	-67,456 -15.4%	N.A.	541,966	0.09
5B:	791,191 2.0%	62,185 3.9%	12.72	419,478	0.07
6:	1,753,287 5.5%	196,151 15.0%	8.94	398,250	0.07
8:	-6,766,780 -1.7%	-821,548 -24.5%	8.24	1,410,892	0.23
9:	781,317 0.9%	-45,168 -4.3%	N.A.	569,206	0.09
10:	3,576,463 3.0%	416,458 30.6%	8.58	1,378,002	0.23
TOTAL:	-2,998,917	-527,218	5.69	6,007,067	1

It is important to note that about 83% of the projected reduction in overdraft in ADWR's draft SMP (which was used to project groundwater costs) is a result of **urban** conservation measures such as significant decreases in municipal use, and increases in augmentation and effluent use. In ASFCs outside of the East and West Salt River sub-basins, such as Tonopah and Rainbow Valley, the policy scenario reductions in groundwater cost are probably overstated. In these ASFCs, groundwater use reductions and negative income impacts are probably underestimated, and positive changes in income or groundwater use are likely to be overestimated. (The directions of these biases is assumed to be the same as the logical impact of groundwater price on income and groundwater use).

The percentage changes listed on table 7.2 are calculated as the change in income or groundwater use over the total income or groundwater use from the no policy scenario. Most notable is the fact that no income change is greater than 6%. (It is important to recall, however, that no fixed costs are included in the LP models. The percentage change figures in table 7.2 thus understate the percentage change in actual profit).

The column titled 'RATIO' in table 7.2 is the calculation of total income change over the total change in groundwater use for each ASFC. When relevant (both changes with the same sign), this ratio provides a convenient means for comparing results. A higher value of this ratio, which is given in units of $/acft, means that groundwater savings are coming at a higher cost in terms of lost agricultural income, or conversely, that the increase in water use is associated with a greater increase in agricultural income. This ratio should not be interpreted as a robust valuation of water, but is useful in comparing results.

The column 'ACRE-YRS' in table 7.2 is the summation of all acres planted from 1990-2025. The final column, 'weight', indicates the relative importance of each ASFC in calculating total AMA impacts. The weights are calculated as the acre-years for an ASFC over the sum of acre years for all ASFCs.

Figure 7.3 demonstrates that the impact of decreased pumping lifts due to conservation efforts can confound attempts to reduce groundwater use. The withdrawal fees and water duties reduce groundwater use until 2009, and then aggregate groundwater savings actually begin to decline. This increase in groundwater use is manifested in LP model results in two ways. In ASFCs of highest groundwater costs, the decrease in future lifts results in farms remaining in operation longer. In other areas, lower groundwater costs result in crop mixes which have a higher percentage of alfalfa

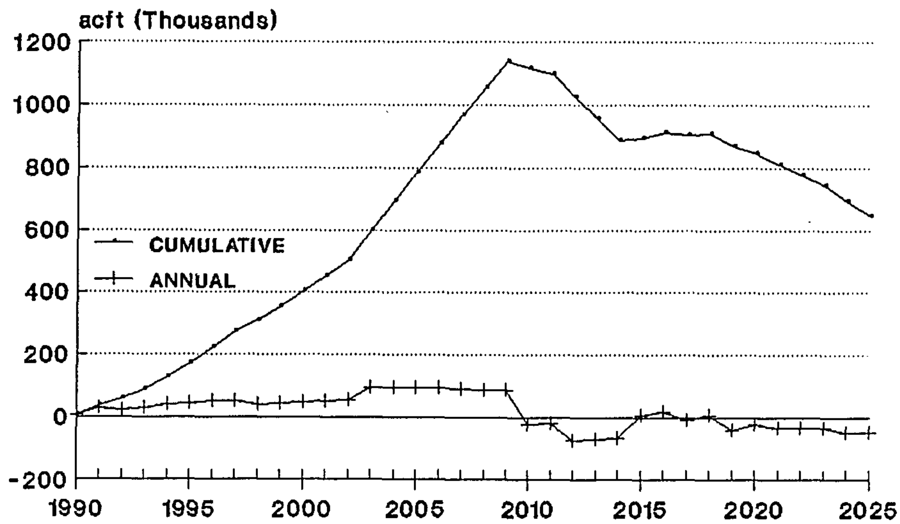


FIGURE 7.3
GROUNDWATER SAVINGS, PHOENIX AMA
BASE CASE SCENARIO

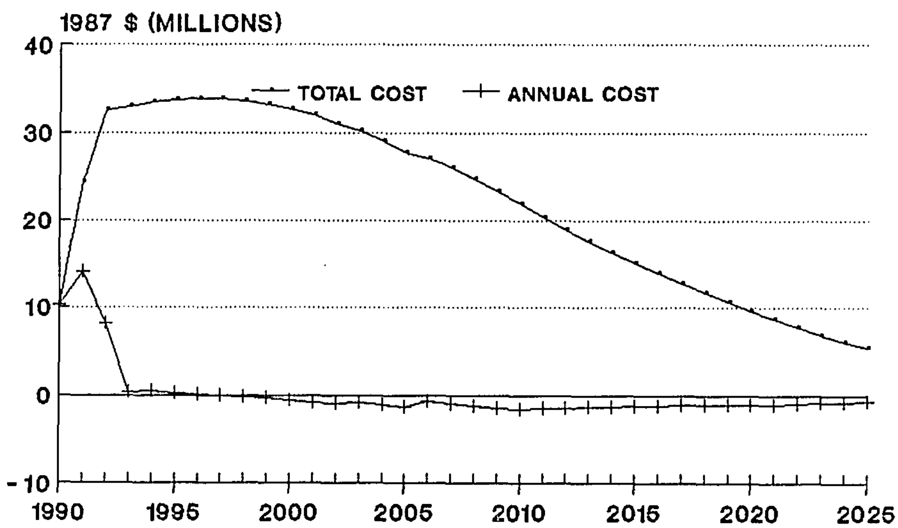


FIGURE 7.4
LOSS OF AGRICULTUAL INCOME:
BASE CASE SCENARIO

in the rotation.

Figure 7.4 shows the aggregate cumulative income impacts in the AMA. After 1994, the model predicts that annual agricultural sector income losses will stabilize and begin to decline. The sharp loss of income between 1990 and 1994 is due to increased investment in irrigation technology in the policy scenario, and due to withdrawal fees, which jump from $1 to $3 in 1991.

To this point, the results of the base case do not make an especially strong argument either for or against conservation policy. Little groundwater is saved, but what is saved is conserved at a relatively minimal cost in terms of lost agricultural income.

The Benefits of Conservation to Urban Pumpers

The benefits and costs of the Groundwater Management Act (GMA) accruing to that portion of the agricultural sector modeled here are internalized in the LP solutions. Other groundwater users will benefit from agricultural conservation, as groundwater costs will be reduced due to reduced overdraft. These other users include all non-agricultural water users, as well as those farms which have not been included in the results.[2] In this section, the calculation of these benefits is discussed. For convenience, all users not included in the LP results are designated under the general heading of urban pumpers, and are assumed to have the same average groundwater cost function as typical urban water providers.

An estimate of the benefit a typical urban pumper will realize for a reduction in future lifts can be calculated by making use of equation 7.2, which is originally introduced in chapter five as equation 5.2:

$$GW = EC * (L * a)/e + R * L + P \tag{7.2}$$

where:

GW = average variable groundwater cost in \$/acft.
L = pumping lift, in feet.
EC = energy cost in \$/kwh.
R = repair costs in \$/acft-ft.
P = the withdrawal fee, in \$/acft.
a = kwh required to lift 1 acft of water 1 foot.
e = the efficiency of the well.

Taking the partial derivative of equation 7.2 with respect to lift (L) reveals the following:

$$\frac{\partial GW}{\partial L} = (a/e) * EC + R \tag{7.3}$$

[2] Specifically, ASFCs 4, 7, 11, and 12. ASFC 4 is the Buckeye Irrigation District, and has largely been exempted from GMA conservation measures. ASFC 7, North Scottsdale contains only 1400 acres of farmland. ASFCs 11 and 12 are farms with Poor Soils or growing Citrus, respectively, and are not included in this analysis.

Blanco [1990] estimates the typical pump efficiencies at Phoenix Water Company to be about 72.5%. Average energy cost for pumping water there is around $.075/kwh. This energy rate is 10% higher than the current rate (including tax) that SRP charges agricultural water pumpers. It is assumed that the average future pumping efficiency for urban users in the AMA is .725. It is also assumed that the $.075/kwh figure is typical of AMA urban water providers. Future urban energy costs are projected by assuming the average urban pumping rate will remain 110% of the projected SRP agricultural user rate (see chapter four, for a discussion of energy cost projections).

The annual net benefit to urban users, given the specifications above, is calculated by the following equation:

$$UB_t = AF_t * \frac{\partial GW_t}{\partial L_t} * \Delta L_t \tag{7.4}$$

where:

UB_t = the annual savings in water cost for urban pumpers.
AF_t = the total acft pumped by urban pumpers.
ΔL_t = the cumulative change in lift at year t due to agricultural conservation.

and other variables are the same as previously defined.

The net urban benefit over 1990 to 2090 is calculated by the following equation:

$$NB = \sum_t (d_t * UB_t) \tag{7.5}$$

where:

NB = discounted net benefit of agricultural conservation to urban pumpers.

d_t = discount factor = $1/(1+.03)^t$.

UB_t = annual reduction in urban pumping costs.

In projecting future urban pumping (AF_t in eq. 7.4), an effort has been made to be consistent with the overdraft projections used previously to generate groundwater costs for the base case (see ch. 5). These overdraft projections come from the water budget in ADWR's Draft Second Management Plan (SMP). The total projected groundwater use for those farms considered by the LP model is subtracted from the total AMA groundwater use projected in the SMP; the difference is the estimate of all groundwater use which is not internalized in the LP model results.

This calculation can best be understood by examining figure 7.5. The upper plot is projected groundwater pumping according to the SMP. The continually declining path on figure 7.5 is agricultural groundwater pumping as projected by the base case results. The remaining plot is pumping by all other users, as calculated by subtracting agricultural pumping from total pumping. This method is not meant to generate the best possible estimate of future urban pumping, but rather is used because it is consistent with input data and results from the LP models.

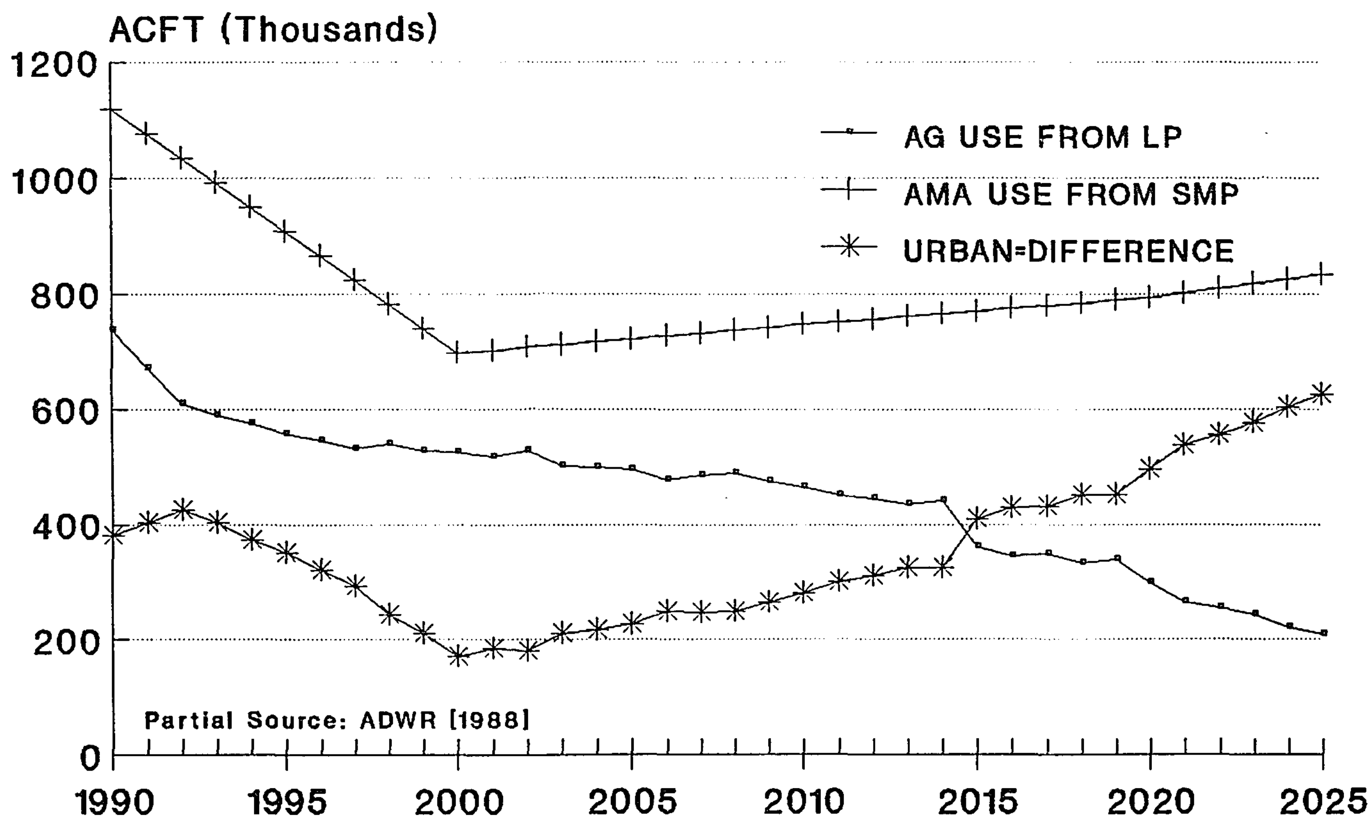


FIGURE 7.5

TOTAL, AG., AND URBAN, PUMPING

based on model results, SMP projections

The net urban benefit resulting from inserting the results of the base case into equation 7.5 comes to $2,367,302. This stream of benefits is calculated over the years 1990 to 2025, and stated in real 1987 dollars. Assuming that the Phoenix AMA is successful in reaching safe-yield levels of groundwater demand, this is an upper bound on urban pumping benefits. The path of urban pumping used in this calculation implies an enormous instantaneous reduction in urban pumping occurring in 2026. If safe-yield is obtained, a realistic scenario would have urban pumping being reduced in a more gradual fashion.

Administration Costs

The final component used to calculate the net benefits of the agricultural conservation measures is the administrative costs of implementing the withdrawal fees and water duties. In 1989 the ADWR Field Services and Operations Department had a total salary cost of $203,405 [Kimberlin 1990]. In nominal terms the salary costs for this department have more than doubled since 1986. Assuming that the salary costs level off to a value of $200,000 (in real 1987 dollars), the discounted stream of these costs from 1990 to 2025 comes to a total of $4,497,444.

At this time, no cost data is available for the capital expenditures necessary to implement the GMA conservation measures. These costs are missing from this analysis.

Summary of The Base Case Results

It terms of economic efficiency, the following balance sheet sums up the partial results of the base case:

Spreadsheet of Results: The Base Case

Agricultural Impacts:	
Change in Agricultural Income:	- $2,998,670
Withdrawal Fee Revenues:	+$38,924,077
Administrative Costs:	- $4,497,444
Urban Sector Impacts:	
External Benefit to Urban Pumpers due to Agricultural Conservation:	+ $2,367,302
Other Net Benefit Impacts due to Urban Conservation:	NB_u
NET SOCIAL BENEFIT:	$33,795,265 + NB_u

Recall once more that negative impacts on agriculture are mitigated by the reduction of future lifts due to conservation by other sectors; the 'Change In Agricultural Income' row above includes the benefits realized by the agricultural sector due to reductions in urban pumping. Also note that the costs of urban conservation and the benefits of urban conservation to urban users are missing from this analysis; these benefits and costs are defined as the residual term NB_u above. Examples of some of the costs and benefits which should be included in NB_u include the loss of consumer surplus by urban users of groundwater, the increase in conservation-related tax revenues, and the public sector expenditures for administration and enforcement of urban GMA conservation policies. A complete estimate of the net social benefit of the GMA conservation programs would require measuring these and other benefits and costs of conservation by the urban sector, a task beyond the scope of this study.

The base case results estimate that the GMA conservation programs will generate a positive net benefit if the NB_u term above is greater than -34 million dollars. With respect to the agricultural sector, the base case scenario indicates that the most significant impact will be a transfer of funds from groundwater pumpers to the government sector (ADWR), and this when assuming that withdrawal fees will be indexed to keep up with inflation. The savings in groundwater costs due to conservation approximately offset the negative impacts of the withdrawal fee and the water duties. The base case results seem to confirm SMP projections that future reductions in overdraft through conservation will come largely from outside the agricultural sector. Moreover, only a 527,218 acft reduction groundwater use is estimated to occur between 1990-2025. This amounts to only 14,645 acft per year, or about 1% to 2% of agricultural groundwater use in the AMA in 1988.

III. Sensitivity Analysis Of GMA Impact Estimates

A specific combination of six factors constitutes the base case. To get estimates of how the results change in response to these six factors, each one is changed while all other factors remain at base case values. The impacts of the factor change on the base case results are then examined. In this section, the order of analysis is reversed in that exogenous factors are examined first. The reason for doing this is that only partial results have been generated to analyze the sensitivity of the endogenous factors. For the endogenous factors, a new set of base-case-scenario results is introduced and used as a reference point for comparison.

An Allowance for Incidental Recharge

There is little data on the rate of incidental recharge, although ADWR estimates that for the agricultural sector, the rate is between .12 and .35 [ADWR 1988]. Assuming that 20%, rather than 10% of agricultural water use is recharged, the results of the base case are modified by reducing groundwater savings by 10%. This leads to a final AMA groundwater savings of 474,496 acft, which in turn translates to an average annual savings of 13,180 acft per year.

A rate of recharge of .2 reduces urban benefits by 10%. This changes net social benefit, as defined in the base case results, to a Sub-Total of -$4,892,081, and a Grand Total (net of withdrawal fees) of $33,558,535. Thus, despite the uncertainty about recharge rates in the Phoenix AMA, agricultural impacts can still be estimated with some confidence. Unless the rate of incidental recharge lays well outside its generally accepted bounds, this factor should not be an important consideration in policy decision-making.

The Rate of Urbanization

Estimates of future AMA acreage available for planting come from an ADWR model which projects the number of acres in each ASFC which will be displaced by urbanization from 1990 to 2025 [Stapleton 1989]. No consideration has been made for farm retirement due to reasons other than urban growth, therefore the estimates of future agricultural activity in the AMA are probably overstated. A more detailed discussion of the land conversion model is found in appendix III.

The projections of land conversion used in the base case are based on a forecast of continued rapid population growth used in a Maricopa Association of Governments (MAG) study. The MAG projections anticipate that Maricopa County's populace will number 5,312,300 in 2025. In contrast to this, the Arizona Department of Economic Security (ADES) projects county population to be only 4,578,000 in 2025 [ADES 1989]. ADES forecasts a population 14% smaller than MAG. The ADES population figures are used to analyze the effect that different rates of urbanization will have on the costs and benefits of GMA conservation policy.

The assumption is made that the allocation of farmland in the AMA will have the same spatial configuration for any given population, regardless of when that population is reached. The ADES forecasts are used to delay ADWR's projections of urbanization to later years. Using the ADES population projections means that more farmland is projected to remain in the AMA throughout the planning horizon. Figures 7.6 and 7.7 show the projections of population and farmland generated from the MAG and ADES population numbers.

The ADES scenario makes a stronger argument for conservation than the base case. Groundwater use is reduced by 645,428 acft, at a direct income loss of $2,731,786. The water savings translate to a reduction of average lifts of about 2.81 feet. Average AMA water savings in this scenario are 17,929 acft per year. Table 7.3 shows the results from the

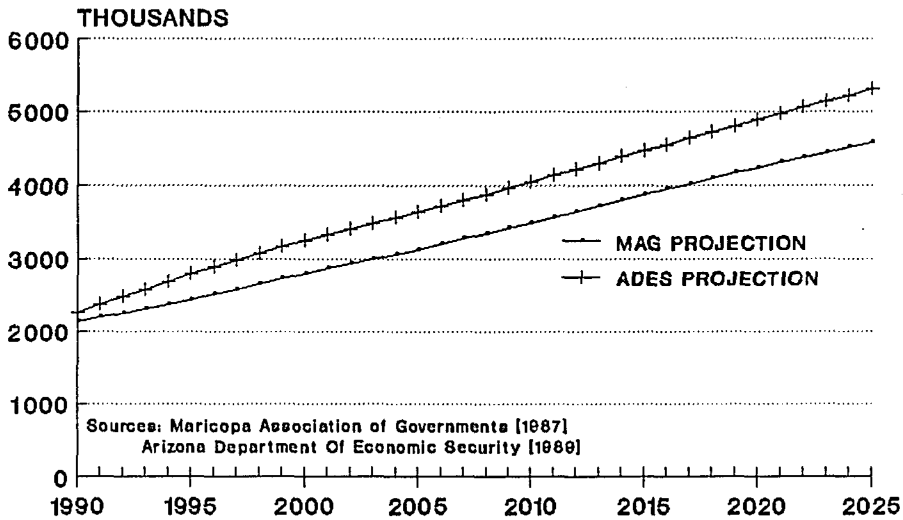
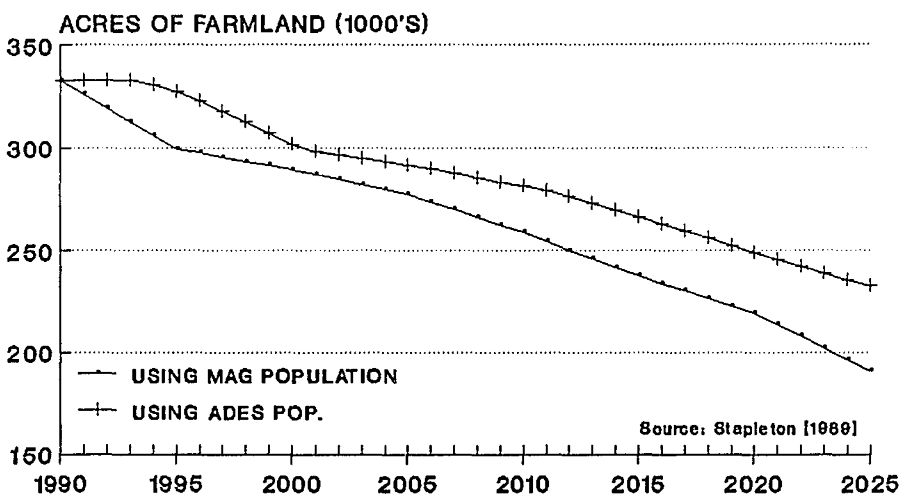


FIGURE 7.6
TWO PROJECTIONS OF POPULATION:
MARICOPA COUNTY



ASFCs 1, 2, 3, 5, 6, 8, 9, 10

FIGURE 7.7
PROJECTED AG. LAND, PHOENIX AMA
[acres available for planting]

TABLE 7.3
RESULTS USING ADES POPULATION PROJECTIONS

ASFC	CHANGE IN INCOME	CHANGE IN GW USE	RATIO $/ac-ft	ACRE-YRS	WEIGHT
1	1,706,541 5.0%	2,090 0.2%	816.53	240,163	0.04
2	-309,178 0.6%	-10,642 -5.7%	29.05	439,364	0.07
3	-4,933,820 3.6%	-287,610 -7.9%	17.15	690,827	0.10
5A	787,176 1.2%	-64,768 -14.0%	N.A.	595,230	0.09
5B	1,159,778 2.7%	87,212 5.1%	13.30	460,704	0.07
6	1,782,554 5.6%	199,122 15.1%	8.95	402,471	0.06
8	-7,842,781 -1.7%	-988,911 -24.9%	18.04	1,680,040	0.25
9	1,260,280 1.3%	-14,758 -1.3%	N.A.	653,702	0.10
10	3,657,664 3.0%	432,840 31.6%	8.45	1,443,785	0.22
TOTAL	-2,731,786	-645,428	4.23	6,606,286	1

ADES population scenario. Of some interest in this scenario, is that the relative weights of the ASFCs shifts to those areas expected to be urbanized first, especially ASFC 8 (Salt River Project) and ASFC 9 (Roosevelt Water Conservation District).

The balance sheet of results for the ADES population scenario follow, where urban pumping is assumed to diminish proportionally with population:

Spreadsheet of Results: ADES Population Scenario

Agricultural Impacts:	
Change In Agricultural Income:	- $2,731,786
Withdrawal Fee Revenues:	+ $42,030,740
Administrative Costs:	- $4,497,444
Urban Sector Impacts:	
External Benefit to Urban Pumpers due to Agricultural Conservation:	+ $2,278,439
Other Net Benefit Impacts due to Urban Conservation:	$NB_{u,ades}$
NET SOCIAL BENEFIT:	+ $37,079,949 + $NB_{u,ades}$

In this partial evaluation, a 14% drop in county population leads to only a 10% increase in net social benefit. It appears that a slow population growth rate in the Maricopa County will increase the social benefits, of the agricultural conservation program. It is meaningful to note that the elasticity of net benefit to urban growth is less than one; a decrease in the urban growth rate of Maricopa County does not necessarily imply a proportional increase in the benefits derived from the agricultural conservation program.

The Rate of Land Use

The rate of land use as defined here is the ratio of acreage planted to acreage available for planting, where acreage available for planting is defined as all Irrigation Grandfathered Right (IGFR) duty acres. Care must be taken in interpreting the land use rates as defined here; a substantial number of small (less than 50 acres) farms hold IGFRs in the AMA which are relatively inactive. A land use rate of .2, for instance, does not necessarily imply vast tracts of abandoned farms, but only means that a large amount of area water rights, obtained in 1980, are not in use now. Data on land use rates are generated from ADWR data by the following equation:

$$\text{Land Use Rate} = \frac{\text{Total Groundwater Use}}{\text{Total Groundwater Allotment}} \tag{7.3}$$

Table 7.4 shows the average land use rate for the ASFC's analyzed, from 1984-1988, based on equation 7.3.
As noted frcm table 7.4, assuming a use rate of .8 is likely to overstate the number of acres actually in production. It

is interesting, though not at all surprising, to note that the highest rates of use occur in areas with the least expensive water.

TABLE 7.4: FARMLAND USE RATES
PHOENIX AMA, 1984-1988

ASFC #	1984-1988 USE RATE
TONOPAH 1	.46
HASSAYAMPA 2	.29
R.I.D. 3	.68
McMICKEN 5	.33
RAINBOW VALLEY 6	.20
S.R.P. 8	.67
R.W.C.D. 9	.77
QUEEN CREEK 10	.35

source: ADWR, Registry of Grandfathered Rights database, 1984-1988.

Assuming that land use rates will be constant at the levels realized between 1984-1988 changes the results of the simulations, though not necessarily in the direction one might expect. Compared to the base case, both income loss and water savings increase, while the ratio of income loss to groundwater savings changes only slightly, from 5.69 $/acft in the base case to 7.76 $/acft in this scenario. Using historical use rates shifts the weights of the individual ASFC

TABLE 7.5
RESULTS USING 1984-1988 RATES OF LAND USE

ASFC	CHANGE IN INCOME	CHANGE IN GW USE	RATIO $/ac-ft	ACRE-YRS	WEIGHT
1:	694,598 3.6%	1,049 0.2%	662.15	126,586	0.03
2:	-125,949 -0.6%	-3,842 -0.6%	32.78	157,844	0.04
3:	-3,817,725 -3.5%	-220,206 -7.8%	17.34	538,637	0.15
5A:	204,804 0.8%	-27,826 -15.4%	N.A.	223,561	0.06
5B:	326,366 2.0%	25,651 3.9%	12.72	173,035	0.05
6:	438,322 5.5%	49,039 15.0%	8.94	99,563	0.03
8:	-5,667,178 -1.7%	-688,046 -24.5%	8.24	1,181,622	0.32
9:	752,017 0.9%	-43,475 -4.3%	N.A.	547,861	0.15
10:	1,564,703 3.0%	182,200 30.6%	8.59	602,876	0.17
TOTAL:	-5,630,042	-725,456	7.76	3,651,584	1

results so that those areas with cheaper water are more heavily factored into the aggregate calculation. The 725,456 acft of groundwater saved in this scenario translates to an average annual reduction of 20,152 acft per year, and a reduction in average lifts of 3.15 feet in 2025. Table 7.5 summarizes. The net benefit spreadsheet for the historical land use scenario follows:

Spreadsheet of Results: Historical Land Use Rate Scenario

Agricultural Impacts:

Change In Agricultural Income:	− $5,630,042
Withdrawal Fee Revenues:	+ $17,219,732
Administrative Costs:	− $4,497,444

Urban Sector Impacts:

External Benefit to Urban Pumpers due to Agricultural Conservation:	+ $2,340,919
Other Net Benefit Impacts due to Urban Conservation:	NB_u
NET SOCIAL BENEFIT:	+ $9,433,165 + NB_u

The observant reader might have noted that in spite of the increased net water savings realized in this scenario, urban pumping benefits are less than in the base case. This is because urban benefits are discounted, and the water savings in the historical-use-scenario occur later in time relative to the groundwater savings in the base case.

Using historical land use rates reduces the social net benefit by a significant amount, from 34 million to 9 million 1987 dollars, or 73%. Also groundwater savings increase by about 30% as compared to the base case. These changes occur because GMA conservation measures generally have a greater impact on water savings and income loss in those ASFCs with higher land use rates (i.e., areas with lower water costs).

Results of The Base Case: 36 Year Planning Horizons

The full battery of planning horizons were not run for every LP model scenario. To make meaningful comparisons among scenarios based on agricultural sector profits and the benefit-cost ratio of leveling, the results for farms with 36 year planning horizons will be compared. The results are useful primarily in a relative light; they reveal the direction of changes in the base case solution which will occur given a change in a certain factor.[3]

Table 7.6 comprises the base case results when only that acreage which will be in production throughout 1990-2025 is employed in the LP models. Net groundwater savings for these

[3] To account for all planning horizons for these factors would require 162 additional LP runs. Utilizing the 36-year planning horizons accounts for 70% of all agricultural activity, and provides a meaningful bench mark for comparing profit and irrigation technology scenarios.

TABLE 7.6: REVISED BASE CASE RESULTS
FARMS WITH 36-YEAR PLANNING HORIZONS ONLY

ASFC #	# OF 36-YR ACRES	36 YEAR CHANGE Y/acre	36 YEAR CHANGE GW/acre	RATIO $/acft
1:	8,339 see note	204.65 4.95%	0.25 0.20%	816.73
2:	13,708	-20.07 -0.56%	-0.69 -0.57%	28.93
3:	17,911	-179.43 -3.31%	-12.01 -8.02%	14.94
5A:	12,536	48.38 1.54%	-3.26 -15.47%	N.A.
5B:	9,703	104.54 4.29%	7.41 7.17%	14.11
6:	13,258	130.58 5.68%	14.62 15.42%	8.93
8:	28,399	-113.56 -1.56%	-19.01 -28.80%	5.98
9:	8,114	76.14 2.03%	1.09 2.28%	69.83
10:	35,754	73.08 3.04%	8.63 31.78%	8.47
TOTALS: {weighted}	147,722	1,575,174	-220,154	N.A.

note: the land conversion model actually projects all acreage in ASFC 1 to be urbanized between 2020 and 2025. The projected acreage at 2020 is used here.

acres is expected to be 220,154 acft (6,115 acft per year). Income for farms which will remain in operation the entire planning horizon is estimated to increase by $1,575,174. This increase in agricultural income is important to note in light of the fact that in the complete set of base case results agricultural income declines. The benefits of conservation fall to those farms with relatively long planning horizons.

The second column in table 7.6 is the number of acres in each ASFC expected to remain in production at 2025. The third and fourth columns of table 7.6 show the net change in income and groundwater on an acre of land over the entire 36 year planning period, assuming a land use rate of .8, and a incidental recharge rate of .1. These two columns are summations of annual income and groundwater impacts on a typical acre in the ASFC, over the years 1990-2025.

The total changes at the bottom of table 7.6 include all AMA acreage with 36 year planning horizons; the per acre impacts from each ASFC are multiplied by the acreage in the ASFC found in the second column. These partial results give extra weight to those ASFCs where the rate of urbanization is slowest. For example, note that ASFC 6 represents 9% of all acreage in these results, whereas when all planning horizons are considered, this ASFC embodied only 6% of the total.

In a manner similar to that used previously in this section, the two remaining factors are now compared against the revised base case results. In calculating net benefits, the quantity of urban pumping used is the same as that used in the complete base case results. Administration costs are reduced by 30%, since the number of acre-years considered in this partial analysis is 70% of the number of acres in the complete analysis.

The net benefit spreadsheet for the base case results for those farms with 36 year planning horizon follows:

Net Benefit Spreadsheet:
Revised Base Case: 36-year Planning Horizons Only

Agricultural Impacts:	
Change in Agricultural Income:	+ $1,575,174
Withdrawal Fee Revenues:	+ $28,770,798
Administrative Costs:	- $3,185,231
Urban Sector Impacts:	
External Benefit to Urban Pumpers due to Agricultural Conservation:	+ $1,217,417
Other Net Benefit Impacts due to Urban Conservation:	NB_u
NET SOCIAL BENEFIT:	+ $28,378,158 + NB_u

Obtainable Irrigation Efficiency: FARM H

All results discussed thus far are based on Farm L, which assumes that the average benefit-cost ratio of laser leveling fields will not be as high as that presumed by ADWR. (See chapter six for details). The choice of Farm L for the base case is the one most likely to be controversial. As it turns out, however, Farm H is a somewhat trivial case. The Farm H scenario assumes that laser leveling will increase yields by 10%, and reduce water use by over 25%. Farm H is generally going to laser level its fields regardless of the existence of the water duties. Farm H results are found in table 7.7.

Groundwater use in this scenario increases by 88,262 acft, a relatively insignificant amount. Agricultural income is estimated to increase by $12,754,996; agricultural users in this scenario realize reductions in water cost due to conservation, while suffering no adverse impact from the water duties.

Net social benefit in the Farm H scenario increases about eight million dollars from the revised base case. However, water use reductions are minimal. Compared to the base case, the benefits of GMA conservation in this scenario are shifted to the agricultural sector. Little modification of irrigation technologies or cropping patterns occur; farmers realize the benefit of urban conservation while not truly being forced, by the GMA, to conserve themselves.

TABLE 7.7: FARM H RESULTS
FARMS WITH 36-YEAR PLANNING HORIZONS

ASFC #	# OF 36-YR ACRES	36 YEAR CHANGE Y/acre	36 YEAR CHANGE GW/acre	RATIO $/acft
1:	8,339	187.04	2.79	66.98
	see note	3.10%	2.44%	
2:	13,708	-25.17	-0.51	49.73
		-0.46%	-0.45%	
3:	17,911	-113.89	0.00	N.A.
		-1.62%	0.00%	
5A:	12,536	89.91	-1.68	N.A.
		1.77%	-11.15%	
5B:	9,703	114.93	0.56	205.66
		2.59%	0.53%	
6:	13,258	172.60	0.00	N.A.
		4.04%	0.00%	
8:	28,399	4.86	0.00	N.A.
		0.05%	0.00%	
9:	8,114	49.37	-0.15	N.A.
		0.86%	-0.37%	
10:	47,174	180.41	2.48	72.73
		4.18%	6.71%	
TOTALS: {weighted}	159,142	12,754,996	88,262	144.51

**Net Benefit Spreadsheet:
Farm H: 36-year Planning Horizons Only**

Agricultural Impacts:

Change in Agricultural Income:	+ $12,754,995
Withdrawal Fee Revenues:	+ $26,542,247
Administrative Costs:	-$ 3,185,231

Urban Sector Impacts:

External Benefit to Urban Pumpers due to Agricultural Conservation:	+ $ 37,440
Other Net Benefit Impacts due to Urban Conservation:	NB_u
NET SOCIAL BENEFIT:	+ $36,149,451 + NB_u

High Profit Levels

The last factor requiring sensitivity analysis is the future profitability of the agricultural sector. This factor is treated within the LP model by assuming different levels of variable cost and gross revenue for the four LP crops (see chapter four). In terms of percentage changes, results from the high profit scenario are very similar to the base case. In the low profit scenario, the absolute and percent reductions in income and groundwater use are often the greatest.

Results from the high profit scenario are listed in table

7.8. Compared to the base case, the policy induced change in agricultural income increases by a magnitude of 5 times, to $7,939,421. Groundwater savings are increased by a factor of 3.2, to 700,965 acft, or 19,471 acft per year.

These deviations from the revised base case results are notable. The change in policy impacts between this scenario and the base case is occurring largely in ASFCs 5B, 6, and 10. These are the ASFCs with the highest groundwater costs. In the base case scenario, lower groundwater costs due to GMA policy allow farms in these ASFCs to remain in operation longer. Thus, total ASFC water use increases due to policy. In the high-profit scenario, the gross margin of crop activity is greater than the water cost of that crop activity, so that farms remain in operation regardless of the existence of conservation policy.

With regards to the change in income, higher profit levels allow model farms in some areas to remain in operation longer in the policy scenario, which allows them to capture the benefits of lower future groundwater costs due to conservation.

TABLE 7.8: HIGH PROFIT SCENARIO RESULTS
FARMS WITH 36-YEAR PLANNING HORIZONS

ASFC #	# OF 36-YR ACRES	36 YEAR CHANGE Y/acre	36 YEAR CHANGE GW/acre	RATIO $/acft
1:	8,339 see note	204.71 3.63%	0.32 0.25%	648.92
2:	13,708	-20.34 -0.40%	-1.39 -1.14%	14.66
3:	17,911	-180.52 -2.60%	-12.06 -8.06%	14.96
5A:	12,536	-4.10 -0.09%	-3.26 -15.47%	1.26
5B:	9,703	84.28 2.15%	-3.26 -2.82%	N.A.
6:	13,258	211.71 5.70%	0.00 0.00%	N.A.
8:	28,399	-112.46 -1.28%	-19.70 -29.54%	5.71
9:	8,114	80.70 1.54%	-0.76 -1.54%	N.A.
10:	35,754	243.61 6.65%	4.75 10.01%	51.31
TOTALS: {weighted}	147,722	7,939,431	-700,965	N.A.

Net Benefit Spreadsheet:
High Profit Scenario: 36-year Planning Horizons Only

Agricultural Impacts:

Change in Agricultural Income:	+ $ 7,939,431
Withdrawal Fee Revenues:	+ $30,287,740
Administrative Costs:	- $ 3,185,231

Urban Sector Impacts:

External Benefit to Urban Pumpers due to Agricultural Conservation:	+$ 1,972,440
Other Net Benefit Impacts due to Urban Conservation:	NB_u
NET SOCIAL BENEFIT:	+ $37,014,380 + NB_u

The high-profit scenario net benefits are 30% more than net benefits the in the revised base case. This result, along with the significant groundwater savings, strongly suggest that conservation programs will be more beneficial when the agricultural sector is enjoying higher profits.

Low Profit Levels

The low profit scenario results are notably different than those from the high profit or average profit (base) case. A significantly greater amount of groundwater is saved, but more importantly the change in agricultural income becomes negative. In the low profit scenario, results indicate that farms in high water cost areas will not stay in operation for the full planning horizon, regardless of policy. This is in spite of the fact that the models do not include fixed costs!

Table 7.9 gives the results of the low profit scenario. The groundwater use increases in ASFCs 6 and 10 are attributable to the fact that farms in these areas stay in operation longer in the policy scenario due to lower groundwater costs. The ratio of income loss to groundwater savings is $10.91/acft, which is somewhat higher than in the original base case (i.e. the base case with all planning horizons, table 7.2).

The calculation of net social benefit for the low profit scenario adds up to the lowest net benefit for any of the 36-year-model scenarios considered. Indeed, if agricultural profits skydive as implied by this scenario, conservation by this sector will be a moot point. In some ASFCs, model farms cease to operate even though no fixed costs are included; the inclusion of fixed costs would mean that even fewer farms would be left to conserve groundwater.

In summary, although assuming different profit levels does impact results, the general flavor of the base case is changed only by the low profit scenario. In this scenario, however, it is doubtful that enough farms will stay in

TABLE 7.9: LOW PROFIT SCENARIO RESULTS
FARMS WITH 36-YEAR PLANNING HORIZONS

ASFC #	# OF 36-YR ACRES	36 YEAR CHANGE Y/acre	36 YEAR CHANGE GW/acre	RATIO $/acft
1:	8,339 see note	-27.22 -1.00%	-1.11 -1.13%	24.57
2:	13,708	-106.43 -4.95%	-3.31 -3.79%	32.20
3:	17,911	-223.13 -5.99%	-17.82 -11.62%	12.52
5A:	12,536	11.74 0.77%	-6.63 -30.94%	N.A.
5B:	9,703	-59.24 -4.07%	-0.62 -1.07%	95.14
6:	13,258	-44.98 -3.14%	3.78 6.95%	N.A.
8:	28,399	-155.19 -2.78%	-22.99 -32.85%	6.75
9:	8,114	-7.26 -0.33%	0.38 1.09%	N.A.
10:	35,754	-6.68 -0.46%	0.47 3.50%	N.A.
TOTALS: (weighted)	147,722	-11,411,394	-1,045,829	10.91

Net Benefit Spreadsheet:
Low Profit Scenario: 36-year Planning Horizons Only

Agricultural Impacts:

Change in Agricultural Income:	- $11,411,394
Withdrawal Fee Revenues:	+ $21,216,516
Administrative Costs:	- $3,185,231

Urban Sector Impacts:

External Benefit to Urban Pumpers due to Agricultural Conservation:	+ $3,001,566
Other Net Benefit Impacts due to Urban Conservation:	NB_u
NET SOCIAL BENEFIT:	+ $9,621,457 + NB_u

business to make agricultural conservation a relevant issue.

Summary Of The Base Case And Sensitivity Analysis

The base case results indicate that the GMA will have little impact on the agricultural sector in the Phoenix AMA. The most significant negative impact is the transfer of funds from the agricultural sector to the government sector via the withdrawal fee, and this only when it is assumed that the withdrawal fee is indexed to keep up with inflation. Negative impacts are approximately negated by the reduction in future groundwater costs primarily due to urban conservation. Water savings of around 15,000 acft per year might be expected from the agriculture sector. This quantity is about one to two percent of the groundwater used by agriculture in 1988.

Changing the rate of incidental recharge for agricultural water use does not significantly change the results. The rate of future urban growth is somewhat more important, but does not seem dramatic enough to warrant special analysis. Assuming a high benefit-cost ratio (i.e. Farm H) for irrigation technology increases net benefits, but very little groundwater savings will arise due to policy. As mentioned previously, the lower benefit-cost ratio may be more plausible and is certainly more interesting. With regards to profit scenarios, the average-profit case seems far more probable than the extremes given by the high-profit and low-profit scenarios.

Of all the factors considered, changing the rate of land use altered the base case results most significantly, while at the same time presenting a very plausible scenario. Using 1984-1988 land use rates shifts the relative weights of the ASFCs in the calculation of total AMA impacts. Those ASFCs with relatively low water costs become more important in this scenario, since a higher percentage of available acreage has historically been planted in these areas.

On the basis of the sensitivity analysis, the historic rate of land use scenario is used to create a bound for the calculation of net social benefit. Figure 7.8 is a diagram of the material covered so far. This figure will be expanded to accommodate other policy scenarios yet to be discussed. All of the results discussed thus far in this chapter compare farm behavior given a no-policy world to farm behavior given full compliance with SMP policy measures. On figure 7.8, this policy change is represented by a movement from the box at the far left of the diagram to the box in the middle. The resulting net benefits and groundwater savings of this policy change is listed at the far right of figure 7.8.

The base case and the historical land use scenario establishes a range of net social benefits from $9,433,165 to $33,795,265. These numbers do not include a full assessment of the urban conservation program which could provide either a positive or negative net benefit (NB_u) to be added to the partial results shown here. Estimates of groundwater savings by the agricultural sector range from 14,645 to 20,152 acft per year.

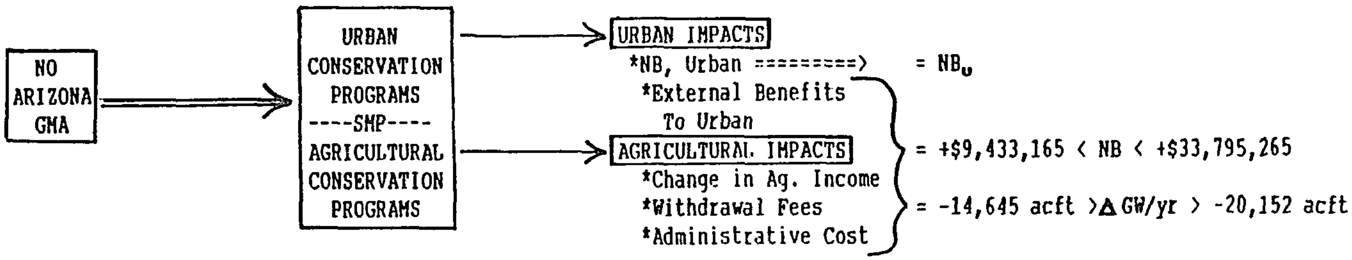


FIGURE 7.8: THE BASE CASE SCENARIO

IV. Potential Revisions Of GMA Policy

In this section, potential revisions to SMP conservation policies are considered. In these scenarios, the SMP world (the middle box in fig. 7.8) serves as the point of reference. Agricultural income and water use are measured against the SMP policy scenario.

Removal Of Urban Conservation

The first policy revision analyzed considers the removal of urban conservation measures, while leaving the agricultural conservation program intact. This change is incorporated into the LP models by assuming that future groundwater costs are the same as in the no-policy case, but the model farms are constrained by the water duties and must pay withdrawal fees.

In this scenario, groundwater use by agriculture is reduced by 1,157,994 acft due to the higher water costs. This translates to an average reduction in use of 32,166 acft per year. The decrease in average lifts in 2025 would be 5.03 feet. The estimated loss of agricultural income is $40,913,551 (1987 real). **These changes in income and groundwater use are relative to the SMP policy scenario.** Comparisons are no longer made between states of no-policy and SMP-policy, but between SMP-policy and other potential policies. Table 7.10 summarizes the results of the no urban conservation scenario.

This policy revision will lead to a greater volume of urban pumping. Therefore, in calculating the urban benefits of the reduction in agricultural pumping, urban pumping projections (AF_t) corresponding to the no policy scenario are used. This level of pumping is approximately double the urban pumping in the SMP case. (Recall that urban pumping is defined here as all pumping in the AMA not considered by the LP models). It is assumed that no change in administrative costs for the agricultural conservation program will occur when urban conservation programs are eliminated.

The spreadsheet of results shows a change of net benefit of -\$40,181,764 - NB_u, where NB_u is the urban conservation impacts from the base case scenario. The cost of these impacts, -NB_u, would have to more than \$40,181,764 to make this policy revision worthwhile in terms of economic efficiency.

Recall, however that the base case results showed a net social benefit of \$33,795,265 + NB_u. It follows, that in terms of economic efficiency, it would be better to drop both conservation policies than to only get rid of the urban program, because whereas the change in urban sector impacts, -NB_u, will be the same in either of these policy revisions, agricultural impacts would increase by \$6,386,499 in going to the no-policy rather than the no-urban-policy revision.

TABLE 7.10: RESULTS
NO URBAN CONSERVATION SCENARIO

ASFC, #	CHANGE IN INCOME	CHANGE IN GW USE	RATIO $/ac-ft	ACRE-YRS	WEIGHT
1:	-3,760,470 -10.8%	-14,098 -1.5%	266.74	220,150	0.04
2:	-4,430,747 -7.7%	-10,600 -0.6%	417.99	435,432	0.07
3:	-4,518,454 -3.6%	-4,428 -0.1%	1020.52	633,690	0.11
5A:	-2,342,816 -3.7%	0 0%	N.A.	541,966	0.09
5B:	-5,064,165 -12.6%	-149,210 -9.0%	33.94	419,478	0.07
6:	-5,191,087 -15.4%	-284,574 -18.9%	18.25	398,250	0.07
8:	-5,015,165 -1.3%	-23 0%	2.2E+05	1,410,892	0.23
9:	-3,711,167 -4.3%	-66,206 -6.5%	56.06	569,206	0.09
10:	-6,879,480 -5.6%	-628,856 -35.3%	10.94	1,378,002	0.23
TOTAL:	-40,913,551	-1,157,994	35.33	6,007,067	1

This figure is calculated by the following difference:

$$-\$33,795,265 - (-\$40,181,764) = \$6,386,499 \qquad (7.4)$$

The first term in equation 7.4 is the change in agricultural impacts (as defined on the results spreadsheet) for a policy change moving from SMP to no conservation policy. The second term is the agricultural impact of the no-urban-policy scenario.

Spreadsheet of Results: No Urban Conservation Scenario

Agricultural Impacts:	
Change In Agricultural Income:	- $40,913,551
Change In Withdrawal Fee Revenues:	- $3,047,351
Change In Administrative Costs:	0
Urban Sector Impacts:	
Change in External Benefit to Urban Pumpers due to Agricultural Conservation:	+ $3,779,138
Change in other Net Benefit Impacts due to Urban Conservation:	$-NB_u$
NET SOCIAL BENEFIT:	- $40,181,764 $- NB_u$

Figure 7.9 will help the reader to place the no-urban-policy scenario in context. The spreadsheet above is an evaluation of a movement from SMP policy (the middle box in figure 7.9) to a policy in which only agriculture users are

affected (the upper box). When historical use rates are applied to create bounds to these results, a net benefit range of -$22,392,064 to -$40,181,764 results. Between 13,535 acft to 32,166 acft of additional groundwater savings per year by the agricultural sector are estimated.

Spreadsheet of Results: No Urban Conservation Scenario; Historical Use Rates

Agricultural Impacts:

Change in Agricultural Income:	- $22,744,224
Change in Withdrawal Fee Revenues:	- $1,293,520
Change in Administrative Costs:	0

Urban Sector Impacts:

Change in External Benefit to Urban Pumpers due to Agricultural Conservation:	+ $1,645,680
Change in Other Net Benefit Impacts due to Urban Conservation:	$-NB_u$

NET SOCIAL BENEFIT: - $22,392,064 - NB_u

{reduction in gw use: 487,272 acft}

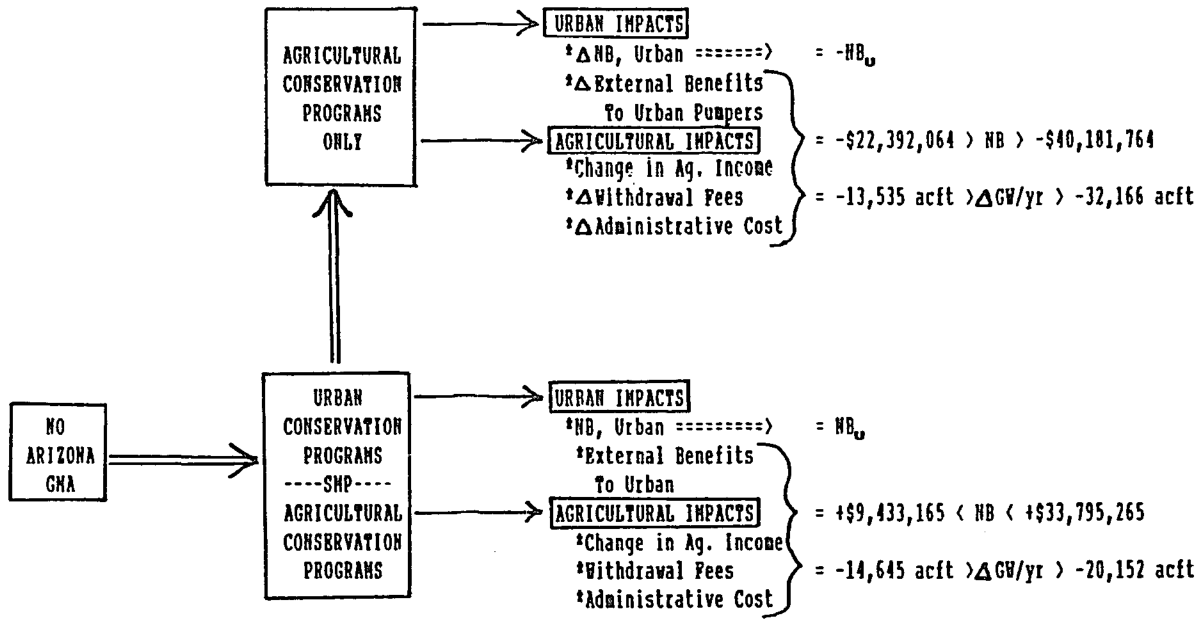


FIGURE 7.9: SMP AND NO URBAN CONSERVATION POLICY SCENARIOS

Removal Of Agricultural Conservation

The next policy revision considers a case where urban conservation programs are left intact, but agricultural policy measures (the withdrawal fee and water duty) are dropped. In this scenario groundwater use by the agricultural sector is at a maximum. Agricultural income is also maximized in this scenario, as lifts are decreased by urban conservation, while in the meantime no restrictions or fees are levied on agricultural pumping.

Agricultural income increases by $54,456,416 over the SMP scenario, and agricultural pumping increases by 1,843,191 acft, or 51,200 acft per year (Table 7.11). Average lifts would be 8.01 feet deeper in 2025 as a result of this policy revision. The measure of net benefit increases by $15,784,295. It is presumed that the non-agricultural impacts included in residual term, NB_u, will be unchanged by the removal of agricultural conservation measures. Therefore, in this case the estimate of net social benefit is complete for those impacts included.

The historical land use rates are again used to put bounds on the estimates, resulting in estimates of between $15,784,295 and $18,410,306 for the change in net social benefit, and between 38,191 acft to 51,200 acft per year

TABLE 7.11: RESULTS
NO AGRICULTURAL CONSERVATION SCENARIO

ASFC, #	CHANGE IN INCOME	CHANGE IN GW USE	RATIO $/ac-ft	ACRE-YRS	WEIGHT
1:	3,161,682 7.63%	104,649 9.73%	30.21	220,150	0.04
2:	4,878,322 8.29%	21,172 1.15%	230.41	435,432	0.07
3:	9,693,929 7.32%	350,680 10.25%	27.64	633,690	0.11
5A:	4,510,165 6.58%	71,790 16.23%	62.82	541,966	0.09
5B:	4,815,842 10.43%	68,169 3.97%	70.64	419,478	0.07
6:	4,121,998 10.78%	32,540 2.10%	126.68	398,250	0.07
8:	14,788,863 3.66%	944,476 27.21%	15.66	1,410,892	0.23
9:	3,044,088 3.41%	81,606 7.46%	37.30	569,206	0.09
10:	5,441,527 4.22%	168,108 8.63%	32.48	1,378,002	0.23
TOTAL:	54,456,416	1,843,191	29.54	6,007,067	1

Spreadsheet of Results: No Agricultural Conservation Scenario

Agricultural Impacts:

Change in Agricultural Income:	+ $54,456,416
Withdrawal Fee Revenues:	- $38,924,077
Administrative Costs:	+ $ 4,497,444

Urban Sector Impacts:

Change in External Benefit to Urban Pumpers due to Agricultural Conservation:	- $ 4,245,488
Change in Other Net Benefit Impacts due to Urban Conservation:	0
NET SOCIAL BENEFIT:	+ $15,784,295

Spreadsheet of Results: No Agricultural Conservation Scenario; Historical Land Use Rates

Agricultural Impacts:

Change in Agricultural Income:	+ $34,399,951
Withdrawal Fee Revenues:	- $17,219,732
Administrative Costs:	+ $ 4,497,444

Urban Sector Impacts:

Change In External Benefit to Urban Pumpers due to Agricultural Conservation:	- $ 3,267,357
Change in Other Net Benefit Impacts due to Urban Conservation:	0
NET SOCIAL BENEFIT:	+ $18,410,306

(increase in groundwater use: 1,374,887 acft) increase in groundwater use. The results indicate that this revision in policy may be a potential Pareto improvement, which is to say it appears that net social benefit will go up if the agricultural conservation program is dismantled.

Figure 7.10 is the completed diagram of the policy scenarios which have been covered in this report.

V. Summary And Conclusions

To put the results herein in some perspective, consider that in 1987, total receipts for crop marketings in Maricopa County totaled over $400,000,000. In the base case, the change in agricultural income, summed over the entire 36 year planning horizon, came to only about $3,000,000, or about .75% of the 1987 crop marketing value! Likewise, the water savings estimated in the base case, 14,645 acft per year, amounts to only about 1% to 2% of the current total agricultural water use in the Phoenix AMA. These numbers might lead one to ask, are the GMA conservation measures worth the trouble?

Getting rid of the urban conservation program could lead to an increase in social net benefit, but our results show that if this change is contemplated, net benefits could be further increased by dropping the agricultural conservation program.

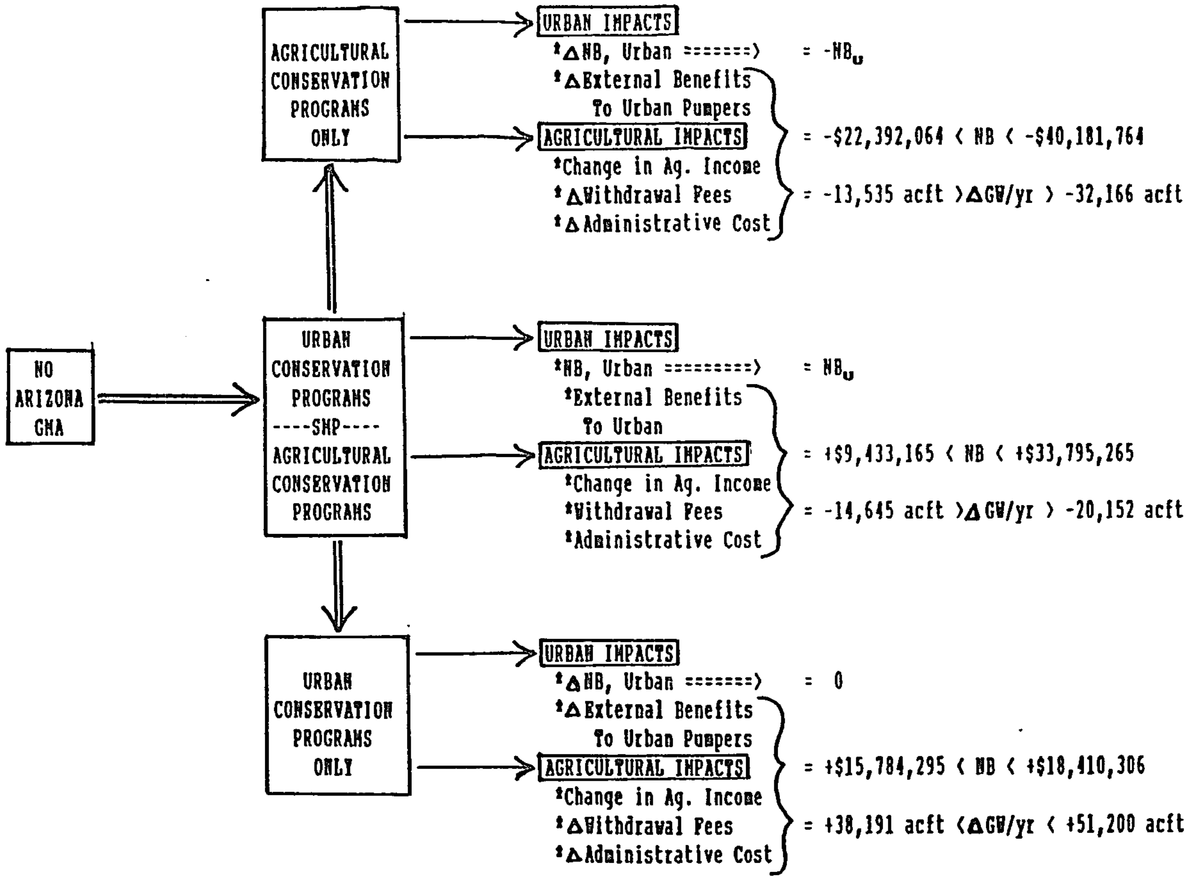


FIGURE 7.10: DIAGRAM OF ALL POLICY SCENARIOS

Elimination of the agricultural conservation program appears to generate positive net benefits, but only in the range of $15 to $18 million. This change in income would be accompanied by an increase of agricultural water use from between 38,191 acft to 51,200 acft per year.

A number of non-direct costs and benefits have not been included in this study. There are also some costs and behavioral considerations which are not accommodated for in the LP model. A discussion of these issues, and the policy implications of these results, is found in the next chapter.

CHAPTER EIGHT

CONCLUSION

I. Presentation Of Results

For purposes of illuminating the discussion, and in order to make this chapter something of an executive summary, figure 7.10 is reproduced here as figure 8.1. This chapter begins by defining the numbers and terms appearing in figure 8.1.

Unique policy scenarios are represented by the four boxes in figure 8.1, and changes in policy are indicated by the double-line arrows between boxes. Estimated income and groundwater use impacts, resulting from a change in policy are listed at the far right of figure 8.1. Four policy scenarios are assessed. The first is a no policy scenario which estimates future conditions assuming non-existence of the Arizona Groundwater Management Act. The no policy scenario is found at the far left of figure 8.1. The policy scenario in the center is the Second Management Plan (SMP) policy scenario, which evaluates the GMA as it now exists. The impacts of SMP conservation programs, as measured against the no policy scenario, are referred to as the base case, and are listed at the center-right of figure 8.1. Two policy revisions are considered. The first, the agricultural-conservation-only policy scenario, is found at the top of figure 8.1. The

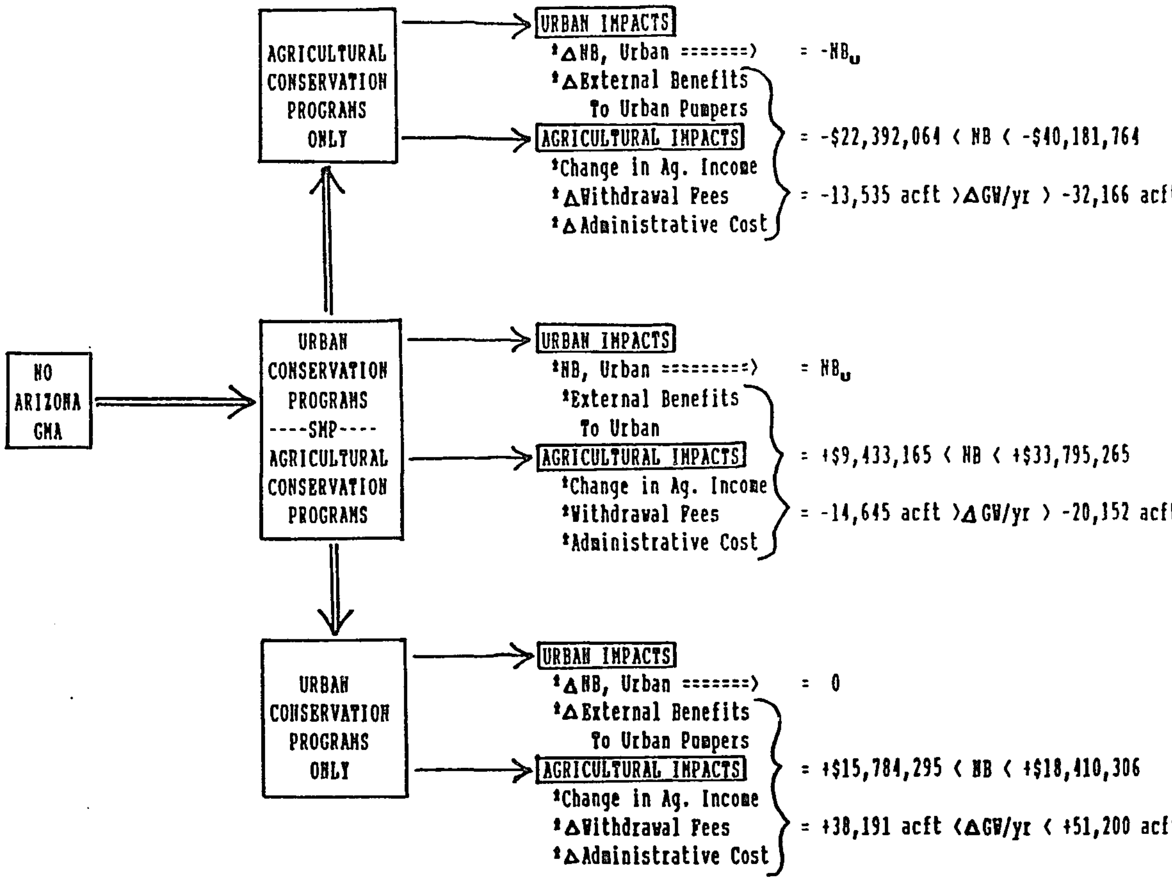


FIGURE 8.1: DIAGRAM OF ALL POLICY SCENARIO RESULTS

second, the urban-conservation-only policy scenario, is found at the bottom of figure 8.1. The changes generated by these two policy revisions are found at the top-right and bottom-right of figure 8.1, respectively, and are **measured against the SMP policy scenario.** That is, whereas the SMP policy scenario results are compared to the no policy scenario, the policy revision scenarios are compared to the SMP policy scenario.

The estimated changes in groundwater use, GW/yr, listed at the right side of figure 8.1 are the change in agricultural groundwater use due to a particular change in policy. For each change in policy, a partial calculation of the change in discounted net social welfare is made. This figure, which is stated in 1987 dollars, is the sum of the following impacts: the reduction in pumping cost paid by urban pumpers due to agricultural conservation; the change in agricultural income; the change in withdrawal fees paid by the agricultural sector; and the change in the administrative costs of the agricultural conservation program. These four estimates are enveloped by the large brackets at the right of figure 8.1. **Included in the change in agricultural income is the reduction in future agricultural groundwater costs due to urban conservation (i.e., reduced lifts).**

Not included in the above partial measure of net benefit is the cost of urban conservation programs and the benefit of urban conservation to urban users. This residual term is denoted NB_u. The urban conservation program is defined here to be all conservation not accounted for by our simulations, and indeed consists mostly of what ADWR describes as its urban conservation program. A complete economic efficiency evaluation of the GMA would require an in depth analysis of the urban conservation program. However, the partial results generated from our simulations provide a good indication of the relative efficiency and the impact on agriculture of the policy scenarios considered.

All dollar values in this chapter are stated in 1987 real dollars, and are discounted at a rate of 3%. Most of the results described in this chapter can be read directly off figure 8.1. More detailed results can be found in chapter seven.

II. Summary Of Results

The Arizona Groundwater Management Act (GMA) established a complex, multi-faceted program of groundwater conservation programs for the Phoenix Active Management Area (AMA). Municipal groundwater users in the AMA are now subject to a variety of restrictions and requirements, including per-capita water use targets and a program which requires prospective land developers to demonstrate a 100-year assured water supply. Industrial users are faced with industry-specific conservation requirements, and golf courses are restricted in the quantity of water which they may apply per acre. Agricultural users are faced with water duty requirements, withdrawal fees, flex account management, and acreage restrictions in an effort to conserve the diminishing stock of groundwater.

The principal purpose of this research is to estimate the impacts that the GMA will have on the agricultural sector, and document the benefits and costs of the agricultural conservation program. The results indicate that the net benefits of the GMA conservation programs could be positive, depending on the net impact of urban conservation, NB_u. The estimate of total net benefit for the base case is NB_u plus between \$9.4 million to \$33.8 million attributable to agricultural impacts.

On the cost side, a public sector cost of at least \$4.5 million will have to be expended to monitor, enforce, and administer the agricultural conservation program. Also, farm income will be detrimentally impacted with discounted losses of approximately $3 million.[1]

On the benefit side, urban pumpers are estimated to receive approximately $2.4 million worth of savings in discounted pumping cost due to conservation by the agricultural sector. In addition, the Arizona Department Of Water Resources (ADWR) could be expected to collect a little over $38.9 million from withdrawal fees. A third benefit of SMP policy is concerned with progressing toward safe yield levels of annual groundwater use in the AMA. In the agricultural sector, an estimated 14,645 to 20,152 ac-ft average annual reduction in groundwater use would occur annually as a result of the SMP program. This groundwater savings is roughly equivalent in terms of overdraft reduction to retiring 2,929 to 5,035 acres of farmland.[2] Currently an

[1] Agricultural income is impacted in two ways by the SMP conservation program. Groundwater pumping costs are reduced as a result of reductions in future pumping lifts in response to groundwater conservation. On the other hand, farm income is adversely affected by the imposition of withdrawal fees and water duties. Reduced groundwater payments due to reduced future lifts approximately equal the negative impacts of the withdrawal fees and water duties. The reduction in future lifts is a product of both agricultural and urban conservation. Details of how projections of lift are translated into future groundwater costs can be found in chapter five.

[2] This calculation assumes a groundwater use per acre of 4 to 5 ac-ft/year. The cost of this retirement would be an upper bound on the value of SMP agricultural conservation, as there may exist some cheaper means of obtaining similar reductions in groundwater use.

acre of farmland in the AMA, outside the influence of urbanization, sells for about $2,500 [Ayer, 1990]. This implies that the agricultural conservation program is reducing farmland retirement costs by $7 million to $12.5 million. But this may be misleading. Model results also indicate that most of the groundwater savings by agriculture occurs before 2006, the earliest date when rights condemnation procedures can be initiated. In fact, the base case simulations estimate that annual groundwater use by agriculture will actually increase towards the end of the planning horizon. Thus, without significant modification of existing SMP water duty and withdrawal fee policy, this potential reduction in land retirement costs could go largely uncaptured, with groundwater conservation by agriculture playing a relatively minor role in attaining safe yield.

If future research can document that the net benefits to urban pumpers generated by the urban conservation program are positive, or at least not less than -$33 to -$7 million, this research indicates that economic efficiency was served by establishing the GMA. On the other hand, safe yield objectives do not appear to be significantly advanced by the agricultural conservation program. The annual average reduction in agricultural groundwater use is estimated to be only between 14,645 ac-ft and 20,152 ac-ft. At most, this amounts to only

3.2% of 1985 AMA overdraft or to 4.8% of projected 2025 overdraft. (The projected 2025 overdraft used to calculate the above percentage assumes full compliance with SMP conservation) [ADWR 1988].

Implications Of Eliminating SMP Conservation Programs

Both the urban and the agricultural conservation programs have generated a great deal of controversy. The state has cited a number of private water companies, and also the city of Tucson, for failing to get their customers to sufficiently lower water use [Volante 1989]. Some smaller urban water providers have complained that the law is being enforced in an inequitable manner [Ibid]. Rural areas are complaining vigorously about 'water ranching', where land outside AMAs is purchased by urban users "...not for the value of the land or its crops or any structures on it, but for its access to surface or ground water" [Woodard 1989]. "The rush to buy water ranches -which state Sen. Jones Osborn, D-Yuma, has called a 'feeding frenzy' by urban interests- is driven by the 1980 Groundwater Management Act" [Volante 1988].[3] Similarly, on the agricultural side, over 1700 Arizona farmers have filed to be granted waivers from water duty requirements,

[3] A more in depth analysis of the water ranching issue can be found in Checchio [1988].

requirements viewed by many as unrealistic and uneconomic (see chapter six, and Halderman [1989] for more detail on this dispute).

Because of the controversial nature of the GMA conservation programs, the economic and groundwater use impacts of eliminating either the urban or the agricultural programs were estimated. Significant change in agricultural impacts are projected to occur if the agricultural conservation program is continued while the urban program is dismantled. Both the benefits and the costs associated with agricultural conservation are dramatically impacted when pumping lifts increase due to the elimination of urban conservation. The change in net benefits is estimated to be $-NB_u$ minus between $22.4 million and $40.2 million.

Discontinuing urban conservation efforts may or may not be economically efficient, depending on the value of NB_u.[4] The simulations estimate that this revision would change the net benefit of the agricultural impacts (as defined in figure 8.1) by -$22 to -$40 million. A thorough appraisal of the benefits, costs, and safe yield implications of such a legislative

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[4] In this no-urban-policy scenario, the agricultural conservation program is estimated to generate groundwater savings of between 13,535 ac-ft and 32,166 ac-ft per year over the SMP policy scenario. This amounts to only 2.0% to 4.8% of total AMA overdraft in 1985, and an even lower percent of what overdraft would be in 2025 if this policy revision were adopted.

revision would have to be made before a determination could be made. However, this research indicates that it would be economically inefficient to continue agricultural efforts if urban conservation efforts halt. If urban conservation were eliminated, the results indicate that net benefits would be increased between $6 and $13 million by also eliminating agricultural conservation. The agriculture-conservation-only scenario amounts to a discarding of the safe yield goal, since 83% of the total reduction in overdraft is projected to come from the urban sector [ADWR 1988].

Moving toward an urban-conservation-only policy is equally problematic. To some extent, economic efficiency objectives may be served by revising existing GMA legislation to continue urban conservation programs while discontinuing agricultural ones. Under this scenario, agricultural withdrawal fees and administrative costs are eliminated while urban pumping costs and agricultural income increase. The net benefit impact of moving from the existing GMA legislation to a revised program of urban conservation only is estimated to be between $15.8 million and $18.4 million between 1990 and 2025. Ignoring safe yield implications, the benefits significantly exceed the costs from this policy revision.

The good news from this policy revision is that agricultural income increases between $34 million and $54 million, and administration costs decrease by $4.5 million. The bad news from this policy revision is that agricultural groundwater use would increase between 38,191 ac-ft to 51,200 ac-ft per year on average, imposing a burden on urban users in the form of higher pumping cost (approximately $3.2 million to $4.5 million in discounted costs over the planning horizon). More importantly, safe yield objectives may be significantly compromised by such a revision. Assuming an average annual use of 4 to 5 ac-ft/acre, the implication is that to counteract this increase in agricultural groundwater use, between 7,638 acres and 12,800 acres of farmland will have to be retired. This means that, in terms of farmland retirement, an offsetting reduction in groundwater use would cost between $19 million and $32 million (1990 dollars). Thus, this policy could not be recommended until another, less costly, way to reduce groundwater overdraft is documented, or unless the safe yield goal is discarded. A full analysis would require a dynamic model which would select the least cost combination of conservation, augmentation, and farmland retirement necessary to reach safe yield levels of water demand by the year 2025.

III. Implications For Revising GMA Legislation

Revision One: No Change

No major revisions of the GMA can be recommended on the basis of these simulations. The results indicate that, as a whole, the GMA will not necessarily have a strong negative impact on the agricultural sector. The base case estimates a loss of agricultural income of only $3 million. The net social benefit of SMP policy is estimated to be the sum of the net benefit of urban sector conservation policy to urban groundwater users (NB_u) plus between $9 million and $34 million associated with agricultural impacts. Thus, if the net benefits to urban groundwater users of the urban conservation program are greater than -$33 to -$9 million, the SMP appears to be an efficient policy.

However, it appears that little conservation is obtained from agriculture in this base case, even though full compliance with the water duties is assumed. From 14,645 ac-ft to 20,152 ac-ft of groundwater per year is saved, which amounts to only to 2.2% to 3.0% of overdraft in 1985, or 3.4% to 4.8% of projected 2025 overdraft.

Revision Two: Elimination Of Urban Conservation Requirements

The simulations indicate that eliminating the urban conservation program could be efficient only if the net benefits of these programs (NB_u) are substantially less than zero (in the range of -$22 million to -$40 million). If the net benefit of the urban programs are greater than zero, such a revision would be very inefficient. Only between 13,535 ac-ft and 32,166 ac-ft of additional groundwater savings per year by agriculture would occur due to this policy revision, and this because of the increase in groundwater costs due to deeper pumping lifts. On the other hand, urban water use would increase dramatically.

Continuation of agricultural conservation in the absence of urban conservation appears to be a bad idea. The simulations indicate that this policy revision is inequitable and without justification in that a hardship in the form of higher groundwater costs would be placed on agriculture, while social net benefit is decreased.

Revision Three:
Elimination Of Agricultural Conservation Requirements

Assuming that the net benefits of urban conservation programs (NB_u) will be the same in the absence of agricultural conservation, eliminating agricultural conservation measures could be an efficient revision of policy. The simulations estimate an increase in net benefits of $15.8 million to $18.4 million for this policy revision. If agricultural conservation is eliminated, urban users will incur an additional $3.3

million to $4.5 millon of groundwater pumping costs. This is more than offset, however, by an increase of $34.4 million to $54.5 million in agricultural income.

However, this policy change would have a significant negative impact on progress towards safe yield. If farmland retirement is used to recoup the lost groundwater savings due to this revision, a quantity of money greater than the increase in net benefits above would have to be spent. Only if measures can be identified that can reduce overdraft by between 38,191 to 51,200 ac-ft, at a cost of less than 15 to 18 million dollars, could this policy revision be recommended.

IV. Other Notable Results

There has been some concern in the Phoenix area about recent increases in the aggregate flex account balance (ch. 2) of AMA farmers. Indeed, model results indicate that in those areas where water duties are binding, a long run profit maximizing strategy is to build up the flex account balance as much as possible before the year 2000, then rely on this stock of water to supplement the annual allotment. In those areas where the water duties are not binding, flex accounts grow unabated. For the 9 areas considered, flex account balances hit peaks of between 1 to 4.66 times the initial flex account balance (i.e. one half of the 1990 allotment). It is important to note that the flex account is a stock of water and not a flow, so that the number 4.66 above implies about a 2.33 year supply of water for the representative farm.

The allotments are generally only a problem for model farms in areas where water costs are low enough to make alfalfa a more profitable crop than wheat. The impact of allotments also hinges on the 1975-1980 crop mix of the representative farm, since this is a factor on which the water duty is based. Specifically, ASFCs 5, 8, and 9 (McMicken, SRP, and RWCD) experience the most significant loss of income due to the water duty. Surprisingly, in general the water duties have less negative impact on the representative farms than the withdrawal fee, even though a relatively low benefit-cost ratio of leveling fields is assumed.

Many of the results are driven by projected escalations of energy costs, which lead directly to high future groundwater costs. In areas completely dependent on groundwater these cost escalations appear to threaten the future viability of the industry. High groundwater costs increase the farmer's incentive to invest in irrigation technology, regardless of the water duty. If energy prices turn out to be substantially lower than those used in the model, the water duty may become a more important policy tool.

The escalation of energy costs also increases the benefits of conservation, both to urban and agricultural users. A reduction in overdraft will generate less external benefits if energy prices are lower.

V. Caveats And Future Research

Caveats

The weaknesses of the Linear Programming model (LP)-representative farm methodology have been oft-explored in economic literature.[5] Therefore, the concentration in this section will be on potential refinement of the analysis in aspects outside of the LP methodology.

Throughout, it is assumed that all groundwater users fully comply with SMP conservation requirements. Assuming less than full compliance by agricultural pumpers will reduce estimated income loss and groundwater savings. Assuming less than full compliance by urban users results in higher groundwater costs, and would tend to increase agricultural income losses and groundwater savings attributable to GMA policy. This is not a trivial issue. If obtaining full compliance by agricultural water users turns out to be relatively costly, the net benefits of the conservation

[5] For example, see Day [1963] for a comprehensive analysis of aggregation bias.

program will likewise be reduced.

Two projections of overdraft are used to create four policy scenarios. High values for overdraft, and thus for future lifts and groundwater costs, are used in the no policy and the agriculture-conservation-only policy scenarios. Low overdraft estimates are used in the SMP policy and urban-conservation-only policy scenarios. The response of future lifts to agricultural conservation is not used to adjust groundwater costs in the LP models. The resulting bias is that the two policy revision scenarios tend to exaggerate the impacts of the policy revision on the agricultural sector. Thus, the results provide an upper bound on the impacts of these policy revisions.

No multiplier effects are included in the changes in income reported. Much of the income impacts are simply transfers from the agricultural sector to the government sector via the withdrawal fee, so that the net multiplier would depend on the relative magnitude of the multiplier impacts for these two sectors.

It is assumed that the GMA will be amended to allow withdrawal fees to keep up with the rate of inflation. This recommendation has been made by the Arizona Auditor General [1989] (see footnote 2 in chapter two, p.54).

Benefits of conservation to groundwater users beyond 2025 are not included in these results. Assuming safe yield is obtained, and the effect of discounting, means that these benefits will be relatively insignificant. No assessment of the costs of continuing conservation beyond 2025 has been made either.

Farmland in the AMA is assumed to go out of production only when urbanized, or when variable production costs are greater than gross revenues from crop production. No farmland retirement due to other reasons is used in the model. Inclusion of fixed costs in the model would increase the rate of farmland retirement. The acreage figures used thus represent an upper bound.

One of the costs of the water duties and withdrawal fees will be the time spent by farmers engaging bureaucratic entities regarding these policies. Public Choice literature catalogues this type of activity under the general heading of 'rent seeking'. No analysis of these costs, or of the potential gains from rent seeking activity is made.

Government subsidy programs have implicitly been incorporated into the LP models by certain investment constraints and by the gross revenue parameter for wheat and upland cotton. No explicit modeling of these programs is included, however.

The possibility exists that, in some areas, water conservation could increase soil salinity. This question is not dealt with here.

Farmers in the AMA have a number of potential responses to water use restrictions which are not included in the LP model. Among these options are the following: double cropping, which is the planting of two crops on one piece of land in the same year; adjustment of crop rotation practices; adoption of higher valued annual crops in rotation; adoption of higher valued permanent crops such as fruits, nuts, or vines, on a reduced amount of acreage; investment in more sophisticated irrigation technologies such as drip or sprinkler systems; participation in various government subsidy programs.

Future Research

As discussed in chapter five, a somewhat ad-hoc method is utilized to translate aggregate AMA overdraft into ASFC water table decline. ADWR is working on a large model which will help to specify the spatial response of the water table to pumping in the AMA. This information will be very useful to others researching the overdraft problem.

The GMA conservation measures will effect the future cost of purchasing farmland, insofar that the cost of land is tied to its productive value in agriculture. This in turn will impact the cost of farmland retirement incurred by ADWR. No estimate of this relationship is made here. Future research should address this relationship in the context of seeking the least-cost combination of conservation policy tools.

At least two policy revisions are not included here which may be worthwhile to evaluate. One would be a scenario in which the agricultural water duties are eliminated but the withdrawal fees remain. One goal might be to determine the magnitude of withdrawal fee increases which would be needed to offset the effect of elimination of the water duties. Another interesting scenario would be one in which some limit is put on the positive flex account balances which can accrue. The flex account controversy in part revolves on the transferability of positive account balances, and is a matter beyond the scope of this study.

VI. Summary

It appears that in most areas of the AMA, agricultural groundwater users have every incentive to conserve water. If current trends in energy cost continue, this incentive will only strengthen over time, making water duties a somewhat frivolous notion. In the one area where water duties do appear to make a big difference, the Salt River Project, urbanization is expected to remove about two-thirds of all farmland by

2025.

Whereas the Auditor General [1989] has indicated that "enforcement of conservation plans is critical for successful water management," and that "a stronger enforcement program may be needed." It could be argued that, at least in regards to agricultural conservation, our analysis leads to an opposite conclusion. Even when full compliance by the agricultural sector is assumed, the resulting reduction in overdraft is not very large. In addition to economic incentives to conserve water, technical assistance is available to farmers through the University and Government extension services. If enforcing the water duties turns out to be a costly endeavor, ADWR may be well advised to make use of these positive incentives rather than punitive regulatory measures.

APPENDICES

APPENDIX I

CROP GROSS REVENUE AND PRODUCTION COST PROJECTIONS

I. Overview

This appendix is a supplement to chapter 4, which delves into the details of how crop gross revenues and production costs are projected. The projections for upland cotton are found in chapter 4. Alfalfa, Pima cotton, and wheat are considered here. For convenience, tables 4.1 and 4.2 are reproduced in this appendix.

II. Scenarios For Alfalfa, Pima Cotton, And Wheat

Alfalfa

Of all the crops to be used in the LP model, alfalfa shows the most definite long run upward trend in gross revenue per acre planted (see figure A1.1). Gross revenue data from 1950-1956, not shown on fig. A1.1, strengthens the overall upward trend. Agricultural experts indicate that this increase in gross revenue per acre has been fueled by the demand for alfalfa from the regional dairy industry [Wade, Ayer 1990].

Over the last 12 years, alfalfa revenues have been relatively trendless, so a slowly-increasing projection is utilized. For the high-profit alfalfa scenario, an AR(1) model is selected. For the low-profit case, the mean from 1984-1988 is utilized. The absolute change from 1990 to 2025

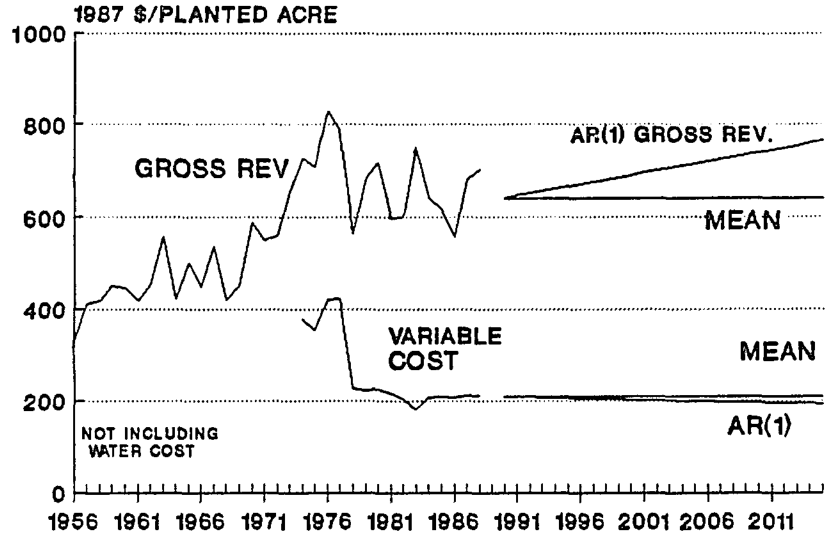


FIGURE A1.1
ALFALFA REVENUE & COST PROJECTIONS

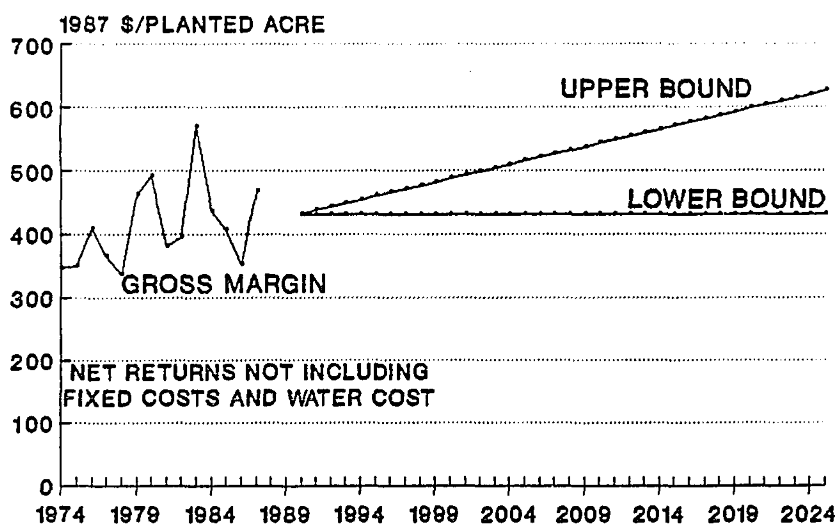


FIGURE A1.2
ALFALFA GROSS MARGIN PROJECTIONS

in the high revenue case is an increase of $172 per planted acre. Table A1.1 illustrates the criteria which goes into selection of the gross revenue projections, and includes the relevant data for alfalfa.

Cost data for alfalfa, as shown in figure A1.1, is downward tending from 1974-1988, although much flatter after 1977. This stability led to the use of 1978-1988 data to obtain the AR(1) projection. Table A1.2 compares projected changes in cost with the yardstick, which is described in chapter four. In the case of alfalfa and wheat, the yardstick is calculated based on data from 1978 to 1988.

The AR(1) projection of alfalfa cost projects a decline of 11% for Alfalfa between 1990 to 2025 (see fig. A1.1). Projections of gross margin for Alfalfa, as with all crops, are generated by subtracting cost projections from gross revenue projections. Lower and Upper bounds for Alfalfa gross margin are shown in figure A1.2. Note that the lower bound case is identical to the mean case.

Pima Cotton

Both Pima and Upland Cotton have shown decidedly downward trends in gross revenue, albeit with a high degree of year to year variability. The upper bound for Pima cotton gross revenue is given by mean gross revenue from 1984-1988. The

TABLE A1.1
SUMMARY OF GROSS REVENUE PROJECTIONS

GROSS REVENUE/ACRE, IN 1987 DOLLARS						
CROP	PARAMETER		GROSS REVENUE	ABSOLUTE CHANGE	MODEL	ADJUSTED R-SQUARE
	DATA:	1948-52 MEAN:	1289	-428		
UPLAND ^^ COTTON		1984-88 MEAN:	861			
		1990 VALUE:	1074	-498	AR(1)	0.4291
	PROJECTION:	2025 VALUE:	576			
	DATA:	1948-52 MEAN:	1324	-281		
PIMA COTTON		1984-88 MEAN:	1043			
		1990 VALUE:	1043	-239	AR(1)	0.2209
	PROJECTION:	2025 VALUE:	804			
	DATA:	1948-52 MEAN:	307	334		
		1984-88 MEAN:	641			
ALFALFA						
		1990 VALUE:	641	173	AR(1)	0.6984
	PROJECTION:	2025 VALUE:	814			
	DATA:	1948-52 MEAN:	219	124		
		1984-88 MEAN:	343			
WHEAT^^						
		1990 VALUE:	386	140	LINEAR	0.6875
	PROJECTION:	2025 VALUE:	526			

SOURCE: BLOYD et. al., 1965-1989

^^ data shown does not include subsidy payments, but projections take subsidies into account.

TABLE A1.2
SUMMARY OF VARIABLE PRODUCTION COST PROJECTIONS

VARIABLE COST/ACRE, IN 1987 DOLLARS

CROP	PARAMETER		VARIABLE COST	YARDSTICK, PROJECTED CHANGE		MODEL	ADJUSTED R-SQUARE
	DATA:	1974-78 MEAN:	548	YARDSTICK:	-319		
UPLAND COTTON		1984-88 MEAN:	423				
		1990 VALUE:	423	PROJECTED:	-198	AR(1)	0.7916
	PROJECTION:	2025 VALUE:	225	CHANGE:			
	DATA:	1975-79 MEAN:	531	YARDSTICK:	-270		
PIMA ^ COTTON		1984-88 MEAN:	438				
		1990 VALUE:	438	PROJECTED:	-137	AR(1)	0.6336
	PROJECTION:	2025 VALUE:	301	CHANGE:			
	DATA:	1978-82 MEAN:	220	YARDSTICK:	-57		
		1984-88 MEAN:	210				
ALFALFA^^							
		1990 VALUE:	210	PROJECTED:	-22	AR(1)	0.0965
	PROJECTION:	2025 VALUE:	188	CHANGE:			
	DATA:	1978-82 MEAN:	165	YARDSTICK:	-86		
		1984-88 MEAN:	148				
WHEAT^^							
		1990 VALUE:	148	PROJECTED:	-55	AR(1)	0.205
	PROJECTION:	2025 VALUE:	93	CHANGE:			

SOURCE: BLOYD et. al., 1965-1989

^^ wheat and alfalfa yardsticks are calculated based on '78-'82 mean.
^ pima cotton data only available beginning in 1975

lower bound is an AR(1) fit of data from 1950 to 1988, and forecasts a decline in gross revenue of $221 per acre between 1990 and 2025. Table A1.1 and figure A1.3, summarize.

Pima cotton production cost has declined significantly over the past 14 years (Pima cotton was not included in the 1974 crop budgets, thus the fewer data points). The lower bound projection of Pima cost forecasts a decrease of $137 per acre. Pima cost projections are summarized in table A1.2 and figure A1.3.

The combination of Pima cotton cost and gross revenue projections leads to the gross margin scenarios pictured in figure A1.4. Note that in spite of the fact gross revenues are at best projected to hold steady, profit increases substantially in the upper bound scenario due to declines in real production cost.

Wheat

Data for Wheat gross revenue and cost exhibit similar trends as those displayed by alfalfa. Likewise, projections of wheat gross margin appear similar to alfalfa gross margin. As with upland cotton, wheat subsidy data only strengthened the general trend of gross revenues per acre seen in non-subsidized revenues. Likewise, the slope of the upper bound scenario for wheat comes from analysis of gross revenue data

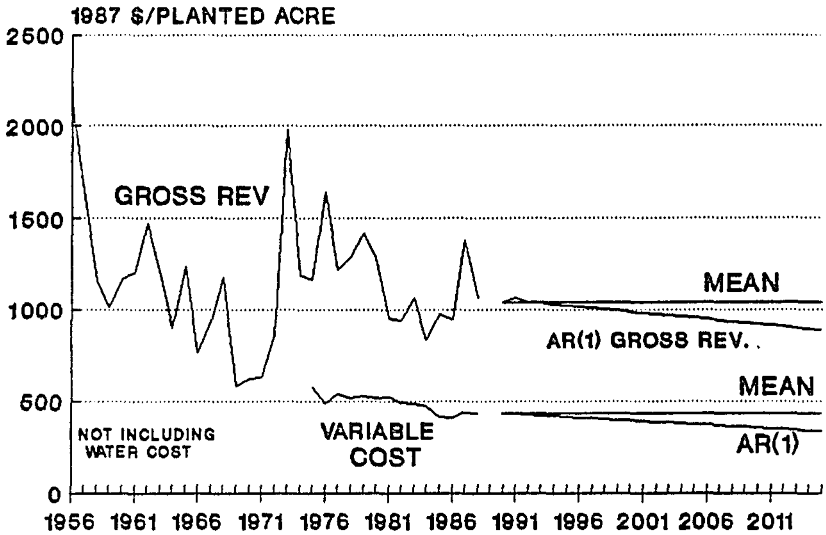


FIGURE A1.3
PIMA COTTON REVENUE & COST PROJECTIONS

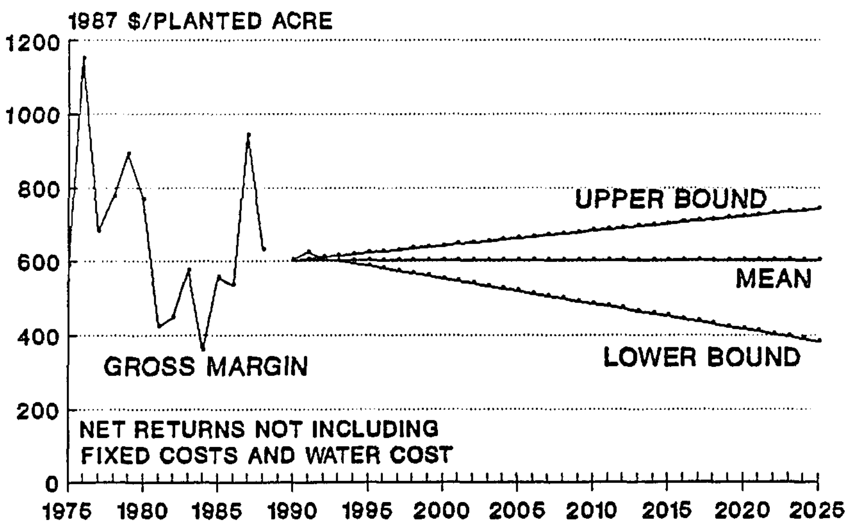


FIGURE A1.4
PIMA COTTON GROSS MARGIN PROJECTIONS

not including subsidies. The 1990 value equals the 1984-1988 mean value of wheat gross revenues including subsidies. A linear model is used to forecast high gross revenue, as summarized in table A1.1 and figure A1.5. The optimistic scenario projects per acre gross revenues to increase by $150 over the next 35 years.

Like alfalfa, the variable cost of producing wheat became relatively stable after 1977. Projections are made based on analysis of cost data from 1978-1988. Accordingly, the yardstick is calculated from the '78-'88 data. The lower bound for wheat cost is given by an AR(1), and projects a decrease in per acre production cost of $55 over the next 35 years. The net result for wheat is a strong upward trend in the high-gross margin case, and a flat trend for the pessimistic scenario. Table A1.2 and figures A1.5-A1.6 summarize.

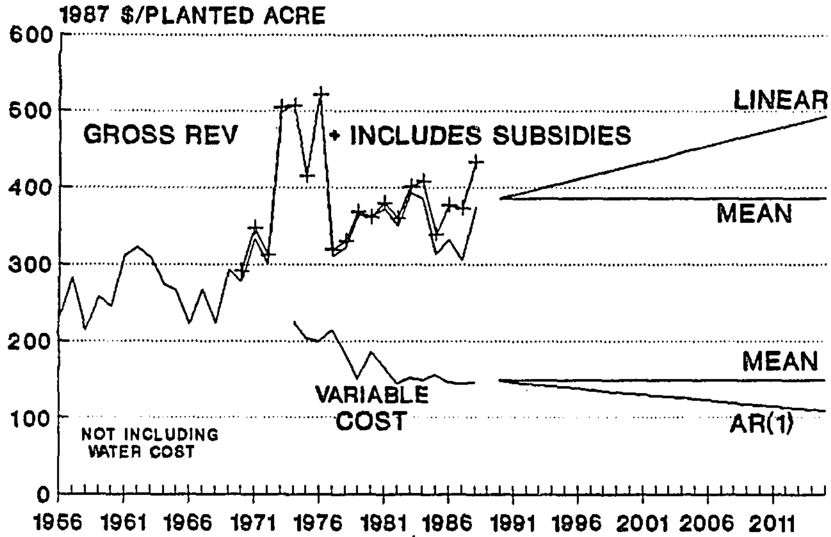


FIGURE A1.5
WHEAT REVENUE & COST PROJECTIONS

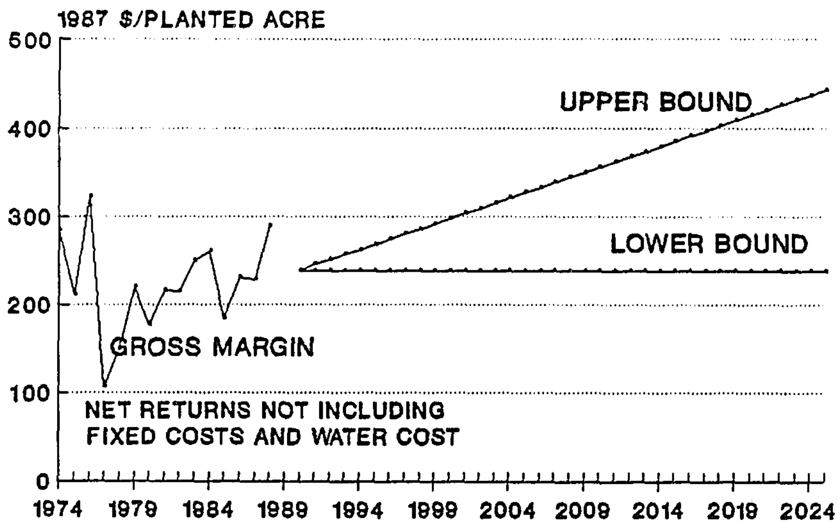


FIGURE A1.6
WHEAT GROSS MARGIN PROJECTIONS

APPENDIX II

WATER SUPPLY BY ASFC

As documented in chapter two, Areas of Similar Farming Condition (ASFCs) are stratified largely on the basis of water supply. Seven of the twelve ASFCs are centered geographically around, and named after, irrigation districts. This appendix contains projections of the variable water cost and available quantities of each source of water used to model each ASFC. Documentation of the techniques used to generate the projections is in chapter five.

ASFC 1: Tonopah

ASFC #1 is located in the Tonopah Irrigation District which is in the western part of the AMA. The ASFC contains approximately 8,700 acres of farmland. The Tonopah ID was created for the purpose of receiving Central Arizona Project (CAP) water, and the district has contracted to receive 1.98% of CAP water allocated to non-Indian agriculture. CAP allocations by ASFC are found in chapter five, table 5.3. Other than CAP, water in ASFC 1 comes from privately owned wells.

Approximately 3450 of the 8700 acres in the ASFC have the infrastructure needed to receive CAP water. Conversations with Tonopah Irrigation District personnel indicate that even these farms are reluctant to take CAP water because pump water is considerably cheaper [Story 1990]. Groundwater, which is supplied by privately owned wells, is relatively cheap in this area because the district has an energy contract with Hoover Dam (ED7). Average energy rates for pumpers are $.0475/kwh in 1990 (real 1987 $). Figure A1.1 shows how energy cost projections vary among the ASFCs. It is assumed that energy costs in each ASFC will be a constant proportion of projected SRP rates. The proportion used is based on 1988 to 1990 energy data collected directly from irrigation districts or from Hathorn, Wade et al. Projected groundwater costs in ASFC 1 are cheaper than projected CAP costs for the entire planning horizon, as shown by figure A2.2.

It is assumed that the Tonopah ID will be successful in marketing its CAP allocation, and thus will rely on groundwater only. This assumption will maximize the impacts of conservation policy, and is reasonable given the projected water costs and the fact that less than half of the farms are set up to receive CAP water.

ASFC 2: Hassayampa

The Hassayampa ASFC is in the extreme western part of the Phoenix AMA. Approximately 17,000 acres of farmland hold irrigation grandfathered rights. It is assumed that the

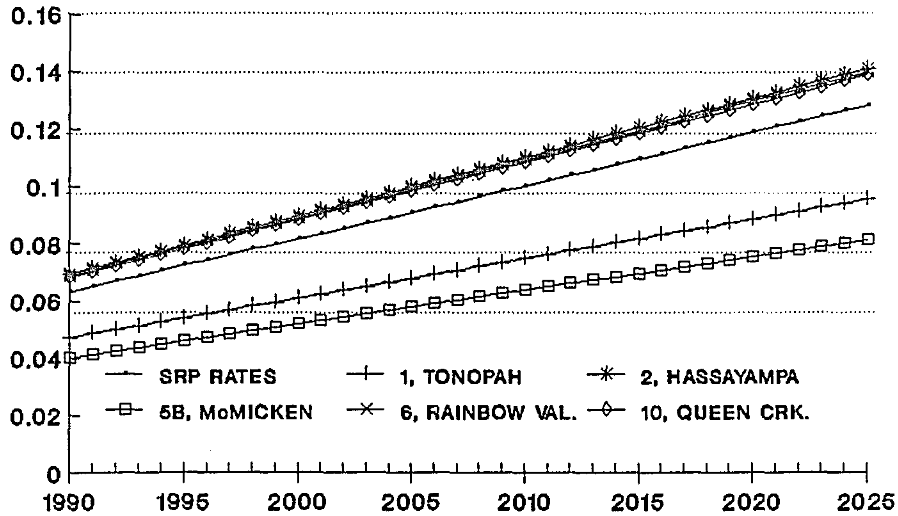


FIGURE A2.1
ENERGY COST PROJECTIONS BY ASFC
(1987 $\kwh, incl. sales tax)

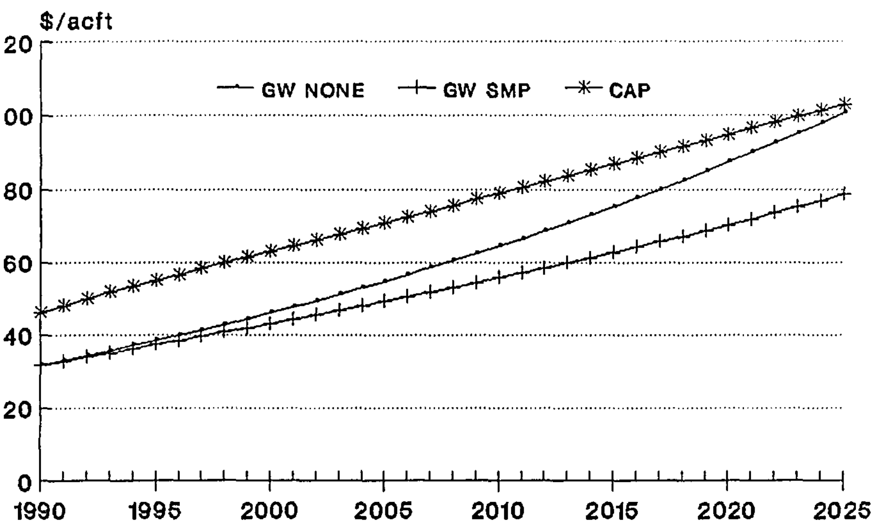


FIGURE A2.2
ASFC 1: WATER COST PROJECTIONS
(Variable cost, 1987 $)

typical farm in this area supplies its own groundwater. Projections of groundwater costs for ASFC 2 are shown in figure A2.3.

ASFC 3: Roosevelt Irrigation District

ASFC consists primarily of lands belonging to the Roosevelt Irrigation District (RID). About 30,000 acres are currently eligible for farming. It is assumed that the representative farm receives its water from RID. Projections of RID water costs are shown in figure A2.4, and are generated by the methods described in chapter five, in the section titled 'other irrigation districts'.

ADWR only requires ASFC 3 to reach a 1999 irrigation efficiency of 70%. This is in contrast to the typical AMA target efficiency of 85%. Water duties are more lenient in ASFC 3 because much of the area has relatively steep terrain, and therefore leveling farmland will be comparatively expensive for farms in the area.

ASFC 4: Buckeye

Due to rising water tables (water logging), farms in this area are not restricted in their water use by a water duty. ASFC 4 farms currently pay a withdrawal fee which is one quarter of that paid by others in the AMA. For these reasons,

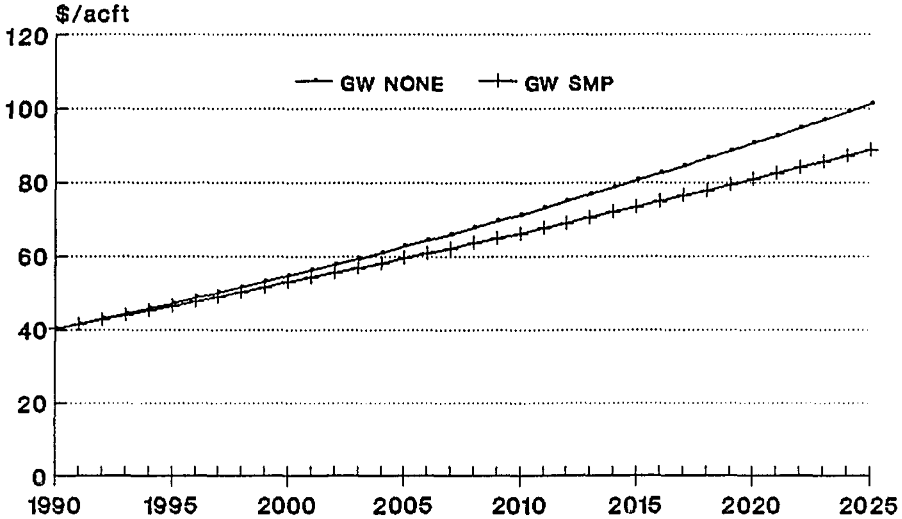


FIGURE A2.3
ASFC 2: WATER COST PROJECTIONS
(Variable cost, 1987 $)

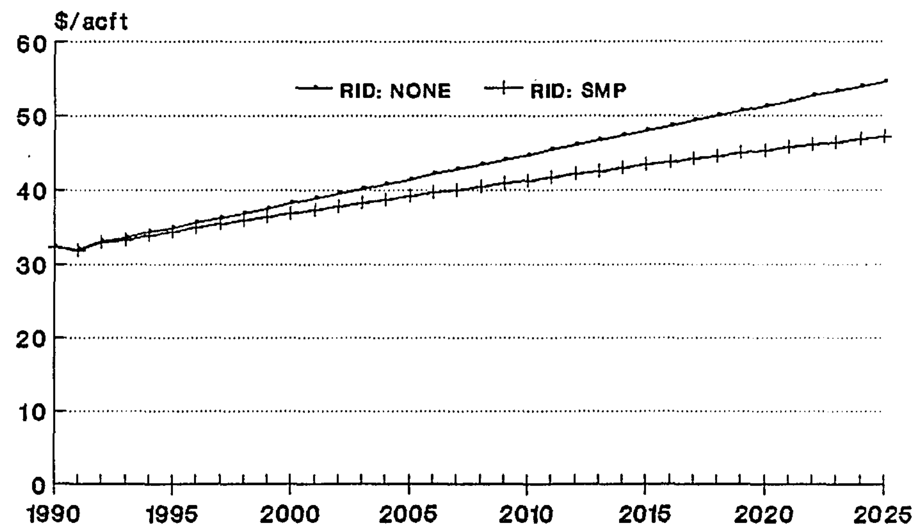


FIGURE A2.4
ASFC 3: WATER COST PROJECTIONS
(Variable cost, 1987 $)

it is assumed that this ASFC will not be significantly effected by the GMA, and policy impacts in this area are estimated to be near zero. No simulations of this area are done.

ASFC 5: McMicken

It is convenient to divide ASFC 5 into two distinct groupings. ASFC 5A is defined to be those farms which receive their water from the Maricopa County Water Conservation District #1 (MCWCD). Currently, MCWCD provides water to about 32,000 acres of farmland [MCWCD 1990]. Water diverted from the Agua Fria river is supplemented by district pumps. In a typical year, 33% of water delivered for irrigation is groundwater [MCWCD 1990]. Projections of the variable cost of water for MCWCD farms are shown in figure A2.5.

ASFC 5B is defined to be those farms which belong to the McMicken Irrigation District. This district was organized in 1964 for the purpose of distributing any available CAP water, although currently no CAP contract has been signed. Approximately 25,000 acres of farmland fall belong to McMicken ID, all of which rely on self-pumped groundwater. Energy is purchased from Electrical District Seven (ED7) at relatively low rates. The 1990 energy rate for irrigators is $.040/kwh [Justice 1990] (real 1987 $). Projections of water costs in

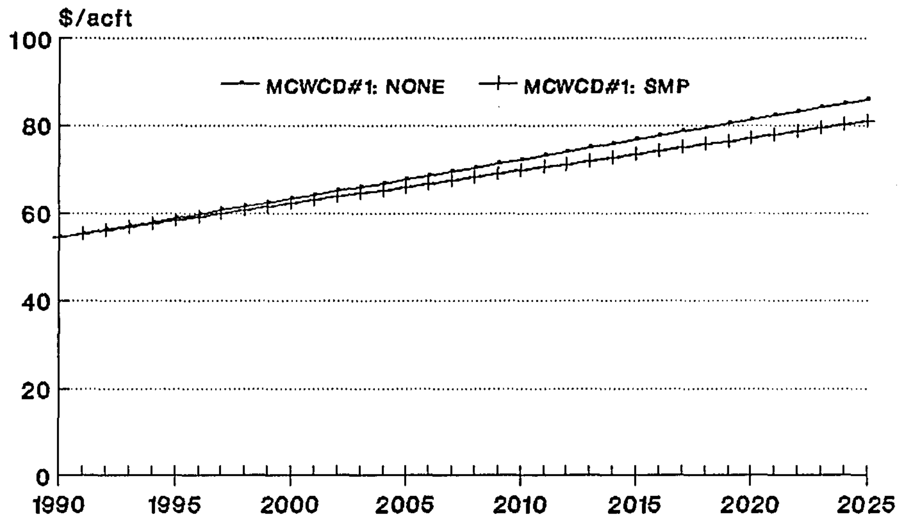


FIGURE A2.5
ASFC 5A: MCMWCD WATER COST PROJECTIONS
(Variable cost, 1987 $)

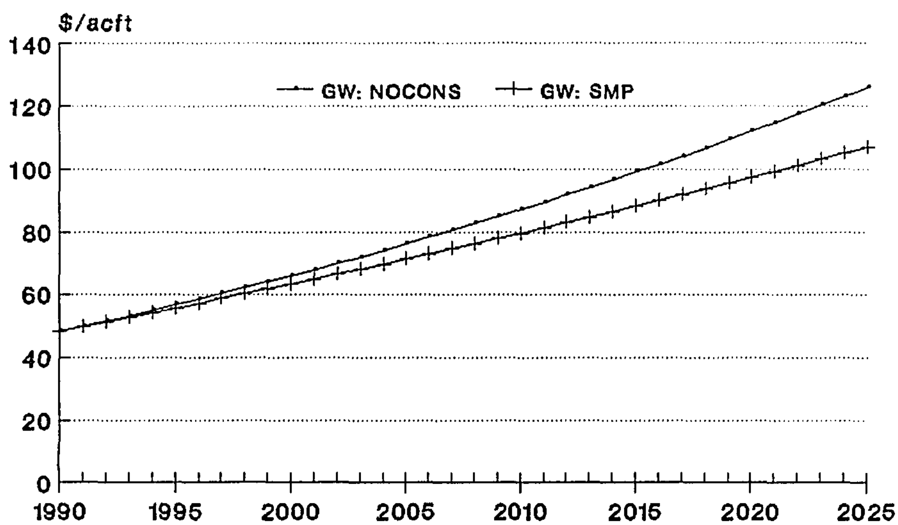


FIGURE A2.6
ASFC 5B: McMICKEN WATER COST PROJECTIONS
(Variable cost, 1987 $)

the McMicken area are shown in figure A2.6.

ASFC 6: Rainbow Valley

This area is also commonly referred to as the Waterman Wash region of the AMA. About 14,000 acres of farmland are currently eligible for irrigation. All farms in this area rely on self-pumped groundwater. Projections of water cost for ASFC 6 are found in figure A2.7.

ASFC 7: North Scottsdale

Approximately 100 small farms make up this ASFC, which totals only 1500 acres of farmland. Due to the insignificant amount of farmland in ASFC 7, and the likelihood of urbanization in this area, it is not included in the analysis.

ASFC 8: Salt River Project

The Salt River Project covers most of the central and southern parts of the Phoenix area. Over 80,000 acres of farmland are currently eligible for irrigation, but urbanization will likely cut this number by half by 2025 [Stapleton 1989]. SRP water costs are documented in chapter five.

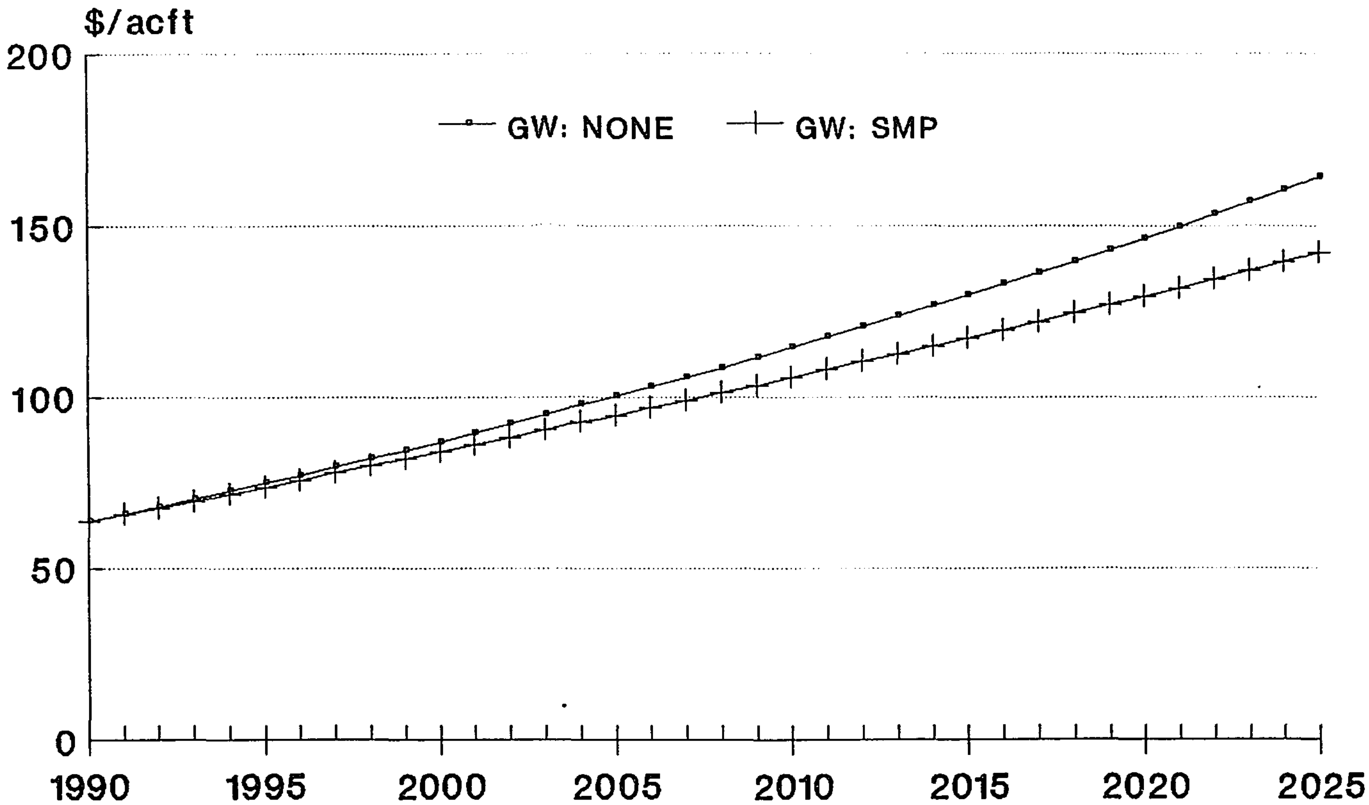


FIGURE A2.7
ASFC 6: WATER COST PROJECTIONS
(Variable cost, 1987 $)

ASFC 9: Roosevelt Water Conservation District

Water supplied by the Roosevelt Water Conservation District (RWCD) comes from three sources; CAP, the Salt River, and district pumps. Water from the three sources is commingled and delivered at a single price, which is roughly calculated as a weighted average of the three [Leonard, 1990]. RWCD is entitled to Salt River water equal in amount to 5.6% of the total agricultural use diversion at Granite Reef Dam.

For the LP model, the three sources of water are treated as separable supplies. In essence, this allows the model to calculate the weighted average water cost. In the base case scenario, the model is constrained to use all available CAP water before using any groundwater. Salt River water will always be used to its full extent due to its very low cost. The projections of variable water cost for the three sources are shown on figure A2.8.

According to Leonard [1990], water from SRP accounts for about 10% of RWCD's total annual supply in the typical year. This proportion is expected to remain steady, or to go down, depending on future settlements of Indian claims against Salt River water. Half an acre foot of Salt River water per acre is projected to be available throughout the planning horizon.

CAP water is assumed to be available in the quantities listed on table A2.1. Total quantities of CAP water are

TABLE A2.1
ASFC 9: RWCD WATER SUPPLY

YEAR	TOTAL CAP	ACTIVE ACRES	CAP/acre	SRP/acre
1990	67,137	20,115	3.34	0.50
1991	63,328	19,839	3.19	0.50
1992	63,645	19,563	3.25	0.50
1993	57,324	19,287	2.97	0.50
1994	54,376	19,010	2.86	0.50
1995	54,322	18,734	2.90	0.50
1996	51,069	18,728	2.73	0.50
1997	48,761	18,722	2.60	0.50
1998	44,521	18,716	2.38	0.50
1999	44,928	18,709	2.40	0.50
2000	43,152	18,703	2.31	0.50
2001	43,630	18,276	2.39	0.50
2002	38,792	17,850	2.17	0.50
2003	34,702	17,423	1.99	0.50
2004	31,939	16,996	1.88	0.50
2005	31,676	16,569	1.91	0.50
2006	33,954	16,180	2.10	0.50
2007	29,733	15,792	1.88	0.50
2008	26,695	15,403	1.73	0.50
2009	28,112	15,014	1.87	0.50
2010	28,949	14,625	1.98	0.50
2011	30,360	13,946	2.18	0.50
2012	29,493	13,268	2.22	0.50
2013	29,320	12,589	2.33	0.50
2014	25,283	11,911	2.12	0.50
2015	26,778	11,232	2.38	0.50
2016	29,649	11,104	2.67	0.50
2017	25,469	10,976	2.32	0.50
2018	26,270	10,848	2.42	0.50
2019	23,274	10,720	2.17	0.50
2020	23,818	10,592	2.25	0.50
2021	27,060	9,684	2.79	0.50
2022	24,309	8,776	2.77	0.50
2023	23,812	7,869	3.03	0.50
2024	22,293	6,961	3.20	0.50
2025	22,963	6,053	3.79	0.50

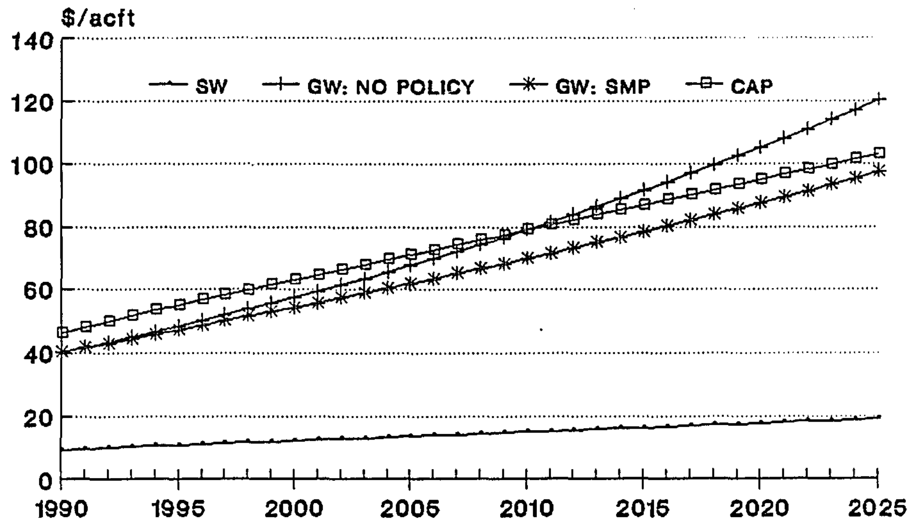


FIGURE A2.8
ASFC 9: WATER COST PROJECTIONS
(Variable cost, 1987 $)

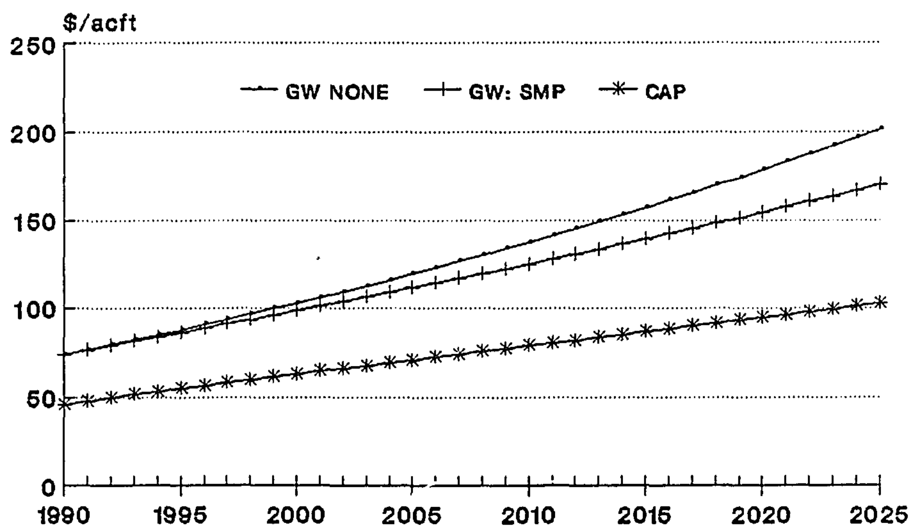


FIGURE A2.9
ASFC 10: WATER COST PROJECTIONS
(Variable cost, 1987 $)

converted to per acre amounts by dividing by the total number of acres projected to be in production over the planninghorizon. The number of acres in production is calculated as the product of total number of acres available for planting times an average rate of land use. A use rate of .77 is used, which is based on DWR data which shows that .77 of RWCDs total water allotments were utilized between 1984 and 1988 [ADWR ROGR database]. The number of acres available for planting is taken from DWR's land conversion model [Stapleton 1989], which is discussed in chapter seven, and appendix III.

The water supply function for ASFC 9 is in reality very complicated, and obviously the way it is modeled here is somewhat of a gross simplification. However, the two scenarios are designed so they will likely encapsulate the impacts of the GMA on irrigators in this area.

ASFC 10: Queen Creek

ASFC 10 includes four major irrigation districts: Queen Creek, New Magma, San Tan, and Chandler Heights. Over 50,000 acres of farmland are currently eligible for irrigation. The area is located in the extreme eastern part of the AMA. As shown on table A2.2, 5.98% of CAP non-Indian agricultural water is destined for this ASFC.

The variable cost of CAP water is projected to be less than the cost of pump water in this area. Therefore no special constraints are needed to force the model to use CAP water. Any more water beyond that supplied by CAP is assumed to come from farmer owned wells. CAP water availability per acre is determined in the same manner as that used for RWCD. Table A2.2 shows the amount of CAP projected to be available per acre in ASFC 10. Figure A2.9 shows projected water costs in ASFC 10.

TABLE A2.2
ASFC 10, QUEEN CREEK: WATER SUPPLY

YEAR	CAP DELIVERED	ACTIVE ACRES	CAP/ACRE
1990	114,740	26901	4.27
1991	108,230	26807	4.04
1992	108,771	26714	4.07
1993	97,969	26620	3.68
1994	92,930	26527	3.50
1995	92,838	26433	3.51
1996	87,279	26433	3.30
1997	83,334	26433	3.15
1998	76,088	26433	2.88
1999	76,783	26433	2.90
2000	73,748	26433	2.79
2001	74,565	26433	2.82
2002	66,297	26433	2.51
2003	59,307	26433	2.24
2004	54,585	26433	2.07
2005	54,135	26433	2.05
2006	58,029	26433	2.20
2007	50,814	26433	1.92
2008	45,622	26433	1.73
2009	48,044	26433	1.82
2010	49,475	26433	1.87
2011	51,887	26286	1.97
2012	50,405	26138	1.93
2013	50,109	25990	1.93
2014	43,210	25842	1.67
2015	45,765	25694	1.78
2016	50,671	25055	2.02
2017	43,527	24416	1.78
2018	44,896	23777	1.89
2019	39,776	23139	1.72
2020	40,706	22500	1.81
2021	46,246	21764	2.12
2022	41,544	21029	1.98
2023	40,696	20293	2.01
2024	38,100	19558	1.95
2025	39,245	18822	2.09

APPENDIX III

THE LAND CONVERSION MODEL

Since 1960, Phoenix has been one of the fastest growing metropolitan areas in the country. Current population forecasts predict that it will continue to grow at a fast rate, doubling in population before 2025. Much of this urban expansion will displace farmland. The Arizona Department of Water Resources has projected the location and quantity of farmland which will be displaced by urbanization in the AMA. The Salt River Project (SRP) has a similar land conversion model for areas within its boundaries. In this appendix the two models are discussed.

The ADWR Land Conversion Model

The ADWR land conversion model begins with a digitized map of the AMA showing the location of Irrigation Grandfathered Rights (IGFRs). Maps which show projected population densities in the AMA are laid over the map of IGFRs. It is assumed that when the future population density becomes greater than 3.0 persons per acre, a parcel of land has made the transition from agricultural to urban use. The choice of 3.0 persons per acre as the cutoff density was made by ADWR on the basis of empirical data.

The projections of population density used by ADWR were made by the Mountain West Co. for the Maricopa Association of Governments [MAG 1987]. The MAG model allocates projected populations to county lands, based on analysis of existing and planned transportation infrastructure. The smallest unit of land considered in the MAG projections is the Traffic Analysis Zone (TAZ). The typical TAZ is about one square mile (640 acres) in area. The population projection used in the MAG study forecasts extremely fast growth; Maricopa County is expected to number 5,312,300 in 2025, which is 2.3 times the 1990 population.

One of the weaknesses of the ADWR land conversion model is that 'lumpy' changes in land use will be predicted. A population density of 3.0 persons per acre in a TAZ will not in reality mean that all land in the TAZ is urban. An example of this weakness is found in the land conversion model's prediction of agricultural land in the Tonopah ASFC. The ADWR model projects that 2,287 acres of IGFRs will be in this ASFC in 1990. Actually, approximately 8,500 acres of agricultural land are currently active in the Tonopah ASFC [ADWR ROGR database]. (This is an extreme example. In general the land conversion model is within 10% of the true number of 1990 IGFR acres).

This problem with ADWR's land conversion model is adjusted for in the following way:

1) The ratio of actual duty acres in each ASFC in 1989 over the land conversion model's projection of 1990 acreage is calculated;

2) The land conversion model's acreage projections for each year are multiplied by the ratio calculated above. This becomes the estimated water duty acres in the ASFC.

In essence, if the conversion model projects 10% of an ASFC's farmland to be urbanized over a certain period, the water duty acres are reduced by this same 10%.

The results of the ADWR land conversion model are tabulated in table A3.1. Only the ASFCs analyzed in this study are included, so the aggregate numbers understate the true AMA total acreage. The total acreage in the areas considered is projected to reduce by approximately half, from 272,907 in 1990 to 133,525 in 2025. The land conversion model projects AMA acreage at 5 year intervals. Linear interpolation is used to generate data for other years.

Accommodating Different Population Projections

The Arizona Department of Economic Security (ADES) has made a projection of population which forecasts significantly slower growth in Maricopa County than the MAG projection. ADES

TABLE A3.1
LAND CONVERSION BASED ON MAG POPULATION PROJECTIONS

{Water Duty Acres}

YEAR	ASFC 1	ASFC 2	ASFC 3	ASFC 5A	ASFC 5B
1990	8,339	15,292	29,354	24,282	18,794
1995	8,339	15,253	25,350	21,879	16,934
2000	8,339	15,253	24,428	20,960	16,223
2005	8,339	15,253	24,428	20,312	15,722
2010	8,339	15,236	20,035	18,774	14,531
2015	8,339	15,234	17,911	16,163	12,510
2020	8,339	15,230	17,911	15,313	11,852
2025	0	13,708	17,911	12,536	9,703
CHANGE:	8,339	1,584	11,443	11,746	9,091
YEAR	ASFC 6	ASFC 8	ASFC 9	ASFC 10	TOTAL
1990	14,183	84,600	26,964	51,099	272,907
1995	14,183	64,107	25,113	50,211	241,369
2000	14,183	57,445	25,071	50,211	232,112
2005	13,812	50,104	22,211	50,211	220,392
2010	13,812	45,060	19,605	50,211	205,603
2015	13,554	37,839	15,056	48,807	185,413
2020	13,554	30,368	14,199	42,739	169,504
2025	13,258	28,399	8,114	35,754	139,382
CHANGE:	925	56,201	18,850	15,345	133,525

source: ADWR Land Conversion Model [Stapleton 1989]
(calibrated to 1989 duty acres, ADWR ROGR database)

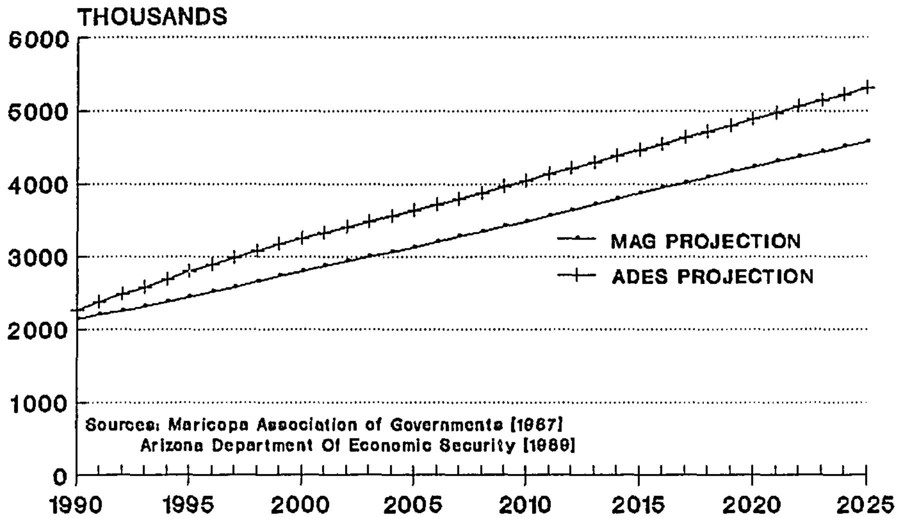
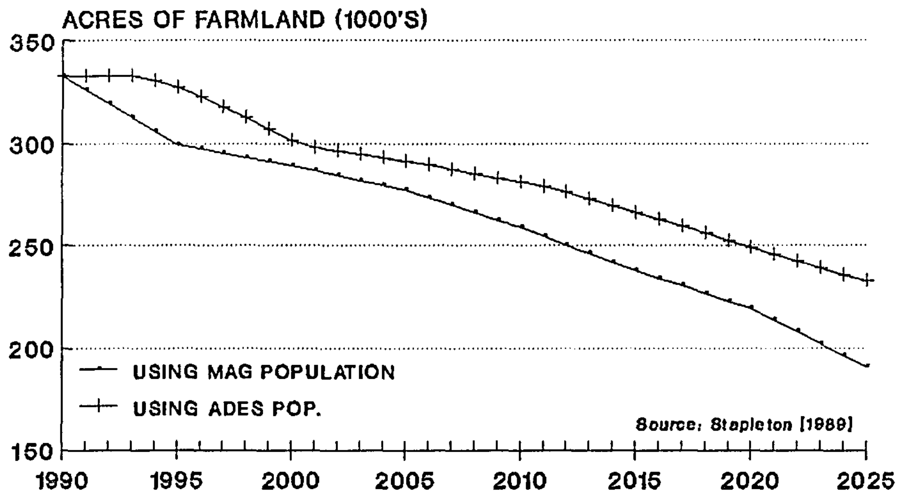


FIGURE A3.1
TWO PROJECTIONS OF POPULATION:
MARICOPA COUNTY



ASFCs 1, 2, 3, 5, 6, 8, 9, 10

FIGURE A3.2
PROJECTED AG. LAND, PHOENIX AMA
(acres available for planting)

predicts population in 2025 to be 14% less than MAG (figure A3.1). It is assumed that population growth will be allocated spatially in the order defined by the ADWR conversion model, regardless of when the growth occurs. This assumption allows alternative projections of population to be incorporated into ADWR's model relatively easily, in the following four steps:

1) A regression of YEAR on Population is estimated, using Ordinary Least Squares methods:

$$T_t = b + b\,P_t + e_t \qquad \text{(A3.1)}$$

where:

T_t = year, from 1990 to 2025.
P_t = MAG population projection for year t.
e_t = the error term.

The Year data used to estimate equation A3.1 is 1990-2025, and Population data is taken from the MAG projections;

2) Population data from the ADES projection is inserted into variable P_t in the estimated equation (A3.1) to generate an estimate of YEAR corresponding to ADES population data. The error terms, e_t, are subtracted from these estimates of Year to increase accuracy. This is the calculation of what year, in terms of MAG projections, is implied by ADES' population projections;

3) The result of step 2 is a data series such as this:

Year(actual)	Year(MAG)	Year(ADES) (from eq. A3.1)
1990	1990	1989.6
1991	1991	1990.4
:	:	:
2025	2025	2016.5;

4) Acreage data corresponding to the ADES population projections is then calculated in the following way. The numbers used are hypothetical:

REAL YEAR	MAG ACRES	ADES YEAR	CALCULATION OF ADES ACRES
1990	100	1988.6	= 1990_{mag} =100 acres
1991	95	1990.4	= 100-((100-95)*.4) = 98 acres
1992	90	1990.9	= 100-((100-95)*.9) = 95.5 acres
1993	85	1991.6	= 95-((95-90)*.6) = 92 acres
:	:	:	

This process may be easier to grasp from a graphical perspective. Figure A3.2 shows plots of AMA farmland which are projected using first MAG, and then ADES, population numbers. Essentially what has been done is to shift the MAG-generated acreage estimates horizontally to the right by the number of years which ADES population lags behind MAG population. Table A3.2 shows that the ADES population projections translate to 91,789 acres of land conversion, which is about 69% of the total conversion resulting when using MAG.

TABLE A3.2
LAND CONVERSION BASED ON ADES POPULATION PROJECTIONS

(Water Duty Acres)

YEAR	ASFC 1	ASFC 2	ASFC 3	ASFC 5A	ASFC 5B
1990	8,339	15,292	29,354	24,282	18,794
1995	8,339	15,286	28,713	23,897	18,496
2000	8,339	15,255	25,607	22,032	17,053
2005	8,339	15,253	24,620	21,151	16,371
2010	8,339	15,253	24,428	20,521	15,883
2015	8,339	15,243	21,818	19,398	15,014
2020	8,339	15,235	19,028	17,536	13,573
2025	8,339	15,233	17,911	15,934	12,333
TOTAL:	0	59	11,443	8,348	6,462

YEAR	ASFC 6	ASFC 8	ASFC 9	ASFC 10	TOTAL
1990	14,183	84,600	26,964	51,099	272,907
1995	14,183	81,321	26,668	50,957	267,861
2000	14,183	65,419	25,231	50,268	243,387
2005	14,183	58,830	25,080	50,211	234,038
2010	13,932	52,468	23,132	50,211	224,166
2015	13,812	47,108	20,663	50,211	211,607
2020	13,690	41,637	17,449	49,545	196,033
2025	13,554	35,822	14,825	47,168	181,118
TOTAL:	629	48,778	12,139	3,931	91,789

The SRP Land Conversion Model

The Salt River Project has developed a land conversion model which is somewhat more sophisticated than ADWR's. Given a projection of population for SRP lands, the SRP model allocates future development by 40 acre parcels. The allocation is based on a list of 'preference coefficients' which determine what land is most likely to be developed and for what type of use the land is best suited. These coefficients are given a directional ('+' or '-') value and a weight, as to the suitability of a parcel of land to a particular type of development.

One of the SRP model's assumptions is that, all other things equal, farmland will be urbanized faster than raw desert. For example, if a 40 acre parcel to be developed has 20 acres of farmland and 20 acres of desert, the farmland will be developed first.

Unfortunately, SRP does not have AMA boundaries such as sub-basins and ASFCs on their maps. However, approximate sub-basin boundaries were drawn on the SRP maps and the conversion numbers for three sub-basins were compared with ADWR's conversion estimates. After some fairly complicated calibration, it appears that ADWR's conversion figures are within about 10% of SRP's. In general, DWR projects a faster rate of urbanization than SRP between 1990 and 2000. Over the entire 1990 to 2025 planning horizon, the rates of conversion are close to equal.

APPENDIX IV

THE LP MODEL IN THE GAMS LANGUAGE

The following is an input file for one of the LP models as it is read into the General Algebraic Modeling System (GAMS) Programming Language. This particular model is the base case scenario for ASFC 8, the Salt River Project ASFC.

```
$TITLE A8ARL
$OFFUPPER

SETS
     T   TIME PERIODS    /1990*2025/

     J   CROPS     /UP, PM, ALF, WHT/

     I   IRRIGATION TECHNOLOGY  /ITA1,ITA2,ITA3/

     N   WATER SOURCE /SW, GW/

     TF(T)  FIRST TIME PERIOD

     P(T)  /1990*2025/;

TF(T) = YES$(ORD(T) EQ 1);


PARAMETERS

     G(T,J,I)      gross revenue per acre

     V(T,J,I)      variable cost per acre

     CF(T,J,I)     undiscounted crop net revenues per acre

     C(T,J,I)      discounted crop net revenues per acre

     WN(T)        farm historical consumptive water needs per
                     acre

     TE(T)         target water use efficiency
```

```
     A(T)            annual water allotment in year T

     DA(T)           farm water duty acres

     WC(T,N)         undiscounted water cost per acft, source n
                      in year t

     PT(T)           pump tax per acre foot in year t

     W(T,N)           discounted water cost in dollars per acre
                      foot

     RQ(I,J,T)     annual crop water consumption in acre-ft per
                     year

     R(I,J,T)        water requirement per acre planted, by ITA

     TMT1(T)         investment cost of lasered to slope system
                      in year t

     TMT2(T)         level basin investment cost in year t

     TMT3(T)         investment cost of ITA2 to ITA3

     T1(T)           discounted investment cost

     T2(T)          discounted investment cost of dead leveling

     T3(T)           discounted investment cost, ITA2 to ITA3

     D(T)            discount factor in year T;

SCALAR DELTA    discount rate    /1.03/;

D(T) = DELTA**(ORD(T)-1);

DA(T) = 153;

TE(T) = .621;

TE(T)$(ORD(T) GT 5) = .7355;

TE(T)$(ORD(T) GT 10) = .85;

WN(T) = 3.7;

A(T) = (WN(T)/TE(T))*DA(T);
```

```
DISPLAY A;

Table RQ(I,J,T)  annual crop water requirements in acre-ft per
                 year

      UP.1990*2025  PM.1990*2025  ALF.1990*2025  WHT.1990*2025
ITA1*ITA3   3.76          4.10            4.69              2.15;


R('ITA1',J,T) = RQ('ITA1',J,T)/.60;

R('ITA2',J,T) = RQ('ITA2',J,T)/.65;

R('ITA3',J,T) = RQ('ITA3',J,T)/.75;


Table G       gross revenue per acre

           ALF.ITA1  PM.ITA1  UP.ITA1  WHT.ITA1
1990*2025   641.19  1042.67  1074.19   386.18 ;


G(T,J,'ITA2') = G(T,J,'ITA1')*1.0125;

G(T,J,'ITA3') = G(T,J,'ITA1')*1.025;


Table V        variable cost per acre

           ALF.ITA1  PM.ITA1  UP.ITA1  WHT.ITA1
1990*2025   210.14   438.22   423.34   148.02 ;


V(T,J,'ITA2') = V(T,J,'ITA1')+10;

V(T,J,'ITA3') = V(T,J,'ITA1')+10;

CF(T,J,I) = G(T,J,I)-V(T,J,I);

C(T,J,I) =CF(T,J,I)/D(T);
```

```
TABLE WC(T,N)

                      SW         GW
          1990      9.48      30.53
          1991      9.79      31.18
          1992     10.09      31.77
          1993     10.37      32.32
          1994     10.65      32.84
          1995     10.93      33.33
          1996     11.20      33.80
          1997     11.47      34.25
          1998     11.75      34.68
          1999     12.02      35.08
          2000     12.29      35.47
          2001     12.57      35.84
          2002     12.84      36.21
          2003     13.11      36.57
          2004     13.38      36.93
          2005     13.66      37.28
          2006     13.93      37.63
          2007     14.20      37.98
          2008     14.48      38.32
          2009     14.75      38.65
          2010     15.02      38.99
          2011     15.29      39.32
          2012     15.57      39.65
          2013     15.84      39.98
          2014     16.11      40.30
          2015     16.38      40.62
          2016     16.66      40.94
          2017     16.93      41.25
          2018     17.20      41.56
          2019     17.47      41.87
          2020     17.75      42.18
          2021     18.02      42.49
          2022     18.29      42.80
          2023     18.56      43.10
          2024     18.84      43.40
          2025     19.11      43.70 ;

PT(T) = 3;

PT(TF) = 1;
```

```
PT(T)$(ORD(T) GT 16) = 5;

DISPLAY PT;

W(T,'GW') = (WC(T,'GW')+PT(T))/D(T);

W(T,'SW') = WC(T,'SW')/D(T);

DISPLAY W;

TMT1(T) =  191.17 ;

TMT2(T) = 1192.01 +.1*G(T+1,'UP','ITA3')/D(T)
                       +.05*G(T+2,'UP','ITA3')/D(T);

TMT3(T) = 1192.01 +.1*G(T+1,'UP','ITA3')/D(T)
                       +.05*G(T+2,'UP','ITA3')/D(T);

T1(T) = TMT1(T)/D(T);

T2(T) = TMT2(T)/D(T);

T3(T) = TMT3(T)/D(T);

T2(T) = TMT2(T)/D(T);

T3(T) = TMT3(T)/D(T);

T2(T)$(CARD(T)-ORD(T) LT 3) = T2(T-2);

T3(T)$(CARD(T)-ORD(T) LT 3) = T3(T-2);


VARIABLES

     X(T,J,I)    crop activity in acres per year

     IR(T,N)     irrigation activity in acre-ft per year

     F(T)        flex account balance in year t

     I1(T)       investment in lasered to slope system

     I2(T)       investment in dead level system

     I3(T)       investment from ITA2 to ITA3

     S(T,I)       fallow land in year t on technology i
```

```
   Z            discounted net revenue;
 POSITIVE VARIABLES  X, IR, I1, I2, I3, S;

EQUATIONS
     OBJECTIVE       maximize discounted net revenue
     CROPUSE(T)      crop water requirements
     SURFACEW(T)     surface water availability
     FIRSTFLEX(T)    flex account in intital year
     FLEX(T)         flex account balance in year T
     ALLOTMENT(T)    annual allotment water use restriction
     FINALALLOT(T)    final year water use restriction
     ENDOWMENT1(T)   acreage of ITA1 in 1990
     ENDOWMENT2(T)   acreage of ITA2 in year 1990
     ENDOWMENT3(T)   laser leveled acreage in year 1990
     TRANSFER1(T)     transfer from ITA1 to ITA2
     TRANSFER2(T)     transfer from ITA1 to ITA3
     TRANSFER3(T)     transfer from ITA2 to ITA3
     INVEST(T)        limit on acres leveled per year
     WHEAT(T,I)         rotational requirement for wheat
     ALFALFA(T,I)        rotational requirement for alfalfa +
                           wheat
     TOTALACRES(T)   total farm acres available for planting;
```

```
OBJECTIVE .. Z =E= SUM(P, SUM((I,J), C(P,J,I)*X(P,J,I))-
                     SUM(N, W(P,N)*IR(P,N))
                       -I1(P)*T1(P)-I2(P)*T2(P)-I3(P)*T3(P));

CROPUSE(P) .. SUM((I,J), R(I,J,P)*X(P,J,I)) =L=
                                        SUM(N, IR(P,N));

SURFACEW(P) .. IR(P,'SW') =L= 3*DA(P);

FIRSTFLEX(P)$(ORD(P) LT 2) .. F(P) =E= A(P)/2;


FLEX(P)$(ORD(P) GT 1) .. F(P) =E= A(P-1)+F(P-1)-
                                   SUM(N, IR(P-1,N));

ALLOTMENT(P) .. A(P)/2+F(P) =G= 0;

FINALALLOT(P)$(ORD(P) EQ CARD(P)) .. SUM(N, IR(P,N)) =L=
                                            A(P)+A(P)/2+F(P);

ENDOWMENT1(TF) .. SUM(J, X(TF,J,'ITA1'))+S(TF,'ITA1') =L= 106;

ENDOWMENT2(TF) .. SUM(J, X(TF,J,'ITA2'))+S(TF,'ITA2') =L= 5;

ENDOWMENT3(TF) .. SUM(J, X(TF,J,'ITA3'))+S(TF,'ITA3') =L= 42;


TRANSFER1(P)$(ORD(P) GT 1) .. SUM(J, X(P,J,'ITA1')) +
  S(P,'ITA1') =L= SUM(J,X(P-1,J,'ITA1'))-
                     I1(P-1)-I2(P-1)+S(P-1,'ITA1');

TRANSFER2(P)$(ORD(P) GT 1) .. SUM(J, X(P,J,'ITA2')) +
         S(P,'ITA2') =L= SUM(J,X(P-1,J,'ITA2'))-
                     I3(P-1)+I1(P-1)+S(P-1,'ITA2');

TRANSFER3(P)$(ORD(P) GT 1) .. SUM(J, X(P,J,'ITA3')) +
                 S(P,'ITA3') =L= SUM(J,X(P-1,J,'ITA3'))+
                             I2(P-1)+I3(P-1)+S(P-1,'ITA3');

INVEST(P) .. .5*I1(P)+I2(P)+I3(P) =L= .25*DA(P);

WHEAT(P,I) .. X(P,'WHT',I)) =G= (X(P,'PM',I)+X(P,'UP',I))*.14;


ALFALFA(P,I) .. X(P,'ALF',I)+X(P,'WHT',I) =G=
                              (X(P,'PM',I)+X(P,'UP',I))*.54;
```

```
TOTALACRES(P) .. SUM((I,J), X(P,J,I)+S(P,I)) =L= DA(P);

MODEL SRP /OBJECTIVE, CROPUSE, SURFACEW, ENDOWMENT1,
           ENDOWMENT2, ENDOWMENT3, TRANSFER1, TRANSFER2,
           TRANSFER3, INVEST, FIRSTFLEX, FLEX, ALLOTMENT,
                  FINALALLOT, WHEAT, ALFALFA, TOTALACRES/;

OPTION ITERLIM = 2500;

SOLVE SRP USING LP MAXIMIZING Z;

PARAMETERS  NREV(T)  net revenue in year t
            PTAX(T)  pump tax payments in year t;

NREV(P) = SUM(I, SUM(J, C(P,J,I)*X.L(P,J,I)))-
                        SUM(N, W(P,N)*IR.L(P,N))-
            I1.L(P)*T1(P)-I2.L(P)*T2(P)-I3.L(P)*T3(P);

PTAX(P) = IR.L(P,'GW')*PT(P)/D(P);

DISPLAY X.L, I.L, IR.L, NREV, F.L, PTAX;
```

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