INNOVATIONS IN GROUND WATER MANAGEMENT: THE ARVIN-EDISON WATER STORAGE DISTRICT OF CALIFORNIA

Henry Vaux, Jr
University of California

INTRODUCTION

The Arvin -Edison Water Storage District is comprised of a little over 53,000 hectares (132,000 acres) located in the extreme southeasterly portion of California=s Central Valley as shown in Figure 1. Rich soils and a long and favorable growing season make California=s Central Valley one of the world=s richest agricultural regions. The area encompassed by the Arvin-Edison Water Storage District is typical of the southern portion of the Central Valley. Despite the favorable climate and soils the region does not have the adequate or reliable precipitation. The long-term average rainfall in the Arvin-Edison District is just over 200 mm (8 inches) annually. In addition, the Mediterranean climate of the region means that precipitation is concentrated in the winter months and there is little or no precipitation during the spring and summer growing seasons from April to October. This means that successful agriculture depends almost wholly upon irrigation and hence upon the availability of water for irrigation.

More than three quarters of the land area of the Arvin-Edison District, 40,500 hectares (100,000 acres) are devoted to irrigated agriculture. Grapes, citrus, vegetable crops, potatoes, fruit and cotton are the predominant crops. The absence of local perennial streams means that District growers must rely on ground water and imported supplies of surface water. Early growers in the region irrigated exclusively with ground water. By the 1930s the advent of increasingly efficient pumps and well drilling technologies led to a situation in which ground water overdraft exceeded 140 million m^3 (113,000 acre feet) annually. It was clear that if irrigated agriculture was to be continued at anything approaching its existing scale, persistent ground water overdraft would have to be halted through the importation of supplemental surface waters.

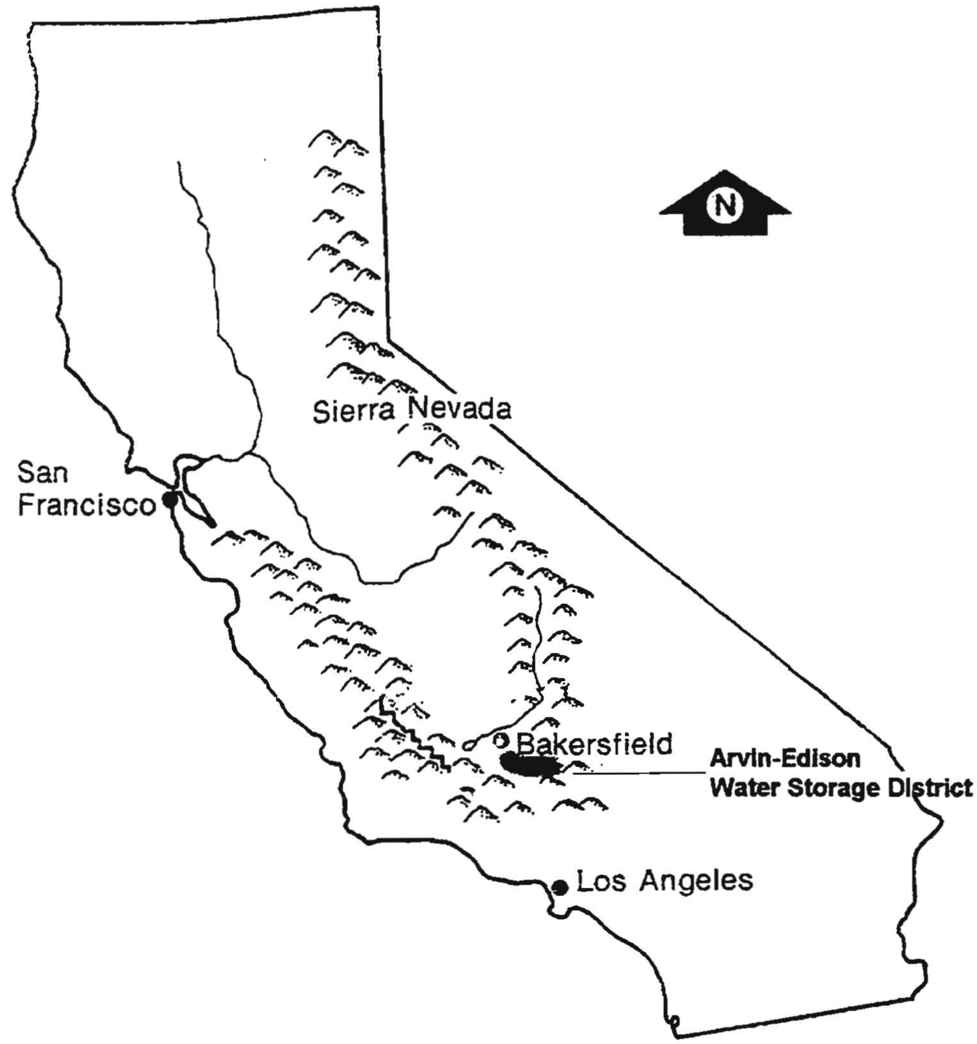


Figure 1: Location of the Arvin-Edison Water Storage District

Most of the lands of the eastern Central Valley that were not adjacent to perennial watercourses had suffered the same fate. Over extension of irrigated agriculture had led to rates of ground water depletion that could not be continued for long. The result was that continuation of significant irrigated agriculture in the entire region would be dependent upon the importation of supplemental surface supplies. Imported supplies were first made available to large areas of the Central Valley through the federal Central Valley Project (CVP). This project was constructed by the U.S. Bureau of Reclamation. The relevant portions of it include Friant Dam, which impounds water on the San Joaquin River and the Friant-Kern Canal which runs150 miles south from Friant Dam to a point immediately north of the lands of the Arvin-Edison Water Storage District as shown in Figure 2. The Friant-Kern Canal conveys water to users along its entire length.

One striking characteristic of California=s agricultural lands is the fact that most fall within the boundaries of a special water district formed to acquire and purvey water to local users. These districts, which were characterized early-on as Auser cooperatives@ have been formed under a variety of provisions in the California Water Code for the general purposes of acquiring, storing, distributing and conserving water. The Water Code permits Districts to tax, to contract with state and federal agencies, issue bonds and receive revenues. Districts are constrained from making a profit and the details of taxing powers, the composition of governing boards, restrictions on areas to be served and the extent of regulation by the state government differ by district type (Bain, Caves and Margolis, 1966).

The Arvin-Edison Water Storage District (hereinafter AEWSD) was organized in 1942 under the California Water Storage District law for the propose of creating an agency that could contract with the United States for water and power services from the CVP. The supplemental

Figure 2: Surface Water Importation Facilities

water to be made available by the CVP was intended not only to alleviate ground water overdraft but to attenuate a potentially serious problem with boron contamination that was attributable to continuing overdraft. Ultimately, the AEWSD executed a water service contract with the United States that entitled it to deliveries of up to 49 million m^3 (40,000 acre feet) annually of firm supply (so-called Class 1 water) and 384 million m^3 (311,675 acre feet) of interruptible or non-firm supply (so-called Class 2 water).

The effect of the water service contract was to provide the AEWSD with a supplemental water supply of which only 11% (the firm supply) would be reasonably reliable. The remaining 89% would be delivered to the District on an Aas available@ basis which would depend primarily on higher than average levels of precipitation. Inasmuch as precipitation and run-off in California is less than normal in 4 years out of 7, such an allocation could hardly be characterized as dependable. In the absence of other developments, it would require the majority of growers in the District to raise annual crops and to bear the significant costs of fallowing lands because of lack of water in many years. Indeed, some growers were faced with the prospect of having to fallow land as frequently as one year in two. Thus, what AEWSD needed was not so much more water as it was more firm or guaranteed water (Arvin-Edison Water Storage District, 2000).

The challenge for the AEWSD was to take a highly variable and uncertain imported surface water allocation and transform it into a more certain (though probably smaller allocation) which would allow irrigation to continue on roughly the same scale as had developed historically while protecting both ground water quantity and quality. This challenge was made more manageable by virtue of the fact that reducing the long-term overdraft would address both the problem of quantitative sustainability and the water quality problem.

ALTERNATIVE WATER SOURCES

The potential annual variability in the supplemental surface supply available to AEWSD was so large that it was immediately apparent that all options for increasing the quantities of supplemental surface imports should be explored prior to designing an optimal conjunctive use program. This is true because the greater the degree of variability, the larger the scale (and cost) of the ground water recharge facilities needed for artificial recharge. Fortunately, there was at hand an attractive option for increasing firm surface water deliveries. The water in question was itself less expensive and its high degree of reliability (firmness) meant that the capital and operating costs of the recharge facilities needed for a conjunctive use program would be reduced.

By taking advantage of this option, the AEWSD was able to acquire additional firm surface water as part of the solution to its water management problem. In order to understand how this was done, it is important to grasp the fact that there are multiple sources of surface water available in the region. In the late 1950s ground water overdraft in the Central Valley again became a problem as irrigated agriculture continued to expand after the completion of the Central Valley Project. The state of California ultimately responded with the construction of a large system of facilities to capture water in the relatively rich regions of northern California and transport them to the relatively water scarce areas of central and southern California. The primary feature of the State Water Project (hereinafter SWP) is the California Aqueduct which stretches from the Sacramento-San Joaquin Delta southward to San Diego, as shown in Figure 2. Thus, for the general area of western Kern County, in which the AEWSD is located, there are two major sources of imported water (Vaux, 1986).

As a general rule, the agricultural beneficiaries of the SWP are located on the west-side of the southern half of the Central Valley while the beneficiaries of the CVP are located on the east side. This is not exclusively the case, however. Some of the contractors for federal CVP water available from the Friant-Kern Canal were unable to obtain sufficient quantities of water to allow for full development of their lands. These districts then contracted with the State of California for water delivered through the SWP even though they had no immediate way to acquire the water physically because their lands were so far removed from the aqueduct. This situation led to the development of a series of physical transfer and exchange facilities at the southern end of the Central Valley which allowed: 1) excess flows from the terminus of the Friant-Kern Canal as well as from the Kern River to be delivered to the California Aqueduct and 2) water to be delivered from the California Aqueduct via the Cross Valley Canal to the City of Bakersfield and directly to agricultural users at the southern terminus of the Valley.

The AEWSD was able to use these circumstances to increase the quantity of its firm supplemental surface water supply more than three-fold. Under the terms of a Memorandum of Understanding with nine other irrigation districts upstream on the Friant-Kern Canal, the AEWSD exchanged a total of 214 million m^3 (174,300 acre feet) - comprised of its total firm entitlement of 49 million m^3 (40,000 acre feet) and the first 165 million m^3 (134,300 acre feet) of its non-firm entitlement - in exchange for 158 million m^3 in firm entitlement water to be conveyed to AEWSD from the California Aqueduct through the Cross Valley Canal. (It is important to understand that the water exchanged to AEWSD from the California Aqueduct could not be delivered directly to the nine exchange districts who were entitled to it because would have required pumping upstream against the flow on the Friant-Kern Canal. The AEWSD was physically in a position to take the water because it is located Adownstream@ of the terminus of both the Friant-Kern and Cross Valley Canals. By contrast the nine exchange contractors could take the AEWSD water by simply diverting it at their diversion points which were upstream of the AEWSD on the Friant Kern Canal.) This exchange benefitted all parties, first, by giving AEWSD access to a significantly enlarged quantity of firm water and, second, by making available to the nine exchange contractors additional quantities of water in partial satisfaction of their entitlements to water from the California Aqueduct which could not otherwise be delivered without substantial investment in additional transfer facilities (Vaux, 1986).

The AEWSD was then left with 158 million m^3 (128,300 acre feet) of firm (Class 1) supply and residual 171 million m^3 (139,000 acre feet) of its original Class 2, non-firm supply. These supplemental surface water supplies formed the basis for an unusual conjunctive use program involving direct deliveries of some surface water and ground water recharge operations which provided both storage and an accessible water supply that would be potentially available to all growers in the District.

THE CONJUNCTIVE USE PROGRAM

The conjunctive use program of the AEWSD was initiated in 1966. The District was divided into two distinct areas. First, a Surface Water Service Area, occupying about 40% of the lands in the District, is serviced in years of normal and above normal water availability directly with the supplemental surface water available to the District. The surface water is distributed through conventional canals and pipes constructed for this purpose. The second area is a ground water service area, occupying the remaining 60% of the land. In this area growers continue to pump ground water from an aquifer that has now been stabilized through a combination of reduced extractions and a formal program of ground water recharge. The division of the District into ground water and surface water service areas was the result of a number of factors that included economies in distribution system construction, relief from the financial burden of operating a dual system to serve individual farms and the benefits to be obtained by introducing surface water into the parts of the District where ground water is at the greatest depths and/or is of poor quality (Arvin-Edison Water Storage District, 2000.)

To the extent that the demand for water from the Surface Water Service Area coincides with the quantities of water imported to the District, imported water is delivered directly to growers in that area through the Districts distribution system. Any imported water that is in excess of the immediate demand from the Surface Water Service Area is routed to the District spreading basins and percolated into the underlying aquifer. The District operates and maintains two spreading basins, each of which occupy a little more than 200 hectares (500 acres). In addition, the District operates and maintains several well fields which allows it to extract water stored underground and deliver it to the Surface Water Service Area in times when surface water deliveries are inadequate to meet prevailing demands.

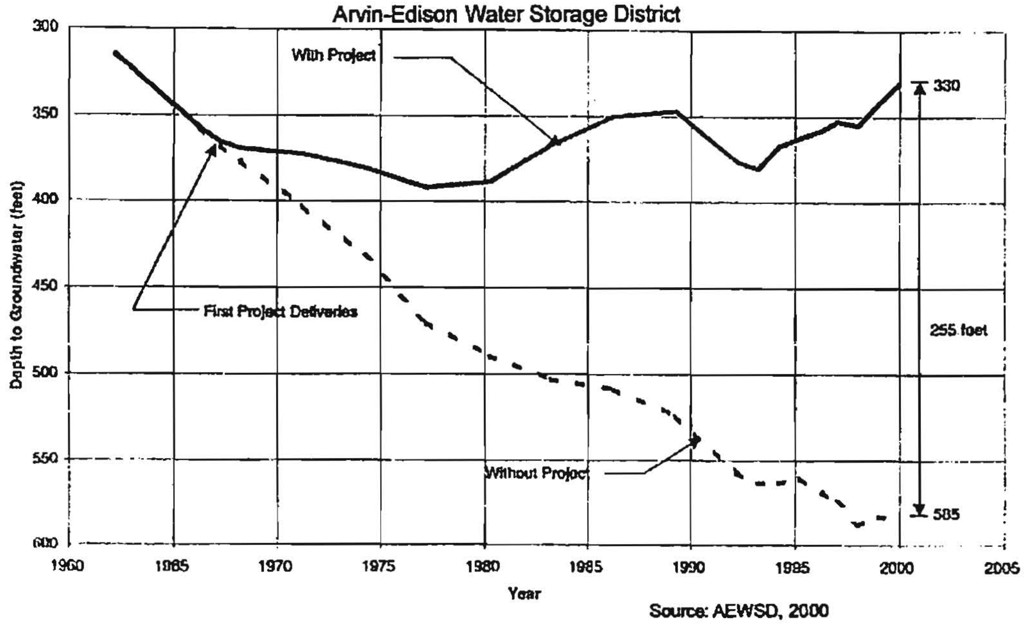
The conjunctive use program was begun in 1966. Between 1966 and 1999 the AEWSD imported 6.2 billion m^3 (5.0 million acre feet). Of that total nearly 1.85 billion m^3 had been percolated into the aquifer and 5.2 billion m^3 (4.2 million acre feet) was delivered directly to users in the Surface Water Service Area. During years of severe drought, 1972, 1976-77, 1987-92 and 1994, surface water deliveries were sharply reduced and large extractions of ground water were needed to maintain firm water service.

By 1980 some 616.5 million m^3 (500,000 acre feet) had been percolated into ground water storage. Ultimately, the accumulation of aquifer storage and the availability of additional firm water as a result of the Cross Valley Canal Exchange permitted the AEWSD to increase its annual firm water delivery to 197.6 million m^3 (160,300 acre feet). This was accompanied by a general stabilization of ground water levels. Figure 3 shows average ground water depths since 1966 and an estimate of the decline in the ground water table that would have prevailed had the pre-project annual decline of between 2.1 and 2.6 meters (7 and 8.5 feet) continued. This analysis suggests that had pre-project rates of extraction continued with no artificial recharge the ground water table would now be almost 80 meters (235 feet) than is the case under project conditions.

A simple cost analysis shows that stabilization of ground water levels has resulted in substantial cost savings. Assuming that the average efficiency of groundwater pumps in the District is 60% and that the marginal cost of energy per kilowatt hour paid by pumpers is between is between $0.12 and $0.20 (US), the savings that accrue to pumpers as a consequence of NOT having to lift the water an additional 80 meters (235 feet) ranges between 3.8 and 6.5 cents/m^3 ($47 and $80/acre foot). Total water costs to AEWSD users in 2000 amounted to 6.5 cents/m^3 ($79.89/acre foot). Water costs, then, are between a half and two-thirds of what they would have been had ground water levels not been stabilized, assuming that all growers continued to extract the same quantities that they had extracted historically in spite of the increased cost.

It is interesting to note that irrigated acreage has remained relatively constant since the advent of the conjunctive use program although there have been significant changes in cropping patterns. In 1970, early in the life of the project, only 20.8 % of the irrigated lands of the District were in permanent crops, including vines, citrus and deciduous orchard. By 2000, the percentage of acreage devoted to permanent crops had grown to 47.6%. It is true that cropping patterns tend to be reflective of a number of variables which influence the costs of production and the patterns

Figure 3
Average Static Groundwater Depth In District
Arvin-Edison Water Storage District



of prevailing demand for food and fiber. Yet, the development of significantly larger quantities of firm or reliable water supply is clearly a necessary condition for a significant increase the relative proportion of land devoted to permanent crops. It is also interesting to note that the mix of permanent crops remains almost exactly the same as it was in 1970. Today, more than 75% of the irrigated acreage in the District is devoted to the cultivation of relatively high valued crops, grapes, citrus, deciduous fruit and vegetable crops. The preponderance of these high valued crops is associated with the successful development and operation of the conjunctive use program. (Arvin Edison Water Storage District, 2002). It suggests that the increasing reliability of the water supply has helped to ensure that agriculture in the AEWSD is more productive and profitable than it would have been in the absence of the conjunctive use project. (Arvin Edison Water Storage

District, 2002).

The District continues to look for ways to build and improve upon its conjunctive use program. In 1997 it entered into a 25 year agreement with the Metropolitan Water District of Southern California to store (bank) approximately 30.8 million m^3 (250,000 acre feet). The Metropolitan Water District, which provides water supply to much of the Los Angeles-San Diego conurbation, will be able to retrieve the banked water in drought years. This program has the advantage of increasing the total quantities of stored water available to the Metropolitan Water District in dry and drought years and works to the advantage of AEWSD by raising the ground water table, thereby lowering extraction costs, and by increasing the quantities of firm water available to AEWSD users. The new facilities required for this project will also facilitate the creation of new water banking programs with other water purveyors (Arvin-Edison Water Storage District, 2000).

ANALYSIS AND LESSONS

The conjunctive use program of the AEWSD is unusual if not unique among the agricultural water districts of California and the western U.S. Typically, ground water is extracted by individual pumpers who often have little incentive to act collectively to attenuate groundwater overdraft. Rather, the historical tradition in California has been to seek relief from the consequences of ground water overdraft from the state or national government in the form of imported surface water supplies. These so-called Aphysical solutions@ are attractive because no user is forced to reduce water use below historically accustomed levels and, frequently, state and/or national government is willing to defray a proportion of the costs of developing and delivering the supplemental surface water. The typical Asolution@ in agricultural areas entails a relatively simple substitution of surface water for ground water. In some cases, the growers receiving surface water abandon their wells altogether (because the surface water is much cheaper) and in a few cases, surface water pricing policies have been manipulated to encourage individual growers to keep wells open and operating so that they can shift to ground water supplies during drought periods when supplemental surface water may not be available.

The conjunctive use program of the AEWSD stands in contrast to these simpler and more common conjunctive use regimes. The program of the AEWSD focused on the integration of surface and ground water supplies in order to: 1) increase the firmness or reliability of the total water supply despite the inherent lack of reliability in much of the surface water supply; 2) minimize the cost of distribution facilities by making surface water directly available to farms in only a portion of the District thereby allowing the natural conductivity of the aquifer to function is an important but nearly costless distribution system; 3) reduce pumping levels (depths) to something more akin to historically prevailing levels and stabilizing the aquifer around these levels thereby lowering pumping costs substantially below what they might otherwise have been and, more importantly, stabilizing those water costs; and 4) improve water quality through recharge which in turn reversed hydraulic gradients which caused the mobilization and transport of boron from the margins of the District into water underlying the lands of the District.

It is reasonable to ask whether there were particular circumstances that might have accounted for the development of a sophisticated conjunctive use program in an agricultural district that appeared not to differ much from neighboring Districts. There are a number of factors which help to explain the success of AEWSD, including several physical and hydrologic factors as well as some important economic and institutional factors. The soils of the AEWSD were relatively permeable and lent themselves to recharge operations through percolation basins. The expense of direct injection including the costs of wells and pumps were avoided. The conductivity of the underlying aquifer was relatively high, meaning that several relatively central recharge basins could be employed, thereby avoiding the costs of a great many decentralized basins.

The location of the AEWSD at the end or well downstream of two major surface water importation facilities was also of critical importance. The fact that these facilities could be tied together physically thereby allowing the simple exchange of waters between facilities coupled with AEWSD=s location meant that the District was in a position to take advantage of potential exchange arrangements in firming up its surface water allocation. The agreement with the Exchange Districts located upstream on the Friant-Kern Canal allowed AEWSD to increase substantially the quantity of its firm surface water allocation at little cost. This, in turn, reduced the scale of the recharge facilities to a level that could be reasonably financed with District sources. Thus the combination of favorable location, soils and water availability reduced the costs of a sophisticated recharge project to levels which were well within the District and its constituent growers ability to pay.

There was one additional and critically important factor that allowed - or rather did not constrain - AEWSD from developing a sophisticated conjunctive use program. California ground water law tends to be complex and fraught with uncertainties. Basically, there are two types of rights to groundwater. The correlative right, which may be established by users overlying a ground water formation, entitles right holders to make reasonable and beneficial use of ground water on overlying lands. Users must share the waters equitably with other correlative users. Correlative rights cannot be established for rights not overlying an aquifer. For these lands, appropriative rights may be established. There is no requirement for filing and licensing to establish an appropriative right to ground water use in California. It is only necessary to initiate use and ensure that it is continuous. The result is that ground water rights are not recorded or quantified except in a few urban basins where there has been extensive litigation. These circumstances have fostered situation in most agricultural areas of California in which there are virtually no restrictions on groundwater pumping other than the economic restrictions imposed by cost (Governor=s Commission, 1978).

An important consequence of the permissiveness of California=s ground water law is that the full promise of ground water banking and conjunctive use cannot be realized in areas that may be subject to competitive exploitation. The reason is that waters banked or stored as part of formal programs are subject, at least in part, to the law of capture and there is thus no assurance that the water banked by one individual or group will not be captured by a competitor who did not participate in the financing of the recharge works. Where such circumstances exist, there is likely to be underinvestment (and perhaps even no investment) in ground water recharge facilities because there is no assurance that the investor can recover fully the returns from investment in ground water recharge facilities. This conclusion, which follows straightforwardly from conventional economic theorizing, helps to explain why there has been relatively little conjunctive use and little investment in sophisticated conjunctive use schemes in the main agricultural regions of California.

Although the growers in the AEWSD area were competitive extractors of groundwater historically, the organization of the District in 1942 provided a means to collectivize their interests and allow them to manage their ground water resource in an cooperative, integrated fashion that would avoid the well known consequences of individualistically competitive extraction. This outcome would be possible in the abstract for any District. What was critical for AEWSD - and remains important to this day - is the absence of competing groundwater extractors *who are not* members of the District. The fact that the upland areas to the east and south of the District are not developed and probably not susceptible of development and the fact that areas to the north and west are not linked through subsurface hydrology in ways that would allow external pumpers to adversely exploit ground waters upon which the District relies means that the conditions that might impinge negatively on incentives to invest in ground water recharge facilities are absent. Thus, the somewhat special and unique physical and hydrologic circumstances in which the AEWSD finds itself offset the lack of specificity and certainty in California ground water law. The presence of such offsetting circumstances appears to be rare in the western U.S. and offers a strong, if partial, explanation for the general absence of sophisticated conjunctive use regimes in regions where agricultural water use predominates.

CONCLUSIONS

Sophisticated and well-integrated conjunctive use programs and systems are most likely to be found in urban areas. Water is generally more valuable in urban uses and the financial resources needed to develop sophisticated schemes of conjunctive use are usually more readily available. Additionally, the unforgiving need for the reliability of urban water supplies creates strong incentives to clarify and resolve the uncertainties related to water rights. The conjunctive use program Arvin-Edison Water Storage District is unusual, if not unique, in that it employs sophisticated and well integrated strategies to create reliable water supplies that are reasonably priced for a large group of agricultural users. The AEWSD was able to do this because of its physical location which provided access to relatively low cost quantities of supplemental surface water which could be managed conjunctively with the underlying ground water to create a reliable supply. In addition, AEWSD was able to develop such a program without costly and protracted litigation over rights to the underlying ground water even though rights to those waters had never been perfected. The absence of external claims and/or conflicts over these rights is attributable to the unique physical location of the District in which adjacent lands on two side are undeveloped and probably undevelopable and the subsurface hydrology which buffers groundwaters underlying the District from the impact of extractions that are made in neighboring areas on the other sides.

This experience helps to identify the geologic, hydrologic, economic and legal factors that are necessary for the development of highly sophisticated, well integrated conjunctive use regimes. While no one factor is sufficient to permit successful development of conjunctive use there are there are various combinations of these factors that will allow conjunctive use to be use effectively and efficiently in many agricultural regions of the world.

:

REFERENCES

Arvin-Edison Water Storage District. 2000. The Arvin-Edison Water Storage District Water Resources Management Program. (Arvin, CA., October)

Arvin-Edison Water Storage District. 2002. Cropping Patterns in the Arvin-Edison Water Storage District, 1970-2002. Unpublished Data. (Arvin, CA., July).

Bain, Joe S., Richard E. Caves and Julius Margolis. 1966. Northern California=s Water Industry (Baltimore: The Johns Hopkins University Press).

Governor=s Commission to Review California Water Rights Law. 1978. Final Report (Sacramento, CA).

Vaux, H. J., Jr. 1986. Water Scarcity and Gains from Trade in Kern County, California *in* Kenneth D. Frederick, ed. Scarce water and Institutional Change (Resources for the Future: Washington, D.C.).

BIOGRAPHICAL SKETCH

Henry J. Vaux, Jr.

DR. HENRY J. Vaux JR. is Associate Vice President for Agriculture and Natural Resources (ANR) of the University of California, System-wide. He is also Professor of Resource Economics at UC Riverside. His principal research interests are in the economics of water use and water quality. He also serves as Co-Chair of the Rosenberg International Forum on Water Policy, an on-going global dialogue to reduce water-related conflict and improve water policy. He previously served as Director of the University of California Water Resources Center. Prior to joining the University of California he worked at the Office of Management and Budget and served on the staff of the National Water Commission. He received a Ph.D in economics from the University of Michigan. Dr. Vaux is immediate past Chair of the Water Science and Technology Board of the National Research Council and is a National Associate of the National Academies.