Irrigation Water Use in the Central Valley of California

A Report of the Central Valley Water Use Study Committee

Division of Agriculture and Natural Resources
University of California

Department of Water Resources • State of California

Contents

Executive Summary

The Central Valley Water Use Study Committee was formed to explore the potential for water supply savings through greater irrigation efficiency and improved management, which would allow increased use of the currently developed water supplies for other beneficial purposes. Available data sources were identified and analyses were conducted for areas of established hydrologic units within the Valley. The 1980 crop year was established as the base year for irrigated acreage and cropping patterns. In addition, the hydrologic data used in the analyses were long- term normal-year values. The area studied was limited to the Central Valley floor and excluded the Sacramento-San Joaquin River Delta. While the committee did not have detailed, comprehensive data for a thorough scientific study, sufficient information was available for a reasonable analysis to define the magnitude of the water lost to further use and assess the potential for agricultural water conservation.

About 25.9 million acre-feet of water are applied annually on 6.8 million acres of irrigated land in the Central Valley (excluding the Delta). To evaluate the potential for real water supply savings, the committee selected three components of the water balance for study: (1) the water used through evapotranspiration of agricultural crops, (2) the water used through evapotranspiration of riparian and native vegetation and evaporation of associated water surfaces, and (3) irrigation water that deep-percolates through the soil to a highly saline sink. These three components of the water balance are considered to be irrecoverable for physical reasons or to be recoverable only at a very high cost.

The largest of the three components of irrecoverable water is evapotranspiration from agricultural crops totaling 15.3 million acre-feet in the Central Valley (excluding the Delta). Without decreasing agricultural production, however, little opportunity exists for decreasing crop evapotranspiration (ET) losses. This conclusion is predicated on the assumption that the existing irrigated acreages and crop mix will remain essentially unchanged in the near future. However, if changing economics and other factors result in some land removed from production or cause a switch to a different crop mix, different amounts of water may be required.

The committee evaluated the ET of riparian and native vegetation and evaporation (E) from open water surfaces (including rivers) by quantifying these areas from vegetation maps and aerial photography and then applying estimated ET and E rates for riparian vegetation and open water to these areas. An estimated 1.1 million acre-feet of water is used in this category. Substantial reduction in this amount, however, was judged to be either physically impractical or likely to result in significant loss of wildlife habitat. It was concluded that little of this water use could be reduced without causing substantial negative impacts. However, cost-effective actions to reduce evaporation from small canals and ditches, which have banks with very little or no vegetative cover may be possible in some cases with only minimal impact on wildlife habitat. It is estimated that this might save as much as 40,000 acre-feet.

The third component of irrecoverable water is the deep percolation of irrigation water to highly saline sinks. The committee evaluated this component by attempting to quantify the area of saline sinks according to three criteria related to the salinity of soils, the substrata, and perched water tables. The amount of water deep-percolating below the root zone of the soils in this area was then estimated by a surface water balance approach. Although these estimates are uncertain because of incomplete data for identifying the areas of saline sinks and for calibrating and validating a model used to estimate deep percolation, it was the conclusion of the committee that the amount of water reaching saline sinks is likely to be around 843,000 acre-feet.

Because it is impractical to apply irrigation water at 100 percent efficiency throughout all fields on a continuous basis and it is necessary to maintain a root-zone leaching fraction for salinity control for continued crop productivity, only a portion of this 843,000 acre-feet of water deep-percolating to saline sinks could be reduced. Assuming that an average distribution uniformity of 80 percent and a leaching fraction of 5 percent might be achievable in the areas of saline sinks and assuming that conveyance losses in the area of saline sinks could be eliminated, the amount of deep percolation water might be reduced by about 230,000 acre-feet. This reduction might be accomplished primarily through use of irrigation scheduling programs, installation of water-measuring devices, and installation of pipelines or concrete-lined ditches. The action taken would probably result in a decrease of about 20,000 acre-feet in head-ditch evaporation and evapotranspiration by field-edge native vegetation. With the addition of the 40,000-acre-foot savings from canals and ditches having very little or no vegetation, the total savings would amount to about 290,000 acre-feet. The average annual cost of accomplishing this savings would be slightly more than $44 million, or about $150 per acre-foot. It is obvious that estimates of the costs of reducing the amount of water irrecoverably lost in agricultural use are highly uncertain because of the lack of complete data. However, it is considered a reasonable estimate based on the best information available.

For locations where water percolates to unusable saline groundwater, the initial estimate of the quantity percolating was about 1.2 million acre-feet. Further analysis showed that, in some of the designated areas, some of this water is usable and/or is being used. Adjustments were made to reflect this finding, resulting in the estimate of 843,000 acre-feet. Additional information indicates that this, too, may be high. However, the committee agreed to base estimates of potential savings on the 843,000 acre-feet figure. In view of the considerable discussion during the course of the study regarding the reliability of some of the data and the validity of some of the specific assumptions, it is interesting to note that, if the calculation were based on the initial, unadjusted percolation estimate of 1.2 million acre-feet, the resulting estimated potential water savings would be about 100,000 acre-feet higher than that based on the 843,000 acre-feet percolation. On the other hand, if the percolation to unusable saline water is less, as some information indicates, the potential savings would be correspondingly lower.

Changes in economics, crop patterns, and irrigated area may occur, which may cause the amount of water lost to saline groundwater to be different from these estimates. However, such speculation was not part of the charge given this committee.

Research to estimate evapotranspiration more accurately from real-time weather data would improve the data base and assist in increasing irrigation efficiency. Research on increasing the distribution uniformity of irrigation systems would also help farmers to decrease the amount of irrecoverable water going to saline sinks.

In summary, some potential for water supply savings through increased irrigation efficiency and water management exists for land where excessive deep percolation would result in an irrecoverable loss to a saline sink. Water conservation programs to decrease this loss would allow for some increased use of currently developed water supplies but not without substantial costs to growers and public agencies.

Irrigation Water Use in the Central Valley of California

Water Use Issues

Water resource planning and development in California have had a long and complex history. Unevenly distributed seasonal and geographical precipitation and competition between agricultural, wildlife, fisheries, municipal, industrial, and environmental demands for water result in complex issues related to the management and utilization of California's water resources. Approximately 25.9 million acre-feet of water is applied to fields to irrigate 6.8 million acres in the floor of the Central Valley, excluding the Sacramento-San Joaquin River Delta area (Department of Water Resources [DWR], 1983).

Since it is expected that an increased supply will be required to meet California's growing demand for water into the next century, the large amount used by agriculture (84 percent of the water supply) is often targeted as offering possibilities for savings of water to be directed to other uses. Agricultural water conservation has been suggested by some as a means of totally overcoming the state's water deficit and of meeting the increasing demand for water. Others believe that the projected deficit can be met only by further development of northern California water sources. Still other points of view lie somewhere between these two extremes.

In response to concern about these issues, a committee was appointed jointly by Lowell Lewis, Director of the Agricultural Experiment Station of the University of California, and David Kennedy, Director of the Department of Water Resources, State of California (appendix 1). The Central Valley Water Use Study Committee (CVWUSC) was formed to explore the potential for water supply savings through increased irrigation efficiency and improved management, which would allow increased beneficial use of the currently developed water supplies. The committee consisted of faculty from the University of California and representatives from federal, state, and local water agencies dealing with water in California. Several subcommittees were also formed to evaluate specific components of the study (appendix 2).

In evaluating the possibilities of water conservation, it is important to distinguish between recoverable and irrecoverable water. Recoverable water is that which moves out of a particular area where applied, but which is still available for reuse, although its recovery may necessitate pumping and therefore added cost. It includes runoff, deep percolation, and seepage, and is not a true physical loss of water but may undergo a significant change in quality (Davenport and Hagan, 1982). Irrecoverable water is (1) that which volatilizes by evaporation or transpiration to the atmosphere, from which it cannot be recovered except through rain and snow in the hydrologic cycle, and (2) that which flows to highly saline sinks such as the ocean, salty inland seas, or saline groundwater reservoirs, from which recovery in usable form is physically possible but at a very high cost (Davenport and Hagan, 1982).

The term "water conservation" has different meanings to different groups of our society. Some of the various interpretations of this term are: prevention of damage, loss, or waste; reduction in rate of use; reduction in demand; efficient use for the good of all; and saving. Webster defines "conservation" as "planned management of a natural resource to prevent exploitation, destruction, or neglect," and "to conserve" as "to keep from being damaged, lost, or wasted; to save." With respect to water conservation, Webster's definitions are controversial. For instance, there is disagreement about what "wasted" water is and when "exploitation," "neglect," and "saving" occur.

Water conservation is a management objective to beneficially use the available water in a manner planned to minimize exploitation and degradation of the resource. Although the general term "beneficial purpose or use" is not subject to precise definition, it generally includes two related, but somewhat different, concepts: social utility and engineering efficiency. Thus, a use is beneficial if it involves some socially accepted purpose and it makes a reasonably efficient use of water (definition adapted from Davenport and Hagan, 1982). Beneficial uses do not include all the reasonable uses of water. The State Water Resources Control Board, for instance, considers that disposal of wastewaters and use of water for dilution of salts are not beneficial uses but may be reasonable and desirable uses of water. For the purposes of this study, beneficial uses are defined as presented in the State Water Resources

Code and in accordance with rulings of the State Water Resources Control Board. The Board has provided a list of beneficial uses of water (State Water Resources Control Board, 1975).

In this report, the following definition of water conservation is used: "Water conservation embodies those practices that result in a decrease in the amount of irrigation water irrecoverably lost during agricultural use."

Objectives

In the first few meetings, the committee focused on developing a set of objectives that would result in fulfilling its charge. The committee also used these meetings to develop common terminology across diverse disciplinary areas (see Glossary). The four objectives were:

1. To evaluate from available data sources the hydrologic balance of existing, developed water supply and water use in the Central Valley.

2. To quantify the amount of irrigation water that is irrecoverably lost during agricultural use and the amount of recoverable losses currently not being recovered by agriculture.

3. To estimate the potential for and costs of reducing the amount of irrigation water irrecoverably lost in agricultural use; to estimate the potential for and costs of increasing the agricultural use of recoverable losses; to identify the impact of such actions on the nonagricultural benefits currently being served by these agricultural losses.

4. To delineate and evaluate prospective research that may result in a net decrease in agricultural water use.

Data Sources

The first major task was to review the available information related to the issue of agricultural water use in California's Central Valley. It was expected that there would be many reports available from a large number of agencies, institutions, and individuals. This turned out to be the case, although it became apparent that significant sharing of information occurs among the larger water organizations in the state. It was also apparent that more information is needed to answer with a high degree of precision the questions the committee was charged to address.

The committee evaluated the many sources of data available on the agricultural water use issue -- primarily federal, state, private, and public water agencies. In addition, because of cooperative agreements between different agencies and the many interagency committees and studies, several data sets are sponsored by combinations of these groups. A tabulated review of the agencies that have been involved with the CVWUSC directly through committee membership or indirectly through data, reports, and information utilized by the CVWUSC is given in appendix 3.

Time Boundaries of Study

Agricultural systems are rarely static. Whether one is considering the weather, the economic market, the technological development, or the skills of the farmer, change relative to time should be taken into account. For this reason, the information developed for this report must be interpreted in light of certain temporal characteristics in the data.

Agricultural development in California's Central Valley was still continuing to very recent times. Total irrigated acreage in the Central Valley increased by 10 percent or 683,000 acres from 1972 to 1980 (DWR, 1983). Recent economic problems have temporarily idled crop production on some land. Future growth is uncertain.

For all calculation purposes, the committee selected 1980 as the base year for this report on the level of agricultural development. For this discussion, "developed land" refers to land in production under specific crops in the 1980 crop year.

Some of the changes in other factors that have occurred since 1980 have been considered in order to provide timely and pertinent information, such as the latest available knowledge on conservation practices. In some cases, the available data were collected before 1980. In all cases, however, the most recent and complete data available were used.

The DWR maps land use in different Central Valley counties each year with each county remapped about every six to seven years. Interpolations and extrapolations of acreages were made for 1980 based on the amount of change between the date of DWR's most recent survey and 1980 as indicated by county agricultural commissioners' annual crop reports and data from the California Crop and Livestock reporting service. Hence, the acreages used in this study may not be actual mapped values in all cases. In the case of annual crops, this may result in some minor difference as county totals had to be disaggregated to smaller study areas. Values for perennial crops, such as vineyards and orchards, should be close to actual due to the long-term nature of the crop.

Data collected for other studies were also used for this report. For consistency, the values used for precipitation and evapotranspiration in this study were the long-term, normal-year values that are the means of all data on record.

The two basic assumptions -- (a) long-term, normal-year and (b) 1980 level of development -- were necessary and helpful in analyzing the data and the development of this report.

The implication of the first assumption is that many years will not fit the long-term average and will have greater or less evapotranspiration than the normal. If changing economic or environmental constraints result in change in irrigated land and/or crop patterns from those which existed in 1980, more or less water may be used to meet evapotranspiration requirements.

Study Areas of the Central Valley

An early task was to define the areas over which the study would be made. An initial decision was to limit the analysis to the 7.45 million irrigated acres of the Central Valley floor (DWR, 1983). This was further reduced to exclude the 700,000 acres that constitute the Sacramento-San Joaquin Delta area. The size of the area and available data dictated the selection of a system that allowed a definitive analysis without undue complexity. Three of the possible study areas that were evaluated for data delineation were: private water-service agency boundaries; county boundaries; and the DWR system, referred to as hydrologic study areas (HSAs), planning subareas (PSAs), and detailed analysis units (DAUs).

In 1981, the Department of Water Resources adopted a system of analysis to facilitate scientific, political, and management research for state water resources. This system generally follows boundaries previously used by the DWR, the State Water Resources Control Board, and the U.S. Geological Survey for hydrologic data compilation purposes. The boundaries generally follow hydrographic boundaries, water-service agency boundaries, county lines, or a combination of these lines to give the most useful breakdown. The committee determined that this system would ease data calculation, analysis, presentation, and understanding. The system follows a hierarchy, as previously given, of hydrologic study area, planning subarea, and detailed analysis units.

Hydrologic Study Areas (HSA)

For planning purposes, the state is divided into 12 HSAs (fig. 1). Three of these are within the floor of the Central Valley: the Tulare Lake HSA, the San Joaquin HSA, and the Sacramento HSA. These HSAs embrace the three major hydrologic basins of the valley floor.

Planning Subareas (PSA)

Most of the analysis for this report was conducted on a PSA basis. The DWR developed this level of study so that its staff could consider geographic units small enough that they could specifically identify resources and problem areas yet large enough that the volume of information, calculations, and logistical paperwork would not overpower the primary purposes of study. For these same reasons, the committee used the PSA as the primary analysis unit. Also, much of the data provided by DWR for the study had already been collated for this entity. The ten PSAs in this study fell within the boundaries of the valley floor, excluding the Delta (fig. 2).

Detailed Analysis Units (DAU)

Where greater definition was needed, DAUs making up PSAs were used. Data from these smaller study units delineated areas of saline sinks. These DAUs follow the same method of formulation as the HSAs and PSAs, but at a smaller scale. Up to 15 DAUs may make up a PSA, and there are 58 DAUs in the Central Valley (excluding the Delta) (see fig. 3, 4, and 5).

Components of Water Balance Selected for Detailed Study

In the water balance evaluation, transfers of recoverable water within the Central Valley or within a study area were not targeted for study, since this water would not affect a real water supply savings. Transfers resulting in irrecoverable losses, however, were evaluated. In this report, the irrecoverable losses are considered to be: (1) losses due to evapotranspiration (ET); and (2) losses that occur when salinity causes the water to become unusable.

Evapotranspiration (ET) and Evaporation (E) of Agricultural Water Supplies

The major loss components of agricultural water supplies are through evapotranspiration by agricultural crops, through evaporation from water surfaces in canals, ditches, drains, ponds, lakes, and reservoirs, and evapotranspiration by riparian or native vegetation along canals, streams, drains, and other wetlands.

Agricultural crop ET. The committee accepted estimates of agricultural crop ET developed by the DWR and presented in Bulletin 160-83, *The California Water Plan - Projected Use and Available Water Supplies to 2010.* That report contains a description of the data and assumptions behind these estimates. Briefly stated:

1. DWR determined the acreage of each crop type by mapping the irrigated area at a scale of 1:24,000, noting field boundaries and individual crop type.

2. Specific crop unit ET (acre-feet/acre), ET of applied water (ETAW), and applied water (AW) values appropriate for each analysis area were determined.

3. And from the crop acreage data and these unit water use values, total ETAW and total crop AW were calculated.

DWR Bulletin 113-3 (DWR, 1974), *Vegetative Water Use in California*, presents the basic data and derivation of the unit ETAW values. The latest bulletin in the series (DWR, 1986) summarizes more recently collected information on crop water use. The data were obtained from extensive field investigations by the Department of Water Resources, the University of California (UC), and the Agricultural Research Service (ARS) of the U.S. Department of Agriculture (USDA).

The specific procedures followed by the DWR, and to some extent the other agencies, were influenced by DWR

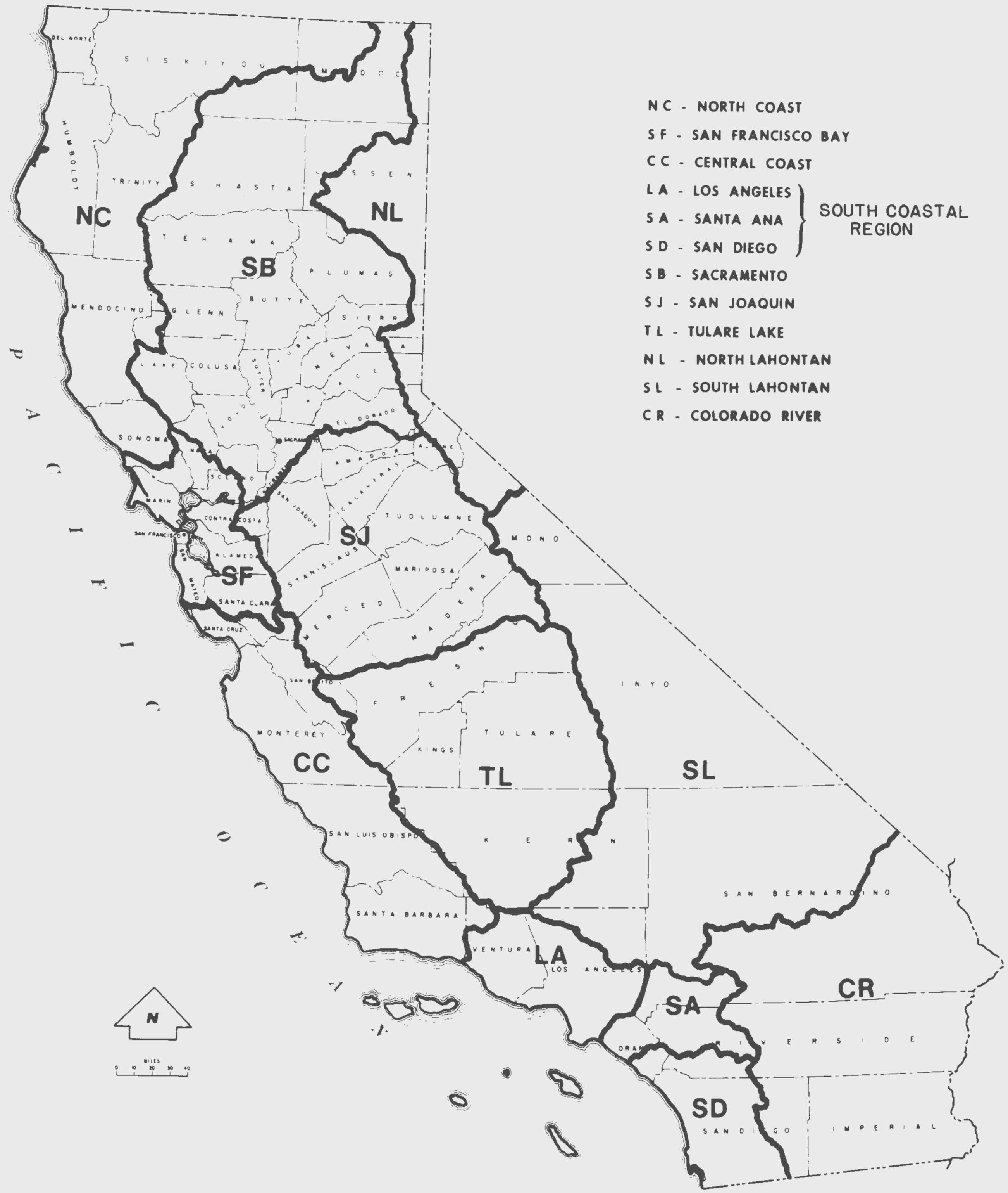


Fig. 1. Hydrologic study areas of California.

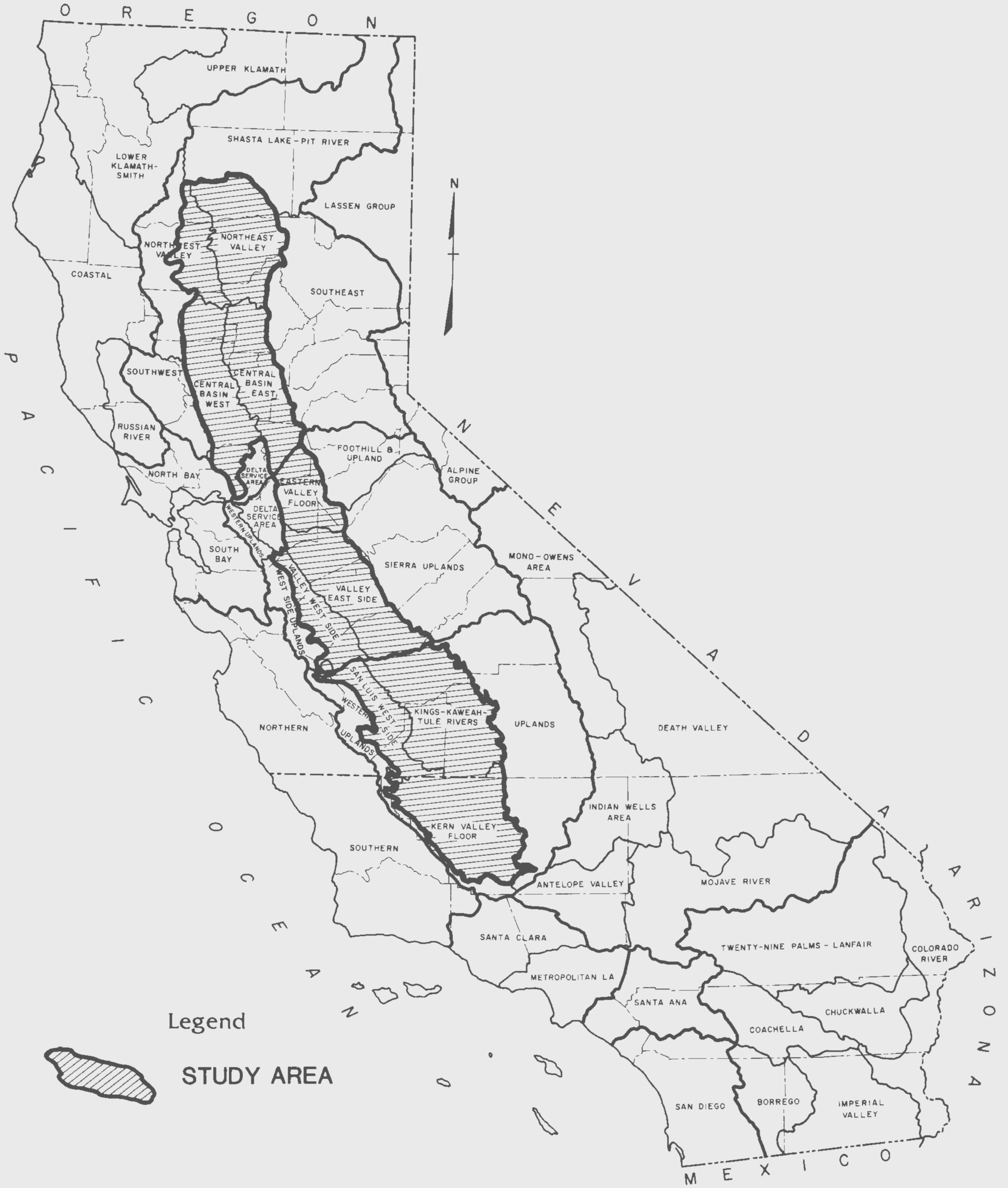


Fig. 2. Hydrologic study areas and planning subareas.

Shasta Lake - Pit River-01
  Gooselake-Alturas (130)
  Big Valley (132)
  MacArthur-Hat Creek (134)
  Upper Shasta Lake (136)

Northwest Valley-02
  Clear-Cottonwood Creek (137)
  Stony-Elder Creek Group (139)
  Redding West (141)
  Red Bluff-Orland (142)

Northeast Valley-03
  Redding East (143)
  Los Molinos (144)
  Cow-Battle Creek (145)
  Eastside Creek Group (147)

Southeast-04
  Feather River (154)
  Yuba-Bear Rivers (156)
  American River (158)
  (Foothill)
  Honcut Foothill (159)
  Yuba Foothill (160)
  Placer Foothill (161)

Central Basin West-05
  Lower Cache (162)
  Willows-Arbuckle (163)
  Glenn-Knights Landing (164)
  Vacaville (191)

Central Basin East-06
  Meridian-Robbins (165)
  Durham-Sutter (166)
  Butte City (167)
  Honcut-Gridley (168)
  Yuba (171)
  Placer (172)
  Sacramento (173)

Southwest-07
  Cache Creek (174)
  Putah Creek (175)

Delta Service Area-08
  Sacramento Delta (186)

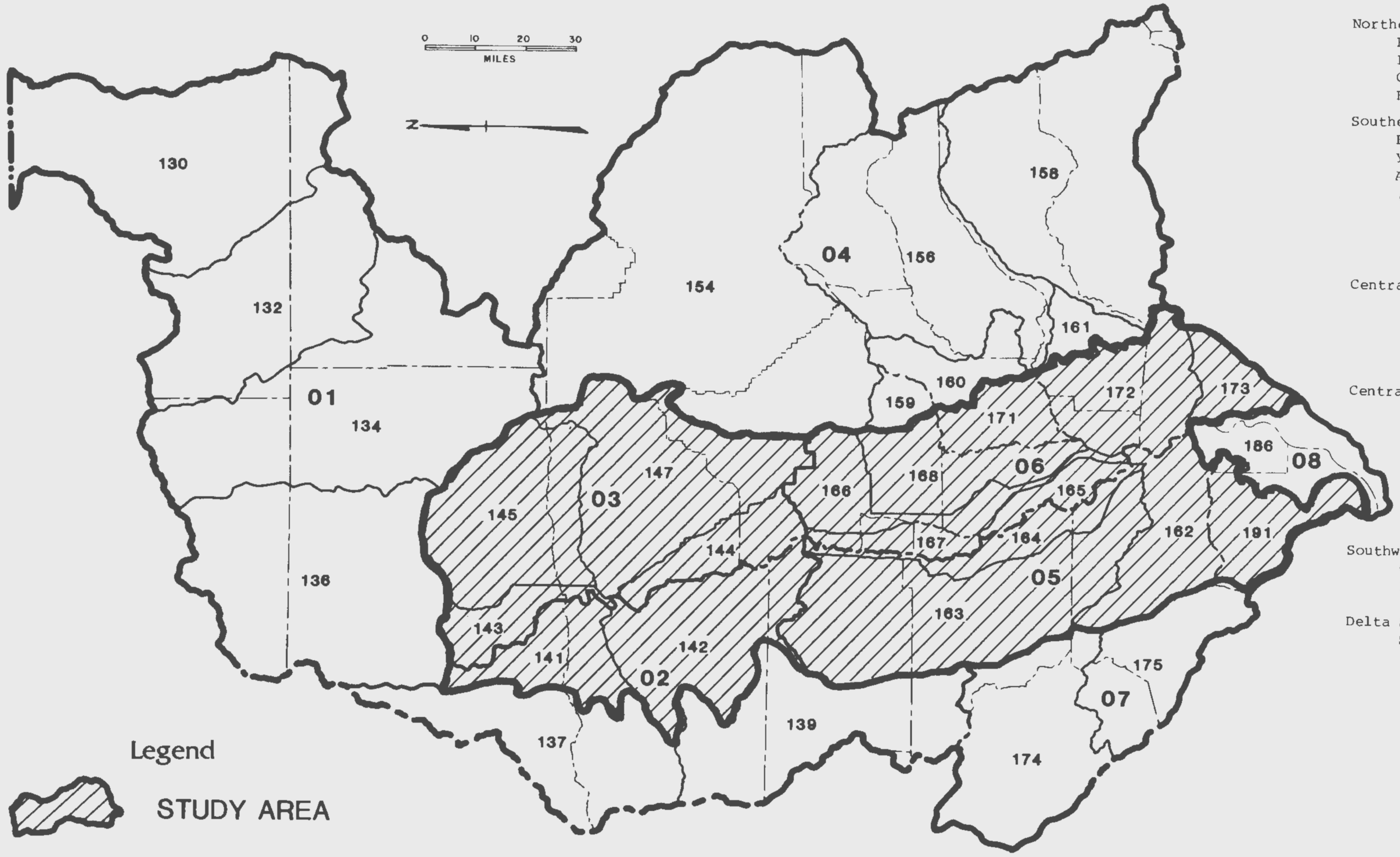
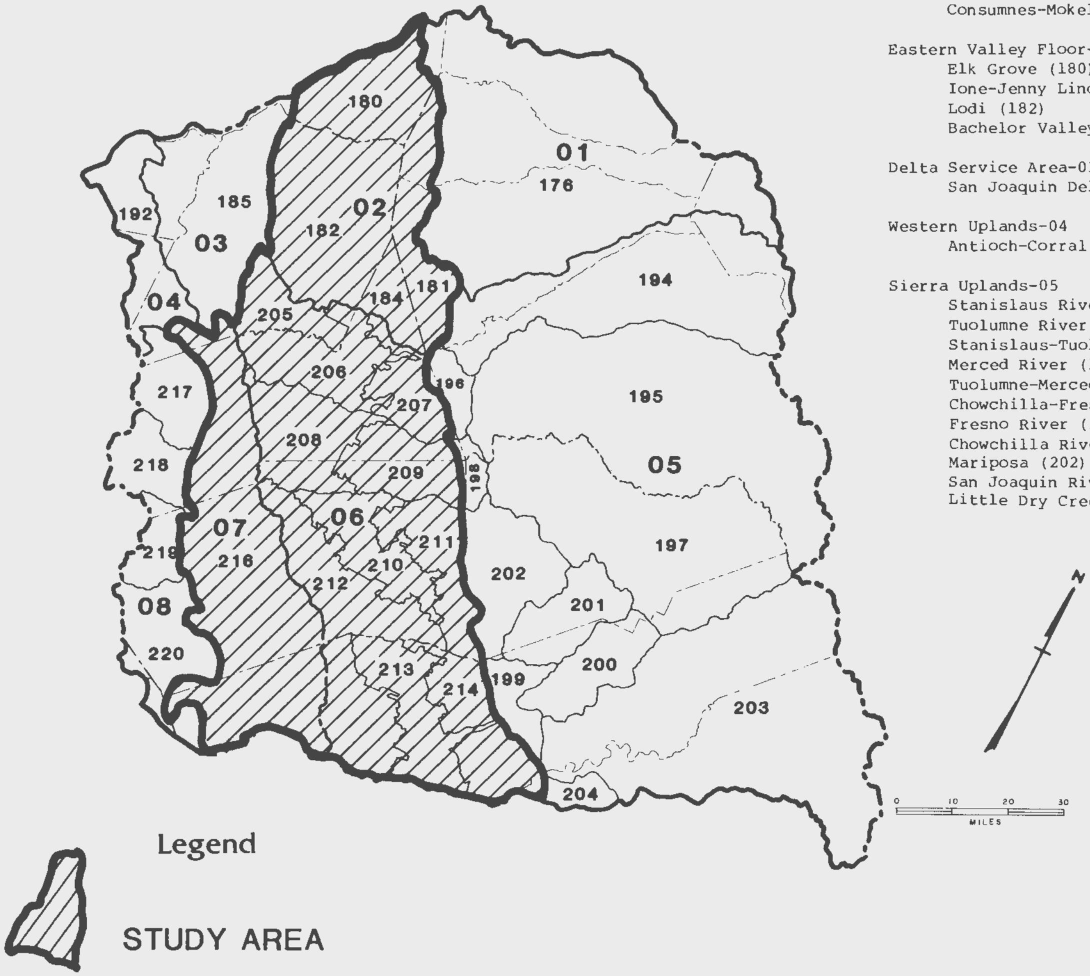


Fig. 3. Planning subareas and detailed analysis units in Sacramento HSA.



Foothill and Upland-01
    Consumnes-Mokelumne-Calaveras (176)

Eastern Valley Floor-02
    Elk Grove (180)
    Ione-Jenny Lind (181)
    Lodi (182)
    Bachelor Valley (184)

Delta Service Area-03
    San Joaquin Delta (185)

Western Uplands-04
    Antioch-Corral Hollow (192)

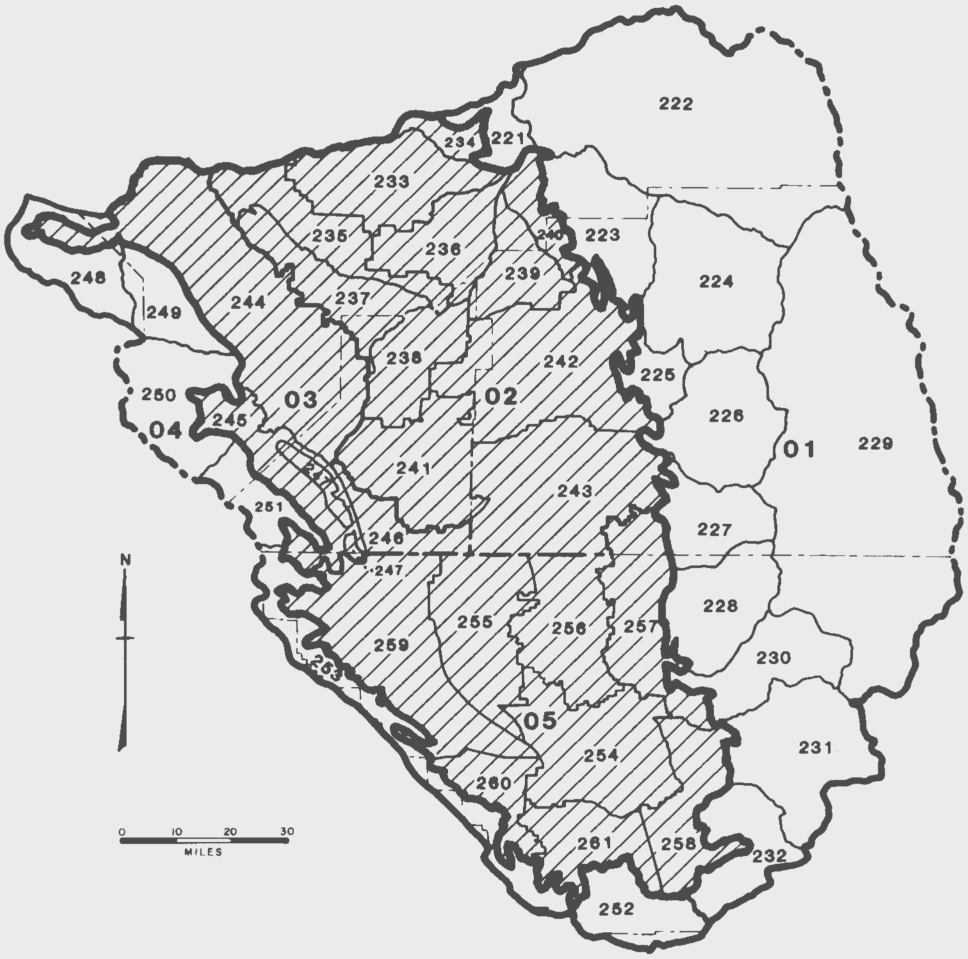
Sierra Uplands-05
    Stanislaus River (194)
    Tuolumne River (195)
    Stanislaus-Tuolumne Interstream (196)
    Merced River (197)
    Tuolumne-Merced Interstream (198)
    Chowchilla-Fresno River Interstream (199)
    Fresno River (200)
    Chowchilla River (201)
    Mariposa (202)
    San Joaquin River (203)
    Little Dry Creek (204)

Valley East Side-06
    South San Joaquin ID (205)
    Modesto-Oakdale (206)
    Modesto Reservoir (207)
    Turlock (208)
    Turlock Lake (209)
    Merced (210)
    Merced Stream Group (211)
    El Nido-Stevinson (212)
    Madera-Chowchilla (213)
    Adobe (214)
    Gravelly Ford (215)

Valley West Side-07
    West Side (216)

West Side Uplands-08
    Del Puerto Creek (217)
    Orestimba Creek (218)
    San Luis Creek (219)
    Los Banos Creek (220)

Fig. 4. Planning subareas and detailed analysis units in San Joaquin HSA



Uplands-01
- San Joaquin-Kings Interstream (221)
- Kings River (222)
- Kings-Kaweah Interstream (223)
- Kaweah River (224)
- Kaweah-Tule Interstream (225)
- Tule River (226)
- Deer Creek (227)
- Poso Creek (228)
- Upper Kern River (229)
- Lower Kern River (230)
- Caliente Creek (231)
- Cummings (232)

Kings-Kaweah-Tule Rivers-02
- Fresno (233)
- Academy (234)
- Raisin (235)
- Consolidated (236)
- Lower Kings River (237)
- Hanford-Lemoore (238)
- Alta (239)
- Orange Cove (240)
- Tulare Lake (241)
- Kaweah Delta (242)
- Tule Delta (243)

San Luis West Side-03
- Westlands - (244)
- Kettleman Plain (245)
- South Tulare Lake (246)
- Kettleman Hills (247)

Western Uplands-04
- Panoche Creek (248)
- Ciervo Hills (249)
- Los Gatos Creek (250)
- Reef Ridge (251)
- Grapevine (252)
- Temblor (253)

Kern Valley Floor-05
- Kern Delta (254)
- Semitropic (255)
- North Kern (256)
- Northeastern Kern (257)
- Arvin-Edison (258)
- Antelope Plain (259)
- Buena Vista Valley (260)
- Wheeler Ridge-Maricopa (261)

Legend

▨ STUDY AREA

Fig. 5. Planning subareas and detailed analysis units in Tulare Lake HSA.

needs for broad-area, regional ET estimates for macro-analysis of the hydrologic balance. The studies measured ET of a standard irrigated crop (grass or alfalfa) at some ten sites in California using lysimeters. Correlations of grass ET with pan evaporation losses were established. These relationships were then applied to evaporation values obtained from scores of pans located in a network of Agroclimate stations (primarily under DWR jurisdiction) to predict monthly values of "potential ET" for some ten California regions (DWR, 1975). Later the University of California (Pruitt et al., 1987) produced maps of the state having superimposed lines of equal reference ET (potential ET) for each month of the year.

In addition to the program to establish potential ET information for the state, soil moisture depletion studies were conducted on many crops and in many locations to establish crop ET data and relationships between crop ET and potential ET or pan evaporation. DWR used neutron probes for their work, while lysimeter studies by UC and the ARS provided much additional information. The combination of all of these studies provided estimates of ET for most regions of the state. The values derived should represent expected ET losses during a year of normal weather conditions. When used in a hydrologic analysis for an average year, they should provide a close approximation of the quantity of agricultural water supply lost to further reuse through evapotranspiration. A summary of ET of applied water for crops in the ten PSAs is given in table 1.

The committee recognizes several factors that create considerable uncertainty in evaluation of expected losses through evapotranspiration. Briefly, they relate to one or more of the following:

> Owing to difficulty in obtaining ideal stands of crops and then of achieving adequate uniformity of irrigation water distribution, many fields produce lower yields in some portions of the field than in others. Poor crop stands or prolonged wilting would result in lower ET values than those listed in table 1.
>
> Any shift in cropping patterns could change ET to more or less than the values in table 1. Such changes could include increased use of double-cropping practices or growth of lower-water-use crops.
>
> With the high value of land and ever-increasing costs of water and power, it is likely that planting of more valuable cash crops, and specifically more permanent crops (orchards, vineyards, and the like), will increase ET and that the annual demand for water may grow rather than decline on a per-acre basis.
>
> A shift in irrigation methods could produce some changes in water requirements needed to meet ET demands. Indeed, the evaporation component of ET has been shown to be reduced considerably through the use of trickle irrigation during early growth stages of trees or vines. Decreased evaporation losses have also been reported for some crops with wide row spacing, especially if surface wetting is avoided by using buried emitters. For more closely spaced row crops and for tree and vine crops providing nearly full shading of the ground, the evidence of water savings is debatable. One aspect of considering any dramatic shifts from surface to trickle or even sprinkler irrigation is the likely prospect of improved distribution uniformity, improved stands, fewer fields with partial wilting, and a higher per-acre demand for water needed to meet ET requirements.
>
> Perhaps one of the greatest uncertainties involving the ET of applied water is the natural variation of climate from year to year. This can be illustrated by an example from UC Davis studies. Although a 16-year record of measured ET for grass showed a record high annual total of only 7 percent above the 51.5-inch average, the annual total of ET minus precipitation (P) showed much greater variation because of a strong negative correlation between ET and P. During one year out of four, ET minus P was at least 25 percent above the average yearly value of 34.4 inches over the 16-year period. This variability would, of course, be much reduced for the southern San Joaquin Valley, where precipitation meets much less of the ET demand. Nevertheless, the use of normal-year data in this analysis might well bias the results towards an underestimation of ET of applied water for one year out of three, on the average.

Nevertheless, assuming long-term, normal-year conditions, and a 1980 level of development, the 15.3 million acre-feet of ET is considered a reasonable estimate. It was concluded that the small amount of reduction in crop ET that could be economically and feasibly obtained did not warrant attention by the committee. Generally, crop ET cannot be decreased without decreasing yield, except for some crops such as cotton or cultivars with shorter growing seasons. If changing economic conditions and other factors result in some land removed from production or cause a switch to different crops, different amounts of water may be required.

ET of riparian vegetation and evaporation from water surfaces. For the determination of water use by riparian vegetation in the Central Valley, the committee used several sources of information (DWR, 1975; DWR, 1982a; Jensen, 1973; Westlands Water District, 1985). The largest single data source was a 1979 study done by the Geography Departments of California State Universities at Fresno and Chico under contract to the State Department of Fish and Game. Reports and maps of riparian vegetation for the Central Valley were prepared in which the riparian vegetation was classified by types that can be identified from aerial photography. Acreages were determined and appropriate unit-area ET values were provided by the Evapotranspiration Subcommittee. Combin-

TABLE 1

EVAPORATION OF WATER APPLIED TO AGRICULTURAL CROPS IN THE CENTRAL VALLEY (EXCLUDNG THE SACRAMENTO-SAN JOAQUIN DELTA)

Planning Subarea	Irrigated Area (1,000 acres)	ETAW (1,000 acre-feet)
Tulare HSA		
Kern Valley Floor	938	2,139
San Luis West Side	623	1,269
Kings-Kaweah-Tule	1,744	3,902
San Joaquin HSA		
Valley West Side	424	957
Valley East Side	1,033	2,301
Eastern Valley Floor	309	664
Sacramento HSA		
Central Basin West	765	1,707
Central Basin East	711	1,853
Northwest Valley	117	284
Northeast Valley	95	214
TOTALS	6,759	15,290

ing the known areas with the ET estimates, an estimate of the riparian vegetation water use was obtained.

Following is a brief review of the steps used in this mapping project:

1. The mapping was done on standard 1:24000 scale U.S. Geological Survey (USGS) 7-1/2' Topographic Quadrangle base (quads). A total of 465 individual overlay maps were developed from 388 original quads. Maps were split by county division, allowing for some quad ranges to be duplicated in overlay maps. Overlay maps were completed on fade-out blue or mylar materials.

2. The riparian vegetation was identified by photo interpretation of DWR's 35 mm Ectachrome slides. DWR had collected these slides over several years for land-use surveys and for identifying riparian vegetation.

3. The California State University researchers reviewed the slides and depicted vegetation (trees, shrubs, and herbaceous cover), urban, agricultural, and open water surface areas. Native vegetation and other areas were classified as follows:

Class

R1 Large woody vegetation: black walnut, western sycamore, Oregon ash, and willow. A dense understory of shrubs and vines is usually associated with the older woody species.

R2 Low woody vegetation: younger trees that will eventually grow tall and become R1. Willows, cottonwood, and brush dominate much of this group.

R3 Herbaceous vegetation: annual and perennial grasses and low-growing flowering plants.

M Marsh: tules, cattail, sedges, and rushes.

W Water surfaces: reservoirs, ponds, lakes, canals, drains.

i Intermittent: Used to designate spottiness or nonconsistent occurrence of a given vegetative type.

4. The above areas were defined by two methods. Lines represented narrow strips of vegetation considered to be less than 60 feet in width. This was necessary because of the scale of mapping. Polygons were used to identify larger areas. These measurements were then converted to acres of polygon or miles of lines per quadrangle and then summarized into county totals (Katibah, Nedeff, and Dummer, 1980).

5. Vegetative types from aerial photographs were interpreted by careful evaluation of standard image characteristics (color, pattern, shape, texture, association, size, shadow, and topographic location). Field checks were made of riparian vegetative types. Also, areas that appeared vague or questionable under photointerpretation were visited.

6. The riparian vegetative data presented by the Department of Fish and Game were listed by quad (class code, area, and length) and by county summary. The DWR reassembled the data for use by planning subareas. The total area of the many miles of narrow strips of riparian vegetation was estimated by assuming that the average width of the riparian vegetation was 30 feet.

For each of the general categories of riparian areas identified in the Fish and Game study, unit area water use was estimated, for the most part, by relating the vegetation characteristics and water use to those for rice. Water use data collected for rice (3.75 acre-feet per acre) were applied as follows for the given types of mapped vegetation:

The ET rate for areas mapped as "marsh" were considered to be 1.0 times the ET rate for rice in that area.

For areas mapped as polygons of riparian vegetation, an ET rate equal to that of rice was utilized.

For areas mapped as strip vegetation, or linear mapped zones, an ET rate of 1.5 times that of rice was used.

This was assumed to be a better estimate of riparian vegetation ET than applying data from studies that may have been completed elsewhere and then modifying the information for the Central Valley. Different multipliers of the rice ET rate used in the case of marsh and linear measurements were based on the subcommittee's knowledge and judgment. The justification for the higher rate for linear strip vegetation over that of rice was that crosswinds cause greater amounts of ET in the riparian vegetation of classes R1 and R2.

Some components were not evaluated in the Department of Fish and Game survey. It mapped open water surfaces of major rivers but did not make an acreage estimate, nor did it include all irrigation distribution and drainage ditch systems (conveyance systems). Only those having shrub and tree cover discernible from aerial photographs were mapped. Also not included were field edges, which are noncropped but may consume irrigation water by native vegetation ET, and head ditches, which use water by evaporation. DWR staff developed estimates of uses of this type, because most water surface areas as well as crop fields have been mapped by DWR land use surveys.

Not all irrigation water distribution and drainage systems have riparian vegetation, but all have evaporation losses. Some may have vegetation so small it is not distinguishable by aerial photography and consequently would not be picked up by the Fish and Game survey. DWR estimated these undetermined losses by comparing Bulletin 160-83 surface water distribution system losses (estimated from hydrologic balance analysis) with the estimates of such losses based on the Department of Fish and Game's linear riparian vegetation data. Any excess losses are presented in tables 2, 3, and 4 under the heading "Additional Distribution System." To derive an acreage estimate, the quantity (in acre-feet) of "Additional Distribution System" losses was divided by a unit water use rate of rice (3.75 acre-feet).

The final area of vegetation and open water surface not included in the Fish and Game study is the noncrop vegetation around field edges and along head ditches. The growth of this vegetation is in direct proportion to available soil moisture and management practices. Pipelines, lined canals, and well-managed weed removal programs create little opportunity for its growth. Based on field experience, DWR's planning staff estimated that the area of head ditches and field edge losses varied with location from 0.25 percent of the total irrigated area in Kern Valley floor to 1.5 percent in the Sacramento Valley. This estimate is based on differences considered to exist between areas south and north of a "base" area chosen for analysis, which lies along the central eastern side of the Valley. For this area, each cropped field was estimated to have 5 feet of vegetation around all sides. This results in about 0.9 acre of vegetation for every 80-acre field (estimated as the average size in this area) or about 1 percent. The total acreage of vegetation was then estimated based on the total cropped acreage. An ET rate of 3 acre-feet per acre was used to estimate the water loss by this category.

The unit rates and acreages used to estimate water use (ET and E) and the total amount of water used by riparian vegetation and associated bodies of water in the Central Valley appear in tables 2, 3, and 4. These two categories use about 1.1 million acre-feet (table 4), a very small amount in relation to crop ET (table 1). Potential decreases in water used for the categories in table 4 will be discussed under "Water Conservation Potential."

Transfers of Agricultural Water to Saline Sinks

The previous section indicated that a significant portion of the water diverted to irrigated agriculture is irrecoverably lost through evapotranspiration by crops and riparian vegetation and through evaporation from water surfaces. The other major quantity of irrecoverable loss occurs as diverted water that is severely degraded by moving into bodies of saline water or through highly saline soils.

This section presents the approach and criteria used to estimate irrecoverable losses of agricultural water to saline sinks. A saline sink is defined as a body of water that is so saline that the potential for water reuse by agriculture is quite limited. A saline sink may also include saline soils and substrata materials from which percolating water picks up dissolved mineral salts to the extent that its quality is severely impaired.

The major sources of salts in irrigation return flows are dissolved mineral salts initially present in the diverted irrigation water and soluble salts and readily soluble minerals (e.g., gypsum) native to the soil and substrata. Other sources of salts include soil and water amendments, animal manures, and fertilizers. More or less pure water is lost to the atmosphere in the evapotranspiration process, and the dissolved mineral salts in the applied irrigation water accumulate in the soil. Actively growing vegetation thus concentrates salts in its root zone. In the west side of the San Joaquin Valley, soil gypsum at varying concentrations is present in surface soils, the underlying stratum, or both. This soil mineral derived from the marine sedimentary rocks in the Coast Range does contribute significantly to the salinity of percolating waters.

The presence of toxic levels of trace elements, such as boron, selenium, molybdenum, arsenic, and chromium, may also impair the quality of irrigation return flows. Of these trace elements, the presence of excessive concentrations of boron is widespread and closely corresponds to salinity. In this investigation, salinity is taken as the principal quality parameter. The committee developed methodology to estimate the quantity of deep percolation of applied agricultural water that is functionally removed from the usable water system because of quality constraints. Three sources of degradation were considered: (1) deep percolation into or through saline geologic formations; (2) mixing with saline perched water table near the ground surface; and (3) percolation of applied water through saline surface soils.

Areas of possible irrecoverable losses. The alluvium of the valley floor is derived from parent material from the mountains of either the Sierra Nevada or the Coast Range. The Sierra Nevada is largely granitic in nature. The Coast Range is made up of sedimentary rock that is marine in origin, as well as metamorphic rocks. The Tehachapi and the neighboring San Emigdio Mountains are composed of both granitic and sedimentary components.

Under most circumstances, the quality of groundwaters and percolating waters varies in relation to the alluvium produced from different rock types. Granitic and metamorphic alluvium are low in salts, and therefore the deep percolation water does not dissolve appreciable amounts of salts from the soil and substrata. Alluvium from marine sedimentary rocks, however, does contain large amounts of mineral salts (Doneen, 1967). The percolating waters passing through these geologic formations and soils can dissolve and transport large amounts of salt (Tanji, Doneen, and Paul 1967; Biggar, Rolston, and Nielsen, 1984). The east side of the Central Valley has little saline groundwater of geologic origin, while the west side of the San Joaquin Valley has large areas with saline groundwater.

Perched water tables occur when alluvium of low permeability impedes percolating waters from penetrating to greater depths. Dense clay layers are generally the cause

TABLE 2

ESTIMATED ACREAGES OF RIPARIAN VEGETATION AND WATER SURFACES IN THE CENTRAL VALLEY (ALL VALUES IN 1,000 ACRES)

Planning Subarea	Major Rivers	Riparian Vegetation (Fish and Game Mapping)			Water Surface (DWR)	Additional Distribution System	Head Ditches & Field Edges (DWR)	Total
		Polygons	Linear	Marsh				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Tulare HSA								
Kern Valley Floor	0	1.8	.3	.1	1.8	3.5	2	9.5
San Luis Westside	0	.3	.3	1.2	.1	2.9	2	6.8
Kings-Kaweah-Tule	4.5	7.6	1.7	1.0	5.4	6.7	9	35.9
San Joaquin HSA								
Valley Westside	5.3	1.8	.5	.1	2.5	5.3	3	18.5
Valley Eastside	21.0	4.4	1.3	2.0	.9	8.5	10	48.1
Eastern Valley Floor	4.3	3.0	.5	.2	2.1	.5	3	13.6
Sacramento HSA								
Central Basin West	16.7	12.1	4.0	2.2	8.3	4.3	11	58.6
Central Basin East	25.1	17.2	.8	12.3	8.1	8.3	11	82.8
Northwest Valley	6.7	2.8	.1	0	1.9	1.3	2	14.8
Northeast Valley	8.6	6.9	.3	.1	0	.5	1	17.4
TOTALS	92.2	57.9	9.8	19.2	31.1	41.8	54	306.0

TABLE 3

ESTIMATED WATER USE RATES OF RIPARIAN VEGETATION AND WATER SURFACES IN THE CENTRAL VALLEY (ALL VALUES IN ACRE-FEET/ACRE)

Planning Subarea	Major Rivers	Riparian Vegetation (Fish and Game Mapping)			Water Surface (DWR)	Additional Distribution System	Head Ditches & Field Edges (DWR)
	(1)	Polygons (2)	Linear (3)	Marsh (4)	(5)	(6)	(7)
Tulare HSA							
Kern Valley Floor	0.0	3.4	5.0	2.0	3.75	1.9	3
San Luis Westside	0.0	4.0	5.0	3.7	3.00	3.8	3
Kings-Kaweah-Tule	3.75	3.4	5.2	3.9	3.75	3.8	3
San Joaquin HSA							
Valley Westside	3.75	3.4	4.6	3.0	3.75	3.8	3
Valley Eastside	3.75	3.4	4.9	3.8	3.75	3.8	3
Eastern Valley Floor	3.75	3.4	5.4	4.0	3.70	4.0	3
Sacramento HSA							
Central Basin West	3.75	3.4	5.2	3.7	3.75	3.7	3
Central Basin East	3.75	3.4	4.8	3.75	3.75	3.7	3
Northwest Valley	3.75	3.4	7.0	0.0	3.75	3.8	3
Northeast Valley	3.75	3.4	5.3	1.0	0.0	4.0	3

TABLE 4

RIPARIAN EVAPORTATIONSPIRATION (ET) AND WATER EVAPORATION (E) FOR CALIFORNIA'S CENTRAL VALLEY
(ALL VALUES IN 1,000 ACRE-FEET)

Planning Subareas	Major Rivers		Other Riparian Vegetation			Other Water Surface	Additional Distribution System	Head Ditch & Field Edges	Total Water E & ET
	Riparian Vegetation	Water Surface	Polygons	Linear	Marsh				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Tulare HSA									
Kern Valley Floor	0	0	6.1	1.5	0.2	6.7	13.0	6.0	33.5
San Luis West Side	0	0	1.2	1.5	4.4	0.3	11.0	6.0	24.4
Kings-Kaweah-Tule	11.0	5.8	25.9	8.9	3.9	20.4*	25.0	27.0	127.9
San Joaquin HSA									
Valley West Side	14.7	5.1	6.2	2.3	0.3	9.4	20.0	9.0	67.0
Valley East Side	56.2	22.5	15.1	6.4	7.6	3.4	32.0	30.0	173.2
Eastern Valley Floor	12.9	3.3	10.2	2.7	0.8	7.7	2.0	9.0	48.6
Sacramento HSA									
Central Basin West	31.9	30.7	41.2	20.6	8.1	31.0	16.0	33.0	212.5
Central Basin East	71.8	22.5	58.6	3.8	46.1	30.2	31.0	33.0	297.0
Northwest Valley	13.5	11.6	9.5	0.7	0	7.1	5.0	6.0	53.4
Northeast Valley	21.5	10.7	23.6	1.6	0.1	0	2.0	3.0	62.4
TOTALS	233.4	112.2	197.6	50.0	71.5	116.2	157.0	162.0	1,099.9

Notes: This list does not include the Delta or upland areas.

Columns 1, 2, 3, 4, and 5 calculated by applying unit ET values to acreages derived from California Fish and Game riparian maps. Column 6 calculated from DWR land use maps. Column 7 calculated as percentage of supply less the portion included in items to right. Column 8 calculated as amount of applied water used by a strip of native vegetation 5 feet wide around 80-acre field, plus evaporation from head ditch.

* 20.4 value for KKT subarea was due to high water year with larger than normal amount of temporary drainage and storage ponds being full at time of photography. All values for this area may be unusually large as this was a wet year.

of this problem, which occurs through much of the San Joaquin Valley trough and in lower portions of alluvial fans at various depths. The shallowest layers are near the surface to depths of 40 feet or more on the west side of the San Joaquin Valley. In these areas, perched water tables may be found within a few feet of the surface, depending on topography, crop, irrigation practices, time of year, and contributions from precipitation and flooding. Major problems for agriculture under these shallow water table conditions may be a lack of adequate aeration of the root zone and a high concentration of salts in the perched water.

Perched water tables can become saline for several reasons, some irrigation-related and some natural. Salts can be applied to the soil with irrigation water, added with soil amendments, or derived from natural chemical weathering of soil minerals. As the crop transpires irrigation water or as evaporation occurs, the salt remains in the soil. The perched water table becomes saline as these salts are flushed downward by irrigation water or precipitation.

Large areas of the valley floor have soils that are saline in their natural state. Before the development of irrigated agriculture in the San Joaquin Valley, much of the valley floor consisted of shallow lakes and marshes fed by runoff from the Sierra and the coastal mountain ranges. These areas would fill with water from the runoff and then, through evaporation and ET of the native vegetation, eventually become dry. Salts in the runoff waters were left behind. The Tulare Lake bed and extensive adjacent areas are an example of this phenomenon. This contributes directly to the salinity of perched water tables and indirectly as the resulting saline soils have been reclaimed for irrigation.

The DWR (1970) mapped the saline soils in the Central Valley in the early 1960s by taking samples of the top 20 feet of soil profiles. These saline soils exist generally in the valley trough and along its edges on both sides of the San Joaquin Valley. Recent estimates indicate that about 2.4 million of the 7.5 million acres of cropland irrigated in the Central Valley are salt-affected (Backlund and Hoppes, 1984). Upon application of irrigation water, salts are dissolved from the soil and carried downward. If small amounts of water, such as rainfall in an arid climate, are applied, not enough water percolates through the soil profile to dissolve the salts and carry them to deep groundwater. Where these soils exist, the groundwater may be of good quality in its natural state, but may be degraded by irrigation water when the amounts applied are greater than ET.

Method of determining irrecoverable losses to saline sinks. This approach consisted of three steps. The first was to develop criteria to determine the areas where excess applied water and water percolating from canals and ditches is lost to further use by becoming too saline. The second step involved determining the areas where these criteria were met. The final step was to estimate the deep percolation occurring in each area. Determinations of the affected areas and amounts were based on criteria and rationale to follow:

Irrigated areas overlying saline sinks are defined by any one or more of three characteristics:

> Areas where average salinity of soil saturation extracts exceeds an electrical conductivity (EC) of 3 deciSiemens per meter (dS/m) (mmhos/cm) in the top 20 feet of soil profiles (as mapped by DWR, 1970);
>
> Areas where water tables occurring within 20 feet of the surface have average annual salinity exceeding 3 dS/m, (Doneen, 1967; Kern County Water Agency, 1985; Tulare Lake Basin Water Storage District, 1981); and/or
>
> Areas overlying coastal range alluvium of marine origin containing high levels of soluble salts and gypsum (DWR, 1978).

This rationale developed was based upon a variety of research projects completed over the past 20 years. Several points should be made concerning this rationale:

> Criteria were established by means of irrigation water quality guidelines adopted in 1973 by the University of California Committee of Consultants at a request by the California State Water Resources Control Board. This information was further adopted by the Food and Agriculture Organization of the United Nations for its publication *Water Quality in Agriculture* (Ayers and Westcot, 1976).
>
> The guidelines for rating irrigation water salinity levels are: less than 0.75 dS/m, no problem; 0.5 to 3.00 dS/m, increasing problem; and greater than 3.00 dS/m, severe problem. It should be recognized, however, that these ranges for the degree of problem indicated are only representative of general crop tolerances. Because different crops can use waters of different quality and because different toxic components of water in varied combinations bring about different results, groundwaters can be utilized in some cases, but not in others.
>
> Waters exceeding 0.75 dS/m present management problems particularly for salt-sensitive crops. Some crops can be grown at salinity levels higher than 3 dS/m; however, management and economic options become increasingly limited.
>
> Water quality parameters other than salinity were evaluated in determining waters that are being degraded to unusable levels. Boron is one constituent that could be a problem, since concentrations above 2 milligrams per liter (mg/L) are present in several areas of the San Joaquin Valley, but, with only a few minor exceptions, these generally appear to be areas already having high

levels of salinity. Other constituents that could cause problems, based on evidence of their presence in the drainage waters of the San Luis Drain, include arsenic, chromium, nickel, selenium, and zinc. As with boron, however, these constituents also tend to occur in areas already defined as saline. Therefore, the use of salinity as the controlling factor was considered to be a reasonable approach.

Work by Tanji, Doneen, and Paul (1967) showed that water percolating through substrata materials in the San Joaquin Valley dissolve soluble minerals (mainly gypsum) on their descent to the water table. Hence, if the quality of the percolating waters is good when leaving the root zone, it may not be good upon arrival at the surface of the aquifer. In addition, if the aquifer is of high quality but overlain by saline substrata, degradation will occur when recharge water reaches the surface of the aquifer. Minimizing deep percolation through saline substrata should minimize degradation of the groundwater. The studies also show that alluvium of the Coast Range, which is of marine origin, has high levels of both dissolved mineral salts and soluble minerals in most substrata (Doneen, 1967).

The specific process used to determine where the potential saline sinks occur was as follows:

Three maps of the San Joaquin Valley floor were prepared from available information, one for each criterion: saline soil, saline perched water table, and saline geologic formation. This information was collected from different reports completed by the U.S. Geological Survey (Croft, 1972), U.S. Bureau of Reclamation (San Joaquin Interagency Drainage Program, 1979), and the DWR (1970). These maps were then combined to create one composite map.

The composite map was then transferred onto DWR's land use maps to determine irrigated acreage of affected area and total amount of this area within each detailed analysis unit. Noncropped areas such as native vegetation, rivers, and urban developments were excluded. Also, the calculated crop acreage was reduced by 5 percent to allow for roads and farmsteads that were not large enough to be noted on DWR land use maps.

The portion of the area considered to have saline sinks as a percentage of the total area for each DAU was then calculated. This value was considered to represent the portion of the total area where deep percolation would be lost to saline sinks.

Spatial variability in soil hydraulic properties make calculations of the amount of water that percolates within the areas identified as salt sinks highly unreliable. Therefore, a water balance approach was used. When the crop ET and collected surface return flow are subtracted from the total applied water, the remainder should represent the deep percolation (fig. 6).

A complicating element is that regional subsurface lateral movement of shallow groundwater may also occur. This factor was not included in the calculation procedures, although it does occur and may slightly alter the results.

First approximation. Because of the complexity of water systems in the Central Valley, hand calculation of water balances necessary to determine irrigation percolation would be a time-consuming, difficult process. The irrigation water balances to determine percolation require knowledge and manipulation of conveyance of water supply, evapotranspiration of applied water, groundwater pumpage, irrigation efficiency, cropping patterns, water exports and imports, and other variables.

The approach taken to estimate these water balance computations was DWR's Surface Water Allocation Model (SWAM). The SWAM is one component of an overall hydrologic-economic model developed for DWR as part of the San Joaquin Valley Ground Water Study. The SWAM was developed to serve as a data base management system for the other physical and hydrologic models of the overall modeling effort (McLaughlin, 1982; DWR, 1980).

The SWAM's primary purpose is to provide a detailed water budget to account for major surface water sources, demands, and losses within the San Joaquin Valley (DWR, 1982b). Historical annual surface water diversions and flows are recorded in the model along with precipitation and other items of water supply. These water supply elements are then compared with water use, primarily agricultural use as determined from cropping patterns and unit water use values. The primary results of the SWAM are estimates of pumpage and recharge in the San Joaquin Valley. In addition, several other parameters are computed in the SWAM water balance, including deep percolation of irrigation water.

A review of the computational methods in the SWAM revealed that it reasonably represented the processes that would otherwise need to be analyzed by hand calculation. The model was based on the data available in the San Joaquin Valley, including whatever data were available from San Joaquin Valley water agencies. The estimates of SWAM irrigation percolation by DAUs were therefore used in further analysis of water percolation within the selected study area.

After determination of the total amounts of irrigation percolation in DAUs through the use of the model, these percolation amounts were adjusted for the affected percentage of each DAU as estimated by the criteria for determining the area of saline sinks discussed in the preceding section. The affected irrigation percolation was derived by multiplying the affected areal percentage of each DAU by the total amount of irrigation percolation.

Areas of concern regarding the selection criteria were raised during this analysis. The first related to using an

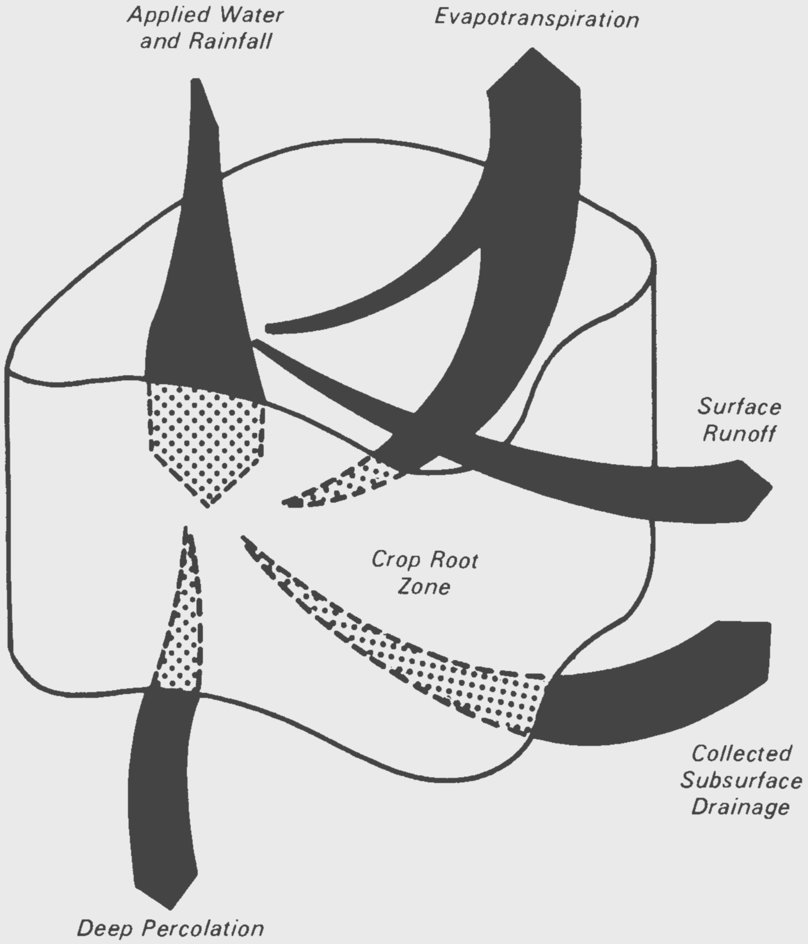


Fig. 6. The major water-flow pathways in the root zone portion of irrigated lands.

electrical conductivity of 3 dS/m of a saturation soil extract as a critical level for usable/unusable water. An EC of 3 dS/m or greater for irrigation water is known to cause severe problems for irrigation of most crops, but not all. To determine the effect of using this saline soil criterion compared with a higher salinity level, the analysis was done with the critical level set at 4.5 dS/m. Because the saline soil criterion acts as a single determinant for only 8 percent of the total affected area identified, and because most of this area has a conductivity of the saturation extract of 4.5 dS/m or greater, only a very small decrease in affected acreage was observed. Because of the relative insensitivity of the criterion to a higher allowable conductivity, the committee decided to apply the 3 dS/m critical level uniformly as a conservative criterion.

Additional analysis of the estimates of irrigation percolation to potential saline sinks revealed other concerns with using the stated criterion uniformly in determining "affected area" and in application of the Surface Water Allocation Model for calculation of percolation. In some cases, further analysis of individual DAUs led to revised estimates of the DAU amounts of irrigation percolation to saline bodies.

Four problem areas were encountered in reviewing the irrigation percolation amounts to saline water bodies by rigid adherence to established criteria. First, the SWAM irrigation percolation estimates are for average irrigation efficiencies within a DAU. This could lead to discrepancies in the portion of a DAU with saline water bodies. In some instances, farmers are cognizant of problems and implement higher irrigation efficiencies and improved management to minimize deep percolation. A second concern is that data used in the SWAM are limited and many SWAM parameters can be only approximately estimated. This problem is especially significant in irrigation reuse estimates on which there is little or no information for model validation. Third, the data for application of the saline soil criterion to define "affected areas" are over 20 years old and irrigation may have reduced this salinity in some cases. Conversely, some of the land previously mapped as nonsaline may now be salt-affected. Finally, in many areas of the San Joaquin Valley identified with the three criteria, percolating irrigation water has historically been and continues to be used for irrigation supplies by groundwater pumpage and recirculation of collected drain waters.

In the San Joaquin Basin, the largest adjustment of the irrigation percolation amounts was made in DAU 216 on the west side of the San Joaquin River. Irrigation in this DAU has been practiced since before the beginning of this century, and groundwater levels have been relatively constant and near the land surface for decades. The amounts of irrigation percolation to unusable groundwater originally identified in this DAU should result in large, noticeable increases in groundwater levels unless they subsequently move out of the area. Such increases have not been observed; water levels in DAU 216 have been relatively stable.

Additional comparison of the SWAM water balance with water management practices in DAU 216 revealed that a large amount of surface tailwater reuse was taking place within the DAU that had not been accounted for. Also, most of the remaining excess irrigation amounts in DAU 216 have been draining to the San Joaquin River both as surface and subsurface flows, providing drainage for the area as well as an incidental (not planned) water supply source for downstream and Delta users. Flows in the middle reaches of the San Joaquin River upstream of the confluence of several Sierra Nevada streams are limited during most summers and consist mainly of irrigation return flows.

The salinity and trace element content of these drainage flows are of concern, and the Regional Water Quality Control Board is examining the lower San Joaquin River to determine if agricultural drainage discharge standards are necessary. Accounting for these direct and indirect amounts of reuse resulted in a reduction in the estimated amount of irrigation percolation lost to further use from what was originally calculated by strictly following the established criteria.

In the Tulare Basin, further analysis of the initial estimates of irrigation percolation to unusable water bodies resulted in reductions in several DAUs. These reductions were primarily in areas with generally good-quality groundwater that has been used on a continuous basis, indicating that some data used in applying the salinity sink criterion must be insufficient.

One problem area fitting this description is the Kern Delta area (DAU 254), where good-quality groundwater has been near the surface since the first groundwater contour maps of the 1920s. Two other DAUs, the Tule Delta area (DAU 243) and the Semitropic area (DAU 255) were analyzed in more detail and adjusted to account for the presence of usable groundwater within areas that had been identified as having a perched water table and saline soils.

In addition to these areas that are exceptions to the originally applied criteria for estimating saline sinks, there is some evidence that other areas, such as DAUs 237 and 238 on the Kings River fan, should also be excluded, decreasing the amount deep percolating to saline sinks to about 500,000 acre-feet.

Tabulated results. Following the above method, the committee determined the values of water percolating to saline sinks for each PSA in the Central Valley. (Tables for each DAU are available from the committee chair.) Table 5 gives the total areas and the ET of water applied to crops in the DAUs examined to determine the amount of area that is in the saline sink area. This table shows that about 3 million acre-feet of irrigation water is used to meet evapotranspiration requirements of crops in these DAUs for the saline sink area. Table 6 contains two estimates of the amount of irrigation water reaching a saline sink through deep percolation. Column 8 gives the estimate if the criteria for defining a saline sink area are strictly applied, show-

TABLE 5

IRRIGATED AREA AND EVAPOTRANSPIRATION OF WATER APPLIED TO AGRICULTURAL CROPS OF SALINE SINK AREA

DAU	Title or Description	Area Irrigated (1,000 Acres)	ETAW (1,000 Acre-Feet)
212	El Nido-Stevenson	9.3	20
215	Gravelly Ford	13.1	30
216	West Side of SJ	100.0	229
235	Raisin	10.6	26
237	Lower Kings River	15.2	27
238	Hanford-Lemoore	44.2	102
241	Tulare Lake	235.3	478
242	Kaweah Delta	4.1	9
243	Tule Delta	36.4	76
244	Westlands W. D.	540.5	1,108
245	Kettleman Plain	46.5	78
246	South Tulare Lake	43.6	72
254	Kern Delta	55.0	133
255	Semitropic	63.0	158
256	North Kern	4.9	11
258	Arvin-Edison	5.2	11
259	Antelope Plain	145.0	308
261	Wheeler Ridge-Maricopa	89.0	189
TOTALS		1,461.0	3,065

TABLE 6

AMOUNTS OF WATER ESTIMATED TO BE DEEP PERCOLATING TO SALINE SINKS
HYDROLOGIC STUDY AREAS: SAN JOAQUIN AND TULARE LAKE

DAU	Title or Description	Area Irrigated (1,000s Acres)	Absolute Areas Meeting GW Criteria: Area Affected (1,000s Acres)	Absolute Areas Meeting GW Criteria: Area Affected & Irrigated (1,000s Acres)	Percentage of Area Irrigated & Affected (a/o)	Unit Loss (ft)	Conveyance & Percolation to Potential Saline Sinks (TAF)*	Potential Areas for Practical Exclusion: Area Affected (1,000s Acres)	Potential Areas for Practical Exclusion: Area Affected & Irrigated (1,000s Acres)	Remainder Areas After Exclusion: Area Affected (1,000s Acres)	Remainder Areas After Exclusion: Area Affected & Irrigated (1,000s Acres)	Remainder Percentage of Area Irrigated & Affected (a/o)	Unit Loss (ft)	Conveyance & Percolation to Potential Saline Sinks (TAF)*
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
212	El Nido-Stevenson	138.2	25.9	9.3	6.73	1.47	13.70	0	0	25.9	9.3	6.73	1.47	13.70
215	Gravelly Ford	107.8	21.0	13.1	12.15	1.47	19.26	0	0	21.0	13.1	12.15	1.47	19.26
216	West Side-SJ Riv.	413.0	346.8	345.2	83.58	1.13	388.35	241.8	245.2	105.0	100.0	24.21	1.13	112.50
235	Raisin	136.6	18.9	10.6	7.76	1.65	17.50	0	0	18.9	10.6	7.76	1.65	17.50
237	Lower Kings River	156.1	17.0	15.2	9.74	1.70	25.84	0	0	17.0	15.2	9.74	1.70	25.84
238	Hanford-Lemoore	148.4	60.8	44.2	29.78	1.65	72.93	0	0	60.8	44.2	29.78	1.65	72.93
241	Tulare Lake	235.3	259.6	235.3	100.00	0	0.00	0	0	259.6	235.3	100.00	0	0.00
242	Kaweah Delta	344.4	4.7	4.1	1.19	1.10	4.51	0	0	4.7	4.1	1.19	1.10	4.51
243	Tule Delta	327.7	139.6	75.9	23.16	1.19	90.30	72.0	39.5	67.6	36.4	11.11	1.19	43.31
244	Westlands W.D.	540.5	540.5	540.5	100.00	.40	216.20	0	0	540.5	540.5	100.00	.40	216.20
245	Kettleman Plain	46.5	46.5	46.5	100.00	.82	38.10	0	0	46.5	46.5	100.00	.82	38.13
246	South Tulare Lake	43.6	43.6	43.6	100.00	.69	30.00	0	0	43.6	43.6	100.00	.69	30.00
254	Kern Delta	211.0	77.5	55.0	26.07	.84	46.20	0	0	77.5	55.0	26.07	.20**	11.00
255	Semitropic	163.0	163.0	91.3	56.01	1.31	119.97	50.5	28.3	112.5	63.0	38.65	1.13	82.78
256	North Kern	184.0	9.3	4.9	2.66	1.25	6.13	0	0	9.3	4.9	2.66	1.25	6.13
258	Arvin-Edison	118.0	6.2	5.2	4.41	.84	4.37	0	0	6.2	5.2	4.41	.84	4.37
259	Antelope Plain	145.0	145.0	145.0	100.00	.63	91.00	0	0	145.0	145.0	100.00	.63	91.00
261	Wheeler R.-Maric.	89.0	89.0	89.0	100.00	.61	54.00	0	0	89.0	89.0	100.00	.61	54.00
	TOTALS	3,548.1	2,014.9	1,773.9			1,238.36	364.3	313.0	1,650.6	1,460.9			843.16

* TAF = Thousand Acre-Feet

** Letter from DWR to Don Grimes dated 9/16/85 put this amount at 14,140 AF of losses by readjusting the Unit Loss to .26 AF/Acre/Year. Personal conversation 9/27/85 between T. Erlewine and C. Woodring further reduced this to 10,480 AF for a Unit Loss of .20 AF/Acre/Year.

ing a total for all DAUs of about 1.2 million acre-feet of water irrecoverably lost to saline sinks. When the estimates excluded some water that is being reused locally, as well as surface and subsurface irrigation return-flow water reaching the San Joaquin River, where it is later diluted and becomes part of additional supply, the amounts in column 8 decreased to those given in column 15. The total of all DAUs in column 15 is about 843,000 acre-feet of water irrecoverably lost to saline sinks. Data exist indicating that there are additional cases where water classed as lost to further use is actually being reused. Considering these cases as not reflecting degraded water quality would reduce the estimate of the water lost to about 500,000 acre-feet. Uncertainty is associated with these estimates, primarily because of inadequate data to quantify deep percolation as discussed in the previous section.

Contrasting opinions within the committee were voiced on how to treat water from subsurface return flows reaching the San Joaquin River. One approach is to consider this water as being reused beneficially and not representing a loss. The reasoning is that it is part of the existing supply used to meet Delta outflow requirements, is diluted in the Delta, and becomes part of the supply for irrigation in the Delta or for export south through the Delta Mendota Canal and California aqueduct. Upon export, some of this water would be reapplied to lands from which return flows were discharged into the San Joaquin River. Since this water is already being used beneficially according to this view, reductions in the quantity of such flow would not result in appreciable net savings but would have to be replaced from some other source to satisfy total Delta requirements for consumptive use, diversion, and outflow. An opposing view is that this water is degrading the quality of the San Joaquin River to the extent that it should be considered unusable and a loss to the agricultural water supply. Present deliberations by the state on establishment of water quality criteria, especially related to trace elements, should shed some light on this issue. Considering both arguments, the majority of the committee believes that the amount of water reaching saline sinks through deep percolation may be around 843,000 acre-feet with uncertainty ranging up to 1.2 million acre-feet and down to 500,000 acre-feet.

Water Conservation Potential

Agricultural water conservation and management practices are designed to use the irrigation water efficiently and may or may not represent any water savings. Agricultural water is also subject to reuse by other downstream users and may be reused several times before it becomes unusable.

The quantity of irrigation water used by any given farm will depend on the crops grown and the mix of crops on that farm. Each crop will have specific water requirements and each soil type will add constraints on the amount of water to be applied to that crop.

The mobile laboratories funded by the State Water Resources Control Board, and the Office of Water Conservation in DWR, which are operated by the Resource Conservation Districts in Hanford and Bakersfield, have found that approximately one-third of the growers are applying the correct amount of water, one-third are applying too much, and the other one-third are not applying enough water to meet the evapotranspiration needs of the crop. These mobile labs have evaluated several hundred growers over a four-year period and, as they gather additional data, these percentages may change. Because of the significant amount of under-application, improvements in irrigation management may increase water use in some cases rather than save water. Computations shown in the following sections did not take this into consideration.

The on-farm water use changes annually because of climate, crop, economics, and other factors. During a shift in climatic conditions, for example, from an extremely hot summer to an extremely cool summer, the amount of water used by a crop can change by as much as 20 percent. Economics will dictate the crops to be grown, increasing or decreasing farm water use. Two other factors that influence the amount of water used are high water tables and salinity. As the water table fluctuates from year to year, an abnormally high water table will generally cause a reduction in the amount of water applied to the surface. An increase in soil salinity will cause an increase in the use of water to move the salts below the root zone. These latter two factors do not, however, have as great an impact as would climate or economics.

Each farm has some sort of distribution system to get the irrigation water to the crop. This may include a ditch or a pipeline with appropriate gates, valves, or flow-regulating devices. From this on-farm distribution system, the grower uses an irrigation system to apply the water to the crop. The most commonly used systems are borders, furrows, sprinklers, or trickle systems (table 7). Each irrigation system type has certain advantages and disadvantages or limitations. (See table 8 for some of the limitations for each irrigation system as well as the expected application efficiency.)

Agricultural Water Management and Conservation Practices

Several agricultural management practices are being considered for improving water management on irrigated lands in the Central Valley. Some of these practices can be applied independently, while others are very dependent upon each other. The practices being considered are not mutually exclusive of others presented, but are the ones thought to be most applicable throughout the Central Valley.

It should be recognized that conservation practices are generally site-specific, and a complete engineering analysis should be done to implement them. Only those conservation practices that are cost-effective for the area would generally be installed.

TABLE 7

DISTRIBUTION OF IRRIGATION SYSTEMS
(1,000 Acres)

	Surface		Pressure		
Basin	Border	Furrow	Sprinkler	Trickle	Other
Sacramento	1,160	520	310	5	100
San Joaquin	2,115	2,430	815	135	5
Totals	3,275	2,950	1,125	140	105
PERCENTAGE	43.1	38.8	14.8	1.9	1.4
	81.9		16.7		

TABLE 8

FACTORS TO CONSIDER IN SELECTING AN IRRIGATION METHOD[1]
(Limitations of Systems)

Factors to Consider	Sprinkler Systems					Surface Flood Systems			Drip Systems
	Portable	Wheel Roll	Solid Set	Center Pivot	Boom (Giant)	Graded Border	Level Border	Furrow	
Slope Limitations:									
Direction of Irrigation	20%	15%	None	15%	5%	0.5 - 4.0%	Level	3%	None
Cross-Slope	20%	15%	None	15%	5%	0.2%	0.2%	10%	None
Soil Limitations:									
Intake Rate (in./hr.)									
Minimum	0.10	0.10	0.05	0.30	0.30	0.30	0.1	0.1	0.02
Maximum	None	None	None	None	None	6.0	6.0	3.0	None
Water Holding Capacity in Root Zone	3.0	3.0	None	2.0	2.0	2.0	2.0	2.0	None
Depth	None	None	None	None	None	Soil should be deep enough to allow for required grading.			None
Erosion Hazard	Slight	Slight	Slight	Moderate	Severe	Moderate	Slight	Severe	None
Saline-Alkali Soils	Slight	Slight	Slight	Slight	Slight	Moderate	Slight	Severe	Moderate
Water Limitations:									
Quality									
Total Dissolved Solids (TDS)	Severe	Severe	Severe	Severe	Severe	Slight	Slight	Moderate	Slight
Suspended Solids	Moderate	Moderate	Moderate	Moderate	Moderate	None	None	None	Severe
Rate of Flow	Low	Low	Low	High	High	Moderate	Moderate	Moderate	Low
Climatic Factors:									
Temperature Control	No	No	Yes	No	No	Yes	Yes	Yes	No
Wind Affected	Yes	Yes	Yes	Yes	Yes	No	No	No	No
Adaptability to All Crops:	Good	Good	Good	Fair	Limited	Very Good	Very Good	Very Good	Good
Potential for Automation:	Poor	Very Good	Very Good	Very Good	Moderate	Moderate	Very Good	Moderate	Very Good
System Costs - (1981 Data):									
Capital Cost ($/acre)	650 - 1000	650 - 1000	1100 - 1900	1100 - 1600	1000 - 1100	800 - 1000	800 - 1000	650 - 800	800 - 1900
Labor Cost[2]	High	Moderate	Low	Low	Moderate	Moderate	Moderate	High	Low
Power Cost[3]	High	High	High	High	High	Low	Low	Low	Moderate
Average Annual Cost[4] ($/ac./yr.)	150 - 300	150 - 300	300 - 500	300 - 500	300 - 500	150 - 300	150 - 300	300 - 500	300 - 500
Application Efficiency:[5]	70 - 80	70 - 80	70 - 80	70 - 80	70 - 80	70 - 85	75 - 90	70 - 85	75 - 90

---

[1] Factor limitations in excess of those specified may be used, but an increase in the number of conservation practices will be required along with a higher level of management.

[2] Low - less than $30/ac./yr.; Moderate - $30-80/ac./yr.; High - over $80/ac./yr.

[3] Low - $0-15/ac./yr.; Moderate - $15-40/ac./yr.; High - over $40/ac./yr.

[4] Amortized capital cost plus operation and maintenance cost.

[5] Assuming good to excellent management.

Water management/irrigation scheduling. This is an all-inclusive conservation practice that has several meanings. In its simplest form, it is applying irrigation water to meet the desired crop response with the proper rate of delivery, for the proper duration, and with the correct frequency of application.

The desired crop response has two components, quality and quantity. Applying irrigation water in growing a crop for quality may be different than in growing a crop for quantity. Economics play a very important part in the grower's decision as to what is an acceptable ratio of quality to quantity.

To achieve efficient irrigation water management, a grower must have considerable knowledge about: (1) the soil on the farm, including its water-holding capacity, soil depth, root-zone depth, infiltration rate, other limiting factors, such as claypans, plowplan, compaction, and salinity status, (2) the crops grown and the critical growth stages, critical stress periods, and crop consumptive use, and (3) climatic factors including temperature, humidity, wind, and precipitation.

For irrigation water management to be effective, comprehensive training and educational programs may be needed for growers, irrigators, and water district personnel. There are a few growers who consistently over- or underirrigate and may not fully understand irrigation water management techniques.

A need also exists for professional services to aid the grower in scheduling irrigations. These professionals have the necessary equipment to determine soil moisture depletion levels, the salt concentration at various levels within the root zone, and the relationship between the root zone and the high water table. Such testing is at minimum an annual practice and may need to be performed several times during a growing season. The average annual costs to promote irrigation water management will vary with each site because of the acreage involved and the crops grown, but for this study we are using the following: 1 to 160 acres, $10 per acre per year; and more than 160 acres, $6 per acre per year.

Salinity management. In some areas, salinity management may be the most crucial element of all water conservation practices. The purpose of salinity management is to maintain a desired salt balance within the crop root zone. Threshold salinity levels have been established for a number of crops grown in the San Joaquin Valley. If a grower wishes to change crops, however, the salt balance in the root zone may also have to change. To grow a more sensitive crop, the grower must flush some of the salt from the root zone, and that means applying more irrigation water to that field.

The leaching requirement is the amount of additional water above the ET requirement that must be applied to the soil to maintain a favorable root-zone environment relative to salinity without causing decreased crop yield. An irrigation system operating at 100 percent efficiency is meeting only the crop ET, and no additional water is applied to move the salts through the root zone. Irrigation water cannot be applied 100 percent uniformly to a field because of soil and irrigation system variabilities. Therefore, enough water is generally applied to a field to meet ET requirements, account for soil and system nonuniformities, and maintain a favorable root zone environment throughout the field. Applying only enough water to meet average ET requirements would decrease crop yield.

A grower may elect to take some reduction in crop yield to reduce the amount of water applied. Because of current constraints in drainage water disposal options, researchers are presently studying the use of saline waters and their effect on crop quality and quantity, the amount of salts remaining in the crop root zone, and the amount of drainage effluent being discharged through the drain tile system in the saline areas.

Salinity management is the careful monitoring of all the forces acting upon the soil and crop. Each crop and each soil will require different levels of monitoring. The factors most commonly monitored are: specific constituents and total amount of salts in the applied water and in the crop root zone, amount of applied water, amount of drainage effluent, crop tolerance level, yield reduction (quantity and quality acceptable to the grower), and economics. The committee estimated the following average annual costs based upon providing technical assistance to the growers: 1 to 160 acres, $20 per acre per year; and more than 160 acres, $10 per acre per year.

Flow measuring devices. To properly schedule an irrigation and to get maximum benefit from the irrigation water and salinity management practices, the grower must use some type of water-flow measuring equipment. There are various types of flow measuring devices on the market, each suited to a particular application. Some of the more common types are weirs, flumes, and propeller meters.

Within each of these broad categories there are very specialized applications. The type of flow measuring equipment to be used will depend on the site-specific application of the grower. Propeller meters were chosen for this study, because they come in a variety of styles and can measure open channel flow as well as flows in a closed conduit. As a minimum, it was assumed that at least one flow measuring device would be needed for each 80 acres of irrigated land. Based on the best information available, the average cost for installation, maintenance, and collecting data will be $1.85 per acre per year.

Tailwater return/recovery systems. Most of the San Joaquin Valley soils that lie within the saline and high water table boundaries also have acres that would benefit from a surface runoff return/recovery system. A tailwater return system returns the irrigation water to the field where it originated, while a tailwater recovery system may use the water on another field. Both systems require a collection, storage, and distribution system.

This practice is site-specific and is not a substitute for good water application management. It is a practice that greatly aids in the management of irrigation. This practice may not "save" any large amounts of irrigation water, but it does assist growers in management of water diversions to their land. Tailwater return/recovery systems allow for faster advance times so there will be smaller deep percolation losses, and they provide a better water distribution within the soil profile. Irrigation tailwater return or recovery systems can be generally limited to applications on those soils where there is an infiltration and/or percolation problem. Growers who use these systems have been able to reduce the amount of water needed from the source, because the water is recirculated, usually within the growers' own operations.

Two sizes of tailwater return systems are used, depending on the size of the farming operation. Average costs are: 40 acres, $16 per acre per year; and 160 acres, $11 per acre per year.

Land leveling and smoothing. Land leveling and smoothing prepare the soil surface with the proper slope for the installation of the two surface irrigation systems, border and furrow. These two irrigation conservation practices may not necessarily "save" any irrigation water but, again, are a necessary component to achieve good irrigation water management. Both practices can provide a better distribution of the water across the field, thereby reducing the amount going to deep percolation from overirrigation and, conversely, reducing the area being underirrigated.

Irrigation land leveling was estimated to have a life span of ten years, and irrigation land smoothing, two years. For good control of water application, growers need to use both practices. The average estimated costs are: land leveling, $27 per acre per year; and land smoothing, $43 per acre per year.

Ditch and canal lining and pipelines. Pipelines or lined canals for on-farm distribution systems reduce conveyance water losses. Concrete, polyethylene, polyvinyl chloride (PVC), or plastic linings reduce seepage losses from the bottom and sides of earth-constructed canals and ditches. Irrigation ditch and canal linings are applicable to the distribution system used to deliver water to the farm, while irrigation ditch linings are applicable to the on-farm distribution system.

The amount of deep percolation that can be reduced in these soils is related to the canal/ditch capacity and the number of alternate wet-dry periods during the irrigation season.

In an unpublished study done by the Soil Conservation Service for the Laguna and Riverdale Irrigation Districts, seepage losses were as high as 20 percent for very short reaches of 500 feet or less in coarse-textured soils. The average loss for a canal system (2 to 3 miles in length) was 3 percent, with higher losses for a short reach of 500 feet or less. On medium- to fine-textured soils, the seepage losses will be even less.

On some soils on the west side of the San Joaquin Valley, it is questionable whether the distribution system should be lined. These soils tend to shift or subside and crack the concrete lining, making the capital investment nonproductive.

Loss of wildlife habitat also occurs when canals and ditches are lined. Phreatophytes and other components of wildlife habitat are also beneficial users of irrigation waters and return flows. Some of the seepage losses may be great enough to cause wetlands to form alongside the ditch or canal. Each site should therefore be evaluated in terms of both seepage losses and this water's importance to wildlife. Average costs were estimated at: concrete irrigation canal lining, $43 per acre per year; on-farm ditch lining -- 0 to 5 cubic feet per second, $75 per acre, or 5 to 30 cubic feet per second, $37 per acre.

Canal ditch structures and turnouts for water control. When irrigation canal linings are used, structures and turnouts are a necessary part of the physical delivery system. Canal linings may not be required under some conditions, but for an irrigation district to have good control of its water, outlet control is necessary. In some cases, only structural replacement need be considered, while in other cases, new structures are warranted. In this study, it was assumed that the cost for either replacement or new structures would be about equal.

The effect of these works on water savings is very difficult to analyze, because they offer better water control in the distribution system. Growers thus have a greater opportunity for better irrigation water management (i.e., rate, duration, and frequency). The amount of water presently leaking past the existing structures is generally unknown and may or may not be used beneficially. Average costs are: canal structures, $0.55 per acre per year; and canal turnouts, $1.80 per acre per year.

On-farm and regional drainage systems. The two purposes of on-farm drainage systems are to control salinity and to control water tables. The prevalence of each condition in any region depends on the soils, salinity of the drainage waters, and crops grown. It is assumed that the drainage waters from any on-farm system will be used on that farm's crops until the salinity level of the drainage water is no longer tolerable for acceptable yields, after which the system will be used for disposal. Drainage reuse will reduce the amount of water being lost to deep percolation, where it may eventually create or enter a saline sink. The amount of water flowing to a saline sink will depend upon the efficiency of the grower and the grower's ability to implement irrigation water and salinity management. Estimated cost of on-farm drainage systems is $81 per acre per year.

District management. How well an irrigation district performs its function in making water deliveries is very dependent upon the management of that district. District managers, through the governing board, determine and implement charges for irrigation water, salaries, debt payments, replacement of structures, and maintenance.

These items all play an important role in the delivery of irrigation water to the users. If the price charged for water is not sufficient to meet the salaries and any debt payments, operation and maintenance usually tend to suffer. The manner in which a district is operated determines the type of irrigation schedule that will be used (see table 9).

Opportunities for changing irrigation district operations will vary. Some districts may be able to make minor management changes that can have a great impact on the way water is delivered to the users. It is therefore difficult to put a cost on improving irrigation district management.

Crop Production Management Considerations

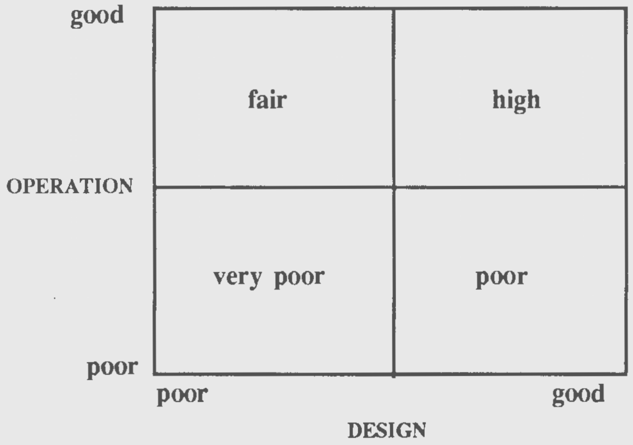
For growers in saline areas, management techniques exist that will improve yields but will not necessarily reduce the amount of water being deep-percolated to a saline sink.

Breeding and selecting salt-tolerant crops. Salt-tolerant crops are presently being used over a large portion of the salinity-affected area. Most growers have recognized the limitations of their soils and irrigation water and have adjusted the crop selection in accordance with those limitations. Researchers are trying to develop different cultivars, varieties, and types of crops that can be grown under saline conditions. However, a reduction in water percolating to a saline water body would occur only if the new crops required less water for maximum production.

Changing type of irrigation system. This method may or may not reduce the amount of water deep-percolated. It strictly depends on how the new system is managed (See table 8 for comparison of systems.)

Two important factors must be considered for each irrigation system: design and operation. The two factors result in four different operational categories given by the following diagram:

Efficiency of Irrigation Systems



Regardless of the type of irrigation system presently being used or the proposed changes, water application inefficiencies can still occur. Table 8 may be used as a guide to determine if an irrigation system change is warranted or should be considered.

Another factor of great concern is the economics of change. Increased costs of installation, energy, and operation and maintenance may not be offset by increased crop production and reduced water requirements.

Changing preirrigation practices. Changing the timing and amount of preirrigations may affect the amount of water being deep-percolated. Studies are under way in the Westlands Water District and surrounding areas to determine the effect of this procedure.

Fall preirrigations are generally applied before any winter precipitation. If the soil profile is already full, then winter precipitation will displace the preirrigation deeper into the soil or will result in surface runoff. Runoff water does not have any effect on leaching or on reducing the salts within the root zone. Changing the preirrigation to the spring may reduce the amount of water normally applied, because the effective precipitation can be accounted for as a part of the preirrigation requirements. A change in water district (irrigation district) policy may be required to make this change in the timing and/or amounts of preirrigations.

It must be kept in mind, however, that California has wide variations from year to year in the patterns of monthly precipitation and runoff. It may be wiser to preirrigate during high runoff periods in late fall or during the winter, rather than gambling on having normal or above-normal late-winter and spring precipitation. In many areas, there is not sufficient storage capacity (considering flood control requirements) to store above-normal fall and winter runoff for spring use.

Modifying planting practices. Most growers have determined the moisture regime required for the crops they wish to grow through either education or experience. There are some planting techniques, however, that may be used to increase germination. Most crops are very sensitive to salty conditions during the germination and the first-leaf stage.

In furrow irrigation, changing the shape of the furrow and the planting techniques can improve germination and the expected crop response at harvest time. Salt concentrations are generally the greatest at the highest point of the furrow, owing to transport of water and salts by capillary action to the surface. Some of the methods may require extensive changes in agricultural equipment design to accomplish the modified planting procedures.

Deficit irrigation. Deficit irrigation is applying irrigation water in amounts less than required to meet the crop's evapotranspiration demand. Two changes may occur simultaneously when deficit irrigation is practiced: crop growth may be reduced and, as a result, the

TABLE 9

WATER DELIVERY CONSTRAINTS

Schedule Name	Frequency	Rate	Duration
Demand	Unlimited	Unlimited	Unlimited
Limited-Rate, Demand	Unlimited	Limited	Unlimited
Arranged	Arranged	Limited	Unlimited
Limited-Rate, Arranged	Arranged	Limited	Unlimited
Restricted-Arranged	Arranged	Constant	Constant
Fixed-Duration Restricted-Arranged	Arranged	Constant	Fixed by Policy
Varied-Amount, Constant-Frequency (Modified-Amount Rotation)	Fixed	Varied as Fixed	Fixed
Constant-Amount, Varied Frequency (Modified-Frequency Rotation)	Varied as Fixed	Fixed	Fixed
Constant-Amount, Constant-Frequency (Rotation)	Fixed	Fixed	Fixed

Unlimited:	Unlimited and controlled by the user.
Limited :	Miximum flow rate limited by physical size of system or turnout capacity but causing only moderate to negligible problems in farm operations. The applied rate controlled by the user and may be varied as described.
Arranged :	Day or days of water availability are arranged between the water agency and the user.
Constant :	The condition of rate or duration remains constant as arranged during the specific irrigation run.
Fixed :	The condition is predetermined by the water agency.
Source :	DWR: <u>Water Conservation in California</u>, Bulletin 198-84, July 1984-Pg. 116.

evapotranspiration demand requirement may be decreased. These changes will occur if the crop cannot utilize water from some other source such as a shallow water table.

An ideal irrigation system and management would consistently provide irrigation water in amounts that would optimize crop yield and water use (100 percent irrigation efficiency) including necessary leaching. Any additional irrigation water applied beyond this point would be considered overirrigation that would increase water inputs and costs.

Spatial and temporal variability of the soils makes it difficult to irrigate crops consistently at the optimum yield point. Irrigating at the optimum yield occurs more frequently by "accident" than by planning through good management. Attempting to irrigate a crop at optimum yield will result in some portion of the field receiving less water due to soil variability. Therefore, a yield reduction will occur.

What this really means is that the grower applies a little more water than needed to meet evapotranspiration to ensure a good yield. How much additional water the grower needs would depend on the cost of irrigation water and the grower's ability to manage the water applied to the crop. A grower who uses too much water would lose through increased costs and possibly some reduction in crop yield.

Generally in areas where deficit irrigation occurs, the crop may use water from a shallow water table (if it exists) to meet its evapotranspiration requirement. It should be pointed out, however, that the total crop water inputs are still being met, and the only deficit portion is the amount of water applied to the surface. Where water costs are extremely high, a grower may deliberately choose to take a yield reduction. The amount of yield reduction may be rather small compared with increased cost of water.

Estimated Amount and Costs of Conservable Water

Riparian vegetation and associated water surfaces. Table 4 gives the estimated amount of water used by riparian vegetation and associated water surfaces in the Central Valley. The amount of water in columns 1 through 6 was judged by the committee to represent water offering few possibilities for savings and reuse for other beneficial uses. Some of the water listed in those columns would be impractical to save for physical reasons, as, for example, in attempting to decrease evaporation from open water surfaces or to modify natural stream channels to the extent that they are not able to handle winter and spring runoff. In other cases, the vegetation constitutes important wildlife habitat as identified by the Fish and Game Survey.

Column 7 of Table 4 represents primarily ET from vegetation along small streams, canals, and ditches that did not show up in columns 1 through 5 from the aerial photography used in the Fish and Game Study. The amounts of water included in column 8 represent both ET and E from head ditches and vegetation at the edges of irrigated fields.

From a physical standpoint, some of the water in columns 7 and 8 could be "saved" by installing pipelines or by manually or chemically controlling natural vegetation. However, much of this water and vegetation is beneficial for wildlife. Water probably could be redirected from certain areas without causing significant impacts to wildlife, but these opportunities would need to be evaluated on a case-by-case basis. In general, nearly all of the water tabulated in table 4 represents beneficial uses for wildlife.

Agricultural water conservation can have a great impact on the value of riparian vegetation. This value to wildlife is based in the great diversity and high productivity of the riparian zone. In contrast to most California habitats that are dry in summer, riparian zones receive ample water supply in conjunction with high light levels and warm temperatures, to support greater plant species diversity and growth rates. The vegetation thus supports a large variety of herbivores, including insects, which in turn support large numbers of birds and other animals.

Since most riparian zones are long and narrow, some being only a few feet wide, they provide an "edge effect." The diversity of species is greater in the transition zone than in either adjacent habitat. In addition, narrow strips of vegetation often provide the only roosting, nesting, and escape habitat for many species that otherwise live in adjacent areas. These narrow strips are also used as migration and other movement corridors for species as diverse as deer, birds, amphibians, and insects.

From a national perspective, the ninth annual report of the U.S. Council on Environmental Quality (1978) states: "No ecosystem is more essential to the survival of the nation's fish and wildlife." For example, western riparian ecosystems contain approximately 42 percent of the mammal species of North America, 38 percent of the reptiles, and 14 percent of the breeding birds (R. R. Johnson et al., 1977), and 75 species of fish of the southwest are dependent upon riparian ecosystems (J. P. Hubbard, 1977).

California supports about 120 native species of amphibians and reptiles, with riparian zones providing for 83 percent and 40 percent of these animals, respectively (Brode and Bury, 1984).

About 135 species of California birds are dependent upon riparian zones; 13 of these species are listed as endangered or threatened. Approximately 25 percent of California's mammal species are dependent upon riparian environments (Williams and Kelburn, 1984).

Riparian vegetation is crucial to life in streams. The vegetation shades and cools the water, decreases erosion, and contributes to organic nutrients.

Although not discussed here, riparian environments also have high recreational, scientific, and economic values.

About 85 percent of the Central Valley's riparian vegetation of presettlement times has been lost. Of that which remains, about two-thirds is either still being degraded or is so damaged that there is no expectation of recovery. The trend is continued deterioration. Conversion of riparian wetlands to cultivated agriculture has been historically, and remains today, the single largest cause of riparian vegetation loss in the Central Valley.

Because of that trend and the high public value of this habitat, fish and wildlife plans have singled out riparian habitat to be of special concern. It has been the position of the California Department of Fish and Game that project impacts shall not result in the net loss of wetland riparian acreage or associated wildlife habitat values. Monetary and other incentives have been identified as needed to encourage private landowners to protect and restore their riparian lands.

Given that such a small fraction of the historical riparian vegetation remains, and that even this fraction is declining, one goal should be to protect, improve, and restore the riparian resources of the state. It is not consistent with this goal to plan the reduction of riparian vegetation in order to make water available for uses other than those benefiting fish and wildlife. Water conservation should not be pursued at the expense of this public resource. Conservation measures that assist or at least do not adversely affect fish and wildlife and their habitats should be pursued vigorously.

This goal can be accomplished and has support in law. Both the conservation of water and the reasonable use of water for agriculture and fish and wildlife resources are in the public interest. Existing law supports the management of all resources in the public interest over the long term (California Constitution; Public Trust Doctrine).

With due regard for the foregoing, it was estimated that about 40,000 acre-feet of the total 1.1 million acre-feet of water use presented in table 4 might possibly be saved without impact on wildlife habitat. Field investigation by DWR of the canals and ditches that account for the water shown in table 4 under the heading of "Additional Distribution System" revealed that the banks of some are entirely bare of vegetation or only sparsely covered by native grasses. The 40,000 acre-feet is the estimate of evaporation losses from such canals and ditches that could reasonably be converted to closed pipe systems. Cost of this is estimated to be about $20 per acre-foot on an average annual basis. It must be kept in mind that each site would need close inspection to ensure that there would not be impacts on fish and wildlife. Cumulative impacts of any regional or statewide program also would have to be evaluated.

Saline sink areas. Water is irrecoverably lost when it is evaporated, transpired, or contaminated so that it cannot be used beneficially. The committee evaluated the agricultural water that is being deep-percolated to a saline sink and is thereby nonrecoverable for another beneficial use. Some of this loss benefits agriculture by reducing the salts within the crop root zone. Included in this study was the amount of irrigation water needed to maintain a leaching requirement and the costs and effects associated with maintaining a favorable salt balance and reducing the amount of water lost by deep percolation.

The effort to improve on-farm irrigation application efficiencies in this area will consist primarily of irrigation water management and water measuring devices. These two on-farm water management practices will aid considerably in bringing the irrigation application efficiency to a minimum level of around 70 percent.

The amount of conservable water depends on the conservation practices required and the affected area. In this section, we discuss in detail the practices required to reduce irrigation water losses to saline sinks, since this water has been deemed nonrecoverable.

To determine how much can be conserved for beneficial uses not currently served, one must consider both the amount of water that must be applied to meet crop needs and that required to leach harmful salts from the soil. Leaching requirement values for the crops grown in each DAU are tabulated and available from the committee chair. With leaching requirements in mind, the committee analyzed four situations:

> Determined the leaching requirement at maximum electrical conductivity of the drainage water (ECdw) that would allow every crop now grown in the DAU to be grown on every parcel of land within the DAU. Then four distribution uniformities were also considered – 100, 90, 80, and 70 percent (see table 10).
>
> Determined a weighted leaching requirement for each DAU based on maximum ECdw. This leaching requirement allows for those crops to continue to be grown as they are presently grown in the DAU. Four distribution uniformities were also considered – 100, 90, 80, 70 percent (see table 12).
>
> Assumed a distribution uniformity of 80 percent and then considered four different leaching requirements – 5, 10, 15, and 20 percent. Crop mix was not a consideration here (see table 14).
>
> Assumed a distribution uniformity of 70 percent and the leaching fractions of 5, 10, 15, and 20 percent. Again, crop mix was not a consideration (see table 16).

Each case includes the same initial percolation from irrigated fields to saline sinks. The estimated amounts of deep percolation from both irrigated fields and conveyance systems are shown in table 6, column 15, totaling 843,000 acre-feet. Of this, 79,000 acre-feet is attributed to seepage from conveyance systems. The remainder is percolation from irrigated fields.

Explanation of tables:

Table 10 is predicated on a maximum leaching requirement that will allow every crop to be grown on every parcel of land within the DAU. Four distribution uniformities were selected (100, 90, 80, and 70 percent DU) to represent the extremes. Distribution at 100 percent uniformity over the entire DAU is not attainable, but it does provide a reference base by which to establish which distribution uniformity might be realistic. Likewise, a distribution uniformity of 70 percent over the entire DAU is not realistic to solve the deep percolation losses that are now occurring in the entire San Joaquin Valley.

Columns 1 to 4 are taken from table 6.

Column 5 is the unit of water per unit of area to grow the combination of crops now grown in a DAU. It is expressed as the ETAW in acre-feet per acre.

Column 6 is the average amount of precipitation that occurs in the DAU and is expressed a acre-feet per acre.

Column 7 is the percentage of leaching needed to allow every crop to be grown on every parcel of land within the DAU.

Columns 8, 11, 14, and 17 are the incremental increases of applied water necessary to meet ETAW, leaching requirements and various distribution uniformities. Example for DAU 212:

$$\text{Column 8} = \frac{\text{column 5}}{(\text{1-column 7})} - \text{column 5} = \frac{2.08}{(1-0.05)} - 2.08$$

$$= 0.10 \text{ acre-feet/acre}$$

$$\text{Column 14} = \left(\frac{\text{column 5}}{\text{distribution uniformity - \%}}\right) - \text{column 5}$$

$$+ \text{ column 8} = \frac{2.08}{0.80} - 2.08 + 0.10 = 0.62 \text{ acre-feet/acre}$$

Columns 9, 12, 15, and 18 show the total incremental increase of applied water needed to meet the percentage of distribution uniformity indicated, while satisfying total ETAW and leaching needs. This is also referred as the incremental gross irrigation requirement (GIR). Examples for DAU 212:

$$\text{Column 15} = \text{column 3} \times \text{column 14} = 9.30 \times 0.62$$

$$= 5.80 \text{ (1,000 acre-feet)}$$

Columns 10, 13, 16, and 19 reflect the amount of reduction to deep percolation that can occur should both the maximum ECdw and DU be implemented over the entire DAU. Example for DAU 212:

$$\text{Column 16} = \text{column 4} - \text{column 15} = 13.70 - 5.80$$

$$= 7.90 \text{ (1,000 acre-feet)}$$

Table 12 is predicated on a weighted leaching requirement that will allow the present mix of crops within a DAU to continue to be grown on the same parcels of land as at present. The column headings and column calculations are similar to those in table 10.

Tables 14 and 16 are similar except that 14 is calculated for a distribution uniformity of 80 percent and 16 is for a 70 percent uniformity. Both tables utilize a set amount of leaching requirement shown as percentages of ETAW. Leaching requirements selected were 5, 10, 15, and 20 percent.

Columns 1 through 6 are the same as shown for table 10.

Column 7 shows the incremental gross irrigation required (GIR) to meet either the 80 or 70 percent distribution uniformity. Example for DAU 212, table 14:

$$\text{Column 7} = \frac{\text{column 5}}{80\%} - \text{column 5} = \frac{2.08}{0.80} - 2.08$$

$$= 0.52 \text{ acre-feet per acre}$$

Columns 8, 11, 14, and 17 present the incremental unit increase of applied water for the respective leaching requirements plus the GIR. Example for DAU 212, table 14:

$$\text{Column 14} = (\text{column 5} \times \text{leaching requirement})$$

$$+ \text{ column 7} = (2.08 \times 0.15) + 0.52$$

$$= 0.83 \text{ acre-feet/acre}$$

Columns 9, 12, 15, and 18 show the total incremental increase of applied water required to meet the leaching requirement plus the distribution uniformity.

Columns 10, 13, 16, and 19 reflect the amount of reduction to deep percolation that can occur should that leaching requirement and distribution uniformity be implemented over the entire DAU.

Tables 11, 13, 15, and 17 reflect the average annual costs to implement each of the four situations. The amount of each conservation/management practice for each DAU was the best judgment of the subcommittee to the nearest 25 percent of the area.

Average annual costs include the necessary installation costs amortized at 12.5 percent for the life of the practice plus any annual operation and maintenance costs for the practice.

Columns 6 through 12 present annual costs per acre. These are conservation and management practices that are applied to the affected irrigated area as shown in column 3.

Columns 16 through 20 refer to the physical structure necessary to reduce the on-farm and off-farm conveyance losses in each DAU. The values shown are also in dollars per acre per year.

Table 17 does not include any calculations for conveyance losses, because they are not considered necessary to achieve a distribution uniformity of 70 percent and a leaching requirement of 20 percent.

Table 18 is a comparison of the four different situations with the associated costs and amount of reduction in water going to a saline sink. Distribution uniformity (DU) is a means of determining how well the irrigation water is distributed over the field. This is usually expressed as a percentage relating the average depth of water infiltrated in the lowest quarter of the area to the average depth of water infiltrated in the total area. There is not necessarily a direct relationship between distribution uniformity and irrigation application efficiency. However, the irrigation application efficiency cannot be better than the irrigation distribution system uniformity, except for cases of deficit irrigation.

From a practical standpoint, it is most difficult to attain a distribution uniformity of 100 percent year after year and on every parcel of land within the DAU. The easiest distribution uniformity to attain would be 70 percent, but 80 percent is reasonable and can be achieved by most growers if they have an incentive to do so.

Two situations are very similar in the amount of leaching. One is using the weighted ECdw and an 80 percent distribution uniformity and the other is using the 5 percent leaching requirement and an 80 percent distribution uniformity. Both are so close to the calculated amount of leaching that either one should allow for all crops to be grown on every parcel of land. Only on lands that are really high in salts will there be no opportunity to choose among crops.

Implementation of these situations would require additional costs by growers and public entities. Some of the administrative costs in each situation include design costs for large structures, contract administration, inspection, and supervision, and each one of these is specific to the project. Using a figure of 20 to 25 percent as overhead would be unfair to costs developed in each of the situations, because some items will not require an overhead charge.

Each situation has other beneficial and adverse effects to other water users, such as reduction of regional drain water disposal or reduction in contributions to downslope wetlands. The beneficial and adverse effects change as the number of improvements changes. There are also cost changes related to each of the beneficial and adverse impacts, and these must be evaluated in a case-by-case analysis. Analysis of all the administrative costs as well as beneficial and adverse effects of each situation is beyond the scope of this report. All environmental and economic impacts must be considered before implementing any project.

Considering the above as some limitations to a complete analysis, the material presented hereafter is a brief discussion of some of the additional costs and the beneficial and adverse impacts of selecting one case for implementation. To consider which situation to discuss, one must first decide what is practical, acceptable, reasonably effective in accomplishing the objective, and economically effective.

All of the situations attempt to display the magnitude of deep percolation that can be reduced by using various distribution uniformities with different leaching requirements. Of these, the distribution uniformity of 100 percent is not achievable. Spatial distribution of the soils and an irrigation system's nonuniformity in distributing the water makes this situation impractical for consideration. The other extreme is the 70 percent distribution uniformity and 20 percent leaching requirement, which is very close to the present condition within the 1.4 million drainage-affected acres.

Therefore, a goal that may be achievable is 80 percent distribution uniformity and a 5 percent leaching requirement. This would reduce on-farm deep percolation by 151,000 acre-feet. In addition, it is rather optimistically assumed that the 79,000 acre-feet of conveyance losses due to seepage could be completely eliminated by pipelining or concrete lining of delivery ditches.

Further, it is estimated that physical works of on-farm improvement that are necessary to attain these reductions in percolation will result in a reduction of about 20,000 acre-feet in evapotranspiration and evaporation from the category titled "Head Ditch and Field Edges," in table 4. This could have significant local impact on wildlife habitat.

As previously discussed, three criteria were developed to help identify areas where percolating water becomes unusable due to its movement into saline groundwater. These criteria were applied to the whole San Joaquin Valley with certain data sets selected because each covered the whole area in question. Subsequent analyses determined that groundwater in some portions of the area identified by this process is in fact usable (and is being used). The discrepancies were attributed to erroneous data for those particular areas. DAU 216 presented another set of circumstances, namely that percolating water is not lost but moves into the San Joaquin River, where it contributes to Delta supplies. A reduction of these flows would require releases of reservoir water, essentially offsetting any "savings" identified. After considerable study of the areas in question, the 1.2 million acre-feet originally estimated was adjusted to 843,000 acre-feet.

For the sake of discussion, however, a calculation was also made of how much water might be saved if the amount of percolation lost to further use were 1.2 million acre-feet, using the same 80 percent distribution uniformity and 5 percent leaching assumptions. This gave a value of 265,000 compared with 151,000 acre-feet based on 843,000 acre-feet of percolation. About 75,000 acre-feet of the difference would occur in DAU 216 and represents a redirection in San Joaquin River flows that would have to be made up by release of additional supply from reservoirs. It should also be kept in mind that certain data indicate that the amount percolating to unusable water may be closer to 500,000 acre-feet rather than 843,000 acre-feet. This

TABLE 10
REDUCTION TO DEEP PERCOLATION AT MAXIMUM ECdw AND VARIOUS DISTRIBUTION UNIFORMITIES

							100% DU and Maximum ECdw			90% DU and Maximum ECdw			80% DU and Maximum ECdw			70% DU and Maximum ECdw		
DAU	DESCRIPTION	1000'S Acres Affected	1000'S Ac. Ft. PERC	Ac. Ft. per Acre ETAW	Ac. Ft. per Acre Prec.	Leaching Required Percent	Ac. Ft. per Acre	1000's Ac. Ft. GIR	1000's Ac. Ft. Reduced	Ac. Ft. per Acre	1000's Ac. Ft. GIR	1000's Ac. Ft. Reduced	Ac. Ft. per Acre	1000's Ac. Ft. GIR	1000's Ac. Ft. Reduced	Ac. Ft. per Acre	1000's Ac. Ft. GIR	1000's Ac. Ft. Reduced
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)
212	El Nido-Stevenson	9.30	13.70	2.08	0.37	5.00	0.10	0.97	12.73	0.34	3.12	10.58	0.62	5.80	7.90	1.00	9.26	4.44
215	Gravelly Ford	13.10	19.26	2.22	0.24	4.65	0.10	1.35	17.91	0.35	4.58	14.68	0.66	8.62	10.64	1.05	13.82	5.44
	VALLEY EASTSIDE	22.40	32.96						30.64			25.26			18.53			
216	West Side San Joaquin	100.00	100.00	2.31	0.29	5.57	0.13	12.87	87.13	0.39	38.53	61.47	0.71	70.62	29.38	1.12	111.87	---
	VALLEY WESTSIDE	100.00	100.00						87.13			61.47			29.38			0.00
235	Raisin	10.60	17.00	2.44	0.19	7.20	0.18	1.86	15.14	0.45	4.74	12.26	0.79	8.33	8.67	1.22	12.95	4.05
237	Lower Kings River	15.20	21.28	2.29	0.16	6.00	0.14	2.09	19.19	0.39	5.96	15.32	0.71	10.79	10.49	1.12	17.01	4.27
238	Hanford-Lemoore	44.20	64.09	2.31	0.19	4.05	0.09	4.14	59.95	0.35	15.48	48.61	0.67	29.66	34.43	1.08	47.89	16.20
241	Tulare Lake	235.30	0.00	2.07	0.16	4.10	0.08	19.97	---	0.31	74.09	---	0.60	141.74	---	0.97	228.71	---
242	Kaweah Delta	4.10	3.70	2.24	0.49	3.50	0.08	0.32	3.38	0.33	1.34	2.36	0.64	2.62	1.00	1.04	4.26	---
243	Tule Delta	36.40	36.31	2.08	0.20	8.79	0.18	6.66	29.65	0.41	15.07	21.24	0.70	25.58	10.73	1.07	39.10	---
	KING-KAWEAH-TULE	345.80	142.38						127.32			99.80			65.40			24.52
244	Westlands Water District	540.50	216.20	2.08	0.05	5.68	0.12	63.86	152.34	0.35	188.77	27.43	0.64	344.92	---	1.01	545.67	---
245	Kettleman Plain	46.50	35.10	1.81	0.06	15.86	0.29	13.35	21.75	0.49	22.70	12.40	0.74	34.39	---	1.06	49.42	---
246	South Tulare Lake	43.60	29.00	1.74	0.12	11.07	0.19	8.40	20.60	0.39	16.83	12.17	0.63	27.36	1.64	0.94	40.91	---
	SAN LUIS WESTSIDE	630.60	280.30						194.70			52.00			1.64			0.00
254	Kern Delta	55.00	0.00	2.43	0.01	12.14	0.30	16.23	----	0.57	31.08	---	0.90	49.64	---	1.34	73.50	---
255	Semitropic	63.00	63.24	2.51	0.05	13.21	0.33	20.89	42.35	0.61	38.46	24.78	0.96	60.42	2.82	1.41	88.66	---
256	North Kern	4.90	5.88	2.24	0.12	5.00	0.11	0.55	5.33	0.36	1.77	4.11	0.67	3.29	2.59	1.07	5.25	0.63
258	Arvin-Edison	5.20	3.10	2.11	0.14	6.29	0.13	0.69	2.41	0.37	1.91	1.19	0.66	3.43	---	1.04	5.39	---
259	Antelope Plain	145.00	86.00	2.13	0.05	3.93	0.08	12.14	73.86	0.32	46.45	39.55	0.62	89.35	---	1.00	144.50	---
261	Wheeler-Ridge Maricopa	89.00	52.00	2.13	0.03	7.29	0.16	13.82	38.18	0.39	34.88	17.12	0.69	61.21	---	1.07	95.06	---
	KERN VALLEY FLOOR	362.10	210.22						162.13			86.75			5.41			0.63
	TOTALS	1460.90	765.86						601.92			325.27			120.36			35.04

TABLE 11

AVERAGE ANNUAL COSTS TO IMPLEMENT MAXIMUM ECdw AT 80% DISTRIBUTION UNIFORMITY

					WATER CONSERVATION MANAGEMENT AND PRACTICES										CONVEYANCE PRACTICES				
DAU (1)	Description (2)	Acres Affected (1,000s) (3)	Acres in DAU (1,000s) (4)	IAE Percent (5)	Irrigation Water Mgt. (6)	Salinity Mgt. (7)	Irrigation Flow Measuring Device (8)	Tailwater Return/ Recovery System (9)	Landlevel or Land-smoothing (10)	On-Farm or Region Drain (11)	Dollars/ Acre/ Year (12)	Dollars/ Year (1,000s) (13)	Acre-Feet Reduced to Sink (1,000s) (14)	Dollars/ Ac.Ft. Water Reduced (15)	Canal Lining or Pipeline (16)	Canal Structures or Turnouts (17)	Conveyance Losses TAF (18)	Dollars/ Year (1,000s) (19)	Dollars/ Ac.Ft. of Conv. Losses (20)
212	El Nido-Stevenson	9.3	138.2	63	10.00	20.00	0.93	7.90	6.75	0.00	45.58	423.8	7.9	53.65	37.40	1.18	0.00	358.75	0.00
215	Gravelly Ford	13.1	107.8	64	10.00	20.00	0.93	7.90	6.75	0.00	45.58	597.0	10.6	56.11	37.40	1.18	0.00	505.33	0.00
	VALLEY EASTSIDE	22.4	246.0	64	-	-	-	-	-	-	45.58	1,020.9	18.5	55.06	-	-	0.00	0.00	0.00
216	West Side San Joa.	100.0	413.0	63	6.00	10.00	0.93	7.90	6.75	0.00	31.58	3,157.5	29.4	107.47	56.10	1.76	12.50	5,786.25	462.90
	VALLEY WESTSIDE	100.0	413.0	-	-	-	-	-	-	-	31.58	3,157.5	29.4	107.47	-	-	12.50	5,786.25	462.90
235	Raisin	10.6	136.6	60	10.00	20.00	1.39	7.90	6.75	0.00	46.04	488.0	8.7	56.29	56.10	1.76	0.50	613.34	1,226.69
237	Lower Kings River	15.2	156.1	60	10.00	20.00	1.39	7.90	6.75	0.00	46.04	699.8	10.5	66.71	56.10	1.76	4.56	879.51	192.88
238	Hanford-Lemoore	44.2	148.4	56	10.00	20.00	1.39	7.90	6.75	0.00	144.50	6,386.9	34.4	185.50	56.10	1.76	8.84	2,557.52	289.31
241	Tulare Lake	235.3	235.3	91	-	-	-	-	-	0.00	-	-	0	-	-	-	-	-	-
242	Kaweah Delta	4.1	344.4	65	10.00	20.00	1.39	3.95	6.75	0.00	42.09	172.6	1.1	159.78	18.70	0.59	0.81	79.08	97.63
243	Tule Delta	36.4	327.7	56	10.00	20.00	1.85	3.95	6.75	0.00	42.55	1,548.8	10.7	144.34	18.70	0.59	7.00	702.07	100.30
	KING-KAWEAH-TULE	345.8	1,348.5	80	-	-	-	-	-	0.00	26.88	9,296.0	65.4	142.14	-	-	21.71	4,831.52	222.55
244	Westlands W.D.	540.5	540.5	88	-	-	-	-	-	0.00	-	-	0	0.00	-	-	-	-	-
245	Kettleman Plain	46.5	46.5	68	6.00	10.00	0.93	3.95	6.75	0.00	27.63	-	0	0.00	18.70	0.59	3.00	896.87	298.96
246	South Tulare Lake	43.6	43.6	76	6.00	10.00	0.46	3.95	6.75	0.00	27.16	1,184.3	1.6	722.13	18.70	0.59	1.00	840.94	840.94
	SAN LUIS WESTSIDE	630.6	630.6	86	-	-	-	-	-	0.00	1.88	1,184.3	1.6	722.13	-	-	4.00	1,737.80	434.45
254	Kern Delta	55.0	211.0	50	6.00	10.00	1.39	11.85	6.75	0.00	35.99	-	0	0.00	18.70	0.59	13.20	1,060.81	80.36
255	Semitropic	63.0	163.0	59	6.00	10.00	0.93	7.90	6.75	0.00	31.58	1,989.2	2.8	705.40	18.70	0.59	19.54	1,215.11	62.19
256	North Kern	4.9	184.0	64	6.00	10.00	0.93	3.95	6.75	0.00	27.63	135.4	2.6	52.26	18.70	0.59	0.25	94.51	378.04
258	Arvin-Edison	5.2	118.0	62	6.00	10.00	0.46	3.95	6.75	0.00	27.16	-	0	0.00	18.70	0.59	1.20	100.30	83.58
259	Antelope Plain	145.0	145.0	69	6.00	10.00	0.93	7.90	6.75	0.00	31.58	-	0	0.00	18.70	0.59	5.00	2,796.69	559.34
261	Wheeler R.-Maricopa	89.0	89.0	78	6.00	10.00	-	3.95	6.75	0.00	26.70	-	0	0.00	-	-	2.00	0.00	0.00
	KERN VALLEY FLOOR	362.1	910.0	64	-	-	-	-	-	0.00	5.87	2,124.6	5.4	392.71	-	-	41.19	5,267.42	127.88
	TOTALS	1,460.9	3,548.1	75	-	-	-	-	-	-	11.49	16,783.3*	120.4*	139.43	-	-	79.40	17,622.99	221.95

* Totals may be slightly distorted due to rounding.

TABLE 12

REDUCTION TO DEEP PERCOLATION AT WEIGHTED ECdw AND VARIOUS DISTRIBUTION UNIFORMITIES

							100% DU and Weighted ECdw			90% DU and Weighted ECdw			80% DU and Weighted ECdw			70% DU and Weighted ECdw		
DAU (1)	Description (2)	1,000s Acres Affected (3)	1,000s Ac. Ft. PERC. (4)	Ac. Ft. Per Acre ETAW (5)	Ac. Ft. Per Acre Prec. (6)	Leaching Required Percent (7)	Ac. Ft. Per Acre (8)	1,000s Ac. Ft. GIR (9)	1,000s Ac. Ft. Reduced (10)	Ac. Ft. Per Acre (11)	1,000s Ac. Ft. GIR (12)	1,000s Ac. Ft. Reduced (13)	Ac. Ft. Per Acre (14)	1,000s Ac. Ft. GIR (15)	1,000s Ac. Ft. Reduced (16)	Ac. Ft. Per Acre (17)	1,000s Ac. Ft. GIR (18)	1,000s Ac. Ft. Reduced (19)
212	El Nido-Stevenson	9.30	13.70	2.08	0.37	3.01	0.06	0.58	13.12	0.29	2.73	10.97	0.58	5.42	8.28	0.95	8.87	4.83
215	Gravelly Ford	13.10	19.26	2.22	0.24	2.70	0.06	0.79	18.47	0.31	4.02	15.24	0.61	8.06	11.20	1.01	13.25	6.01
	VALLEY EASTSIDE	22.40	32.96						31.59			26.21			19.49			10.84
216	West Side San Joaquin	100.00	100.00	2.31	0.29	2.61	0.06	6.03	93.97	0.32	31.70	68.30	0.64	63.78	36.22	1.05	105.03	-
	VALLEY WESTSIDE	100.00	100.00						93.97			68.30			36.22			0.00
235	Raisin	10.60	17.00	2.44	0.19	3.93	0.10	1.02	15.98	0.37	3.89	13.11	0.71	7.48	9.52	1.14	12.10	4.90
237	Lower Kings River	15.20	21.28	2.29	0.16	2.75	0.06	0.96	20.32	0.32	4.82	16.46	0.64	9.66	11.62	1.04	15.87	5.41
238	Hanford-Lemoore	44.20	64.09	2.31	0.19	1.41	0.03	1.44	62.65	0.29	12.78	51.31	0.61	26.97	37.12	1.02	45.20	18.89
241	Tulare Lake	235.30	0.00	2.07	0.16	1.93	0.04	9.40	-	0.27	63.52	-	0.56	131.17	-	0.93	218.15	-
242	Kaweah Delta	4.10	3.70	2.24	0.49	1.19	0.03	0.11	3.59	0.28	1.13	2.57	0.59	2.41	1.29	0.99	4.05	-
243	Tule Delta	36.40	36.31	2.08	0.20	2.76	0.06	2.09	34.22	0.29	10.50	25.81	0.58	21.02	-	0.95	34.54	-
	KING-KAWEAH-TULE	345.80	142.38						136.77			109.25			59.56			29.20
244	Westlands Water District	540.50	216.20	2.08	0.05	1.73	0.04	19.45	196.75	0.27	144.36	71.84	0.56	300.51	-	0.93	501.27	-
245	Kettleman Plain	46.50	35.10	1.81	0.06	5.26	0.10	4.43	30.67	0.30	13.78	21.32	0.55	25.47	9.63	0.87	40.50	-
246	South Tulare Lake	43.60	29.00	1.74	0.12	5.26	0.09	3.99	25.01	0.28	12.42	16.58	0.53	22.96	6.04	0.84	36.50	-
	SAN LUIS WESTSIDE	630.60	280.30						252.43			109.74			15.68			0.00
254	Kern Delta	55.00	0.00	2.43	0.01	3.81	0.09	5.09	-	0.36	19.94	-	0.70	38.50	-	1.13	62.37	-
255	Semitropic	63.00	63.24	2.51	0.05	4.62	0.12	7.31	55.93	0.39	24.88	38.36	0.74	46.84	16.40	1.19	75.08	-
256	North Kern	4.90	5.88	2.24	0.12	1.85	0.04	0.20	5.68	0.29	1.42	4.46	0.60	2.95	2.93	1.00	4.91	0.97
258	Arvin-Edison	5.20	3.10	2.11	0.14	3.01	0.06	0.33	2.77	0.30	1.55	1.55	0.59	3.07	0.03	0.97	5.03	-
259	Antelope Plain	145.00	86.00	2.13	0.05	1.93	0.04	5.96	80.04	0.28	40.28	45.72	0.57	83.17	2.83	0.95	138.33	-
261	Wheeler Ridge-Maricopa	89.00	52.00	2.13	0.03	2.89	0.06	5.48	46.52	0.30	26.54	25.46	0.59	52.87	-	0.97	86.72	-
	KERN VALLEY FLOOR	362.10	210.22						190.94			115.55			22.19			0.97
	TOTALS	1,460.90	765.86						705.71			429.05			153.13			41.01

TABLE 13

AVERAGE ANNUAL COSTS TO IMPLEMENT WEIGHTED ECdw AT 80% DISTRIBUTION UNIFORMITY

					WATER CONSERVATION MANAGEMENT AND PRACTICES										CONVEYANCE PRACTICES				
DAU (1)	Description (2)	Acres Affected (1,000s) (3)	Acres in DAU (1,000s) (4)	IAE Percent (5)	Irrigation Water Mgt. (6)	Salinity Mgt. (7)	Irrigation Flow Measuring Device (8)	Tailwater Return/ Recovery System (9)	Landlevel or Land-smoothing (10)	On-Farm or Region Drain (11)	Dollars/ Acre/ Year (12)	Dollars/ Year (1,000s) (13)	Acre-Feet Reduced to Sink (1,000s) (14)	Dollars/ Ac.Ft. Water Reduced (15)	Canal Lining or Pipeline (16)	Canal Structures or Turnouts (17)	Conveyance Losses TAF (18)	Dollars/ Year (1,000s) (19)	Dollars/ Ac. Ft. of Conv. Losses (20)
212	El Nido-Stevenson	9.3	138.2	63	10.00	20.00	0.93	7.90	6.75	0.00	45.58	423.8	8.3	51.19	37.40	1.18	0.00	358.75	0.00
215	Gravelly Ford	13.1	107.8	64	10.00	20.00	0.93	7.90	6.75	0.00	45.58	597.0	11.2	53.31	37.40	1.18	0.00	505.33	0.00
	VALLEY EASTSIDE	22.4	246.0	64	-	-	-	-	-	-	45.58	1,020.9	19.5	52.41	-	-	0.00	0.00	0.00
216	West Side San Joaquin	100.0	413.0	63	6.00	10.00	0.93	7.90	6.75	0.00	31.58	3,157.5	36.2	87.18	56.10	1.76	12.50	5,786.25	462.90
	VALLEY WESTSIDE	100.0	413.0	-	-	-	-	-	-	0.00	31.58	3,157.5	36.2	87.18	-	-	12.50	5,786.25	462.90
235	Raisin	10.6	136.6	60	10.00	20.00	1.39	7.90	6.75	0.00	46.04	488.0	9.5	51.26	56.10	1.76	0.50	613.34	1,226.69
237	Lower Kings River	15.2	156.1	60	10.00	20.00	1.39	7.90	6.75	0.00	46.04	699.8	11.6	60.22	56.10	1.76	4.56	879.51	192.88
238	Hanford-Lemoore	44.2	148.4	56	10.00	20.00	1.39	7.90	6.75	0.00	144.50	6,386.9	37.1	172.06	56.10	1.76	8.84	2,557.52	289.31
241	Tulare Lake	235.3	235.3	91	-	-	-	-	-	-	-	-	0	0.00	-	-	-	-	-
242	Kaweah Delta	4.1	344.4	65	10.00	20.00	1.39	3.95	6.75	0.00	42.09	172.6	1.3	133.77	18.70	0.59	0.81	79.08	97.63
243	Tule Delta	36.4	327.7	56	10.00	20.00	1.85	3.95	6.75	0.00	42.55	-	0	0.00	18.70	0.59	7.00	702.07	100.30
	KING-KAWEAH-TULE	345.8	1,348.5	80	-	-	-	-	-	-	22.40	7,747.2	59.6	130.10	-	-	21.71	4,831.51	222.55
244	Westlands Water District	540.5	540.5	88	-	-	-	-	-	-	-	-	0	0.00	-	-	-	-	-
245	Kettleman Plain	46.5	46.5	68	6.00	10.00	0.93	3.95	6.75	0.00	27.63	1,284.6	9.6	133.39	18.70	0.59	3.00	896.87	298.96
246	South Tulare Lake	43.6	43.6	76	6.00	10.00	0.46	3.95	6.75	0.00	27.16	1,184.3	6.0	196.07	18.70	0.59	1.00	840.94	840.94
	SAN LUIS WESTSIDE	630.6	630.6	86	-	-	-	-	-	-	3.92	2,468.8	15.7	157.55	-	-	4.00	1,737.80	434.45
254	Kern Delta	55.0	211.0	50	6.00	10.00	1.39	11,85	6.75	0.00	35.99	-	0	0.00	18.70	0.59	13.20	1,060.81	80.36
255	Semitropic	63.0	163.0	59	6.00	10.00	0.93	7.90	6.75	0.00	31.58	1,989.2	16.4	212.29	18.70	0.59	19.54	1,215.11	62.19
256	North Kern	4.9	184.0	64	6.00	10.00	0.93	3.95	6.75	0.00	27.63	135.4	2.9	46.20	18.70	0.59	0.25	94.51	378.04
258	Arvin-Edison	5.2	118.0	62	6.00	10.00	0.46	3.95	6.75	0.00	27.16	141.2	.03	4,708.17	18.70	0.59	1.20	100.30	83.58
259	Antelope Plain	145.0	145.0	69	6.00	10.00	0.93	7.90	6.75	0.00	31.58	4,578.4	2.8	1,617.80	18.70	0.59	5.00	2,796.69	559.34
261	Wheeler Ridge-Maricopa	89.0	89.0	78	6.00	10.00	-	3.95	6.75	0.00	26.70	-	0	0.00	0.00	0.00	2.00	0.00	0.00
	KERN VALLEY FLOOR	362.1	910.0	64	-	-	-	-	-	-	18.90	6,844.2	22.2	308.44	-	-	41.19	5,267.42	127.88
	TOTALS	1,460.9	3,548.1	75	-	-	-	-	-	-	14.54	21,238.7*	153.1*	138.72	-	-	79.40	17,622.99	221.95

---

* Totals may be slightly distorted due to rounding.

TABLE 14

REDUCTION TO DEEP PERCOLATION AT 80% DISTRIBUTION UNIFORMITY WITH LEACHING REQUIREMENTS OF 5%, 10%, 15% AND 20%

							For 5% L.F.			For 10% L.F.			For 15% L.F.			For 20% L.F.		
DAU (1)	Description (2)	1,000s Acres Affected (3)	1,000s Ac. Ft. PERC. (4)	Ac. Ft. Per Acre ETAW (5)	Ac. Ft. Per Acre Prec. (6)	GIR @ 80% DU (7)	Ac. Ft. Per Acre (8)	1,000s Ac. Ft. GIR (9)	1,000s Ac. Ft. Reduced (10)	Ac. Ft. Per Acre (11)	1,000s Ac. Ft. GIR (12)	1,000s Ac. Ft. Reduced (13)	Ac. Ft. Per Acre (14)	1,000s Ac. Ft. GIR (15)	1,000s Ac. Ft. Reduced (16)	Ac. Ft. Per Acre (17)	1,000s Ac. Ft. GIR (18)	1,000s Ac. Ft. Reduced (19)
212	El Nido-Stevenson	9.30	13.70	2.08	0.37	0.52	0.62	5.80	7.90	0.73	6.77	6.93	0.83	7.74	5.96	0.94	8.70	5.00
215	Gravelly Ford	13.10	19.26	2.22	0.24	0.56	0.67	8.79	10.47	0.78	10.24	9.02	0.89	11.70	7.56	1.00	13.15	6.11
	VALLEY EASTSIDE	22.40	32.96						18.37			15.96			13.52			11.10
216	West Side San Joaquin	100.00	100.00	2.31	0.29	0.58	0.70	69.55	30.45	0.81	81.10	18.90	0.93	92.65	7.35	1.04	104.20	-
	VALLEY WESTSIDE	100.00	100.00						30.45			18.90			7.35			0.00
235	Raisin	10.60	17.00	2.44	0.19	0.61	0.73	7.76	9.24	0.85	9.05	7.95	0.98	10.35	6.65	1.10	11.64	5.36
237	Lower Kings River	15.20	21.28	2.29	0.16	0.57	0.68	10.40	10.88	0.80	12.14	9.14	0.91	13.89	7.39	1.03	15.63	5.65
238	Hanford-Lemoore	44.20	64.09	2.31	0.19	0.58	0.70	30.74	33.35	0.81	35.85	28.24	0.93	40.95	23.14	1.04	46.06	18.03
241	Tulare Lake	235.30	0.00	2.07	0.16	0.52	0.62	146.71	-	0.73	171.06	-	0.83	195.42	-	0.93	219.77	-
242	Kaweah Delta	4.10	3.70	2.24	0.49	0.56	0.67	2.76	0.94	0.78	3.21	0.49	0.90	3.67	0.03	1.01	4.13	-
243	Tule Delta	36.40	36.31	2.08	0.20	0.52	0.62	22.71	13.60	0.73	26.50	9.81	0.83	30.28	6.03	0.94	34.07	0.93
	KING-KAWEAH-TULE	345.80	142.39						68.01			55.62			43.24			29.98
244	Westlands Water District	540.50	216.20	2.08	0.05	0.52	0.62	337.27	-	0.73	393.48	-	0.83	449.70	-	0.94	505.92	-
245	Kettleman Plain	46.50	35.10	1.81	0.06	0.45	0.54	25.13	9.97	0.63	29.34	5.76	0.72	33.55	1.55	0.81	37.76	-
246	South Tulare Lake	43.60	29.00	1.74	0.12	0.44	0.53	22.98	6.02	0.62	26.77	2.23	0.70	30.56	-	0.79	34.36	-
	SAN LUIS WESTSIDE	630.60	280.30						15.99			7.99			1.55			0.00
254	Kern Delta	55.00	0.00	2.43	0.01	0.61	0.73	40.23	-	0.85	46.92	-	0.97	53.60	-	1.10	60.28	-
255	Semitropic	63.00	63.24	2.51	0.05	0.63	0.76	47.60	15.64	0.88	55.50	7.74	1.01	63.41	-	1.13	71.32	-
256	North Kern	4.90	5.88	2.24	0.12	0.56	0.67	3.29	2.59	0.78	3.84	2.04	0.90	4.39	1.49	1.01	4.94	0.94
258	Arvin-Edison	5.20	3.10	2.11	0.14	0.53	0.64	3.30	-	0.74	3.85	-	0.85	4.40	-	0.95	4.95	-
259	Antelope Plain	145.00	86.00	2.13	0.05	0.53	0.64	92.29	-	0.74	107.74	-	0.85	123.18	-	0.96	138.62	-
261	Wheeler Ridge-Maricopa	89.00	52.00	2.13	0.03	0.53	0.64	56.65	-	0.74	66.13	-	0.85	75.61	-	0.96	85.08	-
	KERN VALLEY FLOOR	362.10	210.22						18.23			9.78			1.49			0.94
	TOTALS	1,460.90	765.86						151.04			108.23			67.15			42.02

TABLE 15

AVERAGE ANNUAL COSTS TO IMPLEMENT 80% DISTRIBUTION UNIFORMITY WITH A 5% OR 10% LEACHING REQUIREMENT

					WATER CONSERVATION MANAGEMENT AND PRACTICES										CONVEYANCE PRACTICES				
DAU (1)	Description (2)	Acres Affected (1,000s) (3)	Acres in DAU (1,000s) (4)	IAE Percent (5)	Irrigation Water Mgt. (6)	Salinity Mgt. (7)	Irrigation Flow Measuring Device (8)	Tailwater Return/ Recovery System (9)	Landlevel or Land-smoothing (10)	On-Farm or Region Drain (11)	Dollars/ Acre/ Year (12)	Dollars/ Year (1,000s) (13)	Acre-Feet Reduced to Sink (1,000s) (14)	Dollars/ Ac.Ft. Water Reduced (15)	Canal Lining or Pipeline (16)	Canal Structures or Turnouts (17)	Conveyance Losses TAF (18)	Dollars/ Year (1,000s) (19)	Dollars/ Ac.Ft. of Conv. Losses (20)
212	El Nido-Stevenson	9.3	138.2	63	10.00	20.00	0.93	7.90	6.75	40.60	86.18	801.4	6.9	115.65	37.40	1.18	0.00	358.75	0.00
215	Gravelly Ford	13.1	107.8	64	10.00	20.00	0.93	7.90	6.75	40.60	86.18	1,128.9	9.0	125.15	37.40	1.18	0.00	505.33	0.00
	VALLEY EASTSIDE	22.4	246.0	64	-	-	-	-	-	-	86.18	1,930.3	16.0	121.02	-	-	0.00	0.00	0.00
216	West Side San Joa.	100.0	413.0	63	6.00	10.00	0.93	7.90	6.75	20.30	51.88	5,187.5	18.9	274.47	56.10	1.76	12.50	5,786.25	462.90
	VALLEY WESTSIDE	100.0	413.0	-	-	-	-	-	-	-	51.88	5,187.5	18.9	274.47	-	-	12.50	5,786.25	462.90
235	Raisin	10.6	136.6	60	10.00	20.00	1.39	7.90	6.75	20.30	66.34	703.2	8.0	88.45	56.10	1.76	0.50	613.34	1,226.69
237	Lower Kings River	15.2	156.1	60	10.00	20.00	1.39	7.90	6.75	20.30	66.34	1,008.3	9.1	110.32	56.10	1.76	4.56	879.51	192.88
238	Hanford-Lemoore	44.2	148.4	56	10.00	20.00	1.39	7.90	6.75	40.60	144.50	6,386.9	28.2	226.17	56.10	1.76	8.84	2,557.52	289.31
241	Tulare Lake	235.3	235.3	91	-	-	-	-	-	-	-	-	0	0.00	-	-	-	-	-
242	Kaweah Delta	4.1	344.4	65	10.00	20.00	1.39	3.95	6.75	20.30	62.39	255.8	0.5	522.02	18.70	0.59	0.81	79.08	97.63
243	Tule Delta	36.4	327.7	56	10.00	20.00	1.85	3.95	6.75	20.30	62.85	2,287.7	9.8	233.20	18.70	0.59	7.00	702.07	100.30
	KING-KAWEAH-TULE	345.8	1,348.5	80	-	-	-	-	-	-	30.77	10,641.9	55.6	191.30	-	-	21.71	4,831.52	222.55
244	Westlands W.D.	540.5	540.5	88	-	-	-	-	-	-	-	-	0	0.00	-	-	-	-	-
245	Kettleman Plain	46.5	46.5	68	6.00	10.00	0.93	3.95	6.75	20.30	47.93	2,228.5	5.8	386.89	18.70	0.59	3.00	896.87	298.96
246	South Tulare Lake	43.6	43.6	76	6.00	10.00	0.46	3.95	6.75	20.30	47.46	2,069.4	2.2	927.97	18.70	0.59	1.00	840.94	840.94
	SAN LUIS WESTSIDE	630.6	630.6	86	-	-	-	-	-	-	6.82	4,297.9	8.0	537.91	-	-	4.00	1,737.80	434.45
254	Kern Delta	55.0	211.0	50	6.00	10.00	1.39	11.85	6.75	20.30	56.29	-	0	0.00	18.70	0.59	13.20	1,060.81	80.36
255	Semitropic	63.0	163.0	59	6.00	10.00	0.93	7.90	6.75	40.60	72.18	4,547.0	7.7	587.47	18.70	0.59	19.54	1,215.11	62.19
256	North Kern	4.9	184.0	64	6.00	10.00	0.93	3.95	6.75	20.30	47.93	234.8	2.0	115.11	18.70	0.59	0.25	94.51	378.04
258	Arvin-Edison	5.2	118.0	62	6.00	10.00	0.46	3.95	6.75	20.30	47.46	-	0	0.00	18.70	0.59	1.20	100.30	83.58
259	Antelope Plain	145.0	145.0	69	6.00	10.00	0.93	7.90	6.75	20.30	51.88	-	0	0.00	18.70	0.59	5.00	2,796.69	559.34
261	Wheeler R.-Maricopa	89.0	89.0	78	6.00	10.00	-	3.95	6.75	20.30	47.00	-	0	0.00	0.00	0.00	2.00	0.00	0.00
	KERN VALLEY FLOOR	362.1	910.0	64	-	-	-	-	-	-	13.21	4,781.9	9.8	488.94	-	-	41.19	5,267.42	127.88
	TOTALS	1,460.9	3,548.1	75	-	-	-	-	-	-	18.37	26,839.5*	108.3*	247.94	-	-	79.40	17,622.99	221.95

* Totals may be slightly distorted due to rounding.

TABLE 16

REDUCTION TO DEEP PERCOLATION AT 70% DISTRIBUTION UNIFORMITY WITH LEACHING REQUIREMENTS OF 5%, 10%, 15% AND 20%

							For 5% L.F.			For 10% L.F.			For 15% L.F.			For 20% L.F.		
DAU (1)	Description (2)	1,000s Acres Affected (3)	1,000s Ac. Ft. PERC. (4)	Ac. Ft. Per Acre ETAW (5)	Ac. Ft. Per Acre Prec. (6)	GIR @ 80% DU (7)	Ac. Ft. Per Acre (8)	1,000s Ac. Ft. GIR (9)	1,000s Ac. Ft. Reduced (10)	Ac. Ft. Per Acre (11)	1,000s Ac. Ft. GIR (12)	1,000s Ac. Ft. Reduced (13)	Ac. Ft. Per Acre (14)	1,000s Ac. Ft. GIR (15)	1,000s Ac. Ft. Reduced (16)	Ac. Ft. Per Acre (17)	1,000s Ac. Ft. GIR (18)	1,000s Ac. Ft. Reduced (19)
212	El Nido-Stevenson	9.30	13.70	2.08	0.37	0.89	0.99	9.24	4.46	1.10	10.21	3.49	1.20	11.18	2.52	1.31	12.15	1.55
215	Gravelly Ford	13.10	19.26	2.22	0.24	0.95	1.06	13.90	5.36	1.17	15.35	3.91	1.28	16.81	2.45	1.39	18.26	1.00
	VALLEY EASTSIDE	22.40	32.96						9.82			7.40			4.97			2.55
216	West Side San Joaquin	100.00	100.00	2.31	0.29	0.99	1.11	110.55	-	1.22	122.10	-	1.34	133.65	-	1.45	145.20	-
	VALLEY WESTSIDE	100.00	100.00						0.00			0.00			0.00			0.00
235	Raisin	10.60	17.00	2.44	0.19	1.04	1.16	12.32	4.68	1.28	13.61	3.39	1.41	14.90	2.10	1.53	16.20	0.80
237	Lower Kings River	15.20	21.28	2.29	0.16	0.98	1.09	16.64	4.64	1.21	18.38	2.90	1.32	20.12	1.16	1.44	21.86	-
238	Hanford-Lemoore	44.20	64.09	2.31	0.19	0.99	1.11	48.86	15.23	1.22	53.97	10.12	1.34	59.07	5.02	1.45	64.18	-
241	Tulare Lake	235.30	0.00	2.07	0.16	0.89	0.99	233.77	-	1.10	258.12	-	1.20	282.48	-	1.30	306.83	-
242	Kaweah Delta	4.10	3.70	2.24	0.49	0.96	1.07	4.40	-	1.18	4.85	-	1.30	5.31	-	1.41	5.77	-
243	Tule Delta	36.40	36.31	2.08	0.20	0.89	0.99	36.18	0.13	1.10	39.97	-	1.20	43.75	-	1.31	47.54	-
	KING-KAWEAH-TULE	345.80	142.38						24.68			16.41			8.28			0.80
244	Westlands Water District	540.50	216.20	2.08	0.05	0.90	1.00	542.66	-	1.11	598.87	-	1.21	655.09	-	1.32	711.30	-
245	Kettleman Plain	46.50	35.10	1.81	0.06	0.78	0.87	40.48	-	0.96	44.69	-	1.05	48.89	-	1.14	53.10	-
246	South Tulare Lake	43.60	29.00	1.74	0.12	0.75	0.84	36.49	-	0.92	40.29	-	1.01	44.08	-	1.10	47.87	-
	SAN LUIS WESTSIDE	630.60	280.30						0.00			0.00			0.00			0.00
254	Kern Delta	55.00	0.00	2.43	0.01	1.04	1.16	63.88	-	1.28	70.57	-	1.40	77.25	-	1.53	83.93	-
255	Semitropic	63.00	63.24	2.51	0.05	1.08	1.21	75.95	-	1.33	83.85	-	1.46	91.76	-	1.58	99.67	-
256	North Kern	4.90	5.88	2.24	0.12	0.96	1.07	5.25	0.63	1.18	5.80	0.08	1.30	6.35	-	1.41	6.90	-
258	Arvin-Edison	5.20	3.10	2.11	0.14	0.91	1.02	5.28	-	1.12	5.28	-	1.23	6.38	-	1.33	6.93	-
259	Antelope Plain	145.00	86.00	2.13	0.05	0.91	1.02	147.39	-	1.12	162.84	-	1.23	178.28	-	1.34	193.72	-
261	Wheeler Ridge-Maricopa	89.00	52.00	2.13	0.03	0.91	1.02	90.47	-	1.12	99.95	-	1.23	109.43	-	1.34	118.90	-
	KERN VALLEY FLOOR	362.10	210.22						0.63			0.08			0.00			0.00
	TOTALS	1,460.90	765.86						35.13			23.89			13.25			3.36

TABLE 17

AVERAGE ANNUAL COSTS TO IMPLEMENT 70% DISTRIBUTION UNIFORMITY WITH A 20% LEACHING REQUIREMENT

					WATER CONSERVATION MANAGEMENT AND PRACTICES										CONVEYANCE PRACTICES				
DAU (1)	Description (2)	Acres Affected (1,000s) (3)	Acres in DAU (1,000s) (4)	IAE Percent (5)	Irrigation Water Mgt. (6)	Salinity Mgt. (7)	Irrigation Flow Measuring Device (8)	Tailwater Return/ Recovery System (9)	Landlevel or Land-smoothing (10)	On-Farm or Region Drain (11)	Dollars/ Acre/ Year (12)	Dollars/ Year (1,000s) (13)	Acre-Feet Reduced to Sink (1,000s) (14)	Dollars/ Ac. Ft. Water Reduced (15)	Canal Lining or Pipeline (16)	Canal Structures or Turnouts (17)	Conveyance Losses TAF (18)	Dollars/ Year (1,000s) (19)	Dollars/ Ac. Ft. of Conv. Losses (20)
212	El Nido-Stevenson	9.3	138.2	63	10.00	20.00	0.93	7.90	6.75	40.60	86.18	801.4	1.6	517.05	-	-	-	-	-
215	Gravelly Ford	13.1	107.8	64	10.00	20.00	0.93	7.90	6.75	40.60	86.18	1,128.9	1.0	1,128.89	-	-	-	-	-
	VALLEY EASTSIDE	22.4	246.0	64	-	-	-	-	-	-	86.18	1,930.3	2.6	756.99	-	-	-	-	-
216	West Side San Joaquin	100.0	413.0	63	6.00	10.00	0.93	7.90	6.75	20.30	51.88	-	0	0.00	-	-	-	-	-
	VALLEY WESTSIDE	100.0	413.0	-	-	-	-	-	-	20.30	51.88	0	0	0.00	-	-	-	-	-
235	Raisin	10.6	136.6	60	10.00	20.00	1.39	7.90	6.75	20.30	66.43	703.2	0.8	878.97	-	-	-	-	-
237	Lower Kings River	15.2	156.1	60	10.00	20.00	1.39	7.90	6.75	20.30	66.34	-	0	0.00	-	-	-	-	-
238	Hanford-Lemoore	44.2	148.4	56	10.00	20.00	1.39	7.90	6.75	40.60	-	-	0	0.00	-	-	-	-	-
241	Tulare Lake	235.3	235.3	91	-	-	-	-	-	-	-	-	0	0.00	-	-	-	-	-
242	Kaweah Delta	4.1	344.4	65	10.00	20.00	1.39	3.95	6.75	20.30	62.39	-	0	0.00	-	-	-	-	-
243	Tule Delta	36.4	327.7	56	10.00	20.00	1.85	3.95	6.75	20.30	62.85	-	0	0.00	-	-	-	-	-
	KING-KAWEAH-TULE	345.8	1,348.5	80	-	-	-	-	-	-	2.03	703.2	0.8	878.97	-	-	-	-	-
244	Westlands Water District	540.5	540.5	88	-	-	-	-	-	-	-	-	0	0.00	-	-	-	-	-
235	Kettleman Plain	46.5	46.5	68	6.00	10.00	0.93	3.95	6.75	20.30	47.93	-	0	0.00	-	-	-	-	-
246	South Tulare Lake	43.6	43.6	76	6.00	10.00	0.46	3.95	6.75	20.30	47.46	-	0	0.00	-	-	-	-	-
	SAN LUIS WESTSIDE	630.6	630.6	86	-	-	-	-	-	-	-	0	0	0.00	-	-	-	-	-
254	Kern Delta	55.0	211.0	50	6.00	10.00	1.39	11.85	6.75	20.30	56.29	-	0	0.00	-	-	-	-	-
255	Semitropic	63.0	163.0	59	6.00	10.00	0.93	7.90	6.75	40.60	72.18	-	0	0.00	-	-	-	-	-
256	North Kern	4.9	184.0	64	6.00	10.00	0.93	3.95	6.75	20.30	47.93	-	0	0.00	-	-	-	-	-
258	Arvin-Edison	5.2	118.0	62	6.00	10.00	0.46	3.95	6.75	20.30	47.46	-	0	0.00	-	-	-	-	-
259	Antelope Plain	145.0	145.0	69	6.00	10.00	0.93	7.90	6.75	20.30	51.88	-	0	0.00	-	-	-	-	-
261	Wheeler Ridge-Maricopa	89.0	89.0	78	6.00	10.00	-	3.95	6.75	20.30	47.00	-	0	0.00	-	-	-	-	-
	KERN VALLEY FLOOR	362.1	910.0	64	-	-	-	-	-	-	0.00	0	0	0.00	-	-	-	-	-
	TOTALS	1,460.9	3,548.1	75	-	-	-	-	-	-	1.80	2,633.5	3.4	786.12	-	-	-	-	-

TABLE 18

COMPARISON OF SITUATIONS

Condition	Reduction to Deep Percolation (1000's AF)	Average Annual Cost (1000's $)	Average Annual Cost/AF Reduction ($/AF)
Weighted ECdw @ 100% DU	706	*	*
Max. ECdw @100% DU	602	*	*
Weighted ECdw @80% DU	153	21,239	139
80% DU and 5% LR	151	26,839	178
Max. ECdw @80% DU	120	16,783	139
80% DU and 10% LR	108	26,839	248
70% DU and 20% LR	3	26,335	786
Conveyance Losses	79	17,623	222

Note: DU = Distribution Uniformity; LR = Leaching Requirement.

*This is not obtainable and costs were not developed for this.

would give a substantially lower calculated "potential savings."

Other questions to be considered before implementing any plan are: Who will do the implementation? How long will it take? How effective will this be? Will the water be "saved" or used elsewhere within the area? Are current water laws applicable to this development? Is the "up-front" or initial-cost money available for implementation? Will the expenditure of this money benefit society in general or just a few people? Is this a substitute for another alternative? And have all environmental concerns been evaluated?

Summary of costs to implement conservation. As shown in table 19, the total potential water savings identified by this study, if 843,000 acre-feet of deep percolation is assumed, is 290,000 acre-feet. The total annual average cost to accomplish these savings is estimated to be $44 million. The average cost per acre-foot would be about $150.

Data and Research Needs

As the committee evaluated the data available for this study, it became apparent that much more information was needed to answer the questions with additional degrees of certainty. Although California may have a more thorough data collection system than anywhere else in the country, the numerous water supply sources, the enormous amount of water used in agriculture, and the large and diverse irrigated areas greatly complicate data collection.

The actual amount of water applied to a farm, an irrigation district, or a hydrologic area is very difficult to estimate accurately. This difficulty is due to unavailable or inaccurate records of the amount of water delivered from surface supplies and pumped from groundwater. Since applied water is not easily estimated, the amount of water reused or deep-percolated past the root zone is also not easily estimated without independent measurements, which are available in only a few cases.

Information on irrigation practices is available on a micro scale for some individual farms, but is practically nonexistent for some entire water agencies or DAUs. The primary analysis tool, the DWR's Surface Water Allocation Model, was created to provide a water balance of San Joaquin Valley DAUs for groundwater modeling and was not intended to specifically estimate unmeasured quantities of irrigation percolation. Irrigation percolation estimates from SWAM tended to be higher than could be justified on the basis of historically observed changes in groundwater levels. Overestimation of irrigation percolation, where it occurs, seems to be caused by underestimation of irrigation efficiencies and reuse parameters. These were approximated on the basis of limited available on-farm management data and have not been looked at generally on a DAU-wide basis to see how they fit with available measured data on changing groundwater levels.

The next step that needs to be taken is a systematic look at each DAU's water balance, using better data on annual surface water diversions, groundwater pumpage, and ETAW to indirectly determine reasonable estimates of irrigation efficiency and reuse within DAUs. Currently, such a detailed analysis can be performed only for a small number of DAUs where surface deliveries are the only source of water, and delivery records can be compared directly with applied water use. To analyze all the Valley's DAUs would require collection of available surface water delivery records, estimation of groundwater pumpage by the USGS for recent years (the last USGS Valleywide pumpage estimates are for the year 1977), and improved estimation of crop water use. This analysis would ensure that each individual water use estimate, which may appear reasonable by itself, will also result in reasonable DAU-wide water use and pumpage estimates.

Although estimates of applied water evapotranspired by crops were judged to be reasonable, this use is the largest component of water in agriculture. Small errors in these estimates could result in substantial amounts of water unaccounted for in water balances for individual DAUs. It should be noted, however, that there is a considerable body of long-term data on change in groundwater levels and total outflow which indicates that, on a basin-wide level, the total long-term ETAW is reasonably accurate. The research to estimate ET using real-time weather data from many locations around the state should be given a high priority. Research on cropping systems making use of shorter season varieties could potentially result in water savings from crop ET.

Additional and improved methodology for irrigation scheduling using real-time weather data should improve accuracy in estimating crop water needs. Although such methodology has greatly improved in recent years, there is a general lack of incentives for implementing this new technology. The same observation applies to other practices resulting in improved knowledge of amounts of water required and actually applied to crops.

Expansion of irrigation scheduling will require inexpensive, accurate, and easy-to-use water application devices and techniques. Expansion of water application measuring devices will also result in improved and additional information on irrigation application rates, which is often lacking.

Research that develops approaches for increasing the distribution uniformity of irrigation water would lead to a potential decrease in irrigation water use and would result in a real water supply savings for land where deep percolation water is transferred to a saline sink. Improved irrigation systems and better methodology for predicting and describing soil heterogeneity could decrease water deep-percolating to saline sinks.

A thorough economic analysis for various economic and environmental constraints would be useful for expanding the analyses of this report. The study should include the expected water supply savings for removal of land from production and for changes to various crop mixes. Such an

TABLE 19

SUMMARY OF COSTS TO IMPLEMENT WATER CONSERVATION

Source	Acre-feet (1,000's)	Estimated Average Annual Cost ($1,000's)	Average Annual Unit Cost ($/AF)
Reduction to Deep Percolation to Saline Sink with 80% DU and 5% LR	151	26,839	178
Conveyance Loss Reduction to Salt Sink	79	17,623	223
Field Edges & Head Ditch Water Reduction to ETAW and Evaporation	20	*	*
Reduction of Evaporation from Small Canals and Ditches	40	0.8	20
TOTALS	290	44,463	153**

* Cost included in preceding sources.

** Calculated value.

analysis was considered to be outside the scope of the present study.

Conclusions

The following conclusions can be drawn from this committee's evaluations: The largest component of irrecoverable water is the evapotranspiration (ET) from agricultural crops. It is estimated that ET of crops uses about 15.3 million acre-feet of water in the Central Valley (excluding the Delta).

This irrecoverable water use may be reduced by removing agricultural land from production, decreasing production by applying less water than ET, or growing crops with shorter growing seasons. Without decreasing agricultural crop production or changing cropping patterns, little opportunity exists for decreasing this water use without major breakthroughs in developing water-efficient crops.

Another component of irrecoverable water is the evapotranspiration of riparian vegetation and evaporation from open water surfaces supported by agricultural water supplies. The estimated amount of water used in this category is about 1.1 million acre-feet. A large amount of this irrecoverable water was judged to offer little possibility of reduction in use for physical reasons, such as the infeasibility of attempting to decrease evaporation from open water surfaces and the need to keep channels open and available to transport winter and spring runoff. Most of the remainder of the water supports vegetation judged to be beneficial as wildlife habitat. From a physical standpoint, some of this water use could be reduced by eradicating vegetation or by installing pipelines. In general, such actions would result in additional decreases in wildlife habitat. It was thus concluded that very little of the water use in this category could be reduced without having substantial negative impacts. However, cost-effective actions aimed at reducing evaporation from small canals and ditches that have no vegetation or have only a sparse cover of grasses on their banks may be possible in some cases with only minimal impact on wildlife habitat. It was estimated this could save up to 40,000 acre-feet.

An additional component of irrecoverable water is the deep percolation of irrigation water to highly saline sinks such as saline perched water tables or the percolation of water through saline soils and substrata. The lands considered to have saline sinks are primarily on the west side of the San Joaquin Valley. The amount of water reaching saline sinks through deep percolation was estimated at 843,000 acre-feet. Considerable uncertainty existed in relation to this estimate because of inadequate data on amounts of applied water, deep percolation, the exact area considered to be a saline sink, and reuse of water drained to surface channels. Some estimates of deep percolation losses ranged up to 1.2 million acre-feet and others were as low as 500,000 acre-feet.

Of the irrecoverable water estimated to be deep-percolating to saline sinks, some is required for a leaching requirement if the present crop mix and productivity are to be maintained. Spatial variability of soils and irrigation system nonuniformity prevent perfect matching of applied water and evapotranspiration requirements. It is considered that an average distribution uniformity of 80 percent and a leaching fraction of 5 percent is the maximum that could be reasonably achieved in the areas of saline sinks. Using the 843,000 acre-feet of deep percolation, the calculated reduction in on-farm deep percolation (excluding conveyance losses) would be 151,000 acre-feet. In addition, conveyance system seepage losses in areas of saline sinks could be reduced by about 79,000 acre-feet. Such actions would result in removal of some native vegetation, causing about a 20,000 acre-foot decrease in evaporation from head ditches and evapotranspiration from native vegetation on field edges.

Therefore, the total reduction in water to saline sinks and to evapotranspiration and evaporation of native vegetation and water surfaces is estimated to be 290,000 acre-feet.

The average annual cost of this saving is estimated at about $150 per acre-foot. These costs are incurred primarily by installing water-measuring devices, following irrigation scheduling programs, leveling and smoothing land, performing salinity management, installing closed pipe systems, and using tailwater recovery systems.

Additional educational programs on irrigation and salinity management would also have to be implemented.

In view of the considerable discussion during the course of the study regarding the reliability of some of the data and the validity of some of the specific assumptions, it is interesting to note that, if the calculation were based on the initial, unadjusted percolation estimate of 1.2 million acre-feet, the resulting estimated potential water savings would be only about 100,000 acre-feet higher than that based on the 843,000-acre-foot percolation. On the other hand, if percolation to unusable saline water is less, as some information indicates, the potential savings would be correspondingly lower.

To improve the certainty of the above estimates of the potential for irrigation water supply savings and associated costs, particularly with regard to what might be reasonably obtained at the farm level, substantially more information is needed. We need data on amounts and sources of water applied to crops, reuse, percolation to saline sinks, leaching requirements, attainable irrigation distribution uniformities, and economics.

Research to estimate evapotranspiration more accurately from real-time weather data would help improve the data base and is essential for increasing irrigation efficiency. Research on methodology for increasing the distribution uniformity of irrigation systems also might lead to reductions in agricultural water use. Additional economic research should be initiated on the effects of removing irrigated land from production and of changing crop patterns on the potential for reduction in water use.

Appendices

Appendix 1: Sample Letters - Committee Appointment and Charge

February 10, 1984

R. M. HAGAN

Dear Dr. Hagan:

I would appreciate it if you would serve as a member of a Central Valley Water Use Study Committee. The Committee is being formed in order to address the question of potential water supply savings through increased irrigation efficiency and management. The draft objectives of the study are:

1. To determine the quantity, quality, and energy (required for pumping) status of manageable water in the various elements of the hydrologic cycle including use and fate of water in the Central Valley.
2. To estimate the potential for water supply savings through achievable and practical increased irrigation efficiency and management and the related water quality and energy considerations.
3. To delineate and evaluate researchable topics which may result in future water supply savings.

The stimulus for this study is provided by the need for a better understanding regarding the extent to which agricultural water conservation can reduce the need for additional supply development and provide other benefits. This, plus the broad public support for water conservation, suggests that the issue is of a critical enough nature that we should proceed with the study in order to assist in state water resource planning.

The Committee will be comprised of UC faculty and one to two technical representatives from several state and federal agencies concerned with water use and management in the Central Valley. In addition, other interested parties will be given opportunities to review and comment on the study. I have asked Associate Dean Dennis Rolston, College of Agricultural and Environmental Sciences, UC Davis, to chair the Committee. The Committee's activities will have the full support and access to data of the State Department of Water Resources. The Committee will be expected to assemble data from other sources as well.

Committee members will need to make a reasonably steady commitment of time and effort analyzing the data, developing conclusions, and making recommendations for future programs. The goal for completion of the study and publication of a final report is approximately one year.

I hope you will be willing to accept this important assignment and challenge. The proposed time, date, and location for the first meeting of the Committee are 1:30 p.m., February 24, 1984 at Davis. Information on the room and building for the meeting will be provided at a later date.

Sincerely,

Lowell N. Lewis
Assistant Vice President and
Director, Agricultural
Experiment Station

February 13, 1984

Jack C. Parnell
California Department of Fish and Game
1416 Ninth Street
Sacramento, CA 95814

Dear Jack:

We would appreciate it if you would recommend one or two technical members of your staff to serve as members of a Central Valley Water Use Study Committee. The Committee is being formed in order to address the question of potential water supply savings through increased irrigation efficiency and management. The draft objectives of the study are:

1. To determine the quantity, quality, and energy (required for pumping) status of manageable water in the various elements of the hydrologic cycle including use and fate of water in the Central Valley.
2. To estimate the potential for water supply savings through achievable and practical increased irrigation efficiency and management and the related water quality and energy considerations.
3. To delineate and evaluate researchable topics which may result in future water supply savings.

The stimulus for this study is provided by the need for a better understanding regarding the extent to which agricultural water conservation can reduce the need for additional supply development and provide other benefits. This, plus the broad public support for water conservation, suggests that the issue is of a critical enough nature that we should proceed with the study in order to assist in state water resource planning.

The Committee will be comprised of University of California faculty and one to two technical representatives from several state and federal agencies concerned with water use and management in the Central Valley.

In addition, other interested parties will be given opportunities to review and comment on the study. We have asked Associate Dean Dennis Rolston, College of Agricultural and Environmental Sciences, University of California, Davis, to chair the Committee. The Committee's activities will have the full support and access to data of the State Department of Water Resources. The Committee will be expected to assemble data from other sources as well.

Committee members will need to make a reasonably steady commitment of time and effort analyzing the data, developing conclusions, and making recommendations for future programs. The goal for completion of the study and publication of a final report is approximately one year.

We hope that you and members of your staff will be willing to accept this important assignment and challenge. The proposed time, date and location for the first meeting of the Committee are 1:30 p.m., February 24, 1984 at Davis. Information on the room and building for the meeting will be provided at a later date.

Sincerely,

Lowell N. Lewis
Assistant Vice President and
Director, Agricultural
Experiment Station

David M. Kennedy, Director
California Department of Water
Resources

Appendix 2: Committee Members

Members of the Central Valley Water Use Study Committee

Dennis E. Rolston, Committee Chair
Department of Land, Air and
Water Resources
University of California
Davis, CA 95616
(916) 752-2113

Ralph G. Allison
Department of Water Resources
State of California
1416 - 9th Street
Sacramento, CA 95814
(916) 445-2356

Virgil Backlund
U.S. Soil Conservation Service
2121-C 2nd Street
Davis, CA 95616
(916) 449-2819

Suzanne Butterfield
Department of Water Resources
State of California
1416 - 9th Street
Sacramento, CA 95814
(916) 322-3071

Vashek Cervinka
California Department of
Food and Agriculture
Room 409
1220 N Street
Sacramento, CA 95814
(916) 445-6719

Ed Craddock
Department of Water Resources
State of California
1416 - 9th Street
Sacramento, CA 95814
(916) 445-9958

Johannes J. DeVries
Department of Civil Engineering
Water Resources Center
University of California
Davis, CA 95616
(916) 752-1544

Terry Erlewine
Department of Water Resources
State of California
3374 E. Shields Avenue
Fresno, CA 93726
(209) 445-5100

Arthur C. Gooch
Department of Water Resources
State of California
1416 - 9th Street
Sacramento, CA 95814
(916) 445-9610

Donald W. Grimes
Department of Land, Air and
Water Resources
UC Kearney Agricultural Center
9240 S. Riverbend Avenue
Parlier, CA 93658
(209) 646-2794

Om P. Gulati
Water Resources Control Board
State of California
901 P Street
Sacramento, CA 95826
(916) 324-5630

Robert M. Hagan
Department of Land, Air and
Water Resources
University of California
Davis, CA 95616
(916) 752-0457

Delbert W. Henderson
Department of Land, Air and
Water Resources
University of California
Davis, CA 95616
(916) 752-0689

Glenn J. Hoffman
Water Management Research
Laboratory
USDA/ARS
204 South Peach Avenue
Fresno, CA 93727
(209) 251-0437

Richard E. Howitt
Department of Agricultural
Economics
University of California
Davis, CA 95616
(916) 752-1521

William R. Johnston
Assistant Manager
Westlands Water District
P.O. Box 6056
Fresno, CA 93703
(209) 224-1523

John Letey
Department of Soil and
Environmental Sciences
University of California
Riverside, CA 92521
(714) 787-5105

Gordon R. Lyford
U.S. Bureau of Reclamation
MP423
2800 Cottage Way
Sacramento, CA 95825
(916) 978-5062

Miguel Mariño
Department of Land, Air and
Water Resources
University of California
Davis, CA 95616
(916) 752-0684

Jewell Meyer
Soils and Environmental Sciences
Cooperative Extension
University of California
Riverside, CA 92521
(714) 787-5101

Bob Orcutt
Department of Fish and Game
State of California
1416 - 9th Street, 12th Floor
Sacramento, CA 95814
(916) 445-1383

William 0. Pruitt
Department of Land, Air and
Water Resources
University of California
Davis, CA 95616
(916) 752-1833

Susan Ramos
U.S. Bureau of Reclamation
Division of Planning
2800 Cottage Way
Sacramento, CA 95825
(916) 484-4101

Maurice Roos
Department of Water Resources
State of California
1416 - 9th Street
Sacramento, CA 95814
(916) 445-2311

Glenn B. Sawyer
Department of Water Resources
State of California
1416 - 9th Street
Sacramento, CA 95814
(916) 445-6746

Felix E. Smith
U.S. Fish and Wildlife Service
2800 Cottage Way
Sacramento, CA 95825
(916) 484-4106

Arvey Swanson
Department of Water Resources
State of California
3374 E. Shields Avenue
Fresno, CA 93726
(209) 445-5181

Kenneth K. Tanji
Department of Land, Air and
Water Resources
University of California
Davis, CA 95616
(916) 752-0683/0453

William E. Templin
U.S. Geological Survey
2800 Cottage Way, Room W-2235
Sacramento, CA 95825
(916) 978-4648

Henry Vaux
Department of Soil and
Environmental Science
University of California
Riverside, CA 92521
(714) 787-4657

Philip C. Woods
U.S. Environmental Protection
Agency, Region 9
215 Fremont Street
San Francisco, CA 94105
(415) 974-8307

Craig Woodring, Committee
Assistant
Postgraduate Researcher
Department of Land, Air and
Water Resources
University of California
Davis, CA 95616
(916) 752-7415

Subcommittees

Steering Subcommittee. This subcommittee was formed to assist the chair of the committee in determining overall direction of committee activities. The members were:

D. Rolston, Chair
R. Allison
O. Gulati
R. Hagan
D. Henderson
R. Howitt
G. Sawyer

Evapotranspiration Subcommittee. This subcommittee was formed to evaluate the adequacy of data for evapotranspiration of applied water to agricultural crops. The committee also determined appropriate evapotranspiration estimates for native or riparian vegetation. The members were:

W. Pruitt, Chair
W. Johnston
J. Letey
G. Lyford

Groundwater Subcommittee. This subcommittee was formed to evaluate the amount of water percolating past the crop root zone and reaching saline groundwater. Committee members were:

D. Grimes, Chair
R. Allison
V. Cervinka
T. Erlewine
W. Johnston
M. Mariño
G. Sawyer
A. Swanson
K. Tanji
W. Templin
P. Woods

Subcommittee on Conservation Potential, Costs, and Impacts. The subcommittee was charged with evaluating the various tabulated components of water balance with regard to their conservation potential for each component, the potential costs of implementing a conservation practice, and the expected effects on other beneficial uses of water. The subcommittee members were:

V. Backlund, Chair
S. Butterfield
R. Hagan
R. Howitt
W. Johnston
G. Novak
R. Orcutt
F. Smith

Committee Assistant

Craig Woodring was hired in May 1984 as a postgraduate researcher to provide support for the committee activities through data acquisition and analysis, coordination of subcommittee activities, and writing and editing of printed material. Mr. Woodring's activities were critical for completion of the committee's charge.

Appendix 3: Agencies Participating or Providing Information

FEDERAL

U.S. Department of Agriculture

- Agricultural Research Service (ARS)
- Soil Conservation Service (SCS)

U.S. Department of Interior

- Bureau of Reclamation (USBR)
- Geological Survey (USGS)
- Fish and Wildlife Service (USFW)

Environmental Protection Agency (EPA)

National Aeronautics and Space Administration (NASA)

CALIFORNIA STATE

Department of Water Resources

- Division of Planning
  - Sacramento Headquarters
  - San Joaquin District Office - Fresno
  - Central District Office - Sacramento
  - Sacramento District Office - Redding
- Office of Water Conservation

Department of Fish and Game

Water Resources Control Board

University of California

- Riverside Campus
- Davis Campus
- UC Water Resources Center
- Cooperative Extension
- Agricultural Experiment Station

PUBLIC AND PRIVATE:

Kern County Water Agency
Central California Irrigation District
Westlands Water District
Panoche Irrigation District
Tulare Lake Water Storage District
Grassland Water District

Appendix 4: Minority Report

By John Letey and Henry Vaux

In our opinion, the report of the Central Valley Water Use Study Committee suffers from two broad shortcomings. First, the committee has defined the term "conservation" in a way that is unduly restrictive and misleading. In addition, the committee fails to analyze all of the potential sources of water savings that fall under its own definition of the term "conservation." Second, the committee report suggests that the issue of how much agricultural water can be conserved is one that can be resolved scientifically. In contrast, we believe that the question is not susceptible to scientific resolution within a reasonable range of accuracy. We elaborate briefly on both of these points.

The committee defines "conservation" as embodying "those practices that result in a decrease in the amount of irrigation water irrecoverably lost during agricultural use." Under this definition, water that is available or potentially available after agricultural use to serve some subsequent "reasonable and beneficial use" cannot be conserved since, in the committee's view, any savings in water that diminish or extinguish any "reasonable and beneficial" use will simply have to be made up from some alternative source of supply. This is tantamount to saying that all existing "reasonable and beneficial" uses must be served without regard to the degree of reasonableness or the extent of benefit conferred. We believe that this definition is too narrow, given that the legal and administrative interpretations of what constitutes "reasonable and beneficial" use are subject to change and given that it is unrealistic to expect that all "reasonable and beneficial" uses can be served in a state where water is scarce.

This same problem arises in the committee's interpretation of its own definition of "conservation." The committee recognizes that reductions in crop evapotranspiration would be included under its definition of conservation and lists on page 9 various means whereby ET could be modified or errors introduced into estimates of ET, but it ignores these factors in the conclusions. As a consequence, the committee restricts its assessment of potential water savings to water that would otherwise be irretrievably lost to salt sinks, thereby becoming unavailable for further use. In our view, the use of this narrow definition has probably caused the committee to ignore the potential savings in agricultural water that might result from changing economic conditions. Indeed, a 1.5 percent adjustment in ET would be equivalent to the proposed water savings that could be achieved by reducing flows to salt sinks.

California's agricultural economy is currently faced with rising water prices and falling product prices. Growers respond to changes in these relative prices by managing their water more carefully, by shifting away from water-intensive crops, and, in some instances, by taking land out of production. These decisions usually result in the saving of water as a consequence of abandoning some beneficial use because it is no longer an economical use. The committee does not address systematically these kinds of water saving activities, despite the fact that such activities could alter the potential water savings that might be realized within the agricultural sector.

The fact that estimates of quantities of water that can be conserved depend, in part, on how the notion of conservation is defined and interpreted points toward the second broad shortcoming of the committee's report. A majority of the committee believes that the issue of how much agricultural water is conservable can be resolved scientifically. We disagree, principally because there are large gaps in the scientific information needed to resolve the issue within a reasonable range of accuracy. The committee has acknowledged throughout its report that there are substantial uncertainties associated with virtually every step of the analysis. In spite of this fact, we are concerned that the report will be given more scientific legitimacy than it warrants. In this vein, we offer the following detailed comments to illustrate how dependent the committee's conclusions are on arbitrary assumptions.

As noted earlier, water percolating beyond the root zone to an irretrievable or saline receptor is defined as water that can be potentially "conserved" for other uses. Deep percolation losses were computed with the aid of the Surface Water Allocation Model (SWAM) developed for the Department of Water Resources. On page 19, the committee outlines very significant shortcomings and uncertainties surrounding the values computed with the SWAM model. The problem lies not with the model but with the severe limitations on the accuracy of the data that are put into the model, which then yield unreliable estimates of the total quantities of deep percolation. In addition, we believe that the definition of saline sinks is essentially arbitrary. Inasmuch as the effect of salinity on productivity is highly variable, depending upon the crop type and leaching strategies, it is virtually impossible to identify the distinction between saline water and nonsaline water. That is, salinity is always a matter of degree, and this is glossed over in the committee report, where firm distinctions are made between saline and nonsaline groundwater.

The committee's use of results generated by the SWAM model and its essentially arbitrary definition of saline sinks highlight our concerns about the scientific validity of the report. The report acknowledges the fact that the basic estimate of deep percolation from which measures of potentially conservable quantities are developed could be 40 percent lower or 50 percent higher than the calculated figure. (The committee reports that deep percolation is 843,000 acre-feet but indicates that it could be as high as 1.2 million acre-feet or as low as 500,000 acre-feet.) A majority of the committee believes that the results have some validity for planning purposes despite the very substantial uncertainties surrounding the actual quantities of deep percolation. Given the inadequacies of the data used in the SWAM model, the arbitrary definition of saline sinks, and a host of other uncertainties that the committee itself has identified, it is our view that even these very wide confidence intervals are too conservative. Indeed, given the current state of the scientific arts, it is not possible to estimate the quantities of water that are potentially conservable with a degree of accuracy that would make such estimates useful for planning and policy purposes.

We would also note a problem with the way in which costs have been associated with water savings. No direct linkage is established between various farm management practices and the irrigation distribution uniformity. In the absence of these linkages, it is impossible to compute or derive the costs of changing the distribution uniformity. The reported average conservation cost of $150 per acre-foot thus is little more than a guess.

In this minority report, we do not mean to imply that our fellow committee members failed to put forth significant effort or failed to state the important assumptions and limitations underlying the analyses. Nor are we suggesting that the state of the scientific arts would permit the committee to improve the reported estimates. Rather, the purpose of this minority report is to highlight the fact that the estimates found in the committee report are based on specific assumptions that are highly uncertain. In our view, the magnitude of this uncertainty is so large that the committee's findings are unlikely to be useful in guiding planning and policy efforts focused on agricultural water conservation. Moreover, the committee's failure to address issues related to the incentives that lead to water conservation and other institutional adjustments that might be used to create shifts in patterns of agricultural water use also serve to constrain the usefulness of the report in providing planning and policy guidance.

Glossary

Acre-foot. The quantity of water required to cover one acre of surface to a depth of one foot.

Applied water (AW). Water applied to crops by irrigation; measured as the quantity of water delivered to the farm headgate.

Claypan. Dense clay layer occurring below the soil's surface layer.

Conjunctive use. The operation of a groundwater basin in coordination with a surface water-storage and conveyance system. The purpose is to recharge the basin during years of above-average water supply to provide storage that can be withdrawn during drier years when surface supplies are below normal.

Consumptive use. Water transpired by vegetative growth and used in building plant tissue, and water evaporated from plant, soil, and water surfaces.

Crop year. Time of planting to time of harvest; may not coincide with the calendar year.

DeciSiemens per meter (dS/m). A measure of salinity in waters and soils; the SI equivalent of millimhos/cm.

Deficit irrigation. Term used for irrigation practices under which not enough water is applied to meet the full evapotranspiration requirement of the plant.

Distribution uniformity (DU). Ratio of the minimum depth of water infiltrating within a field to the average depth of water infiltrating the whole field.

Effective rainfall. That portion of rainfall evaporated from the soil and transpired by crops. It includes rainfall that (1) occurs during the growing season and (2) occurs outside the growing season but is carried over into the following growing season as stored soil moisture.

Evapotranspiration (ET). The quantity of water transpired and evaporated from plant tissues and surrounding soil surface. Quantitatively, it is expressed in terms of volume of water per unit area or depth of water during a specified period of time.

Evapotranspiration of applied water (ETAW). The portion of the total crop evapotranspiration that is provided by applied water.

Flume. A flow-through device that can be used for measuring quantity of water.

Groundwater. Water that occurs beneath the land surface and completely fills all pore spaces of the alluvium or rock formation in which it is contained.

Head ditch. The water-supply ditch at the upper end of an irrigated field.

Infiltration rate. The rate at which water enters the soil.

Irrigation efficiency. The efficiency of water application on a farm; determined by dividing the quantity of ETAW by the quantity of AW and expressed as a percentage.

Leaching requirement. The amount of water required to flush a sufficient quantity of salts from the root zone downward to maintain full crop productivity.

Perched water table. Groundwater supported by a zone of material of low permeability situated above an underlying main body of groundwater with which it is not hydrostatically connected.

Percolation. The downward movement of water through the soil or alluvium to the groundwater table.

Phreatophytes. Native plants that typically obtain their water supply from the water table.

Plowpan. Soil compacted by tillage equipment at some depth below the surface.

Preirrigation. Irrigation water applied before planting.

Riparian vegetation. Vegetation growing on the banks of a stream or other body of water and receiving its water supply from that source.

Saline sink. A body of water or soil too salty for crop irrigation.

Salt balance. With regard to the crop root zone, a salt balance is obtained by the addition of irrigation water in sufficient quantity to leach salts out of the root zone so that the salinity level does not reduce crop yield.

Seepage. The gradual movement of water through the soil; usually refers to canal or ditch banks.

Soil intake. See "Infiltration rate."

Soil moisture depletion. The quantity of soil moisture extracted by transpiration and evaporation processes.

Tailwater. Applied water that is not transpired or evaporated but runs off the lower end of a field and then, usually, to a surface water body or another field. Does not include drainage water, although tailwater and drainage water may be mixed and reused.

Trough. The lowest land form in the Central Valley, lying between the floodplains immediately adjacent to the Sacramento and San Joaquin rivers and the alluvial fans covering the sides of the Valley.

Water-holding capacity. The amount of soil water retained per depth of a field soil after a deep irrigation and excess water has drained away, usually within two to three days after irrigation.

Water quality. A term used to describe the chemical, physical, and biological characteristics of water, usually in regard to its suitability for a particular purpose.

Wildlife. A term that includes birds, fish, mammals and all other classes of wild animals and all types of aquatic and land vegetation upon which wildlife is dependent.

References

Ayers, R. S., and D. W. Westcot. 1976. Water quality in agriculture. Irrigation and Drainage Paper 29. Rome, Italy: United Nations Food and Agriculture Organization (FAO), 97 pp.

Biggar, J. W., D. E. Rolston, and D. R. Nielsen. 1984. Transport of salts by water. California Agriculture 38(10): 10-11.

Backlund, V. L., and R. R. Hoppes. 1984. Status of soil salinity in California. California Agriculture 38(10):8-9.

Brode J. M., and R. B. Bury. 1984. The importance of riparian systems to amphibians and reptiles, p. 30-36. *In*: R. E. Warner and K. M. Hendrix (ed.). California riparian systems. (University of California, Davis, September 17-19, 1981.) Berkeley, California: University of California Press.

Croft, M. G. 1972. Subsurface geology of the late Tertiary and Quaternary water-bearing deposits of the southern part of the San Joaquin Valley, California. Water Supply Paper 1999-H. Washington, D.C.: United States Geological Survey.

Davenport, D. C., and R. M. Hagan. 1982. Agricultural water conservation in California, with emphasis on the San Joaquin Valley. Paper No. 1010. Davis, California: University of California, Department of Land, Air and Water Resources.

Department of Water Resources. 1970. Land and water use aspect of San Joaquin Valley drainage investigation. Sacramento, California: State of California Memorandum Report.

_________. 1974. Vegetative water use in California. Bulletin 113-3.

_________. 1978. Evaluation of ground water resources: Sacramento Valley. Bulletin 118-6.

_________. 1980. Ground water study: San Joaquin Valley. First Progress Report. June.

_________. 1982a. Recommended water management plan for Tulare Lake Basin Water Storage District. In response to Governor's Executive Order B 68-80. Draft copy.

_________. 1982b. The hydrologic - economic model of the San Joaquin Valley. Bulletin 214.

_________. 1983. The California Water Plan: Projected use and available water supplies to 2010. Bulletin 160-83.

_________. 1986. Crop water use in California. Bulletin 113-4.

Doneen, L. D. 1967. Quality of percolating water I. Properties of deep substrata materials in the west side of the San Joaquin Valley. Hilgardia 38 (9):285-306.

Fogelman, Ronald P. 1982. Compilation of selected groundwater quality data from the San Joaquin Valley, California. Open File Report 82-335. Washington, D.C.: U.S. Geological Survey.

Hubbard, J. P. 1977. Importance of riparian ecosystems: Biotic considerations. *In*: R. R. Johnson and D. A. Jones (tech. coord.). Importance, preservation, and management of riparian habitat: A symposium. USDA Forest Service GTR-RM-43. Fort Collins, Colorado: Rocky Mountain Forest and Range Experiment Station.

Inter-Agency Committee on Land Subsidence in the San Joaquin Valley. 1958. Land subsidence investigations, San Joaquin Valley, California. Progress Report through 1957. Berkeley, California.

Jensen, Marvin E. 1973. Consumptive use of water and irrigation water requirements. A report prepared by the Technical Committee on Irrigation Water Requirements of Irrigation and Drainage Division. New York: American Society of Civil Engineers.

Johnson, R. R., L. T. Haight, and J. M. Simpson. 1977. Endangered species vs. endangered habitats: A concept. *In*: R. R. Johnson and D. A. Jones (tech. coord.). Importance, preservation and management in riparian habitat: A symposium. USDA Forest Service GTR-RM-43. Fort Collins, Colorado: Rocky Mountain Forest and Range Experiment Station.

Katibah, Edwin F., Nichole E. Nedeff, and Kevin J. Dummer. 1980. The aerial and linear extent of riparian vegetation in the Central Valley of California. Final report of work performed for the California Department of Fish and Game. Standard Agreement #DFG-S-1412. Berkeley, California: The University of California.

Kern County Water Agency. May 1985. Water Supply Report 1984. District Report. Bakersfield, California.

McLaughlin, Dennis. 1982. Hydrologic modeling task report for the San Joaquin Valley Groundwater Study-Volume 1. Sacramento, California.

Meade, Robert H. 1967. Petrology of sediments underlying areas of land subsidence in Central California. Professional Paper 497-C. Washington, D.C.: United States Geological Survey

Pruitt, W. 0., Elias Fereres, K. Kaita, and Richard Snyder. 1987. Reference evapotranspiration ET_0 for California. Bulletin No. 1922. Berkeley, California: University of California, Division of Agriculture and Natural Resources.

San Joaquin Valley Interagency Drainage Program. June 1979. Agricultural drainage and salt management in the San Joaquin Valley. Final Report. Sacramento, California.

State Water Resources Control Board. 1975. Water quality control plan report. Central Valley Basin. Sacramento, CA.

Tanji, K. K., L. D. Doneen, and J. L. Paul. 1967. Quality of percolating waters III. The quality of waters percolating through stratified substrata, as predicted by computer analyses. Hilgardia 38(9):319-47.

Tulare Lake Basin Water Storage District. 1981. Report on irrigation, drainage and flooding in the Tulare Lake Basin. Unpublished report.

U.S. Council on Environmental Quality. 1978. Environmental quality. The ninth annual report of the Council on Environmental Quality (December, 1978). Washington, D.C.: U.S. Government Printing Office.

Westlands Water District. 1985. Unpublished data on cropping patterns, drainage volumes, and water use.

Williams, D. F., and K. S. Kilburn. 1984. Sensitive, threatened, and endangered mammals of riparian and other wetland communities in California. *In*: R. E. Warner and K. M. Hendrix (ed.). California riparian systems. (University of California, Davis, September 17-19, 1981.) Berkeley, California: University of California Press.

5m-7/87-bt/pf