

# ECONOMIC ASPECTS OF AGRICULTURAL IRRIGATION AND IRRIGATION RESEARCH IN THE USA

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One of the first things that farmers learn in an arid environment is the limiting nature of the water supply on agricultural production. In an ultimate sense water, rather than land, may be the more limiting factor on agriculture and the world's food supply. This is surely true of selected local, or regional, situations. At least 40 percent of the earth's surface is in arid or semi-arid zones, hence that is sufficient reason we should give attention to water use and irrigation technology. Even stronger justification derives from the fact that one-third of the global harvest comes from the 17 percent of the world's cropland that is irrigated (Postel, pp. 7-8). As examples, 10 percent of US cropland, or 19 million hectares, are irrigated. In Italy it is 25 percent and 3 million hectares.

This paper will not deal with either the technical aspects of irrigation engineering or with cost-benefit analyses of large water projects; neither will it treat underground water modeling, nor the complex legal problems of distributing water across international boundaries. «Water» is a broad subject! Agricultural use of water is also a broad subject. Irrigation in agriculture is narrower in scope, but I should like to limit the paper even further; i.e., to the experience of *one region* as to those water issues associated with irrigating agricultural crops. That region is the arid deserts of the Southwestern United States (Arizona, California, Colorado, Nevada, New Mexico and Utah) which has some of the most productive agriculture in the world. High productivity there is due in great part to sophisticated irrigation technologies and advanced irrigation research programs. Moreover, this region is in the forefront of intragricultural competition in the use of water, as well as competition between farm and city. It leads the country in searching for answers to environmental questions related to the use of water for irrigation. Arizona also has perhaps the most advanced groundwater law in the United States. This law resulted directly from the competition between agriculture and other industries. The world has much to learn about irrigation from what is going on there, and in such places as Israel, among other areas.

Arizona has a long history of confronting problems of economic development in a

## Abstract

This report concerns some economic aspects of farm irrigation in a USA region, where regardless of dryness and water lack, agriculture is in fact one of the most productive in the world. Actually, because of the high water demand for intensive farming, a competition has taken place between the different social aspects and water use in this region.

The problem of water resource management in agriculture concerns not only technical and engineering aspects about the right irrigation system or technologies to use, but also legislative aspects about water preservation.

Scientific research has faced these problems by a careful economic analysis of farm irrigation to maximize yields and profits.

The economic analysis has then focused on both water preservation and water pollution, caused by the exceeding amounts of nitrogen and herbicides applied to the crops.

In order to safeguard water resources and to curtail the effects of some choices on agriculture in the region under study, a specific regulation has been implemented about underground water use, in order to re-establish the usual groundwater levels.

In this sense, it should be stressed that thanks to the «Groundwater law» farmers now have a legalized water use right. However, the competition about farm, urban and industrial uses of water is still strong and as a consequence, flight from the land is still a current problem. That is why, economic studies in agriculture, aiming at a better farm irrigation policy, are very topical subjects.

## Résumé

Cet article concerne certains aspects économiques de l'irrigation dans le domaine de l'agriculture, dans une région des Etats-Unis, où en dépit du climat aride et de la pénurie d'eau, l'agriculture est l'une des plus productives dans le monde entier. En effet, dans cette région, l'agriculture intensive exerce une telle pression sur les ressources hydriques limitées, qu'elle provoque un conflit entre les différentes composantes sociales concernant l'utilisation de l'eau.

La gestion des ressources hydriques en agriculture implique non seulement les aspects techniques et d'ingénierie concernant le choix des systèmes d'irrigation et les technologies relatives, mais aussi des aspects législatifs à propos de la conservation des ressources en eau.

La recherche scientifique a donc abordé ces problèmes, à travers une analyse économique attentive concernant l'irrigation dans le domaine de l'agriculture, dans le but de maximiser aussi bien les productions que le profit.

L'analyse économique a ensuite localisé aussi bien certains aspects relatifs à la conservation des ressources hydriques, que les problèmes de pollution des eaux, dus aux excès d'azote et d'herbicides administrés aux cultures.

Afin de sauvegarder les ressources en eau et de limiter les effets des choix sur l'agriculture de la région en question, on a créé une réglementation spécifique dans le cadre de l'utilisation des eaux souterraines qui devraient rétablir les niveaux hydriques préalables des nappes. La «Groundwater law» devient ainsi à ce propos plus intéressante, grâce à la législation du droit de jouissance de l'eau, reconnu aux agriculteurs.

Des problèmes de concurrence entre les utilisations: agricole, urbaine et industrielle de l'eau existent toutefois encore, tout comme le phénomène de l'exode rurale qui en découle. D'où il paraît utile de mener des études économiques en agriculture, visant à définir les instruments pour la mise en place d'une juste politique concernant l'irrigation dans le domaine de l'agriculture.

water-scarce environment. Historically, the limitations of visible surface water supplies placed an immediate restraint on economic growth. Technological improvements in groundwater pumping opened up a vast new invisible stock of water. The search for an increased supply of water was accelerated and given urgency during the 1950s and 1960s by the striking expansion in the urban-industrial and recreational-retirement activities. The direct consequences of an increasing water scarcity was to be borne primarily by the irrigated agriculture sector of the Arizona economy.

Agriculture in Arizona like all the arid Southwest consumes 80 percent or more of all water used. Present estimates indicate that the State is consuming 1,7 times the annual ground and surface water replenishment. Three factors are primarily responsible for

the increased scarcity of water: declining groundwater tables; increasing energy prices; and competition for water from nonagricultural sectors of the economy. This paper will revolve about these three factors.

## Water procurement and use in irrigated agriculture

Water, when available in unlimited and «regular» quantities may be used at the discretion of the farmer. A major problem arises when water is available in too large quantities such as to necessitate drainage, or, as in the case of arid lands, in too small supplies to make its cost of procurement relatively high. A subset of this problem arises when water is available in irregular and un-

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predictable quantities, as is the case in many regions of the world. One of the strong features of irrigated agriculture — with respect to both total or supplemental irrigation — is its predictability as to outcome, i.e., systematic and dependable crop production and harvest, if adequate storage facilities are available to assure supplies during dry years. Since World War II the accelerated development of intensive agriculture has resulted in an inexorable pressure on limited water supplies in regions such as the southwest desert of the United States. In the past decade we have witnessed the termination in this region of the last major nationally-financed reclamation project, the Central Arizona Project. Further, the energy crisis was a «watershed» in that cheap energy no longer was available to provide abundant groundwater irrigation supplies as in the past. Higher costs of irrigation water to farmers were inevitable. Added to these, the quality of water available to farmers has shown a gradual deterioration. Southwestern rivers have become increasingly saline over the years, with negative implications for crop yields.

The stages of technologies in water development and use in Arizona's irrigated agriculture have evolved as follows: 1) direct appropriation of water from rivers and streams by farmers, going back hundreds of years when its use by native Americans (Indians) was predominant; 2) rudimentary pumping of groundwater from shallow wells for direct on-farm use; 3) increased power pumping, and the delivery of water by gravity to crops over longer distances through large uncedmented ditches; 4) lining of these large ditches with cement to save water, and the invention of larger pumps to lift water from deeper wells; 5) switch from electricity to natural gas-powered pumps when gas as a source of power became cheaper and was made available to remote areas; 6) utilization of sprinkler and pipe irrigation technologies using pressure from large motors; 7) leveling of fields through a combined use of lasers and large-scale moving equipment; 8) use of drip and trickle irrigation technologies and scientific timing of water applications to save water and to regulate its absorption by agricultural plants; 9) irrigation scheduling and more advanced management techniques. As an aside, this experience of Arizona and the arid U.S. Southwest has been (is, or will be) the case with other regions of the world where agriculture is increasingly dependent on irrigation technologies.

Throughout all these stages of water development and utilization, agronomists and plant breeders have been busy in their attempts to develop plant varieties which will adapt to less water and to lower-quality water. Great strides have been made in developing varieties of cotton and grain which will adapt to situations of plant stress brought about by harsher growing conditions, i.e. less water, as well as lower more brackish quality water.

## Managing water under irrigated conditions

It is difficult to discuss the management of water without, at the same time, discussing crop management systems, water law and environmental problems impinging on water use. Crop management systems include activities such as seasonal land preparation, application of fertility supplements, crop protection from weeds, insects and disease, and may also include the application of water to supplement soil moisture.

Water management systems on the other hand, are those aspects of crop management specific to the modification of soil moisture to affect plant growth. They include tillage practices for local adaptability, fallow cropping, contour cropping, terracing and land drainage. Of course, plant varieties and planting dates determine water needs. Water management includes technologies affecting procurement and distribution of water. Here is where irrigation systems come in. However, «water harvesting» technologies also can be used to supplement quantities of water and can affect its distribution. For example, the use of land shaping techniques, catchments, and soil conditioning can affect the amount of water available to plants.

Irrigation systems traditionally consisted of ditches which were designed to move water by gravity from the source of water to the location of its use. Gravity, by sloping the field, delivered water to plants. This is still a popular irrigation method, however electric motors and combustion engines are now used to pump irrigation water at high pressure through pipes and sprinklers. New technology, also, has made possible low-pressure drip and trickle irrigation methods. These methods apply limited amounts of water directly into the root area of plants. Distribution of water by «programming» water and nutrient intake to precisely match plant needs is the desired goal.

Once an irrigation system is developed, the planning and implementation of a water management scheme will depend greatly on its financial aspects. These include evaluating the long-term capital necessary for irrigation wells (where appropriate) delivery pipes or ditches, and water application technology. Also necessary is a farming plan adequate to liquidate loans on borrowed capital. Very important is flexibility in cropping possibilities and water application rates. Efficiency in water use is of utmost importance in planning an irrigation system and in water management. Wade has constructed a simple table (table 1) to account for inefficient water procurement and use (p. 175). In sum, irrigation system capacity, energy requirements, and water quantity and quality are the principal factors that must be considered in designing an irrigation system. Obviously, water procurement cost, irrigation system cost and the complexity of matching available water to plant require-

**Table 1 Sources of Reduced Water Use Efficiency.**

|  |
|--|
| <b>Water sources</b>                   |
| Well equipment                         |
| Engine or motor                        |
| Energy type, timing, reliability, cost |
| <b>Delivery ditches</b>                |
| Dirt ditches/deep percolation          |
| Evaporation                            |
| Leaks in pipes and ditches             |
| <b>Application systems</b>             |
| Run-off                                |
| Nonuniformity/placement                |
| Evaporation                            |
| Deep percolation                       |
| <b>Crop</b>                            |
| Bad timing                             |
| Loss of control                        |
| Competing plants and insect            |
| Water not available in plant root zone |

ments are the important features of sound water management, crop production and enterprise success.

## Research on the economics of irrigation and irrigation technologies

Research on agricultural irrigation has been underway in Arizona for more than 50 years. Much of the economic research combined with applied engineering and agronomic studies controlling the salt content of soils has been given much attention. These studies are of a continuing nature and represent a commitment to a further understanding of water problems as well as to assisting farmers toward improving their profit positions.

Early studies of irrigation concentrated on farm management issues and production economics. Cost of pumping irrigation water was the central question to be answered. Several studies were made along these lines during the first decade after World War II.

Then came the monumental study *Water Supplies and Economic Growth in an Arid Environment* (Kelso, Martin and Mack) which attacked the problem of water in a broad sense, i.e., in terms of physiography, climate and soils as well as in terms of economic development associated with water requirements. Irrigated agriculture, of course, was the centerpiece of the economic analysis and the theory and practice derived from this long-term study became standard text for irrigation economics. One can but summarize this economic analysis. Suffice to say farm budgetary analysis composed a large share of the applied research on this research project.

The following summary of the analytical method used by Kelso, Martin and Mack is all that time and space will allow me to present. I quote directly from their analysis (pp. 47-48):

«We can now summarize our way of looking at the problem of the Arizona economy as a water user and how we approach its economic analysis.

1. There are numerous different water demanders, each with some use(s) for a small quantity of water of great value to them and each with other uses for larger quantities of water but of markedly less worth, up to the point where no more water would be used even if it were "free".

2. The typical water demander's curve is a *brokenbacked curve* - small quantities of water of high value or productivity and relatively large quantities of low values or productivity.

3. Although each water demander is an individual, household, or firm, they can be classified into groups on the basis of relative similarity in patterns of water use. For our purposes, irrigated agriculture is the important class because it uses such large quantities of water at low levels of value of productivity. Thus, irrigated agriculture is the marginal class of users among the totality of all classes of users.

4. Within the irrigated agriculture class of water users, there are some uses that use relatively small quantities of water at relatively high levels of value or productivity, and other uses that use relatively large quantities of water at relatively low levels of value or productivity. The graph picturing this relation of values and quantities is the marginal water demand curve by irrigated agriculture.

5. The volumes of water that will be available, by areas or by state total at various levels of rising cost, can be determined and shown in tabular or graphic form. These are economic marginal supply functions for in-state water.

6. As water costs rise, one can determine from the combined demand and supply curves for water how much less water irrigated agriculture will use and how much loss of gross output and net income in irrigated agriculture this curtailment will cause.

7. By projecting rising costs of water over time, one can project the likely pattern of decline in cropped acres, output per crop, gross dollar output, and net income in irrigated agriculture over time.

8. By determining a multiplier factor between gross output in irrigation agriculture and incomes generated in all related economic activities, and adding in the income not produced in agriculture because of its decline in gross agricultural output, one can estimate the decline in total income in the state resulting from any projected decline in irrigated agricultural gross output resulting from projected growing water scarcity.

9. By estimating the alternative employment opportunities available to men and resources displaced by curtailment of irrigated agriculture, and subtracting that magnitude from the total income decline determined through item 7 above, one can estimate the net loss in income that will be experienced

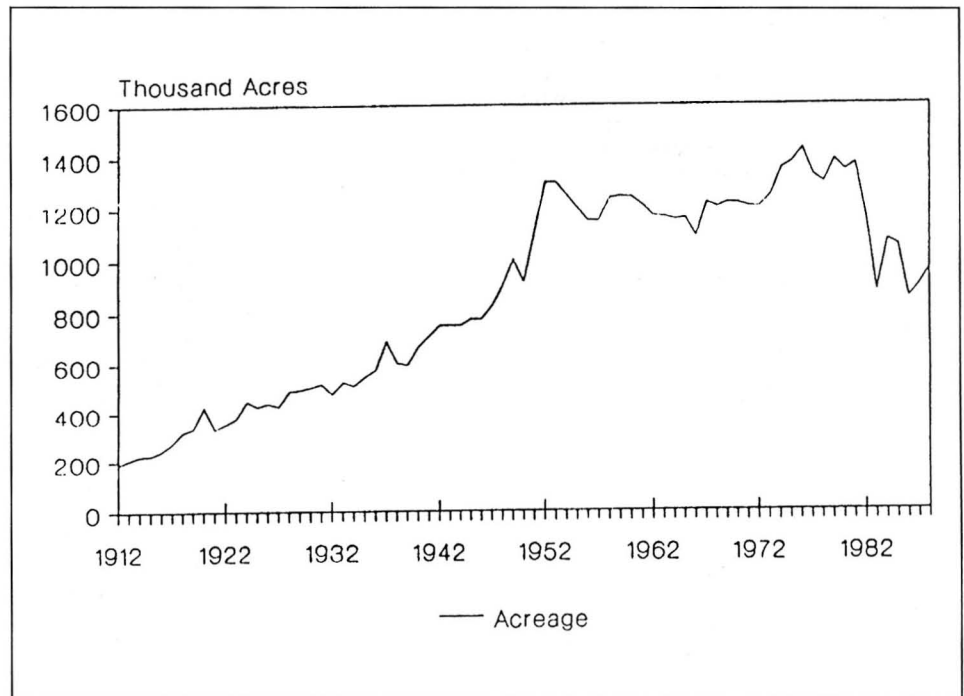


Figure 1 - Arizona Crop Acres. Source: Arizona Agricultural Statistics, Arizona Agricultural Statistics Service, Phoenix, AZ, Yearly Issues.

by affected people over time because of the projected curtailment of irrigated agriculture. This estimate may be put on a per-acre-foot-of-water basis to obtain the real value of an acre-foot of water developed to counteract such agricultural and nonagricultural adjustment to water scarcity».

More refined, smaller segments of research on irrigation economics ensued after this broad, landmark analysis; (of course, Arizona was not the only place such studies took place). Over the past decade in Arizona, for example, economic analyses have been completed as follows:

1. *Crop-Water production Functions: Economic Implications for Arizona* (Ayer and Hoyt). (Reduced water applications: Does it make economic sense?)

2. *Laser Leveling and Farm Profits*. (Daubert and Ayer)

3. *Drip Irrigation for Cotton Implications for Farm Profits* (Wilson, Ayer and Snider). Each of these, essentially production-oriented, specific, studies of a production process in irrigated agriculture pushes further and extrapolates to the ultimate questions of yield maximization and profit maximization for the farmers in question, i.e., those farming under irrigated conditions. Economic theory is used to its fullest.

Ayer and Hoyt derive a number of general implications from their study on crop-water production functions. At the *farm level* they state (p. 16):

«1) Perhaps the most important implication at the farm level is that in areas of medium-to-high water prices, profits can be increased if water applications are cut below common applications which typically are intended to maximize yield. The amount by which water should be cut is frequently six

acre inches (one normal irrigation) or more on cotton, wheat and sorghum, grown on a variety of soil textures and under a wide range of product prices.

2) In those areas of low water prices, farmers can maximize profits by applying nearly the same amount of water as that required to maximize yield. Current recommendations of irrigation management service should be valid in both an economic and technical sense.

3) Irrigation delivery efficiency has very little impact on short-run profits when water is low priced, but has a very large impact on short-run profits for medium-and high-priced water. Accordingly, there is little incentive for the farmer to line irrigation canals and improve delivery efficiency in other ways when water is priced low. However, it may be economically rational to improve delivery efficiency if water is higher priced. For wheat, sorghum and alfalfa, a combination of high water prices (\$5 per acre inch) and low delivery efficiency (50%) implies net financial losses. A long-run, benefit-cost analysis of capital investment in delivery efficiency is required to assess the net benefits of particular investments.

4) Irrigation pump efficiency can greatly affect short-run profits of all crops in medium and deep life areas. Good management, then requires that pump efficiencies be checked and the long-run benefits compared to long-run costs of repairing or replacing pumps.

5) If water available to a farm is limited, wholefarm profits can be maximized by irrigating a relatively large number of acres at relatively low peracre irrigation rates, rather than applying high water rates to fewer acres».

The same authors in their analysis make the following observations on «Water Conservation Policy» (pp. 16-17):

«1) At the regional level and in areas where water recharge is not great, the results imply that large amounts of water may be conserved (cut per acre application) by changing from yield-to - profit-maximizing levels of water in medium-to - high-price water areas. In Arizona, for example, 200,000 to 250,000 acre feet of water could be saved by cutting water applications to an amount which maximizes profits. This water savings is approximately twice the annual municipal-industrial use in Tucson — a city of nearly one-half million people.

2) Attempts to conserve surface water through the price mechanism are unlikely to succeed unless water prices are raised several fold. Current established prices are minimal, about \$0.50 per inch. Estimated elasticities of demand for water on cotton, wheat and alfalfa are so low for all soil textures and a wide range of product prices that even doubling the price of surface water will not significantly affect the water use.

3) Efforts to conserve water through quantity restrictions on surface water can greatly affect farm profits in the short run. On cotton, wheat, and sorghum grown on fine soil, profits are cut by \$80 to \$100 per acre as water is restricted to 20% below profit-maximizing levels. However, in the long run water quantity restrictions could encourage more efficient irrigation systems or practices which would reduce or negate the short run reduction in profits».

Wilson, Ayer and Snider in a substantial analysis of drip irrigation for cotton arrive at some basic results in their research. Here I shall only summarize the highlights of that study (pp. 27-28):

«Drip irrigation systems for cotton can improve profitability under many Arizona conditions. A key to profitability, however, is that cotton yields must increase. Key factors that affect drip yields are the soil, climate, and management. Drip irrigation tends to increase yields on medium to coarse soils, where the weather is hot and dry, and where intensive management is applied. In any event, yield increases of a bale or more per acre seem possible in some cases. If that comes about, drip will be a profitable investment under most energy price, cotton price, and investment cost conditions. Without and increase of 1 bale per acre, circumstances under which drip is profitable are much more limited.

Producers in parts of Arizona (and elsewhere) are concerned that rising electricity prices will make cotton farming unprofitable. Some farms have already stopped producing cotton. When yields increase by a bale or more, drip irrigation may turn shortrun losses to profits even when energy prices are high.

There are some drawbacks to drip irrigation. Drip technology is expensive, management practices are quite different from those used for conventional furrow irrigation, and the

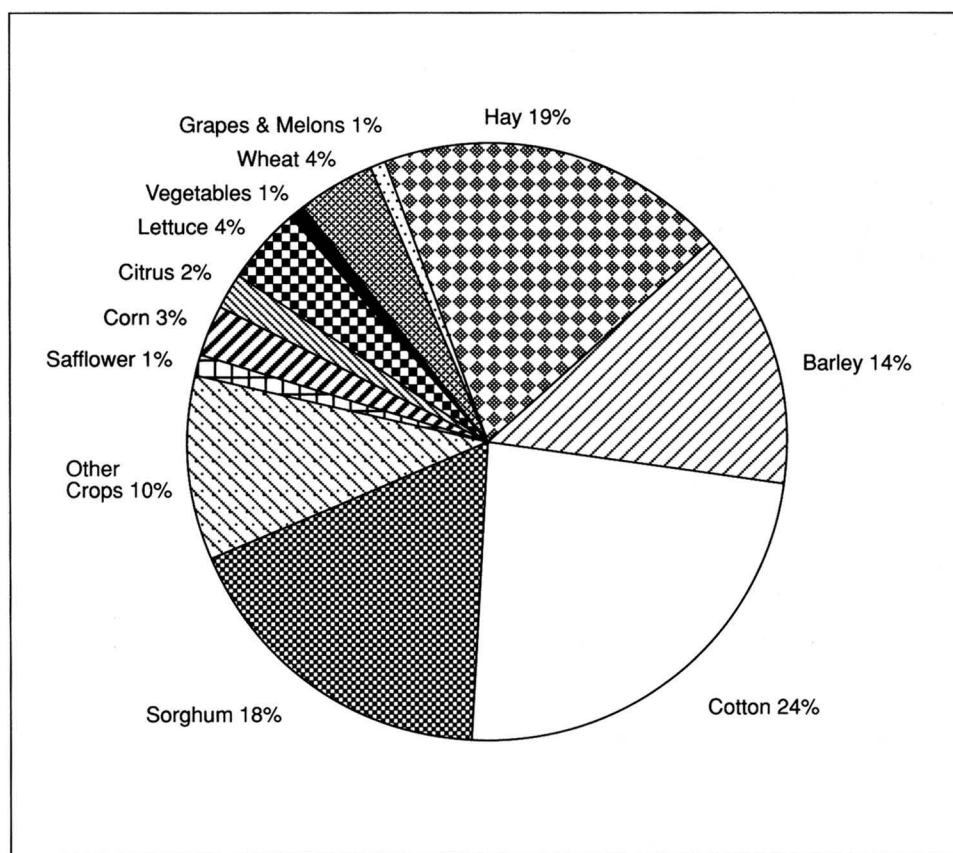


Figure 2 - 1968 Crop Mix (1,204,000 acres). Source: Arizona Agricultural Statistics, Arizona Agricultural Statistics Service, Phoenix, AZ, Yearly Issues.

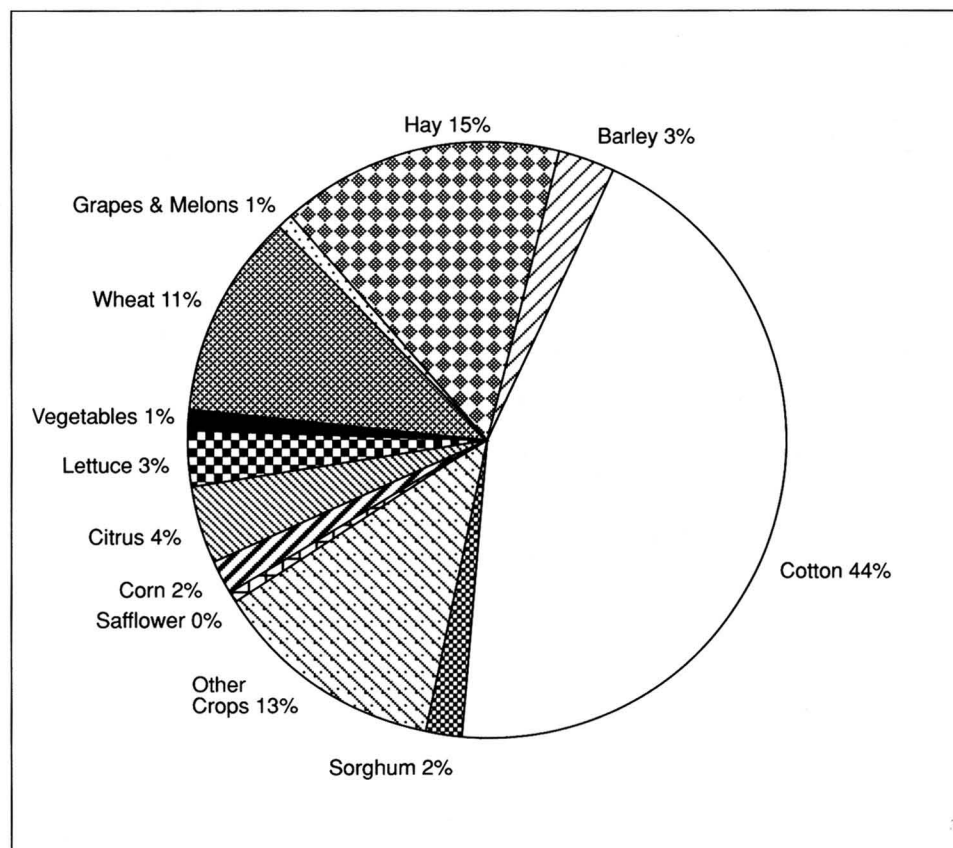


Figure 3 - 1978 Crop Mix (1,298,000 acres). Source: Arizona Agricultural Statistics, Arizona Agricultural Statistics Service, Phoenix, AZ, Yearly Issues.

effects of drip irrigation on yield are not well established. Drip systems usually cost from \$900-\$1,200 per acre installed - approximately half the cost of prime, developed, irrigated land.

The water savings associated with drip irrigation of Arizona cotton are substantial. Several experiments reduced water application by 30-50 percent from furrow applications on medium to coarse soils. These savings are often 20-39 inches per acre. Evaporation, deep percolation, and runoff are all reduced - a fact of particular importance in Arizona where deep percolated and runoff water is often lost to subsequent reuse.

Whether or not these large water savings are realized depends directly upon the profitability of drip irrigation. Where drip appears unprofitable, water conservation policy may be carried out through government cost-sharing of water-saving technologies, tax incentives, or research expenditure programs to encourage technology adoption».

Economic analysis is currently being used also in studies related to environmental questions associated with irrigated agriculture; namely, questions of water quality and the effect of water quality on farm profits; problems of pesticides associated with irrigated farming; issues associated with reducing nitrogen applications in order to improve water quality — does the farmer lose in the process? — and problems associated with herbicide reduction in irrigated agriculture.

Research at the University of Arizona indicates that nitrogen contamination of groundwater may become an even greater issue in the future. In that research test plot experiments were utilized which showed why farmers may over-apply fertilizer and how profits are affected by reduced nitrogen levels (Ayer, et al., p. 7).

«The results support the explanation that fertilizer is overapplied because it is inexpensive to do so - the added nitrogen is inexpensive and yields are not greatly affected. Thus farmers may inexpensively over-apply nitrogen to reduce the riskiness of not knowing what their yields would be at lower nitrogen levels. Our study should help reduce this risk. We also found that for three of Arizona's most important crops, nitrogen applications could be reduced by at least 20-30 percent from yield maximizing levels with little or no negative effect on short run profits. Since supplemental evidence shows that many farmers apply at least enough fertilizer to maximize yield, this result seems quite significant. It suggests that education should have a significant effect in reducing applications».

In sum, obviously, economic analysis is highly important in arid land agriculture; but, more specifically, such analyses are indispensable to irrigated farming. Our analyses in Arizona, for the most part, have been very useful to the farm community.

Most studies have been well accepted except those where the results demonstrated

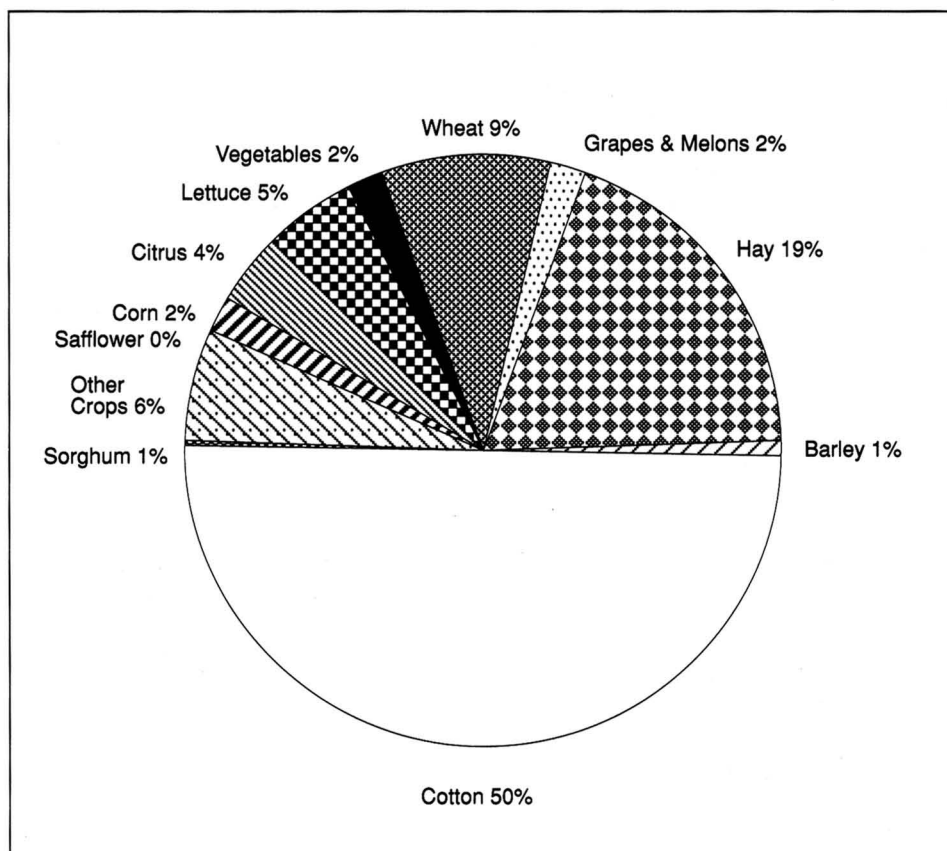


Figure 4 - 1988 Crop Mix (962,500 acres). Source: Arizona Agricultural Statistics, Arizona Agricultural Statistics Service, Phoenix, AZ, Yearly Issues.

a threat to farmer's power in the overall scheme of «water politics».

### Controlled irrigated and conservation schemes

Procurement and use of surface and ground water for irrigated agriculture brings into play many facets of engineering, hydrology and agronomy, property rights and water flow, and most facets of production economics, including financial planning. The above observation is borne out with the experience we have had over the past 50 years in central and southern Arizona agriculture but time will not permit us to explore all these facets. Over this period, total irrigated crop acreage has varied little, with a typical 1.0-1.2 million acres being harvested annually in Arizona (only during the Korean War, the inflationary period of the mid-70s and the unique situation of 1983 did acreage vary more than 20%). Hence, what has occurred over this period is a dynamic pattern of cropping and water use, the principal factors affecting which are, on the one hand, the economic forces associated with supply and demand of agricultural commodities and, on the other, the forces at work in the economics of irrigation. During periods of high prices, farmers have pumped more water to apply to increased acreages of crops, the amounts of water applied being dependent on the price outlook

for the crop. In periods of low prices or unstable situations farmers give up marginal ventures and fall back on dependable crops such as cotton for which they have excellent irrigation technology and stable prices, usually underwritten by programs of the federal government.

In Figure 1 is presented the acres in agricultural crops (mostly irrigated) from 1912-1988. Rising to above a million acres after World War II, the figure has fluctuated between 1.0 and 1.5 million acres depending on prices of crops and energy and other factors such as urban expansion and irrigation technology (the 1980 Water Law in Arizona had not yet had its effect). Table 2 gives the detailed breakdown of these acres by crops since 1949. Note what has happened to barley, sorghum, and hay on the one hand, as compared to cotton, grapes and melons, vegetables and wheat (durham) on the other. A more dramatic picture is drawn by Figures 2, 3 and 4 which show in picture form the Arizona crop mix acreages in the years 1968, 1978, and 1988. Note barley and sorghum versus cotton in this mix. The economics of water and irrigation as well as government farm programs have dictated these changes. There will be more change. Technological change and institutional factors, such as water law, will also bear heavily on Arizona's irrigated agriculture.

Despite this ebb and flow of economic forces, fact is that there has been an inex-

orable tendency to overdraft water in certain regions. As a consequence, a water law was enacted in 1980 mandating that by the year 2025 groundwater overdraft must be halted — that is, only the amount of groundwater that is annually replenished by rainfall and runoff may be pumped each year. This law has as its centerpiece an agricultural conservation program which is specific

and rigorous. The overall program is administered via water management areas. Arizona farms and cities are substituting imported surface water via the Central Arizona Project in order to reduce their reliance on groundwater.

As has already been implied, the competition between agriculture, cities and the copper mines, led to legislation regulating the

pumping of groundwater (the Groundwater Law of 1980). Prior to that legislation farmers — or, broadly speaking, agriculture — had never had a written, legal right to water. Each case was an adjudicated right, based on historical use, precedent, etc. The 1980 law changed all that. Two landmark features stand out: first, the basis-claim or the legal-right to water was changed from the *source*

**Table 2 Arizona Commodity Acreage 1949-1988.**

|      | Total Acres<br>(000) | Cotton | Barley | Hay    | Grapes &<br>Melons | Wheat  | All Veget | Lettuce | All Citrus | Corn  | Safflower | Other Crops | Sorghum |
|------|----------------------|--------|--------|--------|--------------------|--------|-----------|---------|------------|-------|-----------|-------------|---------|
| 1949 | 1,000.00             | 985.00 | 126.00 | 253.00 | 5.50               | 28.00  | 4.20      | 40.70   | 19.10      | 31.00 |           | 31.50       | 76.00   |
| 1950 | 915.00               | 275.00 | 157.00 | 253.00 | 5.00               | 25.00  | 4.90      | 44.80   | 18.20      | 29.00 |           | 7.10        | 96.00   |
| 1951 | 1,100.00             | 573.00 | 98.00  | 249.00 | 5.20               | 18.00  | 3.80      | 42.60   | 18.00      | 35.00 |           | 17.40       | 40.00   |
| 1952 | 1,800.00             | 674.00 | 107.00 | 246.00 | 4.10               | 17.00  | 4.00      | 41.20   | 16.80      | 39.00 |           | 100.90      | 50.00   |
| 1953 | 1,300.00             | 690.00 | 141.00 | 237.00 | 5.00               | 18.00  | 5.70      | 38.40   | 15.00      | 33.00 |           | 61.90       | 55.00   |
| 1954 | 1,250.00             | 420.00 | 268.00 | 257.00 | 6.00               | 15.00  | 4.50      | 33.20   | 13.90      | 31.00 |           | 57.40       | 144.00  |
| 1955 | 1,200.00             | 355.00 | 174.00 | 284.00 | 4.90               | 42.00  | 5.30      | 37.10   | 13.80      | 32.00 |           | 81.90       | 170.00  |
| 1956 | 1,150.00             | 358.00 | 151.00 | 273.00 | 5.00               | 58.00  | 4.30      | 46.00   | 19.60      | 34.00 |           | 64.10       | 143.00  |
| 1957 | 1,150.00             | 352.00 | 148.00 | 250.00 | 5.80               | 63.00  | 6.50      | 52.50   | 13.80      | 35.00 |           | 57.40       | 166.00  |
| 1958 | 1,239.95             | 377.00 | 135.00 | 259.00 | 7.40               | 122.00 | 9.60      | 64.50   | 14.90      | 32.00 |           | 67.55       | 151.00  |
| 1959 | 1,245.97             | 383.00 | 144.00 | 260.00 | 6.20               | 94.00  | 7.80      | 62.00   | 17.30      | 28.00 |           | 88.67       | 155.00  |
| 1960 | 1,243.17             | 426.00 | 150.00 | 275.00 | 6.30               | 22.00  | 9.80      | 56.60   | 18.40      | 27.00 | 3.50      | 86.57       | 162.00  |
| 1961 | 1,210.84             | 392.00 | 165.00 | 277.00 | 6.30               | 26.00  | 10.30     | 57.00   | 20.30      | 30.00 | 13.00     | 65.93       | 148.00  |
| 1962 | 1,168.67             | 405.00 | 111.00 | 257.00 | 6.50               | 24.00  | 8.50      | 53.60   | 22.30      | 35.00 | 52.00     | 64.76       | 129.00  |
| 1963 | 1,165.80             | 387.00 | 127.00 | 236.00 | 6.50               | 27.00  | 9.60      | 56.20   | 24.40      | 35.00 | 55.00     | 64.10       | 138.00  |
| 1964 | 1,154.00             | 375.00 | 144.00 | 249.00 | 7.90               | 33.00  | 8.20      | 58.10   | 27.00      | 31.00 | 5.50      | 70.30       | 145.00  |
| 1965 | 1,160.00             | 339.90 | 153.00 | 240.00 | 8.35               | 26.00  | 11.00     | 55.90   | 27.25      | 35.00 | 12.00     | 67.60       | 184.00  |
| 1966 | 1,087.50             | 252.20 | 110.00 | 240.00 | 7.83               | 23.00  | 12.50     | 55.30   | 30.43      | 25.00 | 38.00     | 77.24       | 206.00  |
| 1967 | 1,222.00             | 244.70 | 160.00 | 233.00 | 7.92               | 50.00  | 10.90     | 47.20   | 32.13      | 37.00 | 96.00     | 52.15       | 251.00  |
| 1968 | 1,204.00             | 298.30 | 176.00 | 239.00 | 8.80               | 52.00  | 10.10     | 45.40   | 27.57      | 39.00 | 9.00      | 78.83       | 220.00  |
| 1969 | 1,222.10             | 310.40 | 144.00 | 224.00 | 26.48              | 73.00  | 19.57     | 49.20   | 44.28      | 35.00 | 25.00     | 87.17       | 184.00  |
| 1970 | 1,219.03             | 273.80 | 140.00 | 243.00 | 19.80              | 150.00 | 18.28     | 50.90   | 45.85      | 35.00 | 11.00     | 57.40       | 174.00  |
| 1971 | 1,205.17             | 285.40 | 119.00 | 240.00 | 20.84              | 173.00 | 16.01     | 45.20   | 44.90      | 38.00 | 20.00     | 63.82       | 139.00  |
| 1972 | 1,205.08             | 310.90 | 97.00  | 259.00 | 20.93              | 170.00 | 15.45     | 46.10   | 34.10      | 32.00 | 33.00     | 68.60       | 118.00  |
| 1973 | 1,250.00             | 310.00 | 110.00 | 253.00 | 18.23              | 185.00 | 17.09     | 46.10   | 37.53      | 31.00 | 23.00     | 101.06      | 118.00  |
| 1974 | 1,352.97             | 426.70 | 60.00  | 245.00 | 13.93              | 200.00 | 14.50     | 42.90   | 39.33      | 32.00 | 15.00     | 146.61      | 117.00  |
| 1975 | 1,376.82             | 297.80 | 65.00  | 220.00 | 14.97              | 260.00 | 10.85     | 38.80   | 55.19      | 31.00 | 44.50     | 230.71      | 108.00  |
| 1976 | 1,429.21             | 370.00 | 57.00  | 200.00 | 17.15              | 431.00 | 12.25     | 37.30   | 58.76      | 30.00 | 0.00      | 168.75      | 47.00   |
| 1977 | 1,327.67             | 557.30 | 55.00  | 205.00 | 18.81              | 140.00 | 11.95     | 37.90   | 57.20      | 30.00 | 10.50     | 166.01      | 38.00   |
| 1978 | 1,298.22             | 572.20 | 35.00  | 200.00 | 18.42              | 138.00 | 11.85     | 42.50   | 45.80      | 30.00 | 6.00      | 167.45      | 31.00   |
| 1979 | 1,385.89             | 618.30 | 43.00  | 190.00 | 20.10              | 125.00 | 13.10     | 45.60   | 47.64      | 31.00 | 11.20     | 210.95      | 30.00   |
| 1980 | 1,344.24             | 591.10 | 50.00  | 195.00 | 14.60              | 215.00 | 10.85     | 35.00   | 43.65      | 32.00 | 3.70      | 119.34      | 34.00   |
| 1981 | 1,371.35             | 632.60 | 36.00  | 190.00 | 14.04              | 258.00 | 10.87     | 29.60   | 46.68      | 32.00 | 1.50      | 90.06       | 30.00   |
| 1982 | 1,159.08             | 511.60 | 38.00  | 185.00 | 18.69              | 143.00 | 12.07     | 34.30   | 42.40      | 35.00 | 4.60      | 114.42      | 20.00   |
| 1983 | 877.57               | 313.30 | 27.00  | 170.00 | 17.43              | 119.00 | 13.20     | 38.00   | 41.20      | 34.00 | 3.60      | 81.84       | 19.00   |
| 1984 | 1,072.23             | 479.30 | 53.00  | 165.00 | 19.47              | 142.00 | 15.90     | 45.30   | 38.40      | 32.00 | 6.10      | 57.76       | 18.00   |
| 1985 | 1,050.43             | 415.90 | 62.00  | 167.00 | 22.57              | 112.00 | 16.20     | 38.40   | 36.50      | 29.00 | 0.00      | 133.46      | 18.00   |
| 1986 | 852.87               | 922.80 | 29.00  | 277.00 | 25.43              | 96.00  | 18.50     | 97.80   | 35.50      | 37.00 | 2.50      | 56.34       | 15.00   |
| 1987 | 898.74               | 379.80 | 22.00  | 190.00 | 26.90              | 89.00  | 18.80     | 46.00   | 35.60      | 29.00 | 2.50      | 45.14       | 14.00   |
| 1988 | 962.48               | 477.00 | 13.00  | 180.00 | 21.70              | 85.00  | 18.80     | 46.00   | 35.60      | 24.00 | 0.75      | 55.63       | 5.00    |

from which water comes to the *use* to which water is put; second, agriculture was given a *use-right* which was «grandfathered» into the legislation.

Even though certain exceptions were made in the legislation its principal effect was to set a maximum groundwater allotment for Arizona farm based on historical usage during the five years prior to January 1, 1980. A new irrigation scheme was established for the period beginning January 1, 1990 and ending December 31, 1999 or the Second Management Period (Arizona Department of Water Resources). To quote the code directly, the new plan is meant to (p. 82):

«Establish a new irrigation water duty for each farm unit to be reached by the end of the second management period and may establish one or more intermediate water duties to be reached at specified intervals during the second management period. 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, considering the time required to amortize conservation investments and financing costs». (Arizona Revised Statutes 45-565.A.1.)

As one would suppose, the irrigation water duty is the primary component of the agricultural water conservation program. The *Irrigation Water Duty* (IWD) is the variable which determines the maximum annual groundwater allotment for the irrigation acres in a farm unit. The calculation of the IWD is not a simple process; but it is very logical. The irrigation water duty for each farm unit is calculated as follows (Arizona Department of Water Resources, pp. 90-102):

1) Irrigated Water Duty =

$$= \frac{\text{Total Irrigation Requirement}}{\text{Assigned Irrigation Efficiency}}$$

2) *Total Irrigation Requirement* =

$$= \text{CU} + \text{ON} + \text{LR} + \text{EP}$$

where

CU = Consumptive Use

ON = Other Needs

LR = Leaching Requirements

EP = Effective Precipitation

3) *Total Planted Acres* is the sum of the acres planted during the period 1975 through 1979. Acres that were double cropped are counted only once in the determination of total planted acres.

4) *Assigned Irrigation Efficiency* is a measure of the general effectiveness of water application through a crop season and is the function of many variables. In the Law it is defined as:

Assigned Efficiency =

$$= \frac{\text{Total Irrigation Requirement}}{\text{Total Volume of Water Applied}}$$

In determining irrigation efficiency during the Second Management Plan (1990-2000) many factors are considered such as: areas of similar farming conditions, prudent long-term farm management practices, irrigation system improvements, etc.

Ultimately a Maximum Annual Groundwater Allotment per farm unit is calculated by multiplying the IWD by the number of water duty acres. The Groundwater Code permits farmers to borrow or to bank groundwater from year to year to allow for varying climatic or market conditions. This is known as the Flexibility Account.

As would be suspected, monitoring and reporting agricultural water use requires a large staff of people. Direction of the program must be done with rigor and justice.

## Current critical issues in irrigated agriculture

A. The overdrafting of underground water for agricultural use. This is not just an economic issue in agriculture based on commodity pricing in domestic and international competitive markets. It is an issue based on competition for water in cities as well as water for nontraditional agriculture and agribusiness, (e.g., golf courses, etc.), recreation and population growth in cities.

B. The depopulation and the bypassing of rural areas because of urban water demand, and the «robbing» of rural residents of their water rights due to power politics and the «heavy hand» of cities where population is concentrated. This is becoming a major issue all over the Western United States; especially in California and in Arizona. Colby et al. have outlined an excellent statement of transferring of water rights in the Western United States. They point out (p. 67):

«In most western states, local government units are not involved formally in the change of water right process and consideration of area-of-origin impacts generally is not incorporated into transfer approval procedures. However, area-of-origin concerns are receiving more attention from state policymakers. Area-of-origin issues have the potential of affecting the conditions under which water transfers will be approved and the costs of implementing such transfers».

Moreover, Colby (pp. 737-741) has an excellent analysis on area-of-origin protection of water rights.

C. Environmental issues associated with intensive irrigated agriculture. It would take us too far afield to explore these issues. I can only list a few.

1. Pesticides
2. Nitrates
3. Salinization issues
4. Subsidence
5. Land abandonment where groundwater is exhausted - it becomes a nuisance due to dust, etc.
6. Aquaculture associated with irrigation schemes.

D. Issues of the recycling of urban-used water by farmers in irrigated agriculture. This is a growing field for economic analysis. For example, currently cities use only 25 percent of the water in my state but as that amount grows the issues will become more controversial. I list three items only:

1. Effluent
2. Sludge
3. Heavy metals.

E. Politics and Irrigated Agriculture.

In sum, irrigation economics will be a very important subject of study in the United States. Agriculture will be the center of controversy as to water use. Ultimately the lowering water table and cost of energy, both economic-oriented factors, will constrain agricultural use of water.

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