ECONOMIC AND HYDROLOGIC IMPACTS OF GROUNDWATER MANAGEMENT ALTERNATIVES FOR ARIZONA

James F. Booker

1994

Proceedings WWRC-94-14

In

Proceedings: Effects of Human-Induced Changes on Hydrologic Systems
American Water Resources Association
June 26-29, 1994
Jackson Hole, Wyoming

Submitted by

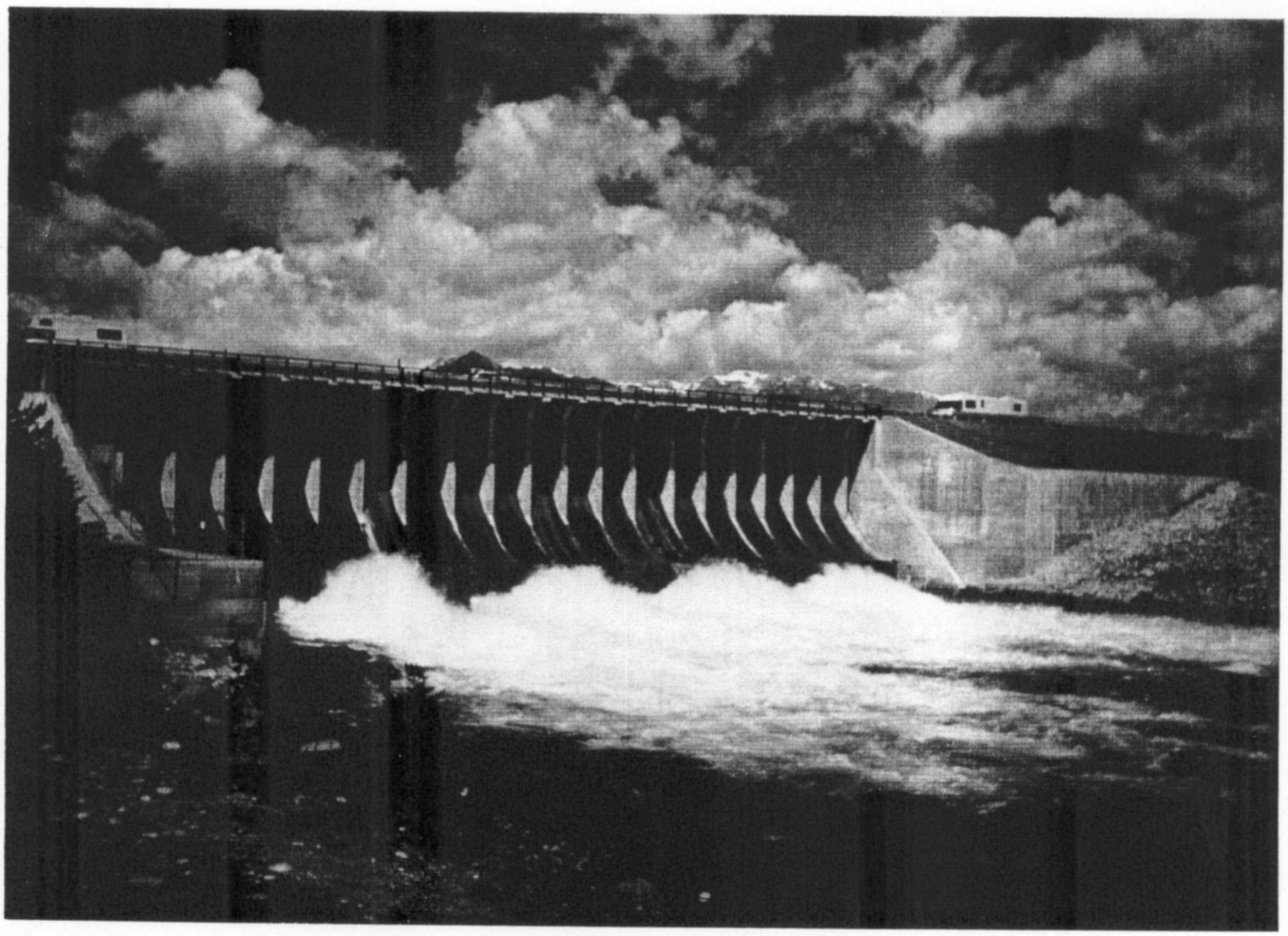
James F. Booker
College of Business
Alfred University
Alfred, New York

PROCEEDINGS

EFFECTS OF HUMAN-INDUCED CHANGES ON HYDROLOGIC SYSTEMS

AWRA 1994 ANNUAL SUMMER SYMPOSIUM
OF THE
AMERICAN WATER RESOURCES ASSOCIATION

AWRA



JUNE 26-29, 1994
JACKSON HOLE, WYOMING

ECONOMIC AND HYDROLOGIC IMPACTS OF GROUNDWATER MANAGEMENT ALTERNATIVES FOR ARIZONA

James F. Booker[1]

ABSTRACT: Non-sustainable groundwater withdrawals are relied upon in central Arizona to meet present agricultural and municipal water needs. While non-renewable groundwater may provide low cost, reliable supplies in the short-term, continuing groundwater depletion will impact both cost and availability of future supplies. Alternative policies (including approaches to use of the Central Arizona Project (CAP), a renewable but relatively costly surface water alternative) for preservation of groundwater stocks are considered. A quantitative approach is pursued through use of a hydrologic-economic model of Arizona surface and groundwater resources and water users. The model is run using a one-year time step for 50 years using present population growth projections for Arizona and typical hydrologic conditions.

Policies which reduce energy price subsidies (but do not include market transfers of water) were found to eliminate most groundwater overdraft after 50 years. Implementation of water use goals set under Arizona's 1980 Groundwater Management Act would be twice as costly while resulting in a greater depletion of groundwater stocks. CAP water can maintain agricultural acreage and income while minimizing groundwater depletion, but its use must be heavily subsidized by non-agricultural users.
KEY TERMS: groundwater; water use; Arizona; economic impacts.

INTRODUCTION

Arizona water resources support a population of 3.7 million and an irrigated agricultural community producing crops valued at over $1.0 billion annually (Arizona Agricultural Statistics Service, 1991). Population centers and agricultural production are highly concentrated in the most arid sections of the state and thus rely on surface water originating from remote sources and local groundwater. Surface water resources are not sufficient to satisfy existing uses, and groundwater is typically relied upon to provide 45% of total state water withdrawals (Eden and Wallace, 1992).

Non-renewable groundwater presently provides low cost, reliable supplies to central Arizona, but anticipated depletion of such stocks demands consideration of sustainable alternatives. These may include increased water use efficiency, outright reductions in consumptive use, or the development of alternative supplies. Such outcomes might be achieved through a variety of policy options, including the use of economic incentives for reducing water use, mandatory adoption of water efficient technologies, or development of new water supplies. In the case of central Arizona, the focus of this paper, one approach has been the development of an alternative supply, the Central Arizona Project (CAP), with the physical capacity to substitute Colorado River surface water for the existing groundwater overdraft. While the physical infrastructure to eliminate Arizona's non-sustainable

[1] Assistant Professor, College of Business, Alfred University, Alfred, NY 14802.

groundwater use is now in place, operation of the CAP may itself be economically non-sustainable. This is suggested by recent CAP usage which has fallen far short of conventional expectations, and the difficulty facing agricultural users in paying for previously contracted CAP supplies (Wilson, 1992). Indeed, the resultant excess capacity in the CAP is the most prominent water supply issue in Arizona today. While such "underuse" may seem surprising, it is easily explained (and was 20 years ago) by consideration of the low cost of pumping groundwater, and by the finite economic benefit of water in municipal, and particularly in agricultural uses.

This paper examines several water use alternatives for central Arizona which explicitly consider the economic incentives faced by water users. The focus is on identifying policies leading to preservation of groundwater stocks while minimizing costs to water users. A quantitative approach is pursued through use of a hydrologic-economic model of Arizona surface and groundwater resources and water users. The model is run using a one-year time step for 50 years using present population growth projections for Arizona and typical hydrologic conditions.

ARIZONA WATER BUDGET

Applying a modeling framework to evaluate policies for managing Arizona water resources required development of a consistent state water budget. In particular, estimates of diversions, consumptive use, groundwater recharge, and pumping depths and drawdown rates for each modeled region were required. The modeled regions, Phoenix, Pinal, and Tucson Active Management Areas (AMAs), West CAP, Colorado River Indian Tribes (CRIT), and Yuma were chosen, closely following the definitions used by Eden and Wallace (1992). Data for the AMA's were obtained largely from the respective Second Management Plans (AMA Plans, 1991a,b,c), modified by use of crop acreages reported by the 1987 U.S. Census of Agriculture (U.S. Bureau of the Census, 1988) and the Arizona Agricultural Statistics Service (1992). The West CAP water budget is derived directly from Eden and Wallace. CRIT and Yuma water budgets are consistent with U.S. Bureau of Reclamation (USBR) Colorado River Simulation System depletion data (USBR, 1991). In general, 1990 water use figures were used.

Arizona's water supply for Arizona includes not only local groundwater sources, but the substantial water resources of the Colorado River, the Salt-Verde system, and the Gila River system. Together, these surface water resources typically account for over half the state's water withdrawals, with groundwater satisfying the remainder. The water use estimates and aquifer characteristics developed for this study are summarized in Table 1.

BENEFITS AND COSTS OF CONSUMPTIVE USES

Water is consumptively used in irrigated agriculture, and for municipal and industrial purposes. Economic demand functions for agricultural and all other uses have been estimated for the six agricultural regions identified in Table 1. Residential demand is used as a proxy for all other demands. A non-agricultural sector is included only for Phoenix and Tucson AMAs, as non-agricultural uses are very small in the other regions.

TABLE 1. Arizona Water Budget.

Region	Diversions	Consumptive Use	Local Return Flows	Depth to Water		Drawdown Coefficient	Total Storage
				Average	Range		
	(kaf)	(kaf)		(feet)	(feet)	(feet/maf)	(maf)
West CAP	286	257	1	450	100	100	53
Phoenix ag	1426	856	0.91	263	150	4	180
Phoenix non-ag	852	690	0.91	263	150	8	51
Pinal	808	590	0.76	306	200	8	51
Tucson ag	113	86	0.74	262	100	16	78
Tucson non-ag	217	165	0.74	262	100	16	78
CRIT	685	384	0	-	-	-	-
Yuma	1053	885	0.5	95	50	~0	145

Estimation of Economic Demands

The agricultural derived demand estimates were derived from the farm-level programming results obtained by Peacock and Colby (1993). Two representative farms in the Yuma region were modeled, one with field crops only, and one with both field and vegetable crops. A third representative farm, growing mostly cotton, was included using the enterprise budget given in Wilson's 1992 assessment of CAP agriculture. Net benefit functions were derived from point estimates of benefits in each of the 3 models. This required an optimization model to maximize net benefits between water users (the 3 farm types). Estimated marginal values at existing use levels range from \$14/af (Colorado River Indian Tribe) to \$27 - \$30/af for irrigation districts in the central Arizona regions.

Municipal demand estimates utilize the observation that the proportion of outdoor to indoor uses varies across regions. The existing literature on summer and winter demand elasticities was used to derive demand functions for Phoenix and Tucson. The recent study by Griffin and Chang (1991) was used, with summer and winter elasticities of -0.41 and -0.30 taken from their generalized Cobb-Douglas estimate. Following Howe (1982) these are converted to indoor and outdoor elasticity estimates of -0.30 and -0.58. A similar procedure utilizing data on indoor and outdoor use in Phoenix and Tucson gives average annual elasticities of -0.43 and -0.39, respectively. These are similar to the range of average elasticities (-0.27 to -0.70) reported in several studies by Billings and Agthe (e.g. 1980) for Tucson, and Planning and Management Consultants (1986) for Phoenix, and the range reported in the numerous other studies on this topic. Municipal demand functions were then estimated using the average water prices and use levels for 1985 , then scaled to 1990 non-agricultural use levels (Phoenix and Tucson AMA Plans, 1991).

Pumping Costs

Variable conveyance costs for delivering water to its point of use are dominated by pumping costs. Such costs are incurred to raise groundwater to the surface, and to lift CAP water from the

Colorado River. Costs of pumping are in turn dominated by energy costs. The social cost of electric power (from a national accounting stance) is estimated at 46 mills/kwh, the estimated marginal cost of baseload electrical generation in the southwest (Booker and Young, 1991). Actual prices paid by groundwater pumpers, and the energy prices implicit in CAP water costs average approximately half this level (Wilson, 1992).

Groundwater pumping costs included in this study were energy costs plus other variable costs. While costs of drilling wells are sunk costs and do not represent economic costs of well utilization, there are significant non-energy variable costs required to maintain individual wells and pumping plants. Because individual wells can be abandoned, non-energy variable costs are included as an economic cost of utilizing groundwater. Non-energy variable costs of utilizing groundwater are dependent on groundwater depth. Following budgets in Wilson (1992), agricultural variable costs were $0.015/af/ft, while municipal costs were $0.010/af/ft. Energy cost calculations assume pumping plant efficiencies of 55% in agricultural sectors (derived from budgets in Wilson), and 60% in municipal sectors.

Variable conveyance costs for CAP water are dominated by the energy cost of pumping. (The initial capital costs of CAP facilities, including regional delivery systems, while large compared to variable costs, are now sunk costs and should not be included in calculations of economic costs of alternative water allocations.) It was assumed that, regardless of delivery levels, all pumping plants in the project would be maintained, and that maintenance costs are independent of diversion levels. Non-energy variable costs are thus excluded. Individual pumping plant lifts and efficiencies were taken from USBR (1986) and are given in Table 2.

THE MODELING FRAMEWORK

Policy options for managing Arizona's surface and groundwater resources are modeled as a nonlinear optimization problem. The hydrologic and water delivery systems, including storage, conveyance, and pumping facilities, are modeled by constraints. The model is driven by maximization of an objective function based on either priorities or economic factors in water use and delivery. The state's major demand regions, water resources, and hydrologic connections are all included in the model structure. Repeated solutions with a one year time step are typically used. Available flows and groundwater resources are allocated by one of several possible policy options and groundwater and reservoir storage is updated with each time step. Figure 1 illustrates the modeling framework.

TABLE 2. Central Arizona Project Conveyance Costs

Reach	Lift	Efficiency	Conveyance Losses
	(feet)		(kaf)
A: Colorado River - West CAP	922	0.80	82
B: West CAP - Phoenix	290	0.81	30
C: Phoenix - Pinal	84	0.76	-
D: Pinal - Tucson	1414	0.80	-

Implementation of Alternative Water Management Policies

Determining water use and its distribution requires an assumption on the set of institutions defining the rules for water allocation. Three fundamental sets of allocation rules have been defined:

I. Allocation by priorities.

II. Allocation by priorities, subject to a benefit-cost constraint on local groundwater pumping.

III. Market allocation, with quantities determined by allocations maximizing total benefits minus costs.

CASE STUDY OF CENTRAL ARIZONA GROUNDWATER DEPLETION

Arizona's rapidly growing population and heavy reliance on groundwater suggests that depletion of groundwater stocks is a potentially critical issue for the future economic development of the state. From 1970 to 1990, population grew at an annual rate of 3.7%, doubling to 3.6 million people. At the same time, estimates suggest that present groundwater overdraft exceeds 1.2 million af annually, down from a high of 2 million af annually (Phoenix AMA Plan, 1991) but still greater than the entire annual yield of central Arizona surface water resources, excluding CAP. Figure 2 illustrates one impact of continued overdrafts, given the base population projections and policy (scenario 1) described below. Groundwater depletion causes water levels to decline, resulting in ever increasing pumping costs. The increasing costs shown in the Figure suggest that economic exhaustion of the groundwater resource is a possibility, and must be considered together with hydrologic limits. The purpose of this modeling application is to examine both economic and hydrologic impacts of alternative policies affecting surface and groundwater use over a 50 year planning period.

Arizona System for Integrated Management of Water Resources (AZSIM)

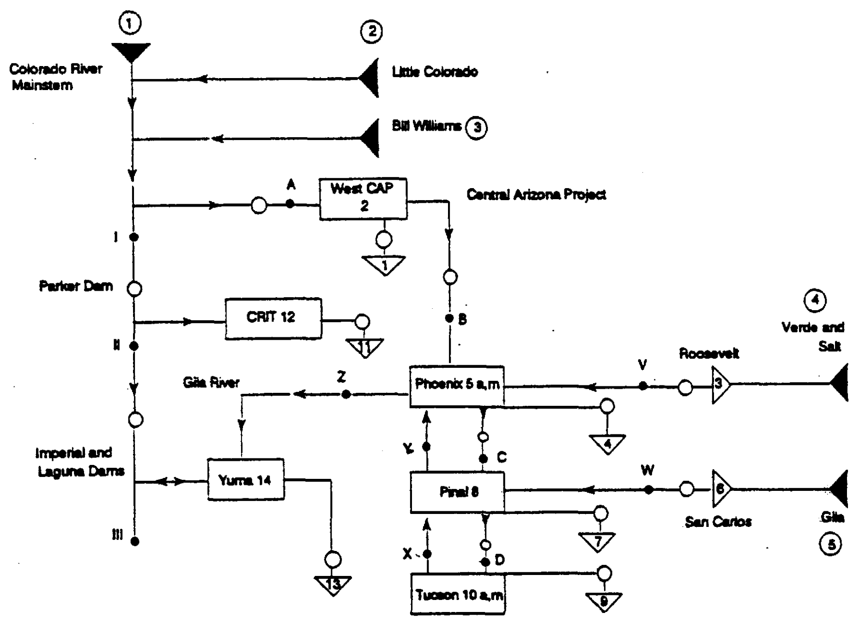


FIGURE 1. Modeling Framework

Socioeconomic Projections

Critical to modeling long term groundwater depletion are population and agricultural use projections, and future CAP utilization. U.S. Census projections (U.S. Bureau of the Census, 1991) for Arizona were judged the most reliable estimates of future state population growth. An annual population increase of 1.8% is used for the first 25 years, with no growth in population for the final 25 years of the simulation. Non-agricultural water uses are assumed to exactly track population changes. Changes in agricultural use levels reflect urbanization in the Phoenix region, water transfers to non-agricultural uses, retirement of non-profitable irrigated land, and development of new irrigated land. The base projection used here is zero change in agricultural water use in all regions except Phoenix. Phoenix AMA agricultural water use is projected to decline at an annual rate of 1.1% due to urbanization, a figure derived from the Phoenix AMA Plan, base use level figures. Use is constant after 25 years. Central Arizona Project utilization is difficult to forecast. While physically capable of delivering in excess of 1.5 maf, demand for CAP water has been significantly limited by costs to users. In 1991 use was only 500 kaf, down from 745 kaf in 1990, the year in which the largest deliveries to date were made. With the focus of this study on groundwater depletion, a conservative assumption on CAP utilization of 500 kaf annually is made as the base projection.

Alternative Policy Scenarios

Five alternative water management policies, ranging from representations of existing institutions to radical growth controls and market mechanisms are examined. The alternative policies suggest paths which limit groundwater depletion and economic impacts of water shortages, while clearly exposing the tradeoffs between competing objectives. Given the completion of the CAP linking Central Arizona water users, the system approach used here is necessary to fully explore the interactions between users and groundwater resources in the West CAP, Phoenix, Pinal, and Tucson regions. Distinctive characteristics of the alternative policies modeled for this case study are discussed below.

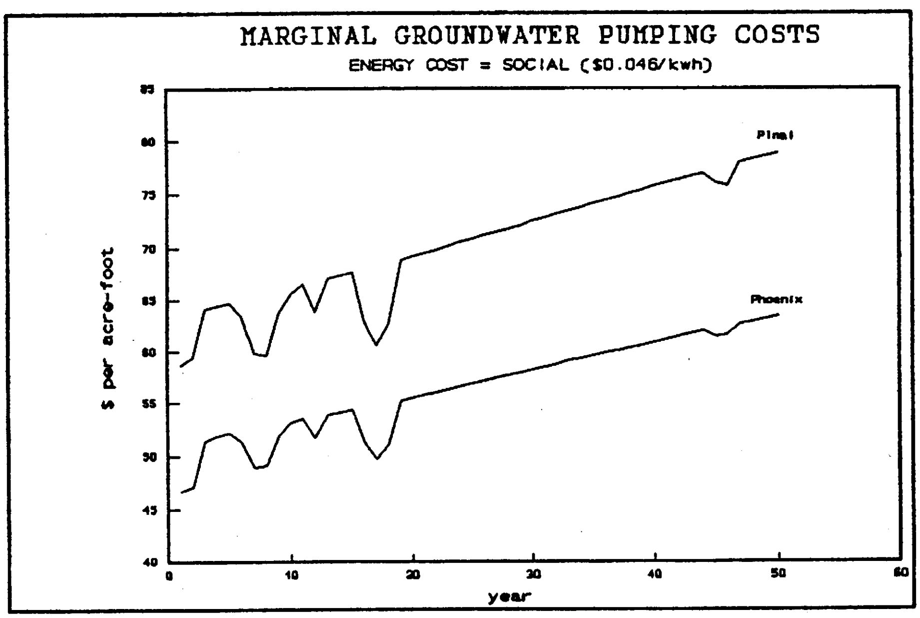


FIGURE 2. Impacts of Groundwater Depletion on Pumping Costs

1. Historic water use: No policy imposed limits to water use are imposed under this base case scenario. Water use is limited by available flows, physical pumping capacity, and historic use levels, adjusted for population growth and associated urbanization of agricultural lands. Conveyance and pumping costs do not limit water use; implicitly, subsidies are present when costs of use exceed benefits. Water allocation is by priority.

2. Water use quotas: Arizona's 1980 Groundwater Management Act sets limits to groundwater overdraft in the Phoenix, Pinal, and Tucson regions. Water use goals established by the Second Management Plans for these AMAs are used to derive alternative water use growth rates from those utilized without quantity constraints on water use. In particular, annual growth rates for non-agricultural water use in Phoenix and Tucson are reduced by 0.6%, agricultural rates for Phoenix are reduced by 0.7%, and agricultural rates for Pinal and Tucson are reduced by 1.8%. CAP diversions increase from 500 to 781 kaf annually over a 25 year period. Water allocation is by priority.

3. Zero population growth: It has been suggested that water resource limits justify rigid growth controls. A no growth policy is modeled here by fixing all water use limits at existing levels. Water allocation is by priority.

4. Marginal cost energy pricing: Costs of groundwater pumping in Central Arizona are in many cases similar to marginal benefits derived from water use. Efficient resource use requires that pumping occur only when marginal benefits exceed costs. This condition could be met by pricing energy at full social cost. Energy costs under this scenario are 46 mills/kwh, the estimated marginal cost of baseload electrical generation in the southwest (Booker and Young, 1991). Growth projections reflect those used in scenario 1. Water allocation is otherwise determined by priorities.

5. State water market: Maximizing beneficial use of Arizona's water resources requires the possibility of mutually advantageous transfers among users throughout the state. This "market" scenario is instituted using marginal cost energy pricing (46 mills/kwh) for all pumping and hydropower production, including CAP deliveries. Growth projections reflect those used in scenario 1.

Simulation Results

An initial examination of water supply costs and benefits under existing allocations and water supply conditions is instructive. Table 3 provides estimates of marginal benefits of diversions, and marginal costs of providing groundwater and CAP diversions. Year 1 of the simulation and scenario 1 allowing unrestricted water use are used, and energy is valued at its marginal social cost, roughly twice the average price paid by water users in pumping groundwater and in CAP pumping.

Simulation of the alternative policies over the 50 year policy horizon revealed a broad range of impacts on groundwater depletion, pumping costs, agricultural uses, and costs to water users. Table 4 provides an estimate of the annual costs and benefits of alternative policies. Costs are defined as the foregone benefits due to reductions in consumptive uses from base levels, plus total groundwater and CAP pumping costs and foregone benefits of mainstem hydropower production. The annual averages given below are calculated without discounting. Qualitative impacts on two categories of benefits are given: depletions of groundwater stocks, and maintenance of irrigated agriculture. Quantitative estimates of these impacts are provided in more detail, below.

TABLE 3. Marginal Benefits and Costs of Diversions with Energy Valued at 46 mills/kwh, in $/af. Opportunity cost of lost hydropower production of $10/af not included in CAP costs.

Region	Marginal Benefits	Marginal Pumping Costs	
		Groundwater	CAP
Phoenix ag	27.2	46.7	67.9
Phoenix non-ag	340	46.7	67.9
Pinal	36.7	58.7	72.8
Tucson non-ag	486	38.0	152.2

The use quotas (scenario 2) proposed under the AMA Management Plans are the most costly alternative because of the policy imposed reductions in non-agricultural use called for under the Plans. Costs of the AMA Plans (scenario 2) are dominated by these shortages. (The no growth alternative (scenario 3) does not include damages from restricted immigration. If such costs were included, it is likely that the annual costs of the no growth alternative would far exceed that of the AMA use quotas.) In contrast, a state water market (scenario 5) would eliminate all non-agricultural shortages, and, by definition, impose the lowest water supply costs. These costs include not only pumping costs, but also foregone income to agricultural users. Pricing energy for groundwater pumping at its true social cost (scenario 4) and limiting pumping to uses for which benefits exceed social costs imposes only slightly higher costs (when pumping costs are based on variable pumping depths.)

Policies which impose opportunity costs on agricultural water uses (social energy cost and markets) result in the smallest groundwater depletion over time. Policies reflected in the AMA Management Plans (scenario 2) are less effective in preserving aquifer stocks, while population growth policies (scenario 3) appear, taken in isolation, to be ineffective.

TABLE 4. Costs and Benefits of Alternative Water Management Policies.

POLICY	Annual Cost[1] ($ million)	Benefits of Policy[2]	
		Groundwater Stocks	Maintaining Agriculture
BASE	250	-	+
USE QUOTA	450	0	0
ZERO POP GROWTH	225	-	+
SOCIAL COST ENERGY	175	+	0
WATER MARKET	150	+	- -

1. Includes all pumping costs, drought damages, and long run reductions in agricultural incomes.

2. Key to qualitative, relative benefit measures:
+ beneficial - costly
0 average – very costly

One objective of water allocation policies is the preservation of benefits of agricultural water use. No growth policies (scenario 3) have the smallest impact on agricultural incomes because competition for surface water resources is limited during drought. Market policies (scenario 5) result in both retirement of low valued production with high pumping costs, but also transfer of agricultural water to non-agricultural uses in preference to utilization of CAP supplies. Income impacts to agriculture are less under social energy cost pricing (scenario 4) than with a market policy, largely because of CAP utilization. Wealth impacts to agricultural producers differ greatly between the market and social energy cost scenarios (5 and 4, respectively), however. In particular, agricultural users sell their rights to groundwater production to non-agricultural users at a mutually beneficial price under a market policy and are thus fully compensated for lost income. With a social energy cost policy, no compensation for reductions in income are received by agricultural producers. One impact of social energy cost pricing would thus be a large wealth transfer from existing water users.

DISCUSSION

Economic exhaustion of groundwater stocks for agricultural uses in central Arizona is likely long before physical stocks are limiting. The specific timing of economic exhaustion for agricultural uses depends on factors including output prices and the energy prices faced by producers. Substituting the assumption of variable pumping depths within regions by an assumption of average pumping depths significantly altered the modeled outcomes for scenario 4. In particular, agricultural production remained near existing levels for many decades, while groundwater levels declined significantly. This suggests that the precise energy costs, and the variance in energy costs among producers are critical determinants of future agricultural production in central Arizona. More generally, the response of central Arizona agriculture to continued pumping cost increases is extremely sensitive to small changes in production costs and revenues. Because of the diversity of producers (which is not formally modeled here beyond variable pumping costs), it is likely that cost increases due to declining groundwater levels will result in a continued decrease in central Arizona agricultural water use and output over time.

While agricultural users face the prospect of economic costs exceeding benefits in the near future, non-agricultural users face no such constraint on use of groundwater or Central Arizona Project water. Further, if water allocation and use in Arizona were based on economic factors alone (the market solution of scenario 5), groundwater overdraft would be nearly eliminated. If non-economic agricultural uses were to continue (through subsidies) in central Arizona, then declining groundwater levels and increasing pumping costs would make Central Arizona Project water increasingly attractive. Pumping costs of $70/af and $150/af (at social energy costs of 46 mills/kwh) for Phoenix and Tucson, respectively, are well within the willingness to pay for residential, municipal, and industrial users. Relatively low cost supplies are thus available to non-agricultural users from a portfolio of groundwater pumping and foregone agricultural uses, while higher cost supplies are available by pumping from greater depths (if agricultural uses continue at near existing levels), and by importing Colorado River supplies through the Central Arizona Project.

ACKNOWLEDGEMENTS

Much of this work was completed while the author was with the Wyoming Water Resources Center and the Department of Agricultural Economics, University of Wyoming. Critical support was also provided by the Department of Agricultural and Resource Economics, University of Arizona.

REFERENCES

Arizona Agricultural Statistics Service. *Arizona Agricultural Statistics 1991*. Phoenix, August, 1992.

Arizona Department of Water Resources. *Regional Water Resource Summaries*. 1990.

Arizona Department of Water Resources, Phoenix Active Management Area. *Second Management Plan: 1990-2000*. Phoenix: Department of Administration, Printing Services. March, 1991.

Arizona Department of Water Resources, Pinal Active Management Area. *Second Management Plan: 1990-2000*. Phoenix: Department of Administration, Printing Services. January, 1991.

Arizona Department of Water Resources, Tucson Active Management Area. *Second Management Plan: 1990-2000*. Phoenix: Department of Administration, Printing Services. January, 1991.

Billings, B.R., and D.E. Agthe. "Price Elasticities for Water: A Case of Increasing Block Rates." *Land Economics* 56(1980):73-84.

Booker, J.F., and R.A. Young. *Economic Impacts of Alternative Water Allocation Institutions in the Colorado River Basin*. Completion Report No. 161, Colorado Water Resources Research Institute, Colorado State University, Fort Collins, August, 1991.

Eden, Susanna, and M.G. Wallace. *Arizona Water: Information and Issues*. Issue Paper 11, Water Resources Research Center, University of Arizona, Tucson, August, 1992.

Griffin, R.C., and C. Chang. "Seasonality in Community Water Demand." *West. J. Agr. Econ.* 16(1991):207-217.

Howe, C.W. "Impact of Price on Residential Water Demand: Some New Insights." *Water Resour. Res.* 18(1982):713-716.

Kelso, M.M., W.E. Martin, and L.E. Mack. *Water Supplies and Economic Growth in an Arid Environment: An Arizona Case Study*. Tucson: University of Arizona Press, 1973.

Peacock, Bruce, and B.G. Colby, University of Arizona. Personal Communication. 1993.

Planning and Management Consultants. *A Disaggregate Water Use Forecast for the Phoenix Water Service Area*. Report Phoenix Water and Wastewater Department, March, 1986.

U.S. Bureau of the Census. "Arizona State and County Data." *1987 Census of Agriculture*, U.S. Government Printing Office, Washington DC, 1988.

U.S. Bureau of the Census. *Projections of the Population of States, by Age, Sex, and Race: 1989 to 2010*. Current Population Reports, Series P-25, No. 1053. U.S. Government Printing Office, Washington DC, 1990.

U.S. Bureau of Reclamation. *Colorado River Simulation System: Inflow and Demand Input Data*. Engineering and Research Center, Denver, Colorado, 1991.

Wilson, Paul N. *An Economic Assessment of Central Arizona Project Agriculture*. Report to the Office of the Governor and the Arizona Department of Water Resources, Phoenix. November, 1992.