# WATER MANAGEMENT WITHIN THE

# IMPERIAL IRRIGATION DISTRICT

**by**


## The Water Advisory Committee
**for**
## Coachella Valley Water District


**May 2003**

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# WATER MANAGEMENT WITHIN THE IMPERIAL IRRIGATION DISTRICT

## I. INTRODUCTION

### I. A. Water Advisory Committee (WAC)

Dr. Marvin Jensen, under contract with the United States Department of Interior Bureau of Reclamation, prepared an assessment in 1995 of the Imperial Irrigation District (IID) water use of Colorado River Water. Management personnel within the IID organization took exception to some of Dr. Jensen's conclusions and then formed a "Water Study Team" (WST) to review and critique his report. The Coachella Valley Water District (CVWD) subsequently established a "Water Advisory Committee" (WAC) to review available data and background information and analyze this information to determine the Beneficial Use of Colorado River Water in IID. This report, entitled "Water Management within the Imperial Irrigation District", reports WAC's efforts on analyzing IID's use of Colorado River Water.

The CVWD – WAC team, as then composed, commenced their study with a meeting in Denver with Dr. Jensen in late 1996. The WAC team currently consists of:

Dr. James R. Gilley, Agricultural Engineer, Professor and Head of the Biological and Agricultural Engineering Department, Texas A and M University, College Station, Texas;
Dr. Robert W. Hill, Irrigation Engineer, Professor and Extension Specialist, Biological and Irrigation Engineering Department, Utah State University, Logan, Utah;
Mr. Joseph M. Lord, Jr., P.E., President JMLord, Inc, Fresno, California (WAC Chair);
Dr. Charles V. Moore, Senior Research Agricultural Economist, University of California, Davis, California;
Dr. Earl C. Stegman, Agricultural Engineer, Professor and Chair, Agricultural and Biosystems Engineering Department, North Dakota State University, Fargo, North Dakota;
Dr. Kenneth K. Tanji, Soil and Water Chemist, Professor Emeritus in Hydrology, Departments of Land, Air and Water Resources, University of California, Davis, California;
Dr. Wesley W. Wallender, Agricultural Engineer, Professor, Departments of Land, Air and Water Resources and Biological and Agricultural Engineering, University of California, Davis, California.

This Committee reports to Mr. Gerald Shoaf, Chief Counsel for CVWD.

The WAC team has individually and collectively reviewed and thoroughly considered reports from Jensen (1995), WST (1998), Jensen and Walter (1997), and numerous other documents and reports in the course of the committee's analysis. The WAC team members have also participated in team and individual field visits to the IID service area to observe conditions generally.

## I. B. Objectives

The primary objective of this report is to review available data and background information and analyze this information to determine the Beneficial Use of Colorado River Water in IID. To satisfy this objective, the assignment of the WAC team included further review and analysis of available IID data for a longer time series than reported by Jensen and Walter (1997). The time series of the review and analysis considers available IID data for the period 1972 – 2000. Other objectives include evaluation of the possible conditions leading to the increased IID diversions realized in the late 1980's through the mid 1990's and scrutiny of tail water and other losses. The focus of this report is threefold:

1. Is the annual volume of water discharged to the Salton Sea from the Imperial Irrigation District the result of reasonable and prudent irrigation operations?

2. Was increase in annual diversions by the Imperial Irrigation District beginning in the late 1980's justified, particularly in light of the capital investment in water management facilities and conservation activities associated with IID's water transfer agreement with Metropolitan Water District of Southern California (MWD)?

3. A thorough review and analysis of the Imperial Irrigation District's General Manager's letter to the State of California, dated March 22, 1999: "Will the conservation for the IID-SDCWA transfer involve tail water and why has IID use gone up since 1992?" (See Jessie P. Silva's letter under Prolog, Chapter III, Section III A.)

Even before the time that IID initially began exploring the opportunities for selling and transferring Colorado River water to the Metropolitan Water District of Southern California (MWD) in 1986, there have been numerous reports and assessments produced, both internally and externally, discussing water use and management within IID, along with critiques of these documents. Associated with these reports are claims of beneficial use of water by IID. Most of the data and reports currently available are associated with contractual obligations relating to Colorado River use. For the most part, they reflect District diversions and gross discharges to the Salton Sea. To develop a detailed assessment of beneficial use of water by irrigated agriculture or to document irrigation performance, farm water-use data is desirable. The Imperial Irrigation District maintains the position that farm water-use and farm water management data are not available.

To help overcome the lack of available farm level water use data, the WAC conducted a district wide assessment of IID's water use and management. District wide crop water use was quantified and performance measures calculated by developing crop water budgets based on documented historical weather in IID, cropping patterns, diversions, and discharges to the sea.

The WAC also developed corresponding salinity budgets, using salinity data and soil salinity models, which corroborated the water balance analysis. These, along with anecdotal information of farming practices in IID, were used to evaluate water management within IID.

## I. C. Imperial Irrigation District

The Imperial Valley of southeastern California is in a low desert arid climate regime characterized by hot summers, mild winters, high evaporation, and very little precipitation. Year round cropping is possible with very low probability of winter frosts. The hot summertime temperatures can be detrimental to crop (such as alfalfa) growth and yield.

The diversion and use of adequate amounts of irrigation water through out the year from the Colorado River, at Imperial Dam, is essential to maintain a viable agricultural economy on an irrigated area varying between 441,000 to 468,000 acres (1972 – 2000). Total cropped area varied from about 500,000 to 600,000 acres in the same time period. Cropped area is larger than irrigated area primarily due to double cropped land, for which two or more crops are grown annually. Field crops have dominated in IID, being about 80 percent of the area with the balance in garden crops. Alfalfa and wheat are the dominant field crops, whereas lettuce and melons are the major vegetables.

Diversions of Colorado River water to the IID service area occur through the All-American Canal from Imperial Dam and are measured at Drop One. Water delivery volumes at Drop One fluctuated from 2.4 to over 3.1 million-acre feet during the period 1972 – 2000. Jensen and Walter (1997) concluded that diversions in IID generally increased over the ten year period 1987 - 1996, rising to levels exceeding 3.1 million acre feet per year.

On the cracking clay soils of the Imperial Valley California the water infiltration during surface irrigation is zero or near zero shortly after ponding. Because the infiltration rate is zero or near zero, the speed of water advance along borders is constant and surface flow along the border is steady shortly after ponding. Further evidence of this infiltration behavior is that there is no correlation between ponding time and total infiltration. Accordingly, there are readily available procedures that can be used to greatly reduce the amount of tailwater from surface irrigation. This was amply demonstrated by the evaluation of these reduced-runoff procedures for alfalfa and sudan grass grown in the Imperial Valley, California (Bali et al., 2001).

There are several reasonable and economically attractive methods for effectively eliminating tailwater runoff. However, it is much more difficult and expensive to capture and pumpback tailwater, once created, than to control the flow of irrigation water to minimize the amount of tailwater produced.
In a three-year study on moderately saline field soils of the Valley (Bali et al., 2001), tailwater runoff was reduced to less than two percent, thereby reducing the annual water

application by approximately 28% with no loss in alfalfa hay yield or quality in comparison to countywide averages. Soil salinity accumulated (from 6 to 14 dS/m) at the 0-1.5 m depth interval of the soil profile, particularly in the lower 15% of the border checks by the end of the study. However, disking, a single leaching irrigation, and sweet corn production after termination of alfalfa were adequate to reclaim the soil.

## I. D. Background

Allocations of water, within southern California, from the Colorado River have become increasingly contentious as the lower basin states of Arizona and Nevada are approaching full utilization of their respective apportionments. Based on the Colorado River Decree, California's annual allocation is not to exceed 4.4 million acre feet (assuming no surplus flows are available). Within California, the Colorado River allocation flows predominately to irrigated agriculture (about 3.85 million acre feet per year) and largely to the Imperial Irrigation District. However, as water needs of large metropolitan districts (Los Angeles and San Diego) continue to increase, water transfers from irrigated agriculture have become an important option

In 1989, the Metropolitan Water District (MWD) of Los Angeles agreed to finance a water conservation program in IID. In return, IID agreed to reduce requests for Colorado River Water in the amount equal to the quantity of water conserved by the conservation program.

In an assessment of annual water use in IID, Jensen and Walter (1997) concluded that, except for the unusual years of 1992 and 1993, diversions by IID have gradually increased over the 10 year period 1987-1996, rising recently to levels exceeding 3.1 million acre feet per year. Jensen and Walter (1997) noted that conservation practices in IID were successful in reducing some delivery system losses, but that other water losses associated with rising diversions in this period more than offset the effect of these conservation practices.

Criticism by IID officials and others of the Jensen and Walter assessment was that it reflected a relatively short period of IID operating history, namely the 1987-1996 period. IID officials have also offered the following reasons for the recent operating trends by the District. They are (Clinton, December 17, 1996 communication to R. Johnson, USBR):

a. Changing crop distributions and economic opportunities;
b. Increasing salinity of Colorado River water;
c. Less rainfall in recent years (CA experienced 6 year drought period, ´87-´92);
d. IID's water diversions have historically fluctuated in tandem with the rise and fall of agricultural markets (diversion highs were near 3.0M ac-ft in the late ´50s, early '70s and late ´80s; diversion lows occurred in the early '60s, early '80s, and early '90s.

## I. E. Summary Conclusions

The following summary of the WAC team main conclusions was derived from individual opinions (presented later). These summary conclusions are the result of thorough internal WAC team critique and peer review.

**Issue**: Increase in IID Diversions late 1980's – early 1990's

Weather related

There is no compelling trend of greatly increasing reference crop evapotranspiration (ETo), calculated from CIMIS or derived from evaporation pan data, that would suggest major changes in Imperial Valley weather conditions leading to substantially increased irrigation diversions.

Colorado River Salinity related

The assertion by IID that increased Colorado River water salinity is the cause of substantial irrigation delivery increases is not supported. While a five percent increase in diversion would be justified from 1986 through 1995 in the Imperial Valley based on changes in Colorado River water salinity, over the longer term, 1982 through 1998 a decrease in IID diversion of two percent may have been expected (See **Figure V.6**).

Cropping Pattern related

The assertion by IID that substantial increased Colorado River water diversions are caused by changing cropping patterns is not supported.

The calculated net crop consumptive use per acre increased from the mid 1980's period. The calculated average net crop consumptive use for the period 1972-87 was 3.04 ac-ft/ac. The calculated average for 1988-00 was 3.25 ac-ft/ac.

In the two periods, the annual delivery at Drop One averaged 4.92 and 5.44 ac-ft/ac, respectively. Thus, the average increase in water delivery exceeded the average increase in net crop consumptive use by 0.31 ac-ft/ac.

Therefore, cropping pattern changes have not caused substantial increase water use within IID.

**Issue:** Beneficial Use of Colorado River Water by IID

The annual water delivery volumes at Drop One significantly exceed the annual volume requirements for net crop consumptive use (CCUnet) and leaching requirement (LRvol) in IID.

For widely varying cropping patterns in the climatic period 1972-00, the annual net crop consumptive use volume (i.e., CCUnet = crop ET minus effective precipitation) was calculated by the WAC analysis (Chapter V.A.) to average 1,720,000 ac-ft. The calculated annual crop leaching requirement volume for this period averaged 292,000 ac-ft (Chapter V.E). The combined annual net crop consumptive use and annual leaching requirement averaged 2,012,000 ac-ft with standard deviation of 109,000 ac-ft. The mean plus two standard deviations indicates a potential maximum combined volume requirement of about **2,230,000 ac-ft**. In the 29 year period of analysis, the combined calculation of net crop consumptive use and crop leaching requirement exceeded 2,230,000 ac-ft in only one year (by 40,000 ac ft). The annual water delivery volume at Drop One in the period 1972-00 has averaged about **2,826,000 ac-ft** (IID Annual Inventory Reports, Robinson)**.** In the period 1996-00 (last 5 years) the annual deliveries at Drop One have averaged 3,074,800 ac-ft. The calculated CCUnet + LRvol in the 1996-00 period has averaged 2,123,800 ac-ft (WAC analysis, Chapter V).

In other analyses, the WST (1998) calculated that CCUnet + LRvol averaged 2,034,000 ac-ft in the 1987- 1996 period. Similarly, in this same period of analysis, Jensen and Walter (1997) calculated that CCUnet + LRvol averaged 2,046,000 ac-ft. Whereas, the delivery volume in the 1987-1996 period at Drop One averaged 2,856,000 ac-ft (CVWD 1998a, CVWD 1999a, and CVWD 2001a).

**Issue:** Irrigation Related Flows to the Salton Sea are Excessive

Irrigation related flows from IID to the Salton Sea are excessive. Based on IID water balance data reported by Silva (1990), the 32-year average (1958-1989) water balance index (WBI) is 0.385 or, in other words, 38.5% of IID's inflow water is discharged into the Salton Sea.

**Issue:** Tailwater as Waste

Surface runoff from irrigated fields discharged into Salton Sea through agricultural drains is not a beneficial use of water. The weighted average tailwater production in IID is 15.6% of delivered water (O'Halloran, 1990). Jensen and Walter (1997) used 16.8% of delivered water for their water balance.

**Issue:** Reduction of Tailwater

Discharge of tailwater from farms or the district should be prohibited.

There are several reasonable and economically attractive methods for effectively eliminating tailwater runoff within the Imperial Irrigation District. These range from capital-intensive design, installation and management of reservoir water reuse systems to the application of improved irrigation management of cracking-clay soils. Viable tailwater management alternatives result in water conservation costs between $30 and $60 per acre-foot of conserved tailwater.

The Imperial Irrigation District has not effectively implemented tailwater runoff policy, nor conservation practices like those already in existence in irrigation districts in both California and other states in the U.S. If the Imperial Irrigation District would aggressively enforce its own Triple Charge penalty for tailwater, there could be substantial water savings.

## II. OPINIONS OF THE AUTHORS

### A. Dr. James R. Gilley

### A. 1 Opinion

Non-recirculated tailwater runoff within the Imperial Irrigation District is a non-beneficial and unreasonable use of water and is thus, a waste of water. See Chapter VII.

### A. 1 Basis

As cited by the State of California Water Resources Control Board in Decision 1600 (Decision 1600, Jun 84), the State's policy on prevention of waste and unreasonable use of water is based upon Article X, Section 2 of the California Constitution, which provides (italics added for emphasis):

*"It is hereby declared that because of the conditions prevailing in this State the general welfare requires that the water resources of the State be put to beneficial use to the fullest extent of which they are capable, and that the waste or unreasonable use or unreasonable method of use of water be prevented, and that the conservation of such waters is to be exercised with a view to the reasonable and beneficial use thereof in the interest of the people and for the public welfare. The right to water or to the use or flow of water in or from any natural stream or water course in this State is and shall be limited to such water as shall be reasonably required for the beneficial use to be served, and such right does not and shall not extend to the waste or unreasonable use or unreasonable method of use or unreasonable method of diversion of water. This section shall be self-executing and the Legislature may also enact laws in the furtherance of the policy in this section contained."*

The Water Resources Control Board in Decision 1600 (Decision 1600, Jun 84) concluded, *"The Board believes that a thorough review of the record leaves no doubt that the Department (of Water Resources) concluded that IID practices result in a misuse of water."* (italics added for emphasis).

As cited by the State of California Water Resources Control Board; The California Supreme Court has described the nature of reasonable and beneficial use requirement of the California Constitution as follows (italics added for emphasis):

*"What is beneficial use, of course, depends upon the facts and circumstances of each case. What may be a reasonable beneficial use where water is present in excess of all needs, would not be a reasonable beneficial use in an area of great scarcity and great need. What is a beneficial use at one time may, because of changing conditions, become a waste at a later time."*

The State Water Resources Control Board in Decision 1600 (Decision 1600, Jun 84*) "… there is considerable evidence that various components of the water loss within IID could be reduced through reasonable conservation measures."* (italics added for emphasis).

The State Water Resources Control Board of the State of California in its Decision 1600 ordered that the Imperial Irrigation District shall do the following (italics added for emphasis):

*1.1 "Submit evidence to the Board by February 1, 1985, demonstrating that the District has fully implemented its announced policy of monitoring the tailwater discharge of all fields receiving water deliveries.*

*1.2 Repair or require the water users within the District to repair defective tailwater structures and approach channels by February 1, 1985. The District shall also submit a plan by February 1, 1985, to ensure that the tailwater structures and approach channels are properly maintained on a continuing basis.*

1.3 *Develop and submit by February 1, 1985, a water accounting and monitoring procedure which will result in quantifying the following with reasonable accuracy: (1) actual deliveries to farmers' headgates, (2) tailwater, (3) canal spills, (4) canal seepage and leachwater. The water accounting procedure shall be capable of normalizing the data in order to make the information comparable from year to year. The District shall specify a schedule for implementing the water accounting procedure."*

The State Water Resources Control Board further ordered the Imperial Irrigation District to submit a "detailed and comprehensive plan by February 1, 1985, which includes the following elements (italics added for emphasis):

*"a. Tailwater Control: The plan shall specify maximum acceptable tailwater limits and shall state how such limits were determined. A means of reducing tailwater from all deliveries to the specified limits within one year of the plan's initial implementation shall be specified. The plan shall describe an accurate method to be used for measuring tailwater from fields receiving deliveries. The plan shall include an evaluation of the present tailwater monitoring program, particularly the requirement that assessment for excessive tailwater must be preceded by two measurements at least nine hours apart. The plan shall specify in detail the role which an expanded irrigation education will play in assisting to reduce tailwater."*

Analysis of the water management within the Imperial Irrigation District by the Water Advisory Committee (**Figure VII.3** and **Figure VII.4**) has clearly demonstrated that the irrigation return flows to the Salton Sea from the Imperial Irrigation District have substantially increased between the date of the above State Water Resources Control Board orders issued in 1984 and 1995. Clearly, the orders of the California State Water Resources Control Board in Decision 1600 (Decision 1600, Jun 84) have not been

followed and further, the actual irrigation water waste taking place from the Imperial Irrigation District has increased between 1985 and today.

Utilizing a water balance model for the Imperial Irrigation District, Jensen and Walter (1997) calculated a surface irrigation tailwater runoff as a closure term of the water balance model. Their calculations indicated that the surface irrigation tailwater runoff from the Imperial Irrigation District for 1996 increased approximately 250,000 acre-feet or 66 percent more than that calculated for 1987. Jensen and Walter (1997) further indicate that the tailwater runoff from the Imperial Irrigation District has increased from approximately 16% of the farm deliveries in 1987 to approximately 24% of the farm deliveries in 1996. During the same time period, the irrigation return flows to the Salton Sea has increased from approximately 36% of the deliveries to approximately 42%, resulting in substantial increases in the elevation of the Salton Sea and increased flooding of lands adjacent to the Sea. These data demonstrate the dramatic increase in surface irrigation tailwater runoff from the Imperial Irrigation District during the 1987-96 time period.

### A. 2 Opinion

There are several reasonable and economical methods for effectively eliminating tailwater runoff within the Imperial Irrigation District.

### A. 2 Basis

A comprehensive analysis of potential application of alternative tailwater recovery systems, within the Imperial Irrigation District, was performed by the Water Advisory Committee (**Figure VI.1**). A comparison of the costs of water conservation was determined for a range of tailwater recovery systems and included the incorporation of improved irrigation water management on cracking-clay soils. There are several alternative (and available) technologies that can be appropriately and effectively utilized to reduce tailwater runoff within the Imperial Irrigation District. These technologies range from the capital-intensive design, installation and management of reservoir water reuse systems, which have been evaluated on several farms in the District (Boyle Engineering Corporation, 1990), to the application of improved irrigation management of cracking-clay soils (Bali, et al., 2001; Grismer and Bali, 2001; Tod and Grismer, 1999). In all cases, there appears to be several economical tailwater management alternatives that result in water conservation costs between $30 and $60 per acre-foot of conserved tailwater. In many cases, the utilization of improved irrigation water management on cracking-clay soils will actually save money over current practices of not controlling tailwater.

### A. 3 Opinion

The Imperial Irrigation District has not effectively put in place tailwater runoff conservation practices similar to those already in existence in similar irrigation districts in both California and other states in the U.S.

### A. 3 Basis

Several studies have documented the amount of tailwater runoff taking place within the Imperial Irrigation District (Boyle Engineering Corporation, 1990; O'Halloran, 1990; Oster, et al., 1986). These include the results of measurements taken by the District staff (O'Halloran, 1990). These studies indicate that the magnitude of tailwater runoff from individual fields has not decreased.

Provisions for the capture, storage and recovery of tailwater must be included in any graded furrow or corrugation irrigation system if effective use of irrigation water is to be achieved (Burt, 1995). For efficient and effective management of surface irrigation systems the tailwater runoff should be collected and reused on the farm. Publications from the University of California (Schulbach and Meyer, 1979) as well as other states have been available for several years.

A recent publication by Burt, et al. (1997) has provided further insight into definition and clarification regarding beneficial versus nonbeneficial use of irrigation water as well as the reasonable versus nonreasonable use of applied irrigation water. These authors state that while tailwater is necessary for some irrigation methods, they concluded that any uncollected (unrecirculated in the field) tailwater is considered a field-scale nonbeneficial use. They further list "excessive tailwater" as both a nonbeneficial use as well as an unreasonable use.

Some states now require that irrigation runoff water not be allowed to trespass on lands not under the control of the irrigator. It is then necessary to provide some means of collecting the tailwater, transporting it to a reservoir or sump, and either storing or providing recovery facilities as needed. See Chapter VII.

## B. Dr. Robert W. Hill

### B. 1 Opinion

There is no compelling trend of greatly increasing ETo (CIMIS and pan derived) that would suggest major changes in Imperial Valley weather conditions leading to the substantially increased irrigation diversions by IID in the late 1980's to the early 1990's.

### B. 1 Basis

ETo derived from pan evaporation gradually increases, during the period 1970 through 1990, from 72 inches to 76 inches. Thereafter, with the exception of 1996, a decreasing trend is evident down to 67 inches in 1998. The average derived ETo was 71.7 inches. The gradual increase of 72 to 76 inches from 1970 through 1990 is about a 5 percent increase. Whereas, from 1990 to 1998 there was 12 percent decrease. The CIMIS ETo data also exhibit a decreasing trend since 1987 continuing through 2000.

### B. 2 Opinion

Diversions in 1995 may have justifiably been five percent greater than in 1986 in the Imperial Valley Irrigation District (IID), based on Colorado River salinity at Imperial Dam. This assumes that the effect of salinity (as reflected by the LR) is the only influence on irrigation diversions, and that diversions respond year by year. A decrease in Colorado River salinity at Imperial Dam from 1982 to 1998 suggests a corresponding two percent decrease in IID diversions.

### B. 2 Basis

There is a declining trend of Colorado River salinity (Total Dissolved Solids or TDS) at Imperial Dam and of associated leaching fractions from 1971 through mid-1998. However, there are two shorter-term trends (1983-1986 and 1994-1998) of more pronounced decreases. These are separated by an increasing trend from 1986 through 1993, which may have been related to drier than normal water years in the Upper Colorado River Basin.

## C. Dr. Charles V. Moore

### C. 1 Opinion

There is unreasonable use of water in IID.

### C. 1 Basis

Twenty (20) percent of the water delivered to farm head gates flows over the lower end of the field and into a drain that leads the water to a salt sink (Jensen and Walter, 1997). It has been demonstrated by University of California personnel at the UC Desert Research & Extension Center at El Centro that this tailwater loss can be eliminated by cutting back the flow of water into the field (Bali, et all, 2001, Grismer and Bali, 2001). It is cost effective to prevent these losses without a major capital investment by either a tenant farmer or an owner-operator (Moore, 2000).

### C. 2 Opinion

If the Imperial Irrigation District would aggressively enforce it's own Triple Charge penalty for tailwater, there would be a fifty (50) percent reduction in tailwater flows to the Salton Sea. No land need be fallowed. No farm workers would lose their jobs, i.e. no Third Party Impacts. And additional farm workers and zanjeros may be hired which in turn would boost the local economy.

### C. 2 Basis

The Imperial Irrigation District Rules Concerning Tailwater Assessments and Delivery Adjustments to Conserve Water requires, "An inventory of surface field discharge water

will be taken daily and an assessment shall be levied against all discharges which equal 15 percent or more of the water being delivered and measurement thereof shall have been taken on two successive occasions not less than nine hours apart in a 24-hour period. The term assessment used herein shall mean the quantity of water charged (in second feet and reduced to acre-feet, times the scheduled water rate) multiplied by 3 for the day in which the measurements were taken." (Imperial Irrigation District Resolution No. 18-087, 1987)

The above loophole allows up to 15 percent tailwater. This loss must be taken on two successive occasions not less than nine hours apart in a 24-hour period.

### C. 3 Opinion

Absentee landlords seeking to conserve water in order to sell it at M&I rates will be offered lower cash rents by tenants. The tenants would then have to adjust their farming practices including salt management to accommodate the reduced water supply available after the transfer. To obtain the same financial return as before, tenants will have to be compensated with lower cash rents or other cost sharing activities to maintain financial viability.

### C. 3 Basis

Cost sharing between tenants and landlords of major structural and institutional changes will shift the income streams in agriculture from absentee landlords to suppliers of the goods and services required to increase irrigation efficiency and reduce the waste of water. If tenants choose to invest in human capital such as better trained and/or more labor hours per acre per irrigation through the use of lower irrigation flows, the major beneficiaries will be local farm workers who will receive higher pay or work more hours per week than at present.

That portion of reduced cash rents formerly going to absentee landlords residing outside of the Imperial Valley will have a possible effect on the local economy. The income multiplier affect of local expenditures for agricultural goods and services has a ripple effect as this money is exchanged in the Valley. The Giannini Foundation of the University of California in 1962 (Martin and Carter, 1962) calculated that for each $1.00 expended for agricultural goods and services in California agriculture, $1.64 of income was generated in the region. Because much of the expenditure for improved irrigation efficiency, whether through increased hired labor or capital investment, would be made locally as contrasted with those same funds being spent in the domicile of the absentee landlord, the economy of the Imperial Valley would benefit.

## D. Dr. Earl C. Stegman

### D. 1 Opinion

Irrigation water management and control methods in IID result in annual water delivery volumes (at Drop One) that greatly exceed the required volumes for net crop consumptive use (CCUnet), the primary beneficial use of water in IID.

### D. 1 Basis

Annual volume-based crop evapotranspiration minus effective precipitation (CCUnet = $ET_c$ - $P_e$ ) in IID has been analyzed by the CVWD Water Advisory Committee (Chapter V.A.), the IID Water Study Team (WST, 1998), and by Jensen and Walter (1997).

The annual ratio of net crop consumptive use volume to annual irrigation delivery volume at Drop One (CCUnet/IRdiv) was calculated to average 0.61 in the period 1987-'96 by both the WST and Jensen and Walter analyses. The WAC analysis (Chapter V.E.) calculated that this ratio also averaged 0.61 over a much longer 29 year period (1972-'00). These three studies (using differing analysis methods) have each calculated that about 39 percent of the annual irrigation delivery volume to IID at Drop One is not beneficially used to meet net crop consumptive use requirements. Furthermore, this calculated ratio has averaged 0.60 in the 1995-'00 period (Chapter V.E.).

### D. 2 Opinion

Irrigation water management and control methods in IID result in annual water delivery volumes (at Drop One) that greatly exceed the required volumes for net consumptive-use (CUnet). As described by the WST, CUnet equals the annual sum of irrigation water evaporation from canals and reservoirs, irrigation water consumed on agricultural land, and irrigation water consumed within the drain-river system.

### D. 2 Basis

Using water balance methods, the WST and Jensen and Walter studies each calculated that the ratio of net consumptive use to irrigation delivery volume at Drop One (CUnet/IRdiv) averaged 0.64 in the period 1987-'96. The WAC (Chapter V.E.) analysis calculated this ratio with the relationship CUnet/IRdiv = (1 – SS/IRdiv), where SS = the annual measured flow volume to the Salton Sea less flows from Mexico. Thus, it should be noted that this relationship gives CUnet/IRdiv using measured annual volumes for both SS and IRdiv (using IID supplied data). These annual CUnet/IRdiv ratios averaged 0.65 over the 29 year period, 1972-'00. Thus, these three analyses (using differing methods) have each calculated that about 35 percent of the annual irrigation delivery at Drop One is not being used by the principal consumptive uses in IID. Likewise, this calculated ratio has averaged 0.66 in the 1995-'00 period (Chapter V.E.)

## D. 3 Opinion

Annual delivery volumes (at Drop One, i.e., IRdiv) exceed annual net consumptive use (CUnet) plus annual crop leaching requirement volumes (LRvol) by about 25 percent.

## D. 3 Basis

Using the Ayers-Westcot equation (1985) and selected procedures for heavy cracking soils and for light non cracking soils, the WST (1998) calculated annual crop leaching requirement volumes to average 296,000 ac-ft in the 1987-'96 period. Also using the Ayers-Westcot equation and a weighted average distribution of crops, Jensen and Walter (1997) calculated annual crop leaching requirement volumes to average 14.1 percent of net crop consumptive use or 309,000 ac-ft in the same 10 year time period 1987-'96. Also, using the Ayers-Westcot equation and crop-area weighted ECe = 1.85 (ECe = threshold salinity affecting crop yield), the WAC (Chapter V.E.) calculated annual crop leaching requirement volumes to average 292,000 ac-ft for the 29 year period 1972-'00. The ratio of crop leaching requirement volume to annual Drop One delivery volume (LRvol/IRdiv) averaged 0.10, 0.11, and 0.10, respectively, for these three studies. Thus, the combined annual net consumptive use volume (CUnet) and crop leaching requirement volume (LRvol) as a ratio of irrigation delivery volume at Drop One ((CUnet + LRvol)/IRdiv) has averaged 0.75 in the 1987-'96 period and also about 0.75 in the 29 year period, 1972-'00. Hence, about 25 percent of the annual delivery volume at Drop One is not being used for these two needs. The WAC analysis (Chapter V.E.) calculated this loss volume (i.e., 25%) has averaged about 706,000 ac-ft per year. In comparison, the WST (1998) calculated that the combined losses of tailwater (414,000 ac-ft average), operational spills (94,000 ac-ft average), district canal seepage (90,000 ac-ft average) and All American Canal seepage (94,000 ac-ft average) averaged 692,000 ac-ft in the 10 year period 1987-'96. Jensen and Walter (1997) calculated these combined losses averaged 747,000 ac-ft in the 1987-'96 period.

## D. 4 Opinion

The potential maximum combined annual water volume requirement for net crop consumptive use (CCUnet) and crop leaching requirement (LRvol) is about 2,230,000 ac-ft.

## D. 4 Basis

For widely varying cropping patterns in the climatic period 1972-00, the annual net crop consumptive use volume (i.e., CCUnet = crop ET minus effective precipitation) was calculated by the WAC analysis (Chapter V.A.) to average 1,720,000 ac-ft. The calculated annual crop leaching requirement volume for this period averaged 292,000 ac-ft (Chapter V.E.). The combined annual net crop consumptive use and annual leaching requirement averaged 2,012,000 ac-ft with standard deviation of 109,000 ac-ft. The mean plus two standard deviations gave a potential maximum combined volume requirement of about 2,230,000 ac-ft. In the 29 year period of analysis, the combined

value of net crop consumptive use and crop leaching requirement exceeded 2,230,000 ac-ft in only one year (by 40,000 ac-ft).

## E. Dr. Kenneth K. Tanji

### E. 1 Opinion

Surface runoff from irrigated fields discharged into Salton Sea through agricultural drains is not a beneficial use of water. The on-farm surface runoff of applied water in IID is a significant loss of freshwater if it is not recaptured and used for irrigation. Tailwater production by itself does not lead to unreasonable use of water but tailwater produced that is not recovered and used is considered a non-beneficial use of water. Alternative management options are available to reduce tailwater production and recover tailwater with pump-back systems (See Chapter VI.A).

### E. 1 Basis

The weighted average tailwater production in IID is calculated to be 15.6% of delivered water (O'Halloran, 1990). Jensen and Walter (1997) used 16.8% of delivered water for their water balance. The observed production of tailwater varied from 6.3% for flat flood to 28.5% for onions (O'Halloran, 1990). A second data source indicated tailwater runoffs ranged from 17% for wheat to 38% in cantaloupe (Oster et al, 1987). A third source of data reported tailwater runoffs ranged from 12% for wheat to 48% for carrots and onions (Boyle Engineering Corp., 1990).

Surface runoffs in IID are discharged into open drains that convey saline tile drainage effluents and intercepted shallow ground waters, and the collected drainwater is ultimately discharged into the Salton Sea. Since tailwater is a freshwater resource it needs to be recycled before commingling with saline tile drainage effluents. One option is to reduce tailwater production and the other option is to recycle tailwater for irrigation (See Chapter VI.A).

### E. 2 Opinion

Irrigation related flows from IID to the Salton Sea are excessive.

### E. 2 Basis

Silva (1990) has summarized annual water and salt flows for IID from 1958 through 1989. Based on IID water balance data reported by Silva (1990), the 32-year average (1958-1989) water balance index (WBI) is 0.358 or 35.8% of IID's inflow water is discharged into the Salton Sea. The water outflows consist of: (i) operational spills, (ii) subsurface drainage (intercepted deep percolation or rootzone drainage and intercepted shallow ground waters), and (iii) tailwater runoff.

## F. Dr. Wesley W. Wallender

### F. 1 Opinion

Surface irrigation can be designed to prevent runoff for the cracking clay soils in Imperial Valley.

### F. 1 Basis

The design for surface irrigation requires specification of flow rate and irrigation time duration (cutoff time) for a steady inflow rate (without cutback). Both flow rate and irrigation time duration (cutoff) can be calculated, thus, surface irrigation can be designed to prevent runoff. In the Imperial Valley, where the infiltration rate quickly approaches near-zero after ponding, the minimum steady flow rate equals or exceeds that required to spread the water laterally across the field and the maximum flow rate is less than that which overtops the lateral side dikes, which contain the flow and that which is erosive. The cutoff time is the field area multiplied by the infiltration depth divided by the inflow rate. Infiltration depth is calculated from a measurement of the time for the wetting (advancing) front to arrive at the midpoint of the field length (for example), the inflow rate and the surface flow depth.

### F. 2 Opinion

Surface irrigation can be managed to prevent runoff for the cracking clay soils in Imperial Valley.

### F. 2 Basis

The management of surface irrigation requires setting the inflow to the design rate and the set-time to the design cutoff time for each set of a water turn. Farm irrigation systems in IID have the flexibility to control both flow rate and cutoff time at the field. Because infiltration depth is determined prior to cutoff time, the irrigation can be terminated such that runoff is avoided. Thus, for each set prior to the last one during a turn, the flow rate and irrigation time can be that of the design rate. Time of cutoff during the last set may be constrained by the turnout stop time. In order to adequately irrigate the last set, some tailwater may result.

### F. 3 Opinion

Tailwater should be prohibited from leaving the district or from farms.

### F. 3 Basis

According to tailwater policy written in 56 water conservation plans (see Appendix C), of irrigation districts receiving water from the United States Bureau of Reclamation of the Mid-Pacific Region (Federal) and from the State of California, available from the Office

of Water Conservation, tailwater is prohibited from leaving the district or from farms. Farm tailwater is recycled on the farm or the district collects and either reuses directly or blends it with new supply water and resells it to the water users. These plans are available from: United States Bureau of Reclamation, Mid Pacific Region Office, Sacramento, CA., or from State of California Department of Water Resources, Office of Water Use Efficiency, Sacramento, CA.

# III. SCIENTIFIC AND ECONOMIC CRITERIA FOR DETERMINING THE REASONABLE USE OF WATER IN CALIFORNIA

## III. A. Introduction

This section presents two opposing views of tailwater management in IID.

The first viewpoint is contained in a letter from Jessie Silva (**Section III.B**) that is referenced several times throughout this document. It is presented here for convenience and has been italicized for emphasis. The Silva letter states without supporting data or justification that "*…no one suggests that the soil type and water salinity could support farming in the Imperial Valley without the existence of "tile" water or "tailwater"*".

The second and opposing point of view of water management is supported by data and analysis (**Section III.C)**. It documents that tailwater can be reduced significantly based on scientific, engineering, and economic considerations.

## III. B. IID – Jessie P. Silva Letter

*"March 22, 1999*
*Honorable Michael J. Machado, Chair*
*Assembly Committee on Water, Parks & Wildlife*
*California State Capitol Building*
*Sacramento, CA 95814*

*Honorable Jim Costa, Chair*
*Senate Committee on Agriculture and Water Resources*
*California State Capitol Building*
*Sacramento, CA 95814*

*Gentlemen:*

*On behalf of the Imperial Irrigation District ("IID"), I would like to thank you and your fellow committee members for your interest and oversight role in helping resolve the California 4.4 Plan issues and the looming shortage that the Metropolitan Water District of California ("MWD") may face as MWD is weaned from its priority 5 diversions of Colorado River water. Although I am very mindful of the Committees' desire to have everyone curtail the exchange of letters and press releases, I am concerned that Wednesday's questions and my answers might not have been clear enough with respect to two basic inquiries raised by MWD and explored by Committee members: Will the conservation for the IID-SDCWA transfer involve tailwater and why has IID use gone up since 1992?*

***IID EFFICIENCY AND THE ROLE OF TILE WATER AND TAILWATER***

*The IID's delivery efficiency is about 90%. (Some may quibble with this number, but no one alleges it is materially off.) That means that about 10% of the volume diverted at Imperial Dam is lost to evaporation, seepage and operational spills. Opportunities for improvement with the assistance of outside funding exists for seepage (i.e., the lining of the All American Canal) and operational spills (i.e., by further reservoir construction). Evaporative losses from the 82 mile-All American Canal, 1,675 miles of other open canals, 1,400 miles of open drains, and the 10 existing open regulatory reservoirs would be very difficult to materially reduce.*

*On-farm efficiency in the Imperial Valley is about 79%. (Again, some may assert it is as "low" as 76%). That means some of the water delivered to farmers' headgates leave the farms in the form of either "tile" or "tail" water drainage. "Tile" water is the subsurface drain water used to flush salts past the root zone and prevent salt poisoning of the crop and ground. Tailwater is the surface drain flow produced as a byproduct of slow percolation rates in heavy soil. Without tailwater, the low end of the field would receive inadequate irrigation water and inefficient leaching. Although some may debate the minimum volumes necessary to maximize crop yields, no one suggests that the soil type and water salinity could support farming in the Imperial Valley without the existence*

*of "tile" water or "tailwater". It is incorrect to assert that tile water or tailwater should be eliminated because it serves no beneficial use purpose.*

*It is the potential to recycle the tailwater and/or reduce its volume by other delivery or application devices that will be paid for as part of the on-farm conservation program funded with SDCWA payments. The direct product of such tailwater recycling or reduction will be to reduce the volume of ordered water by a corresponding measured amount.*

## ***IID WATER USE 1992-1998***

*The IID is blessed with one of the oldest, senior-most and largest water rights on the Colorado River. The primary benefit of such perfected and vested rights is to have sufficient water to meet the Imperial Valley's reasonable and beneficial use needs. The Imperial Valley economy depends on irrigated agriculture. Half of the County's income is directly or indirectly based on irrigated agriculture. The IID has never diverted more water than its senior water rights support. Thus, the fact of increasing water use by the IID at times when others-with smaller and more junior rights to the Colorado River, or others with different and less reliable water rights-are limited in supplies by the extent of their rights, is not a basis for asserting that IID is somehow diverting an unfairly large quantity of water.*

*It is proper, however, to require that the IID's water be reasonably and beneficially used. The IID has asked the State Water Resources Control Board to review and confirm what the IID believes: that its current uses at 3.2 to 3.3 million acre-feet ("MAF") are reasonable and beneficial. MWD suggests, however, that by virtue of the IID's increase in use from 1992 to 1998 by about 400,000 acre-feet, the IID has unreasonably used that amount of water.*

*IID water use depends on a variety of factors, such as (a) conservation projects, (b) rainfall, (c) salinity of diverted Colorado River water, (d) crop selection by farmers, (e) acreage in production, and (f) pests. MWD has ignored all but the first factor in focusing on the changes from 1992 to 1998. A broader look at IID's variable historical use is illuminating. IID's consumptive use in 1975 was 3.07 MAF; in 1990, 3.06 MAF, and in 1996-1998, 3.16, 3.16 and 3.10 MAF, respectively. Conversely, IID's consumptive use in 1978 was only 2.76 MAF; in 1983, only 2.56 MAF, and in 1992 only 2.57 MAF. The consumptive uses bracketing 1992 illustrate its "non-representativeness": 1990 consumptive uses were 3.05 MAF; 1991 consumptive uses were 2.90 MAF; 1992 consumptive uses were 2.57 MAF; 1993 consumptive uses were 2.77 MAF; and 1994 consumptive uses were 3.05 MAF.*

*How can rainfall, salinity, crop selection, acreage and pests produce such dramatic impacts? Examples can best illustrate this: Rainfall in the Imperial Valley averages about 3 inches per year for a year round growing season. For 500,000 irrigated acres, the loss of 3 inches of rainfall can require additional water orders of approximately*

*100,000 to 200,000 acre-feet of water. Historically, annual rainfall has varied from almost zero to almost six inches. 1996 and 1997 were particularly low rainfall years.*

*Salinity of Colorado River water varies at Imperial Dam as a result of river flows and the uses and return flows in the thousands of miles upstream. As salinity goes up, the amount of water needed to effectively leach salt also rises. Salinity variations in Colorado River water can account for water order increases in the vicinity of 25 to 50,000 acre-feet, with impacts lasting more than one calendar year.*

*Crop selection can also materially affect the amount of water used by IID farmers. IID farmers grow a wide variety of crops. Crop selection by a farmer is an individual decision based on soil quality and water quality factors, necessary crop rotation for ground preservation, and market conditions. Water needs for different crops vary significantly because of differing evapotranspiration requirements and salt tolerance. For example, wheat has an average water use of less than 3.5 acre-feet per acre; melons less than 2.5 acre-feet per acre; and alfalfa at 6.5 to 7.5 acre-feet per acre. Thus, a change in the selection of crops on even only10% of the 500,000 irrigated acres can change water use by hundreds of thousands of acre-feet.*

*Acreage in production produces a similar effect. Although the IID has been relatively stable at about 450,000 to 500,000 acres in recent years, the acreage double-and triple-cropped has increased by over 60,000 acres between 1988 and 1997. The planting of a second or third crop rather than allowing the land to lie fallow for part of the year is in direct response to farmer perceptions of strong prices for their additional crops.*

*Pests played a significant role in reducing IID's water use in the 1992 "base" year selected by MWD. In mid-to late 1991, a devastating whitefly infestation arose in the Imperial Valley and reached crisis proportions in 1992. Two dominant factors produced dramatic reductions in water use: first, many farmers disked their ruined crops mid-growth, thus minimizing losses and thereby reducing water orders; second, the valley used a summer "dry-up" strategy to deny the whitefly food in an attempt to cripple the pests' reproductive cycle. These two factors reduced IID water use by hundreds of thousands of acre-feet.*

*I apologize that I was unable in the time permitted and under the format used to adequately inform your committees of these fundamental facts about IID water use. We look forward to the upcoming discussions with DWR Director Hannigan, David Hayes, and CVWD and MWD to see if an amicable resolution to the existing impasse can be reached.*

*Very truly yours,*

*/s/*
*JESSIE P. SILVA*
*General Manager"*

## III. C. Scientific and Economic Criteria For Determining The Reasonable Use Of Water In California

Both the Federal Ninth Circuit Court and the California Supreme Court have spoken on the issue of "Reasonable Use" of water. The California Constitution, article X, section 2, limits the right to use the State's waters to being both reasonable and beneficial, "to the maximum extent possible."

The Federal Ninth Circuit Court of Appeals stated the following regarding beneficial use. "There are two qualifications to what might be termed the general rule that water is beneficially used ... when it is employed by the appropriator. First, the use cannot include any element of "waste" which among other things precludes unreasonable transmission loss and use of cost-ineffective methods. Second, and often overlapping, the use cannot be "unreasonable" considering alternative uses of water." United States v. Alpine Land & Reservoir Co. (1983)(9th Cir.) 697 F.2nd 851,854.

The California Supreme Court in the Tulare Dist. v. Lindsay-Strathmore Dist. (1935) 3 C. 2d 489 at 547, said: "In determining what is a reasonable quantity of beneficial uses, it is the policy of the state to require within reasonable limits the highest and greatest duty from the waters of the state. However, an appropriator cannot be compelled to divert according to the most scientific method known. He is entitled to make a reasonable use of the water according to the general custom of the locality, so long as the custom does not involve unnecessary waste." (Emphasis added.)

## EXISTING CONDITIONS

The California State Water Resource Control Board in its "Water Rights Decision 1600 of June 1984" (Decision 1600, Jun 84), focuses on the wasteful use of water in the Imperial Irrigation District. For example, in Table 2 at page 31 of the 1984 Decision, the Board reported that tailwater plus excess leaching water in IID could be as high as 570,000 acre feet per year or 22 percent of total agricultural deliveries based on California Department of Water Resources, (DWR) estimates. In a study for the U.S. Bureau of Reclamation, Jensen and Walter, (1997), reported tailwater flows into the Salton Sea from IID during the period 1987 to 1996 ranged from 370,000 to almost 650,000 acre feet per year. The average tailwater flow during this period was 415,580 (Jensen and Walter, 1991, See Figure 4.1) acre-feet per year; see Figure 4.2 of the Jensen report. This was 19.4 percent of all agricultural diversions.

High tailwater flows into the Salton Sea are a substantial cause of an increase in the elevation of the surface of the Sea and in turn has caused flooding over a relatively large area of public and private lands. The State Water Resources Control Board in it's Decision 1600 (Decision 1600, Jun 84) report stated that, during the 1968–1971 period, the maximum annual level of the Salton Sea reached about –231 feet below sea level but increased to a higher level during the years 1972–1981. During this later period, it reached a maximum level of 226.2 feet. The State Water Resources Control Board calculated that at this elevation, an additional 15,750 acres of adjoining private and public

land became flooded. For reference purposes, the maximum elevation of the Salton Sea based on USGS data in 1998 was –226.9 feet. This indicates there has been little or no change in the level of water conservation in IID as called for in the District's own 13 point and 21 point Water Conservation Plans. In it's Decision 1600, The State Water Resources Control Board concluded, "that the failure to implement additional water conservation measures at this time is unreasonable and constitutes a misuse of water under Article X, Section 2 of the California Constitution and Section 100 of the California Code", (see page 66). Clearly, little or nothing has changed since 1984.

## OPPORTUNITIES FOR IMPROVEMENT

The question at hand is, what criteria can be applied to determine which practices, methods and technologies are reasonable and therefore should be required in the transport and application of water and which of these are cost-ineffective in the words of the Ninth Circuit Court?

Economics has developed a very simple procedure for decision making in such cases. It is referred to in the economics literature as Benefit/Cost analysis or Internal Rate of Return analysis. For example, the Imperial Irrigation District's own Water Study Team's (WST) report, "Imperial Irrigation District Water Use Assessment for the Years 1987-1996", chapter 1, p. 1-8, enumerates several sources of loss in the irrigation water delivery system but declares them a "reasonable use" with no justification other than it would be "too expensive" to prevent these losses.

The criteria for judging reasonable or unreasonable use are based on the cost effectiveness of alternative methods of preventing these losses. The WST report states, "if a seepage study shows it to be uneconomical to line a canal reach, because the water saved would not justify the cost, then that seepage loss is "reasonable" even though it does not contribute towards crop production." This is correct up to a point. The unanswered questions are, first, what is the value in use of the water lost and second, what is the value of damages caused by allowing these losses? If the landowner invested in water conserving practices, would the present value of the sum of benefits (value of water no longer wasted and therefore no longer causing damages) exceed the present value of the costs incurred in eliminating that loss?

The value of the lost water varies widely depending on the viewpoint of the decision-maker. If, as in the Imperial Irrigation District case, the cost to the District is the out of pocket cost of capturing and transporting the water through the All American Canal, the decision variable, i.e., the marginal cost of water, is very small. Given this is a Federal project built with an interest free loan using a gravity flow system, the variable cost of water to the district is nominal. Thus, it was only when pressed by the Bureau of Reclamation and after non-District funds were available that there was movement to line the Canal to eliminate this loss. From the point of view of the IID, it was not cost effective for the District to stop the waste due to canal seepage when the cost of increasing diversions was so small.

From the point of view of the agricultural landowners of IID, who are already paying one of the lowest water rates of any water district in California, it is not cost effective to line lateral canals. This is because the benefit from increasing the supply of water per irrigated acre through waste reduction in the District is almost nil. That is, it has been possible in the past to obtain increased diversions and deliveries from the Colorado River without any additional investment either by the District or by the landowners.

From the point of view of the farm operator in IID who pays only about $13 per acre-foot for water, it is not cost effective to eliminate tail water. However, the contention that tailwater and seepage losses are reasonable because their elimination is not cost effective under current nominal water charges is incorrect and contrary to public policy. Note that the current cost of water in IID is approximately $16 per acre-foot, but this analysis is based on the $13 per acre-foot value, which has no impact on the conclusions of this report. This water, which is applied in excess of the soil's ability to absorb it, flows over the lower end of the field, mixes with salty drainwater flowing in a drain and ultimately flows into a salt sink, the Salton Sea. Tail water in the IID case is lost to any other irrigation use and thus is wasted.

Improving Irrigation Control: The key to improved irrigation management depends upon knowing with some precision the moisture status of the soil. Moisture levels can be measured directly with various devices including tensiometers and neutron probes. Soil water content can also be estimated from weather data (CIMIS). Adjustments still must be made for the osmotic stress generated by the salt content of the soil.

An order must then be placed with the District for water to be delivered to the farm headgate. The amount of water ordered must be able to refill the root zone plus an additional amount to leach accumulated salts existing in the root zone with a reasonable accuracy. For a crop with a given tolerance to soil salinity such as alfalfa, the greater the electrical- conductivity of the irrigation water supply, the greater the quantity of water which must be leached through the plant's root zone (leaching fraction), to maintain salt concentrations below a level injurious to the plant. Increased leaching requirements however are no justification for increased irrigation tail water.

Determination of the optimal leaching requirement is a subject of continued research. Hoffman, Mass, Rhodes and van Schilfgaarde (1984) defined the leaching requirement as "The minimum fraction of the total amount applied water that must pass through the soil root zone to prevent a reduction in crop yield from an excess accumulation of salts". Nonuniformity of soil moisture and salts within a field is caused in large part by irrigation systems that supply water unevenly. As a consequence of this and irrigation scheduling that exceeds evapotranspiration, a large fraction of the applied water may leach through the root zone and be wasted as drainage", ibid, (p. 73).

Using the above definition of leaching requirement, Hoffman, Maas, Rhoades and Van Schilfgaarde published a report (1984) in their study to determine the minimum leaching requirement for a moderately salt tolerant crop, cotton, using Colorado River water. They concluded that full yields could be attained with as little as 5 percent leaching.

Given Jensen's estimate (1997) that the total flow to the Salton Sea from IID ranges from 27 to 32 percent of water deliveries to agriculture with tail water losses as indicated earlier ranging from 17 to 21 percent of deliveries, there is an apparent excess leaching requirement in the District constituting 10 to 12 percent of farm deliveries. This conclusion is reinforced by the following quote. "In most irrigation projects, currently used leaching fractions could be reduced considerably without harming crops or soils, especially with improvements in irrigation management," (Rhodes, 1974).

Minimizing the leaching requirement not only reduces the quantity of water diverted but as Oster and Rhoades, (1975), point out, it reduces the tons of salt that must be removed from the soil to maintain a salt balance. It also maximizes the precipitation of applied Ca, HCO3 and SO4, all contributing to the long term sustainability of irrigated agriculture.

Improving Irrigation System Performance: The technology available for the application of irrigation water has increased dramatically in the past 40 years. Prior to the 1960's almost all field crops were irrigated from an earthen head ditch which carried the water down a furrow in the case of row crops or into a border or check for high planting density crops such as alfalfa hay, wheat, barley and pasture. Water was applied based on a calendar or the growers skill in sensing a change in the shade or the hue of green observed in the plants. Irrigation labor was hired to start the water flowing and then to return 12 or 24 hours later and change the furrows or check being irrigated. Little direct supervision of the water was involved as it moved down the field. Irrigation system performance was not a high priority because in many areas, water was cheap relative to other inputs. Unfortunately, this still describes the typical irrigation methods in IID today. Additionally, little use is now being made of the public and private irrigation management information systems that are available.

The rapid growth in California's population has forced a change in water users' attitude towards waste in irrigated areas outside of Imperial County. A State/Federal Taskforce, CALFED, has been working on solutions to the problem of the intense competition for water by agriculture, urban, environmental and recreational uses, focusing primarily on the Central Valley. CALFED has developed a list of priority actions to be implemented in order to improve irrigation efficiency but also to improve water quality of any return flows. A partial list applicable to field application and water conservation follows:

| Practice | Process | Effect |
|---|---|---|
| Land leveling | Decrease slope | Reduce water velocity |
| Cutback stream | Reduces runoff | Reduces water flow when water reaches end |
| Surge irrigation | Reduces runoff | Automated water mgt. |
| Sprinkler germin. | Reduces water | Elimin. pre-irrigation |
| Drip irrigation | Reduces water | Automated water mgt. |
| Shorten Run | Reduces stream | Reduce water volume |
| Gated pipe | Reduce runoff | Improved water mgt. |
| Tailwater return | Reduces water | Returns water to farm |

Source: CALFED Water Quality Program 1998

Each of the water conservation technologies listed above individually or in combination has the potential to increase control over the water being applied, increase application performance and reduce salt loading in the soil. However, none of these goals will be achieved without improving the management and supervision of these technologies. Bali et All (2001) in their Progress Report to the US Bureau of Reclamation "Irrigation and Drainage Management and Surface Runoff Reduction in the Imperial Valley," demonstrate unequivocally the importance of the skills of the irrigator in minimizing irrigation runoff.

Preliminary results of the Bali et All, 2001 Study show for a 1/4-mile long border planted to alfalfa the measured runoff was zero percent at a cutoff time of 235 minutes and increased to 10 percent when the cutoff time was delayed until 258 minutes. That is, the runoff increased from zero to 10 percent over a time span of only 23 minutes. These results were replicated in other fields in different years. Clearly, careful timing of irrigation shutoff will prevent waste. The concomitant decline in application efficiency is directly related to the increase in tailwater runoff. The level of irrigation performance that can obtain with these "no tailwater" results cannot be achieved on a basin wide basis without a significant amount of training and supervision leading to improved irrigation management.

The quality of irrigation labor becomes increasingly important because the soil properties in a given field are variable over space and time. Soil properties such as the rate at which water infiltrates can change within a furrow, along the furrow and among furrows in the same field and all will vary from one irrigation to the next over an irrigation season. Additional discussion of the interaction of the large number of complex engineering variables that must be resolved to achieve a high level of application efficiency are discussed in Chapter IV. The economic loss incurred when insufficient water reaches the lower end of a field causes growers and irrigators to order "extra" water from the District as an insurance policy against this potential loss.

Given that there is no penalty enforced for creating tailwater in IID, most growers are not willing to pay the premium required to hire and train such high quality irrigators. They are willing to purchase excess water just to ensure no plants go under watered even though a significant proportion spills into the drains.

These IID farm operators also fail to take into account the damages imposed upon other landowners with lands bordering the Salton Sea, which have become flooded due to the rising level of the Sea caused by excess tailwater inflows. These damages are referred to in the public policy literature as negative externalities. Externalities are defined as injuries imposed on innocent third parties due to the behavior of other producers. Examples of externalities include air and water pollution. The literature goes on to suggest the most efficient method to eliminate externalities is to have the cost of these injuries reflected in the production costs of the pollution emitter. In short, this policy is

one of, "making the polluters liable for the injuries they have caused". This is referred to as internalizing the externality.

The decision variable in each of the above cases is the average variable out of pocket cost of water. That is, the water cost used in determining if conservation measures are cost effective or not. First, in IID, the delivered cost of water is so low there is no incentive to the grower to reduce or eliminate waste. Clearly, when a water district has been offered, in an open market transaction, a significantly higher price than that now charged it's users, that district is compelled to reevaluate the value of water used in it's calculation of the cost effectiveness of water conservation measures. Second, "internalizing the costs" (i.e. requiring the cost of the damages to third parties to be reflected in the cost function of the individual causing the injury) will change the manner in which growers view the total cost of water. Including the impact on third party landowners whose lands are flooded by excess tailwater in the total cost paid for irrigation water would increase the cost effectiveness of improved on-farm irrigation practices.

The State Water Resource Control Board in its, Water Rights Decision 1600 (Decision 1600, 1984), was highly critical of irrigation practices in IID and the resultant waste of water and flooding of agricultural lands bordering the Salton Sea. "The average annual contribution of IID to Salton Sea inflow for the period 1965 to 1980 was about 71 percent of total inflows. During the period 1972 to 1982, however, the average annual contribution of IID increased to 78 percent of total Salton Sea inflow", (Decision 1600, 1984, see page 57). This flooding was attributed by the State Water Resource Control Board to wasteful use of irrigation water in the Imperial Irrigation District and in turn triggered private law suits seeking compensation for damages.

As of 1995, damages, settlement, pending cases, unsettled cases, litigation, and purchases for Salton Sea flooding have totaled an estimated $34.06 million. The share attributed to IID is 88% or $29.97 million. These costs are for compensation for damages incurred in the past by land owners bordering the Salton Sea. In addition to these past damage claims IID entered into a program in 1996-97 to construct a system of levees to minimize flooding damages in the future. The estimated cost of this levee system is $ 8.0 million, (see Imperial Irrigation District Annual Report, 1996, and Imperial Irrigation District Annual Report, 1997).

What would be the impact of internalizing the damages caused by flooding the lands bordering the Sea due to wasted water from improper irrigation methods? If the costs were annualized and assessed as to increase IID's per acre foot water charges or as a penalty for producing tailwater, a significant reduction in tailwater flowing to the Sea could be expected. For example, using estimates from SWRCB Decision 1600, (Decision 1600, 1984, page 60), a 100,000 acre feet per year reduction in wasted tailwater would lower the elevation of the Sea by about 2.26 feet over time. (Other estimates increase this to as much as 5.0 feet. See Elmore petition to the SWRCB as noted in its Decision 1600, 1984.) Starting with the time of the SWRCB order to implement a comprehensive tailwater monitoring, structure repair and control program in February 1985 (Decision

1600, 1984, see pages 68-70), 17 years have passed and as yet there has been no change in the elevation of the Sea.

Applying an interest rate of 8% and a 15-year payback period, the Capital Recovery Factor on $29.97 million plus an additional $8 million for protection from future flooding translates into an annual payment of $4.436 million. If this annual value is spread over a 100,000 acre foot reduction in tailwater waste, the per acre-foot charge to the grower would be $44.00 for each acre-foot of this marginal tailwater. Adding this damage cost per acre-foot to the current $13.00 per acre-foot District water charge equals a $57 per acre-foot total loss to the District and to society. In other words, the incremental damages caused by the last 100,000 acre foot of annual tail water loss is more than triple the cost of storage, transport and delivery of that same water.

The tools needed for implementation of a policy to "make the water waster pay" in IID is already available. All that is necessary is for the District to strictly enforce its current Triple Charges Program, which penalizes growers who produce excess tail-water. This would require repair and increased maintenance of existing tail-water boxes and improved supervision by the zanjero staff.

Given the demands on California's very limited water supply, the contention that tailwater and seepage losses are reasonable because their elimination is not cost effective under current nominal water charges is incorrect and contrary to public policy. In a statewide water market economy where water transfers between river basins can be effectuated by simply throwing a switch or opening a valve, the opportunity cost (value) including the externalities of water must be used in the optimizing the allocation of California's water. Thus, when excess tailwater damages are internalized to the grower who is wasting the water, cost effectiveness is not a shield.

In summary, to paraphrase an old saying, "The proof of the pudding is in the flooding". That is, the test of the effectiveness of any water conservation program in IID can be measured in large part by changes in the elevation of the Salton Sea. Protestations to the contrary, there has been no significant change.

# IV. BACKGROUND AND EXISTING CONDITIONS

## IV. A. Economics of Irrigation in the Imperial Irrigation District of California

**Introduction**. This section describes the factors that impact the economic framework for landowners and growers in the Imperial Irrigation District in their decisions on the application of irrigation water.

The problem faced by growers directly and agricultural land owners indirectly is to choose the least cost method of irrigating a field subject to the constraint of long term physical and economic sustainability of the valley. To irrigate a single field, a grower in the Imperial Valley must choose from a wide range of possible combinations of three major inputs. First, the irrigation technology, i.e. the capital input; second, the quality and quantity of irrigation labor used; and third, the quantity of water to be ordered from the irrigation district. For each irrigation event, the grower's objective is to choose that combination of the three inputs which minimizes the cost of production subject to the constraint that there be no significant yield decrement (a constrained optimization problem).

**Water Supply.** The goal of any irrigator is to distribute sufficient water across the field in order to replace the soil moisture removed by evapotranspiration. Growers have the added problem of managing the water dimension of this input by an additional volume of water being applied to maintain a salinity level in the plant root zone commensurate with the salt sensitivity of the crop. This additional increment of water, usually called the "leaching requirement", has been quantified and is generally well known by growers.

The most primitive form of irrigation is known as "wild flooding". In this case water is diverted from a stream or canal onto a field, which has not undergone land leveling, or other water management preparation. The required capital investment is low in this case but the ratio of water used by plants to water applied is also low. If the cost of the applied water is low and unused water is of satisfactory quality and returns to the stream or becomes a source for other irrigators, this method may be cost effective to the grower.

Increasing water costs provide an incentive to improve the performance of irrigation application. The slope of the demand curve (the demand per unit of water relative to the unit price of water) for irrigation water is negative (downward to the right) and relatively flat at low water prices but the curve becomes steeper at high water costs. The explanation for this relationship is straightforward. At low water prices (costs), a wide range of low valued, high consumptive use crops can be profitably grown using a low efficiency irrigation technology. As water costs increase to a significantly higher level, low valued, high water using crops drop out of the cropping pattern and are replaced by higher valued but more capital intensive and financially risky crops. At the same time it becomes profitable to invest in a more efficient irrigation technology. The end result is that the growers demand a lesser amount of irrigation water and that water is applied more efficiently.

**Irrigation Techniques.** There are three broad categories of farm irrigation technology; surface, either furrow or border, sprinkler, and drip. Within each of these categories growers still have many decision opportunities. For example, for surface irrigation, the length of run (field) impacts the degree of control the irrigator has over the water flowing down the length of the field. The use of siphons, spiles or gated pipe increases the irrigator's ability to manage and control the flow of water into the field. In addition, the slope or grade of the field both from top to bottom and across the field and duration of irrigation can impact the irrigation system performance and uniformity of water application.

Important to irrigation system performance is the ability to eliminate tailwater at the lower end of the field through the ability to control and cutback the movement of the stream of water down the slope of the field. Tailwater is defined here as any surface water flowing off the lower end of a field and into a drain. If the irrigator is skillful and careful in the timing of the cutback no additional investment is required. Labor cost per irrigation under current payment methods is $1.56 per acre ($125/80 acres). Alternatively, a tailwater capture and pump-back system can be installed but this requires significant additional capital investment. Depending upon the type of tailwater recovery system utilized, the annual capital costs range between $28 and $78 per acre (see Chapter VI). Additional details' describing the performance of surface irrigation systems is provided in Chapter IV G.

Sprinkler systems, the second category, require investment in the sprinkler lines themselves, a pump and motor plus energy to pressurize the water. Depending on the growers desire to substitute capital and energy for hand labor, a hand move, side roll or a linear move sprinkler system may be chosen. A hand move system will require an initial investment of approximately $400 per acre, while the initial investment for an automated linear move sprinkler system would be over $600 per acre based on cost estimates reported by USBR in 1997.

Surface and subsurface drip systems are now available for field crops grown on beds. A few experimental systems have been tested in the Imperial Irrigation District. While drip systems can significantly increase water application efficiency as well as field labor efficiency the initial investment is costly at $1,000 per acre due to the cost of the mainline, sub-mains, drip line, laterals, control system, sand filters, screen filter and pump outlay based on USBR calculations (Bureau of Reclamation, 1971).

**Land Ownership.** Land tenure, the way land is owned and operated including which party provides specific farm inputs, repairs and upkeep, can impact the way irrigation water is applied and conserved.

It is customary under the terms of their lease for a tenant farmer to pay for the quantity of water used in irrigation. Under this situation there is little or no incentive for tenants to invest in long term water conservation measures where water charges are less than about $15 per acre-foot. Even if a water conservation investment were cost effective, such as a

tailwater return system, the tenant would be unable to recapture the investment which has a useful life of 15 years during the life of a four or five year lease. At the same time, there is no incentive for absentee landlords to invest in water conservation because these individuals generally pay only the real-estate taxes plus land based assessments made by the irrigation district.

The U.S. Census of Agriculture, taken every five years, collects data on farmland ownership and farm tenancy in agriculture and publishes reports down to the county level. The Census reports land tenure in three groups, Full Owners, Part Owners, (farm operators that own land as well as renting some land), and Full Tenants. The characteristics of land tenure in Imperial County are significantly different than for the State of California as a whole. Statewide, Full Owners operate approximately 70 percent of all privately held farmland (Carter, 1997). The land tenure characteristics in Imperial County from 1978 through 1997 are shown in **Table IV.1**. These data indicate that Tenancy is the predominate form of land tenure in Imperial County with the proportion of rented farm land ranging from a low of 64.7 percent in 1978 up to 72.6 percent in 1997. Clearly the trend in renting farmland increased through-out this 20-year period and is most likely to continue.

Farmland leases range widely among growers and landlords. Some leases are still based on the traditional crop share arrangement where the tenant gains a right to farm the land by agreeing to deliver a share of the harvested crop to the landlord. This share varies by crop and the magnitude of the cash outlays contributed by the tenant. That is, the tenant would receive a higher proportion of the crop proceeds for a capital-intensive crop such as lettuce or tomatoes as compared to wheat or sugar beets.

Over time, as landowners became more geographically and emotionally removed from farming in the Valley, cash rents have become the predominate method of securing the right to farm a parcel of land. Cash leases in the Imperial Valley can be as short as four months for a fresh produce crop such as lettuce or broccoli when rented by a produce specialist who only needs land for the winter growing season, to as long as four or five years for alfalfa land.

Under both crop share and cash leases the landlord pays the real-estate taxes and land-based assessments collected by the irrigation district. Due to the long-term nature of the asset, the landlord typically pays for the cost of subsurface tile drains, land leveling and other permanent improvements to the land.

Annual cash rents vary widely because the market value of the land is determined primarily by the expected productivity of the parcel of land in question. Coarse textured soils that produce above average yields for both garden crops and field crops such as alfalfa hay command the highest rents. For example, one professional farm manager[1] in the Imperial Valley who was contacted (January 2001) reported cash rents for land capable of producing 9 tons of alfalfa hay per year would rent for $175 per acre whereas

[1] A certified California Farm Managers and Rural Appraiser who wished to remain anonymous.

fine textured soils capable of producing only 7 tons of hay per acre rented for only $125 per acre. This same professional farm manager reported that some soils in the Valley were so difficult to farm and produced such low yields that commercial growers were unwilling to rent these lands at any price. This is strong evidence of an active and efficient cash rental market for farmland sensitive to productivity and profitability that operates in the Valley.

**Table IV.1.** Land tenure in Imperial County (Census of Agriculture).

**Land Tenure Imperial County**

| | Year 1997 | Year 1992 | Year 1987 | Year 1982 | Year 1978 |
|---|---|---|---|---|---|
| Land in Farm Acres | 489,726 | 532,866 | 542,928 | 559,423 | 490,690 |
| Harvested Acres | 433,119 | 405,699 | 409,682 | NA | 431,542 |
| **Full Owners** | | | | | |
| Farms | 162 | 165 | 209 | 233 | 214 |
| Harvested Acres | 57,900 | 35,056 | 55,270 | 81,572 | 49,786 |
| **Part Owners** | | | | | |
| Farms | 163 | 206 | 244 | 211 | 277 |
| Acres | 266,379 | 315,994 | 306,354 | 276,225 | 319,666 |
| Owned Acres | 70,886 | 100,824 | 96,393 | 100,393 | 119,057 |
| Rented Acres | 195,493 | 215,170 | 210,261 | 175,886 | 200,609 |
| Harvested Acres | 248,676 | 278,620 | 249,514 | 243,860 | 283,568 |
| **Tenants** | | | | | |
| Farms | 172 | 186 | 229 | 203 | 220 |
| Acres | 145,820 | 103,097 | 129,042 | 118,994 | 109,388 |
| Harvested Acres | 126,543 | 92,023 | 104,898 | NA | 98,188 |
| **Percent Rented** | 72.6% | 70.1% | 69.2% | 61.9% | 64.7% |

**NA** = Data not available.

Under a cash rent lease, the tenant pays all crop production and harvesting costs including the cost of measured water delivered by the Imperial Irrigation District. Thus, landlords are very reluctant to invest in capital improvements that would conserve irrigation water because all financial savings generated by the investment would accrue to the tenants.

**Irrigation Labor.** There is a large pool of unskilled and semiskilled farm labor in the Imperial Valley. Although the total demand for farm labor in the Valley is relatively uniform through-out the year, there is seasonality in the demand for specific job skills. Based on information from the California Employment Development Department (EDD) (State of California, EDD "Agricultural Employment Report", NO.882) and interviews with local labor contractors, most growers hire their own irrigation workers. Old irrigators train the new employees, passing on irrigation techniques both good and bad from one generation to the next.

Piece Rate or "flat rate" pay for irrigation labor is a common payment method in the Valley according to the local Labor Commissioner who supervises adherence to State and Federal minimum wage rates and working conditions. The Commissioner reported a typical rate of pay was $125 for one man to irrigate an 80-acre (gross) field in 24 hours using a water flow rate of from 10 to 14 cubic feet per second (4,500 to 5,400 gallons per minute).

Given the diversity of crops grown in the Imperial Valley, the demand for farm labor is relatively uniform over the year with a low in late July through August period. However, because of the skills required, the work pattern for individuals may show much more variability than the aggregate.

Prior to 1997, the California Employment Development Department collected and published data on gross weekly earnings before deductions and hours worked for many occupations including agriculture (State of California, EDD "Agricultural Employment Report", NO.882). Data for general farm labor in the Desert Region, which includes Imperial, Riverside and San Bernardino Counties, is presented in **Table IV.2.**

Hourly earnings in **Table IV.2** can be compared to the Federal Minimum Wage as follows:

| | |
|---|---|
| 95 to 3/97 | $4.75/hr. |
| 3/97 to 9/97 | $5.00/hr |
| 9/97 to 3/98 | $5.15/hr |
| 3/98 to present | $5.75/hr |
| 1/01 to 1/02 | $6.25/hr |
| 1/02 to present | $6.75/hr |

The relatively low wages paid for agricultural labor in both the San Joaquin and Imperial Valley are a reflection of the abundant supply of relatively unskilled labor in the two regions. Whereas in 1991 through 1993, the farm workers in the San Joaquin Valley earned slightly lower hourly wages compared to the Desert Region, the situation was reversed for the period 1994 through 1996, the last year of the survey. More importantly, if the Consumer Price Index, (a measure of changes in the cost of living) is applied, the hourly wage in 1996 in the Desert Region would have to have been increased to $7.24 just to have kept up with inflation in the economy. That is, the real wages of farm workers in both Regions is declining relative to inflation and other purchased inputs.

Labor for irrigation requires some skills and in the Imperial Valley most growers maintain their own irrigation crews, according to local labor contractors and the head of California Economic Development's Labor Commission in the Imperial Valley. A survey of labor contractors in Imperial County indicated that irrigators hired through labor contractors were paid the prevailing minimum wage. The local EDD Labor Commissioner reported that piece-rate pay for irrigators was very common under direct grower hiring and one of his major enforcement problem areas.

Piece-Rate irrigators in general work as follows: the irrigator is hired for a lump sum fee to irrigate a given field. Currently, many irrigators are being offered, according to the Labor Commissioner, $125 to irrigate an 80-acre field using surface irrigation, either borders or furrow. The grower would then order a head of water (volume of water flow) to be delivered to the field by the Irrigation District over a 24-hour period. The Labor Commissioner is well aware that $125/24 hours = $5.21 per hour which is less than the current Federal Minimum Wage Rate of $5.75 per hour. The Labor Commissioner reported that growers using this payment method respond to his Office with the argument that the irrigator takes three one hour rest/lunch breaks within this 24 hour period. This raises the apparent hourly wage rate to $5.95 per hour. Of course, no one is supervising the inflow during these extended break periods. Under this payment method, a farm worker can earn almost as much in completing two irrigations as would be earned by a field hand working an entire week. Thus a 24-hour irrigation assignment is a much sought after job.

An informal survey of labor contractors and growers indicated the training of irrigators was primarily the task of older irrigators so that irrigation techniques, both good and bad, are passed on from generation to generation. There was no evidence that, good irrigators were paid a premium over those who were just entering the labor market.

Using the $125 per irrigation rate for an 80 gross acre field translates to a cost of $1.56 per acre per irrigation. Allowing a 10 percent reduction for roads, ditches and wasteland, the $125 flat fee becomes $1.74 per acre per irrigation or 0.29 hours of labor per acre for a field of 72 net-planted acres. University of California Cooperative Extension Service (Mayberry, 1996-97) cost of production studies use an average value of 0.6 hours per acre per irrigation with a range of from 0.36 up to 0.8 hours per acre for surface irrigation of field crops in Imperial County.

**Water Costs.** Water for irrigation in the Imperial Irrigation District is sold to district members at a relatively low cost compared to other districts receiving water from U.S. Bureau of Reclamation facilities in California. Compared to 21 water districts or irrigation districts in the San Joaquin Valley, who also benefit from USBR water supply contracts, Imperial Irrigation District water charges are the lowest (reported in their Water Conservation Plans). Recent water rates in IID have been in the $13 to $16 per acre foot range compared to USBR contractors in the San Joaquin Valley where the lowest reported water charge was $16 per acre foot. The remaining San Joaquin Valley water districts reported charging from $20 per acre foot up to as high as $128 per acre foot in the Terra Bella Irrigation District. As shown in **Table IV.3**, seven of the 21 districts reported water charges between $20 and $30 per acre foot and an additional six districts reported charges in the $30 to $40 per acre foot range. Each of these districts, except Fresno Irrigation District, which charges a flat rate per acre, charges significantly higher water rates per acre foot than the Imperial Irrigation District. The median water charge in the above 21 San Joaquin Valley districts was $35 per acre foot compared to IID's $13 per acre foot for the same time period. Further, the San Joaquin districts have significantly greater proportions of high value crops such as fruit, nuts, vines and cotton in their crop pattern than the Imperial Irrigation District.

**Table IV.2.** Farm Worker Earnings in California 1991-96. (Source EDD).

| LOCATION | YEAR | WEEKLY WAGE $/week | HOURS WORKED per WEEK | HOURLY WAGE $/hr | HOURLY INFLATION INDEX |
|---|---|---|---|---|---|
| **DESERT** | 1996 | 285 | 48.80 | 5.89 | 459.1 |
| | 1995 | 261 | 45.10 | 5.78 | 446.1 |
| | 1994 | 256 | 43.40 | 5.89 | 433.8 |
| | 1993 | 254 | 40.00 | 6.35 | 423.1 |
| | 1992 | 257 | 41.00 | 6.28 | 411.4 |
| | 1991 | 291 | 46.10 | 6.31 | 399.9 |
| **SAN JOAQUIN** | 1996 | 295 | 47.30 | 6.23 | 459.1 |
| | 1995 | 296 | 47.70 | 6.20 | 446.1 |
| | 1994 | 286 | 47.20 | 6.07 | 433.8 |
| | 1993 | 278 | 45.20 | 5.85 | 423.1 |
| | 1992 | 253 | 43.40 | 5.85 | 411.4 |
| | 1991 | 254 | 43.50 | 5.85 | 399.9 |

**Table IV.3.** Water Rates for USBR Contractors.

| District | Rates |
|---|---|
| Alpaugh ID | $55/ac. ft. |
| Arvin Edison | Varies by Lift |
| Banta-Carbona | $23/ac ft |
| Broadview WD | 38.35 ac ft |
| Chowchilla WD | $30/ac ft |
| Fresno ID | $25/acre flat |
| Gateway Water Conservation | $20-$28 ac ft |
| Kanawha WD | $25 ac ft |
| Lower Tule ID | $25-$38 ac ft |
| Madera | $16 ac ft |
| Panoche WD | $56 - $59 |
| Patterson WD | $29 ac ft |
| Pixley ID | $30-$37 ac ft |
| Plain View WD | $42 ac ft |
| Saucelito I | $35 ac ft |
| Shafter Wasco ID | $40 ac ft |
| South S J MUD | $40 - $94 ac ft |
| Terra Bella ID | $71 -$128 ac ft |
| Tulare ID | $20 -$30 ac ft |
| West Side ID | $21.42 ac ft |
| West Stanislaus | $34 ac ft |

**Owner/Operator Responsibilities.** In brief, what policies and procedures will be necessary to assure and maintain reasonable use of irrigation water in IID? Requirements on the maximum proportion of tailwater, as a percent of total water, delivered to the farm head gate should be mandatory.

Under the current cost/benefit relationships, given the relatively low direct cost of water and the relatively high cost of any major improvement in irrigation system performance, any significant improvement in irrigation performancy must be driven by an ability on the part of the owner/operator to include in his/her decision the opportunity cost of the water saved or prevented from being wasted. An opportunity cost of water of approximately $50 per acre foot or greater would appear to be the threshold price (**Figure VI.1**) where owner operators would be willing to invest in long term capital improvements, structural and nonstructural, to increase their irrigation system performance. However, this is applicable to only about 30 percent of the land in IID, that is, the land operated by the landowner. The particular combination of investment in irrigation hardware, irrigation scheduling and training of irrigation labor, which is optimal for owners/operators, will vary from grower to grower based on crop mix and soil conditions.

Using the basic economic principle that projects should be accepted only when the incremental savings or benefits are greater than their incremental costs, in this case based on a $13.00 per acre-foot water cost, a tail water return system fails the test of financial feasibility. However, an opportunity cost of this saved water of approximately $50 per acre-foot is taken into account in the investment decision, water conservation becomes feasible for Owners/Operators.

**Tenant Farmers.** Tenants in IID are placed in an awkward position with respect to water conservation. Whereas they are faced with the same water charges and labor wage rates as owner operators, tenants would not share in the benefits of water conservation under current practices in the District. Second, their leases are so short, <1 to 5 years, that they can not recoup their investment in any large capital items such as sprinklers, drip irrigation or tail water return systems through cost savings when water is priced at current IID rates.

Tenant operators, who farm about 70 percent of the land in the District as well as owners/operators have the alternative of investing in human capital rather than physical structures to increase irrigation system performance. The major benefit of this alternative is that the grower does not have to wait 15 years to recoup his investment. By using increased training and supervision of irrigation labor, significant increases in irrigation system performance can be demonstrated. Bali et Al (2001) in their on-going study of irrigation water use in the Imperial Irrigation District have demonstrated that tailwater can be nearly eliminated by the close supervision of experienced irrigation labor during an irrigation event with no significant yield reduction.

Better utilization of and investment in irrigation labor can take two forms. First, the flow of water can be retained at the 12 to 14 cfs level and another irrigator added or second the

head of water can be reduced to 7 to 8 cfs and a single irrigator can take more time to do a better job of irrigating the same field. In either case, tenants/growers will face increased irrigation costs but neither group would be required to make large capital outlays. From an economist's point of view, training of irrigation labor is an investment in human capital, i.e., a nonstructural investment.

Tenants who are forced by Federal, State or District regulations to drastically reduce or eliminate tail water and operational losses will invest in either human or physical capital, or both to meet new water conservation regulations. Such a requirement could increase production costs and negatively impact the demand for rented land and lower the cash rental value of land in IID. This same phenomenon, i.e. of a general reduction in cash rental rates in the face of a decrease in farming profitability, has been observed in the Salinas Valley when a pump tax was threatened and in the San Joaquin Valley at the time of the Reclamation Reform Act, which limited the acreage of Federal Irrigation Project land that could be rented by a single operator to 960 acres (Moore, 2000).

## IV. B. Climate of the Imperial Irrigation District

The Imperial Valley is in a low desert arid climate regime characterized by hot summers, mild winters, high evaporation, and very little precipitation. The Imperial Irrigation District (IID) service area is situated in the Imperial Valley generally to the south and southeast of the Salton Sea and bordering on Mexico. Irrigated lands in IID vary in elevation from –220 feet (below sea level) to about sea level in the area to the east and are served by the Coachella Canal. Year round cropping is possible with very low probability of winter frosts. About 10% of IID irrigated lands are double cropped with vegetables and wheat in the winter to early spring and sudan in the summer. The hot summertime temperatures can be detrimental to crop (such as alfalfa) growth and yield.

The average annual temperature in the Imperial Valley is about 73 °F and varies from 71 °F to 75 °F **(Figure IV.1).** Monthly average temperatures vary from 56 °F in January to 92 °F in July as shown in **Figure IV.2** (data from the Imperial NWS, 1961-1998 (NOAA 1997)). Annual Class A pan evaporation averaged 115 inches and varied from about 110 inches to over 125 inches during 1970-1998 at the Brawley USDA Agricultural Research Service (ARS) site (**Figure IV.1**).

The normal annual precipitation (1961-1990) is 2.86 inches (note: agrees with Divine's data for "75-"95, in ECS spreadsheet it averaged 3.26 inches using data of Divine and Hill for the "72-'00 period) as given in **Table IV.4** (average of five NWS stations: Brawley 2SW, Calexico 2NE, El Centro 2SSW, Imperial and Niland). The annual normal (1961-1990) precipitation total varied from 2.71 inches at El Centro to 3.05 inches at Brawley 2SW. The five station average normal precipitation is highest in December, 0.41 inches, followed by 0.39 inches in August. Normal precipitation is the lowest in June, 0.01 inches, and May with 0.02 inches.

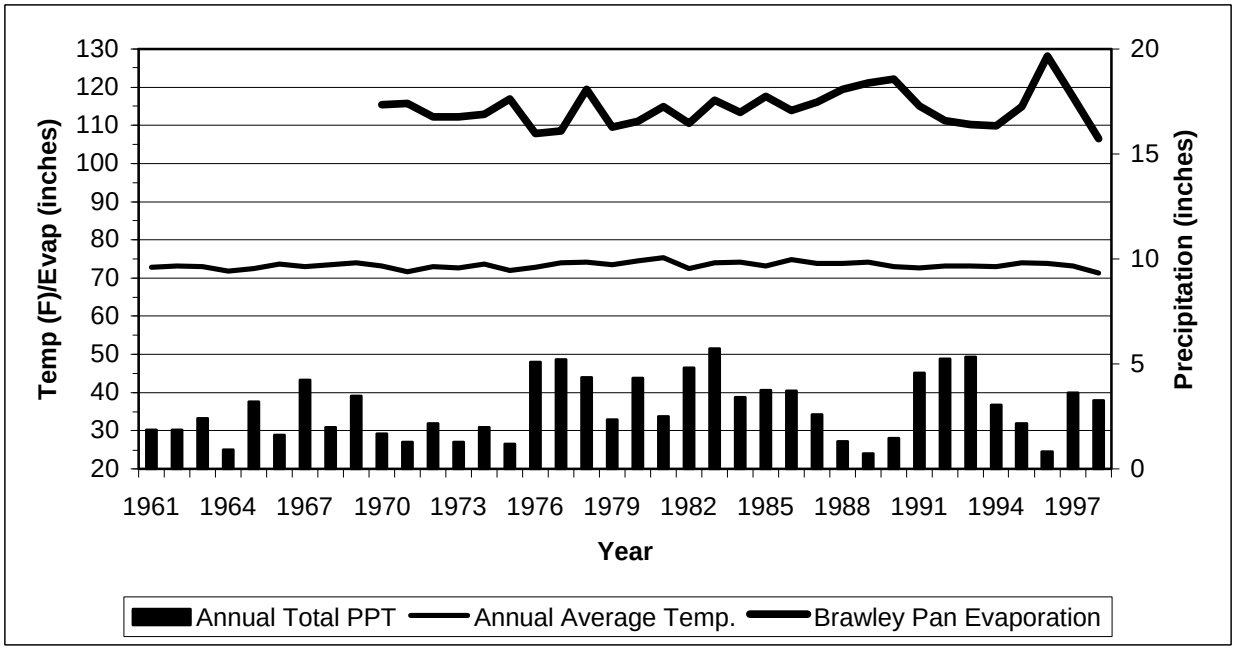



**Figure IV.1**. Annual Average Temperature and Precipitation (Imperial NWS 1961-1998) and Total Annual Class-A Pan Evaporation (Brawley 1970-1998).

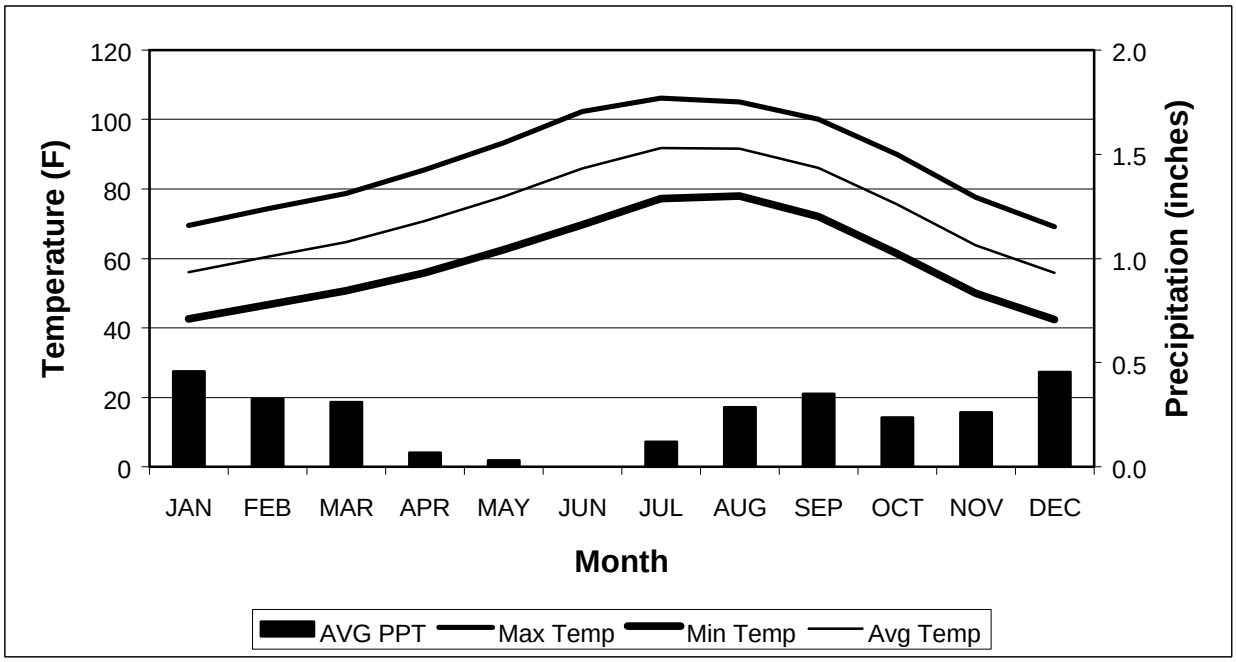



**Figure IV.2.** Monthly Average Maximum, Minimum, and Average Temperature and Total Precipitation (Imperial NWS 1961-1997)

The number of measurable precipitation events during the year is also very low. There were a total of 617 events at the Imperial NWS station (for example) from January 1961 through December 1998 (**Table IV.5**). This is an annual average of 21 rainfall events. There were only 2 events in this period for June and 11 in May, whereas 103 precipitation events occurred in January and 97 in December. The highest number of precipitation events in a year was 29 in 1994 (28 in 1993), whereas the lowest was 5 in 1964 (6 in 1972 and 7 in 1989).

**Table IV.4**. Imperial Valley Normal Monthly Precipitation, 1961-1990 normal period, inches.

| **Station** | **Jan** | **Feb** | **Mar** | **Apr** | **May** | **Jun** | **Jul** | **Aug** | **Sep** | **Oct** | **Nov** | **Dec** | **Annual** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Brawley | 0.37 | 0.31 | 0.32 | 0.09 | 0.04 | 0.01 | 0.12 | 0.46 | 0.37 | 0.29 | 0.26 | 0.41 | 3.05 |
| Calexico | 0.32 | 0.26 | 0.22 | 0.06 | 0.02 | 0.00 | 0.14 | 0.41 | 0.39 | 0.30 | 0.21 | 0.47 | 2.80 |
| El Centro | 0.37 | 0.27 | 0.21 | 0.05 | 0.02 | 0.01 | 0.09 | 0.37 | 0.31 | 0.32 | 0.27 | 0.42 | 2.71 |
| Imperial | 0.35 | 0.29 | 0.27 | 0.07 | 0.01 | 0.00 | 0.11 | 0.35 | 0.34 | 0.28 | 0.27 | 0.41 | 2.75 |
| Niland | 0.34 | 0.31 | 0.34 | 0.12 | 0.01 | 0.02 | 0.33 | 0.34 | 0.28 | 0.30 | 0.26 | 0.34 | 2.99 |
| | | | | | | | | | | | | | |
| **5 sta ave.** | **0.35** | **0.28** | **0.27** | **0.08** | **0.02** | **0.01** | **0.16** | **0.39** | **0.34** | **0.30** | **0.25** | **0.41** | **2.86** |

**Table IV.5.** Monthly Number of Measurable Precipitation Events at Imperial NWS Station, 1961-1998.

| Month<br>Year | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | ANNUAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1961 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 0 | 0 | 2 | 4 | 11 |
| 1962 | 3 | 3 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 2 | 10 |
| 1963 | 1 | 2 | 2 | 0 | 0 | 0 | 0 | 3 | 3 | 2 | 5 | 0 | 18 |
| 1964 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 5 |
| 1965 | 1 | 1 | 2 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 6 | 18 |
| 1966 | 3 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 2 | 0 | 10 |
| 1967 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 2 | 0 | 4 | 6 | 15 |
| 1968 | 0 | 2 | 1 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 2 | 8 |
| 1969 | 6 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 2 | 1 | 3 | 1 | 15 |
| 1970 | 0 | 3 | 3 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 2 | 11 |
| 1971 | 1 | 1 | 0 | 2 | 0 | 0 | 0 | 2 | 1 | 3 | 0 | 2 | 12 |
| 1972 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 0 | 6 |
| 1973 | 1 | 6 | 7 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 16 |
| 1974 | 3 | 0 | 2 | 0 | 0 | 0 | 2 | 0 | 2 | 4 | 0 | 2 | 15 |
| 1975 | 1 | 0 | 2 | 1 | 0 | 0 | 1 | 0 | 2 | 0 | 0 | 1 | 8 |
| 1976 | 0 | 7 | 0 | 3 | 1 | 0 | 3 | 0 | 3 | 0 | 2 | 1 | 20 |
| 1977 | 2 | 2 | 1 | 0 | 0 | 0 | 1 | 3 | 0 | 1 | 0 | 5 | 15 |
| 1978 | 7 | 4 | 3 | 2 | 0 | 0 | 1 | 0 | 0 | 3 | 1 | 2 | 23 |
| 1979 | 8 | 1 | 6 | 0 | 1 | 0 | 1 | 3 | 1 | 0 | 0 | 0 | 21 |
| 1980 | 4 | 8 | 5 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 20 |
| 1981 | 2 | 2 | 4 | 0 | 1 | 0 | 0 | 2 | 0 | 0 | 1 | 0 | 12 |
| 1982 | 3 | 2 | 6 | 0 | 0 | 0 | 0 | 5 | 3 | 0 | 2 | 3 | 24 |
| 1983 | 2 | 5 | 4 | 0 | 0 | 0 | 0 | 4 | 3 | 0 | 0 | 3 | 21 |
| 1984 | 2 | 0 | 0 | 0 | 0 | 0 | 2 | 3 | 1 | 0 | 3 | 9 | 20 |
| 1985 | 1 | 2 | 0 | 0 | 0 | 0 | 1 | 2 | 4 | 3 | 3 | 3 | 19 |
| 1986 | 2 | 2 | 4 | 0 | 0 | 0 | 1 | 2 | 1 | 2 | 3 | 2 | 19 |
| 1987 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 5 | 3 | 5 | 20 |
| 1988 | 1 | 1 | 0 | 2 | 0 | 1 | 1 | 3 | 0 | 1 | 0 | 0 | 10 |
| 1989 | 4 | 0 | 1 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 7 |
| 1990 | 2 | 1 | 1 | 1 | 0 | 0 | 0 | 4 | 1 | 1 | 0 | 0 | 11 |
| 1991 | 5 | 3 | 5 | 0 | 0 | 0 | 1 | 0 | 2 | 1 | 2 | 8 | 27 |
| 1992 | 2 | 6 | 6 | 1 | 3 | 0 | 0 | 2 | 0 | 1 | 0 | 5 | 26 |
| 1993 | 12 | 5 | 1 | 0 | 1 | 0 | 0 | 2 | 0 | 2 | 4 | 1 | 28 |
| 1994 | 2 | 4 | 4 | 0 | 2 | 0 | 0 | 4 | 1 | 0 | 2 | 10 | 29 |
| 1995 | 8 | 2 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 15 |
| 1996 | 0 | 3 | 2 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 2 | 10 |
| 1997 | 6 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 4 | 0 | 1 | 4 | 19 |
| 1998 | 3 | 7 | 2 | 0 | 0 | 0 | 0 | 2 | 3 | 0 | 2 | 4 | 23 |
| Total Events | 103 | 92 | 80 | 19 | 11 | 2 | 23 | 57 | 42 | 35 | 56 | 97 | 617 |

## IV. C. Soils of the Imperial Irrigation District of California

**Extent and Distribution.** The Imperial Valley is in the southern part of California and the extent of area reported in the "Soil Survey of Imperial County, California, Imperial Valley Area" is bounded by Mexico on the south, the Algodones Sand Hills on the east, the Salton Sea on the north, San Diego County on the northwest, and the alluvial fans bordering the Coyote Mountains and the Yuha Desert on the southwest. Elevation ranges from 230 feet below sea level to about 350 feet above.

The watersheds of the Imperial Valley Area all drain into the Salton Sea, which is a closed water body with no outlet except for evaporation. The main inflow to the Salton Sea comes from the New and Alamo Rivers. These rivers flow north from the ridge of the Colorado River Delta through the irrigated area of Imperial Valley and serve as outlets to agricultural drains and tailwater, which are their main sources of water. The irrigated area is nearly level, with a slope toward the Salton Sea of about 0.1 percent. From the east and west edges toward the center, the slope is about 0.3 percent. New and Alamo Rivers also conveys return flows from the Mexicali Valley in Mexico.

The irrigated area served by the Imperial Irrigation District is in the lakebed floor between the international boundary on the south and the Salton Sea on the north. This area is in the Group "well drained to poorly drained soils dominantly in the lacustrine basin" comprised of Map Units 1, 2, 3, 4, 5 and 6 which make up about 66 percent of the 989,450 acres. The irrigated area is dominated by Imperial, Holtville, Glenbar and Meloland series soils which have characteristics that affect infiltration and surface irrigation performance.

**Description of Imperial, Holtville, Glenbar and Meloland Series Soils.** The soils in the Imperial Irrigation District are formed in stratified alluvial materials and vary greatly in texture and thickness of layers. The fine and moderately fine textured lakebed sediments are parent materials of the Imperial, Holtville, Glenbar and Meloland series soils.

A soil series consists of soils that formed in a particular kind of material and have horizons or layers that, except for texture of the surface soil or of the underlying layers, are similar in differentiating characteristics and in arrangement in the soil profile. Among these characteristics are color, texture, structure, reaction, consistence, and mineral and chemical composition. Texture is the relative proportions of sand, silt and clay. Structure is the arrangement of primary soil particles into compound particles or aggregates that are separated from adjoining aggregates. Reaction is the degree of acidity or alkalinity of a soil, expressed in pH values. Consistence is the feel of the soil and the ease with which a lump can be crushed by the fingers.

Imperial series soils consist of very deep, moderately well drained soils formed in alluvial deposits on flood plains and basin floors. Imperial soils are similar to and near the Glenbar, Holtville and Meloland soils. Glenbar soils have a fine-silty control section. A control section is the part of the soil on which classification is based. The thickness

varies among different kinds of soil, but for many it is 40-80 inches. Holtville soils have a clayey over loamy control section. Meloland have a coarse-loamy over a clayey control section. Thus, with the exception of the Glenbar series soils, there is a clay layer within or at the bottom of each profile.

In the Imperial soils vertical cracks in the dry soil extend from the surface to a depth of 3 feet or more and are commonly ½inch wide at a 20-inch depth. In some places cracks are filled with windblown silt and fine sand. In the 17 to 24 inch interval of the Holtville series, vertical cracks about 2 inches wide at top and 12 to 18 inches apart are filled with loamy fine sand. Permeability is 0.06 to 0.2 inches per hour (very slow) for all layers of the Imperial soils and it is also very slow for one or more layers of the Holtville and Meloland series but not for the Glenbar series soils.

Water infiltrates slowly into and moves slowly through the majority of these District soils. In addition, many shrink and swell severely to moderately and have low strength. The characteristics of cracking clay soils influence the soil's water intake rate which play a dominant role in the design of field slope and length of surface irrigation runs and the selection of sprinkler application rates.

**The Nature of Cracking Clay Soils.** The structure of swelling clay soils and thus cracking and bulk density may be modified by cultural practices, by irrigation water and soil water salinity and sodicity, and by wetting and drying caused by irrigation or rainfall. Cracking behavior may influence water application uniformity and soil profile wetting (Van der Tak and Grismer, 1987). Water content and salinity affect cracking bulk density of the soils.

**Soil Moisture and Cracking.** There are three phases of shrinkage as molded blocks (disturbed soils) of clay soils dry in the laboratory; the first is normal shrinkage at high water contents (soil volume change equals water volume lost), the second is residual shrinkage at intermediate water contents (soil volume change is less than water volume lost), and finally, no further volume change (all water extracted is replaced by air).

When natural clay aggregates collected from the field are soaked from below (capillary rise) and then allowed to dry the behavior is changed. Initially, during drying, water content decreases, but aggregates do not shrink. Higher structural development and porosity restrict shrinkage because air enters into larger pores before normal shrinkage begins. For example, no cracks formed during the first day after irrigation on montmorillonitic (smectite) soils of the Imperial Series (Waller and Wallender, 1993) despite a decrease in soil moisture. If no cracks formed, then there was no horizontal shrinkage because the soil had high structural development and porosity that delayed normal shrinkage. After the first day, normal and residual shrinkage occur as water content falls, and bulk density (the mass of soil per unit volume) increases and the percent surface area covered by cracks increases to above 25% by day four. Thereafter the cracks area increases only slightly as the soil water content declines.

**Salinity, Sodicity, and Shrinkage.** Both percent crack area and bulk density data show that shrinkage increases with sodicity and salinity. Shainberg (1984) indicates that the magnitude of swelling increases as the percentage of sodium in the soil increases to from 5 to 15%. Bulk density increases more as soil dries in more saline soils. In higher salinity cases, there is only normal shrinkage and no residual shrinkage.

**Infiltration.** As swelling clay soils dry, large cracks form which dominate subsequent infiltration. When swelling clay soils are ponded, infiltration is controlled by flow through cracks. In Imperial soils, cracks swelled shut within a few minutes of ponding. After cracks swell shut, infiltration decreases dramatically to near zero for Imperial Clay soils. Infiltration rates were less than 0.02 in/hr (0.42 mm/hr) (Luthin and Robinson, 1969) and for a Tulare soil in the San Joaquin Valley containing 40-60% clay the rate was only 0.24 in/hr (6 mm/hr). Field evaluations of the impact of soil cracking on irrigation, drainage and soil salinity conducted on Imperial Series soil estimated crack volume of 1600 $m^3$/ha (169 mm or more than six inches, van der Tak and Grismer, 1987) after a two-month drying period, and Waller and Wallender (1991) estimated infiltration of 68 mm for an approximately two-week drying period between irrigations.

## IV. D. Salinity and Salinity Status in Imperial Irrigation District

**Comparing Colorado River Water with Other River Waters in California.** The chemical characteristics of Sacramento River water at Knights Landing, San Joaquin River at Vernalis and Colorado River at Imperial Dam (DWR, 1971) are shown in **Table IV.6**. In terms of EC, the Colorado River is about ten times more saline than the Sacramento River and about three times more saline than the San Joaquin River. Furthermore, the chemical composition of the Colorado River differs from the other two river waters. **Figure IV.3** shows a pie diagram with half of the pie devoted to cations (positively charged ions) and other half to anions (negatively charged ions). The percent values are based on milligram-equivalents per Liter or meq/L (the combining weight of chemical constituents). The percent values may be viewed as the reacting percentages. It shows that the Colorado River is a mixed cation-sulfate type water, San Joaquin River is a sodium-chloride type water, and Sacramento River is a calcium-bicarbonate type water.

Much of the salinity in the Colorado River comes from chemical weathering of saline geologic formations and their soils as well as irrigation return flows from the Upper Colorado River Basin. The Sacramento River at Knights Landing is dominated by snowmelt and rainfall runoff mainly from the northern Sierra Nevada along with some irrigation drainage. In contrast, the San Joaquin River at Vernalis conveys a mix of snowmelt and rainfall runoff from the southern Sierra Nevada to the east with some non-saline irrigation drainage as well as significant saline irrigation drainage (mainly subsurface drainage) from the West Side of the valley. The comparatively high salinity of the Colorado River water used in irrigated agriculture will be addressed later.

**The Importance of Water and Soil Salinity in Crop Production.** Evapotranspiration (ET) is water removed from moist soils by direct evaporation from the soil and by plant roots to meet transpiration needs. A wet soil has a lower suction potential for plants to

obtain water while a dry soil has a higher suction potential (tensiometer potential). For example, **Figure IV.4** shows that a salt-free soil (ECe = 0 dS/m) at water saturation would have zero suction potential, at field capacity moisture content (after a well irrigated soil has stopped draining) it has a suction potential of about 0.3 atmospheres and at wilting point (lower limit when plants wilt) it has a suction potential of about 15 atmospheres. It should be noted that plants might wilt in moist soil if the rate of ET is far larger than the rate of root uptake of soil water as occurs during the summer months in the Imperial Valley.

The presence of soluble salts in irrigation waters and soil solutions makes it more difficult to remove fresh water from soil to meet ET. Salinity makes soil water less available to plants by increasing the suction potential due to an osmotic (solute) potential. The presence of soluble salts increases the osmotic potential by approximately the product of EC (dS/m) and 0.36. For instance, if the rootzone salinity were 10 dS/m, the plant would need to overcome an additional 3.6 atmospheres (one atmosphere at sea level = 14.7psi) due to the osmotic suction potential. Thus, for a saline soil containing EC of 10 dS/m, the plant would require a suction potential of 3.6 atmospheres at saturation, 3.9 atmospheres (3.6 atmosphere osmotic potential + 0.3 atmosphere) at field capacity, and 18.6 atmospheres at wilting point. But since wilting point for plants is at 15 atmospheres, the plant will not be able to remove much water between 15 and 18.6 atmospheres. Thus, water is less readily available to plants from a wet soil containing soluble salts.

**Table IV.6**. Chemical characteristics of California river waters (DWR, 1971). Ion concentrations are reported in mg/L and meq/L.

| | **Sacramento River** | **San Joaquin River** | **Colorado River** |
|---|---|---|---|
| TDS, mg/L | 71 | 274 | 852 |
| EC, dS/m | 0.12 | 0.46 | 1.28 |
| Na, mg/L | 7.0 | 53 | 152 |
| Na, meq/L | 0.30 | 2.31 | 6.61 |
| Ca, mg/L | 12 | 21 | 93 |
| Ca, meq/L | 0.60 | 1.05 | 4.64 |
| Mg, mg/L | 3.2 | 10 | 35 |
| Mg, meq/L | 0.26 | 0.82 | 2.88 |
| HCO3, mg/L | 52 | 88 | 169 |
| HCO3, meq/L | 0.85 | 1.44 | 2.77 |
| Cl, mg/L | 5.2 | 61 | 137 |
| Cl, meq/L | 0.15 | 1.72 | 3.86 |
| SO4, mg/L | 9.0 | 48 | 366 |
| SO4, meq/L | 0.19 | 1.00 | 7.61 |

In addition, a number of dissolved mineral constituents such as sodium, chloride and boron are toxic to plants to varying degrees (specific ion toxicity). General guidelines on the suitability of waters for irrigation are found in water classification schemes as in

Ayers and Westcot (1985). Maas (1990) tabulates crop-specific tolerance for salinity, boron, sodium and chloride.

**The Salt Tolerance of Major Crops Grown in IID.** The threshold soil salinity (Maas, 1990) of major crops grown in IID is shown in **Figures IV.5** and **IV.6**. The threshold salinity is the average rootzone salinity in ECe (EC of extract from a saturated soil paste) above which the yield of the crops would decline. The salt tolerance of crops is reduced by elevated temperature and low humidity (Maas, 1990), but most of the least salt tolerant crops (e.g., vegetables) in IID are planted in early fall and harvested in the winter when temperatures are cooler.

Of the field crops, alfalfa is moderately salt sensitive, Sudan grass is moderately salt tolerant and all other field crops are salt tolerant, about 3 to 4 times more tolerant than garden crops. Of the garden crops, carrot is a salt sensitive crop while onion, lettuce, tomato and broccoli are moderately sensitive crops, and asparagus is salt tolerant. Grapefruit and other citrus crops range from salt sensitive to moderately salt sensitive. Date palm is a salt tolerant plant.

When average rootzone salinity is greater than the threshold salinity, the crop yield is expected to decline linearly (Maas, 1990). As shown in **Figure IV.7**, this line of yield decline is steeper for salt sensitive crops like lettuce and flatter for salt tolerant crops like Bermuda grass.

One may ask: "Why is it possible to produce salt-sensitive to moderately salt-tolerant crops with moderate concentration of salts in the Colorado River water and in salt-affected Imperial Valley soils?" This question will be addressed later in this section.

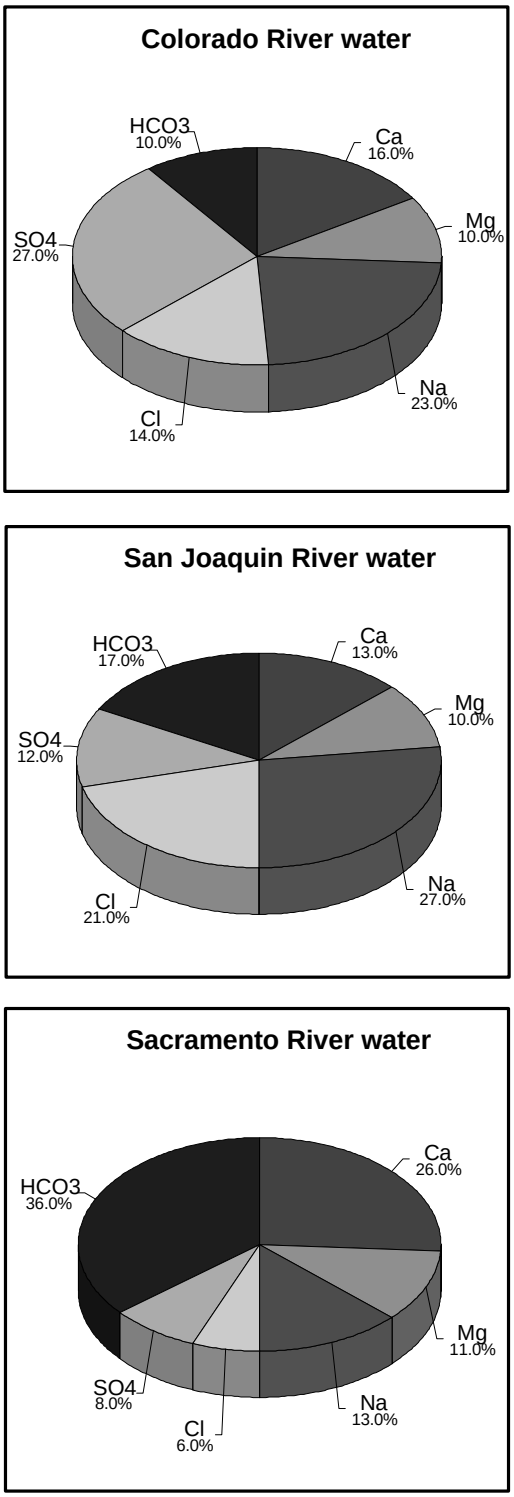



**Figure IV.3**. Contrasting chemical composition of California River waters. The ion composition is given in % of meq/L with cations on the right-hand side and anions, left-hand side (based on DWR, 1971).

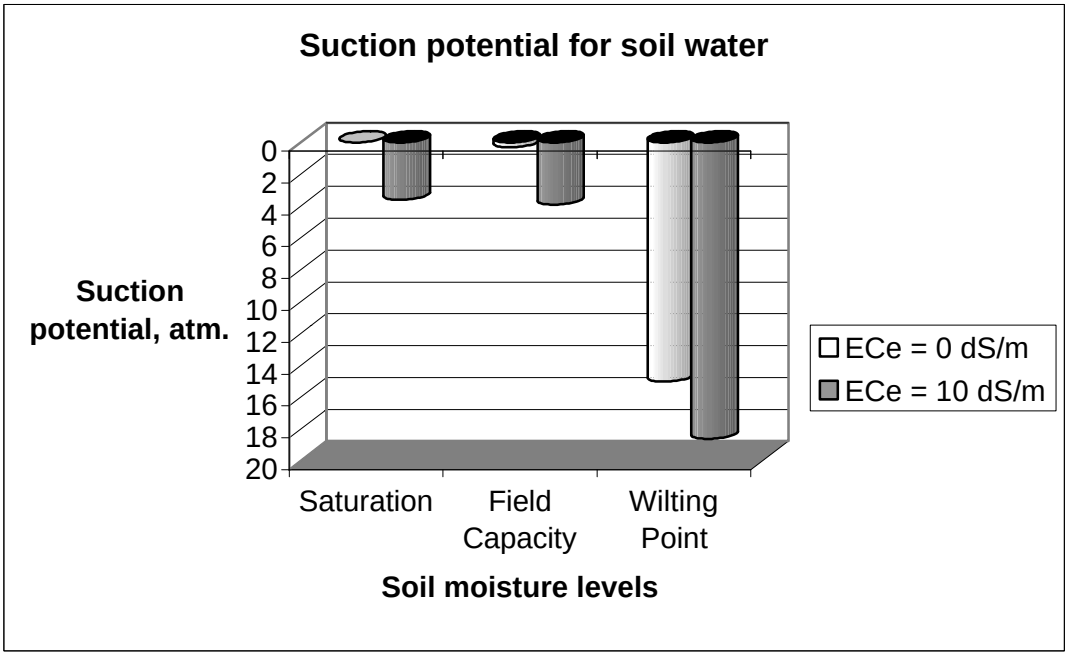



**Figure IV.4**. Comparison of soil water potential (suction) for salt-free soils and soils with a high salinity.

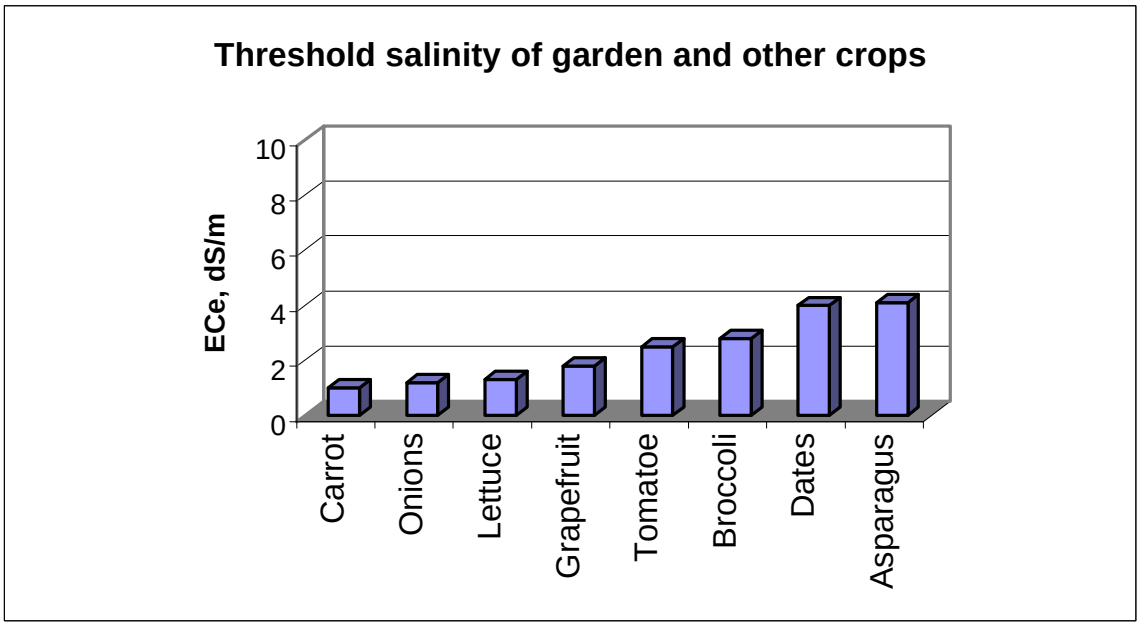



**Figure IV.5**. Threshold salinity of garden and other crops (Maas, 1990).

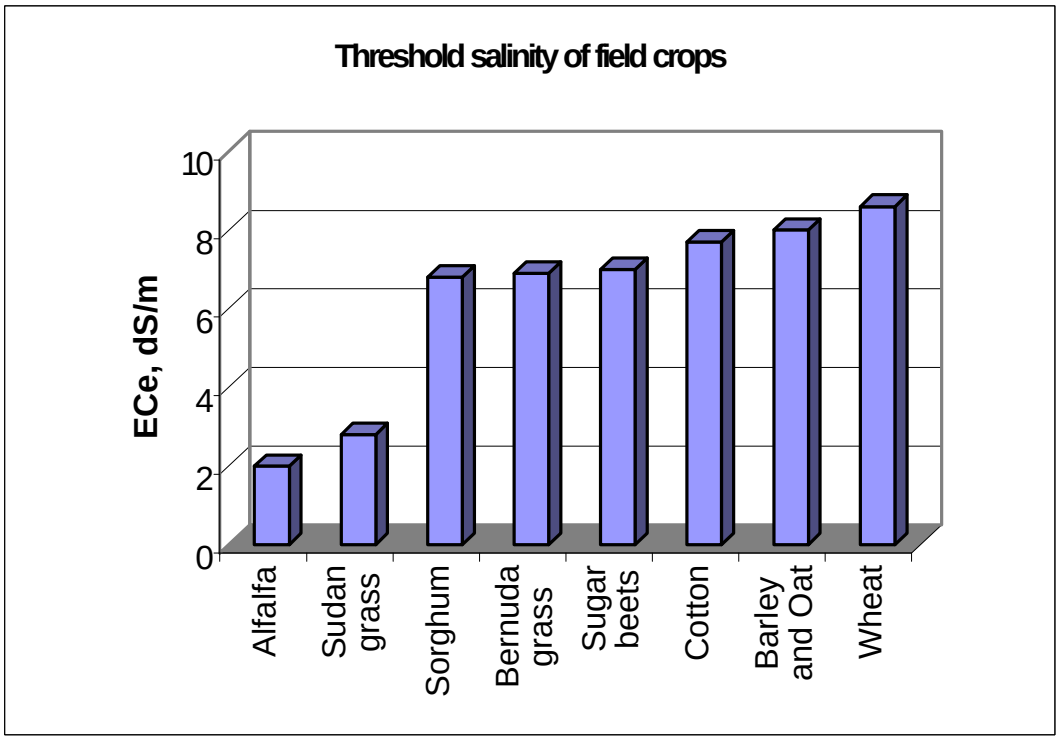



**Figure IV.6**. Threshold salinity of field crops (Maas, 1990).

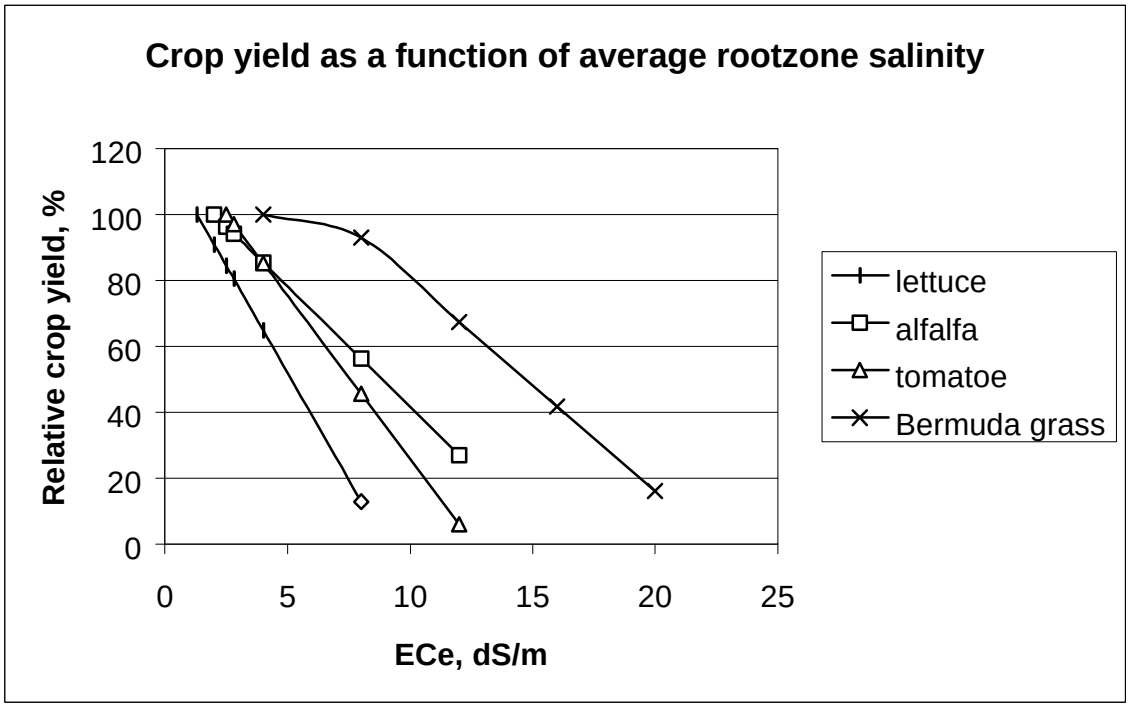



**Figure IV.7**. Crop salt tolerance as a function of average rootzone salinity (Maas, 1990).

**The Effects of Crop ET on Soil Salinity Under Surface Irrigation.** Actively transpiring cultivated and native vegetation are "salt concentrators" because they transpire more or less pure water into the atmosphere leaving most of the dissolved mineral salts in the rootzone. Some halophytes (salt-loving plants like Atriplex or saltbush) deposit salt crystals on their transpiring leaves and when the leaves die back, salts are returned to the soil.

An irrigated soil profile containing 3.3 ft of water is conceptually shown in **Figure IV.8**. After 2.3 ft of plant transpiration and evaporation, 1.0 ft of water remains in the rootzone. The ET process has evapoconcentrated the soil water to 30% of its initial depth of water and that becomes the drainage from the rootzone. This steady-state model assumes that there is no change between the initial (prior to irrigation interval) and final (after irrigation interval) soil water content in the rootzone. This extent of drainage is commonly known as Leaching Fraction or LF (USSL, 1954), a decimal fraction. The product of depth of infiltrated water and LF is the depth of water that leaches beyond the rootzone.

The EC of the irrigation water in **Figure IV.8** is assumed to be 1 dS/m. The soil EC after ET is expected to proportionally increase because the soil water content has been decreased from 3.3 to 1.0 ft. If the salt remains in solution the EC increases by the ratio 3.3 to 1.0 ft or 3.3. times. Further, the soil EC after ET can be calculated using the ratio of irrigation water EC to LF or 3.33 dS/m. The EC of the drainage water is expected to be 3.33 dS/m in this rather simplified illustration. There is an inverse relationship between soil water content and salt concentration (EC). The assumed distribution of crop water uptake used and resulting evapoconcentration is shown in **Figure IV.9**.

An illustrative computation of seasonal LF and salt distribution for a case of 3.28 ft surface irrigation, crop ET of 2.30 ft and water EC of 1 dS/m is given in **Table IV.7**. Deci is the unit depth of seasonal effective (infiltrated) crop irrigation and Dcet is unit depth of seasonal crop ET. Wq is the extraction pattern in the rootzone quartile q, i.e., 0.4, 0.3, 0.2, and 0.1. ECiw is the EC of the applied irrigation water. LFq and ECq are, respectively, the leaching fraction and EC at the bottom of the qth quartile.

An example of the EC in the rootzone quartile for EC of 1 dS/m with LF varied is shown in **Figure IV.10**. Note that in sprinkler, basin or furrow irrigation methods, the upper rootzone is the zone of salt leaching and the lower rootzone, the zone of salt accumulation. This distribution of salts favors crop plants because rootwater extraction occurs more intensively in the upper zone where salinity is lowest.

**Salt Distribution Patterns in Irrigated Soils as Affected by Irrigation Application Methods.** An approximation of rootzone salinity distribution as affected by differing irrigation application methods (Ayers and Westcot, 1985) is shown in **Figure IV.11**. Salts tend to accumulate at or near the wetting front of exposed moist soil, as in furrow beds from wicking action. Salts also tend to accumulate at the wetting fronts of drip irrigation.

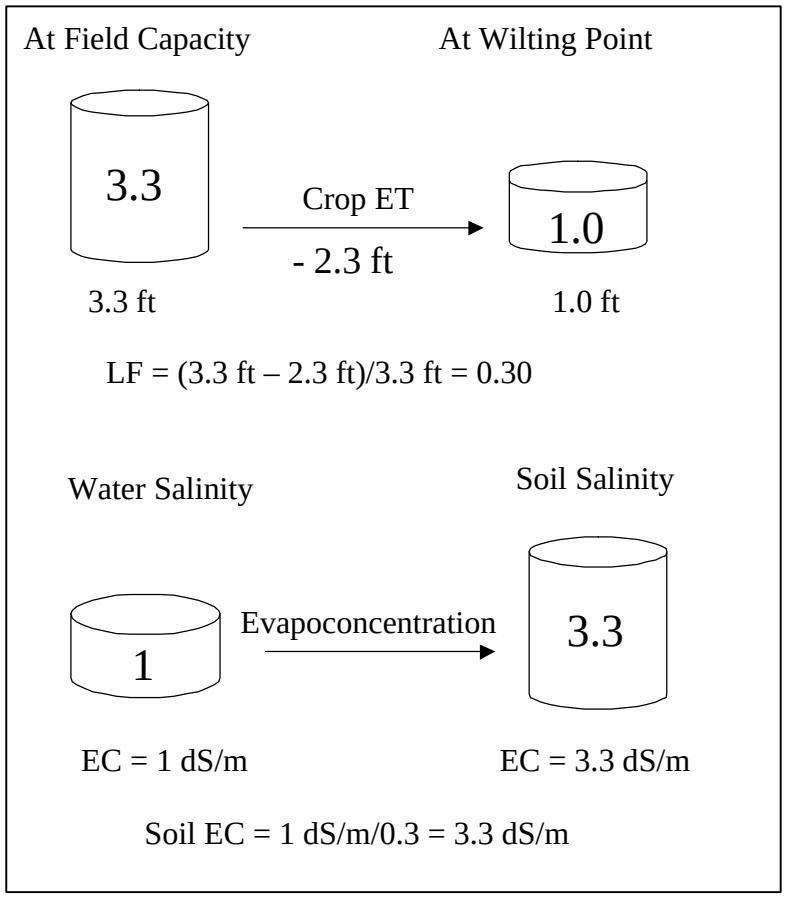



**Figure IV.8**. The inverse relationship between water content and soil salinity.

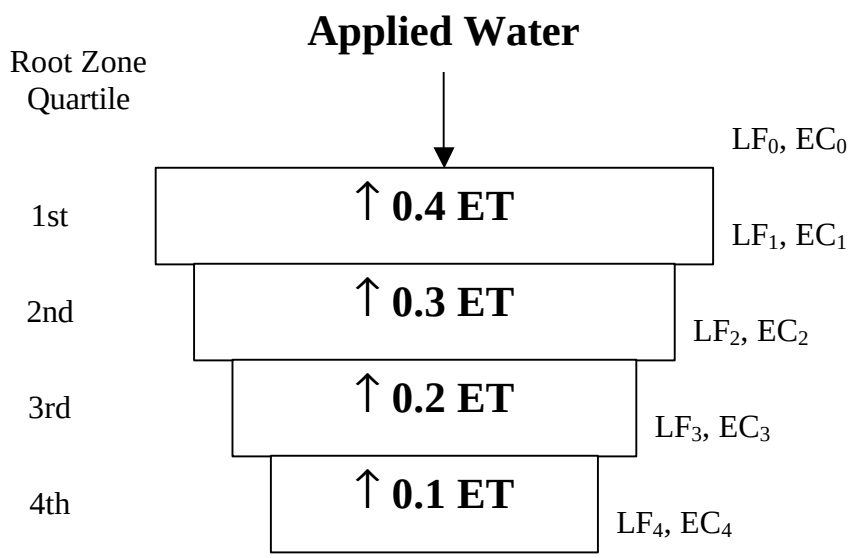



**Figure IV.9**. Rootwater extraction pattern in rootzone quartiles and quartile LFs (Ayers and Westcot, 1985).

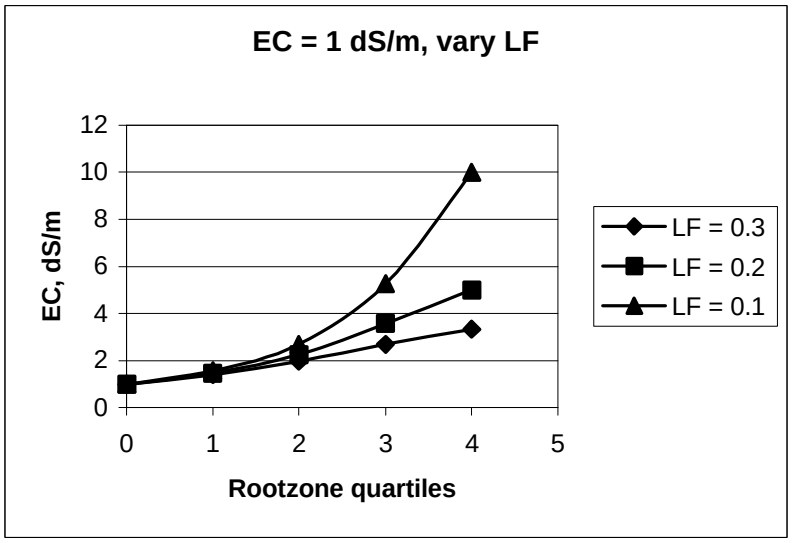



**Figure IV.10**. An example of the EC in the rootzone quartile for EC of 1 dS/m with LF varied.

**Table IV.7**. LF and EC by rootzone quartiles for surface irrigation.

| Rootzone quartile | $LF_q = \frac{D_{eci} - \sum W_q D_{cet}}{D_{eci}}$ | $EC_q = \frac{EC_{iw}}{LF_q}$ |
|---|---|---|
| 0th, surface | $LF_0 = \frac{3.28\,ft - (0)2.30\,ft}{3.28\,ft} = \frac{3.28}{3.28} = 1.0$ | $EC_0 = \frac{1.0dS/m}{1.0} = 1.0dS/m$ |
| 1st | $LF_1 = \frac{3.28\,ft - (0.4)2.30\,ft}{3.28\,ft} = \frac{2.36}{3.28} = 0.72$ | $EC_1 = \frac{1.0dS/m}{0.72} = 1.39dS/m$ |
| 2nd | $LF_2 = \frac{3.28\,ft - (0.7)2.30\,ft}{3.28\,ft} = \frac{1.67}{3.28} = 0.51$ | $EC_2 = \frac{1.0dS/m}{0.51} = 1.96dS/m$ |
| 3rd | $LF_3 = \frac{3.28\,ft - (0.9)2.30\,ft}{3.28\,ft} = \frac{1.21}{3.28} = 0.37$ | $EC_3 = \frac{1.0dS/m}{0.37} = 2.70dS/m$ |
| 4th, bottom | $LF_4 = \frac{3.28\,ft - (1.0)2.30\,ft}{3.28\,ft} = \frac{0.98}{3.28} = 0.30$ | $EC_4 = \frac{1.0dS/m}{0.30} = 3.33dS/m$ |

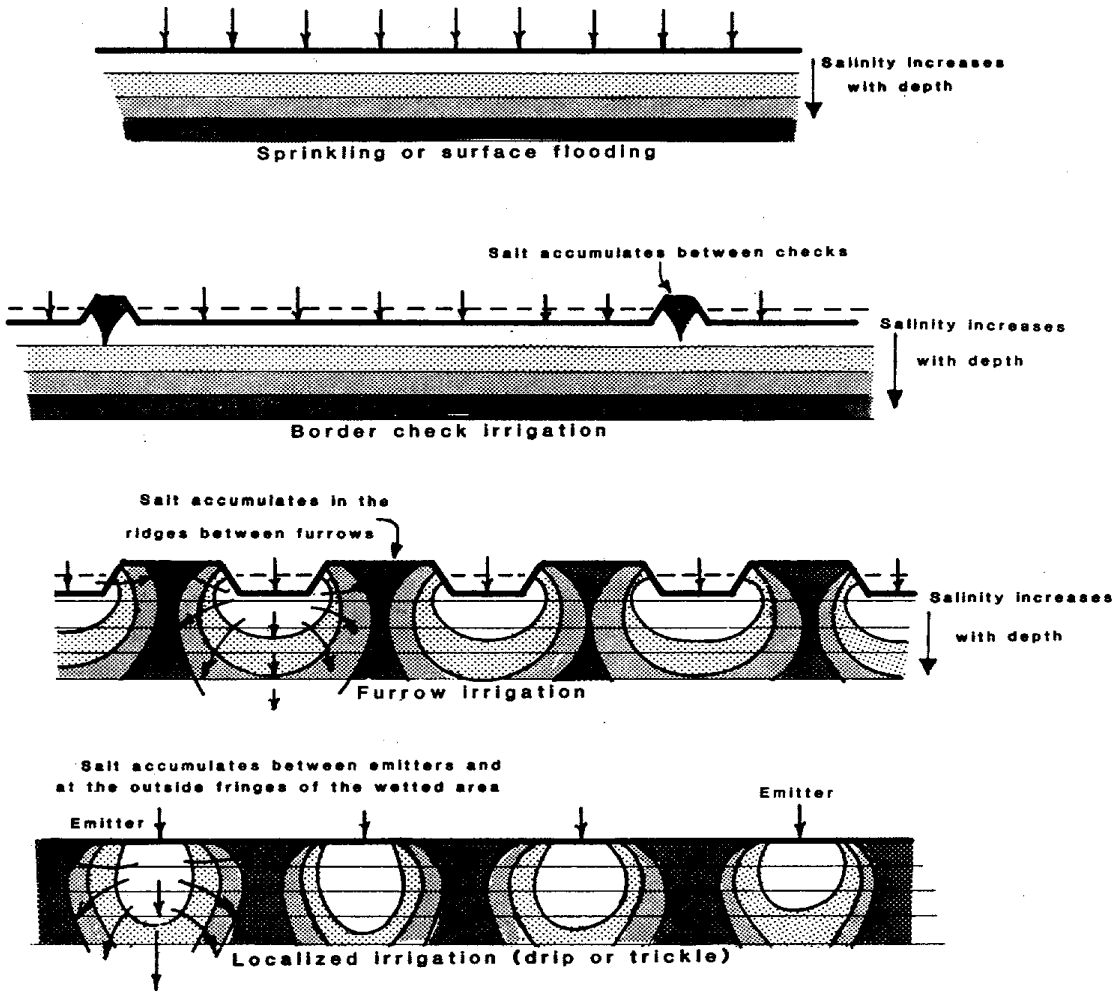



**Figure IV.11**. Approximate distribution of soil salts from irrigation with several application methods (Ayers and Westcot, 1985).

**<u>Rootzone Salinity and Leaching Requirement</u>**. The Leaching Fraction regulates salt distribution in the rootzone. The extent to which rootzone salinity is to be controlled is dependent upon the salt tolerance of the crop, i.e., threshold salinity. This extent of crop-specific leaching is known as Leaching Requirement (LR), defined as

$$LR = \frac{ECiw}{5(Coeff \quad a) - ECiw} \qquad \text{(Equation IV-1)}$$

where ECiw is EC of the irrigation water in dS/m, Coefficient "a" is the threshold soil salinity (ECe) in dS/m for the crop, and factor "5" is an empirically derived relationship to partially account for profile salt distribution (USSL, 1954).

For example, if ECiw is 1.0 dS/m and threshold ECe for 100% yield of Bermuda grass, a salt tolerant crop, is 6.9 dS/m (Maas, 1990), then

$$LR = \frac{1}{5(6.9) - 1} = 0.03 \qquad \text{(Equation IV-2)}$$

But if the crop is lettuce, a moderately salt sensitive crop, with a threshold salinity of 1.3 dS/m (Maas, 1990), then

$$LR = \frac{1}{5(1.3) - 1} = 0.18 \qquad \text{(Equation IV-3)}$$

Thus, the LR of these two crops varies by six-fold, 3% vs. 18% leaching of the irrigation water applied (more correctly the water infiltrated into the soil).

**<u>The Water Depth Needed to Satisfy Crop ET and Crop-Specific Salt Tolerance</u>.** The depth of infiltrated water (Deci) required to satisfy both crop ET (Dcet) and crop LR is obtained from

$$Deci = \frac{Dcet}{(1 - LR)} \qquad \text{(Equation IV-4)}$$

Dcet is the product of ETo (reference ET) during the crop-growing period and Kc, the average crop coefficient for the growing period. Inserting values reported by Jensen and Walter (1997) for Bermuda grass, Dcet is 4.93 ft x 0.875 or 4.31 ft. Thus, Deci is

$$Deci = \frac{4.31}{1 - 0.03} = 4.44\,ft \qquad \text{(Equation IV-5)}$$

And for fall-planted lettuce, Dcet is 1.63 ft x 0.869 or 1.42 ft. So that Deci is

$$Deci = \frac{1.42}{1 - 0.18} = 1.73\,ft \qquad \text{(Equation IV-6)}$$

The estimated total irrigation water required for Bermuda grass and fall-planted lettuce for the conditions specified is given in **Table IV.8**. About 97% of the 4.44 ft effective applied irrigation for Bermuda grass is for crop ET and 3% for rootzone salt control. In contrast, about 82% of the 1.73 ft effective applied irrigation for lettuce is for ET, and 18% for rootzone salt control. In this illustrative example, tailwater production is assumed to be negligible.

**Table IV.8**. Summary of total irrigation for Bermuda grass and lettuce to meet crop ET and LR.

| Description | Bermuda grass | Fall-planted lettuce |
|---|---|---|
| ETo x Kc, ft | 4.93 x 0.875 | 1.63 x 0.869 |
| Evapotranspiration (ET), ft | 4.31 | 1.42 |
| Threshold salinity (ECe), dS/m | 6.9 | 1.3 |
| Leaching requirement (LR) | 0.03 | 0.18 |
| Rootzone drainage for LR, ft | 0.13 | 0.31 |
| Total depth of effective applied water, ft | 4.44 | 1.73 |

**Salt Balance.** Salt balance of irrigated lands is a concept proposed by Scofield (1940). He defined regional salt balance (SB) as the difference between the mass of salt output (as in drainage) and mass of salt input (as in irrigation). Salt mass is the product of salt concentration (tons salt per ac-ft) and water volume (ac-ft). Moreover, Scofield defined Salt Balance Index (SBI) as the ratio of mass of salt output to mass of salt input. A SBI less than 1.0 indicates salts are being stored in the irrigation project and greater than 1.0, salts are being leached from the project. The corresponding water balance (WB) would be the difference between volume of water output (drainage) and volume of water input (irrigation). The water balance index (WBI) would be the ratio of volume of water output to volume of water input. The WBI in irrigation projects is much less than 1.0 because much of the applied water is lost as ET.

This salt balance concept best applies to large spatial units such as irrigation projects and irrigated river basins and to time scales of annual to decades of years. The original intent of the application of the salt balance concept was to assess gross salinity status of irrigated lands and to track temporal changes. Typically, annual salt and water balances for a region are based on surface inflow and surface outflow. Not typically considered are subsurface inflows into an irrigation project (e.g., horizontal ground water inflow and vertical rise of ground water) and subsurface outflows (e.g., horizontal ground water outflow and vertical recharge of ground water). Thus, the original salt balance concept was a black-box approach based on readily available database of surface inflow and surface outflow.

Scofield (1940) recognized that there are limitations to this concept because impacts of ground water flow (underground plumbing) are not explicitly considered nor the many sources of salts (e.g., naturally occurring soil salts) and sinks of salts (e.g., precipitation of dissolved mineral salts in the crop rootzone). Nevertheless, salt balance and salt balance index are widely used evaluation indices in irrigated agriculture.

**Linking the Salt Problem In IID To The Salinity Of the Colorado River Water.** The salt problem in the Imperial Valley is linked to the Colorado River even before the advent of irrigated agriculture. Imperial Valley is the southern portion of the Salton Trough that has been filled with alluvium from the Colorado River to more than 20,000 feet (Loeltz et

al., 1975). The prehistoric Lake Cahuilla deposited silts and clays to a thickness of 50 to 100 feet of the present land surface. As Lake Cahuilla desiccated, the waters were evapoconcentrated to very high salt concentrations that upon drying formed salt crusts (efflorescence). The soils formed in the valley floor ranged from moderately well drained sandy soils to poorly drained clay soils (Zimmermann, 1981). Some of the soils contain lime (calcium carbonate), which has a very low solubility and gypsum, a moderately soluble earth mineral that readily goes into solution when in contact with water. The solid phase salts in soils and substrata and the dissolved mineral salts in the ground water are largely derived from the Colorado River.

Irrigated agriculture in the Imperial Valley began about 1901 with water imported from the Colorado River through the Imperial Canal built by the California Development Company (Setmire et al., 1990). Then in 1905, a temporary diversion of the Colorado failed, causing the entire flow of the Colorado River to empty into the Imperial Valley until 1907 to form the present day Salton Sea.

The Imperial Irrigation District (IID) was formed in 1911 consolidating a number of water companies. In 1922, IID began installing a checkerboard pattern of deep open drains because of water logging of croplands. High water table and salt accumulation continued to increase and that led to installation of closed subsurface tile drainage beginning in 1929.

The collected irrigation drainage is discharged into the Salton Sea, which now is 25% more saline than the oceans. In most other irrigated valleys in the west, irrigation drainage is discharged into freshwater streams (e.g., Upper Colorado River Basin) and the drainage after commingling with freshwater is reused incidentally (not by plan) by downstream water users (e.g., Lower Colorado River Basin).

**Regional Salt Balance in IID.** Following Scofield's approach (1940) to estimating salt balance by surface inflow and surface outflow, Molof (1963) evaluated salt balance in IID from 1943 through 1962, Kaddah and Rhoades (1976) from 1943 through 1973 with detailed analyses for 1973, and Silva (1990) from 1958 through 1989.

Molof (1963) reported that the SBI (see Salt Balance above) was from 0.85 to 0.96 from 1943 through 1948 and 1.01 to 1.20 from 1949 through 1961. He believed that salts were accumulating in IID (SBI < 1.0) until 1948 when about 2,000 miles of tile drains were installed by then and a favorable salt balance is being met since then. For the first 6 months of 1962, Molof evaluated the dissolved mineral salt species of the influent and effluent waters of IID. He noted that the Ion Balance Index (IBI or SBI of individual ions) for magnesium, sodium and chloride was greater than 1.0 and for calcium, bicarbonate and sulfate less than 1.0. Molof interpreted these results as "calcium and bicarbonates were tied up releasing an excess of chlorides and sodium from base exchange". Unfortunately, Molof (1963) did not correct for the salt and water flows into the New and Alamo Rivers from Mexicali Valley, Mexico.

Silva (1990) also compiled a salt balance for IID from 1958 through 1989, excluding the discharges into the rivers from Mexicali Valley. Both a salt balance index (SBI) and water balance index (WBI) from 1958 through 1989 (Silva, 1990) are shown in **Figure IV.12**. The database was extended from 1990 to 2000 in IID's Water Department Report of 2000 (Imperial Irrigation District, 2001). There appears to be a parallel trend between SBI and WBI. The 43-year average WBI is 0.36 or 36% of IID's inflow water is discharged into the Salton Sea. The 43-year average SBI is 1.19 or 119% more salts were discharged than brought in with the irrigation water. Some of the salts discharged came from the interception of saline regional ground water by the drainage systems.

Kaddah and Rhoades (1976) also evaluated SBI and WBI in IID for the period 1943 to 1973 and obtained similar values to those of Molof (1963) and Silva (1990). But in addition, Kaddah and Rhoades as shown in **Figure IV.13** obtained an estimate of the distributed flows for drain discharge in 1973 based on certain assumptions and using chloride ions as a tracer. They estimated that the mass discharge of salts comprised of 54.7% intercepted ground water by open and closed drains, 33.0% intercepted root zone drainage by the tile drains, and 12.2% tailwater production. More recently, Tanji (2000) using the Kaddah and Rhoades method obtained for 1975-89 mass discharge of salts comprised of 54.4% intercepted ground water, 36.0% intercepted deep percolation, and 9.6% tailwater production. These 15-year average values are in good agreement with that of Kaddah and Rhoades.

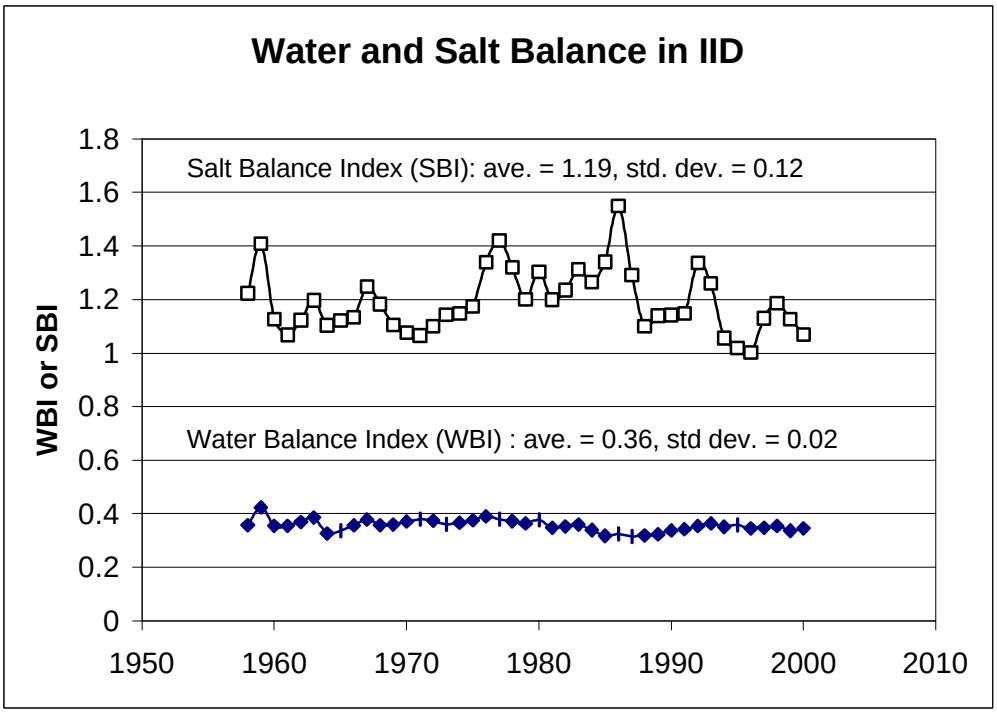



**Figure IV.12**. Water Balance Index (water volume outflow/water volume inflow) and Salt Balance Index (salt mass outflow/salt mass inflow) for IID (Silva, 1990; IID, 2001).

Clearly, there is a large unknown volume of saline regional ground water underlying IID and a large source of yet to be dissolved soil minerals in the substrata. It is expected that intercepted ground water will be a major contributor of the salts discharged by IID for decades to hundreds of years.

As indicated previously, some of the salts discharged came from interception of shallow regional ground water by the drainage system.

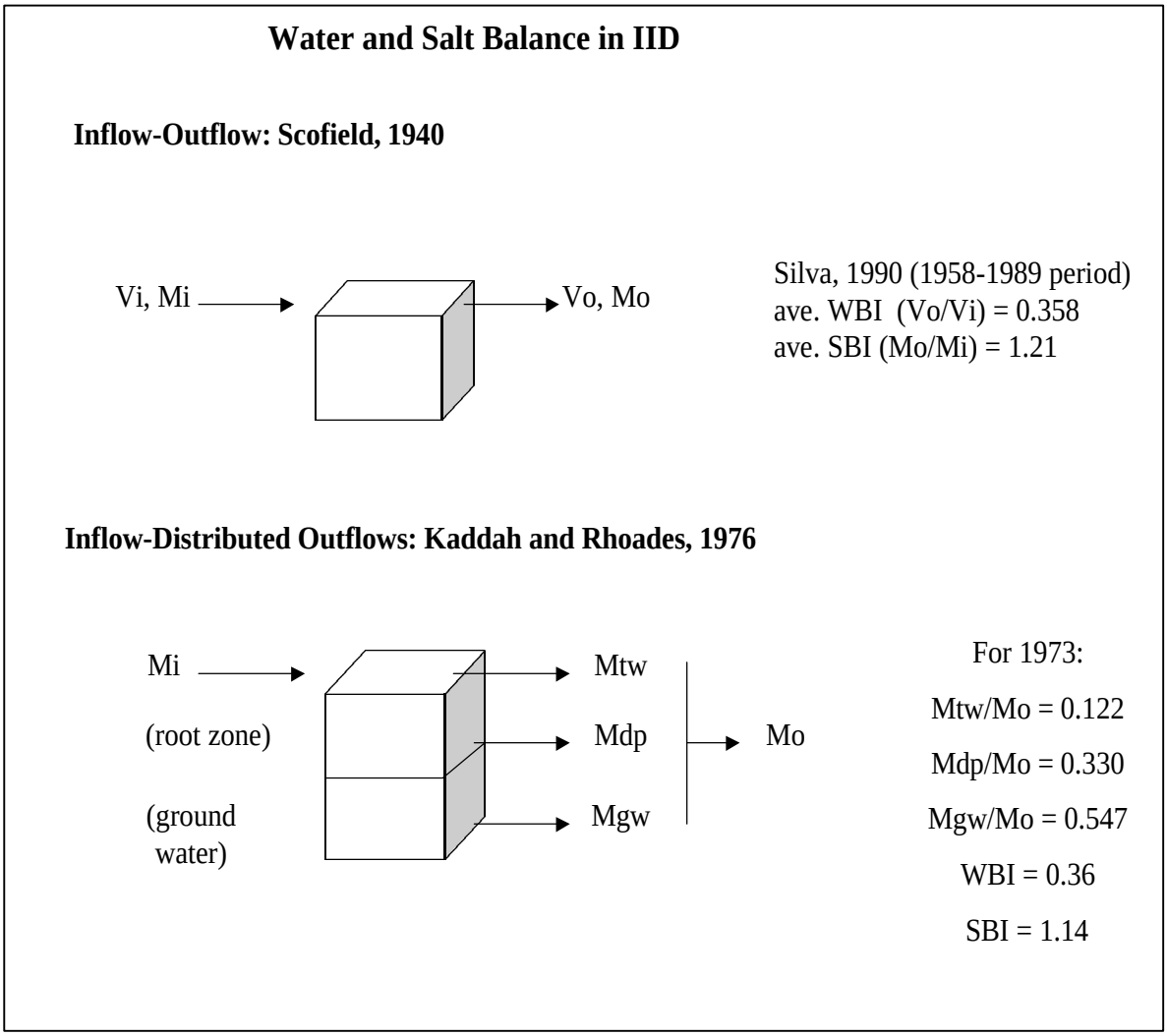



**Figure IV.13**. The distributed outflows of irrigation return flows (tailwater (tw), intercepted deep percolation (dp), intercepted ground water (gw)) for 1973 as compared to 30-year average WBI and SBI.

**<u>Current Practices Utilized to Maintain Salt Balance In The Rootzone</u>.** In spite of the comparatively high-salinity irrigation water supply and large ratio of evaporation to precipitation (rainfall) as well as slowly permeable soils, growers in IID have been successful in crop production. Lonkerd et al. (1979) investigated the LF (Leaching

Fraction) of five major crops grown on four slowly permeable Imperial Valley soils. Based on chloride concentrations in the applied water and soils sampled in or near the bottom of rootzone, the median LFs achieved in Holtville, Imperial, Indio and Meloland soils ranged from 3 to 9% for alfalfa, 3 to 6% for cotton, 4 to 28% for lettuce, 4 to 23% for wheat, and 5 to 28% for sugarbeets. Assuming an EC of 1 dS/m for Colorado River water, the calculated LR based on threshold salinity of alfalfa, cotton, lettuce, wheat and sugarbeets is respectively 11, 3, 18, 3 and 3 %. Based on measured soil salinity, they recommended that desirable LFs for lettuce is 15 to 20% and for alfalfa, cotton, sugarbeets and wheat, 5 to 10%.

As was shown in **Figure IV.10** surface application of irrigation waters result in a zone of leaching in the upper portion of the rootzone and zone of salt accumulation in the lower portion. Coincidentally, the distribution of roots and water uptake is greater in the upper portion of the rootzone (**Figure IV.9)** than in the lower portion that is more saline. Thus, acceptable production of salt sensitive crops like lettuce can be achieved with moderately saline irrigation waters provided the LR (or LF) is sufficient to maintain the shallow rootzone at low salinity in the surface 2-ft depth.

Water infiltration into slowly permeable soils typically results in increased runoff if the application rate is much larger than the infiltration rate. Moreover, slow infiltration makes it difficult to leach salts from the rootzone during the irrigation season. Some growers practice reclamation leaching between crops if the soil salinity is too high for the succeeding crop. Still others practice pre-irrigation, i.e., irrigate the field before planting for ease of preparation of seed beds and/or to fill the rootzone with soil moisture before planting that causes salt leaching. Irrigation for seed germination and seedling growth also contributes toward salt leaching.

Some of the soils in IID are known as cracking soils (Zimmerman, 1981). These soils crack upon drying and swell upon wetting due to the dominance of smectite type of soil clays. When cracked soils are irrigated, the applied water quickly fills the cracks that may extend two or more feet in depth (Rhoades et al., 1997). Then, there is a slow horizontal movement of moisture toward the inside of the soil peds at the same time the cracks are sealing from soil swelling. Upon drying from rootwater extraction and evaporation from walls of cracks, the salts from the interior of the peds slowly diffuse outwards to the crack surface (Maruyama and Tanji, 1997). This phenomenon of cracking and swelling greatly complicates water and salt movement in the soil profile. The cracks on the one hand tend to help get water infiltrated into slowly permeable soils but on the other hand cause less efficient salt leaching. Wallender (2000) has formulated and validated a salt flow model in cracking soils as well as rootwater extraction from a shallow water table.

**Water Required For Salt Control As A Reasonable and Beneficial Use in IID.** The primary reasonable and beneficial use of water for irrigated agriculture is to replenish the soil moisture depleted by the crop between irrigation events (Burt et al., 1997; Solomon and Davidoff, 1999). Other beneficial uses of water in agriculture include the extra water used for seedbed preparation, seed germination and seedling growth as well as climate control such as cooling and frost protection. Another beneficial use of irrigation water is

for salinity control and management to avoid reductions in crop yield (Ayers and Westcot, 1985). Due to the soil and water salinity conditions as well as crops grown in IID, water used for vertical salt leaching in proper amounts as a means of root zone salinity control and management represents a reasonable and beneficial use of irrigation water (e.g., Lonkerd et al., 1979). However, use of tailwater as a means of horizontal leaching for salinity control is not a beneficial use because salt pickup from the near soil surface is small compared to vertical leaching.

## IV. E. Irrigated Area within the Imperial Irrigation District

**Annual Total Net Acres In Crops.** The land area irrigated within the Imperial Irrigation District is shown in **Figure IV.14** for the period 1972-02 (CVWD 1999, CVWD 2001). These data range from 441,000 to 468,000 acres, averaging near 458,000 acres. Most of the data points fall within 450,000 to 465,000 acres. Exceptions occurred in 1991, in the 1972-74 period, and in the 1983-84 period. In this latter period considerable land area was fallowed.

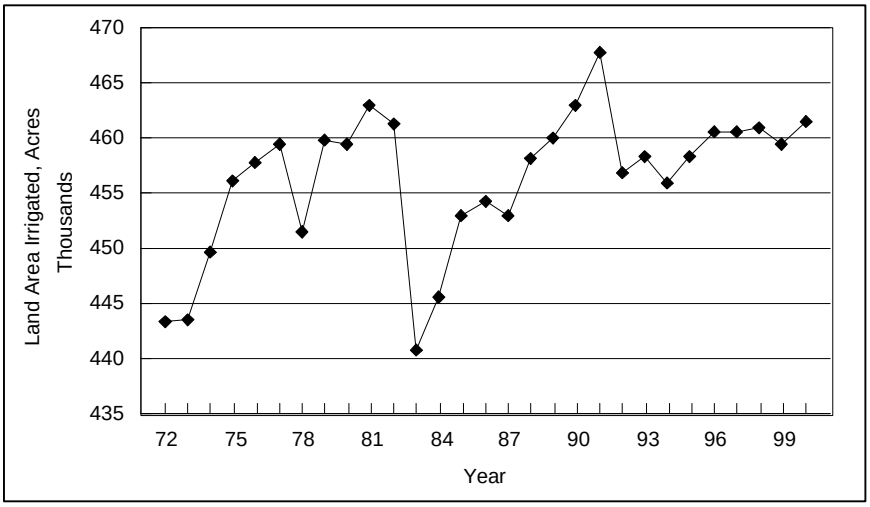



**Figure IV.14.** Land area in irrigated crop production in IID

**Annual Total Acres Of Crops.** The time distribution of annual total irrigated crop acres within IID is shown in **Figure IV.15**. These data include the annual double cropped area. Total crop area in the middle 1970s and early 1980s was as high as 600,000 acres. From these highs, total cropping area declined to near 500,000 acres in 1987 and 1988. Since then, total cropping area has trended upward to approximately 560,000 acres in 1996-98. It declined to near 540,000 acres in 1999-00.

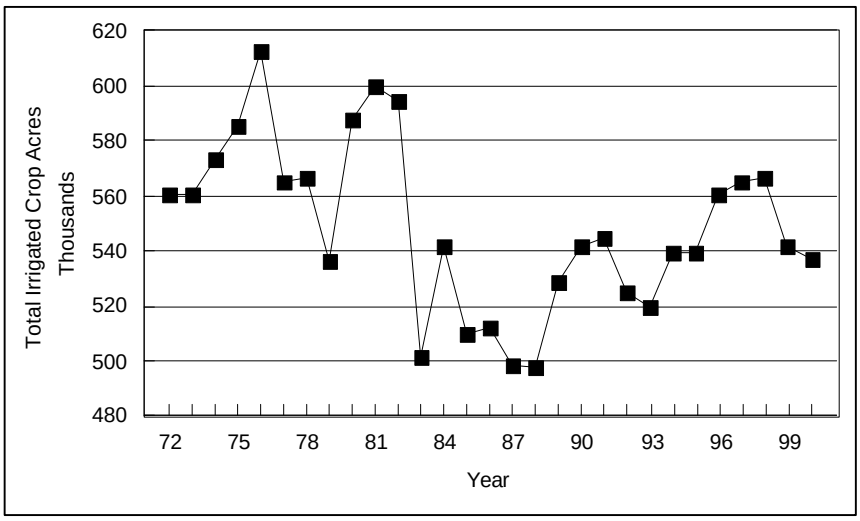



**Figure IV.15.** Total acres of crop production in IID (includes double cropped acres)

**Cropping Intensity**. The ratio of cropping area to land area is plotted in **Figure IV.16.** This plot illustrates the relative "intensity" of double cropping. The degree of double cropping was highest throughout much of the 1970s. It declined during the 1980s and then again has increased, averaging 1.19 in the 1995-00 period.

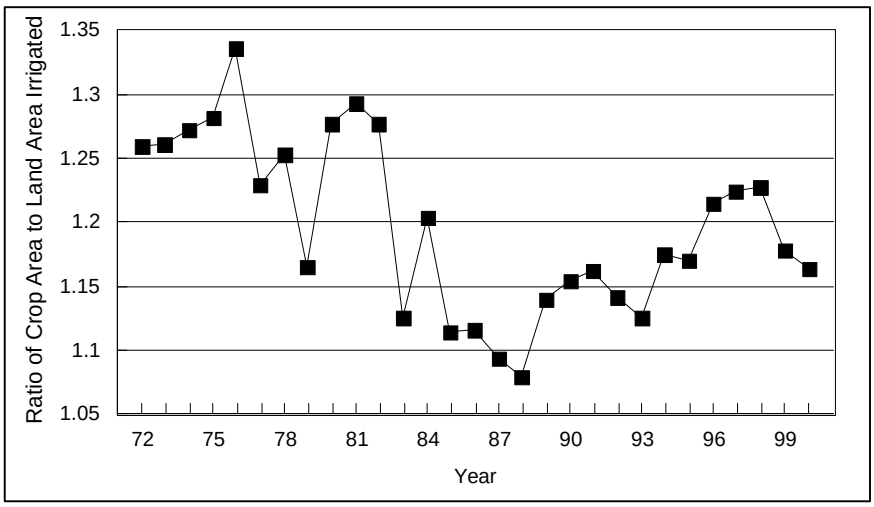



**Figure IV.16.** Cropping intensity of the land area in IID

**Annual Fractions Of Total Acres In Crops Occupied By Field, Garden, And Permanent Crops.** Field crops (**Figure IV.17**.) have dominated the cropping in IID, generally exceeding 80 percent of the total crop area. The fractional area in field crops declined in the years 1984 to1990 when the garden crop fraction increased from 19 to 26 percent. Since 1990 this trend has reversed with production returning to the longer term characteristic percentages of area for each crop type.

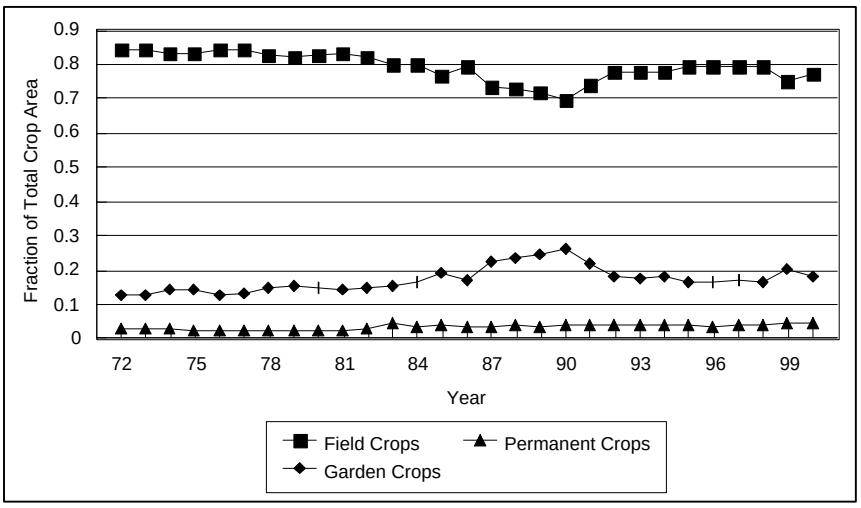



**Figure IV.17.** Annual fractions of crop area (including double crop) occupied by field, garden, and permanent crops.

**Annual Acreages Of Major Field Crops.** Annual areas of the major field crops grown in IID are shown in **Figure IV.18**. Alfalfa has dominated, averaging nearly 184,000 acres in the 1972-98 time period. Wheat generally exceeded 100,000 acres in the 1974-84 period and it was occasionally above 150,000 acres. Thereafter, wheat acres trended downward to about half this area by the late 1980s. A rebound to near 100,000 acres occurred in the mid 1990s, but acreage has fallen further to about 50,000 acres in 1999-00. Sugar beet acreage was about 70,000 acres in the 1972-76 period. Thereafter, it has trended downward to a relatively consistent annual area near 34,000 acres in the 1995-00 period.

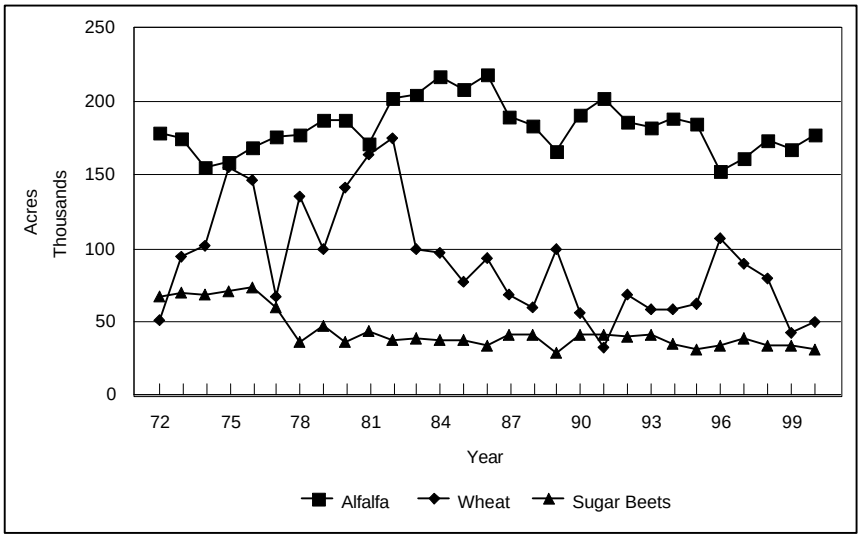



**Figure IV.18.** Annual acreages of alfalfa, wheat, and sugar beets.

Acreage trends for cotton, sudan grass, and bermuda grass are shown in **Figure IV.19.** Cotton area declined from 75,000-80,000 acres (peaking above 135,000 acres in 1977) in the 1974-81 period to very low annual areas, beginning in 1983. Sudan grass/seed was

generally under 25,000 acres until 1988. Thereafter, acreage rose steadily to more than 80,000 acres in the mid 1990s with subsequent decline to 54,000 acres in 2000. Bermuda grass/seed area was generally less than 20,000 acres until 1990; since then rising to about 64,000 acres in 2000.

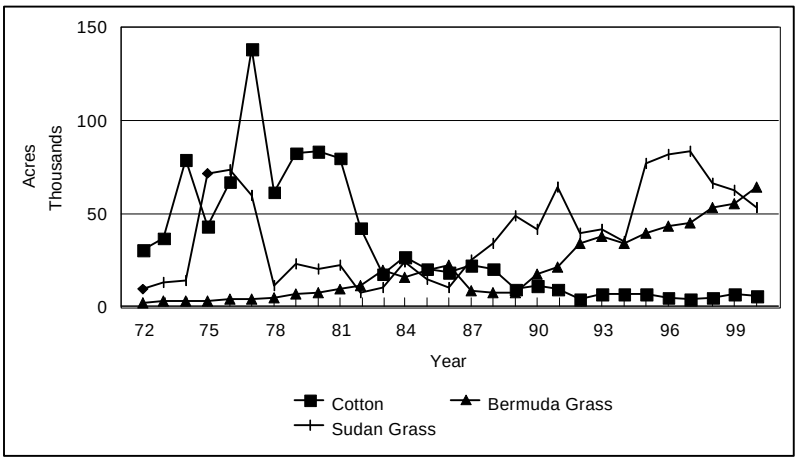



**Figure IV.19.** Annual acreages of cotton, sudan grass, and bermuda grass.

**Annual Acreages Of Major Garden Crops.** Of the major garden crops, lettuce area was slightly above 40,000 acres in the 1974-80 period and near 40,000 acres in the 1987-90 period. Subsequently, it has declined to near 20,000 acres in the 1992-00 period (**Figure IV.20.**). Melon area rose steadily from near 10,000 acres in the mid 1970s to highs near 40,000 acres in 1990 with a subsequent decline averaging about 17,500 acres in the 1995-00 period. Annual broccoli area increased from very low acreage in the 1970s and early 1980s to near 10,000 acres since the mid 1980s.

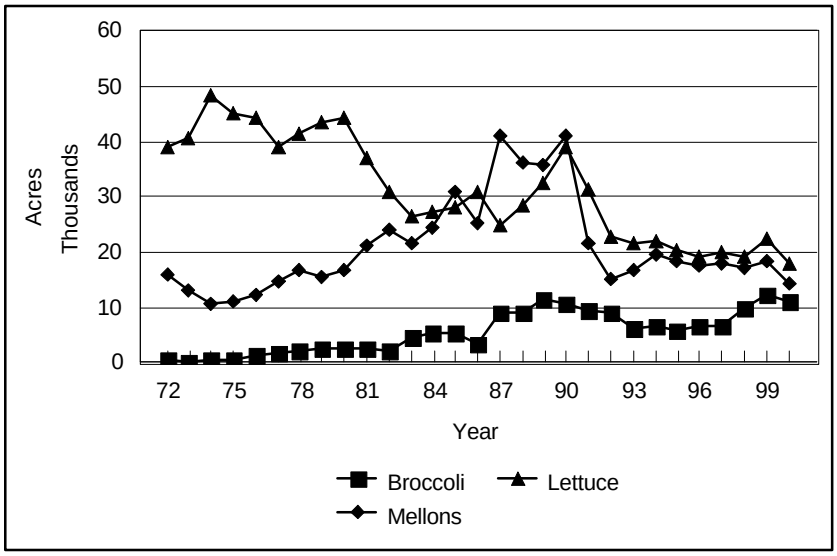



**Figure IV.20.** Annual acreages of broccoli, melons, and lettuce.

The annual area in carrots and onions has increased steadily from about 5,000 acres in the early 1970s to 15,000-18,000 acres in the 1995-00 period (**Figure IV.21**). Area in tomatoes was below 5,000 acres from 1972 to 1988. Then it rose to 12,000-13,000 acres in 1989-90. Since then it has declined to less than 2,000 acres in the 1995-00 period.

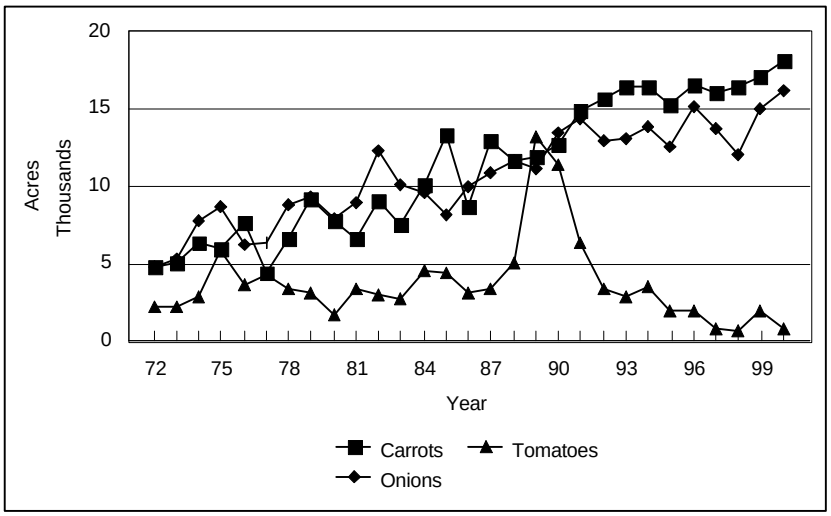



**Figure IV.21.** Annual acreages of carrots, onions, and tomatoes.

**<u>Annual Acreages Of Major Permanent Crops.</u>** The area in permanent crops has been dominated by asparagus, duck ponds, and citrus (**Figure IV.22.**). The area in duck ponds has steadily been near 8,000 acres with an exception in 1983, when it was above 12,000 acres. Since 1995 this area has trended upward to about 10,000 acres. Asparagus area varied between 2,000 and 6,000 acres in the 1972-00 period. Citrus area was near 2,000 acres from 1972-90; thereafter trending upward to about 6,000 acres in 2000.

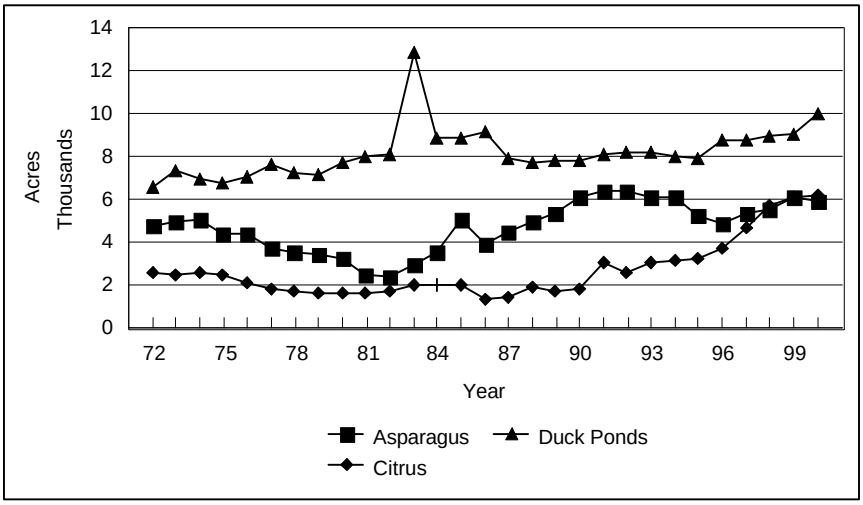



**Figure IV.22.** Annual acreages of asparagus, duck ponds, and citrus.

## IV. F. Irrigation Methods and Practices

### Distribution and Drainage System

The irrigation system operated by IID includes the All-American Canal (82 miles) and 1,675 miles of other canals, serving about 5,600 head gates. There are ten regulating reservoirs with a combined capacity of more than 3,300 acre-feet within IID's service area. The drainage systems in the Imperial Valley have about 1,460 miles of drain ditches and 33,627 miles of tile drains that underlie cultivated fields. Flows from the tile drains enter the drain ditches and flow into the New River or Alamo River, or directly into the Salton Sea. The distribution system and the off-farm drainage collection system are operated by IID, while tile drains and tailwater discharge systems have been constructed and operated by farmers.

Management of the irrigation system is complex because the water travels approximately 400 miles (travel time of about five days) from the primary water storage at Lake Mead on the Colorado River to the field. IID places orders for water each week, typically about five days before the beginning of the week in which deliveries are required. Farmers in IID order water approximately one to two days in advance of delivery; thus, IID may be requesting water from the U. S. Bureau of Reclamation (USBR) up to ten days before the farmers require water. Users order water in 12- or 24-hour blocks of time, specifying the desired flow rate in cubic feet per second (cfs or colloquially as "feet"). In making deliveries, IID diverts water from the main canals to laterals and then to headgates. There is water regulation on the Colorado River below Hoover Dam at David Dam, Parker Dam and Imperial Dam, which allows for daily adjustments at Imperial Dam. However, after the water has been diverted into the All-American Canal, there is little storage (0.1 percent of annual diversions) provided to regulate delivery of the water supply within IID.

Zanjeros (ditch riders) open and close headgates and adjust lateral canal checks and gates to deliver water orders at the specified time and flow rate. All headgate deliveries and tailwater outflow are measured at regular intervals during delivery periods. Due to the many complexities and constraints of the present gravity open canal delivery system, there are operational water discharges (spills) at the end of the canals. IID delivers approximately 90 percent of the Colorado River water entering the Imperial Valley to its users. The water that is not delivered includes evaporation, seepage, and operational spill water.

### Farm Water Application

IID is located within the desert region of the Southwest, which is often associated with sandy, coarse soils. However, the central irrigated area of the District is an old lakebed below sea level, which is quite level, and contains very deep, fine textured soils. Unlike the central portion of the District, both the East and West Mesas of the District have predominantly coarse desert soils. The dominant soil type in the District is Imperial silty

clay and nearly level followed by Imperial-Holtville-Glenbar, which is also nearly level with textures of silty clay, silty clay loam, and clay loam.

The soils, topography, and crops in the Imperial Valley are particularly well-suited for surface irrigation methods, including either border, furrow, corrugation, or basins. Other irrigation methods in the Valley include sprinkler and drip.

The majority of crops in the Valley are surface irrigated. Nearly all the presently irrigated soils and crops in the Valley are well suited for surface irrigation. Additionally, surface irrigation in this setting is economical, energy efficient, and water efficient when properly managed. Sprinkler irrigation is being used for seed germination, crop establishment, and occasionally, leaching and land preparation. Drip irrigation is used when it is determined to have an economic advantage, depending on such factors as crop type, water quality management, yield, and economic return. One of the primary reasons why gravity irrigation is used more is that the cracking clay soils in the central portion of IID are more conducive to surface irrigation then to either sprinkler or drip irrigation.

## 1. Surface Irrigation

Most irrigation throughout the world is accomplished via surface (gravity) techniques. Surface irrigation systems generally require a smaller initial investment (except when extensive land smoothing is needed), are more labor intensive, and may apply water less efficiently than other types of irrigation systems. Surface irrigation systems are best suited to soils with moderate to low infiltration capacities and land with relatively uniform terrain and slopes less than 2 percent.

An ideal irrigation system would apply water throughout a field only in the amount needed for crop ET and leaching. However, all irrigation systems are less than ideal and have demands in addition to the water required for crop ET and leaching.

Many factors influence irrigation practices and efficiencies. Some considerations are valid while some should be challenged.

a. Some crops receive six to twelve inches of water for tillage and leaching purposes (pre-irrigation and seed bed preparation) prior to planting. Much of the water is used for leaching or is stored in the soil and is available for crop use after planting.

b. After planting sugar beets or other row crops, irrigation is used to allow the water to sub (wet) to the ridge where the seeds are planted to provide moisture for germination. The germination and establishment of sugar beets require that the soil's wetting front move past the seed line to move salts away from the seeds. These irrigations apply more water than is necessary for routine crop ET during germination.

c. After germination, plants have a shallow root system and require shallow irrigation for establishment. Because a shallow irrigation is believed to be difficult using surface irrigation, more water may be applied than necessary.

d. The cross slope on fields requires irrigators to construct tanks (small ponds at the head of field) that will regulate the water entering the furrows. Without these tanks it is very difficult to control the amount of water entering each furrow.

e. Tractors and other heavy equipment compact the soil and reduce the furrow intake rate. Thus, on adjacent furrows the intake rate is different, requiring adjustments in furrow inflow rates.

f. Trash and moss in water inhibit the flow of water through slide gates, field turnouts, siphons and furrow tubes. This results in non-uniform application of water. Under such conditions, irrigators must focus their continual attention on removing trash, making it more difficult and expensive to irrigate efficiently.

g. The salinity and chemistry of soils, especially those with a high clay content, greatly influence the infiltration rate. The salinity at the tail of the field is often higher than at the head of the field. This affects the infiltration rate and adds to the irrigation uniformity problems caused by difference in intake opportunity time along the length of the field.

## 2. Sprinkler Irrigation

Sprinkler irrigation systems use sprinklers operating at pressures ranging from 70 to over 700 kPa (10 to over 100 psi) to form and distribute "rain like" droplets over the land surface. Sprinkler systems apply water efficiently, have relatively high capital costs and low labor requirements, and use more energy than other application methods. Sprinkle irrigation is adaptable to many soils and terrains. It can be successfully used to irrigate:

a. Permeable soils that are difficult to irrigate using other application systems,

b. Lands with combinations of shallow soils and terrain that prevent proper land smoothing needed for other application systems,

c. Land having steep slopes and easily erodible soils, and

d. Undulating terrain that would be too costly to smooth for use of surface application systems.

The majority of the soils in the District have high clay content with a low intake rate, which causes ponding and may lead to excessive runoff when using sprinkler irrigation. The sprinkler water drops tend to seal the surface of the soil, reducing infiltration, compounding ponding and poor distribution uniformity problems, and, ultimately, resulting in excessive surface runoff. In addition, temperatures in the Valley are high, which increases evaporation of irrigation water even before the water reaches the soil. Another factor is the salinity content in the Colorado River water, after air born evaporation, is high enough that leaf surface contact during hot summer days may burn the foliage, damaging most vegetable and some field crops. Although sprinklers are not extensively used in the Valley for the reasons summarized above, they are used, when appropriate, for seed germination, crop establishment, leaching, and in some cases for land preparation.

### 3. Drip or Trickle Irrigation

Trickle irrigation is the frequent, slow application of water either directly onto the land surface or into the root zone of the crop. It is based on the fundamental concepts of irrigating only the root zone of the crop (rather than the entire land surface) and maintaining the water content of the root zone at near optimum level. Trickle irrigation is accomplished using pressures ranging from 15 to 200 kPa (2 to 30 psi).

From horticultural and technical perspectives, drip irrigation could be used on many crops grown in the Imperial Valley. Because drip irrigation systems are costly, they are most practical on permanent crops where the investment is for several years or on high value annual crops. Most of the crops in the Imperial Valley are not permanent, and crops grown on a specific field can change up to three times in a single year. Since the majority of the irrigated lands in the District are used to grow field crops, it is not practical and/or cost effective, in most cases, to serve those lands using drip irrigation.

## IV. G. Surface Irrigation Systems

**Introduction.** The term 'surface irrigation' refers to a broad class of irrigation methods in which water is distributed over a field by gravity. A flow of water is introduced at one edge of the field and covers the remainder of the field with time by overland flow. The rate of water coverage along the field (advance) for non-shrinking soils is dependent almost entirely on the differences between the discharge onto the field and the accumulating water infiltration into the soil. Secondary factors include field slope, surface roughness, and the geometry or shape of the flow cross-section (Walker, 1989).

Typically, water is diverted into the field from a supply ditch or pipe and flows behind a distinct wetting front over the soil surface. As water flows along the field some water infiltrates the soil and the remainder is available for further advance along the field. Under normal conditions water flow continues until the advancing wetting front reaches the opposite end of the field. The advancing front of water then either begins to leave the field as surface runoff (often termed tailwater) or is stored on the soil surface, if surface runoff is prevented through diking the downstream end of the field.

One primary consideration of surface irrigation systems is that the soil, which must be used to convey the water over the field, has properties that are highly varied both spatially and temporally. These properties, such as the soil infiltration rate, can best be predicted during the irrigation event itself. This creates a management requirement where two of the primary design variables, inflow to the field and time of application, must be estimated not only at the field layout stage but also evaluated by the irrigator during every surface irrigation event. These are typical things that any good surface irrigator will do to be effective.

**Irrigation of Soil with Time Varying Infiltration.** A surface irrigation event is composed of four phases: advance, ponding, depletion, and recession, which are illustrated graphically in **Figure IV.23**. When water is applied to the field, it 'advances' across the surface until the water covers the entire length of the field. The advance phase begins when water is turned into the field and ends when water reaches the downstream end of the field. At this time, the irrigation water either runs off the end of the field (tailwater) or it is blocked (diked).

Following the advance phase, there is a water-storage or ponding phase while the irrigation stream is still flowing onto the upstream end of the field. During ponding, part of the irrigation stream is running off the lower end of graded fields (if the lower end of the field in not diked) but the depth of water stored on the soil surface is still increasing.

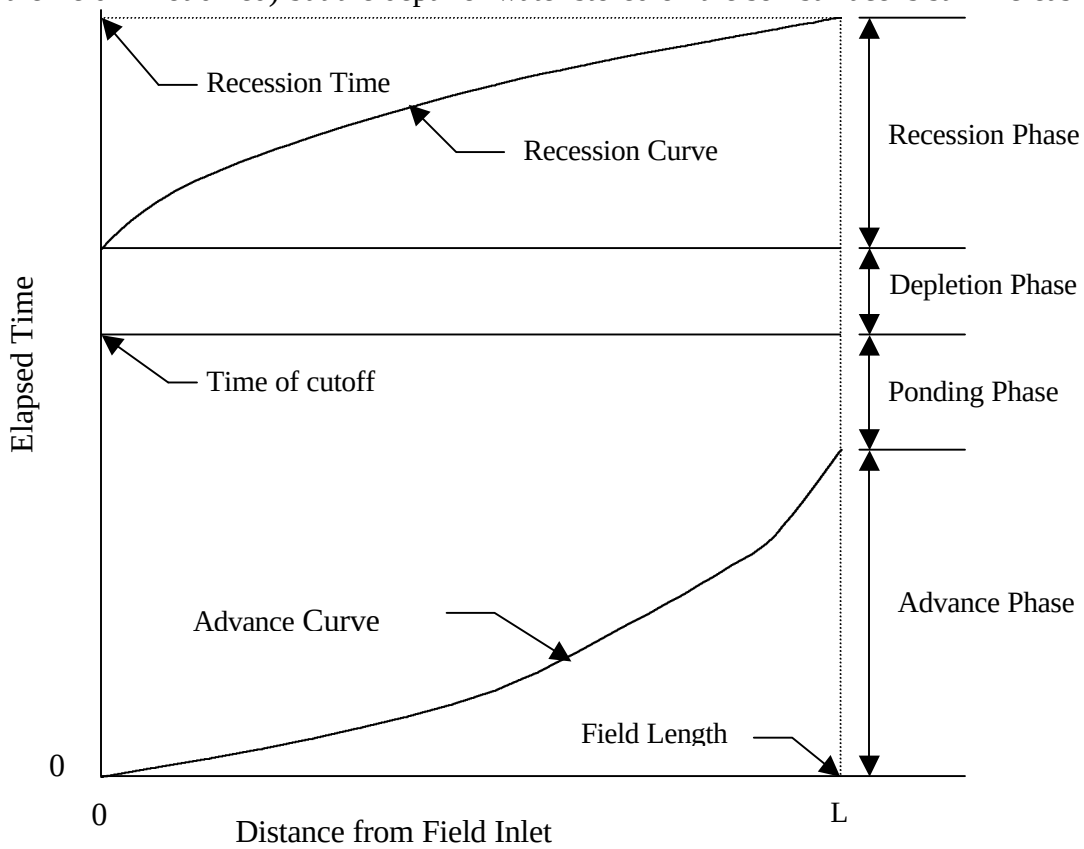



**Figure IV.23**. Time space trajectory of water for a soil with time varying infiltration during a surface irrigation event showing its advance, wetting, depletion and recession phases. Adapted from Walker (1989).

The depletion phase begins when the storage phase ends (i.e. when inflow is terminated). The water depth at the inflow end of the field and the volume of water on the soil surface begins to decline after the water is no longer being applied. Water then drains from the surface (runoff), infiltrates into the soil or is evaporated from the soil surface. The depletion phase is the interval between cut off and the appearance of the first bare soil under the water and during depletion the surface water may be redistributing within the field.

Finally, in the recession phase, a "drying" (ponded water disappears) front moves from the inflow end of the field to the downstream end of the field. Recession continues until either the front reaches the end of the field or it encounters a receding front moving toward the inflow end of the field from the downstream end of the field. Similar to the advance stage, the rate of recession depends upon the inflow rate, the slope of the field, the infiltration rate of the soil, furrow geometry, and the hydraulic roughness. Recession will tend to be most rapid when the inflow rate is low, the field slope is steep, the infiltration rate is high, and the soil hydraulic roughness is small.

The time and space plots shown in **Figure IV.23** are relatively typical in irrigation practice. Time is cumulative starting with the beginning of the irrigation and distance is referenced from the point water enters the field. The advance and recession curves are trajectories of the leading and receding edges of the surface flows. The time difference between the advance and the recession curves at any point along the field is often termed the intake opportunity time and is the time water is infiltrating into the soil along the length of the field.

Surface irrigation systems have two primary sources of water losses, surface runoff or tailwater and deep percolation below the crop root zone; however, the remedies for these two losses are somewhat competitive. To control deep percolation losses, the advance phase should be completed quickly so that the intake opportunity time over the field will be uniform, and the inflow onto the field should be stopped when the design irrigation water depth has been added to the crop root zone. This can be accomplished with a relatively large, but non-erosive, discharge onto the field. However, this practice increases the volume of tailwater leaving the field if the flow at the downstream end is maintained until a sufficient irrigation water depth has infiltrated at that location on the field. In the case of larger inflow rates, the advancing front reaches the end of the field sooner and generally increases the runoff volume.

There are four opportunities to address the surface runoff problem: (1) dike the downstream end to prevent runoff, (2) reduce the inflow discharge to a rate more closely approximating the total infiltration rate along the field prior to or following the advance phase, a practice termed 'cutback', (3) select a discharge and irrigation time which minimizes the sum of deep percolation and tailwater losses, and (4) install a tailwater recovery and reuse system to collect and recycle the tailwater runoff which takes place during the irrigation.

**Cut-off Time and Flow Rate Management**. The most limiting problem associated with the design and management of surface irrigation systems on non-cracking clay soil is that the soil infiltration characteristics change in space and time. The soil infiltration characteristics may be highly variable within a field because soil properties are heterogeneous and soil moisture is non-uniform. The infiltration rate also changes after each irrigation event and from season to season. Further, the infiltration rate can change over a period of years, for example, as the soil organic matter changes, as salinity and sodicity in both the water and soil changes, and as irrigation methods are altered. Despite this complexity, the rate that the water advances across the field is used by experienced irrigators to adjust the flow rate and cutoff time which prevents runoff, minimizes excess deep percolation and meets the crop water requirements. If the process is less predictable, a tailwater reuse system can significantly reduce and, in most cases, eliminate tailwater runoff. The discussion of the management of surface irrigation systems on cracking clay soils is given in the following sections.

Three typical results of surface irrigation are illustrated in **Figure IV.24**. When the inflow is turned off too soon after the advance phase, the water application at some locations in the field may be less than the design irrigation depth, typically at the lower end of the field (curve a). The application may just satisfy the irrigation design in the least watered areas (curve b). Finally, the applied depths exceed the design depth, at all locations (curve c). As shown in **Figure IV.24** the volume of tailwater runoff increases as one moves from curve (a) to curve (b) to curve (c).

If the discharge onto a field varies during the irrigation event it is likely that the performance of the irrigation system may be affected as well. If the discharge is reduced prior to the completion of the advance phase, it is likely that deep percolation losses will increase. If the flow is unexpectedly increased following the advance phase, runoff losses may increase or ponding on the field surface will be excessive. Conversely, reducing the inflow rate (cutback) just prior to or following the completion of the advance phase will reduce both surface runoff and deep percolation losses.

Provisions for the storage and recovery of tailwater must be included in any graded furrow or corrugation irrigation system if effective use of irrigation water is to be achieved according to Burt (1995). To obtain acceptable water distribution in a surface irrigation system, the advance time should be as rapid as practical. As described above, this usually requires an initial furrow stream size considerably larger than that needed to meet the intake infiltration rate all along the run, which results in considerable outflow or tailwater runoff if cutback flows are not implemented.

For efficient and effective management of surface irrigation systems the tailwater runoff, if produced, should be collected and reused. Some states now require that irrigation runoff water not be allowed to trespass on lands not under the control of the irrigator. It is then necessary to provide some means of collecting the tailwater, transporting it to a reservoir or sump, and either storing or providing recovery facilities as needed.

**<u>Irrigation of Soil with Time Independent Infiltration (Cracking Clay Soils</u>):** As described earlier, the four phases of a surface irrigation event are the advance, storage, depletion and recession. However, for the case of cracking clay soils (time independent infiltration) these phases are different as shown in **Figure IV.25** and described below.

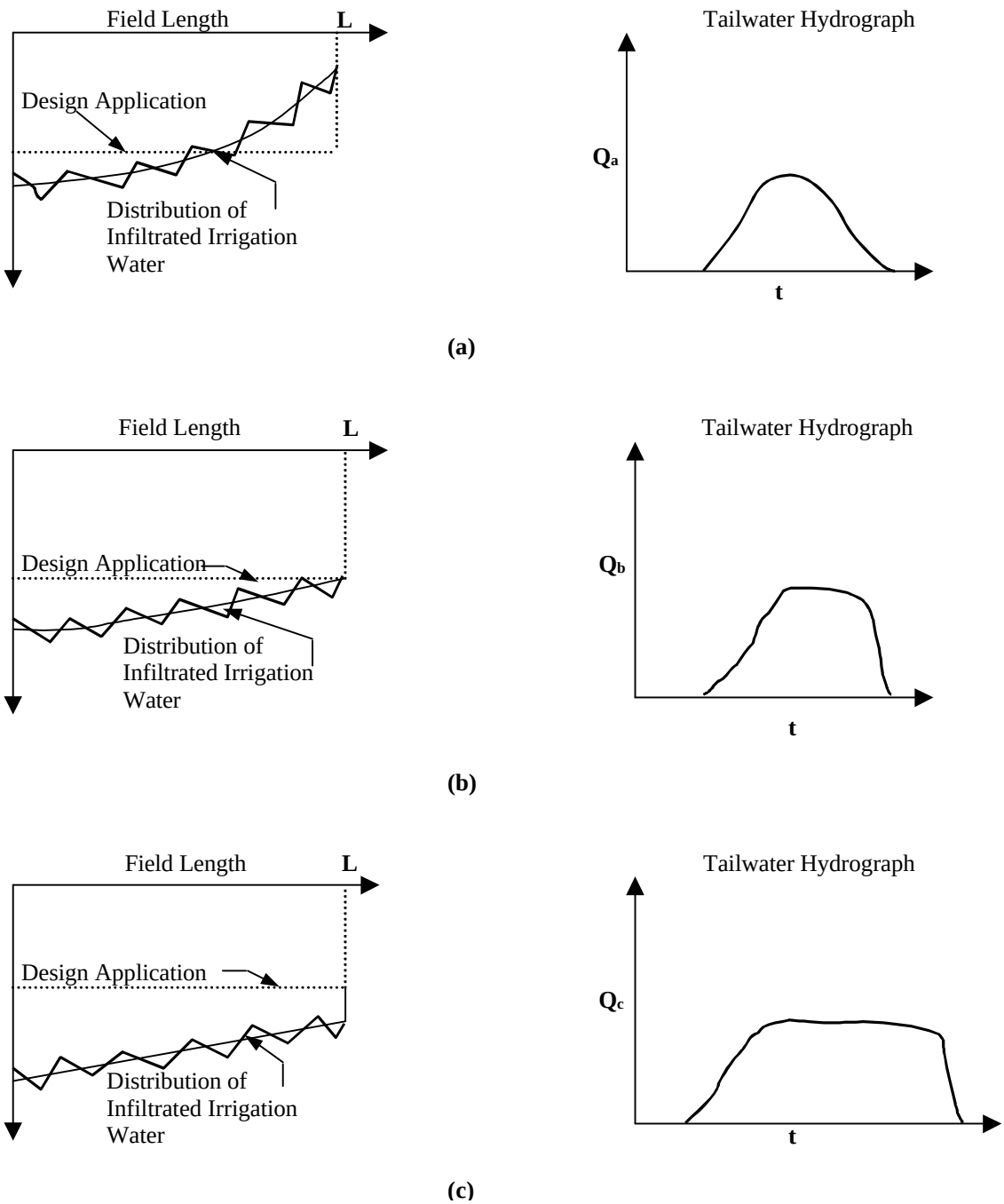



**Figure IV.24**. Typical irrigation application patterns under surface irrigation: a) under irrigation at the lower end of the field, b) full irrigation at the lower end of the field and c) over irrigation at the lower end of the field. Adapted from Walker and Skogerboe (1987).

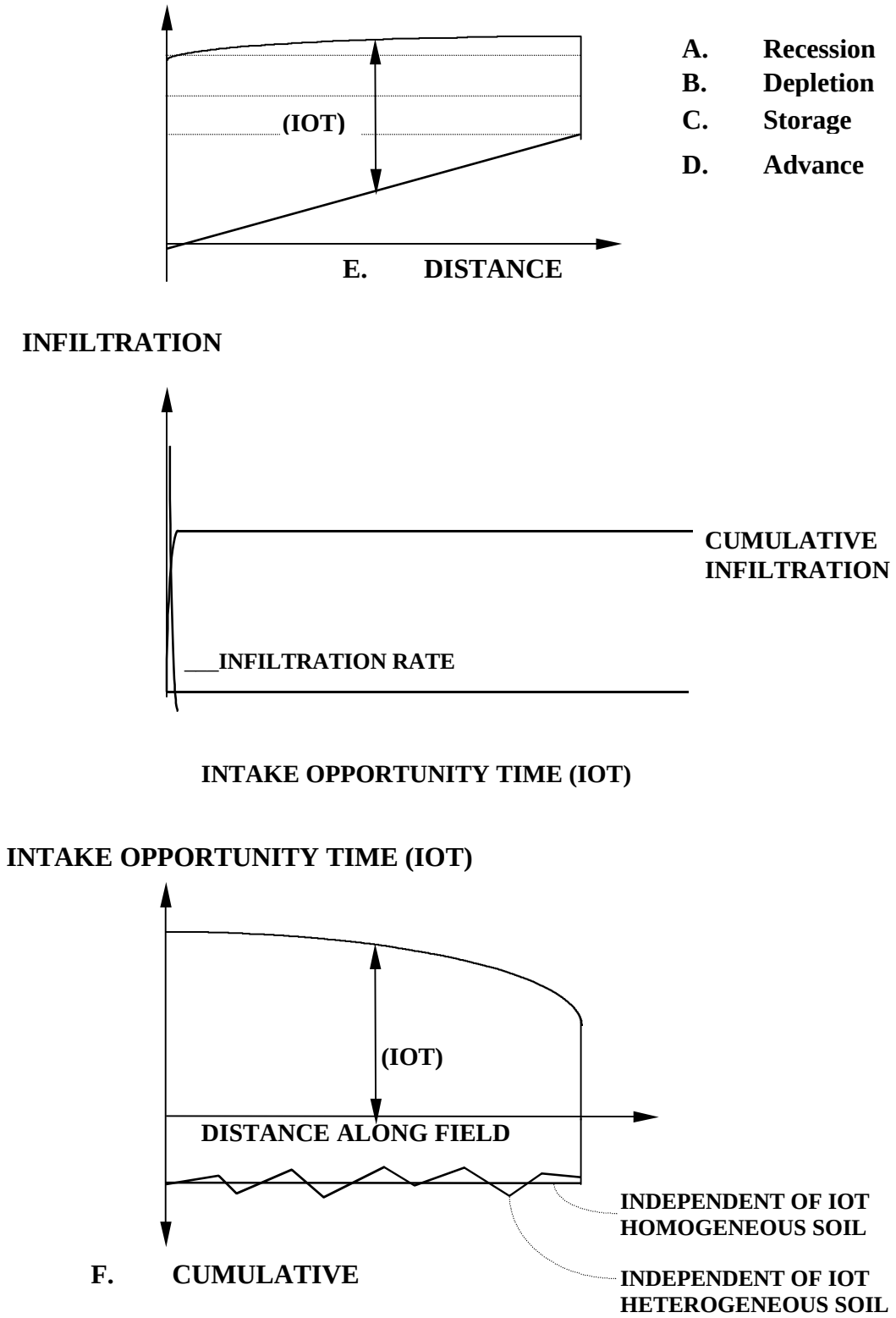



**Figure IV.25.** Infiltration patterns under cracking clay soils (time independent infiltration).

Advance phase

- Flow is introduced at the upstream end of the field and water spreads (advances) down the field.
- The rate of advance remains constant (slope of the advance curve does not change) because the infiltration rate at each point falls to near zero after ponding.
- Ignoring evaporation losses, the flow rate at the upstream end is available near the advancing front and thus the advance rate does not decline.
- This is in contrast to the case where the infiltration rate does not fall to near zero and the total infiltration losses along the field increase, as a greater fraction of the field is ponded.
- One can image an analogous process of filling a field of containers. Inflow to the field matches the flow directed to container and surface storage filling.
- Eventually the advancing front arrives at the field end.

Storage phase

- Flow to the field continues.
- Surface storage on the field increases (momentarily), infiltration stops and water runs off (tailwater), if not impounded.

Depletion phase

- Flow to the field is stopped (cut off).
- Surface storage decreases as water runs off (tailwater) the field end.

Recession phase

- Surface water recedes along the field.
- The irrigation event is complete when all the surface water disappears.

Infiltration relation

- Cracks fill and swell shut, and cumulative infiltration does not increase measurably.
- Infiltration rate drops to near zero.

Intake opportunity time (IOT)

- The difference between the recession time and the advance time is the intake opportunity time.
- IOT decreases with distance along the field.

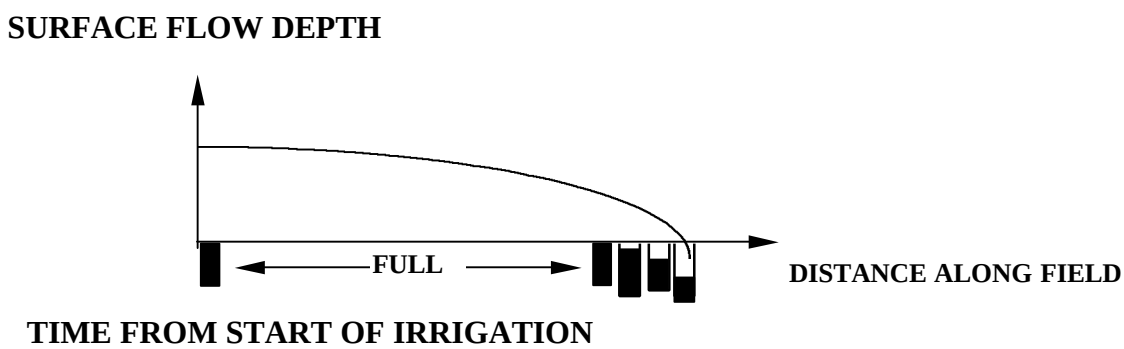
Cumulative infiltration along the field

- Infiltration is independent of intake opportunity time.
- Infiltration is heterogeneous not homogeneous.

**The Imperial Irrigation District Case.** For cracking-clay soils within the Imperial Irrigation District the volume or depth of infiltration does not depend on the ponding time after the cracks swell shut. For example, the total infiltration depth was independent of ponding time but Waller and Wallender (1991) found significant correlation between elevation and infiltration variability. They suggest that careful land surface smoothing will improve water distribution uniformity as well as improve salinity control.

This infiltration function behavior affects the rate that water spreads or advances along a sloped border or furrow. Van der Tak and Grismer (1987) as well as Waller and Wallender (1991) observed linear advance on Imperial clay soils and the latter authors reported linear advance on Tulare soils in the San Joaquin Valley. A volume balance model was developed which assumes that an average spatially constant infiltration volume along the field is equivalent to the difference in applied water and surface storage volumes during the advance phase of the irrigation. This model was used to calculate the infiltration amounts. Furthermore, the model is useful in estimating the volume of water to apply to a field to avoid or control runoff (tailwater).

For sloped fields on Imperial clay soils in which inflow rate is steady and the infiltration quickly approaches near zero after ponding, the flow rate leaving the distal end increases sharply to approximately the flow rate applied at the upstream end. The runoff remains steady until water is stopped at the upstream end. Runoff following crack filling at the field end is wasted.




**Tail Water Management.** Linear advance of flow and steady surface flow within 5 min along the border shows that infiltration rate is near zero within a few minutes of ponding. Measurements of infiltration from changes in soil moisture were independent of measured intake opportunity time and thus demonstrate that there is no correlation between intake opportunity time and infiltration. Using measurements of advance time and surface flow depth, infiltration and its variability can be calculated.

Using the findings from Grismer and Tod (1991) the following procedure is used to calculate the cutoff time such that the average infiltration depth is applied while avoiding runoff on sloping borders. A mass balance relation is written for the expanding control volume shown in the figure above to support the development. During advance, volume

applied (left-hand side of Equation IV-7) is partitioned into surface storage (first term on the right-hand side) and infiltration (second term on the right-hand side).

$$QT = 0.8\ d\ X + z\ X \qquad \text{(Equation IV-7)}$$

in which Q is the inflow rate per unit width of border, T is irrigation time, d is flow depth measured at the upstream end, X is advance distance at time T along the border of length L. Before the advancing front has reached half the field length, infiltration depth z can be calculated using Equation IV-8 (rearrangement of Equation IV-7) knowing Q, T, d and X.

$$z = \frac{QT - 0.8\ d\ X}{X} \qquad \text{(Equation IV-8)}$$

Having calculated z, the cutoff time Tco is

$$Tco = \frac{zL}{Q} \qquad \text{(Equation IV-9)}$$

In summary, a single measurement of advance time to a fractional distance along the border combined with a knowledge of inflow rate and flow depth at the upstream end can be used to calculate the average infiltration depth as well as cutoff time to avoid runoff. Multiple measurements of advance time can be used to estimate the variation in infiltration (Waller and Wallender, 1991).

**Surface Irrigation Tailwater.** The amount and distribution of runoff from surface irrigation systems (tailwater) has been measured in several locations over many years, including the Imperial Irrigation District (Oster, et al., 1986; Boyle Engineering Corporation, 1990 and O'Halloran, 1990).

The Bureau of Reclamation collected information at a number of sites between 1964-1972 for the purpose of documenting existing irrigation water use practices and water return flows on Bureau irrigation projects, and suggesting means of water use improvements on Federal Projects. For example, the variation of tailwater runoff from the Bureau of Reclamation data (Hamburg, 1980) is shown in **Figure IV.26** and **Figure IV.27**.

A similar analysis indicating the probability of tailwater runoff from selected Bureau of Reclamation projects is shown in **Figure IV.28**. Not only are the average runoff values from each location quite variable with average values between 17 and 30 percent of the applied water, their probability distribution is variable as well. For example, the distribution of tailwater runoff from the Columbia Basin (**Figure IV.28**) has both a lower average and lower variability (smaller slope) than the tailwater runoff from the Torrington, Wyoming location (**Figure IV.28**).

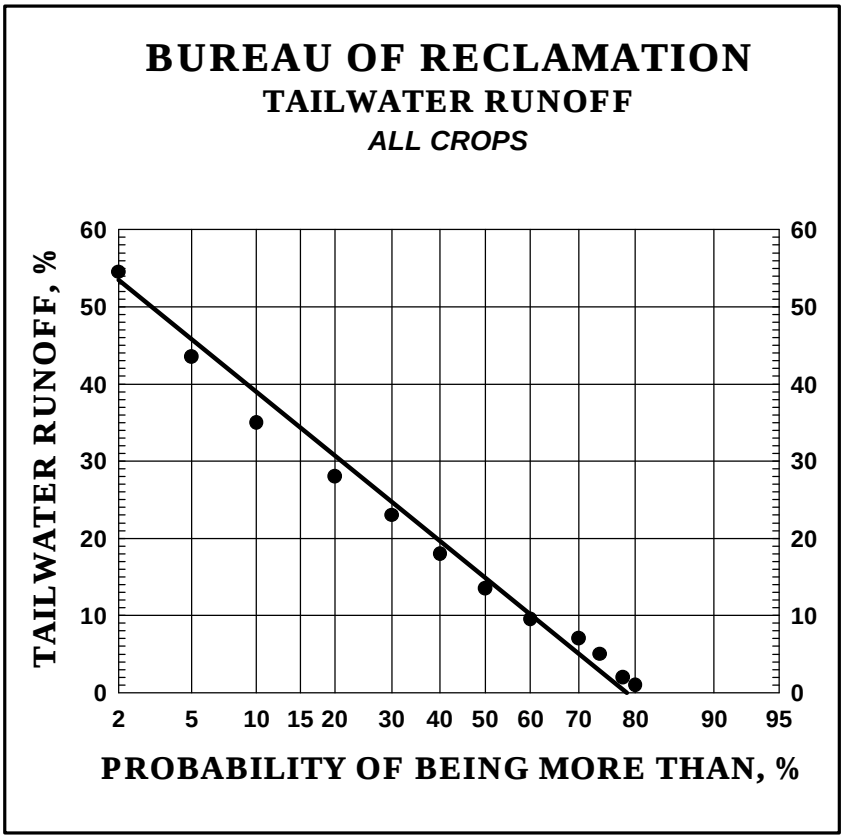



**Figure IV.26**. Surface irrigation tailwater runoff from Bureau of Reclamation projects. Adapted from Hamburg (1980), all crops.

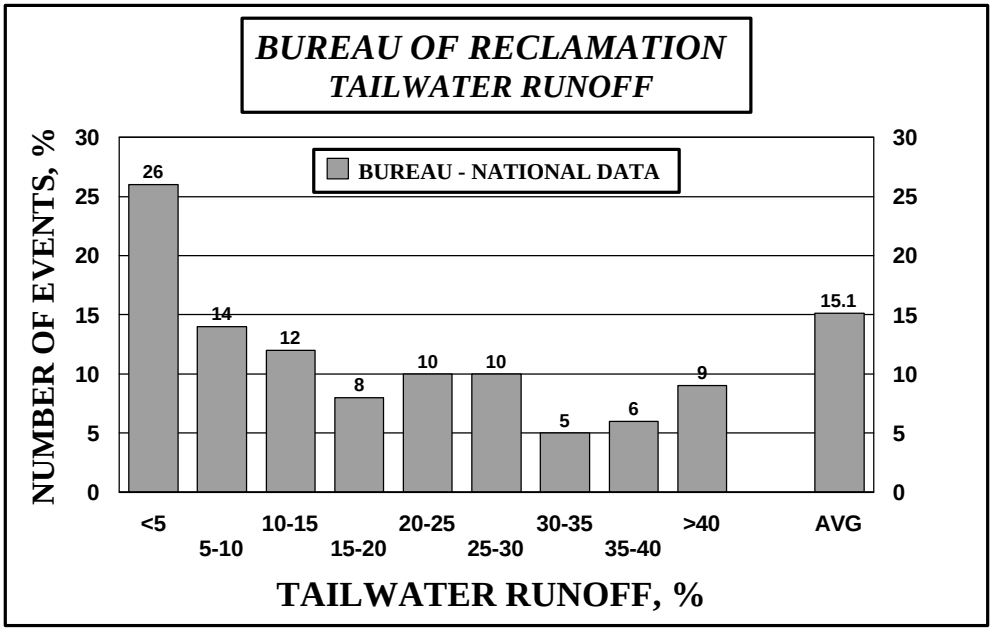



**Figure IV.27**. Surface irrigation tailwater runoff from Bureau of Reclamation projects. Adapted from Hamburg (1980), national data.

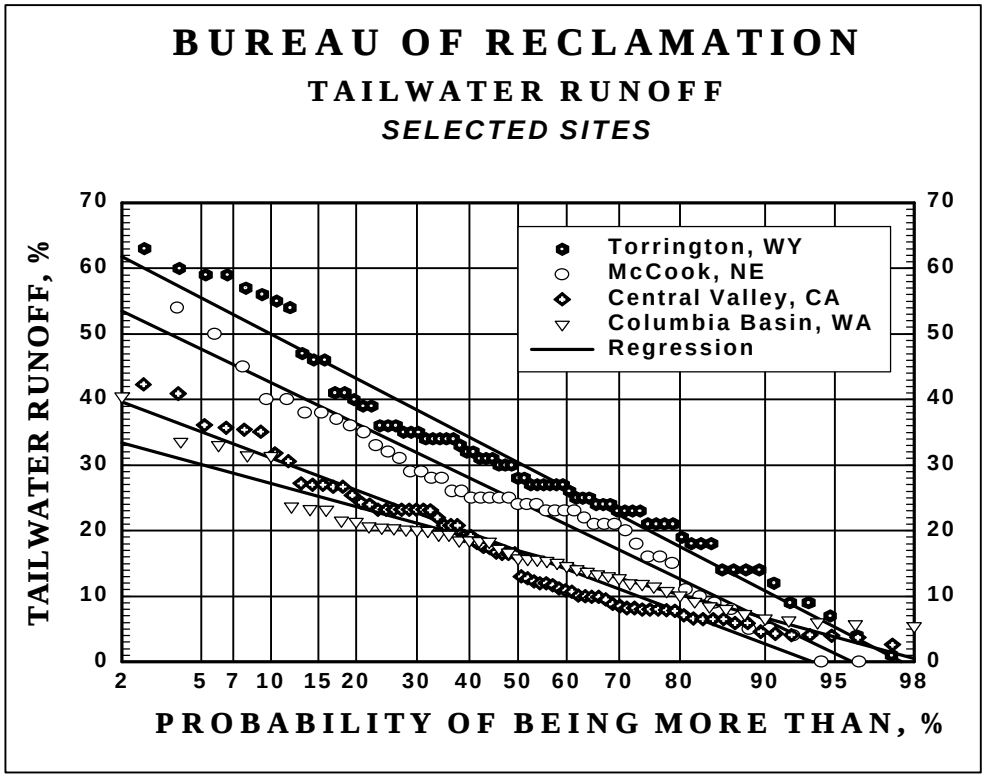



**Figure IV.28**. Surface irrigation tailwater runoff from selected Bureau of Reclamation projects. Adapted from Bureau of Reclamation reports, selected sites.

Oster et al. (1986) summarized the results of an intensive irrigation evaluation study conducted in the Imperial Irrigation District between 1977-1981. Surface irrigation tailwater runoff and its variation by crop is summarized in **Table IV.9**. The variation by field evaluated by Oster (1986) is shown in **Figure IV.29**. The average runoff (50% probability) ranges from approximately 12% for field number eight to a value of over 27% for field number one **(Table IV.10)**. Likewise, the variation in tailwater runoff (slope of the lines in **Figure IV.30**) is lower for field number one compared to field number five.

Returning to crop data, the probability distribution of tailwater runoff from the fields producing alfalfa is shown in **Figure IV.31**. The 50% probability tailwater runoff ranges from approximately 11% for field number eight to 24% for field number three. The variation in tailwater runoff between those fields producing alfalfa indicates that the management of individual irrigation events is critical in controlling tailwater runoff from surface irrigated fields.

A summary of the tailwater runoff distribution from all individual irrigation events monitored by Oster et al. (1986) is shown in **Figure IV.32**. Over eight percent of the tailwater runoff events have runoff values exceeding 40 percent of the delivery to the field.

Tailwater runoff values, measured by the Imperial Irrigation District staff, was obtained from an inter-office memo from O'Halloran (1990) and are summarized in **Table IV.11** and shown in **Figure IV.33**. Average tailwater runoff values ranged from a low of 13.2% for alfalfa to a high of 28.5% for onions (**Figure IV.33**). The weighted average for all crops was 15.6 percent.

The Imperial Irrigation District funded and conducted a Tailwater Recovery Demonstration Program between 1985 and 1990 (Boyle Engineering Corporation, 1990). Five pump back tailwater recovery systems were designed and installed on grower/cooperator fields and intensively monitored to determine potential impacts on soil and water resources resulting from recycled tailwater in the District. The program cooperators indicated that the operation of the pump back systems was a successful alternative to reduce surface tailwater discharges to the drain and to facilitate water conservation.

The results of these demonstrations (Boyle Engineering Corporation, 1990) are given in **Table IV.12** and **Table IV.13** and shown in **Figure IV.34**. The weighted average of tailwater runoff (expressed as a percentage of the water delivered to the fields) for the five demonstration systems was 22.9 percent (**Table IV.12**). The tailwater runoff (expressed as a percentage of the water delivered to the field) varied from a low of 6.7 percent for cotton to a high of 48 percent for vegetable crops (**Table IV.13** and **Figure IV.34**).

**Table IV.9**. Surface irrigation tailwater runoff within the Imperial Irrigation District by crop. Data taken from Oster et al. (1986).

| CROP | NUMBER OF OBSERVATIONS | TAILWATER RUNOFF AVERAGE % | TAILWATER RUNOFF STD DEV % | TAILWATER RUNOFF COEFFICIENT OF VARIATION |
|---|---|---|---|---|
| BARLEY | 5 | 19.0 | 9.0 | 0.47 |
| ALFALFA | 190 | 16.5 | 9.6 | 0.58 |
| WHEAT | 45 | 17.0 | 9.0 | 0.53 |
| SUGAR BEETS | 44 | 21.0 | 9.0 | 0.43 |
| COTTON | 46 | 26.0 | 17.0 | 0.65 |
| BERMUDA GRASS | 16 | 30.0 | 11.0 | 0.37 |
| LETTUCE | 5 | 26.0 | 10.0 | 0.38 |
| CANTALOUPE | 7 | 38.0 | 14.0 | 0.37 |

Data taken between 1977 and 1981.

**Table IV.10**. Surface irrigation tailwater runoff within the Imperial Irrigation District by field. Data taken from Oster et al. (1986).

| FIELD NUMBER | TAILWATER RUNOFF AVERAGE % | TAILWATER RUNOFF STD DEV % | TAILWATER RUNOFF COEFFICIENT OF VARIATION |
|---|---|---|---|
| 1 | 27.4 | 10.6 | 0.39 |
| 2 | 20.3 | 13.9 | 0.68 |
| 3 | 23.1 | 12.7 | 0.55 |
| 4 | 10.5 | 7.8 | 0.74 |
| 5 | 20.4 | 17.6 | 0.86 |
| 5 W/O COTTON | 13.0 | 7.7 | 0.59 |
| 6 | 19.3 | 7.8 | 0.40 |
| 7 | 19.9 | 7.8 | 0.39 |
| 8 | 14.2 | 12.8 | 0.90 |
| 9 | 12.1 | 6.5 | 0.53 |
| ALL | 19.4 | 13.4 | 0.69 |

Data taken between 1977 and 1981.

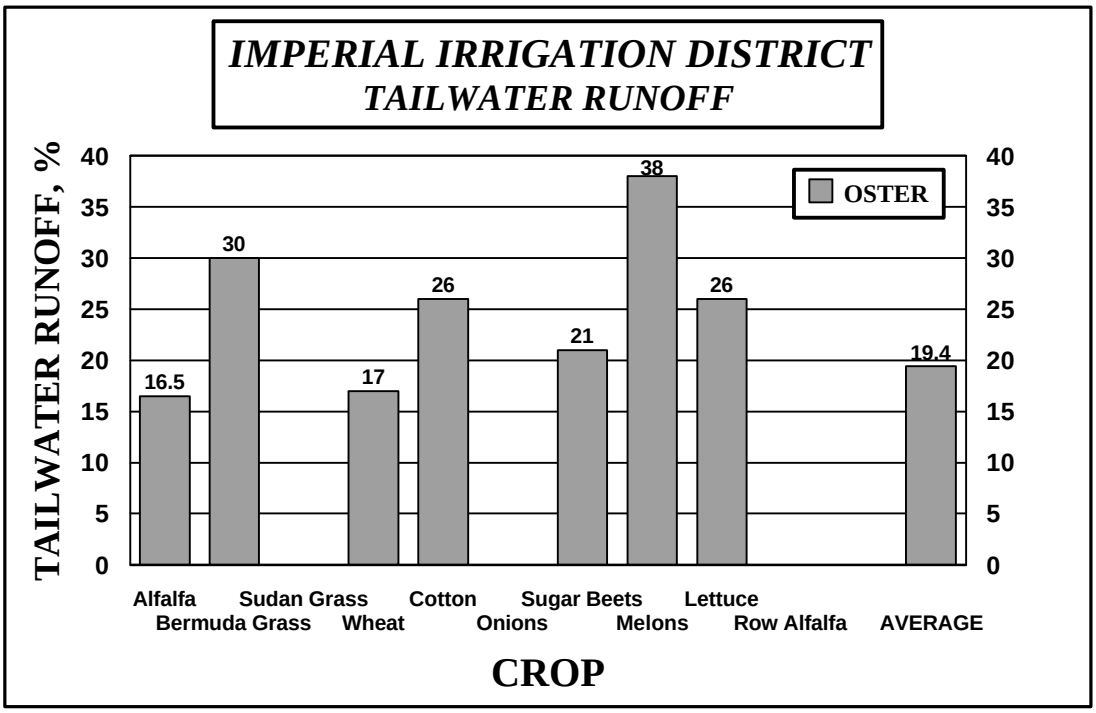



**Figure IV.29**. Tailwater runoff from Imperial Irrigation District. Data from Oster et al (1986).

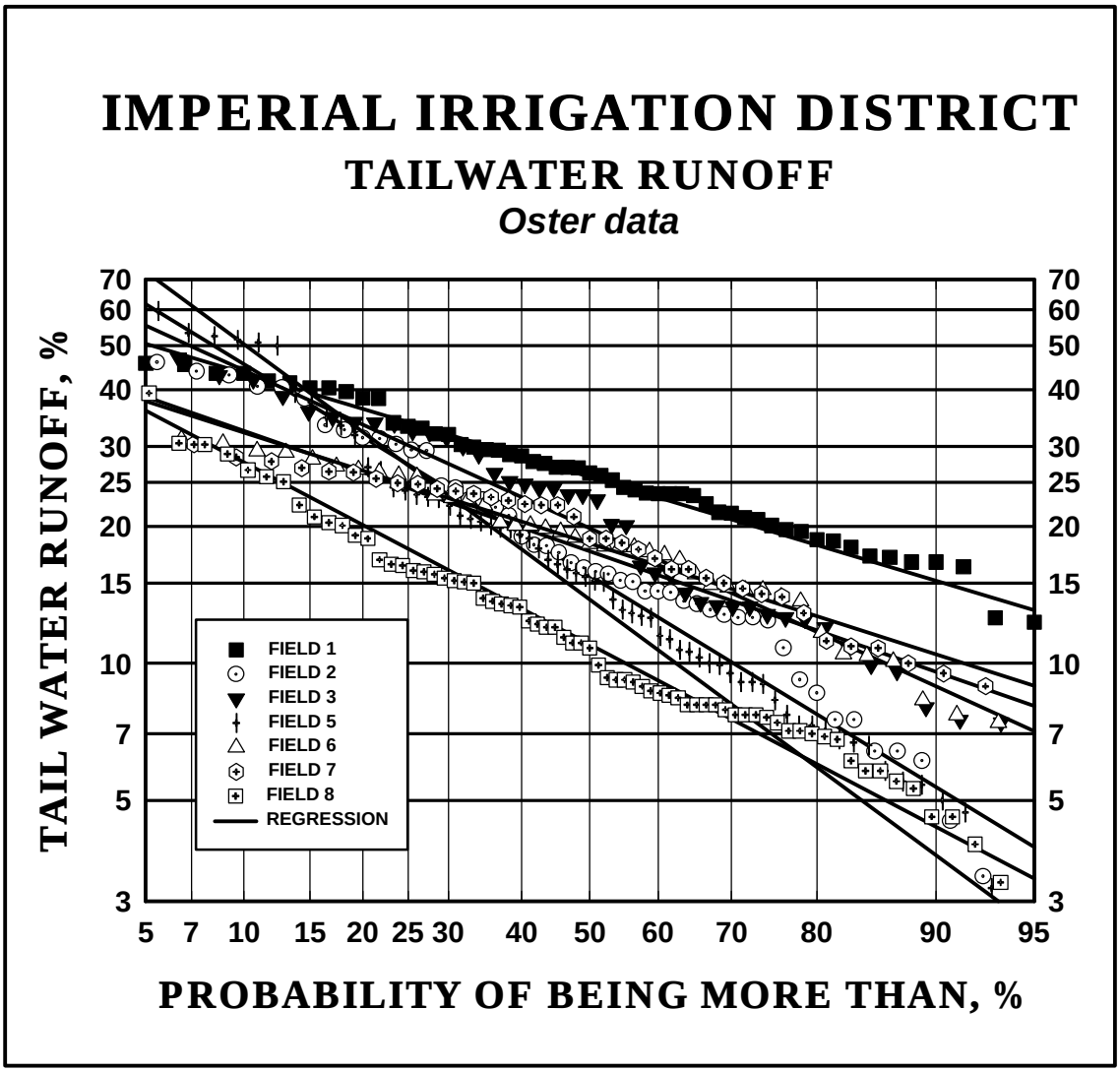



**Figure IV.30**. Surface irrigation tailwater runoff from fields within the Imperial Irrigation District over a five-year time period (1977-1981). Adapted from Oster et al. (1986).

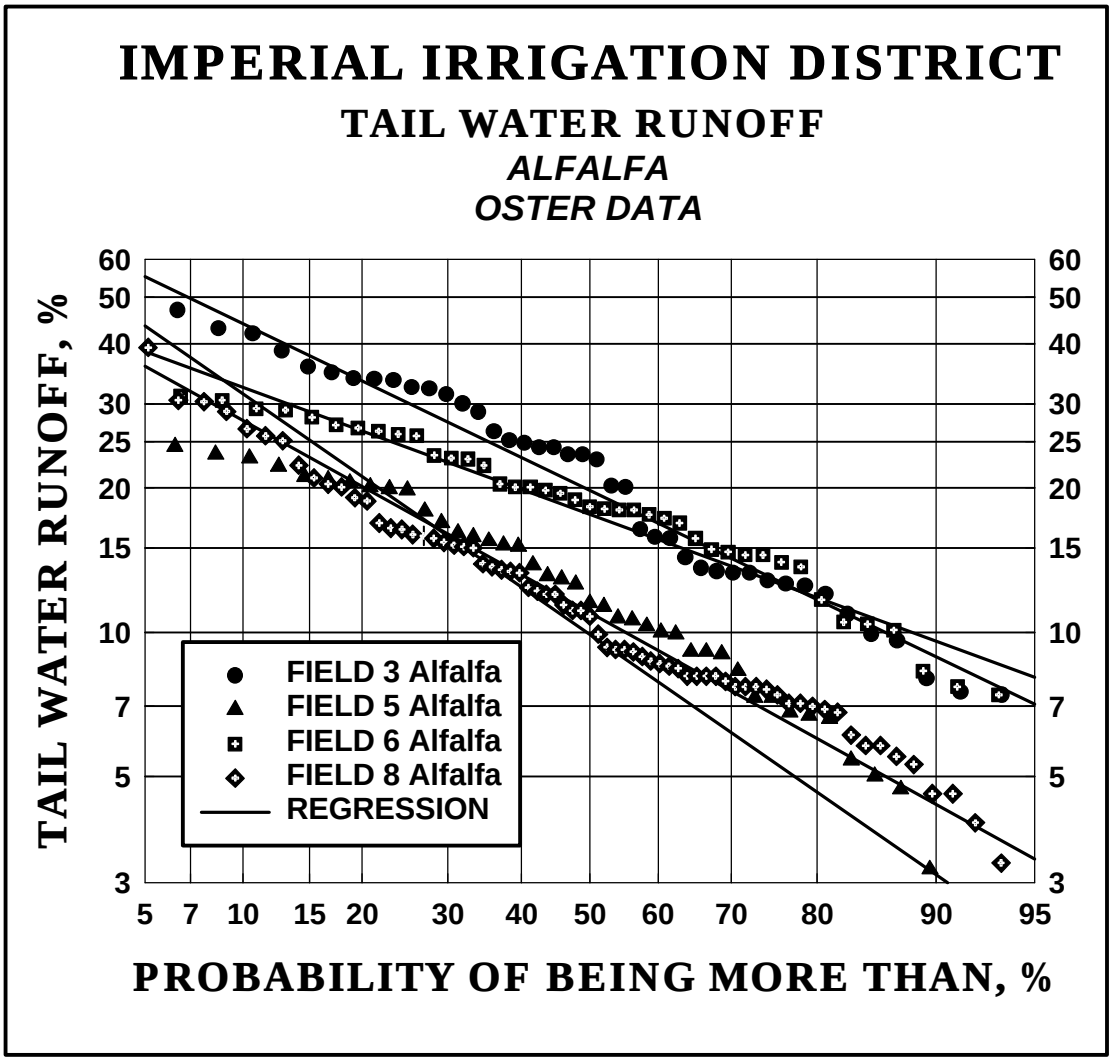



**Figure IV.31**. Surface irrigation tailwater runoff from four alfalfa fields within the Imperial Irrigation District over a five-year time period (1977-1981). Adapted from Oster et al (1986).

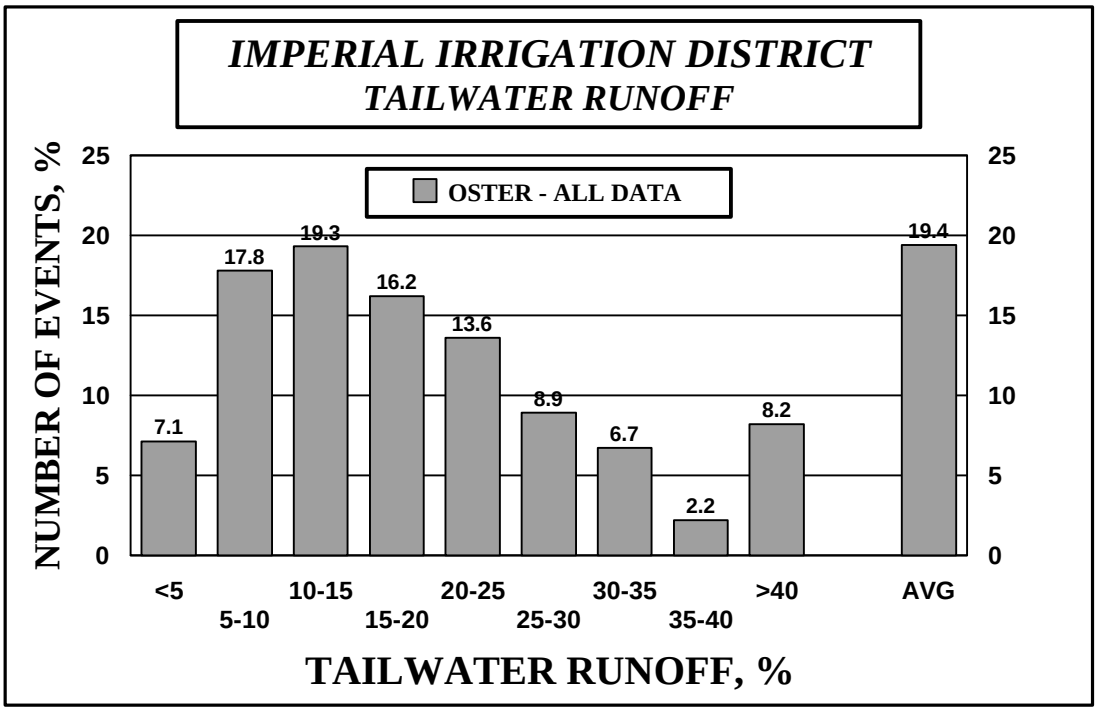



**Figure IV.32**. Surface irrigation tailwater runoff from fields within the Imperial Irrigation District over a five-year time period (1977-1981). Adapted from Oster et al. (1986), all data.

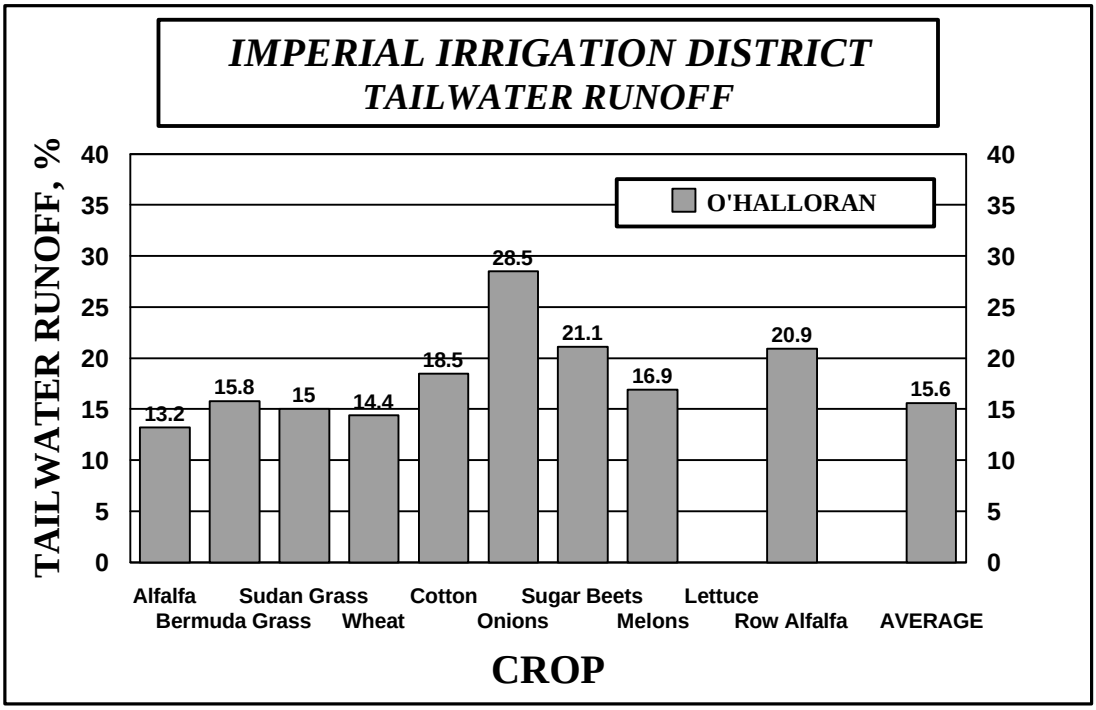



**Figure IV.33**. Tailwater runoff by crop in Imperial Irrigation District. Data from O'Halloran (1990).

**Table IV.11**. Tailwater runoff by crop in the Imperial Irrigation District. Data from O'Halloran (1990).

| CROP | AVERAGE DELIVERY acft | AVERAGE TAILWATER acft | AVERAGE TAILWATER % | NUMBER OF RECORDS |
|---|---|---|---|---|
| Onions | 24.6 | 7.0 | 28.5 | 92 |
| Sugar Beets | 36.1 | 7.6 | 21.1 | 669 |
| Row Alfalfa | 41.6 | 8.7 | 20.9 | 829 |
| Cotton | 34.1 | 6.3 | 18.5 | 615 |
| Melons | 24.8 | 4.2 | 16.9 | 48 |
| Bermuda Grass | 33.0 | 5.2 | 15.8 | 280 |
| Sudan Grass | 40.8 | 6.1 | 15.0 | 154 |
| Wheat | 36.1 | 5.2 | 14.4 | 470 |
| Alfalfa | 36.3 | 4.8 | 13.2 | 4259 |
| Flat Flood | 77.6 | 4.9 | 6.3 | 73 |
| | | | | |
| Totals | 38.5 | 6.0 | 15.6 | 7489 |
| Flat Crops | 36.6 | 5.3 | 14.5 | 5163 |
| Row Crops | 34.1 | 7.4 | 21.7 | 2205 |

**Table IV.12.** Tailwater recovery from the Tailwater Recovery Demonstration Program in the Imperial Irrigation District, 1985-1990. Data taken from Appendix A through E of Boyle Engineering Corporation (1990).

| PUMPBACK SYSTEM NUMBER | TAILWATER RUNOFF AVERAGE % | TAILWATER RUNOFF STD DEV % | TAILWATER RUNOFF COEFFICIENT OF VARIATION |
|---|---|---|---|
| **1** | **25.90** | **22.51** | **0.87** |
| **2** | **22.09** | **15.20** | **0.69** |
| **3** | **14.40** | **8.77** | **0.61** |
| **4** | **16.18** | **16.02** | **0.99** |
| **5** | **34.86** | **20.07** | **0.58** |
| **ALL** | **22.91** | **19.54** | **0.85** |

**Table IV.13**. Surface water runoff from the Tailwater Recovery Demonstration Program in the Imperial Irrigation District, 1985-1990. Data taken from Table 4-3 and Appendix F of Boyle Engineering Corporation (1990).

| CROP | AVERAGE DELIVERY VOLUME, Acft | NUMBER OF EVENTS MEASURED | TAILWATER RUNOFF % OF DELIVERY |
|---|---|---|---|
| **Alfalfa** | 42.1 | 122 | 14.5 |
| **Carrots & Onions** | 27.7 | 16 | 48.0 |
| **Cotton** | 37.9 | 12 | 6.7 |
| **Lettuce** | 35.9 | 12 | 29.6 |
| **Melons** | 65.0 | 6 | 27.2 |
| **Onions** | 33.8 | 10 | 37.7 |
| **Row Alfalfa** | 84.9 | 40 | 12.6 |
| **Sudan Grass** | 28.1 | 12 | 13.6 |
| **Sugar Beets** | 52.5 | 37 | 16.1 |
| **Wheat** | 62.8 | 8 | 12.0 |

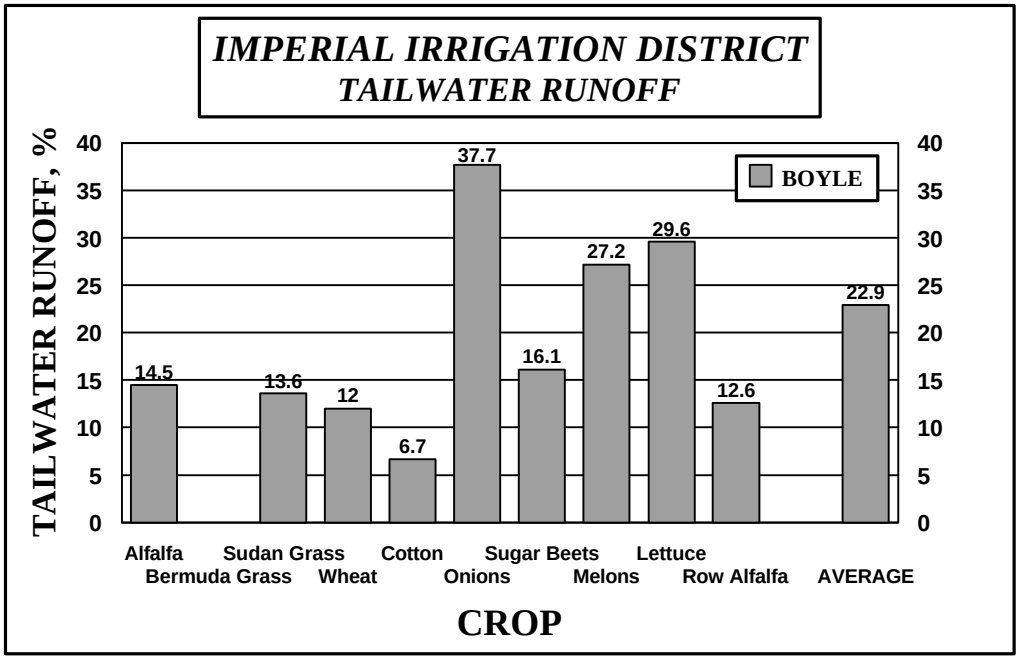



**Figure IV.34**. Tailwater runoff by crop in Imperial Irrigation District. Data from Boyle Engineering Corporation (1990).

The analysis presented here clearly indicates a wide variation in tailwater runoff volume leaving the irrigated fields within the Imperial Irrigation District. Further, large differences in tailwater runoff volume exist throughout the year for any given field. Usually, the largest runoff values are associated with the initial irrigation following planting/or land preparation.

This initial irrigation usually results in larger infiltration depths resulting from slower rates of water advance across the field and higher infiltration rates. In most cases, the irrigation depths applied in the first irrigation are much larger than the depth needed for crop growth during this time period. Furthermore, the initial irrigation events of the year often result in surface runoff. While, deep percolation may be of beneficial reclamation leaching, the tailwater runoff is clearly unjustified.

During a ten-year period, mobile irrigation laboratories evaluated irrigation systems in California (Hanson et al., 1993). These evaluations provided a database on performance characteristics of various irrigation systems related to both irrigation system design and management. Most of the furrow and border irrigation evaluations were conducted in the Shafter and Los Banos areas.

Surface runoff occurred during approximately 70 percent of the furrow irrigation events in the Shafter area and approximately 70 percent reused the runoff. About 90 percent of the furrow systems had runoff in the Los Banos area, with 59 percent reusing the runoff. Nearly 80 percent of the border systems had runoff in the Los Banos area and approximately 48 percent reused the runoff, while 88 percent of the border systems had surface runoff in the Shafter area, and 84 percent reused the runoff. At the district scale there is a zero tailwater runoff policy so water is reused regionally, if not locally.

Existing data on surface irrigation runoff from the irrigated crops within the Imperial Irrigation District (Oster et al., 1986; O'Halloran, 1990 and Boyle Engineering Corporation, 1990) are not dissimilar from the performance of some other irrigation projects across the United States, but this does not suggest that IID's tailwater is not excessive. First, any tailwater leaving an irrigation project may be considered excessive. Second, ID's tailwater flows exceed average values according to the analyses of Oster et al. (1986), O'Halloran (1990), and Boyle Engineering Corporation (1990). Third, IID's tailwater enters a salt sink and is ultimately lost.

The average tailwater runoff from all crops within the Bureau of Reclamation was 15.1% (**Figure IV.27**) and the Oster data was 19.4% **(Table IV.9**). Further, the average tailwater runoff for five tailwater demonstration systems within the Imperial Irrigation District evaluated between 1985-1990 showed 22.9 percent (**Figure IV.34**). Likewise, the inter-office memo of O'Halloran (1990) stated that tailwater runoff values ranged between 6 and 28 percent with an average of 15.6 percent. The results of the tailwater runoff data collected within the Imperial Irrigation District and the Bureau of Reclamation is summarized in **Figure IV.35** and **Figure IV.36**.

In some cases, tailwater runoff from surface irrigated fields may not be lost from the watershed. This water may become the source of water for additional use for a variety of purposes downstream, including irrigation, particularly when it is not mixed with saline drainage water. However for the Imperial Irrigation District, the surface runoff, if it is not captured and reused, is combined with saline drainage water and is ultimately lost to the Salton Sea.

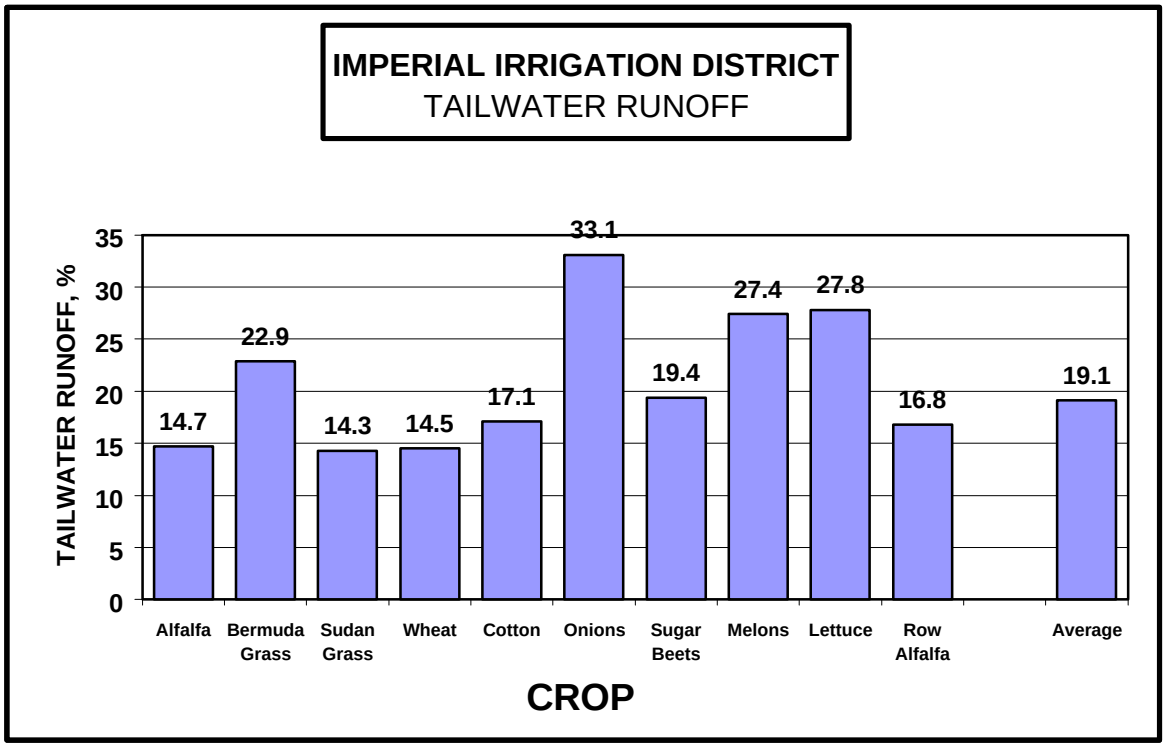



**Figure IV.35.** Tailwater runoff from Imperial Irrigation District. Data from Boyle Engineering Corporation (1990), Oster et al. (1986) and O'Halloran (1990).

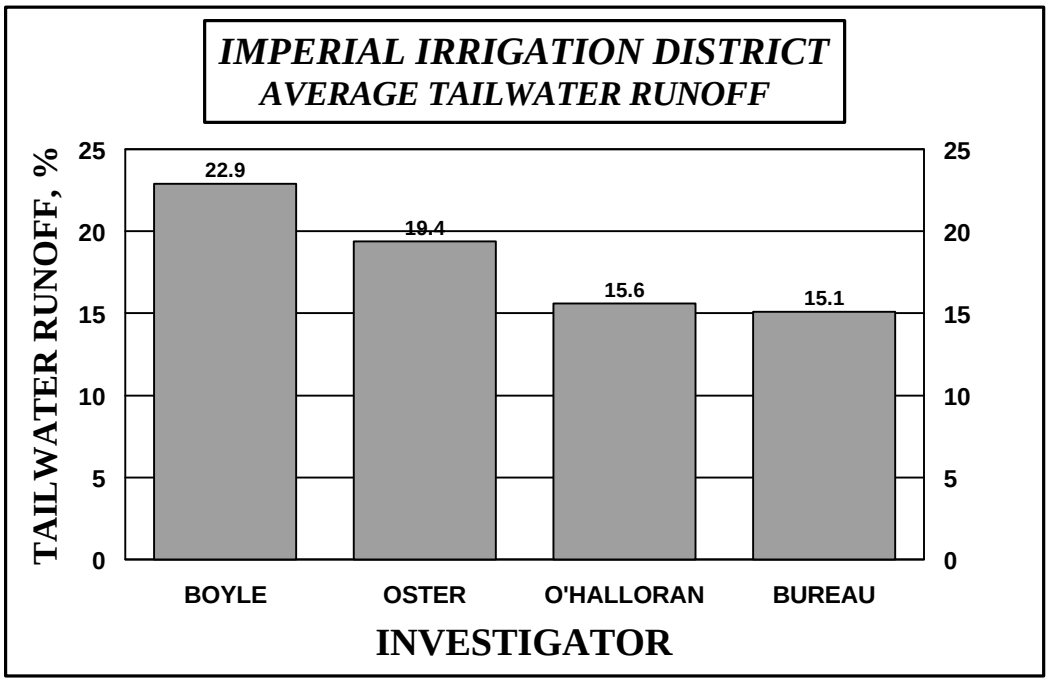



**Figure IV.36**. Tailwater runoff from Imperial Irrigation District. Data from Boyle Engineering Corporation (1990), Oster et al. (1986), O'Halloran (1990) and Bureau of Reclamation (Hamburg, 1980).

## IV. H. Water Budget Components

A water budget is a useful water management tool because it requires a complete accounting of all water within specified spatial and temporal bounds. The water budgeting or balance approach is used in the Boyle Engineering Corporation (1990) report as well as Jensen and Walter (1997) report to calculate an unknown component (closure term) from independently measured or calculated components. For the comparison analysis reported below in this report, a control volume water budget is used to calculate CUnet, the irrigation water delivered to agriculture and used for evaporation and evapotranspiration.

The structure of the Imperial Irrigation District Water Budget is shown in **Figure IV.37**. The district is conceptualized as a single volume or cell with defined horizontal and vertical boundaries. The horizontal range of the water budget is defined as the total land area that occurs within the District boundary. Flow across the top surface as well as the edges of the service area are considered in **Figure IV.37**. The control volume depth is defined such that there is no flow across the bottom boundary. Canal seepage and evaporation is subtracted from flow at Drop 1 (IRdiv) to calculate the flow at the East highline canal (IRdivEHL) which is at the edge of the control volume. After identifying inflows and outflows during the year, the annual water balance equation is solved for CUnet in what follows.

*Surface Inflow*

| | |
|---|---|
| *Diversion (IRdivEHL)=* | *East highline canal* |
| *Rain=* | *municipal*<br>*agricultural*<br>*river and drain*<br>*canal and reservoir* |
| *River=* | *Alamo and New Rivers in to IID* |
| *Runon=* | *mesa storm flow in* |

*Subsurface Inflow*

| | |
|---|---|
| *Groundwater=* | *Coachella canal seepage*<br>*west mesa*<br>*east mesa*<br>*Mexico* |

*Surface Outflow*

*Salton Sea flow =* *Alamo and New Rivers out to Salton Sea*
*Alamo and New Rivers in to IID*
*irrigation lateral canal spill*
*irrigation main canal spill*
*irrigation canal seepage recovery*
*irrigation drainage*
*irrigation tailwater*
*irrigation runoff from municipalities, etc.*
*rain tailwater from agriculture*
*rain drainage from agriculture*
*rain runoff from drain, canal, river and reservoir*
*rain runoff from municipalities etc.*
*external groundwater recovery*
*mesa storm flow in*
*direct surface flow to sea from irrigation, rain, and external groundwater*

*Evaporation (rain, IRdivnet) =*
*municipal*
*agricultural*
*river and drain*
*canal and reservoir*

*Evapotranspiration (rain, IRdivnet) =*
*municipal*
*river and drain (phreatophytes)*
*agricultural crops*

*Subsurface Outflow*

*Groundwater=* *Salton Sea*

The combined surface and subsurface water budget follows from the above assuming no annual change in water storage.

*Inflow-outflow = 0 =*

*+ IRdivEHL*
*+rain*
*+ Alamo and New Rivers in to IID*
*+mesa storm flow in*
*+groundwater in*
*-Alamo and New Rivers out to Salton Sea*
*-direct surface flow to sea from irrigation, rain, and external groundwater*
*-evaporation (rain, IRdivEHL)*
*-evapotranspiration (rain, IRdivEHL)*
*-groundwater out*

Now set

*CUnet, =*

*+evaporation (IRdivEHL)*
*municipal,*
*agricultural,*
*river and drain,*
*canal and reservoir*
*+evapotranspiration (IRdivEHL)*
*municipal*
*river and drain (phreatophytes)*
*agricultural crops.*

Substitute the above and solve the water budget equation for CUnet and group related terms

*CUnet =*

*+ IRdivEHL*

*+rain*
*-evaporation (rain)*
*-evapotranspiration (rain)*

*+Alamo and New Rivers in to IID*
*-Alamo and New Rivers out to Salton Sea*
*-direct surface flow to sea from irrigation, rain, and external groundwater*

*+mesa storm flow in*

*+groundwater in*
*-groundwater out.*

The second group (rain terms) on the right hand side of the equation sums to zero if the rainfall only evaporates and evapotranspires, the third group is defined for later use as SS (net Salton Sea flow) and if, mesa storm flow in and net groundwater inflow are insignificant in comparison to IRdivEHL, the following equation is available for later use in analysis.

$$CUnet = IRdivEHL - SS$$

Or if Drop 1 flow (IRdiv) is used,

$$CUnet = IRdiv - \text{Canal seepage and evaporation between Drop 1 and the East highline canal} - SS.$$

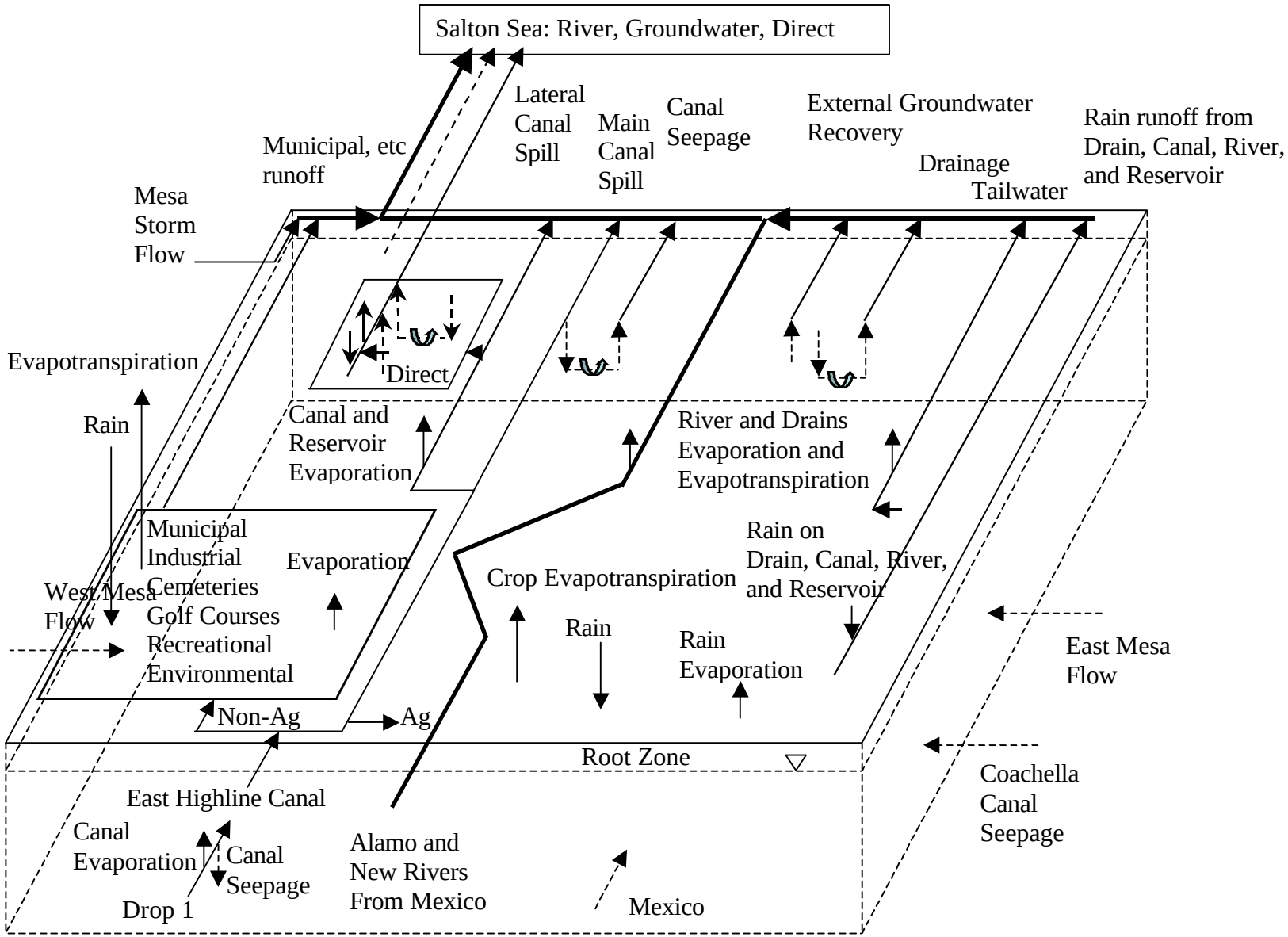



**Figure IV.37.** Imperial Irrigation District Water Budget Components

# V. WATER USED IN THE IMPERIAL IRRIGATION DISTRICT

## V. A. Evapotranspiration and Crop Water Use within the Imperial Irrigation District

**Evapotranspiration Defined.** Evapotranspiration is the sum of water transpired into the air through plant leaves, water retained in plant tissues, and water evaporated from the soil surface adjacent to the plant. The study described in this section was undertaken to calculate and analyze evapotranspiration data in the Imperial Irrigation District to determine what, if any, weather related trends might have influenced historical crop water use.

The effect of weather on crop water requirements reflects crop response to air temperature, sunshine, wind and relative humidity as these variables vary from day to day and across seasonal changes. Current day methodologies for calculating crop water requirements (also denoted evapotranspiration) utilize equations relating evapotranspiration (ET) of a reference crop such as well-watered clipped grass (ETo) or full growth alfalfa (ETr) to weather data or pan evaporation (Jensen, et al., 1990). The simplest equations are based only on air temperature (i.e., Hargreaves, et al., 1985) whereas the more complex Penman type equations (Jensen, et al, 1990) use all the variables mentioned above. The National Weather Service (NWS) reports daily maximum and minimum air temperatures and daily total precipitation at nearly all their observation stations across the United States. However, the other variables are not usually collected. The availability of electronic remote weather stations since the late 1970's has made it possible to readily collect all the variables and provide near real time weather data. Subsequently, networks have been established to provide Penman Equation ET data for agricultural use. One of the better known of these networks is the CIMIS system in California (Snyder and Pruitt, 1992).

**Available Data.** The California CIMIS weather station network has three agriculture related stations in the Imperial Valley with several years of daily weather data sufficient for calculating ET with a Penman type equation. The three stations are #41 Mulberry (1984-2000), #68 Seeley (1990-2000) and #87 Meloland (1990-2000). The date and other details are given in **Table V.1**. The 1990-1996 average of CIMIS ETo (grass reference Et) from all three stations was used by Jensen and Walter (1997) in their analysis of IID irrigation water use. They obtained estimated ETo for 1987-1989 by extrapolation from IID evaporation pan data as a ratio (ETo/Epan) derived from 1990-1994 CIMIS ETo values. Herein, the Mulberry ETo data was used for the entire period of calculation.

There are five national weather service stations in Imperial Valley. These are (from north to south) Niland, Brawley 2 SW, Imperial, El Centro 2 SSW, and Calexico 2 NE. The length of record and other details for each are given in **Table V.2.** Additionally, Class A evaporation pan data were available at the Brawley Irrigation Desert Research Station (USDA/ARS). These data were provided by Mr. Clifford Brown as monthly total evaporation (hand transcribed) for January 1970 through December 1998.

**Table V.1**. Imperial Valley CIMIS Stations, Location, Date Opened, Period of Record, and Site Parameters

| Sta # | Station | Nearby City | Opened | Period | Elev Ft | Latitude North Deg | Min |
|---|---|---|---|---|---|---|---|
| 41 | Mulberry | Calipatria | 7/17/83 | 1984-2000 | -50 | 33 | 07 |
| 68 | Seeley | Seeley | 5/29/87 | 1990-2000 | -10 | 32 | 44 |
| 87 | Meloland | El Centro | 12/12/89 | 1990-2000 | -50 | 32 | 48 |

**Table V.2.** Imperial Valley NWS Stations, Location, Years of Record, and Site Parameters

| Index | Station | Years of Record[a] Temp | Precip | Elev. Ft | Latitude North Deg | Min | Longitude West Deg | Min |
|---|---|---|---|---|---|---|---|---|
| 1048 | Brawley 2SW | 90 | 91 | -100 | 32 | 57 | 115 | 33 |
| 1288 | Calexico 2NE | 0 | 78 | 12 | 32 | 41 | 115 | 28 |
| 2713 | El Centro 2 SSW | 66 | 68 | -30 | 32 | 46 | 115 | 34 |
| 4223 | Imperial | 79 | 81 | -64 | 32 | 51 | 115 | 34 |
| 6197 | Niland | 0 | 58 | -60 | 33 | 17 | 115 | 31 |

[a]Years of record as of December 1997

**Procedure.** Daily weather and ETo data for each site and year for the period shown in **Table V.1** were extracted from CIMIS text report files. Data value screening was performed in the extraction process to correct any ETo values less than 0.03 inches/day and flagged by CIMIS. Missing data were estimated as the average of the preceding two days ETo. Monthly and annual sums, averages and standard deviations were calculated for each site and year on the corrected data set. The weather station equipment is assumed to be adequately operated and maintained to CIMIS standards throughout the period of record.

Daily and monthly air temperature and precipitation were obtained for Brawley, El Centro and Imperial for 1961 through 1997 in electronic format from the Utah Climate Center. Inspection of the data indicated that Imperial had less missing data than the other two sites. Thus, Imperial was selected for use herein. Monthly average maximum and minimum and mean air temperatures and precipitation were extracted from the data set.

The monthly total pan evaporation values for January 1970 - December 1998 were hand entered into a text file and imported into a spreadsheet for calculations. Monthly calculations of ETo prior to 1990 were derived from pan evaporation as:

$$\text{ETo derived} = \text{Kpan} \times \text{Epan} \qquad \text{(Equation V-1)}$$

where ETo derived is the calculated grass reference ET (inches), Kpan is a monthly pan coefficient and Epan is the monthly total Brawley Class A pan evaporation (inches). The monthly pan coefficient was derived from CIMIS ETo as:

$$Kpan = ETo\ CIMIS/Epan \qquad \text{(Equation V-2)}$$

where ETo CIMIS is the monthly total ETo obtained from the CIMIS text data report for each corresponding month.

**Results and Discussion CIMIS ETo (1984-1998).** The annual CIMIS ETo values for Mulberry are shown in **Figure V.1**. The average annual total was 72.3 inches (s.d. = 4.4), varying from 83 inches in 1987 down to 66 inches in 1992 and 1998. There is a decreasing trend in ETo for the period. The ETo decreases markedly from a high in 1987 to a low in 1992. Annual ETo increases from 1992 to 1996 and then drops again in 1998.

Monthly ETo at Mulberry for the 1984-1998 periods is shown in **Figure V.2**. The monthly ETo values vary from about 2 inches in December to between 9 and 10 inches in June and July. The monthly ETo for June, July, August and September 1987 are considerably higher than for other years.

The three-station nine-year (1990-1998) annual average ETo values are given in **Table V.3**. Mulberry ETo is below the three-station average of 71.8 inches, whereas Seeley is above. Meloland ETo is near the average. Annual total ETo values for the three stations are shown in **Figure V.3**. Generally, ETo of the three stations show similar variations, except for Seeley in 1997 and 1998. Annual ETo generally increases from 1992 through 1996 and then decreases through 1998. Also, annual ETo at Meloland, while paralleling that at Mulberry, shifts to about 5 inches greater for 1996-1998.

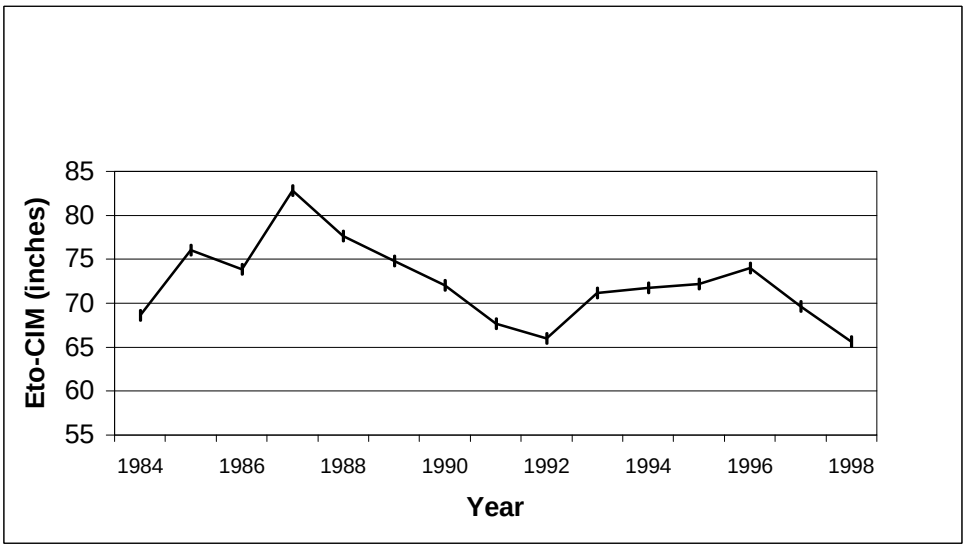
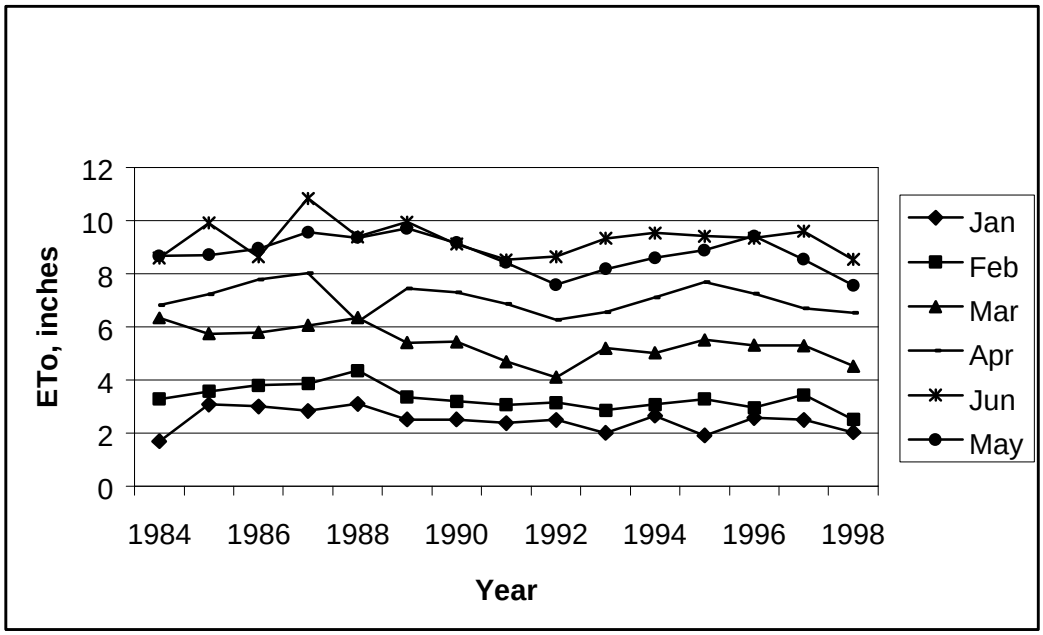



**Figure V.1**. Annual CIMIS ETo - #41 Mulberry (1984-1998)

**Table V.3**. Nine-Year (1990-1998) Average Annual ETo and standard deviations for three Imperial Valley CIMIS stations and for Mulberry (1984-1998)

| Station | Average ETo, inches | Standard Deviation ETo, inches |
|---|---|---|
| 1990-1998 | | |
| Mulberry | 70.0 | 2.79 |
| Meloland | 71.4 | 3.97 |
| Seeley | 73.8 | 2.96 |
| Three Station Average | 71.8 | 2.88 |
| 1984-1998 | | |
| Mulberry | 72.3 | 4.42 |



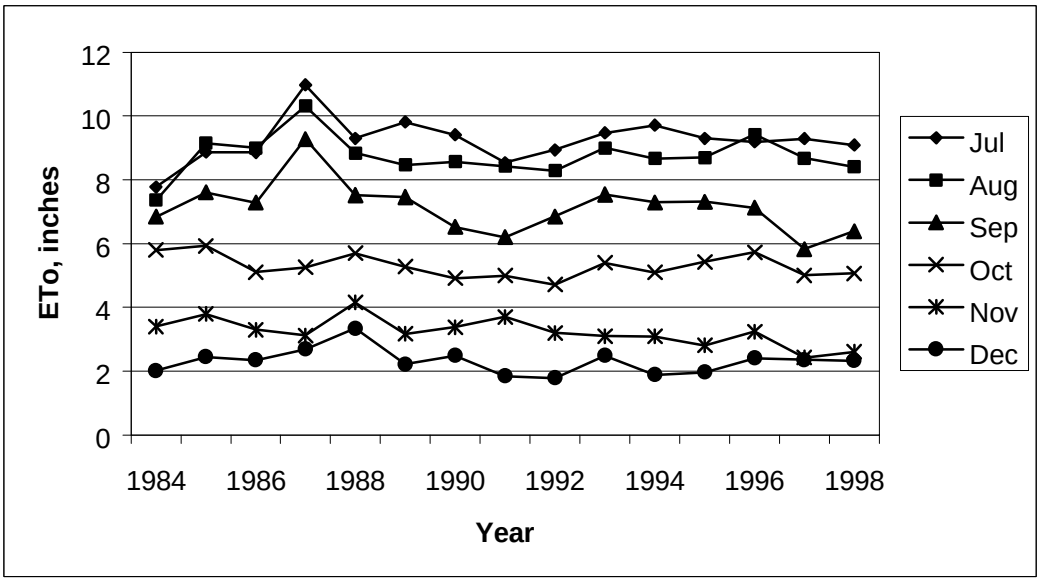




**Figure V.2.** Monthly CIMIS ETo at Mulberry, 1984-1998

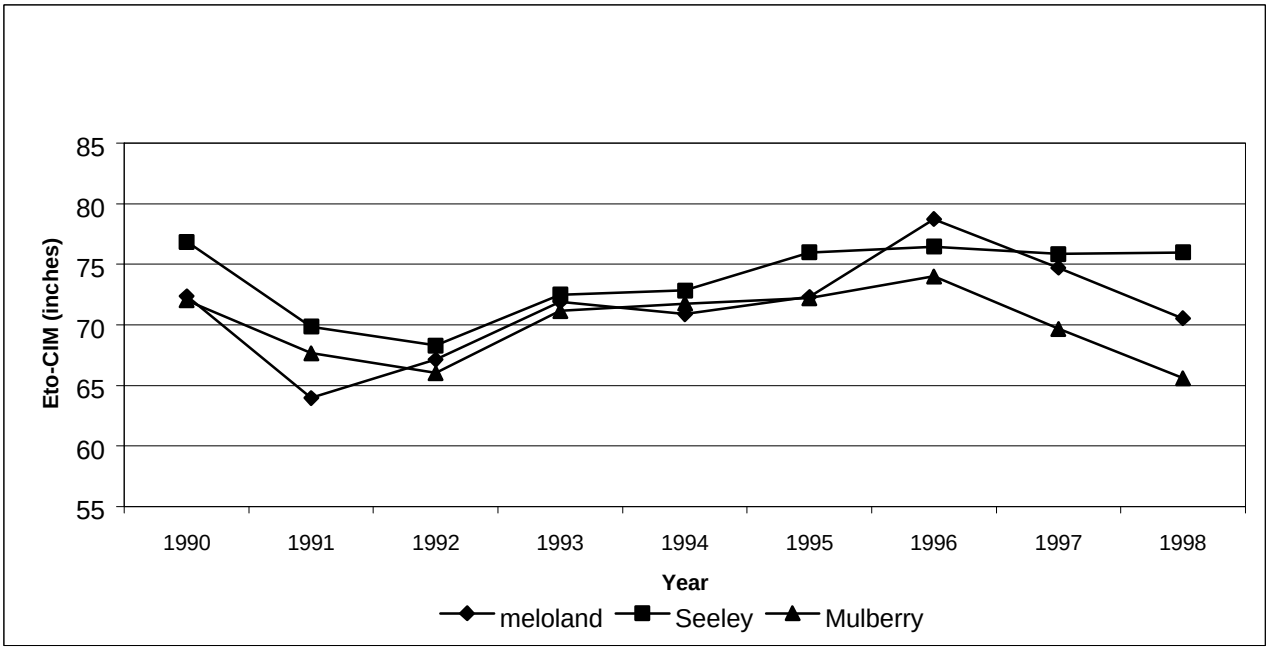



**Figure V.3.** Annual CIMIS ETo (1990-1998) - #41 Mulberry, #87 Meloland, and #68 Seeley

**Long Term ETo Estimates (1970-1998).** The monthly CIMIS ETo data for Mulberry, Meloland, and Seeley (1990-1998) were used to derive Kpan values as defined in Equation V-2. The nine-year monthly Kpan calibration is summarized in **Table V.4**. The average Kpan values vary from 0.60 (September) to 0.68 (December) and are lower in the summer and fall months (June-October) than in the winter and spring.

The Kpan values of **Table V.4** were used for each month in Equation V-1 to estimate historical monthly and annual ETo for the period 1970-1998.

Annual total pan evaporation, CIMIS ETo and derived ETo from pan are shown in **Figure V.4**. The CIMIS ETo and pan derived ETo exhibit similar trends, except for 1987 when the CIMIS value was considerably higher and 1996 when the pan value was higher. From 1970 through 1990 the derived ETo gradually increases from about 72 inches to 76 inches. Thereafter, with the exception of 1996, a decreasing trend is evident down to 67 inches in 1998. The average derived ETo was 71.7 inches.

**Table V.4**. Nine-Year (1990-1998) Average Monthly Pan Evaporation Coefficients for Estimating ETo from Brawley Pan Data

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Average | .66 | .66 | .66 | .63 | .64 | .62 | .61 | .62 | .60 | .61 | .63 | .68 |
| St dev. | .11 | .10 | .06 | .04 | .04 | .04 | .04 | .05 | .06 | .06 | .06 | .12 |

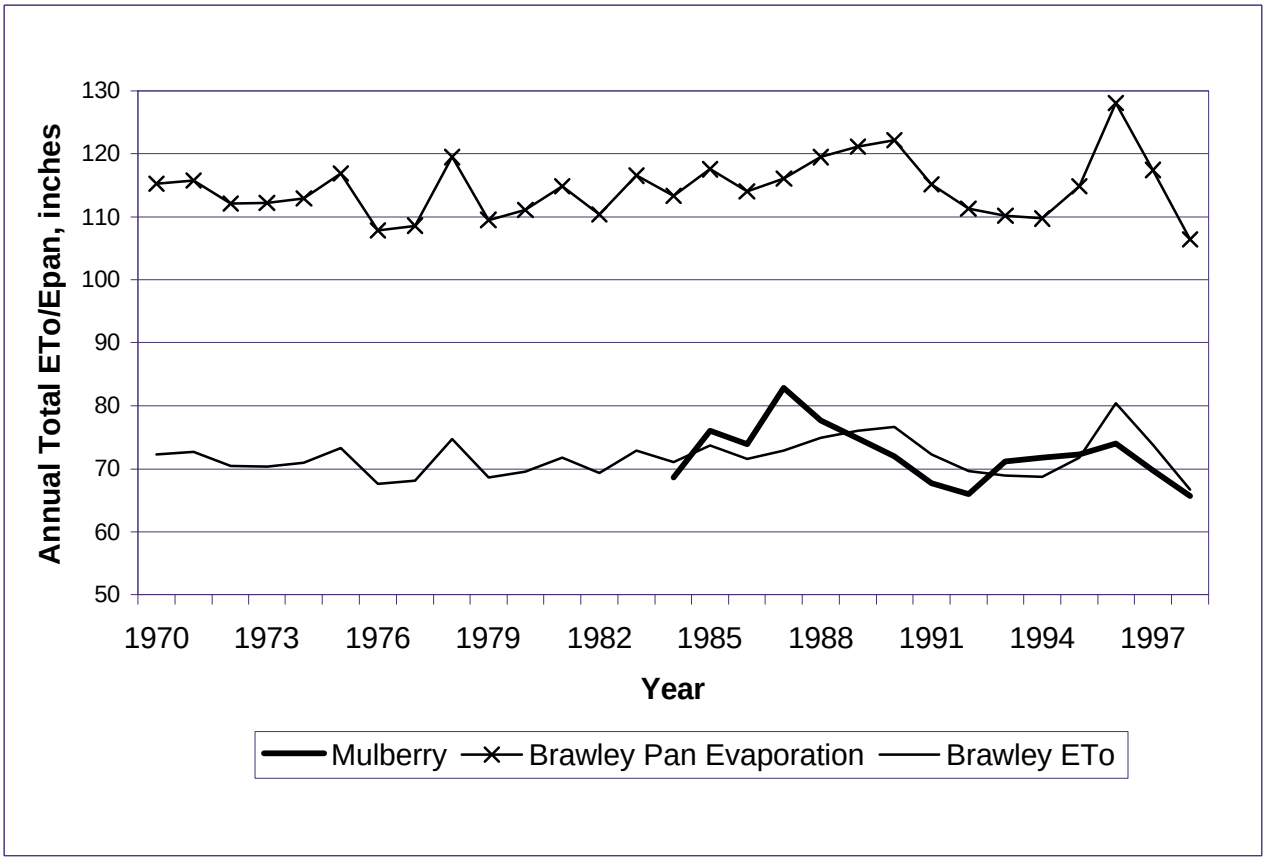



**Figure V.4.** Annual Total Pan Evaporation at Brawley, CIMIS ETo at Mulberry and Derived ETo from Pan Evaporation (1970-1998).

The gradual increase from 72 to 76 in/yr between 1970 and 1990 is 5 percent increase whereas, from 1990 to 1998, it was a 12 percent decrease. The CIMIS ETo data also exhibited a decreasing trend from 1987 continuing through 1998.

There is no compelling trend of increasing ETo (CIMIS and pan derived) that would suggest major changes in Imperial Valley weather conditions leading to increased irrigation diversions.

**Crop Consumptive Use**

**Estimated Annual Net Crop Consumptive Use (CCUnet).** Annual volume-based crop evapotranspiration minus effective precipitation ($ET_c$ - $P_e$) estimates, as summed for the field, garden, and permanent crops (Volume = (ETc-Pe) x respective crop area), are plotted in **Figure V.5** for the 1972-00 time period. These estimates were made using the Jensen Spreadsheet Model (Jensen, 1995) for water use assessment in IID.

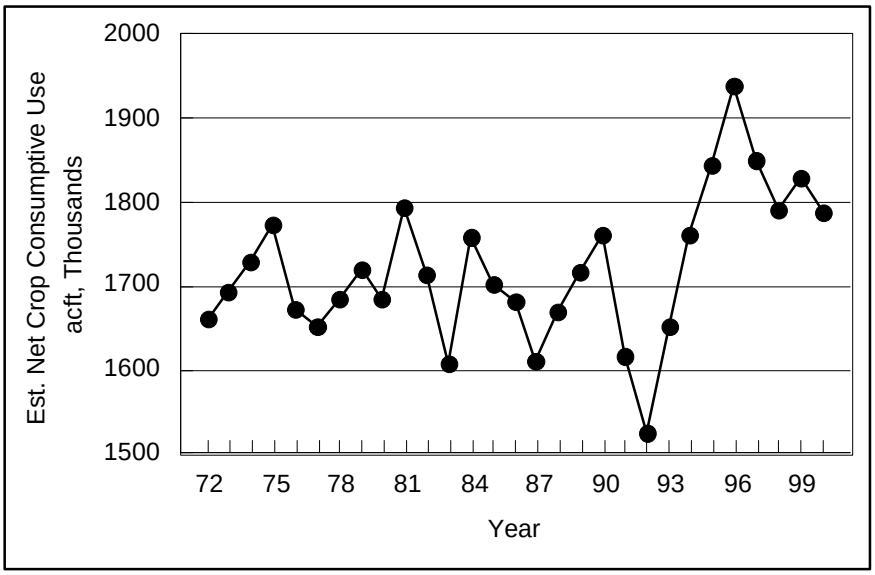



**Figure V.5.** Estimated annual net crop consumptive use (CCUnet) for total crop area (field + garden + permanent) in each year.

Crop coefficients were applied to calculations of grass-reference evapotranspiration (ETo) to calculate crop evapotranspiration (ETc). The crop coefficients (i.e., values for each 10 day interval over the respective growing seasons for each major field, garden, and permanent crop) in this spreadsheet model were based on the values given in the report by Jensen and Walter (1997). The adjusted crop curve for alfalfa (per the Jensen model, 1995) was also used for this crop. Estimates of reference evapotranspiration (ETo) in the 1990-00 period (i.e., each 10 day interval) were based on averaged values of three CIMIS stations located in IID at Mulberry, Meloland, and Seeley (**Figure V.3**).

The 3-station ETo data set (i.e., averaged data over 3 sites) from 1990 to 1998 was also used to derive calibration coefficients for the estimation of grass-reference ETo from daily evaporation pan data. The evaporation pan data were obtained from the Brawley-pan site (**Figure V.4**) for the period January 1972 through December 1998. Pan-based ETo calculations (i.e., 10 day sums) were applied to the Jensen Water Use Assessment Model to calculate annual crop evapotranspiration (ETc) for the years 1972-89.

The average annual ETo was 71.6 inches for the entire 29-year period using these two methods of calculation. For the period 1990-00, the average annual ETo (based solely on the three CIMIS stations) was 71.8 inches. For the period 1972-89 the average annual ETo (based on calibration coefficients applied to the Brawley pan evaporation data) was 71.5 inches.

Effective precipitation (Pe), for computation of net crop consumptive use (i.e., ETc - Pe) values, per 10-day intervals, was calculated as 0.75 times the recorded precipitation amounts. The precipitation data were those of the National Weather Service site at Imperial, CA. At this site, the annual rainfall has averaged 3.26 inches over the 29-year period (i.e., 1972-00). The

methodology for estimating Pe (i.e. selection of a 0.75 coefficient) was based on USDA-Soil Conservation Service methods (Dastane, 1974).

Using the above methodology, the annual calculations (**Figure V.5**) of net crop consumptive use for the 10-year period 1987-96 averaged 1,710,000 ac-ft (std. dev = 122,000 ac-ft). Comparatively, the water balance-based calculations of net crop consumptive use, as summarized in the Jensen and Walter (1997) report, averaged 1,737,000 ac-ft (std. dev. = 97,000 ac-ft).

For the entire 1972-00 period, the **Figure V.5** calculations of annual net crop consumptive use averaged 1,720,000 ac-ft (std. dev = 87,000 ac-ft). Further, **Figure V.5** also illustrates that the calculated annual net crop consumptive use volumes fall within plus or minus 100,000 ac-ft of the long-term average in all but 7 years. The year-to-year variations are largely attributable to the effects of a combination of factors such as total crop area, cropping mix, and the annual magnitudes of ETo and effective precipitation. The much lower net crop consumptive use in 1992 (1,524,000 ac-ft vs. 1,720,000 ac-ft average), for example, was caused by a lower than average annual ETo (67.1 inches vs. 71.6 inches average) and higher than average annual precipitation amount (6.1inches vs. 3.3 inches average). Likewise, the higher net crop consumptive use in 1996 (1,939,000 ac-ft vs. 1,720,000 ac-ft average) was caused by a higher than average annual ETo (76.4 inches vs. 71.6 inches average).

Calculations of net crop consumptive use in the last five years, 1996-00, averaged 1,840,000 ac-ft which is above the 29-year mean of 1,720,000 ac-ft. The calculated annual ETo in this period averaged 72.6 inches or also 1.00 inches above the 29-year average of 71.6 inches.

## V. B. Water Salinity within the Imperial Irrigation District

**Salinity Trends in Colorado River at Imperial Dam (Historical Salinity Trends).** The flow and chemical quality of the Lower Colorado River water prior to the impoundment of the Colorado River by Hoover Dam in 1935 varied widely seasonally and annually (McDonald and Loeltz, 1976). The TDS probably ranged from less than 200 mg/L during flood flows to more than 2,000 mg/L during dry year flows. The lower TDS waters consisted mainly of Ca-$HCO_3$ type water while higher TDS waters, NaCl- $Na_2SO_4$ type. McDonald and Loeltz (1976) believe that the weighted average TDS at Grand Canyon is representative of the flows into Lake Mead. The 40-year (1926-1965) weighted average TDS of the Colorado River at Grand Canyon was 600 mg/L. The TDS in outflow from Lake Mead is higher than inflow due to evapoconcentration and dissolution of lakebed materials that are offset by the precipitation of calcite from the water. The average TDS between Hoover and Imperial Dams have ranged from 600 to 900 mg/L. Increased diversions, development of new lands and additional reservoirs have increased the salinity in the Lower Colorado River in the past. But, since the 1980s, the implementation of the Colorado River Salinity Control Program appears to be reducing downstream salinity.

The recent trend in salinity of the Colorado River water at Imperial Dam from January 1941 to mid December 1999 (USBR 1999, USBR 2001) is shown in **Figure V.6**. The monthly TDS varied from about 550 mg/L to occasional values above 950 mg/L. The average TDS over the

29-year period (January 1971 – December 1999) was 767 mg/L with a standard deviation of 94.8 mg/L. There is a decreasing trend in TDS from 1971 through mid 1998. Two shorter-term trends are evident in **Figure V-6**. The first short-term trend is a rather rapid decrease in TDS during the high-flow water years of 1983 to 1986 in the Upper Colorado River Basin. Monthly average TDS were below 600 mg/L for several months from late 1985 into early 1987. The second short-term trend is a rapid increase in TDS from 1988 to about 1993 during the drought years in the Upper Basin. Since about 1994, salinity is declining at a greater rate than the overall trend line.

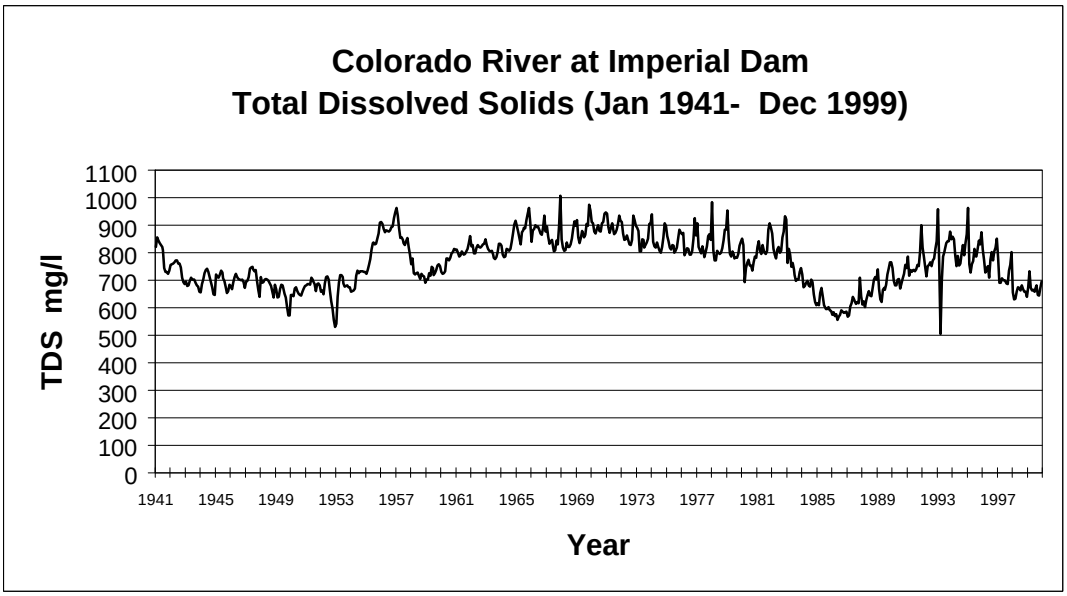



**Figure V.6**. Trend in salinity of Colorado River water at Imperial Dam from 1941 through 1999 (USBR 1999, USBR 2001).

**District-wide Leaching Requirement in IID.** Leaching requirements were calculated based on monthly TDS of Colorado River salinity at Imperial Dam from 1971 to 1998 (**Figure V.6**) and with two assumed levels of crop threshold salinity. The TDS in **Figure V.6** was converted to EC in dS/m by dividing by a factor 640 (USSL, 1954). The assumed levels of threshold ECe in the LR Equation IV-1 were 3.4 dS/m for 90% yield potential for alfalfa (a moderately salt sensitive crop) and 2.0 dS/m for 100% yield potential of alfalfa and some vegetable crops.

The monthly LR for threshold ECe of 3.4 and 2.0 dS/m are shown in **Figures V.7** and **IV.8 r**espectively. Similar long-term and short-term trends are evident as in **Figure V.6** because EC was calculated from TDS. For threshold ECe of 3.4 dS/m (**Figures V.7**), the average LR was 0.076 with a low of 0.05 and a high of 0.10. Whereas for threshold ECe of 2.0 dS/m (**Figures V.8**), the average LR was 0.136 with a low of about 0.09 and a few highs near 0.18. Both figures show long-term trend in decline of LRs along with short-term sharper decreases in the late 1980s, sharper increases in the early 1990s, and followed by sharper decrease in the late 1990s for the reasons stated earlier for **Figure V.6**.

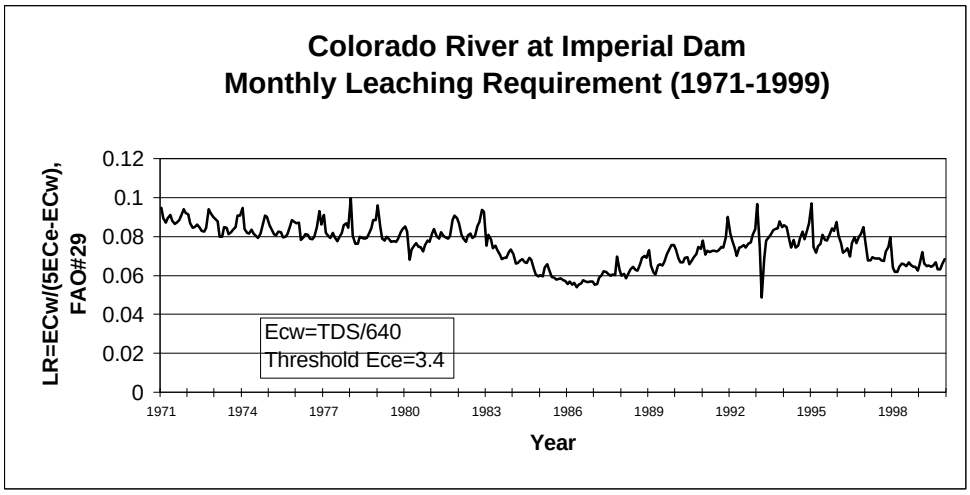



**Figure V.7.** Monthly calculated LR values for threshold ECe of 3.4 dS/m for Colorado River water at Imperial Dam.

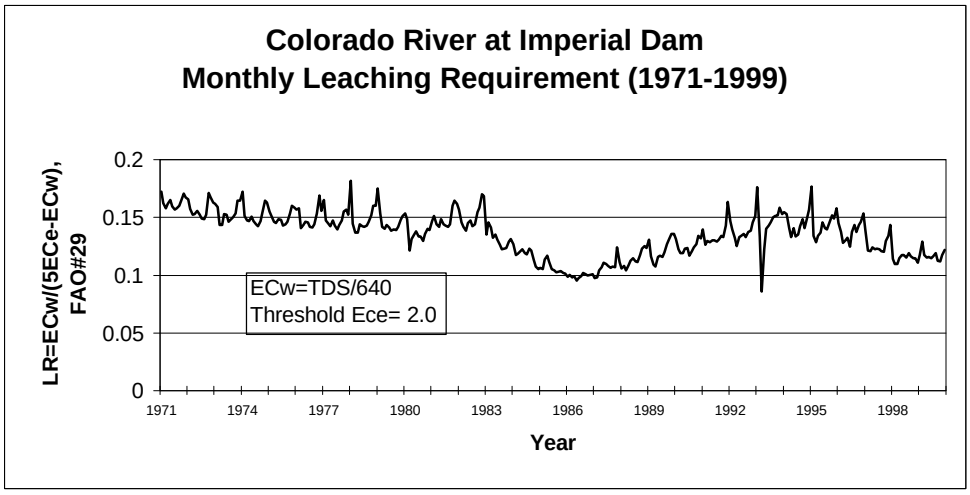



**Figure V.8.** Monthly calculated LR values for threshold ECe of 2.0 dS/m for Colorado River water at Imperial Dam.

The Colorado River water is moderately saline as compared to many other rivers in the west. The average salt concentration in the All-American Canal below Drop 1 ranges from 0.70 to 1.30 tons per acre-feet (Silva, 1990). The average annual volume of water delivered to agriculture between 1987 and 1994 was 2,433,400 acre-feet (IID, 1996). If the average salt concentration in the irrigation water is assumed to be 1.0 ton per acre-feet, the average annual salt load brought into the valley for irrigation is 2,433,400 tons of salt. This annual salt load is equivalent to 6,670 tons of salt per day or 133 gondola railroad cars of salt delivered every day to farmlands. The average total area being irrigated between 1987 and 1994 was 459,200 acres (IID, 1996) and they received on the average about 5.30 tons of salt per acre per year or 10,600 pounds of salt per

acre per year. By contrast, annual fertilizer applications are in the 100 to 400 pounds per acre range. Thus, salt brought in with irrigation water is a large annual loading in IID.

During 1987, 1988 and 1989, the average annual flow in the All-American Canal below Drop One was 2,831,600 acre-feet and drainage discharge from IID into the Salton Sea was 912,100 acre-feet. Silva (1990) reported that the average salt concentration in the canal water was 0.88 tons per acre-feet, so that the average annual salt load in the irrigation water was 2,491,800 tons. This 2,491,800 tons per year is equivalent to 6,800 tons of salt delivered per day or 136 gondola railroad cars of salt deposited on IID. In contrast, the average salt concentration in the drain discharged into Salton Sea over this period was 3.23 tons per acre-feet so that the average annual salt load discharged was 2,946,100 tons of salts. This 2,946,100 tons of salts discharged into the Salton Sea is equivalent to 8,070 tons of salt discharged per day or about 161 gondola railroad cars of salt per day delivered to Salton Sea. There was more salts discharged from IID than received from irrigation water. The salt balance index (tons discharged/tons received) is 1.18 or 18% more salts were discharged than brought in with supply water. Some of the salts discharged may have come from regional ground water.

## V. C. Annual Deliveries to the Imperial Irrigation District

**Annual Water Delivery at Drop One.** The time series (1972-00) of annual water delivery volumes as measured at Drop One (CVWD 1998a, CVWD 1999a, CVWD 2001a) on the All American Canal is shown in **Figure V.9**. Annual delivery volumes generally declined from the early 1970s to the mid 1980s. A return to much higher volumes occurred by the mid 1990s. Exceptions took place in 1992-93 when alfalfa was not watered in a normal manner due to severe whitefly damage. About 150,000 acres of alfalfa were dried up or not watered for a period of 6 weeks or longer in 1992 (Divine, 1996).

The annual water delivery volume should be affected by the total crop area, the mix of cropping, the effective precipitation, the consumptive use, the salinity management needs, and the water management practices of the irrigation district.

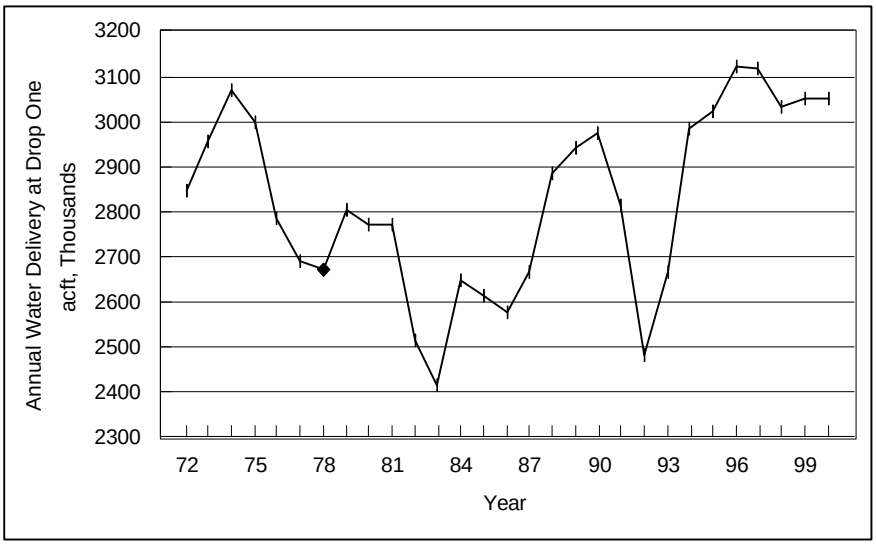



**Figure V.9.** Annual water delivery volume at Drop One.

Annual Drop One delivery volumes are expressed in equivalent volumes per crop acre (i.e. ac-ft/ac) in **Figure V.10** (CVWD 1998, CVWD 1999, and CVWD 2001). These data also indicate a period of declining volumes per crop acre in the 1970s to mid 1980s followed by an increase to higher volumes per acre since the mid 1980s with exception of years 1991, 1992, and 1993. Further comparisons of these data are given later in **Figure V.12,** i.e., the water delivered at Drop One per crop acre vs. calculated net crop consumptive use per crop acre.

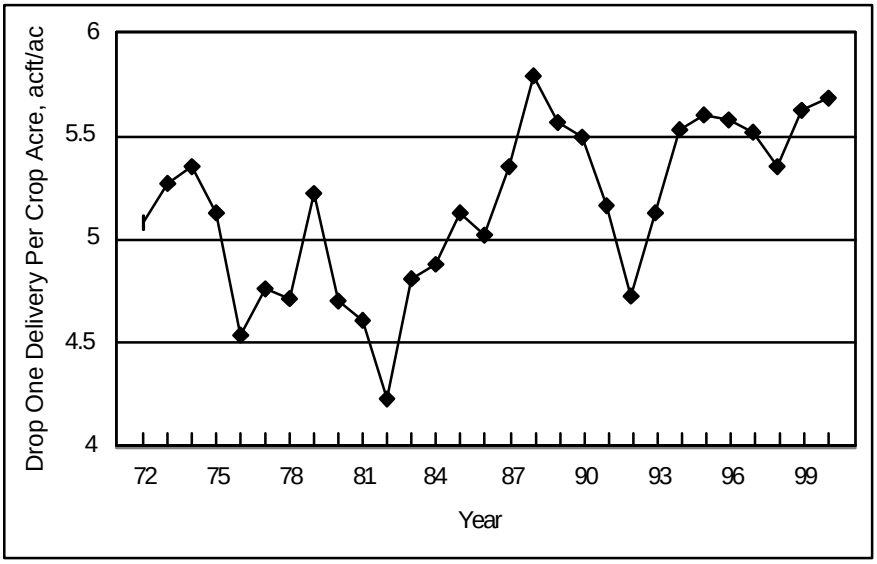



**Figure V.10.** Annual water delivery volume at Drop One in equivalent volume per crop acre (i.e., ac-ft/ac---crop area included double crop)

Annual rainfall volumes (based on averaged valley-wide data; Divine, 1996) are compared with annual water delivery at Drop One (**Figure V.11**). Mean annual rainfall in IID is approximately 0.27 feet (3.21 inches), or 124,200 ac-ft for an average irrigated land area of 460,000 acres. Annual water delivery volumes have been inversely correlated with annual rainfall (**Figure V.11**).

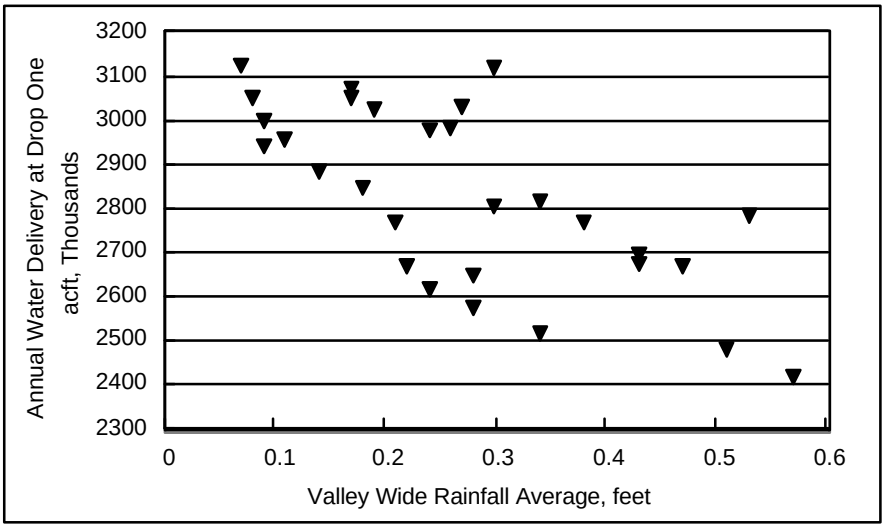



**Figure V.11.** Annual water delivery (at Drop One) and annual mean valley-wide rainfall.

**<u>Delivery Vs Estimated Consumptive Use</u>.** Annual water delivery at Drop One per crop acre (i.e., ac-ft per acre of crop, including double cropping) is compared to calculated annual net crop consumptive use per acre of cropping in **Figure V.12** (where CCUnet was calculated by the WAC analysis described in Chapter V.A). These data indicate that the calculated net crop consumptive use per acre increased from the mid 1980s relative to the 1970s and early 1980s period. The calculated average net crop consumptive use for the period 1972-87 was 3.03 ac-ft/ac. The calculated average for 1988-00 was 3.25 ac-ft/ac.

In comparison in these two periods, the annual delivery at Drop One averaged 4.90 and 5.44 ac-ft/ac of crop area, respectively. Thus, it appears that the average increase in water delivery has exceeded the average increase in net crop consumptive use.

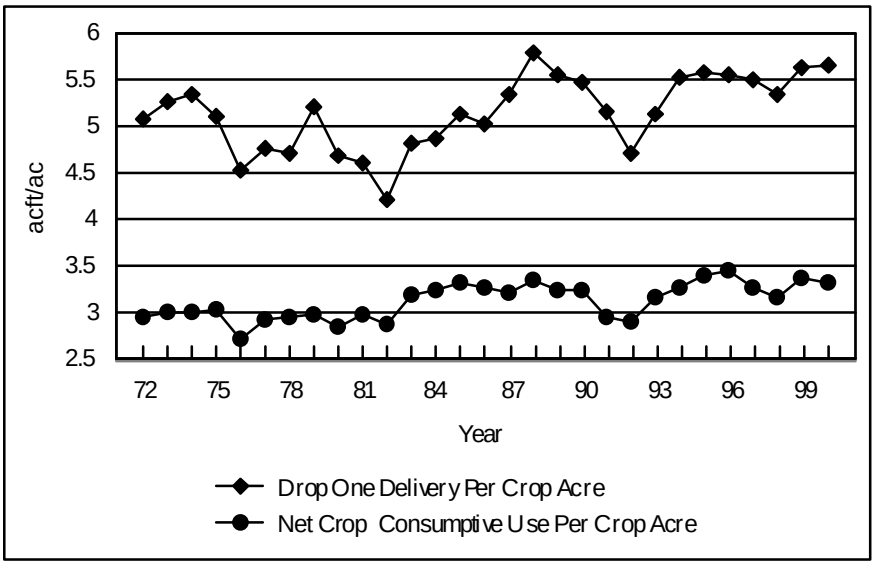



**Figure V.12.** Comparison of annual water delivery (at Drop One) to calculated annual net crop consumptive use (each expressed in ac-ft per acre of crop area)

## V. D. Discharges to the Salton Sea

**Flow to the Salton Sea – Annual Losses.** The annual surface flow volumes (minus flow from Mexico) for IID to the Salton Sea (CVWD 1999b, CVWD 2001b) have been closely related to the annual water delivery volumes at Drop One (**Figure V.13**). In the period 1972 to 1986, water delivery at Drop One declined from highs near 3,050,000 ac-ft to lows of about 2,600,000 ac-ft. This decline coincided generally with a reduction in total cropping area (including double crop) from about 570,000 acres in the early 1970's to about 510,000 acres in the mid 1980's (see **Figure IV.10**). Correspondingly, flows to the Salton Sea declined from highs near 1,125,000 ac-ft in the early 1970's to lows near 825,000 ac-ft in the mid 1980s. After the mid 1980's, the annual total cropping area (including double crop) again increased, averaging 555,000 acres in the 1996-00 period. Water delivery at Drop One also increased, averaging 3,075,000 ac-ft in 1996-00. The annual flow volumes to the Salton Sea also again returned to about 1,055,000 ac-ft. Thus, for a decline in total crop acres of nearly 60,000 acres in the 1972-86 period, the Drop One water delivery and Salton flow loss declined by about 450,000 ac-ft and 300,000 ac-ft, respectively. With a subsequent increase in total crop area of about 45,000 acres, the annual water delivery at Drop One increased by about 475,000 ac-ft and the flow volumes to the Salton Sea increased by about 230,000 ac-ft.

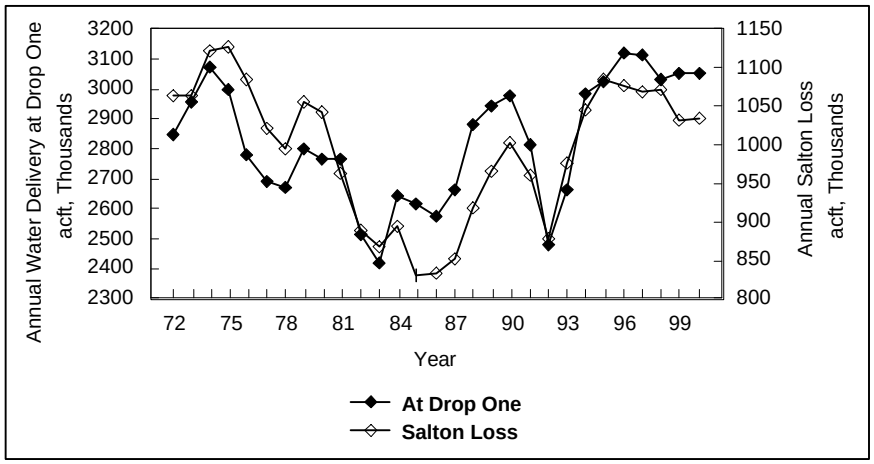



**Figure V.13.** Comparison of annual water delivery volume at Drop One with annual losses (minus flow from Mexico) to the Salton Sea.

**Flow to the Salton Sea – Annual Loss Ratio**. The ratio of Salton Sea loss to Drop One delivery declined from levels of 0.37 – 0.38 in the mid 1970's to about 0.32 in the mid 1980's (**Figure V. 14**). These ratios have returned to about 0.36 - 0.34 in the 1990's.

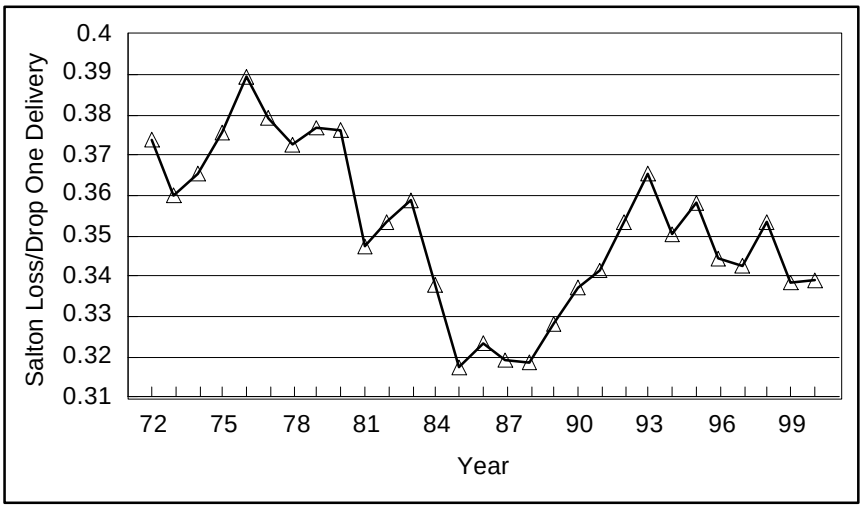



**Figure V.14.** Ratio of Salton Sea loss volume to Drop One delivery volume.

## V. E. Irrigation Performance of the Imperial Irrigation District

**Irrigation Crop Consumptive Use Ratio**. The ratio of the annual net crop consumptive use volume in IID to the annual water delivery volume at Drop One (All-American Canal) is defined as the Irrigation Crop Consumptive Use Ratio (ICCUR). It is an indicator of the proportion of annual irrigation water delivery required to beneficially supply the net evapotranspiration requirements of crop production from agricultural land. A ratio of 0.50, for example, implies that 50 percent of the Drop One delivery volume in that year was needed to beneficially supply irrigation water to crop production net evapotranspiration. This ratio is computed as:

ICCUR = CCUnet/(IRdiv) (Equation V-3)

Where: CCUnet = annual net crop consumptive use volume (ETc - Pe), IRdiv = the annual volume of irrigation water diverted at Drop One, ETc = crop evapotranspiration volume, and Pe = effective precipitation volume.

**ICCUR From Weather-Based Estimates Of Net Crop Consumptive Use.** Weather-based calculations of annual net crop consumptive use were summarized earlier in Section III. The calculated annual Irrigation Crop Consumptive Use Ratios (ICCUR) in **Figure V.15** indicate that these ratios rose from about 0.57 in the early 1970's to highs exceeding 0.65 in the early 1980's. Subsequently, these ratios appear to have returned to lower levels. In the mid-late 1990s they were near their 29-year average of 0.61

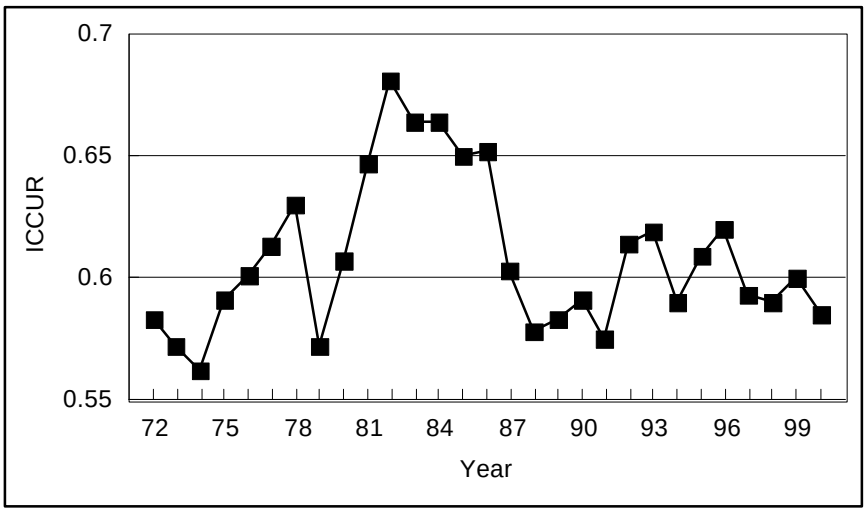
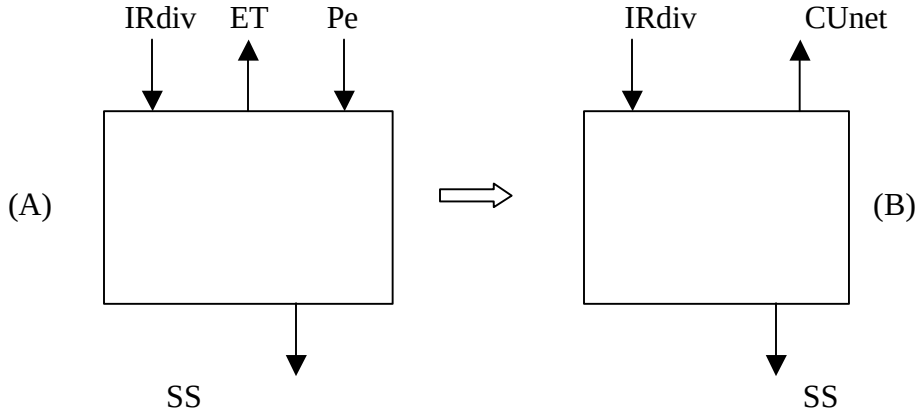



**Figure V.15.** Estimated irrigation crop consumptive use ratios, ICCUR (Stegman and Hill, 2001)

**Comparisons to alternative data.** The following diagram is a summary of the water budget presented in Chapter IV and illustrates the major water balance components for the Imperial Irrigation District.



In diagram (A), IRdiv = annual irrigation volume diverted at Drop One, ET = annual evapotranspiration volume from all vegetation, Pe = annual effective precipitation volume, and SS = annual surface flow volume (less surface inflow from Mexico) to the Salton Sea. Diagram (A) reduces to diagram (B) if net consumptive use is defined as CUnet = (ET - Pe) = the total irrigation water consumed, which as defined here includes evaporation from canals and reservoirs plus irrigation water consumed by crops on agricultural land plus irrigation water consumed within the drain-river system. This CUnet calculation (Equation V-4) also includes the irrigation water consumed for non-agricultural use. However, the WST (1998) and Jensen and Walter (1997) reports estimated that non-agricultural consumption has averaged less than two percent of annual IRdiv volume.

From diagram (B) above:

CUnet = IRdiv – SS (Equation V-4)

ICUR = CUnet/IRdiv = 1 - SS/IRdiv (Equation V-5)

Irrigation Consumptive Use Ratios (ICUR), as estimated by (1 - SS/IRdiv), are plotted in **Figure V.16.** As shown, these ratios rose from values of about 0.62 to 0.63 in the 1970s to highs of about 0.68 in the mid 1980s. In the 1990s, ICUR's again declined to values near the 29-year mean of 0.65 (std dev = 0.02).

**Figure V.16.** Estimated Irrigation Consumptive Use Ratios (ICUR) based on IID water balance data.

Further comparisons are made in **Table V.5** using data from the Water Study Team report (WST, 1998). The WST used water-balance-based methods (rather than calculated ETo and crop curves) to calculate the annual irrigation water consumed on agricultural land for the 1987-96 period. Because they subtracted effective precipitation amounts, their annual water balances estimated the "net crop consumptive use" (i.e., CCUnet = ETc - Pe) in IID. They further computed the total irrigation water consumed (CUnet) by summing the estimates of irrigation water evaporation from canals and reservoirs, the calculation of irrigation water consumed on

agricultural land, and calculations of irrigation water consumed within the drain-river system. The WST calculated the annual precipitation to be about 90 percent effective.

It is shown in **Table V.5.** that the WST-based ICCUR ten-year calculations averaged 0.61 (like in the 29 year WAC analysis shown in **Figure V.15**). Also, the ten-year WST-based ICUR calculations averaged 0.64. This average ICUR value (**Table V.5**) compares very closely to the 29-year average ICUR (i.e., 0.65) that was based (in this study) on computations of the annual (1 - SS/IRdiv) values (illustrated above in **Figure V.16**) and it also compares to the average value of 0.64 that was computed by Jensen and Walter (1997). They also used the water balance method of analysis.

**Table V.5.** Irrigation water consumption and calculated ratios for the IID

| Year | IRdiv[1] (@ Drop One) ac-ft (thousands) | CCUnet[2] (i.e. Irrig. Water Consumed on Ag Land) ac-ft (thousands) | **ICCUR** = CCUnet/IRdiv Ratio | Cunet[3] (i.e., Total Irrig. Water Consumed) ac-ft (thousands) | **ICUR** = CUnet/IRdiv Ratio |
|---|---|---|---|---|---|
| 1987 | 2667 | 1687 | 0.63 | 1781 | 0.67 |
| 1988 | 2885 | 1809 | 0.63 | 1902 | 0.66 |
| 1989 | 2942 | 1815 | 0.62 | 1921 | 0.65 |
| 1990 | 2975 | 1815 | 0.61 | 1915 | 0.64 |
| 1991 | 2813 | 1728 | 0.61 | 1815 | 0.65 |
| 1992 | 2482 | 1538 | 0.62 | 1622 | 0.65 |
| 1993 | 2668 | 1610 | 0.60 | 1700 | 0.64 |
| 1994 | 2984 | 1780 | 0.60 | 1875 | 0.63 |
| 1995 | 3023 | 1755 | 0.58 | 1854 | 0.61 |
| 1996 | 3124 | 1839 | 0.59 | 1946 | 0.62 |
| **Average** | **2856** | **1738** | **0.61** | **1833** | **0.64** |

[1] IID Annual Inventory Reports (CVWD 1998, CVWD 1999, CVWD 2001)
[2] CCUnet = Irrigation water consumed on agricultural land (based on Table A5-1 of WST Report, 1998).
[3] CUnet = sum of irrigation water evaporation from canals and reservoirs, irrigation water consumed on agr. Land, and irrigation water consumed within the drain-river system (based on Table A5-1 of WST Report, 1998).

Values of ICCUR = CCUnet/IRdiv can also be computed from the Jensen and Walter (1997) report. The Jensen and Walter calculations (also water-balance-based) of CCUnet in the 10-year 1987-96 period averaged 1,737,000 ac-ft. IRdiv (i.e., diversion volumes at Drop One) in this 10-

year period averaged 2,856,000 ac-ft (CVWD 1998, CVWD 1999, CVWD 2991). Their computed ICCUR averaged 0.61. Comparatively, the 29-year (crop coefficient-weather-based) CCUnet calculations in this study/analysis averaged 1,720,000 ac-ft (see Section III) an as illustrated in **Figure V.15** the ICCUR averaged 0.61. IRdiv in this 29 period averaged 2,826,000 ac-ft. These parameter values are further compared in **Table V.6.**

**Crop Leaching Requirement Volume (LRvol. as a Ratio of IRdiv**. Crop leaching requirement volumes were calculated by the WST (1998) by applying the Ayers-Westcot (1985) equation with procedures defined for heavy cracking soils involving "a leaching multiplier" and "miles of tile drainage" (WST report Table A4-11). The net effect of these procedures was equivalent to using an average threshold ECe = 1.97 in the Ayers-Westcot equation. For light or non-cracking soils (estimated to cover 50% of the district-wide CCUnet), the WST used a threshold ECe = 1.70. For these procedures and the mean salinity level of Colorado River water at Imperial Dam (ECiw = 1.16 DS/m), the WST calculations of annual crop leaching volume requirement (WST report Table A2-24) averaged 296,000 ac-ft in the 1987-1996 period. Thus, the ratio LRvol/IRdiv averaged 0.10 (i.e., 296,000/2,856,000) in this ten year period.

Similarly, in this (WAC) analysis the Ayers-Westcot equation was applied to the 1972-00 period to calculate annual crop leaching requirement volumes. These volumes averaged 292,000 ac-ft for a crop-area weighted threshold ECe = 1.85. Their calculated LRvol/IRdiv ratios averaged 0.10. The annual ratios are plotted in **Figure V.17**.

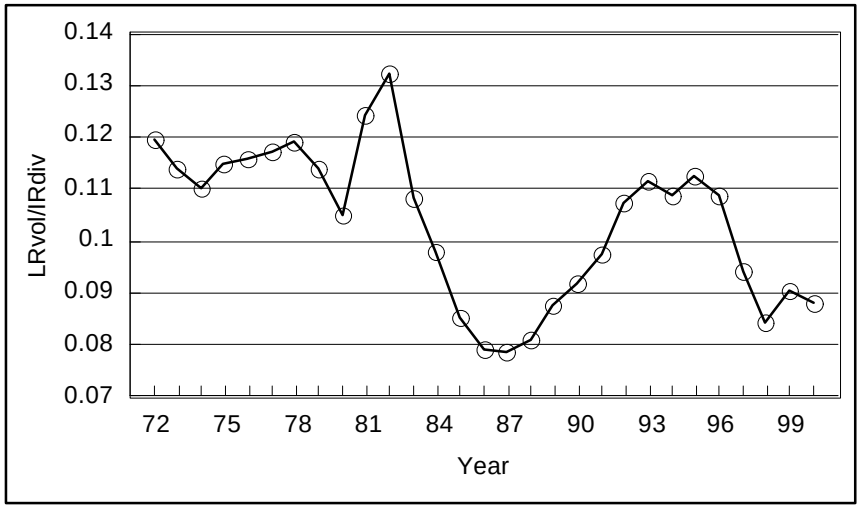



**Figure V.17.** Leaching requirement volume (LRvol) as a ratio of irrigation diversion volume (IRdiv) at Drop One.

The annual CUnet/IRdiv + LRvol/IRdiv sums are plotted in **Figure V.18**. The annual CUnet/IRdiv ratios for these sums were calculated using Equation V-5, i.e., (1 - SS/IRdiv). Hence, the CUnet/IRdiv ratios were based on "measured" annual volumes of SS and IRdiv (using IID data). The annual LRvol data were based on the Ayers-Westcot equation using threshold ECe = 1.85, and the annual flow-weighted mean salinity values for the Colorado River at Imperial Dam. These summed ratios in **Figure V.18** average 0.75 for the 29-year period with standard deviation = 0.01. This average agrees closely with the calculated average value that was computed by the WST (1998). The WST computations were based on water-balance methods and a 10-year period of time (see **Table V.6**).

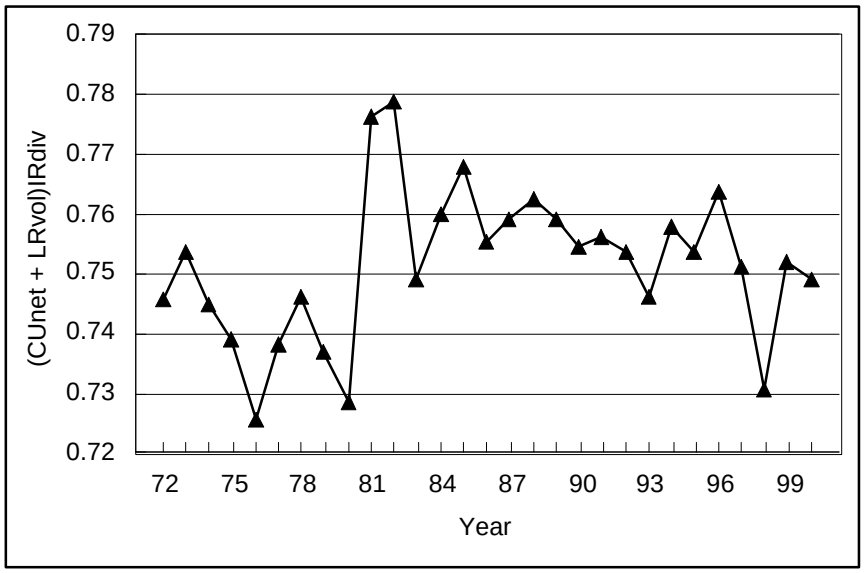



**Figure V.18.** Net consumptive use (CUnet) plus leaching requirement (LRvol) volumes as ratios of Drop One delivery volumes in IID.

**Beneficial and Non-Beneficial Volumes**. The ratio CUnet/IRdiv (i.e., ICUR) has averaged about 0.65 over the 29 period (1972-00) when calculated from the annual (1 – SS/IRdiv) values or about 0.64 when calculated using the water-balance-based methods of the WST (1998) and also of Jensen and Walter (1997). Also, the crop leaching requirement analyses summarized above indicate LRvol/IRdiv ratios have averaged about 0.10 (as summarized in this report and by WST, 1998; and Jensen and Walter, 1997).

The average volume fraction of beneficial use in IID has averaged about 0.75 (i.e., 0.65+ 0.10). The average volume fraction of non-beneficial use is thus calculated at 0.25. Hence, the average volume of non-beneficial delivery below Drop One has been on the order of 706,000 ac-ft (based on an average delivery volume at Drop One of 2,826,000 ac-ft).

## TableV.6. Summary of comparative performance parameters in IID (part one)

| **Study** | Period | IRdiv Ac-ft (thous) | **CUnet** Ac-ft (thous) | LRvol Ac-ft (thous) | LRvol/IRdiv | **ICUR** = CUnet/IRdiv | (CUnet + LRvol)/IRdiv |
|---|---|---|---|---|---|---|---|
| **WAC** | ’72-‘00 | 2826[1] | 1836[2] | 292[7] | 0.10 | 0.65 | 0.75 |
| **WST** | ’87-’96 | 2856[1] | 1833[3] | 296[8] | 0.10 | 0.64 | 0.74 |
| **Jensen Walter** | ’87-’96 | 2856[1] | 1826[3] | 309[9] | 0.11 | 0.64 | 0.75 |

## Table V.6. Summary of comparative performance parameters in IID (part two)

| **Study** | Period | IRdiv Ac-ft (thous) | **CCUnet** Ac-ft (thous) | LRvol Ac-ft (thous) | LRvol/IRdiv | **ICCUR** = CCUnet/IRdiv | (CCUnet + LRvol)/IRdiv |
|---|---|---|---|---|---|---|---|
| **WAC** | ’72-‘00 | 2826[1] | 1720[4] | 292[7] | 0.10 | 0.61 | 0.71 |
| **Jensen Walter** | ’87-’96 | 2856[1] | 1737[5] | 309[9] | 0.11 | 0.61 | 0.72 |
| **WST** | ’87-’96 | 2856[1] | 1738[6] | 296[8] | 0.10 | 0.61 | 0.71 |

[1] Average annual Drop One Delivery for the indicated period
[2] Calculated average Net Consumptive Use (CUnet = IRdiv - SS); where SS = annual flow volume to Salton Sea (i.e., less flow volume from Mexico)
[3] Calculated average Net Consumptive Use {(ETc - Pe) + (irrigation evaporation from canals and reservoirs) + (irrigation water consumed within drain-river system)}
[4] Calculated average Net Crop Consumptive Use (ETc - Pe); i.e., crop-curve-weather based;
Pe = 0.75 X measured precipitation
[5] Calculated average Net Crop Consumptive Use (ETc - Pe); i.e., water-balance-based;
Pe = 0.62 X measured precipitation
[6] Calculated average Net Crop Consumptive Use (ETc - Pe); i.e., water-balance-based;
Pe = 0.90 X measured precipitation
[7] Calculated average crop Leaching Requirement Volume based on Ayers-Westcot equation
(crop-area weighted ECe = 1.85)
[8] Calculated average crop Leaching Requirement Volume based on Ayers-Westcot equation and procedures for heavy cracking soils (ECe=1.97) and light non-cracking soils (ECe=1.70)
[9] Calculated average crop Leaching Requirement Volume based on Ayers-Westcot equation (calculated as 14.1% of net crop consumptive use; average crop-area weighted ECe = 2.10)

**Summary.** In this section, irrigation performance in the Imperial Irrigation District over an extended period of time, i.e. from 1972 to 2000 has been analyzed.

***Irrigation crop consumptive use ratio (ICCUR)*** was defined as the ratio of annual net crop consumptive use volume to the annual irrigation delivery volume at Drop One. This ratio indicates the proportion of annual delivery volume needed to supply the net crop consumptive use requirement. Using crop curve and weather-based data to calculate reference evapotranspiration (ETo), the calculated ICCUR has averaged about 0.61 over the 29-year period 1972-00. Recent mid to late 1990s values of ICCUR continue to average near 0.61. Thus, 39 percent of the annual irrigation delivery at Drop One has not been beneficially used to meet crop water requirements. Calculations of this ratio by Jensen and Walter (1997) and by the WST (1998) using water balance methods over the 10-year period 1987-96 have also averaged 0.61.

***Irrigation consumptive use ratio (ICUR)*** was defined above as the ratio of total annual irrigation water volume consumed (i.e., net crop consumptive use + irrigation evaporation from canals and reservoirs + irrigation water consumed within the drain-river system) to the annual irrigation delivery volume at Drop One. This ratio was calculated using **measured** data (i.e., IRdiv and SS). This ratio (ICUR) ranged from 0.61 to 0.68 and averaged 0.65 over the 29 year period of assessment. Recent mid-late 1990s values of ICURs also averaged near 0.65. Calculations of this ratio by Jensen and Walter (1997) and by the WST (1998) using water balance methods over the 10 year period 1987-96 both averaged 0.64, respectively.

Annual leaching requirement volumes (LRvol) were calculated using the Ayers-Westcot (1985) equation and a crop area weighted calculation of salinity tolerance (threshold ECe = 1.85). When expressed as ratios of annual irrigation delivery volume at Drop One (LRvol/IRdiv), these ratios averaged 0.10 for the 29 year period. Calculations of this ratio by Jensen and Walter (1997) and by the WST (1998) over the 10 year period 1987-96 also averaged 0.11 and 0.10, respectively.

The combined beneficial uses (annual irrigation consumptive use + annual leaching requirement) when expressed as ratios of annual irrigation delivery volume at Drop One averaged 0.75. Hence, on average 25 percent of the annual delivery volume at Drop One has not been beneficially used for these needs. The non-beneficial use volume was calculated to average (based on the average annual Drop One delivery volume of 2,826,000 acre-feet) 706,000 acre-feet in the 29 year period 1972-00. In comparison, the WST (1998) calculated the combined losses of tailwater, operational spills, district canal seepage and All American Canal seepage to average 692,000 acre-feet in the 10 year period 1987-96. Jensen and Walter (1997) calculated these combined losses to average 747,000 acre feet in the same 10-year period.

## V. F. Agricultural Tailwater within the Imperial Irrigation District

Annual agricultural tailwater volumes in IID were calculated as follows:

DStot = IRfarm – CCUnet

Where:

DStot = annual agricultural irrigation volume entering the drainage system (surface tailwater + tilewater volumes)

IRfarm = annual delivery to agricultural users (IID annual data)

CCUnet = net crop consumptive use, described in section **V. A.**

And:

TW = DStot - LRvol

Where:

TW = annual agricultural tailwater volume not used for leaching requirement

LRvol = leaching requirement volume, described in section **V. E.**

**Figure V.19.** compares the annual tailwater volumes (DStot and TW) to the annual irrigation deliveries (IRdel and IRfarm), to the annual net crop consumptive use (CCUnet), and to the net annual outflow to the Salton Sea (SS).

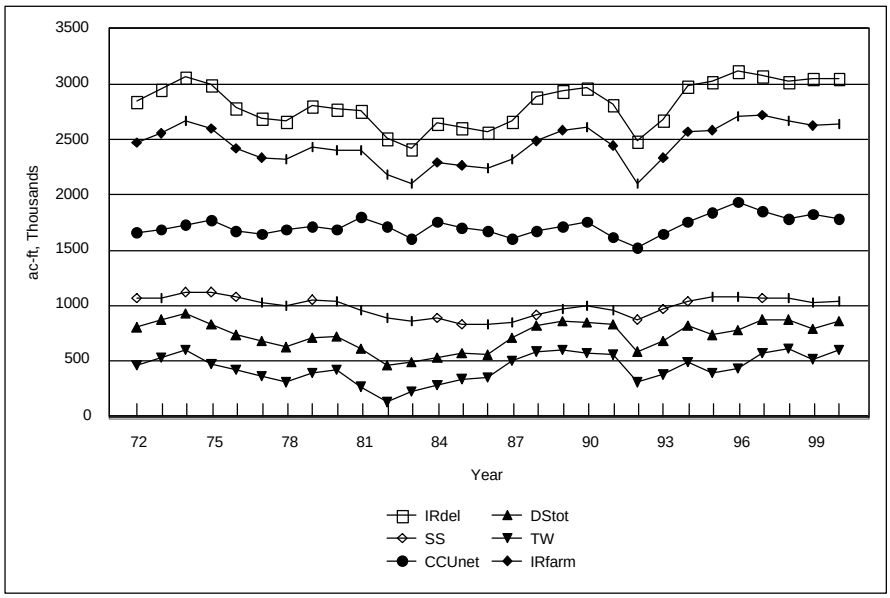



**Figure V.19.** Comparison of annual tailwater volumes (DStot and TW) to water delivery volumes (IRdel and IRfarm), to net annual crop consumptive use volumes (CCUnet) and to net annual outflow volumes to the Salton Sea (SS)

**Figure V.19** shows DStot and TW volumes generally declined in the period from 1972 to the mid 1980s. Since then the DStot volumes have increased, rising to magnitudes in the 1996-2000 period that averaged 832,000 ac-ft annually. Similarly the TW volumes not required for leaching in this period have averaged 548,000 ac-ft annually.

**Figure V.20**. compares the calculated annual ratios of DStot/IRfarm and TW/IRfarm. These ratios, as expected, follow the same patterns as exhibited by the DStot volumes in **Fig. V.19**. In the 1996-2000 period, the DStot/IRfarm ratio averaged 0.31, indicating that annual irrigation volume entering the drainage system (surface tailwater plus tilewater) averaged 31 percent of the irrigation delivery volume to agricultural users.

In the 1996-2000 period the annual TW volume not required for leaching averaged 21 percent (average ratio = 0.21) of the annual irrigation delivery volume to agricultural users.

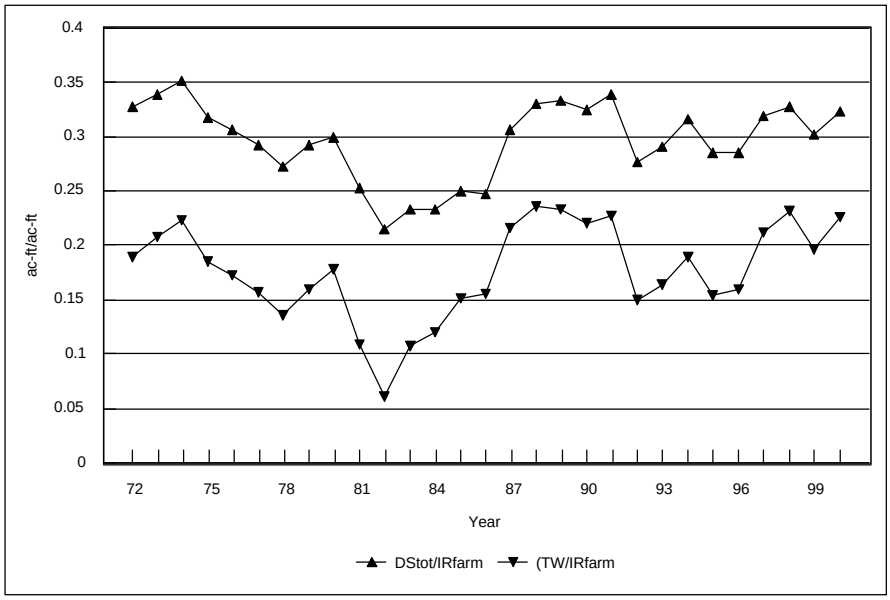



**Figure V.20.** Annual ratios of total agricultural tailwater volume to agricultural delivery volume (DStot/IRfarm) and of tailwater volume not required for leaching to agricultural delivery volume (TW/IRfarm).

# VI. OPPORTUNITIES FOR IMPROVEMENT

## VI. A. Tailwater Control/Management

**Tailwater Recovery Systems**. If tailwater is present, the utilization of a tailwater recovery system is essential for successful operation and water management of a surface irrigation system. These systems collect irrigation tailwater runoff from surface irrigated fields and return it to the same, adjacent or lower fields for further irrigation use. A tailwater recovery system has the following components:

- Surface drainage ditches to collect and convey surface tailwater runoff water to the storage facility.

- A storage reservoir to store the water until a sufficient volume has been collected, or a sump with incorporated control systems to recycle the water.

- Inlet facilities to the reservoir or sump. These include a desilting basin for sediment, screens for removing trash from the water, and a chute, drop, or pipe inlet to deliver the water to the sump while controlling erosion.

- A pump and power unit (pumping plant) for withdrawing the water from the reservoir or sump and, if necessary, pressurizing the water for conveyance. Under certain conditions where gravity flow can be used, neither the pump nor the pipeline may be necessary.

Storage for tailwater recovery is usually classified in two categories:

1. Reservoirs, usually of earth construction, are designed to store relatively large volumes of water. The volume of return flow and thus the reservoir size is usually designed as a fraction of the inflow into the first irrigation set. The recovery system may be operated conjunctively with the irrigation supply or separately. The pumping units may be either manually or automatically controlled.

2. Sumps with cycling pumps utilizing automatic controls are designed to return tailwater runoff directly to the irrigation supply. Sumps are generally constructed with concrete or other suitable material. The storage volume for these systems is usually relatively small. This type of sump is used where a high degree of control is available over the irrigation system.

Traditional design procedures for reservoir tailwater recovery systems (those described in item number 1 above) usually result in flow rate capacity of between 20 and 35 percent of the inflow rate to the field (ASAE, 1998; Schulbach and Meyer, 1979; and High Plains Underground Water Conservation District No. 1, 1977). The larger flow rate design for these reservoir systems provides increased flexibility in management of the tailwater recovery system. The suggested

storage volumes for the tailwater reservoirs are approximately one-half of the inflow volume to the first set.

The smaller sump systems described in item number 2 above are designed, installed and operated under conditions of smaller runoff volumes and flow rates. Thus, these systems require reduced tailwater storage volumes.

**Benefits of Tailwater Recovery Systems**. Burt (1995) identifies the following five benefits of Tailwater Recovery Systems (for non-cracking soils):

***Improved irrigation performance due to less uncollected runoff***. Through capture and reuse of the tailwater runoff the performance of the surface irrigation system will improve. This benefit will occur if the irrigation practices with the tailwater recovery system are not modified in an effort to minimize tailwater runoff. For example, if water is applied relatively slowly with small stream sizes to furrows or border strips in order to obtain a longer advance time (at which time the water is shut off). In this case, there may be an increased amount of non-beneficial deep percolation (water flows below the root zone) as compared to the previous practices without tailwater recovery systems. This problem is especially acute on coarse textured soils.

***Reduced labor***. This benefit will occur for furrow irrigation systems if the following are utilized: 1) Large but non-erosive flow rates per furrow are used. If larger flow rates are used, the water will advance to the end of the field more rapidly. 2) Tailwater is allowed to runoff for at least half of the total irrigation time. Then, the downstream end of the furrow will receive water for at least half of the time the head end receives water. 3) Capture and automatically recycle the tailwater runoff.

***Reduced salt problem***. Salt concentrations within the crop root zone along the length of a furrow generally show a buildup of soil salinity toward the lower end of a field. This is because the lower end of the field is typically under-irrigated, as the irrigators are usually trying to avoid tailwater runoff or scalding effect on crops such as alfalfa. Thus, at this location of the field the water infiltration is not enough to meet crop water requirements plus leach the salts. Tailwater return systems allow irrigators to obtain more even intake opportunity times along the furrow, and thereby provide better salt leaching in the lower half of the field. The same can also be true for border strip systems.

***Reduced surface drainage problem***. This benefit occurs if farmers use larger flow rates, resulting in faster advance times to the end of the field than without reuse systems. Drainage is reduced because the farmers can now shut off the water earlier than before and thereby applying less water per irrigation event.

***Uniform crop yield***. Reduced under-irrigation and better salt leaching at the lower end of the field, and fewer drainage problems at the head end of the field combine to provide better crop growth and yield. In addition, less fertilizer is often needed as the water uniformity and timing is improved.

## VI. B. Economics of Reservoir Tailwater Recovery Systems

**Capital and Operating Costs.** Capital costs for surface irrigation tailwater recovery systems for the Imperial Irrigation District utilizing reservoirs were obtained in 1985 as part of the *Tailwater Recovery Demonstration Program Study* (Boyle Engineering Corporation, 1990) and are summarized in **Table A1** in **Appendix A**. The total capital costs for typical tailwater recovery systems in the Imperial Irrigation District in 1985 dollars ranged from $241 per acre to $495 per acre with an average cost of $389 per acre (**Table A1**, **Appendix A**). As expected, the total capital investment costs per land area ($/acre) were typically larger for those units serving relatively small areas and, conversely, the unit costs ($/acre) were smaller for individual systems serving larger areas. Further, these systems were designed to hold relatively large volumes of water and utilized large pumping rates thereby resulting in relatively high capital investments. In addition, special pumping units that were specified for these systems resulted in higher costs than traditional tailwater recovery systems.

The primary cost of these tailwater recovery systems, as summarized in the ***1990 Tailwater Recovery Demonstration Program Study*** (Boyle Engineering Corporation, 1990), is the installation of the pipelines for redistribution of the tailwater (**Table A1**, **Appendix A**).

Annual capital costs for reservoir tailwater recovery systems for the Imperial Irrigation District in 1985 are summarized in **Table A2** in **Appendix A**. Annual capital costs for typical tailwater recovery systems in the Imperial Irrigation District ranged from $26.17 per acre per year to $55.21 per acre per year with an average cost of $42.35 per acre per year (**Table A2, Appendix A**).

Annual operation and maintenance costs are given in **Table A3** in **Appendix A** and the combined total annual costs for operating a tailwater recovery system in the Imperial Irrigation District are given in **Table A4** in **Appendix A**. These total annual costs range between $37 and $73 per acre per year with an average of $56 per acre per year (**Table A4**).

The 1985 costs given in **Tables A1, A2, A3 and A4 in Appendix A** were adjusted to July 1999 costs and these data are given in **Tables A5, A6, A7 and A8**, respectively in **Appendix A.** The cost adjustments were made using the composite cost index for the U.S. Bureau of Reclamation Cost Trends (US Bureau of Reclamation, 1999) for January 1985 and July 1999. The total annual costs for reservoir tailwater recovery systems in the Imperial Irrigation District, based on July 1999 cost estimates are given in **Table VI.1**. These total annual costs range from a low of $51 per acre per year to a high of $103 per acre per year and average $78 per acre per year.

A summary of the capital costs for tailwater recovery systems taken from several locations in the U.S. is shown in **Table VI.2**. In most cases, the fixed costs of these tailwater recovery systems are much higher in the Imperial Irrigation District than in most other locations in the U.S. and are in general, the result of larger expenditures for the underground piping systems installed during the **1990 Tailwater Recovery Demonstration Program Study** (Boyle Engineering Corporation, 1990).

Further, as stated in ***1990 Tailwater Recovery Demonstration Program Study*** (Boyle Engineering Corporation, 1990) alternative design strategies, including portable pumping units could be lower than the cost estimates for 1985 given in **Table A1, Appendix A** and adjusted for July 1999 dollars in **Table A5, Appendix A**.

**Agronomic Benefits.** The changes in agronomic practices may result in positive economic values, or in some cases, increased costs may result in negative economic benefits. The economic benefits (or increased costs) realized from the incorporation of tailwater recovery systems for several crops grown in the Imperial Irrigation District are summarized in **Table VI.3**. Included in these estimates are the water savings resulting from the installation of tailwater recovery systems, the fertilizer savings, and the increased labor and management costs for managing tailwater return flow. The total agronomic savings range from a low of a negative of $4.54 per acre (costs exceed benefits) for broccoli to a high of $6.56 per acre for sudan grass.

**Cost of Conservation with Reservoir Tailwater Recovery Systems.** The cost of water conservation for reservoir tailwater recovery systems located in the Imperial Irrigation District is given in **Table VI.4**. Factors included in the cost of conservation include the fixed cost of the tailwater recovery system, maintenance and operating cost of the tailwater recovery system, the potential water savings resulting from the tailwater recovery system, and the agronomic benefits resulting from use of tailwater recovery systems. The resulting cost of conservation range from a low of $59 per acre-foot of water saved for onions to a high of $213 per acre-foot of water saved for wheat. The cost of water conservation for alfalfa was $94 per acre-foot of water saved. A rotation of alfalfa-alfalfa-alfalfa-wheat-lettuce was also analyzed and the resulting cost of water conservation with tailwater recovery systems was $83 per acre-foot of water saved (**Table VI.5**).

**Table VI.1.** Surface irrigation tailwater recovery system costs for the Imperial Irrigation District. Data listed are annual total costs for July 1999 and are updated from Boyle Engineering Corporation (1990).

| Pumpback System # | Area Served acres | Annual Pump Costs 1999 $ | Annual Pipe Costs 1999 $ | Annual Reservoir Costs 1999 $ | Annual Total Costs 1999 $ | Annual Total (F+M) Costs 1999 $/acre | Annual Operating Costs 1999 $/acre | Annual Total Costs 1999 $/acre |
|---|---|---|---|---|---|---|---|---|
| 1 | 165 | 4,970 | 7,314 | 1,063 | 13,347 | 80.89 | 6 | 86.89 |
| 2 | 175 | 3,516 | 8,280 | 1,412 | 13,209 | 75.48 | 6 | 81.48 |
| 3 | 283 | 4,079 | 6,540 | 2,127 | 12,746 | 45.04 | 6 | 51.04 |
| 4 | 152 | 6,636 | 7,053 | 1,065 | 14,754 | 97.07 | 6 | 103.07 |
| 5 | 230 | 3,358 | 10,116 | 886 | 14,360 | 62.44 | 6 | 68.44 |
| | | | | | | | | |
| **Average** | **201** | **4,512** | **7,861** | **1,311** | **13,683** | **72.18** | **6** | **78.18** |

Total annual costs are the sum of the annual capital costs **(Table A6 in Appendix A)** and the annual maintenance and operating costs **(Table A7 in Appendix A)**. Average operating costs ($6 per acre-foot) are taken from SECTION 5.4 of the *Tailwater Recovery Demonstration Program Study, Special Technical Report for the Imperial Irrigation District* (Boyle Engineering Corporation, 1990) where an assumption of 1 acre-foot of recycled tailwater per acre was used to estimate the annual operating cost on a per acre basis.

**Table VI.2.** Capital costs for surface irrigation tailwater recovery systems. Costs have been adjusted to 1999 dollars.

| | **Capital Cost** 1999 $/acre | | |
|---|---|---|---|
| **SOURCE** | **TOTAL** | **ANNUAL** | **REFERENCE** |
| Nebraska (CC371) | 160 | 19 | Selley (1997) |
| Central Valley California | 330 | 40 | Kinney et al. (1977) |
| California | 43 - 214 | 5 – 25 | Schulbach and Meyer (1979) |
| Colorado | 230 - 410 | 27 – 48 | Evans (1978) |
| California – IID | 340 - 698 | 40 – 82 | Boyle (1990) |
| California – IID | 449 | 53 | JMLord (1997) |
| California | 212 | 25 | Moore (1998) |

Costs from each of the sources were indexed to July 1999 using the composite cost index for the Bureau of Reclamation Construction (US Bureau of Reclamation, 1999) Cost Trends for the years 1984 through 1999 and the U.S. Department of Labor Consumer Price Index (US Department of Labor, 1999) for the years from 1971 and 1984.

**Table VI.3**. Agronomic benefits and direct costs for reservoir tailwater recovery systems within the Imperial Irrigation District. Values are for July 1999.

| Crop | Water Applied[2] acft/acre | Tailwater Runoff [3] % | Water Saved [4] acft/acre | Value of Water Saved [5] $/acre | Value of Fertilizer Saved [6] $/acre | Increased Irr Labor Costs [7] $/acre | Total Agronomic Benefits $/acre |
|---|---|---|---|---|---|---|---|
| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| Alfalfa | 6.50 | 13 | 0.85 | 10.99 | 3.00 | 18.00 | -4.02 |
| Broccoli | 2.60 | 28 | 0.73 | 9.46 | 4.00 | 18.00 | -4.54 |
| Carrots | 3.30 | 28 | 0.92 | 12.01 | 7.00 | 22.00 | -2.99 |
| Lettuce | 3.00 | 28 | 0.84 | 10.92 | 8.00 | 16.00 | 2.92 |
| Onions | 4.40 | 28 | 1.23 | 16.02 | 11.00 | 22.00 | 5.02 |
| Sudan | 4.90 | 15 | 0.74 | 9.56 | 5.00 | 8.00 | 6.56 |
| Sugar Beets | 4.00 | 21 | 0.84 | 10.92 | 9.00 | 16.00 | 3.92 |
| Wheat | 2.50 | 14 | 0.35 | 4.55 | 5.00 | 8.00 | 1.55 |

**Table VI.4**. Annual net cost to conserve water with reservoir tailwater recovery systems within the Imperial Irrigation District. Values are for July 1999.

| Crop | Water Saved [8] acft/acre | Capital Costs [9] $/acre | Maintenance Costs [10] $/acre | Operating Costs $/acre | Agronomic Benefits [11] $/acre | Total Cost $/acre | Cost to Conserve $/acre-foot |
|---|---|---|---|---|---|---|---|
| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| Alfalfa | 0.85 | 61.08 | 11.11 | 3.00 | -4.02 | 79.20 | 93.72 |
| Broccoli | 0.73 | 61.08 | 11.11 | 3.00 | -4.54 | 79.72 | 109.50 |
| Carrots | 0.92 | 61.08 | 11.11 | 4.00 | -2.99 | 79.17 | 85.68 |
| Lettuce | 0.84 | 61.08 | 11.11 | 1.00 | 2.92 | 70.26 | 83.65 |
| Onions | 1.23 | 61.08 | 11.11 | 5.00 | 5.02 | 72.17 | 58.58 |
| Sudan | 0.74 | 61.08 | 11.11 | 3.00 | 6.56 | 68.63 | 93.37 |
| Sugar Beets | 0.84 | 61.08 | 11.11 | 4.00 | 3.92 | 72.26 | 86.03 |
| Wheat | 0.35 | 61.08 | 11.11 | 4.00 | 1.55 | 74.63 | 213.23 |

[2] Data from JM Lord, Inc. (1997).
[3] Data from O'Halloran (1990).
[4] Calculated from columns 2 and 3.
[5] Benefits of water savings are calculated using a water cost of $13.00 per acre-foot.
[6] Fertilizer costs are calculated from a 10 % reduction (JM Lord, Inc. 1997).
[7] Irrigation labor and management cost increase 25% above normal amounts.
[8] Data from Table VI.3.
[9] Data from Table A6 in Appendix A.
[10] Data from Table A7 in Appendix A.
[11] Data from Column 8 in Table VI.3.

**Table VI.5**. Annual net cost to conserve water with reservoir tailwater recovery systems utilizing a crop rotation within the Imperial Irrigation District. Values are for July 1999.

| Crop | Water Saved [12] acft/acre | Capital Costs [13] $/acre | Maintenance Costs [14] $/acre | Operating Costs $/acre | Agronomic Benefits [15] $/acre | Total Cost $/acre | Cost to Conserve $/acre-foot |
|---|---|---|---|---|---|---|---|
| **(1)** | **(2)** | **(3)** | **(4)** | **(5)** | **(6)** | **(7)** | **(8)** |
| Alfalfa | 0.85 | 61.08 | 11.11 | 3.00 | -4.02 | 79.20 | 93.72 |
| Alfalfa | 0.85 | 61.08 | 11.11 | 3.00 | -4.02 | 79.20 | 93.72 |
| Alfalfa | 0.85 | 61.08 | 11.11 | 3.00 | -4.02 | 79.20 | 93.72 |
| Wheat | 0.35 | 61.08 | 11.11 | 4.00 | 1.55 | 74.63 | 213.23 |
| Lettuce | 0.84 | 61.08 | 11.11 | 1.00 | 2.92 | 70.26 | 83.65 |
| **Rotation Total** | 3.73 | 244.30 | 44.42 | 14.00 | -7.58 | 310.30 | 83.30 |

[1]Data from Column 4 in Table VI.3.
[2]Data from Table A6 in Appendix A.
[3] Data from Table A7 in Appendix A.
[4] Data from Column 8 in Table VI.3.

## VI. C. Economics of Sump Tailwater Reuse Systems

**Capital and Operating Costs.** Estimates for the total capital costs for sump tailwater recovery systems for irrigated areas of 73, 145, and 290 acres within the Imperial Irrigation District are given in **Appendix B (Tables B1, B2, and B3)** and are summarized in **Table VI.6**. The total capital costs (in 1999 dollars) for typical sump tailwater recovery systems within the Imperial Irrigation District range between $201 and $342 per acre with an average cost of $255 per acre.

As expected, the total capital investment costs per land area ($/acre) are typically larger for those units serving relatively smaller areas and conversely the unit costs ($/acre) were smaller for individual systems serving larger areas. The primary cost of these tailwater recovery systems is the installation of the pipelines for redistribution of the tailwater.

Average annual capital costs for owning and operating typical sump tailwater recovery systems in the Imperial Irrigation District range from $21 to $37 per acre and average $27 per acre (**Table VI.7**). Estimated costs for annual maintenance costs are given in **Table VI.8** and range between $3 and $7 per acre.

**Agronomic Benefits.** The changes in agronomic practices may result in positive economic values, or in some cases, increased costs may result in negative economic benefits. The economic benefits (or increased costs) realized from the incorporation of tailwater recovery systems for several crops grown in the Imperial Irrigation District are summarized in **Table VI.9**. Included in these estimates are the water savings resulting from the installation of tailwater recovery systems, the fertilizer savings, and the increased labor and management costs for managing tailwater return flow. The total savings range between a negative $4.54 per acre for carrots (costs exceed benefits) to a high of $6.56 for sudan grass. For some crops, increased labor and management costs for sump tailwater recovery systems more than offset the benefits from water savings and reduced fertilizer costs.

**Cost of Conservation with Sump Tailwater Recovery Systems.** The cost of water conservation resulting from the use of sump tailwater recovery systems within the Imperial Irrigation District are given in **Table VI.10**. Factors included in the cost of conservation include the capital cost and the maintenance and operating costs of the tailwater recovery system plus the agronomic benefits resulting from use of tailwater recovery systems. The cost of conservation varies from a low of $26 per acre-foot of water saved for onions (average value given in **Table VI.10**) to a high of $91 per acre-foot of water saved for wheat (average value given in **Table VI.10**). The cost of water conservation for alfalfa was $47 per acre-foot of water saved. A rotation of alfalfa-alfalfa-alfalfa-wheat-lettuce was also analyzed and the resulting cost of water conservation with tailwater recovery systems was $40 per acre-foot of water saved **(Table VI.11).**

**Table VI.6.** Total capital costs for sump tailwater recovery systems within the Imperial Irrigation District.[1] Values are for July 1999.

| Tailwater Recovery System # | Crop or Net Area Served Acres | Total Pump Cost 1999 $ | Total Pipe Cost[2] 1999 $ | Total Sump Cost 1999 $ | Total Cost 1999 $ | Total Cost 1999 $/acre |
|---|---|---|---|---|---|---|
| 1 | 73 | 6,242 | 16,607 | 2,116 | 24,965 | 342 |
| 2 | 145 | 6,678 | 22,780 | 2,700 | 32,158 | 222 |
| 3 | 290 | 7,237 | 40,886 | 10,103 | 58,226 | 201 |
| AVERAGE | 169 | 6,719 | 26,758 | 4,973 | 38,450 | 255 |

**Table VI.7.** Annual ownership costs for sump tailwater recovery systems within the Imperial Irrigation District.[1] Values are for July 1999.

| Tailwater Recovery System # | Crop or Net Area Served Acres | Annual Cost for Pump 1999 $ | Annual Cost for Pipe[2] 1999 $ | Annual Cost for Sump 1999 $ | Total Annual Cost 1999 $ | Total Annual Cost 1999 $/acre |
|---|---|---|---|---|---|---|
| 1 | 73 | 821 | 1,698 | 216 | 2,735 | 37.47 |
| 2 | 145 | 878 | 2,329 | 276 | 3,484 | 24.02 |
| 3 | 290 | 951 | 4,181 | 1,033 | 6,166 | 21.26 |
| AVERAGE | 169 | 883 | 2,736 | 509 | 4,128 | 27.58 |

[1] Calculation data are given in Appendix B (Tables B1, B2 and B3).
[2] Includes engineering costs and taxes.

**Table VI.8.** Annual operating and maintenance costs for sump tailwater recovery systems within the Imperial Irrigation District.[16] Values are for July 1999.

| Tailwater Recovery System # | Crop Area Served Acres | Annual O&M Pump Cost 1999 $ | Annual O&M Pipe Cost 1999 $ | Annual O&M Pond Cost 1999 $ | Total O&M Cost 1999 $ | Total O&M Cost 1999 $/acre |
|---|---|---|---|---|---|---|
| 1 | 73 | 375 | 83 | 21 | 479 | 6.56 |
| 2 | 145 | 401 | 114 | 27 | 542 | 3.74 |
| 3 | 290 | 434 | 204 | 101 | 740 | 2.55 |
| AVERAGE | 169 | 403 | 134 | 50 | 587 | 4.28 |

**Table VI.9.** Annual agronomic benefits from sump tailwater recovery systems within the Imperial Irrigation District. Values are for July 1999.

| Crop | Water Applied [17] acft/ac | Tailwater Runoff [18] % | Water Saved [19] acft/ac | Value of Water Saved [20] $/acre | Value of Fertilizer Saved [21] $/acre | Increased Labor Costs [22] $/acre | Total Agronomic Benefits $/acre |
|---|---|---|---|---|---|---|---|
| (1) | (2) | (3) | (3) | (4) | (5) | (6) | (7) |
| Alfalfa | 6.5 | 13 | 0.85 | 10.99 | 3.00 | 18.00 | -4.02 |
| Broccoli | 2.6 | 28 | 0.73 | 9.46 | 4.00 | 18.00 | -4.54 |
| Carrots | 3.3 | 28 | 0.92 | 12.01 | 7.00 | 22.00 | -2.99 |
| Lettuce | 3 | 28 | 0.84 | 10.92 | 8.00 | 16.00 | 2.92 |
| Onions | 4.4 | 28 | 1.23 | 16.02 | 11.00 | 22.00 | 5.02 |
| Sudan | 4.9 | 15 | 0.74 | 9.56 | 5.00 | 8.00 | 6.56 |
| Sugar Beets | 4 | 21 | 0.84 | 10.92 | 9.00 | 16.00 | 3.92 |
| Wheat | 2.5 | 14 | 0.35 | 4.55 | 5.00 | 8.00 | 1.55 |

[16] Values are given in Appendix B (Tables B1, B2 and B3).
[17] Data from JM Lord, Inc. (1997).
[18] Data from O'Halloran (1990).
[19] Calculated from columns 2 and 3.
[20] Benefits from water savings are calculated using a water cost of $13 per acre-foot.
[21] Fertilizer costs are calculated from a 10 % reduction (JM Lord, Inc. 1997).
[22] Irrigation labor and management cost increase 25% above normal amounts.

**Table VI.10.** Annual net cost to conserve water utilizing sump tailwater recovery systems within the Imperial Irrigation District. Values are for July 1999.[1]

| Crop | Area Irrigated acres | Capital Costs $/acre | Maintenance Costs $/acre | Operating Costs $/acre | Agronomic Benefits $/acre | Total Cost $/acre | Total Savings acft/acre | Cost to Conserve $/acre-foot |
|---|---|---|---|---|---|---|---|---|
| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
| Alfalfa | 73 | 37.47 | 6.56 | 3.38 | -4.02 | 51.42 | 0.85 | 60.85 |
| | 145 | 24.02 | 3.74 | 3.38 | -4.02 | 35.15 | 0.85 | 41.60 |
| | 290 | 21.26 | 2.55 | 3.38 | -4.02 | 31.21 | 0.85 | 36.93 |
| | | | | | | | **Average** | **46.46** |
| Broccoli | 73 | 37.47 | 6.56 | 2.91 | -4.54 | 51.47 | 0.73 | 70.71 |
| | 145 | 24.02 | 3.74 | 2.91 | -4.54 | 35.21 | 0.73 | 48.36 |
| | 290 | 21.26 | 2.55 | 2.91 | -4.54 | 31.26 | 0.73 | 42.94 |
| | | | | | | | **Average** | **54.00** |
| Carrots | 73 | 37.47 | 6.56 | 3.70 | -2.99 | 50.71 | 0.92 | 54.88 |
| | 145 | 24.02 | 3.74 | 3.70 | -2.99 | 34.44 | 0.92 | 37.28 |
| | 290 | 21.26 | 2.55 | 3.70 | -2.99 | 30.50 | 0.92 | 33.00 |
| | | | | | | | **Average** | **41.72** |
| Lettuce | 73 | 37.47 | 6.56 | 3.36 | 2.92 | 44.47 | 0.84 | 52.94 |
| | 145 | 24.02 | 3.74 | 3.36 | 2.92 | 28.20 | 0.84 | 33.57 |
| | 290 | 21.26 | 2.55 | 3.36 | 2.92 | 24.25 | 0.84 | 28.87 |
| | | | | | | | **Average** | **38.46** |
| Onions | 73 | 37.47 | 6.56 | 4.93 | 5.02 | 43.94 | 1.23 | 35.66 |
| | 145 | 24.02 | 3.74 | 4.93 | 5.02 | 27.67 | 1.23 | 22.46 |
| | 290 | 21.26 | 2.55 | 4.93 | 5.02 | 23.72 | 1.23 | 19.26 |
| | | | | | | | **Average** | **25.79** |
| Sudan | 73 | 37.47 | 6.56 | 2.94 | 6.56 | 40.41 | 0.74 | 54.98 |
| | 145 | 24.02 | 3.74 | 2.94 | 6.56 | 24.14 | 0.74 | 32.85 |
| | 290 | 21.26 | 2.55 | 2.94 | 6.56 | 20.20 | 0.74 | 27.48 |
| | | | | | | | **Average** | **38.44** |
| Sugar Beets | 73 | 37.47 | 6.56 | 3.36 | 3.92 | 43.47 | 0.84 | 51.75 |
| | 145 | 24.02 | 3.74 | 3.36 | 3.92 | 27.20 | 0.84 | 32.38 |
| | 290 | 21.26 | 2.55 | 3.36 | 3.92 | 23.25 | 0.84 | 27.68 |
| | | | | | | | **Average** | **37.27** |
| Wheat | 73 | 37.47 | 6.56 | 1.40 | 1.55 | 43.88 | 0.35 | 125.36 |
| | 145 | 24.02 | 3.74 | 1.40 | 1.55 | 27.61 | 0.35 | 78.88 |
| | 290 | 21.26 | 2.55 | 1.40 | 1.55 | 23.66 | 0.35 | 67.60 |
| | | | | | | | **Average** | **90.62** |

[1] Calculation data are given in Appendix B (Tables B1, B2, and B3) and data in Tables VI.6 through VI.9.

**Table VI.11.** Annual net cost to conserve water utilizing sump tailwater recovery systems for a crop rotation within the Imperial Irrigation District. Values are for July 1999.[23]

| Crop | Area Irrigated acres | Capital Costs $/acre | Maintenance Costs $/acre | Operating Costs $/acre | Agronomic Benefits $/acre | Total Cost $/acre | Water Savings acft/acre | Cost to Conserve $/acre-foot |
|---|---|---|---|---|---|---|---|---|
| **(1)** | **(2)** | **(3)** | **(4)** | **(5)** | **(6)** | **(7)** | **(8)** | **(9)** |
| Alfalfa | 73 | 37.47 | 6.56 | 3.38 | -4.02 | 51.42 | 0.85 | 60.85 |
| | 145 | 24.02 | 3.74 | 3.38 | -4.02 | 35.15 | 0.85 | 41.60 |
| | 290 | 21.26 | 2.55 | 3.38 | -4.02 | 31.21 | 0.85 | 36.93 |
| | | | | | | | **Average** | **46.46** |
| Alfalfa | 73 | 37.47 | 6.56 | 3.38 | -4.02 | 51.42 | 0.85 | 60.85 |
| | 145 | 24.02 | 3.74 | 3.38 | -4.02 | 35.15 | 0.85 | 41.60 |
| | 290 | 21.26 | 2.55 | 3.38 | -4.02 | 31.21 | 0.85 | 36.93 |
| | | | | | | | **Average** | **46.46** |
| Alfalfa | 73 | 37.47 | 6.56 | 3.38 | -4.02 | 51.42 | 0.85 | 60.85 |
| | 145 | 24.02 | 3.74 | 3.38 | -4.02 | 35.15 | 0.85 | 41.60 |
| | 290 | 21.26 | 2.55 | 3.38 | -4.02 | 31.21 | 0.85 | 36.93 |
| | | | | | | | **Average** | **46.46** |
| Wheat | 73 | 37.47 | 6.56 | 1.40 | 1.55 | 43.88 | 0.35 | 125.36 |
| | 145 | 24.02 | 3.74 | 1.40 | 1.55 | 27.61 | 0.35 | 78.88 |
| | 290 | 21.26 | 2.55 | 1.40 | 1.55 | 23.66 | 0.35 | 67.60 |
| | | | | | | | **Average** | **90.62** |
| Lettuce | 73 | 37.47 | 6.56 | 3.36 | 2.92 | 44.47 | 0.84 | 52.94 |
| | 145 | 24.02 | 3.74 | 3.36 | 2.92 | 28.20 | 0.84 | 33.57 |
| | 290 | 21.26 | 2.55 | 3.36 | 2.92 | 24.25 | 0.84 | 28.87 |
| | | | | | | | **Average** | **38.46** |
| **Rotation** | 73 | 149.88 | 26.23 | 14.90 | -7.58 | 198.58 | 3.73 | 53.31 |
| | 145 | 96.10 | 14.94 | 14.90 | -7.58 | 133.51 | 3.73 | 35.84 |
| | 290 | 85.04 | 10.20 | 14.90 | -7.58 | 117.72 | 3.73 | 31.60 |
| | | | | | | | **Average** | **40.25** |

[23] Calculation data are given in Appendix B (Tables B1, B2, and B3) and data in Tables VI.6 through VI.9.

## VI. D. Economics of Tailwater Management of Cracking Soils

**The Imperial Irrigation District case.** On those cracking-clay soils present within the Imperial Irrigation District the volume or depth of irrigation water infiltrated does not depend on the ponding time after the cracks swell shut. This infiltration function behavior affects the rate that water spreads or advances along a sloped border or furrow. Van der Tak and Grismer (1987) as well as Waller and Wallender (1991) observed linear advance on Imperial clay soils and the latter authors reported linear advance on Tulare soils in the San Joaquin Valley. A volume balance model of surface irrigation on cracking-clay soils was developed by Waller and Wallender (1991). The model uses a spatially constant infiltration volume per unit area along the field equivalent to the difference in applied water and surface storage volumes during the advance phase of the irrigation and the model estimates infiltration amounts and the volume of water to apply to a field to avoid or control runoff (tailwater).

For sloped fields on Imperial clay soils in which inflow rate is steady and the infiltration quickly approaches zero after ponding, the flow rate leaving the distal end increases sharply to approximately the flow rate applied at the upstream end. The runoff remains steady until water is stopped at the upstream end. Any tailwater runoff following crack filling at the end of the field end is wasted.

**Tail Water Management and Reduced Runoff.** Linear advance of flow and steady surface flow along the border indicates that the soil infiltration rate is zero. Measurements of infiltration from changes in soil moisture were independent of measured intake opportunity time and thus demonstrated that there was no correlation between intake opportunity time and infiltration.

In summary, a single measurement of advance time to a fractional distance along the border combined with a knowledge of inflow rate and flow depth at the upstream end can be used to calculate the average infiltration depth as well as cutoff time to avoid runoff (Waller and Wallender (1991)). This technique, when applied to the cracking-clay soils within the Imperial Irrigation District, could significantly reduce the tailwater from each irrigation event.

The procedures of Waller and Wallender (1991) were used by Grismer and Bali (2001) for sudan grass grown in the Imperial Irrigation District and by Bali et al. (2001) for alfalfa grown in the Imperial Irrigation District. Throughout a three year production for alfalfa a net reduction in annual water application of approximately 28 percent was achieved with no apparent loss in alfalfa hay yield or quality (Bali et al., 2001). Reduced water application occurred through reduction of tailwater runoff to less than two percent throughout the study. It was suggested that the reduced-runoff method may be successfully applied in the Imperial Irrigation District as a water conservation procedure. Tod and Grismer (1999) determined that the production costs with use of the method are slightly less than the IID average, suggesting that this method is also economically feasible. Similar results were obtained for sudan grass grown in the Imperial Irrigation District (Grismer and Bali, 2001). For this crop, the reduced-runoff method reduced the seasonal irrigation water application by approximately 1.3 feet through a reduction of tailwater runoff without incurring additional production costs.

**Agronomic Benefits.** The changes in agronomic practices may result in positive economic values, or in some cases, increased costs may result in negative economic benefits. The economic benefits (or increased costs) realized from improved irrigation management of cracking-clay soils for several crops grown in the Imperial Irrigation District are summarized in **Table VI.12**. Included in these estimates are the water savings resulting from improved irrigation practices, the fertilizer savings, and the increased labor and management costs for managing tailwater return flows. The total savings range between a negative $4.54 (therefore increased cost) per acre for broccoli to a positive $6.56 per acre for sudan grass. For some crops, the value of water and fertilizer saved through improved irrigation management was more than offset with the increased labor costs.

**Cost of Conservation with Tailwater Management.** The cost of water conservation through improved irrigation water management within the Imperial Irrigation District is given in **Table VI.13**. Factors included in the cost of conservation are the agronomic benefits resulting from improved irrigation management. The cost of conservation varies from improved irrigation water management practices varies from a cost of $6.23 per acre-foot of water saved for broccoli to a net positive benefit of $9 per acre-foot of water saved for sudan grass. Negative values of column 6 (Cost to Conserve) in Table **VI.13** indicate that if the cost to conserve water is negative then the producer will make more money using tailwater management than current practices. A rotation of alfalfa-alfalfa-alfalfa-wheat-lettuce was also analyzed and the resulting cost of water conservation with improved water management practices was $2 per acre-foot of water saved (**Table VI.14**).

## VI. E. Comparison of the Economics of Tailwater Recovery

A comparison of the costs of water conservation ranging from the installation of tailwater recovery systems to incorporation of improved irrigation water management on cracking-clay soils is given in **Table VI.15** and is shown in **Figure VI.1**. There are several alternative (and available) technologies, which can be appropriately and effectively utilized within the Imperial Irrigation District to manage tailwater runoff. These range from the capital-intensive design, installation and management of reservoir reuse systems to the application of improved irrigation management on cracking-clay soils. In all cases, there appears to be several economically attractive tailwater management alternatives that result in water conservation costs between $30 and $60 per acre-foot of conserved tailwater (**Table VI.15** and **Figure VI.1**). In some cases, on cracking-clay soils, improved water management will actually same money over current practices.

**Table VI.12.** Annual agronomic benefits from improved irrigation on cracking-clay soils within the Imperial Irrigation District. Values are for July 1999.

| Crop | Water Applied[24] acft/ac | Tailwater Runoff [25] % | Water Saved [26] acft/ac | Value of Water Saved [27] $/acre | Value of Fertilizer Saved [28] $/acre | Increased Labor Costs [29] $/acre | Total Agronomic Benefits $/acre |
|---|---|---|---|---|---|---|---|
| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| Alfalfa | 6.5 | 13 | 0.85 | 10.99 | 3.00 | 18.00 | -4.02 |
| Broccoli | 2.6 | 28 | 0.73 | 9.46 | 4.00 | 18.00 | -4.54 |
| Carrots | 3.3 | 28 | 0.92 | 12.01 | 7.00 | 22.00 | -2.99 |
| Lettuce | 3 | 28 | 0.84 | 10.92 | 8.00 | 16.00 | 2.92 |
| Onions | 4.4 | 28 | 1.23 | 16.02 | 11.00 | 22.00 | 5.02 |
| Sudan | 4.9 | 15 | 0.74 | 9.56 | 5.00 | 8.00 | 6.56 |
| Sugar Beets | 4 | 21 | 0.84 | 10.92 | 9.00 | 16.00 | 3.92 |
| Wheat | 2.5 | 14 | 0.35 | 4.55 | 5.00 | 8.00 | 1.55 |

**Table VI.13.** Annual cost to conserve water from improved irrigation on cracking-clay soils within the Imperial Irrigation District. Values are for July 1999.

| Crop | Reuse System Cost $/acre | Agronomic Benefits [30] $/acre | Total Cost $/acre | Water Savings [31] acft/acre | Cost to Conserve $/acre-foot |
|---|---|---|---|---|---|
| (1) | (2) | (3) | (4) | (5) | (6) |
| Alfalfa | 0 | -4.02 | 4.02 | 0.85 | 4.75 |
| Broccoli | 0 | -4.54 | 4.54 | 0.73 | 6.23 |
| Carrots | 0 | -2.99 | 2.99 | 0.92 | 3.23 |
| Lettuce | 0 | 2.92 | -2.92 | 0.84 | -3.48 |
| Onions | 0 | 5.02 | -5.02 | 1.23 | -4.07 |
| Sudan | 0 | 6.56 | -6.56 | 0.74 | -8.92 |
| Sugar Beets | 0 | 3.92 | -3.92 | 0.84 | -4.67 |
| Wheat | 0 | 1.55 | -1.55 | 0.35 | -4.43 |

[24] Data from JM Lord, Inc. (1997).
[25] Data from O'Halloran (1990).
[26] Calculated form columns 2 and 3.
[27] Benefits from water savings are calculated using a water cost of $13 per acre-foot.
[28] Fertilizer costs are calculated from a 10 % reduction (JM Lord, Inc. 1997).
[29] Irrigation labor and management cost increase 25% above normal amounts.
[30] Data from Table VI.12.
[31] Data from Table VI.12.

**Table VI.14.** Annual cost to conserve water from improved irrigation on cracking-clay soils with a crop rotation within the Imperial Irrigation District. Values are estimated for July 1999.

| Crop | Reuse System Cost $/acre | Agronomic Benefits $/acre | Total Cost $/acre | Water Savings Acft/acre | Cost to Conserve $/acre-foot |
|---|---|---|---|---|---|
| (1) | (2) | (3) | (4) | (5) | (6) |
| Alfalfa | 0 | -4.02 | 4.02 | 0.85 | 4.75 |
| Alfalfa | 0 | -4.02 | 4.02 | 0.85 | 4.75 |
| Alfalfa | 0 | -4.02 | 4.02 | 0.85 | 4.75 |
| Wheat | 0 | 1.55 | -1.55 | 0.35 | -4.43 |
| Lettuce | 0 | 2.92 | -2.92 | 0.84 | -3.48 |
| **ROTATION** | 0 | -7.58 | 7.58 | 3.73 | 2.03 |

**Table VI.15.** Annual net cost ($/acre-foot) to conserve water from tailwater recovery systems and improved irrigation on cracking-clay soils within the Imperial Irrigation District. Values are for July 1999.

| CROP | Reservoir Reuse Systems [32] $/acft | Sump Reuse Systems [33] $/acft | Improved Management Practices [34] $/acft |
|---|---|---|---|
| **Alfalfa** | 93.72 | 46.46 | 4.75 |
| **Broccoli** | 109.50 | 54.00 | 6.23 |
| **Carrots** | 85.68 | 41.72 | 3.23 |
| **Lettuce** | 83.65 | 38.46 | -3.48 |
| **Onions** | 58.58 | 25.79 | -4.07 |
| **Sudan** | 93.37 | 38.44 | -8.92 |
| **Sugar Beets** | 86.03 | 37.27 | -4.67 |
| **Wheat** | 213.23 | 90.62 | -4.43 |
| **Rotation** | 83.30 | 40.25 | 2.03 |

[32] Data from Table VI.4 for Reservoir Tailwater Recovery Systems.
[33] Data from Table VI.10 for Sump Tailwater Recovery Systems.
[34] Data from Table VI.13 for Improved Irrigation Water Management on Cracking-Clay Soils.

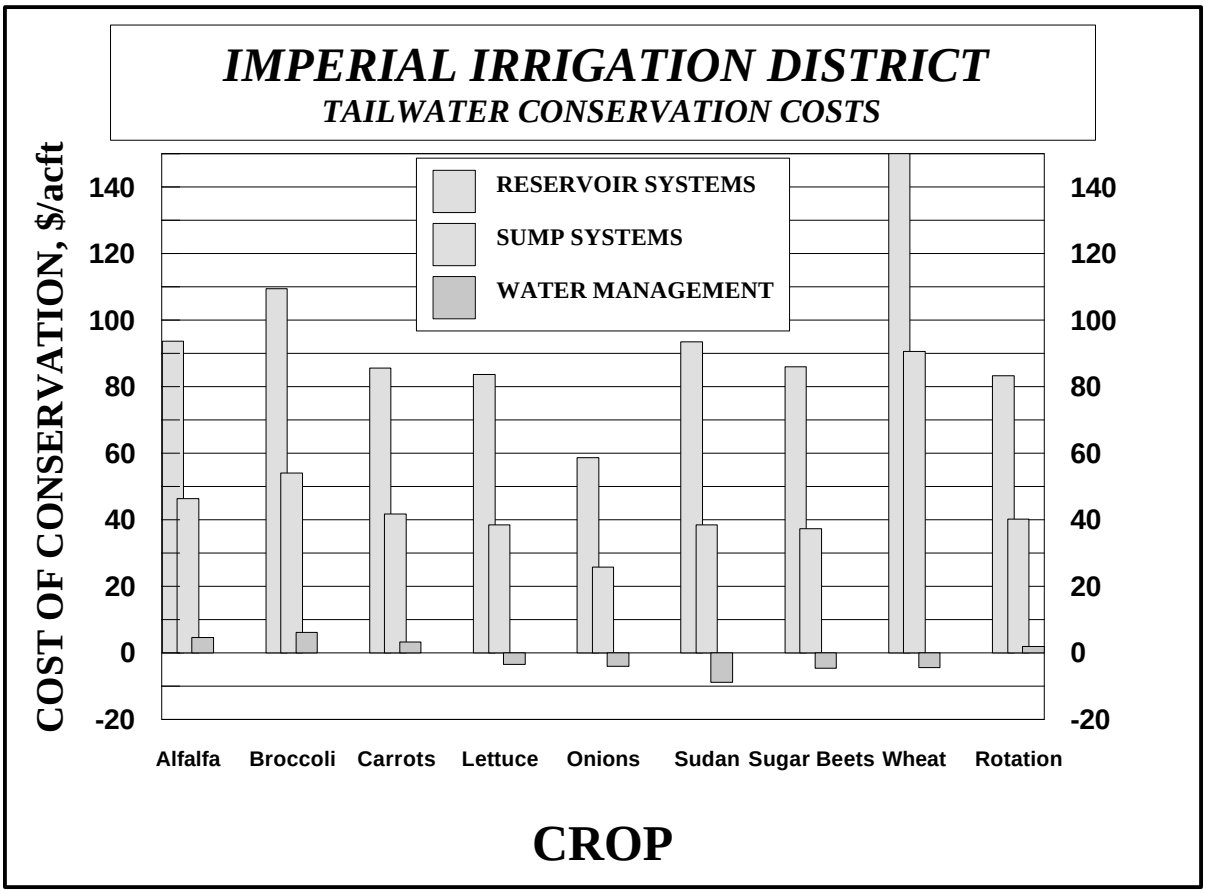



**Figure VI.1**. Comparison of the water conservation costs from reservoir tailwater recovery systems, sump tailwater recovery systems and improved irrigation water management on cracking clay soils within the Imperial Irrigation District.

## VII. TAILWATER

Key points regarding surface irrigation tailwater runoff within the Imperial Irrigation District are listed below.

**1. Non-recirculated tailwater runoff within the Imperial Irrigation District is a non-beneficial and unreasonable use of water and is thus, a waste of water.**

As cited by the State of California Water Resources Control Board in Decision 1600 (Decision 1600, Jun 84), the State's policy on prevention of waste and unreasonable use of water is based upon Article X, Section 2 of the California Constitution, which provides (italics added for emphasis):

*"It is hereby declared that because of the conditions prevailing in this State the general welfare requires that the water resources of the State be put to beneficial use to the fullest extent of which they are capable, and that the waste or unreasonable use or unreasonable method of use of water be prevented, and that the conservation of such waters is to be exercised with a view to the reasonable and beneficial use thereof in the interest of the people and for the public welfare. The right to water or to the use or flow of water in or from any natural stream or water course in this State is and shall be limited to such water as shall be reasonably required for the beneficial use to be served, and such right does not and shall not extend to the waste or unreasonable use or unreasonable method of use or unreasonable method of diversion of water. This section shall be self-executing and the Legislature may also enact laws in the furtherance of the policy in this section contained."*

The Water Resources Control Board in Decision 1600 (Decision 1600, Jun 84) concluded that *"The Board believes that a thorough review of the record leaves no doubt that the Department (of Water Resources) concluded that IID practices result in a misuse of water."* (italics added for emphasis).

As cited by the State of California Water Resources Control Board; The California Supreme Court has described the nature of reasonable and beneficial use requirement of the California Constitution as follows (italics added for emphasis):

*"What is beneficial use, of course, depends upon the facts and circumstances of each case. What may be a reasonable beneficial use where water is present in excess of all needs, would not be a reasonable beneficial use in an area of great scarcity and great need. What is a beneficial use at one time may, because of changing conditions, become a waste at a later time."*

The State Water Resources Control Board in Decision 1600 (Decision 1600, Jun 84*) "… there is considerable evidence that various components of the water loss within IID could be reduced through reasonable conservation measures."* (italics added for emphasis).

The State Water Resources Control Board of the State of California in its Decision 1600 (Decision 1600, Jun 84) ordered that the Imperial Irrigation District shall do the following (italics added for emphasis):

*1.4 "Submit evidence to the Board by February 1, 1985, demonstrating that the District has fully implemented its announced policy of monitoring the tailwater discharge of all fields receiving water deliveries.*

*1.5 Repair or require the water users within the District to repair defective tailwater structures and approach channels by February 1, 1985. The District shall also submit a plan by February 1, 1985, to ensure that the tailwater structures and approach channels are properly maintained on a continuing basis.*

1.6 *Develop and submit by February 1, 1985, a water accounting and monitoring procedure which will result in quantifying the following with reasonable accuracy: (1) actual deliveries to farmers' headgates, (2) tailwater, (3) canal spills, (4) canal seepage and leachwater. The water accounting procedure shall be capable of normalizing the data in order to make the information comparable from year to year. The District shall specify a schedule for implementing the water accounting procedure."*

The Water Control Board further ordered the Imperial Irrigation District to submit a "detailed and comprehensive plan by February 1, 1985, which includes the following elements (italics added for emphasis):

*"a. Tailwater Control: The plan shall specify maximum acceptable tailwater limits and shall state how such limits were determined. A means of reducing tailwater from all deliveries to the specified limits within one year of the plan's initial implementation shall be specified. The plan shall describe an accurate method to be used for measuring tailwater from fields receiving deliveries. The plan shall include an evaluation of the present tailwater monitoring program, particularly the requirement that assessment for excessive tailwater must be preceded by two measurements at least nine hours apart. The plan shall specify in detail the role which an expanded irrigation education will play in assisting to reduce tailwater."*

Utilizing a water balance model for the Imperial Irrigation District, Jensen and Walter (1997) calculated surface irrigation tailwater runoff as a closure term. Surface irrigation tailwater runoff from the Imperial Irrigation District for 1996 was approximately 257,000 acre-feet or 66 percent more than that calculated for 1987. The calculated agricultural tailwater runoff for the 1987-1996 time period (Jensen and Walter, 1997) is shown in **Figure VII.1**. The amount of agricultural tailwater runoff as a percentage of the volume of water delivered by the Imperial Irrigation District to agricultural users is shown in **Figure VII.2**. These data demonstrate the dramatic increase in surface irrigation tailwater runoff from the Imperial Irrigation District during the 1987-96 time period, in direct contrast to the signed contract by IID with Metropolitan Water District of Southern California (MWD) to conserve and transfer 106,000 acre feet per year.

The tailwater runoff data in **Figure VII.1** and **Figure VII.2** are further supported by the increase in the volume of drainage to the Salton Sea from the Imperial Irrigation District during the same time period (**Figure VII.3** and **Figure VII.4**). Nearly one-third of the water delivered to agricultural users is deposited in the Salton Sea (**Figure VII.4**). The data presented in Figure

**VII.3** and **Figure VII.4** clearly demonstrates that the irrigation flows to the Salton Sea from the Imperial Irrigation District has substantially increased between the date of the above Water Control Board orders issued in 1984 and 1995. Cleary, the orders of the California State Water Resources Control Board in Decision 1600 (Decision 1600, Jun 84) have not been followed and further, the actual irrigation water waste taking place from the Imperial Irrigation District has not improved between 1994 and today.

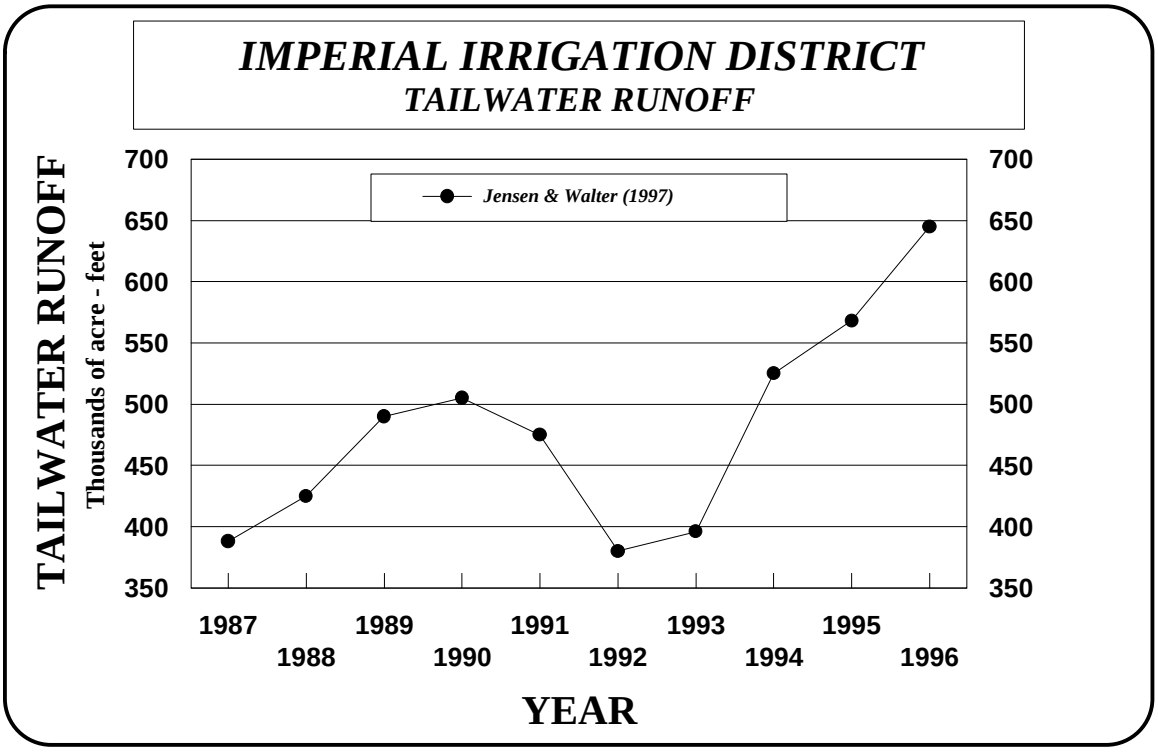



**Figure VII.1**. Surface irrigation tailwater runoff from the Imperial Irrigation District. Adapted from Jensen and Walter (1997).

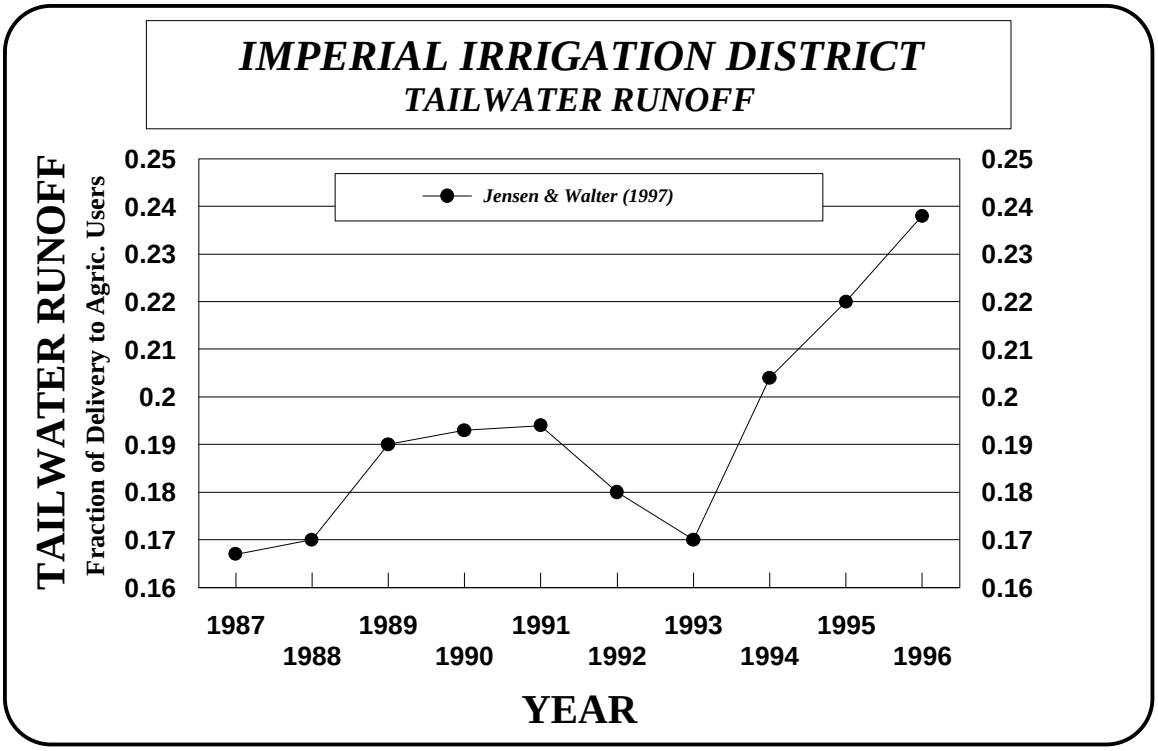



**Figure VII.2**. Surface irrigation tailwater runoff from the Imperial Irrigation District. Adapted from Jensen and Walter (1997).

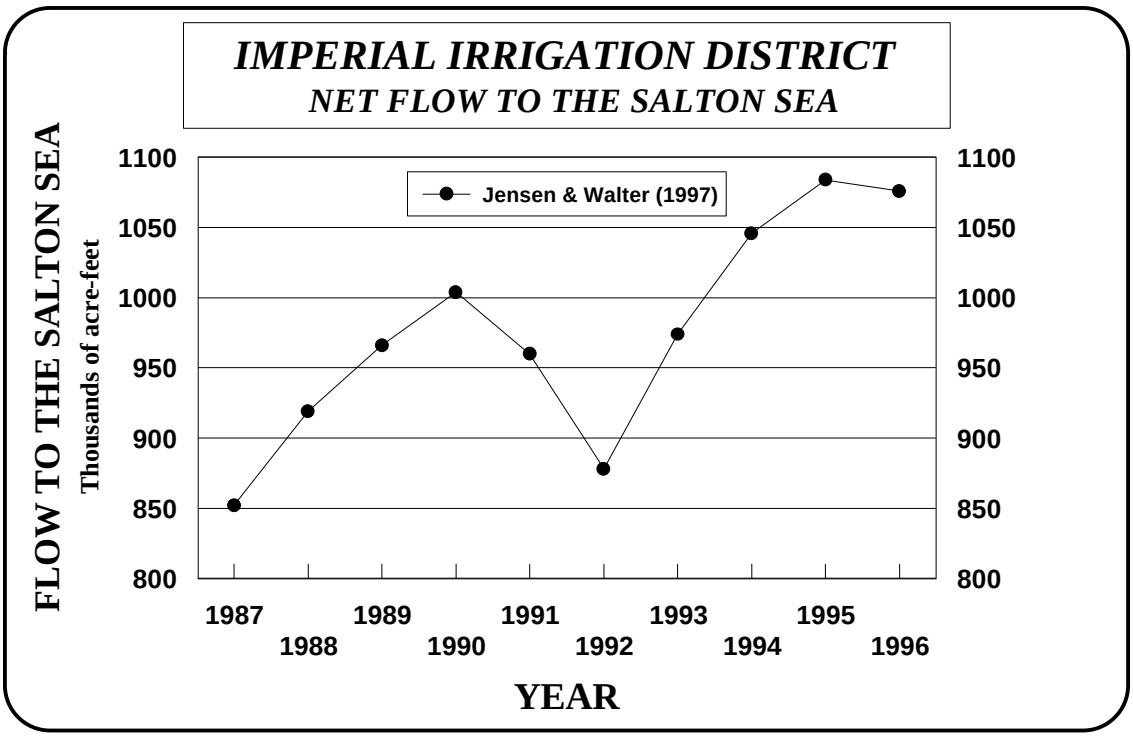



**Figure VII.3**. Flow to the Salton Sea from the Imperial Irrigation District. Adapted from Jensen and Walter (1997).

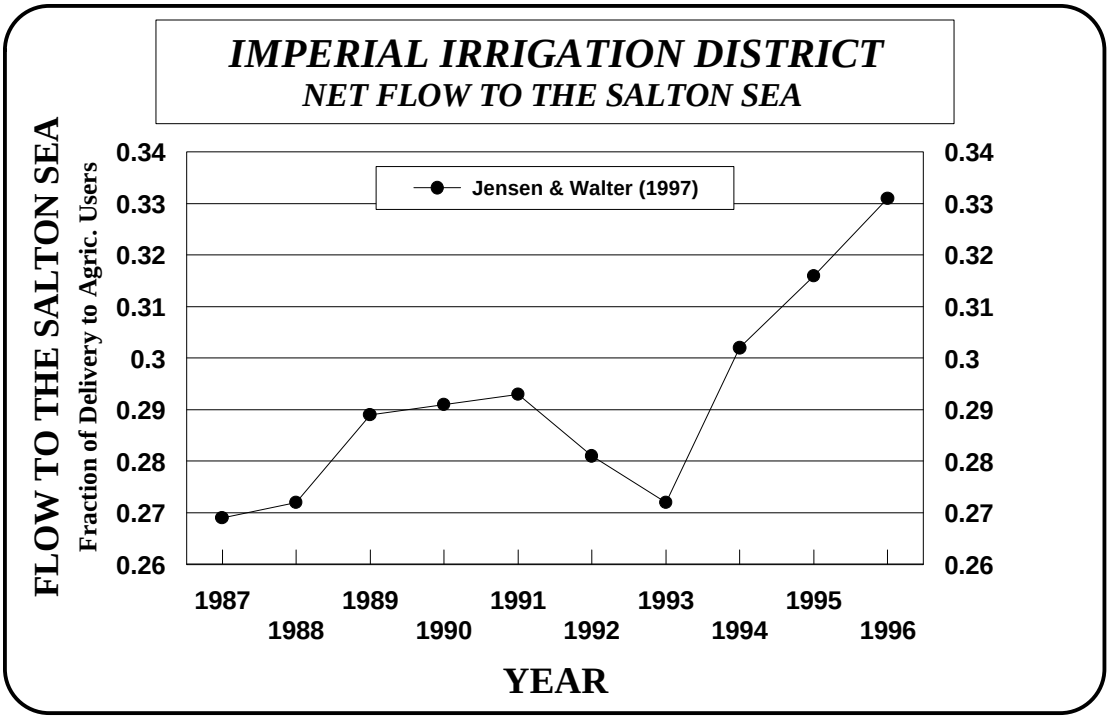



**Figure VII.4**. Flow to the Salton Sea from the Imperial Irrigation District. Adapted from Jensen and Walter (1997).

**2. There are several reasonable and economical methods for effectively eliminating tailwater runoff within the Imperial Irrigation District.**

A comprehensive analysis of potential application of alternative tailwater recovery systems, within the Imperial Irrigation District, was performed by the Water Advisory Committee (**Figure VI.1**). A comparison of the costs of water conservation was determined for a range of tailwater recovery systems and included the incorporation of improved irrigation water management on cracking-clay soils. There are several alternative (and available) technologies, which can be appropriately and effectively utilized within the Imperial Irrigation District to eliminate tailwater runoff within the Imperial Irrigation District. These range from the capital-intensive design, installation and management of reservoir water reuse systems, which have been evaluated on several farms in the District (Boyle Engineering Corporation, 1990) to the application of improved irrigation management of cracking-clay soils (Bali, et al., 2001; Grismer and Bali, 2001; Tod and Grismer, 1999). In all cases, there appears to be several economical tailwater management alternatives that result in water conservation costs between $30 and $60 per acre-foot of conserved tailwater. In many cases, the utilization of improved irrigation water management on cracking-clay soils will actually save money over current practices of not controlling tailwater.

**3. The Imperial Irrigation District has not effectively put in place tailwater runoff conservation practices similar to those already in existence in similar irrigation districts in both California and other states in the U.S.**

Several studies have documented the amount of tailwater runoff taking place within the Imperial Irrigation District (Boyle Engineering Corporation, 1990; O'Halloran, 1990; Oster, et al., 1986). These include the results of measurements taken by the District staff (O'Halloran, 1990). These studies indicate that the magnitude of tailwater runoff from the individual fields has not decreased.

Provisions for the capture, storage and recovery of tailwater must be included in any graded furrow or corrugation irrigation system if effective use of irrigation water is to be achieved (Burt, 1995). For efficient and effective management of surface irrigation systems the tailwater runoff should be collected and reused on the farm. Publications from the University of California (Schulbach and Meyer, 1979) as well as other states have been available for several years. Further, prior to the sale of water from the Imperial Irrigation District to MWD, there is no indication that the District had any interest in conserving tailwater runoff.

A recent publication by Burt, et al. (1997) has provided further insight into definition and clarification regarding beneficial versus nonbeneficial use of irrigation water as well as the reasonable versus nonreasonable use of applied irrigation water. These authors (Burt, et al. 1997) state that while tailwater is necessary for some irrigation methods, they concluded that any uncollected (unrecirculated in the field) tailwater is considered a field-scale nonbeneficial use. They further list "excessive tailwater" as both a nonbeneficial use as well as an unreasonable use.

Many states now require that irrigation runoff water not be allowed to trespass on lands not under the control of the irrigator. It is then necessary to provide some means of collecting the tailwater, transporting it to a reservoir or sump, and either storing or providing recovery facilities as needed.

**California.** According to tailwater policy written in water conservation plans of the United States Bureau of Reclamation of the mid-Pacific Region as well as selected State of California districts, tailwater is prohibited from leaving the district or from farms. If not, water is recycled and blended with new supply water and is then resold to the water users.

**Kansas.** In Kansas waste of water is defined as any act or omission which causes water to be diverted or withdrawn from a source of supply and not used or reapplied to a beneficial use or water that is intended for irrigation use to escape and drain from the authorized place of use.

**Nebraska.** With passage of LB 577 (the Nebraska Groundwater Management Act) in 1975 the Nebraska Legislature directed the Natural Resource Districts (NRD's) to formulate and enforce rules and regulations to conserve groundwater supplies by all irrigators using groundwater supplies within the district. Many of the NRD's have formulated regulations that recognize violations and waste of irrigation water.

**Texas.** An example of the changing attitude of tailwater reuse is the program undertaken by the High Plains Underground Water Conservation District No. 1. Irrigation tailwater runoff from the land on which it is produced is a violation of state law and of the rules of the High Plains Underground Water Conservation District No. 1. The Water District rule defines waste as it relates to irrigation tailwater as "willfully or negligently causing, suffering, or permitting underground water to escape into any river, creek, natural watercourse, depression, lake, reservoir, drain, sewer, street, highway road or road ditch, or onto any land other than that of the owner of the well; or ground water pumped for irrigation that escapes as irrigation tailwater onto land other than that of the owner of the well unless permission has been granted by the occupant of the land receiving the discharge."

**4. Surface irrigation can be designed to prevent runoff for the cracking clay soils in Imperial Valley.**

The design for surface irrigation requires specification of flow rate and irrigation time duration (cutoff time) for a steady inflow rate (without cutback). In the Imperial Valley where the infiltration rate quickly approaches near-zero after ponding, the minimum steady flow rate equals or exceeds that required to spread the water laterally across the field and the maximum flow rate is less than that which overtops the lateral side dikes which contain the flow and that which is erosive. The cutoff time is the field area multiplied by the infiltration depth divided by the inflow rate. Infiltration depth is calculated from a measurement of the time for the wetting (advancing) front to arrive at the midpoint of the field length (for example), inflow rate and surface flow depth.

**5. Surface irrigation can be managed to prevent runoff for the cracking clay soils in Imperial Valley.**

The management of surface irrigation requires setting the inflow to the design rate and the time to the design cutoff time for each set of a water turn. Farm irrigation systems in IID have the flexibility to control both flow rate and cutoff time at the field. Because infiltration depth is determined prior to cutoff time, the irrigation can be terminated such that runoff is avoided. Thus, for each set prior to the last one during a turn, the flow rate and irrigation time can be that of the design. Time of cutoff during the last set may be constrained by the turnout stop time. In order to adequately irrigate the last set, some tailwater may result.

**6. Tailwater should be prohibited from leaving the district or from farms.**

According to tailwater policy written in 56 water conservation plans, of irrigation districts receiving water from the United States Bureau of Reclamation of the mid-Pacific Region (Federal) and from the State of California, available from the Office of Water Conservation, tailwater is prohibited from leaving the district or from farms. If not, water is recycled and blended with new supply water and is then resold to the water users. These plans are available from: United States Bureau of Reclamation, Mid Pacific Region Office, Sacramento, CA., or from State of California Department of Water Resources, Office of Water Use Efficiency, Sacramento, CA.

**7. The Imperial Irrigation District allows unreasonable use of water by growers.**

Over 16% of the water diverted to the Imperial Irrigation District and over 20% of the water delivered to the farm head gates becomes tailwater runoff and flows into a drain that leads the water to the Salton Sea (Jensen and Walter, 1997). It has been demonstrated by University of California personnel at the Desert Research and Extension Center that this tailwater loss can be eliminated by a diligent irrigator by cutting back the flow of water into the field or check at a time easily determined by the irrigator (Bali, et al., 2001; and Grismer and Bali, 2001). Economic analysis has shown that it is cost effective to prevent these losses without a major capital investment by either a tenant farmer or an owner-operator (Tod and Grismer, 1999).

**8. The Imperial Irrigation District should aggressively enforce tailwater penalty charges.**

If the Imperial Irrigation District would aggressively enforce its own Triple Charge penalty for tailwater, there would be water savings exceeding the quantities under negotiation with MWD, SDWD and CVWD. No land need be fallowed. No farm workers would loose their jobs, i.e. no Third Party Impacts. And additional farm workers and zanjaros may be hired which in turn would boost the local economy.

The Imperial Irrigation District Rules Concerning Tailwater Assessments and Delivery Adjustments to Conserve Water requires, "An inventory of surface field discharge water will be taken daily and an assessment shall be levied against all discharges which equal 15 percent or more of the water being delivered and measurement thereof shall have been taken on two successive occasions not less than nine hours apart in a 24-hour period. The term assessment used herein shall mean the quantity of water charged (in second feet and reduced to acre-feet, times the scheduled water rate) multiplied by 3 for the day in which the measurements were taken." (Imperial Irrigation District Resolution No. 18-087, 1987)

The above loophole allows up to 15 percent tailwater. This loss must be taken on two successive occasions not less than nine hours apart in a 24-hour period.

# REFERENCES

## PREPARED BY THE WAC

## FOR THE

## COACHELLA VALLEY WATER DISTRICT

## REFERENCES


ASAE. 1998. Irrigation Runoff Reuse Systems. ASAE Standards 1998, 45th Edition. ASAE, The Society for Engineering in Agricultural, Food and Biological Systems. St. Joseph, Michigan. P. 876-879.

Ayers, R.S. and D.W. Westcot. 1985. Water Quality for Agriculture. FAO Irrigation and Drainage Paper 29 (rev. 1), Rome, Italy.

Bali, K. M., Grismer, M. E. and Tod. 2001. Reduced-runoff irrigation of alfalfa in Imperial Valley, California. *Journal of the Irrigation and Drainage Engineering*, ASCE, 127(3), 123-130.

Boyle Engineering Corporation. 1990. Tailwater Recovery Demonstration Program Study. Special Technical Report for the Imperial Irrigation District. September 1990.

Bureau of Reclamation. 1970. Use of Water on Federal Irrigation Projects. Summary Report. 1965-1969. Region 7, Denver, Colorado. 32 p.

Bureau of Reclamation. 1971. Use of Water on Federal Irrigation Projects. Central Valley Project. Summary Report. Volume 1, 1967-1970. U. S. Department of the Interior, Bureau of Reclamation, Region 2, Fresno, California. 118 p.

Bureau of Reclamation. 1973. Use of Water on Federal Irrigation Projects, Columbia Basin Project, Washington. Crop and Irrigation Data 1070-72. Summary Report. U. S. Department of the Interior, Bureau of Reclamation, Region 1, Boise, Idaho. 85 p.

Burt, C. M. 1995. The Surface Irrigation Manual. Waterman Industries, Inc. Exeter, CA.

Burt, C. M., A. J. Clemmens, T. S. Strelkoff, K. H. Solomon, R. D. Bliesner, L. A. Hardy, T. A. Howell, and D. E. Eisenhauer. 1997. Irrigation Performance Measures: Efficiency and Uniformity. *Journal of Irrigation and Drainage Engineering*, ASCE, 123 (6): 423-442.

Carter, H.O., 1962. Inter Industry Analysis of California Agriculture, Giannini Foundation, University of California, Berkley

Carter, H.O. 1997, Agricultures Contribution to California's Economy, Agriculture Issues Center, University of California, June, pp 1-4.

CVWD 1998. Unpublished tabular data, Imperial Irrigation District Annual Inventory of Areas Receiving Water. Years 1972-1997, Robinson, R.

CVWD 1998a. Unpublished tabular data, Imperial Irrigation District Annual Inventory of Water Delivery Volumes at Drop One, Robinson, R.

CVWD 1998b. Unpublished tabular data, Imperial Irrigation District Annual Inventory of Flow Volumes to Salton Sea. Robinson, R.

CVWD 1999. Unpublished tabular data, Robinson, R.

CVWD 1999a. Unpublished tabular data, Imperial Irrigation District Annual Inventory of Water Delivery Volumes at Drop One, Robinson, R.

CVWD 1999b. Unpublished tabular data, Imperial Irrigation District Annual Inventory of Flow Volumes to Salton Sea. Robinson, R.

CVWD 2000. Unpublished tabular data, Robinson, R.

CVWD 2001. Unpublished tabular data, Robinson, R.

CVWD 2001a. Unpublished tabular data, Imperial Irrigation District Annual Inventory of Water Delivery Volumes at Drop One, Robinson, R.

CVWD 2001b. Unpublished tabular data, Imperial Irrigation District Annual Inventory of Flow Volumes to Salton Sea. Robinson, R.

Dastane, N.G. 1974. Effective rainfall in irrigated agriculture. Food and Agricultural Organization. United Nations. Irrigation and Drainage Paper. 61 p.

Decision 1600, Jun 1984, Decision Regarding Misuse of Water by Imperial Irrigation District, Water Rights Decision, State of California, State Water Resources Control Board.

Department of Water Resources. 1971. Hydrologic data: 1969. Bulletin No. 130-69, 555 pages.

Divine, A. 1996. Draft IID internal memorandum from Engineer Assistant to Mike Clinton, Water Use Assessment for IID for USBR, Report (Jensen, 1995).

Evans, R. G. 1978. Tailwater recovery for surface irrigation. Colorado State University Extension Service Publication No. 4.709.

Grismer, M.E. and I.C. Tod. 1991. Drainage of clay overlaying artesian aquifer: I. Hydrologic Assessment. *Journal of the Irrigation and Drainage Engineering*, ASCE, 117(2):255-270.

Grismer, M.E. and K.M. Bali. 2001. Reduced-runoff irrigation of sudan grass hay, Imperial Valley, California. *Journal of the Irrigation and Drainage Engineering*, ASCE, 127(5), 319-323.

Hamburg, R. G. 1980. Final Report. Use of Water on Federal Irrigation Projects. Summary of 1964-1972 studies. United States Department of the Interior, Water and Power Resources Service. Denver, Colorado. 116 p.

Hanson, B. R., W. Bowers, B. Davidoff and A. Carvajal. 1993. An analysis of mobile laboratory irrigation system evaluation: irrigation systems. University of California-Davis. 23 p.

Hargreaves, G.L., G.H. Hargreaves, and J.P. Riley. 1985. Agric. Benefits for Senegal River Basin. J. Irrig. and Drain. Engr., ASCE 111(2): 113-124.

High Plains Underground Water Conservation District No. 1. 1977. Guide to Irrigation Tailwater Recovery. Report 77-01. 78 p.

Hoffman, J. D. Mass, J. D. Rhodes and J. van Schilfgaarde, 1984

Imperial Irrigation District Resolution No. 18-87, 1987, Exhibit A, "Imperial Irrigation District Rules Concerning Tailwater Assessments and Delivery Adjustments to conserve water (To Combine the 13-Point and 21-Point Water Conservation Programs)", 4 pages.

Imperial Irrigation District. 1996. Water requirements and availability study. IID Water Resources Unit, 89 pages.

Imperial Irrigation District Annual Report, 1996, External Affairs Department, 44 pages.

Imperial Irrigation District Annual Report, 1997, External Affairs Department, 60 pages.

Imperial Irrigation District. 2001. Water Department. Water Information 2000, 79 pages.

Jensen, M.E. 1995. Water Use Assessment of the Imperial Irrigation District. Special Report Prepared for the U.S. Bureau of Reclamation. Boulder City, NV

Jensen, M. E. and I. A. Walter. 1997. Assessment of the 1987-1996 water use by the Imperial Irrigation District using water balance and cropping data (REVISED). Special Report for the Bureau of Reclamation, Boulder City, Nevada. June 1997.

Jensen, M.E., and I.A, Walter. 2002. Assessment of 1997-2001 water use by the Imperial Irrigation District. Special Report to the USBR, 32 pages plus appendices.

Jensen, M.E., R.D. Burman and R.G. Allen (ed). 1990. Evapotranspiration and Irrigation Water Requirements. ASCE Manual and Reports on Engineering Practices No. 70. Am. Soc. Civil Engrs. New York, N.Y.

JMLord, Inc. 1997. Imperial Irrigation District Water Conservation Study.

Kaddah, M.T., and J.D. Rhoades. 1976. Salt and water balance in Imperial valley, California. *Soil Science Society of America Journ*al 40: 93-100.

Kinney, W., G. L. Horner, and K. K. Tanji. 1977. An economic analysis of irrigation return flow recycle systems in the Central Valley of California. In: J. P. Law, Jr. and G. V. Skogerboe (eds.), Proceedings, National Conference on Irrigation Return Flow Quality Management, Fort Collins, Colorado, May 16-19. Sponsored by U.S. Environmental Protection Agency and Colorado State University. P 175-182.

Loeltz, O. J., B. Irelan, J.H. Robison, and F.H. Olmsted. 1975. Geohydrologic reconnaissance of the Imperial Valley, California. Geological Survey Professional Paper 486-K, 54 pages.

Lonkerd, W.E., C.F. Ehlig, and T.J. Donovan. 1979. Salinity profiles and leaching fractions for slowly permeable irrigated field soils. *Soil Science Society of America Journal* 43: 287-289.

Luthin, J. N. and F. E. Robinson. 1969. Depth of drainage irrigated areas. *Transactions of the ASAE* 12(1):27-28.

Maas, E.V. 1990. Crop salt tolerance. Chapter 13, pages 262-304, IN Agricultural Salinity Assessment and Management, K.K. Tanji, Editor, American Society of Civil Engineers Manual No. 71, New York.

Martin, W. E. and H. O. Carter, An Interindustry Analysis of California Agriculture, Giannini Foundation Research Report #250, University of California, 1962

Maruyama, T, and K.K. Tanji. 1997. Physical and Chemical Processes of Soil Related to Paddy Drainage. Shinzansha Science and Technology, Tokyo, Japan, 229 pages.

Mayberry, K.S. 1996-97. Guidelines to Production Costs and Practices for Imperial County Field Crops, Circular 104F, University of California Cooperative Extension

Mayberry, K.S. Principle Editor. 1998-1999. Guidelines to production costs and practices, 1998-1999. UC Circular 104-V, Vegetable Crops, University of California, Imperial County, Cooperative Extension, 81 pages.

McDonald, M.C., and O.J. Loeltz. 1976. Water resources of the Lower Colorado River – Salton Sea area as of 1971, Summary Report. Geological Survey Professional Paper 486-A, 34 pages.

Molof, J.J. 1963. Salt Balance. Imperial Valley, California. US Soil Conservation Service in cooperation with Imperial Irrigation District. 13 pages + tables and figures.

Moore, Charles V., 2000, Report on the Economic Impact of Section 203(b) of P.L. 97-293, (Reclamation Reform Act of 1982), USDI, Unpublished.

NOAA. 1997. Climatological Data - Annual Summary, California. NOAA National Climatic Center. Asheville, N.C.

O'Halloran, T. F. 1990. Imperial Irrigation District Inter-office memorandum summarizing tailwater runoff within IID. August 9, 1990.

Oster, J. D., and J. D. Rhodes, 1975, "Calculated Drainage Water Composition and Salt Burdens", in J. Environmental Quality, 4:73-79

Oster, J. D. and J. L. Meyer, L. Hermsmeier, and M. Kaddah. 1986. Field Studies of Irrigation Efficiency in the Imperial Valley. *Hilgardia* 54(7): 1-15.

Rhoades, J.D., S. M. Lesch, S.L. Burch, J. Letey, R.D. Lemert, P.J. Shouse, J.D. Oster and T. O'Halloran. 1997. Salt distributions in cracking soils and salt pick up by surface runoff waters. ASCE Journal of Irrigation and Drainage Engineering 123(5): 323-328.

Rhoades, J.D. 2002. Assessment of Imperial Valley leaching requirement:1994-1996. Special Report to the USBR, 79 pages plus figures, tables and appendices.

Schulbach H. and J. L. Meyer. 1979. Tailwater Recovery Systems: Their Design and Cost. Leaflet 21063. Division of Agricultural Sciences, University of California. 14 p.

Scofield, C.S. 1940. Salt balance in irrigation areas. Agricultural Research 61: 17-30.

Seitmire, J.G., J.C. Wolfe, and R.K. Stroud. 1990. Reconnaissance investigation of water quality, bottom sediment, and biota associated with irrigation drainage in the Salton Sea Area, California, 1986-87, USGS Water-Resources Investigation Report 89-4102, 68 pages.

Selly, R. 1997. Estimated Irrigation Costs, 1997. Nebraska Cooperative Extension CC371.

Shainberg, I. 1984. Response of soils to sodic and saline conditions. *Hilgardia*. 52(2):1-57.

Silva, J.P. 1990. Imperial Irrigation District 1989 Water Report, 74 pages.

Snyder, R.L. and W.O. Pruitt. 1992. Evapotranspiration Data Management in California. ASCE Water Forum 92, Irrig. And Drain. Session Proceedings. Baltimore, MD. Aug. 2-6.

Solomon, K. H., and B. Davidoff. 1999. Relating unit and sub-unit irrigation performance. *Transactions of the ASAE* 42(1): 115-122.

State of California, Economic Development Department, "Agricultural Employment Report", NO. 882, (periodical).

Tanji, K. K. 2000. Salinity in the soil environment. Chapter 2, pages 1-35, IN Environment-Plants-Molecules, A. Lauchli and U. Luttge, editors, Kluwer Academic Publishers (in press).

Tanji, K.K 2000. Salt balance in the Imperial Irrigation District. Technical Paper, WAC to CVWD, 22 pages.

Tod, I.C. and M.E. Grismer. 1999. Economic assessment of reduced frequency and surface runoff reduction irrigation methods in the Imperial Valley: The on-farm level. Contract (Grant Agreement No 1425-98-FG-30-00046). Final Report to the Southern Colorado Region, Bureau of Reclamation, U. S. Department of Interior, Denver. 23p.

US Bureau of Reclamation. 1997. Colorado River Basin – Historical flow and quality of water data, Table 20b, Colorado River at Imperial Dam, Arizona-California.

US Department of Commerce, Census of Agriculture, 1997, California

US Salinity Laboratory (USSL). 1954. Diagnosis and Improvement of Saline and Alkali Soils. USDA Handbook No. 60, L.A. Richards, Editor, Washington, DC, 160 pages.

USBR. 1999. Quality of Water, Colorado River Basin. Progress Report No. 19, U.S. Dept. Interior, Bur. Rec. January (Table 20b, … Col Riv at Imperial Dam, through Dec 1997)

USBR. 2001. Quality of Water, Colorado River Basin. Progress Report No. 20, U.S. Dept. Interior, Bur. Rec. January (Data for 1998 and 1999 in table for Col Riv at Imperial Dam on web site: http://www.uc.usbr.gov/progact/salinity/index.html)

US Bureau of Reclamation, 1999. Bureau of Reclamation Construction Cost Trends.

US Department of Labor, Bureau of Labor Statistics, 1999. Consumer Price Indexes.

University of California News Letter, Spring 1999, Agricultural Issues Center, University of California, Davis

Van der Tak, L. and M. E. Grismer. 1987. Irrigation, drainage and soil salinity in cracking soils. *Transactions of the ASAE* 30:740-744.

Walker. W. R. 1989. Guidelines for Designing and Evaluating Surface Irrigation Systems. Food and Agriculture Organization of the United Nations. FAO Irrigation and Drainage Paper 45. Rome. 135 p.

Walker, W. R. and G. V. Skogerboe. 1987. Surface Irrigation Theory and Practice. Prentice-Hall, Inc., Englewood Cliffs, New Jersey. 386 p.

Wallender, W.W. 2000. Water flow and salt transport in cracking clay soils of the Imperial Valley. Technical Paper, Water Advisory Committee to CVWD, 37 pages

Waller, P. M. and W. W. Wallender. 1991. Infiltration in surface irrigated swelling soils. "Irrigation and Drainage Systems", 5:249-266.

Waller, P. M. and W. W. Wallender. 1993. Changes in cracking, water content, and bulk density of salinized swelling clay field soils. *Soil Science* 156(6): 414-423.

Water Study Team (WST). 1998. Imperial Irrigation District Water Use Assessment for the Year 1987-1996. Report Prepared for Imperial Irrigation District.

Zimmerman, R.P. 1981. Soil survey of Imperial County, California, Imperial Valley area. U.S. Department of Agriculture, Soil Conservation Service, 112 pages.

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# APPENDIX A

# COST ESTIMATES FOR

# RESERVOIR

# TAILWATER RECOVERY SYSTEMS

**Table A1**. Total capital costs for surface irrigation tailwater recovery systems for the Imperial Irrigation District, based on 1985 data. Data taken from **Table 5-2** of the report: Tailwater Recovery Demonstration Program Study, Special Technical Report for the Imperial Irrigation District (Boyle Engineering Corporation, 1990).

| Pumpback System # | Area Served Acres | Total Pump Cost 1985 $ | Total Pipe Cost 1985 $ | Total Reservoir Cost 1985 $ | Total Cost 1985 $ | Total Cost 1985 $/acre |
|---|---|---|---|---|---|---|
| 1 | 165 | 17,997 | 47,277 | 5,572 | 70,846 | 429 |
| 2 | 175 | 12,733 | 53,522 | 7,404 | 73,659 | 421 |
| 3 | 283 | 14,771 | 42,278 | 11,149 | 68,198 | 241 |
| 4 | 152 | 24,030 | 45,590 | 5,584 | 75,204 | 495 |
| 5 | 230 | 12,161 | 65,391 | 4,644 | 82,196 | 357 |
| | | | | | | |
| **AVERAGE** | **201** | **16,338** | **50,812** | **6,871** | **74,021** | **389** |

**Table A2.** Annual capital costs for surface irrigation tailwater recovery systems for the Imperial Irrigation District, based on 1985 data. Data taken from Boyle Engineering Corporation (1990).

| Pumpback System # | Area Served acres | Annual Pump Cost 1985 $ | Annual Pipe Cost 1985 $ | Annual Reservoir Cost 1985 $ | Annual Total Cost 1985 $ | Annual Total Cost 1985 $/acre |
|---|---|---|---|---|---|---|
| 1 | 165 | 2,366 | 4,835 | 570 | 7,770 | 47.09 |
| 2 | 175 | 1,674 | 5,473 | 757 | 7,904 | 45.17 |
| 3 | 283 | 1,942 | 4,323 | 1,140 | 7,405 | 26.17 |
| 4 | 152 | 3,159 | 4,662 | 571 | 8,392 | 55.21 |
| 5 | 230 | 1,599 | 6,687 | 475 | 8,761 | 38.09 |
| | | | | | | |
| **AVERAGE** | **201** | **2148** | **5196** | **703** | **8047** | **42.35** |

Calculations based on the data given in **Table A1** and the following annualized capital cost assumptions:

Pump and motor (15 years and 10% interest, capital recovery factor = 0.13147), reservoir (40 years and 10% interest, capital recovery factor = 0.10226), pipeline (40 years and 10 % interest, capital recovery factor = 0.1226).

**Table A3.** Annual operating and maintenance costs for surface irrigation tailwater recovery systems for the Imperial Irrigation District, based on 1985 data. Data taken from Boyle Engineering Corporation (1990).

| Pumpback System # | Area Served acres | Annual O&M Pump Cost 1985 $ | Annual O&M Pipe Cost 1985 $ | Annual O&M Reservoir Cost 1985 $ | Annual O&M Total Cost 1985 $ | Annual O&M Total Cost 1985 $/acre |
|---|---|---|---|---|---|---|
| 1 | 165 | 1,080 | 236 | 167 | 1,483 | 8.99 |
| 2 | 175 | 764 | 268 | 222 | 1,254 | 7.16 |
| 3 | 283 | 886 | 211 | 334 | 1,432 | 5.06 |
| 4 | 152 | 1,442 | 228 | 168 | 1,837 | 12.09 |
| 5 | 230 | 730 | 327 | 139 | 1,196 | 5.20 |
| | | | | | | |
| **AVERAGE** | **201** | **980** | **980** | **254** | **206** | **7.70** |

Maintenance costs are estimated using the same procedure as the Boyle (1990) report.
Pump maintenance cost = 6% times the total initial cost.
Reservoir maintenance cost = 3% times the total initial cost.
Pipeline maintenance cost = 0.5% times the total initial cost.

**Table A4.** Total annual costs for surface irrigation tailwater recovery systems for the Imperial Irrigation District, based on 1985 data. Data taken from Boyle Engineering Corporation (1990).

| Pumpback System # | Area Served acres | Annual Pump Costs 1985 $ | Annual Pipe Costs 1985 $ | Annual Reservoir Costs 1985 $ | Annual Total Costs 1985 $ | Annual Total(F+M) Costs 1985 $/acre | Annual Operating Costs 1985 $/acre | Annual Total Costs 1985 $/acre |
|---|---|---|---|---|---|---|---|---|
| 1 | 165 | 3,446 | 5,071 | 737 | 9,254 | 56.08 | 6 | 62.08 |
| 2 | 175 | 2,438 | 5,741 | 979 | 9,158 | 52.33 | 6 | 58.33 |
| 3 | 283 | 2,828 | 4,535 | 1,475 | 8,838 | 31.23 | 6 | 37.23 |
| 4 | 152 | 4,601 | 4,890 | 739 | 10,230 | 67.30 | 6 | 73.30 |
| 5 | 230 | 2,328 | 7,014 | 614 | 9,957 | 43.29 | 6 | 49.29 |
| **AVERAGE** | **201** | **3,128** | **5,450** | **909** | **9,487** | **50.05** | **6** | **56.05** |

Total annual costs are the sum of the annual capital costs **(Table A2)** and the annual maintenance and operating costs **(Table A3)**. Average operating costs ($6 per acre-foot) are taken from SECTION 5.4 of the report*: Tailwater Recovery Demonstration Program Study, Special Technical Report for the Imperial Irrigation District* (Boyle Engineering Corporation, 1990). An assumption of 1 acre-foot of recycled tailwater per acre is used to estimate the annual operating cost on a per acre basis.

**Table A5.** Total capital costs for surface irrigation tailwater recovery systems for the Imperial Irrigation District, updated to July 1999. Data updated from Boyle Engineering Corporation (1990).

| Pumpback System # | Area Served acres | Pump Cost 1999 $ | Pipe Cost 1999 $ | Reservoir Cost 1999 $ | Total Cost 1999 $ | Total Cost 1999 $/acre |
|---|---|---|---|---|---|---|
| 1 | 165 | 25,957 | 68,188 | 8,037 | 102,182 | 619 |
| 2 | 175 | 18,365 | 77,195 | 10,679 | 106,239 | 607 |
| 3 | 283 | 21,304 | 60,978 | 16,080 | 98,363 | 348 |
| 4 | 152 | 34,659 | 65,755 | 8,054 | 108,467 | 714 |
| 5 | 230 | 17,540 | 94,314 | 6,698 | 118,552 | 515 |
| | | | | | | |
| **AVERAGE** | **201** | **23,565** | **73,286** | **9,910** | **106,760** | **561** |

Data taken from **Table 5-2** of the report: *Tailwater Recovery Demonstration Program Study, Special Technical Report for the Imperial Irrigation District* (Boyle Engineering Corporation, 1990). The data given for 1985 were updated to 1999 using the composite cost index for the Bureau of Reclamation Construction Cost Trends from January 1985 (156) to July 1999 (225).

**Table A6.** Annual capital costs for surface irrigation tailwater recovery systems for the Imperial Irrigation District, updated to July 1999. Data updated from Boyle Engineering Corporation (1990).

| Pumpback System # | Area Served acres | Annual Pump Cost 1999 $ | Annual Pipe Cost 1999 $ | Annual Reservoir Cost 1999 $ | Annual Total Cost 1999 $ | Annual Total Cost 1999 $/acre |
|---|---|---|---|---|---|---|
| 1 | 165 | 3,413 | 6,973 | 822 | 11,207 | 67.92 |
| 2 | 175 | 2,414 | 7,894 | 1,092 | 11,400 | 65.15 |
| 3 | 283 | 2,801 | 6,236 | 1,644 | 10,681 | 37.74 |
| 4 | 152 | 4,557 | 6,724 | 824 | 12,104 | 79.63 |
| 5 | 230 | 2,306 | 9,645 | 685 | 12,635 | 54.94 |
| | | | | | | |
| **AVERAGE** | **201** | **3,098** | **7,494** | **1,013** | **11,606** | **61.08** |

Calculations based on the data given in **Table A5** and the following annualized capital cost assumptions:
Pump and motor (15 years and 10% interest, capital recovery factor = 0.13147), reservoir (40 years and 10% interest, capital recovery factor = 0.10226), pipeline (40 years and 10 % interest, capital recovery factor = 0.1226).

**Table A7.** Annual operating and maintenance costs for surface irrigation tailwater recovery systems for the Imperial Irrigation District, updated to July 1999. Data updated from Boyle Engineering Corporation (1990).

| Pumpback System # | Area Served acres | Annual O&M Pump Cost 1999 $ | Annual O&M Pipe Cost 1999 $ | Annual O&M Reservoir Cost 1999 $ | Annual O&M Total Cost 1999 $ | Annual O&M Total Cost 1999 $ | Annual Operating Cost 1999 $/ac-ft |
|---|---|---|---|---|---|---|---|
| 1 | 165 | 1,557 | 341 | 241 | 2,139 | 12.97 | 6 |
| 2 | 175 | 1,102 | 386 | 320 | 1,808 | 10.33 | 6 |
| 3 | 283 | 1,278 | 305 | 482 | 2,066 | 7.30 | 6 |
| 4 | 152 | 2,080 | 329 | 242 | 2,650 | 17.43 | 6 |
| 5 | 230 | 1,052 | 472 | 201 | 1,725 | 7.50 | 6 |
| | | | | | | | |
| **AVERAGE** | **201** | **1,414** | **366** | **297** | **2,078** | **11.11** | **6** |

Maintenance costs are estimated using the same procedure as the Boyle (1990) report.
Pump maintenance cost = 6% times the total initial cost.
Reservoir maintenance cost = 3% times the total initial cost.
Pipeline maintenance cost = 0.5% times the total initial cost.

**Table A8.** Total annual costs for surface irrigation tailwater recovery systems for the Imperial Irrigation District, updated to July 1999. Data updated from Boyle Engineering Corporation (1990).

| Pumpback System # | Area Served acres | Annual Pump Costs 1999 $ | Annual Pipe Costs 1999 $ | Annual Reservoir Costs 1999 $ | Annual Total Costs 1999 $ | Annual Total(F+M) Costs 1999 $/acre | Annual Operating Costs 1999 $/acre | Annual Total Costs 1999 $/acre |
|---|---|---|---|---|---|---|---|---|
| 1 | 165 | 4,970 | 7,314 | 1,063 | 13,347 | 80.89 | 6 | 86.89 |
| 2 | 175 | 3,516 | 8,280 | 1,412 | 13,209 | 75.48 | 6 | 81.48 |
| 3 | 283 | 4,079 | 6,540 | 2,127 | 12,746 | 45.04 | 6 | 51.04 |
| 4 | 152 | 6,636 | 7,053 | 1,065 | 14,754 | 97.07 | 6 | 103.07 |
| 5 | 230 | 3,358 | 10,116 | 886 | 14,360 | 62.44 | 6 | 68.44 |
| | | | | | | | | |
| **AVERAGE** | **201** | **4,512** | **7,861** | **1,311** | **13,683** | **72.18** | **6** | **78.18** |

Total annual costs are the sum of the annual capital costs **(Table A6)** and the annual maintenance and operating costs **(Table A7).** Average operating costs ($6 per acre-foot) are taken from SECTION 5.4 of the report: *Tailwater Recovery Demonstration Program Study, Special Technical Report for the Imperial Irrigation District* (Boyle Engineering Corporation, 1990). An assumption or 1 acre-foot of recycled tailwater per acre is used to estimate the annual operating cost on a per acre basis.

# APPENDIX B

# COST ESTIMATES FOR

# SUMP

# TAILWATER RECOVERY SYSTEMS

**Table B1**. Cost Estimates for a Typical Sump Tailwater Recovery System for an Irrigated Area of 73 acres within the Imperial Irrigation District.

| DESCRIPTION | | UNIT PRICE $ | TOTAL COST $ |
|---|---|---|---|
| **PIPE COSTS ---- TOTAL** | | | **13,709** |
| **Pipe Costs, 8 inch Class 100 PVC pipe, 3900 Feet** | | **2.1** | **8,190** |
| **Pipe Fittings, 15 % of pipe costs** | | | **1,229** |
| **Pipe Installation** | | **1.1** | **4,290** |
| | | | |
| **PUMP AND MOTOR COSTS ---- TOTAL** | | | **6,242** |
| **Tailwater pump, motor, controls and panel (single-phase)** | | | **5,242** |
| **Tailwater pump installation** | | | **1,000** |
| | | | |
| **SUMP COST ----TOTAL** | | | **2,116** |
| **Sump Cost** | | | **1,116** |
| **Sump Installation** | | | **1,000** |
| **3-PHASE UPGRADE INCLUDING INSTALLATION** | | **0** | **0** |
| | | | |
| **SUBTOTAL COST** | | | **22,067** |
| **ENGINEERING AND INSPECTION (5% of subtotal cost)** | | | **1,103** |
| **TAX (7.75 % of Subtotal Cost plus Engineering)** | | | **1,796** |
| | | | |
| **TOTAL CAPITAL COST (AUGUST, 1999)** | | | **24,965** |
| | | | |
| **TOTAL CAPITAL COST per acre (AUGUST, 1999)** | | | **342** |
| | | | |
| **ANNUALIZED CAPITAL COSTS** | | | **ANNUAL** |
| | **CRF** | **COST, $** | **COST, $** |
| **PUMP (15 year, 10% interest)** | **0.13147** | **6,242** | **821** |
| **PIPE (Includes Eng and Taxes)(40 years, 10% interest)** | **0.10226** | **16,607** | **1,698** |
| **SUMP (40 years, 10% interest)** | **0.10226** | **2,116** | **216** |
| **TOTAL** | | **24,965** | **2,735** |
| **TOTAL ANNUALIZED CAPITAL COST PER ACRE (73 acres)** | | | **37.47** |
| | | | |
| **ANNUALIZED MAINTENANCE COSTS** | | | **ANNUAL** |
| | **FACTOR (%)** | **COST, $** | **COST, $** |
| **PUMP** | **6** | **6,242** | **375** |
| **PIPE (includes ENG & Taxes)** | **0.5** | **16,607** | **83** |
| **SUMP** | **1** | **2,116** | **21** |
| **TOTAL** | | **24,965** | **479** |
| **TOTAL ANNUALIZED MAINTENANCE COST PER ACRE (73 acres)** | | | **6.56** |
| **ENERGY COSTS ($/acre foot)** | | | **4.20** |

**Table B2**. Cost Estimates for a Typical Sump Tailwater Recovery System for an Irrigated Area of 145 acres within the Imperial Irrigation District.

| DESCRIPTION | | UNIT PRICE $ | TOTAL COST $ |
|---|---|---|---|
| **PIPE COSTS ---- TOTAL** | | | **19,046** |
| **Pipe Costs, 10 inch Class 100 PVC pipe, 3900 Feet** | | **3.29** | **12,831** |
| **Pipe Fittings, 15 % of pipe costs** | | | **1,925** |
| **Pipe Installation** | | **1.1** | **4,290** |
| | | | |
| **PUMP AND MOTOR COSTS ---- TOTAL** | | | **6,678** |
| **Tailwater pump, motor, controls and panel (single-phase)** | | | **5,678** |
| **Tailwater pump installation** | | | **1,000** |
| | | | |
| **SUMP COST ---- TOTAL** | | | **2,700** |
| **Sump Cost** | | | **1,700** |
| **Sump Installation** | | | **1,000** |
| **3-PHASE UPGRADE INCLUDING INSTALLATION** | | **0** | **0** |
| | | | |
| **SUBTOTAL COST** | | | **28,424** |
| **ENGINEERING AND INSPECTION (5% of subtotal cost)** | | | **1,421** |
| **TAX (7.75 % of Subtotal Cost plus Engineering)** | | | **2,313** |
| | | | |
| **TOTAL CAPITAL COST (AUGUST, 1999)** | | | **32,158** |
| | | | |
| **TOTAL CAPITAL COST per acre (AUGUST, 1999)** | | | **222** |
| | | | |
| **ANNUALIZED CAPITAL COSTS** | | | **ANNUAL** |
| | **CRF** | **COST, $** | **COST, $** |
| **PUMP (15 year, 10% interest)** | **0.13147** | **6,678** | **878** |
| **PIPE (Includes Eng and Taxes)(40 years, 10% interest)** | **0.10226** | **22,780** | **2,329** |
| **SUMP (40 years, 10% interest)** | **0.10226** | **2,700** | **276** |
| **TOTAL** | | **32,158** | **3,484** |
| **TOTAL ANNUALIZED CAPITAL COST PER ACRE (145 acres)** | | | **24.02** |
| | | | |
| **ANNUALIZED MAINTENANCE COSTS** | | | **ANNUAL** |
| | **FACTOR (%)** | **COST, $** | **COST, $** |
| **PUMP** | **6** | **6,678** | **401** |
| **PIPE (includes ENG & Taxes)** | **0.5** | **22,780** | **114** |
| **SUMP** | **1** | **2,700** | **27** |
| **TOTAL** | | **32,158** | **542** |
| **TOTAL ANNUALIZED MAINTENANCE COST PER ACRE (145 acres)** | | | **3.74** |
| **ENERGY COSTS ($/acre foot)** | | | **4.20** |

**Table B3**. Cost Estimates for a Typical Sump Tailwater Recovery System for an Irrigated Area of 290 acres within the Imperial Irrigation District.

| DESCRIPTION | | UNIT PRICE $ | TOTAL COST $ |
|---|---|---|---|
| **PIPE COSTS ---- TOTAL** | | | 34,125 |
| Pipe Costs, 12 inch Class 100 PVC pipe, 5200 Feet | | 4.75 | 24,700 |
| Pipe Fittings, 15 % of pipe costs | | | 3,705 |
| Pipe Installation | | 1.10 | 5,720 |
| | | | |
| **PUMP AND MOTOR COSTS ---- TOTAL** | | | 7,237 |
| Tailwater pump, motor, controls and panel (3-phase) | | | 6,237 |
| Tailwater pump installation | | | 1,000 |
| | | | |
| **SUMP COST ----TOTAL** | | | 10,103 |
| Sump Cost | | | 1,583 |
| Sump Installation | | | 1,500 |
| 3-PHASE UPGRADE INCLUDING INSTALLATION | | 1.80 | 7,020 |
| | | | |
| **SUBTOTAL COST** | | | 51,465 |
| **ENGINEERING AND INSPECTION (5% of subtotal cost)** | | | 2,573 |
| **TAX (7.75 % of Subtotal Cost plus Engineering)** | | | 4,188 |
| | | | |
| **TOTAL CAPITAL COST (AUGUST, 1999)** | | | 58,226 |
| **TOTAL CAPITAL COST per acre (AUGUST, 1999)** | | | 201 |
| | | | |
| **ANNUALIZED CAPITAL COSTS** | | | **ANNUAL** |
| | **CRF** | **COST, $** | **COST, $** |
| PUMP (15 year, 10% interest) | 0.13147 | 7,237 | 951 |
| PIPE (Includes Eng and Taxes)(40 years, 10% interest) | 0.10226 | 40,886 | 4,181 |
| SUMP (40 years, 10% interest) | 0.10226 | 10,103 | 1,033 |
| TOTAL | | 58,226 | 6,166 |
| | | | |
| **TOTAL ANNUALIZED CAPITAL COST PER ACRE (290 acres)** | | | 21.26 |
| | | | |
| **ANNUALIZED MAINTENANCE COSTS** | | | **ANNUAL** |
| | **FACTOR (%)** | **COST, $** | **COST, $** |
| PUMP | 6 | 7,237 | 434 |
| PIPE (includes ENG & Taxes) | 0.5 | 40,886 | 204 |
| SUMP | 1 | 10,103 | 101 |
| TOTAL | | 58,226 | 740 |
| **TOTAL ANNUALIZED MAINTENANCE COST PER ACRE (290 acres)** | | | 2.55 |
| **ENERGY COSTS ($/acre foot)** | | | 6.00 |

# APPENDIX C

# TAILWATER POLICY

# FROM

# WATER CONSERVATION PLANS

# OF THE

# USBR MIDPACIFIC REGION AND THE STATE OF CALIFORNIA

## TAILWATER POLICY FROM WATER CONSERVATION PLANS OF THE USBR MIDPACIFIC REGION

### Alpaugh Irrigation District

May 1996

p.1-45 All water in the District delivery canals and laterals remains in the system until utilized. On-farm tailwater returns systems have been constructed by majority of the District landowners. Water users have installed small PVC pipe lines which allow tailwater to be pumped back into open ditch laterals for reuse within the District.

p. 1-14 Many water users have also installed small PVC pipelines which allow tailwater to be pumped back into laterals or open ditch laterals for reuse within the District. This policy is encouraged by the District.

p.1-19 Tailwater overflowing an individual water user's field and flowing into another field is quickly noticed and stopped.

p. 1-30 All surface drainage within Alpaugh Irrigation District remains within the District. Many of the water users have installed tailwater return systems which pump tailwater back into the existing delivery system. At other locations, surface drainage flows by gravity back into the District's open canal distribution system. No return flow water leaves the District service area.

**Arvin-Edison Water Storage District**

July 1997

p. 13 Each water user is responsible for controlling drainage water or else their water service is shut off. There is no surface water leaving the District.

**Bana-Carbona Irrigation District**

March 1994

p. 27 The District return flow policy recommends all landowners construct tailwater ponds to pump return flows to the head of the field for reuse. Not all landowners have accomplished this and the program is on-going. Non-compliers are urged to seek Soil Conservation Service design and monetary assistance. However, no return flows leave the District. If the tailwater ponds do not have pump back features, their overflow leads to District laterals. The water is then resold to other water users.

**Bella Vista Water District**

January 1995

p. 2-43 There are no return flow practices within the District thereby negating need for a specific policy to address this.

p. 3-43 There have never been irrigation evaluations District staff is aware of that would provide information regarding tailwater in flood irrigation application-water audits in the BMP's may reveal their existence in the future.

**Broadview Water District**

December 1993

p. 2-9 Because Broadview has the ability to recapture tail water flows for the entire District, it does not have a policy that limits tail water releases from farm field. The recycled water is blended with new supply water and is then resold to the water users. Beginning with the 1994 crop year, water users have been requested to voluntarily limit tail water from their fields. This should aid in water management throughout the entire District.

**Carpinteria County Water District**

December 1993

p. 17 The District has not developed or implemented policies designed to regulate the return flows from agricultural irrigation operations. Growers in the District service area utilize drip and micro-mister irrigation equipment, separately or in combination, for their irrigation operations. Surface runoff and deep percolation quantities resulting from these operations are small, therefore the return flows to the underlying aquifer are not significant.

**The Central San Joaquin Water Conservation District**

December 1993

p. 27 The District has yet to make delivery of any surface water. The problem of return flows will be addressed at such time as the District has surface water supplies and is able to determine quantities and flows of drain water, if any.

**Chowchilla Water District**

September 1995

p. 10, 26 Tailwater is collected and held on-farm.

**Clear Creek Community Services District**

November 1994

p. 9 The District has no return flow policy. Tailwaters drain to ravines.

p. 19 The runoff (tailwater) from irrigated pastures and the large orchard is small, therefore, return flows to the underlying aquifer is not significant.

p. 19 On the East side of the District Olinda Creek is the only known area where runoff could leave the District. This creek drains winter runoff into the Sacramento River.

However, Olinda Creek is seasonal and is dry during the irrigation season.

**Contra Costa Water District**

January 1995

p. 44 This section addresses Step 3, part F of the CVPIA Criteria and is to identify where surface and subsurface drainage goes and water quality monitoring programs for surface and subsurface drainage water. However, since 99 percent of CCWD's water use is for municipal and industrial purposes, there is no significant drainage water except for that collected and treated by area waste water agencies and the rainwater flows through the network of small creeks to the Sacramento and San Joaquin Delta.

**Colusa County Water District**

February 1995

p. 10 To avoid drainage problems, it shall be the responsibility of every water user to control the water to be applied to his land. Any water user who deliberately, carelessly, or otherwise wastes water on roads, adjoining land or creeks will be informed by District personnel that he is not complying with this rule. He will be allowed a reasonable time to correct the situation. If he makes no prompt effort of correction, his water service will be discontinued.

p. 10 The above rule eliminates the potential for substantial drainage ever leaving the District boundaries. It is the intention of the Board of Directors in adopting such a rule that no irrigation drainage waters shall leave the land to which it is applied. Some farm operations, which create a return flow, capture the flow for pumping back onto the field. As can be concluded from the above policy, no return flows leave the District's service area for reuse.

**Corning Water District**

December 1993

p. 13 The District return flows policy is that all tail-water should be kept on-farm. The District will impose a fine for excessive runoff.

**Dudley Ridge Water District**

December 1992

p. 6 All permanent crops in the District are currently irrigated with drip or low-volume microsprinkler systems. Permanent crops planted since the late 1970's were developed with these types of low-volume systems. Since 1983, District farmers have converted to approximately 3,034 acres of older orchards from hand-move sprinkler, gated pipe and furrow irrigation systems to low-volume microsprinkler application. These conversions have alleviated high groundwater conditions in the southeastern portion of the District; additionally, the use of tailwater recirculation systems for these fields have been idled or abandoned since the drip and microsprinkler systems have been operating.

p. 13 Tailwater is not an issue on permanent crop lands due to the extensive use of drip and microsprinkler irrigation systems. On row crop land, tailwater runoff from individual fields are returned to adjacent supply canals for use on downstream fields. Individual landowners have installed tailwater return systems, allowing tailwater from the most downstream field to be reused on that field, or more commonly, returned by a series of lift pumps to the main supply canals.

p. 49 Tailwater is produced on some sprinkler and furrow irrigated lands. Historically, each water user estimates the quantity of tailwater recovered (generally by knowing the capacity of the tailwater return pump, in some cases the pumps are equipped with

flowmeters) and rarely monitors the quality, which is not expected to degrade significantly.

**Dunnigan Water District**

February 1994

p. 23 It is the policy of the District that no irrigation water supplied by this District drain beyond the boundaries of the District. Therefore, all water users shall either install recirculating structures or capture ponds to capture and/or reuse drainage water, employ a method of irrigation that will control drain water spillage, or make an agreement with one or more downstream District water users to capture his drain water. All water users are advised, therefore, to review their irrigation methods in advance of the irrigation season in order to avoid drain water spillage and conserve water. Any water user who deliberately, carelessly, or otherwise wastes water on road, roadside ditches, adjoining land or drainage channels, or who does not have an adequate recirculating system, will be informed by District personnel that he is not complying with this rule. The water user will be allowed such length of time as the District, in its sole discretion, deems reasonable to correct such drainage problem. If such water user does not make such corrections promptly, water service may be discontinued by the District.

**Eldorado Irrigation District**

November 1994

p. 23 Due to ever-increasing use of efficient irrigation systems on agricultural lands within EID, as well as the high-quality and well drained loamy soils, very little, if no, measurable agricultural drainage water leaves the District.

p. 23 Although not agricultural drainage water, EID's raw water ditch systems do return water back to the two main river systems as part of normal ditch operations. These flows, , are of high quality, that can be reused by downstream users.

**Exeter Irrigation District**

January 1998

p. 15 No local drainage, return flows or runoff leaves the District other than the intermittent Yokohl Creek runoff water which flows to the Kaweah River. Farmers that still employ furrow irrigation have a tailwater system which returns any runoff back to the head of the system for re-use and/or deep percolation.

**Feather Water District**

April 1993

p. 1-16 The District reclaims all drain water and pumps it back into our system and is reused by everyone in the District.

p. 1-34 The District has a return system. The drainage water is reused within the service area for agricultural crops. Drain water collected by the District is monitored and is good quality for agriculture. Drain water does not leave the area.

**Fresno Irrigation District**

March 1993

p. 3-9 There are no return flows or drainage in the District.

p. 3-9 There is no drainage water from the District. From time-to-time, primarily in wet years when the District is encouraging water use by delivering extra water for deep percolation, some water growers will prematurely cease irrigation once basic crop needs are met resulting in excess flow in the west end of the District. During these periods the

District may experience a small operational spill. These waters are used by growers to the west of the District who otherwise rely solely on groundwater. Because the District permits no drainage water within FID canals (see rule #33 of Rules Governing Water Distribution and Canal Maintenance) there is no known constituent that would limit reuse.

p. 5-4 On farm irrigation system evaluations may be valuable to growers in the FID to help them improve their irrigation management. The benefits of improved management can include lower energy bills, reduced loss of fertilizer, and reduction of labor costs. However, since deep percolation rejoins a useable groundwater body, there will be little, if any, water that is truly conserved by this practice. For this reason, the District feels that this practice should be promoted mainly for its benefits other than water conservation.

**Gateway Regional Water Conservation Planning Area**

(Hospital Water District, Kern Canon Water District, Del Puerto Water District, Salado Water District, Sunflower Water District, Orestimba Water District, Foothill Water District, Davis Water District, Mustang Water District, Quinto Water District, Romero Water District)

December 1993

p. 14 Insofar as all drainage systems are owned, operated and/or maintained by the individual water users and remain their responsibility, these district have not instituted any formal return flow policy. They do, however, maintain a cooperative stance with

down slope districts in regard to any problems arising from drainage leaving District boundaries and will initiate and take all actions required to remediate any problems.

p. 25 These Districts have been very active in encouraging the development and installation of tailwater return systems designed to reduce drainage and improve irrigation efficiency. Significant improvements in design coupled with increased water costs and persistent water shortages have made this popular practice among the regions water users. District referrals outlining assistance available from the U.S. Soil Conservation Service, local farm advisors, private consultants and other users have made this a highly successful program throughout the region.

**Glenn-Colusa Irrigation District**

January 1993

Volume 2, Appendix F p.4. IV Crops other than Rice-Special Conservation Rules 1.1.

(i) Recapture and reuse system. The landowner will install and operate for the full season a recapture and reuse system for the fields; or

(ii) Impermeable barrier. The landowner will provide an impermeable barrier at the bottom of his fields and not drain water except under circumstances in which the ditch tender and landowner agree, and a memorandum in accordance with this memorandum; or

(iii) Sprinkler irrigation. The landowner will utilize sprinkler irrigation during the pre-irrigation phase, emergence, and early stage of the crop if the crop to be grown is a row crop. Thereafter, furrow irrigation will be conducted in a reasonable fashion without excessive drainage and utilizing intense management of the water during furrow irrigation period; or

(iv) Meter to reflect University of California requirements. The landowner elects to install, at his cost, a meter under the program described in Paragraph 2 ("meter") and the meter reading reflects for the full season use by the Board for the crop year. The landowner will not be permitted to plant more acreage because his land is metered or water use is…

**Glide Water District**

March 1995

Step 4 p. 2 The requirement of recapture and re-use of tailwater has always been strictly enforced by the District in the old plan as well as the new plan. It is estimated that approximately 5-10% of the irrigation water applied to field will reach the end of the field and run-off. This practice has resulted in a substantial water savings. The costs relating to the re-use system is approximately $20,000-30,000 per system.

Step 4 p.4 Growers have done an excellent job over the years developing irrigation systems and water re-use systems. Many types of systems are utilized within the District (open ditch with siphon pipes, underground pipeline with alfalfa valves, open ditch with cuts, sprinklers, poly pipes, gated pipe and drip), all of which are very efficient when properly managed. The above-mentioned irrigation systems coupled with the District mandated tail water re-use system have proven very effective.

p. 13 No return flows are allowed to leave the district. Glide Water District oversees the operation of the last recovery system within the district to avoid any tailwater spill.

p. 16 Recapture and recycling of water- The requirement of recapture and re-use of tailwater has always been strictly enforced by he District. This policy pre-dates any conservation plan by the District. It is estimated that approximately 5-10% of the irrigation water applied to fields will reach the end of the field as run-off. This practice

has resulted in a substantial water savings and some ground water recharge. The cost related to the re-use system is approximately $20,000-30,000 per system.

**Goleta Water District**

July 1993

p. 5 The District's agricultural customers consists of about 200 very efficient water managers almost without exception, irrigation is through drip systems, micro-sprinklers, or systems of similar efficiency.

p. 16 A return flow policy is not required at Goleta, because the local system consists of closed pipes, water use is very efficient, and irrigation runoff is nil.

**Gravelly Ford Water District**

January 1994

p. 8 No return flows are allowed.

**Hills Valley Irrigation District**

July 1998

p. 5-13 There are no operational spill losses in the District. All water transmitted within the District's distribution system remains within the system until utilized. On-farm tailwater return systems have been constructed by those landowners not utilizing permanent on-farm distribution systems. All deep percolation losses return to a usable groundwater source and no water leaves the service area in the form of surface runoff.

p. 2-31 It is the responsibility of the water user to manage their water supply after it is taken from a District facility. The landowners are encouraged to be considerate of neighbors and manage their tailwater on their own property.

**Ivanhoe Irrigation District**

July 1998

p. 2-10 Each landowner has a tail-water return system which pumps any runoff back into their system for irrigation or for deep percolation during the rainy season. All deep percolation losses return to usable groundwater sources.

p. 2-31 Each landowner has a tail-water return system which pumps any runoff back into the farmers system for irrigation or for deep percolation during the rainy reason.

**James Irrigation District**

June 1992

p. 9 An estimated five percent of the District has on-farm tailwater return systems. Of the fields without tailwater return systems, some have blocked ends, some drain tailwater into lower lying fields where it is reused for irrigation and on the remainder growers have portable pumps to pump tailwater back into the JID's canal laterals.

p. 13 The District does not own or operate any surface or subsurface drainage facilities. The District does receive tailwater back into its canal system as well as storm runoff from the City of San Joaquin. Surface drainage of tailwater in much of the District is handled by privately owned pumps which discharge into JID's canal system.

p. 20 Tailwater return systems have been installed on an estimated 5 percent of the District's fields. These allow growers to use larger furrow flowrates and faster advance times, both of which lead to an improved distribution uniformity (DU).

**Kanawho Water District**

March 1995

p. 4 Each farm is required by the District to have a on-farm recirculating system to capture and re-use all irrigation drainage. The District prefers on-farm recirculating for the following reasons:

1. Agricultural chemicals cannot be spread to the farms' neighbors, or to adjoining districts and lands.
2. Slit or trash will not be entered into the District's pipelines.
3. On-farm recirculating use will encourage beneficial usage.
4. District maintenance responsibilities on drains will be minimized.

p. 12 No returns flows are allowed to leave the district.

p. 17 Recapture and recycling of water-The requirement of recapture and re-use of tailwater has always been strictly enforced by the District. This policy pre-dates any conservation plan by the District. It is estimated that approximately 5-10% of the irrigation water applied to fields will reach the end of the field as run-off. This practice has resulted in a substantial water savings and some ground water recharge. The cost related to the re-use system is approximately $20,000-30,000 per system.

**Kern Tulare and Rag Gulch Water Districts**

February 1996

p. 12 As a result of efficient irrigation methods, there is little or no return flow. Neither district takes return flow into their system.

p. 20 The districts are not aware of any return flows. Water costs, coupled with significant use of low-volume irrigation methods, are believed to substantially eliminate return flows.

**Laguna Irrigation District**

June 1992

p. 5` Most of the fields utilize buried concrete pipelines with valve risers and/or head ditches with siphons. Some fields have tailwater return systems, but no inventory has been made of them.

p. 16 Runoff return systems have been installed on some fields which allow use of large furrow flowrates and fast advance times, both of which lead to an improved distribution uniformity (DU).

Table 4 Tailwater discharge is zero.

**Lost Hills Water District**

December 1992

p. 17 Some of the landowners have installed tailwater return systems on the irrigated land to handle surface drainage. Most of the systems route the tailwater for irrigation use on adjacent fields. None of the tailwater is allowed into the District distribution system.

p. 55 Many of the growers that furrow irrigate utilize runoff return systems which allow the use of large furrow flowrates and fast advance times, both of which can lead to an improved DU. Most growers within the District utilize land leveling as a normal cultural practice. Use of gated pipes has replaced some earth head ditches and siphon pipes. Growers have also tried furrow torpedoes, reducing the run length and cutback streams in an effort to maximize efficient water use by improving the DU and hence, the IE.

**Lower Tule Irrigation District**

July 1998

p. 2-29 Most landowners have a tailwater return system which pumps any runoff back into the system to be deep percolated.

p. 3-27 Most of the District's growers have installed tailwater return systems. All deep percolation losses return to a usable groundwater source and virtually no water leaves the service area in the form of surface runoff.

p. 5-47 On-farm tailwater returns systems have been constructed by the majority of the District landowners. All deep percolation losses return to a usable groundwater source and virtually no water leaves the service area in the form of surface runoff.

**Madera Irrigation District**

February 1994

p. 2-18 The District discourages return flows into the canal system. Over the years, the number of return flow locations have been greatly reduced. The District now has only 15 locations where grower return flows re-enter the canal system. These are done under permission of an encroachment permit. Any new requests are considered only on a case by case basis. No new permits have been issued for several years.

p. 3-18 Return flows go back to the District's system which includes natural channels.

**Mercy Spring Water District**

February 1995

p. 9 The District has no formal drainage policy since the bulk of the drainage leaving the District goes into the Panoche Drainage District. A per acre fee is paid to Panoche and all appropriate monitoring is handled by them.

p. 18 The District water use during 1989 consisted of crop water use, (evaporation, leaching, and cultural practices) water leaving the district through drainage to Panoche Water District, conveyance loses (est. 5%), water transfers out of the district, and deep percolation (not quantified). The District has not operation spills, consumptive use by riparian vegetation, environmental use, groundwater recharge, or M&I use.

**Monterey County Water Resources Agency**

January 1995

p. 11 There is very little or no return flow water within Zone 2B. Irrigation systems within Zone 2B are generally operated without tailwater or surface water losses. A return flow policy for Zone 2B is therefore unnecessary.

p. 21 Field surface drainage in Zone 2B discharges into a system of existing surface ditches and sloughs that eventually drain into Monterey Bay. Significant surface drainages in Zone 2B are the Castroville Slough, Tembladero Slough/Reclamation Ditch, Alisal Slough, Blanco Ditch and the Salinas River. A combination of furrow and sprinkler irrigation systems are predominantly used in Zone 2B. These irrigation systems are generally operated without tailwater or surface water losses. Surface drainage primarily results from excess wintertime precipitation.

**Orland-Artois Water District**

January 1989

p. 2-10 The District discourages return flows from leaving the users property. Participation is voluntary, but there has not been a need to make it mandatory since all available return flows are utilized prior to leaving the District.

**Pacheco Water District**

December 1996

p. 8 Most return flows are captured by the District and 1) recycled, 2) released as surface drain outflow. Some on-farm return systems are within the District. The District is considering a policy to encourage the use of on-farm return systems. See Figure 2, which delineates the disposition of tailwater.

p. 15 There are numerous opportunities for reuse of the released water as it moves through portions of CCID, the Grassland Water District, and non-water right lands; ultimately, finding its way to the San Joaquin River. Water reuse is not tracked by the District.

p. 29 This BMP is not applicable to the District, since no operational spills leave the District. Spill water is captured for use in the lower irrigation laterals or captured in the tailwater return system and is recirculated.

**Panoche Water District**

January 1996

p. 10 The District, which is a part of Panoche Drainage District, requires that all return flow be retained on farm and be managed by each water user. Tailwater management may consist of using that water on adjacent field by the same water user, or releasing that water for use by other water users. Discharge of tailwater into the Panoche Drainage District system is not allowed. In some cases, the District can accommodate tailwater into the supply channels as long as it is free of silt and debris. The District has no operational spill.

**Patterson Water District**

September 1994

p. 10 The District captures and reuses tailwater, of which about 90% is reused and 10% is spilled. Recently, farmers have begun to install tailwater return systems, three of which have been installed in the last two years.

p. 26 Return flow is captured by the lower laterals. The return flow from the last lateral is drained into the San Joaquin River for reappropriation and reuse.

**Pixley Irrigation District**

July 1998

p. 2-29 Most landowners have a tailwater return system which pumps any runoff back into the District's system to be deep percolated.

p. 3-23 Most of the District's growers have installed tailwater return systems. The District uses Deer Creek, a natural channel, for any return flows. All deep percolation losses return to a usable groundwater source and virtually no water leaves the service area in the form of surface runoff.

**Plain View Water District**

January 1994

p. 10 Control and disposition of drainage flow is the landowner's responsibility. About 60% of surface drainage is recirculated within the District by water users; privately installed return flow systems. About 20% of the drainage is discharged to another district and is reused within the District. The remaining 20% of the drainage is drained back to the Delta Mendota Canal and reused downstream by other Districts.

**Porterville Irrigation District**

July 1998

p. 2-31 …return flows to the District's distribution systems are not allowed. Construction and management of on-farm return systems are encouraged.

p. 3-39 There is no subsurface drainage within the District and therefore no effluent from such drainage into or out of the District. Surface drainage into District facilities is prohibited. Where incidental return flows may occur, such water is available for reuse.

**Proberta Water District**

July 1993

p. 6 Sump ponds and ditches on the farmers property is where the water stays. All water not used goes back to district water bank for redistribution to other users.

**San Joaquin River Exchange Contractors Water Authority**

(Columbia Canal Company, Firebaugh Canal Water District, San Luis Canal Company)

September 1997

p. 13 There are two District tailwater recovery points which operate during the irrigation season which pump tailwater back into the main canal; each system has a 20 CFS capacity. There are no regulating reservoirs or recharge area. There are no storage facilities aside from the District's conveyance system.

p. 14 FCWD has no storage facilities at this time aside from the canal system. The District has six areas where both tailwater and subsurface tile water is recycled. SLCC does have a community drain water recovery system. This system has 32 pump stations with a combined capacity of 220 CFS during peak periods.

**Santa Ynez River Water Conservation District**

August 1996

p. 10 There is no such policy because there is no return flow attributable to "tail waters".

**Saucelito Irrigation District**

July 1998

p. 2-25 The District does not allow individual water users to pump return flows into the District system. Many lands within the District are level and individual water users have installed sumps equipped with return systems to pump their tailwater back into their main line to recirculate any tailwater back onto their crops.

p. 3-23 All water used within the District stays within the District. Many farms have return systems to allow for tailwater reuse.

p. 5-29 There are no operational spill losses in the District. All water transmitted within the District's distribution systems remains within the system until utilized. On-farm tailwater return systems have been constructed by those District landowners not utilizing permanent on-farm distribution systems. All deep percolation losses return to a usable groundwater source and no water leaves the service area in the form of surface runoff.

**Shafter-Wasco Irrigation District**

March 1995

p. 29 The water user's on-farm irrigation systems recapture their tail water and

no surface water leaves the District boundaries.

**Southern San Joaquin Municipal Utility District**

July 1998

p. 2-26 Each landowner has a tail-water return system which pumps any runoff back into the farmer's system to be deep percolated.

p. 5-63 There are no operational spill losses in the district. All the water transmitted within the District's distribution system remains within the system until utilized. On-farm tailwater return systems have been constructed by those District landowners not utilizing permanent on-farm distribution systems. All deep percolation losses return to a usable groundwater source and no water leaves the surface area in the form of surface runoff.

**Stockton East Water District**

May 1996

p. 1-16 The District policy is to claim all return flow as District water.

p. 1-34 Soils in the District are permeable, so most irrigation tail water penetrates rapidly beyond the root zone of the crops and presents no problems during the irrigation season. Some drainage water collects in open farm ditches and flows to natural water ways where it is reused for irrigation. Present drainage practices present no problem to agriculture. District drainage water has not significantly affected receiving surface or groundwater quality in the past.

**Stone Corral Irrigation District**

July 1998

p. 2-27 District has no return flow policy, though 95% of the District landowners have a return flow system or do not need a system due to the lack of any substantial runoff.

p. 5-17 There are no operational spill losses in the District. All water transmitted within the District's distribution system remains within the system until utilized. On-farm tailwater return systems have been constructed by those District landowners not utilizing permanent on-farm distribution systems. All deep percolation losses return to the usable groundwater source and no water leaves the service area.

**Tea Pot Dome Water District**

December 1993

p. 1-16 None, and the reason is that we do not have a return flow problem within our District.

p. 1-34 There are no return flows.

**Terra Bella Irrigation District**

July 1998

p. 5-20 There are no operational spill losses in the District. The entire District is irrigated through a highly sophisticated metered and pressurized system. All water transmitted within the District's distribution system remains within the system until utilized. All furrow irrigation was phased out about 15 years ago, eliminating any need for tailwater return systems. Defective systems must be repaired or water service will not be provided.

**Thomes Creek Water District**

October 1993

p. 11 It is the responsibility of each individual landowner to keep drainage on-farm. Most drainage from irrigated lands is captured in tail-water ponds and is re-used for irrigation either on-farm or on adjacent farms. A small amount of water leaves the District via Thomes Creek and is used by farms downstream.

Step 3.F Most of the drain water stays on-farm in tailwater catch ponds. On some farms, this water is reused. Any irrigation water from the District that is not caught in tail-water ponds ultimately reaches Thomes Creek, which traverses the District. Because of the past efforts of District members, the amount of drain water that leaves the District is very small. Any water that does leave the District is used by farms downstream for irrigation.

**Tulare Irrigation District**

December 1996

p. 10 Does not accept return flows, all on farm systems.

p. 21 All return flow goes on the Ag. Land with the District.

**The West Side Irrigation District**

January 1995

p. 9 The District provides a drainage system for irrigation return flows for all the land in the District. The District will not hesitate to shut off water service to user, if water is wasted or improperly used.

p. 16 The District has a tail water return flow collection (surface drainage) system to provide drainage to the lands within the District. For a map of the facilities See Appendix A. The return flow from the lands above the Lower Main Canal is discharged

into that facility and reused. The main drain is a dual purpose facility that not only collects irrigation tail water, but it also collects sub-surface water. Some of the sub-surface water seeps into the drain and some is introduced by non-farm under ground tile systems. All of the collected water is conveyed by the Main Drain to the District's Intake Canal where it is pumped back into the District's distribution systems for reuse.

**Westside Water District**

November 1994

p. 32 Return flows enter either one of eleven District drains or one of five natural creeks. District drains terminate in either the natural creeks or Glenn-Colusa Irrigation District conveyance facilities. GCID has a weir facility at the confluence of Freshwater Creek and Salt Creek where the water is diverted into GCID's conveyance facilities for reuse. Following reuse by GCID, water enters the Colusa Basin Drain. Water is reused many times for agricultural and environmental water before re-entering the Sacramento River and Knights Landing.

p. 38 The District will inform water users of the evaluation services available within the area to improve soil conditions for better penetration of applied surface water. This will allow for more efficient application and reduced run-off.

**West Stanislaus Irrigation District**

March 1994

p. 10 The District maintains a drainage system for irrigation return flows for all the lands in the District. The District will not hesitate to shut off water service to user, if water is wasted or improperly used.

p. 17 The District has a tail water return flow collection (surface drainage system) system to provide drainage to the lands within the District. Although the District utilizes the natural channels (Creeks) that cut through the District, these are not considered as part of the District's drainage system. All of the surface drainage eventually find its way to the San Joaquin River, the water that flows in the natural channels goes direct and the other facilities discharge onto riparian land adjacent to the river, which enhances riparian habitat.

**Westland Water District**

December 1993

p. E-16 Each water user shall take reasonable steps to reuse or control tailwater. The failure to do so shall constitute a waste of water which the District may take appropriate measures to prevent.

# ACRONYMS

**PREPARED BY THE WAC**

**FOR THE**

**COACHELLA VALLEY WATER DISTRICT**

## LIST OF ACRONYMS

| TERM | ACRONYM |
|---|---|
| CALFED | California Water Policy Council and Federal Ecosystem Directorate |
| CCUnet | Net Crop Consumptive Use |
| CIMIS | California Irrigation Management Information Systems |
| CUnet | Net Consumptive Use |
| CVWD | Coachella Valley Water District |
| d | Flow Depth |
| Dcet | Unit Depth of Seasonal Crop Evapotranspiration |
| Deci | Unit Depth of Seasonal Effective Crop Irrigation |
| DWR | California Department of Water Resources |
| EC | Electrical Conductivity |
| ECe | Electrical Conductivity of Saturated Soil |
| ECiw | Electrical Conductivity of the Applied Irrigation Water |
| ECq | Electrical Conductivity of the qth Quartile |
| ECw | Electrical Conductivity of the Water Applied |
| Epan | Class A Pan Evaporation |
| ET | Evapotranspiration |
| ETc | Crop Evapotranspiration |
| ETo | Grass Reference Crop Evapotranspiration |
| ETp | Alfalfa Reference Crop Evapotranspiration |
| ETr | Reference Crop Evapotranspiration |
| IBI | Ion Balance Index |
| ICCUR | Irrigation Crop Consumptive Use Ratio |
| ICUR | Irrigation Consumptive use Ratio |
| IID | Imperial Irrigation District |
| IOT | Intake Opportunity Time |
| IRdiv | Irrigation Delivery |
| Kc | Crop Coefficient |
| Kpan | Monthly Pan Coefficient |
| L | Border Length |
| LF | Leaching Fraction |
| LFq | Leaching Fraction of the qth Quartile |
| LR | Leaching Requirement |
| LRvol | Leaching Requirement Volume |
| M & I | Municipal and Industrial |

## LIST OF ACRONYMS (Cont)

| TERM | ACRONYM |
|---|---|
| MAF | Million Acre Feet |
| MWD | Metropolitan Water District of Southern California |
| NWS | National Weather Service |
| Pe | Effective Precipitation |
| q | quartile |
| Q | Inflow Rate Per Unit Width of Border |
| SB | Salt Balance |
| SBI | Salt Balance Index |
| SDCWA | San Diego County Water Authority |
| SS | Salton Sea |
| SWRCB | State Water Resource Control Board |
| T | Irrigation Time |
| Tco | Cutoff Time |
| TDS | Total Dissolved Solids |
| USBR | United States Bureau of Reclamation |
| USDA | United States Department of Agriculture |
| WAC | Water Advisory Committee |
| WB | Water Balance |
| WBI | Water Balance Index |
| Wq | Extraction Pattern in the Rootzone Quartile |
| WST | Water Study Team |
| X | Advance Distance at Irrigation Time T along the Border |
| z | Infiltration Depth |

# GLOSSARY

**PREPARED BY THE WAC**

**FOR THE**

**COACHELLA VALLEY WATER DISTRICT**

**advance time**: Time required for a given stream of irrigation water to move from the upper end of a field to the lower end.

**Albedo**: The ratio of electromagnetic radiation reflected from a soil and crop surface to the amount incident upon it. The value commonly is approximately 0.23 for a green growing crop.

**alkali soil**: (See saline-sodic soil.)

**allowable depletion**: That part of soil water stored in the plant root zone managed for use by plants, usually expressed as equivalent depth of water in mm (acre-inches per acre, or inches).

**alternate set irrigation**: A method of managing irrigation whereby, at every other irrigation, alternate furrows are irrigated, or sprinklers are placed midway between their locations during the previous irrigation.

**application efficiency (Ea)**: The ratio of the average depth of irrigation water infiltrated and stored in the root zone to the average depth of irrigation water applied, expressed as a percentage.

**application efficiency low half (Eh )**: The ratio of the average of the low one-half of measurements of irrigation water infiltrated and stored in the root zone to the average depth of irrigation water applied, expressed as a percentage.

**application efficiency of low quarter**: The ratio of the average depth of irrigation water infiltrated and stored in the root zone as determined from the lowest 25% of the area, to the average depth of irrigation water applied, expressed as a percent.

**application rate**: Rate that water is applied to a given area. Usually Expressed in units of depth per time.

**application time, set time**: The amount of time that water is applied to an irrigation set.

**Appropriation Doctrine**: The system of water law dominant in the Western United States under which (1) the right to water is acquired by diverting water and applying it to a beneficial use, and (2) a right to water is superior to a similar right acquired later in time. Usually under modern statutes, approval must be secured from some state agency before acquiring a new water right or making a change in use of the water.

**aquiclude**: Underground geologic formation that neither yields nor allows the passage of an appreciable quantity of water, although it may be saturated with water itself.

**aquifer**: A geologic formation that holds and yields useable amounts of water. Aquifers can be classified as confined or unconfined.

**aquitard**: Underground geologic formation that is slightly permeable and yields inappreciable amounts of water when compared to an aquifer.

**artesian aquifer**: Aquifer that contains water under pressure as a result of hydrostatic head. For artesian conditions to exist, an aquifer must be overlain by a confining material or aquiclude and receive a supply of water. The free water surface stands at a higher elevation than the top confining layer.

**available soil water**: (See available water capacity.)

**available water capacity, AWC**: The portion of soil water that can be readily absorbed by plant roots of most crops, expressed in mm water per mm soil (inches per inch, inches per foot, or total inches) for a specific soil depth. It is the amount of water stored in the soil between field capacity (FC) and permanent wilting point (WP). It is typically adjusted for salinity (electrical conductivity) and rock fragment content. Also called available water holding capacity (AWHC), or available soil water.

**available water holding capacity (AWCH)**: (See available water capacity.)

**average annual precipitation**: The long-term or historic arithmetic mean of annual precipitation (rain, snow, dew) received by an area.

**average daily use rate**: Calculated or measured water used by plants in one day through evapotranspiration, expressed as an equivalent depth, mm per day (inches per day).

**base saturation**: Extent to which a material is saturated with exchangeable cations other than hydrogen, expressed as a percentage of the cation-exchange capacity.

**basic intake rate**: Rate at which water percolates into soil after infiltration has decreased to a low and nearly constant value.

**basin irrigation**: Irrigation by flooding areas of level land surrounded by dikes. Used interchangeably with level border irrigation, but usually refers to smaller areas.

**black alkali soil**: A soil with a pH of 8.5 or higher or with an exchangeable sodium percentage greater that 15%. Dissolved organic matter may be deposited on the soil surface as soil water evaporates (see saline-sodic soil).

**Blaney-Criddle Method**: An air temperature based method to estimate crop evapotranspiration (see FAO Blaney-Criddle Method).

**border irrigation**: Irrigation by flooding strips of land, rectangular in shape and cross leveled, bordered by dikes. Water is applied at a rate sufficient to move it down the strip in a uniform sheet. Border strips having no downfield slope are referred to as level border systems. Border systems constructed on terraced lands are commonly referred to as benched borders.

**bubbler irrigation**: The application of water to flood the soil surface using a small stream or fountain. The discharge rates for point-source bubbler emitters are greater than for drip or

subsurface emitters but generally less than 225 L/h (1 gpm). A small basin is usually required to contain or control the water.

**cablegation**: A method of surface irrigation that uses gated pipe to both transmit and distribute water to furrows or border strips. A plug, moving at a controlled rate through the pipe, causes irrigation to progress along the field and causes flow rates from any one gate to decrease continuously from some maximum rate to zero.

**cation exchange capacity (CEC)**: The sum of exchangeable cations (usually Ca, Mg, K, Na, Al, H) that the soil constituent or other material can adsorb at a specific pH, usually expressed in centimoles of charge per Kg of soil ($cmol_c$/Kg), millimoles per charge per Kg ($mmol_c$/Kg) or milliequivalents per 100 grams of soil at neutrality (pH=7.0), meq/100g).

**centrifugal pump**: Pump consisting of rotating vanes (impeller) enclosed in a housing and used to impart energy to a fluid through centrifugal force.

**check irrigation**: Modification of a border strip with small earth ridges or checks constructed at intervals to retain water as the water flows down the strip.

**chemigation**: Application of chemicals to crops through an irrigation system by mixing them with the irrigation water.

**Christiansen's uniformity coefficient**: A measure of the uniformity of irrigation water application. The average depth of irrigation water infiltrated minus the average absolute deviation from this depth, all divided by the average depth infiltrated.

**compensating emitter**: Microirrigation system emitters designed to discharge water at a near constant rate over a wide range of pressures.

**confined aquifer**: An aquifer whose upper, and perhaps lower, boundary is defined by a layer of natural material that does not transmit water readily.

**consumptive use**: The total amount of water taken up by vegetation for transpiration or building of plant tissue, plus the unavoidable evaporation of soil moisture, snow, and intercepted precipitation associated with vegetal growth. Synonymous with evapotranspiration.

**continuous-flow irrigation**: System of irrigation water delivery where each irrigator receives the allotted quantity of water continuously.

**continuous flushing emitter**: Microirrigation system emitter designed to continuously permit passage of large solid particles while operating at a trickle or drip flow, thus reducing filtration requirements.

**conveyance efficiency ( Ec )**: The ratio of the water delivered to the total water diverted or pumped into an open channel or pipeline at the upstream end, expressed as a percentage.

**conveyance loss**: Loss of water from a channel or pipe during transport, including losses due to seepage, leakage, evaporation, and transpiration by plants growing in or near the channel.

**crop coefficient (Kc )**: The ratio of the crop evapotranspiration to its reference crop evapotranspiration.

**crop evapotranspiration (ETc )**: The amount of water used by the crop in transpiration and building of plant tissue, and that evaporated from adjacent soil or intercepted by plant foliage. It is expressed as depth in mm (inches, or as the volume-depth ratio of acre-inches per acre) and can refer to daily, peak, design, monthly or seasonal quantities. Sometimes referred to as consumptive use, CU.

**crop irrigation requirement**: Quantity of water, exclusive of effective precipitation, that is needed for crop production. It also may include water requirements for germination, frost protection, prevention of wind erosion, leaching of salts and plant cooling.

**crop water use**: Calculated or measured water used by plants, expressed in mm per day (inches per day). Same as ETc except it is expressed as daily use only.

**cumulative intake**: The depth of water infiltrated into the soil from the time of initial water application to the specified elapsed time.

**cutback irrigation**: The reduction of the furrow or border inflow stream after water has advanced partially or completely through the field in order to reduce runoff.

**cutback stream**: Reducing surface irrigation inflow stream size (usually a half or a third) when a specified time period has elapsed or when water has advanced a designated distance down the furrow, corrugation or border.

**deep percolation**: Water that moves downward through the soil profile below the root zone and cannot be used by plants.

**deficit irrigation**: An irrigation water management alternative where the soil in the plant root zone is not refilled to field capacity in all or part of the field.

**demand irrigation system**: Irrigation water delivery procedure where each irrigator may request irrigation water in the amount needed and at the time desired.

**dew point**: The temperature to which a given parcel of air must be cooled at constant pressure and at constant water vapor content until saturation occurs, or the temperature at which saturation vapor pressure of the parcel is equal to the actual vapor pressure of the contained water vapor.

**distribution system**: System of ditches, or conduits and their controls, which conveys water from the supply canal to the farm points of delivery.

**distribution uniformity**: Measure of the uniformity of irrigation water distribution over a field.

**distribution uniformity of low quarter**: The ratio of the average of the lowest one-fourth of measurements of irrigation water infiltrated to the average depth of irrigation water infiltrated, expressed as a percent.

**drain**: Any closed conduit (perforated tubing or tile) or open channel, used for removal of surplus ground or surface water.

**drainage**: Process of removing surface or subsurface water from a soil or area.

**drainage pumping plant**: Pumps, power units, and appurtenances for lifting drainage water from a collecting basin to an outlet.

**drainage system**: Collection of surface and/or subsurface drains, together with structures and pumps, used to remove surface or ground water.

**drip irrigation**: A method of microirrigation wherein water is applied to the soil surface as drops or small streams through emitters. Discharge rates are generally less than 8 L/h ( 2 gal/h) for single-outlet emitters and 12 L/h ( 3 gal/h) per meter for line-source emitters.

**duty of water**: The total volume of irrigation water required to mature a particular type of crop. It includes that portion of consumptive use not satisfied by precipitation, evaporation and seepage from ditches and canals and the water eventually returned to streams by percolation and surface runoff.

**effective precipitation**: That portion of total precipitation which becomes available for plant growth.

**electrical conductivity (EC)**: A measure of the ability of the water to transfer an electrical charge. Used as an indicator for the estimation of salt concentration, measured in deciSiemens per meter (dS/m, equivalent to mmhos/cm), at 25 °C (77 °F).

—ECe =Electrical conductivity of soil water extract.
—ECi =Electrical conductivity of irrigation water.
—ECaw =Electrical conductivity of applied water.

**emission uniformity**: An index of the uniformity of emitter discharge rates throughout a microirrigation system. Takes account of both variations in emitters and variations in the pressure under which they operate.

**emitter**: A small microirrigation dispensing device designed to dissipate pressure and discharge a small uniform flow or trickle of water at a constant discharge, which does not vary significantly because of minor differences in pressure head. Also called a ‘‘dripper’’ or ‘‘trickler’’.

— compensating emitter: Designed to discharge water at a constant rate over a wide range of lateral line pressures.

— continuous flushing emitter: Designed to continuously permit passage of large solid particles while operating at a trickle or drip flow thus reducing filter fineness requirements.
— flushing emitter: Designed to have a flushing flow of water to clear the discharge opening every time the system is turned on.
— line-source emitter: Water is discharged from closely spaced perforations, emitters, or a porous wall along the tubing.
— long path emitter: Employs a long capillary sized tube or channel to dissipate pressure.
— multi-outlet emitter: Supplies water to two or more points through small diameter auxiliary tubing.
— orifice emitter: Employs a series of orifices to dissipate pressure.
— vortex emitter: Employs a vortex effect to dissipate pressure.

**environmental control**: Controlling air temperature and humidity or soil water conditions to minimize effects of low and high air temperatures on crop quality and quantity.

**evaporation**: The physical process by which a liquid is transformed to the gaseous state, which in irrigation is restricted to the change of water from liquid to vapor.

**evaporation pan**: 1. A standard U.S. Weather Bureau Class A pan (48-inch diameter by 10-inch deep) used to estimate the reference crop evapotranspiration rate. Water levels are measured daily in the pan to determine the amount of evaporation. 2. A pan or container containing water. Water evaporated from the device is measured and adjusted by a coefficient to represent estimated crop water used during the period.

**evapotranspiration**: The combination of water transpired from vegetation and evaporated from the soil and plant surfaces. Synonymous with consumptive use.

**exchangeable cation**: A positively charged ion held on or near the surface of a solid particle by a negative surface charge of a soil or colloid and which may be replaced by other positively charged ions in the soil solution.

**exchangeable sodium percentage (ESP)**: The fraction of the cation exchange capacity of a soil occupied by sodium ions determined as: exchangeable sodium (meq/100 gram soil) divided by CEC (meq/100 gram soil) times 100. It is unreliable in soil containing soluble calcium silicate minerals or large amounts of gypsum.

**exchange capacity**: The total negative charge of the soil exchange complex.
**FAO Blaney-Criddle Method**: A method to calculate grass reference crop evapotranspiration (ETc ) based on long-term air temperature data, estimates for humidity, wind movement and sunshine duration, and a correction to ETc downward for elevations above 1,000 meters above sea level. (See Blaney-Criddle Method).

**field capacity**: Amount of water remaining in a soil when the downward water flow due to gravity becomes negligible. Usually it is assumed that this condition is reached about two to three days after a full irrigation or heavy rain.

**furrow**:
- A trench in the soil made by a tillage tool;
- Small channel for conveying irrigation water.

**furrow irrigation**: Method of surface irrigation where the water is supplied to small ditches or furrows for guiding across the field.

**gated pipe**: Portable pipe with small gates installed along one side for distributing irrigation water to corrugations or furrows.

**geographic information system, GIS**: Computer data base management system for spatially distributed attributes.

**gravimetric (oven dry) soil water method**: A method of measuring total soil water content by sampling, weighing, and drying to constant weight in an oven at 105 °C. Percent water, usually on the basis of dry soil weight, is calculated.

**gross irrigation**: Total water applied to a given area, that may or may not equal total irrigation water requirement.

**gross irrigation requirements (Fg )**: The total irrigation requirement including net crop requirement plus any losses incurred in distributing and applying water and in operating the system. It is generally expressed as depth of water in mm or cubic meters per hectare (ac- inch per ac. or inches).

**gross irrigation system capacity**: Ability of an irrigation system to deliver the net required rate and volume of water necessary to meet crop water needs plus any losses during the application process.

**ground water**: Water occurring in the zone of saturation in an aquifer or soil. Sometimes referred to as ‘‘groundwater.’’

**growing season**: The period, often the frost-free period, during which the climate is such that crops can be produced. In the case of annual plants, it approximates the time interval between planting and crop maturity; for perennial crops, it is the period between certain temperature conditions that establish growth and dormancy. This growing season is sometimes restricted to the period between killing frosts.

**hydrologic cycle**: The continuing process by which atmospheric water condenses, falls to the surface of the earth in any of various forms of precipitation, runs through surface of subterranean passages toward the sea and again returns to the atmosphere by evaporation from either the sea or land surface.

**impermeable layer (soil)**: Layer of soil resistant to penetration by water, air, or roots.

**infiltration**: The downward entry of water through the soil surface into the soil.

**infiltration opportunity time**: The time that water inundates the soil surface, with opportunity to infiltrate.

**infiltration rate**: The quantity of water that enters the soil surface in a specified time interval. Often expressed in volume of water per unit of soil surface area per unit of time.

**instantaneous application rate**: The maximum rate that a sprinkler application device applies water to the soil, expressed in mm per hr (inches per hr).

**intake characteristic curves**: Curves reflecting cumulative water intake versus time for irrigation systems.

**intake family**: A grouping of intake characteristics into families based on field infiltrometer tests on many soils, developed by the SCS (now the Natural Resources Conservation Service). Used to analyze and design border and furrow irrigation systems.

**intake rate**: The rate at which irrigation water enters the soil at the surface (see infiltration). Expressed as mm per hour (inches per hour).

**irrecoverable water loss**: Water loss that becomes unavailable for reuse through evaporation, phreatophyte transpiration, or ground-water recharge that is not economically recoverable.

**irrigate**: To distribute water to land through artificial means, especially to enhance crop production where either natural water sources are so deficient as to make crop production impossible otherwise or where it is advantageous to supplement the natural water supply at certain critical stages in the development of crops.

**irrigable area**: Area capable of being irrigated, principally as regards to availability of water, suitable soils, and topography of land.

**irrigation check**: Small dike or dam used in the furrow alongside an irrigation border to make the water spread evenly across the border.

**irrigation conveyance loss**: Loss of water in transit from a reservoir, point of diversion or well to the point of application to the land, usually due to evaporation or seepage.

**irrigation district**: A cooperative, self-governing, semipublic organization set up as a subdivision of a state or local government to provide irrigation water.

**irrigation efficiency**: The ratio of the volume of irrigation water that is beneficially used to the volume of irrigation water applied, expressed as a percent. Beneficial uses include satisfying the soil water deficit and any leaching requirement to remove salts from the root zone. It is commonly interpreted as the volume of water stored in the soil for evapotranspiration compared to the volume of water diverted for this purpose, but may be defined and used in different ways.

**irrigation frequency, interval**: The time between irrigation events.

**irrigation runoff percentage**: The equivalent depth of irrigation water running off a field expressed as a percentage of the depth of irrigation water applied.

**irrigation scheduling**: The process of determining when to irrigate and how much water to apply, based upon measurements or estimates of soil moisture or water used by the plant.

**irrigation set**: The area irrigated at one time within a field.

**irrigation set time, irrigation period**: The amount of time required to apply a specific amount of water during one irrigation to a given area.

**irrigation system**: Physical components and configuration used to apply water by irrigation. May include pumps, pipelines, valves, nozzles, ditches, gates, siphon tubes, turnout structures, land shaping, furrows etc.

**irrigation water management (IWM)**: Managing plant, soil and water resources (precipitation, applied irrigation water, humidity, etc.) to optimize water use by the crop.

**irrigation water requirement**: The calculated amount of water needed to replace soil water used by the crop (soil water deficit), for leaching undesirable elements through and below the plant root zone, plus other production needs, less effective precipitation.

**land capability**: Classification of soil units for the purpose of showing their relative suitability for specific uses without permanent damage, such as crop production with minimum erosion hazard.

**land grading**: The operation of shaping the surface of land to predetermined grades. Also called ‘‘land shaping’’ (see land leveling for a special case).

**land leveling**: Process of shaping the land surface to a level surface. A special case of land grading.

**land smoothing**: Shaping the land to remove irregular, uneven, mounded, broken, and jagged surfaces without using surveying information.

**Langley**: A unit of energy per unit area commonly used in radiation measurements which is equal to gram calorie per square centimeter.

**laser leveling**: Land leveling in which a stationary laser transmitter and a laser receiver on each earthmoving machine are used for grade control.

**leaching**: Removal of soluble material from soil or other permeable material by the passage of water through it.

**leaching fraction**: The ratio of the depth of subsurface drainage water (deep percolation) to the depth of infiltrated irrigation water (see leaching requirement).

**leaching requirement**: Quantity of irrigation water required for transporting salts through the soil profile to maintain a soil salinity level in the rootzone that gives maximum crop yield. Salt tolerance of crops vary.

**length of run**: Distance water must flow in furrows or borders over the surface of a field from the head to the end of the field.

**limited irrigation**: Management of irrigation applications to apply less than enough water to satisfy the soil water deficiency in the entire root zone. Sometimes called ‘‘deficit’’ or ‘‘stress irrigation.’’

**line source**: Continuous source of water emitted along a line.

**low elevation spray application (LESA)**: Irrigation method using a low pressure spray applicator designed to operate near the ground, 0.3 to 0.6 m (1.0 to 2.0 ft), from drop tubes, on either a center-pivot or a lateral-more sprinkler system (see low pressure in canopy).

**low energy precision application (LEPA)**: A water, soil, and plant management regime where precision down-in-crop applications of water are made on the soil surface at the point of use. Application devices are located in the crop canopy on drop tubes mounted on low-pressure center pivot and linear move sprinkler irrigation systems. Furrow dikes, good soil condition, and crop residue are usually required to control water translocation.

**low pressure in canopy (LPIC)**: A system that may or may not include a complete water, soil, and plant management regime as required in LEPA. Application devices are located in the crop canopy with drop tubes mounted on low-pressure center pivot and linear move sprinkler irrigation system (see low elevation spray application).

**lysimeter**: An isolated block of soil, usually undisturbed and in situ, for measuring the quantity, quality, or rate of water movement through or from the soil. A device such as a tank or large barrel that contains a mass of soil and vegetation similar to that in the immediate vicinity, which is isolated hydrologically from its surroundings. It is commonly used in research to determine the water use of various crops in field conditions.

**management allowed depletion**: The desired soil-water deficit at the time of irrigation.

**manufacturer’s coefficient of variation**: A measure of the variability of discharge of a random sample of a given make, model, and size of microirrigation emitter, as produced by the manufacturer and before any field operation or aging has taken place; equal to the ratio of the standard deviation of the discharge of the emitters to the mean discharge of the emitters.

**microirrigation**: The frequent application of small quantities of water as drops, tiny streams, or miniature spray through emitters or applicators placed along a water delivery line. The microirrigation method encompasses a number of systems or concepts, such as bubbler, drip,

trickle, line source, mist, or spray.

**miner's inch**: Discharge from an orifice 1 in.2 under a definite head, fixed by statute or practice but differing from state to state. In Colorado, a miner's inch equals 0.00074 m 3 /s. In Arizona, northern California, Montana, Nevada, and Oregon, a miner's inch equals 0.00071 m 3 /s. In southern California, Idaho, Kansas, New Mexico, North Dakota, South Dakota, Nebraska, and Utah, a miner's inch equals 0.00057 m 3 /s (no longer in common use).

**mist irrigation**: A method of microirrigation in which water is applied in very small droplets.

**moisture deficit, soil moisture depletion**: The difference between soil water at field capacity and the actual soil water.

**net irrigation**: The actual amount of applied irrigation water stored in the soil for plant use or moved through the soil for leaching salts. Also includes water applied for crop quality and temperature modification; i.e., frost control, cooling plant foliage and fruit. Application losses, such as evaporation, runoff and deep percolation are not included. Generally measured in mm (inches) of water depth applied.

**net irrigation water requirement**: The depth of water, exclusive of effective precipitation, stored soil moisture, or ground water, that is required for meeting crop evapotranspiration for crop production and other related uses. Such uses may include water required for leaching, frost protection, cooling and chemigation.

**nonsaline-alkali soil**: (See sodic soil.)

**opportunity time**: The time that water inundates the soil surface with opportunity to infiltrate.

**pan coefficient**: A factor to relate actual evapotranspiration of a crop to the rate water evaporates from a free water surface in an evaporation pan. The coefficient usually changes by crop growth stage.

**pan evaporation**: Evaporation from a class A or similar pan. The U.S. Weather Bureau class A pan is a cylindrical container fabricated of galvanized iron or monel metal with a depth of ten inches and a diameter of forty-eight inches. The pan is accurately leveled at a site which is nearly flat, well sodded, and free from obstructions. The pan is filled with water to a depth of eight inches, and periodic measurements are made of the changes of the water level with the aid of a hook gage set in the stilling well. When the water level drops to seven inches, the pan is refilled.

**peak irrigation period**: The period of highest consumptive use that is used in irrigation design to size on-farm or project facilities such as pumping plants, pipelines, canals, distribution systems, etc.

**peak period ET**: The average daily evapotranspiration rate for a crop during the peak water use period. Sometimes commonly called peak period CU (consumptive use).

**peak use rate**: Maximum rate of consumptive use of water by plants.

**Penman-Monteith Method**: A method used to estimate reference crop evapotranspiration (ETo ) using current climatic data including air temperature, relative humidity, wind speed and solar radiation.

**permanent wilting point**: Soil water content below which plants cannot readily obtain water and permanently wilt. Sometimes called ‘‘permanent wilting percentage’’.

**precipitation intensity**: Rate of precipitation, generally expressed in units of depth per time (see rainfall intensity).

**preplant irrigation**: Irrigation applied prior to seeding. Sometimes called ‘‘preirrigation’’.

**project efficiency (Ep )**: The overall efficiency of irrigation water use in a project setting that accounts for all water uses and losses, such as crop ET, environmental control, salinity control, deep percolation, runoff, ditch and canal leakage, phreatophyte use, wetlands use, operational spills and open water evaporation.

**pumping plant or station**: A complete installation of one or more pumps together with all necessary appurtenances such as power units, sumps, screens, valves, motor controls, motor protection devices, fences, and shelters.

**pyranometer**: A general name for instruments which measure the combined intensity of incoming direct solar radiation and diffuse sky radiation.

**Radiation**: Process by which electromagnetic radiation is propagated through space. Classified for agricultural purposes as:

extraterrestrial radiation: Incoming solar radiation above Earth's atmosphere ($R_a$).

global radiation: Total of direct solar radiation and diffuse sky radiation received at Earth's surface by a unit horizontal surface ($R_s$).

clear day radiation: Theoretical incoming radiation at Earth's surface assuming complete absence of clouds ($R_{so}$).

net back radiation: The thermal or long wave radiation that is outgoing from Earth's surface ($R_b$).

net clear day outgoing long wave radiation: Theoretical outgoing long wave radiation at Earth's surface assuming complete absence of clouds ($R_{bo}$).

net radiation: The difference of the downward and upward solar and long wave radiation flux passing through a horizontal plane just above the ground surface ($R_n$).

**rainfall intensity**: Rate of rainfall for any given time interval, usually expressed in units of depth per time.

**reasonable-use rule**: A concept of water law in which a landowner is given the right to the reasonable use of water for domestic or similar needs.

**recharge**: Process by which water is added to the zone of saturation to replenish an aquifer.

**recharge area**: Land area over which water infiltrates and percolates downward to replenish an aquifer. For unconfined aquifers, the area is essentially the entire land surface overlaying the aquifer and for confined aquifers, the recharge area may be a part of or unrelated to the overlaying area.

**reference crop evapotranspiration**: Rate at which water, if available, would be removed from soil and plant surfaces.

**relative humidity**: Ratio of the amount of water present in the air to the amount required for saturation of the air at the same dry bulb temperature and barometric pressure, expressed as a percentage.

**return flow**: That portion of the water diverted from a stream which finds its way back to the stream channel, either as surface or subsurface flow.

**riparian doctrine**: The system of law dominant in Great Britain and the Eastern United States, in which owners of lands along the banks of a stream or waterbody have the right to reasonable use of the waters, and a correlative right protecting against unreasonable use by others that substantially diminishes the quantity or quality of water. The right is appurtenant to the land and does not depend upon prior use.

**root zone**: Depth of soil that plant roots readily penetrate and in which the predominant root activity occurs.

**rotational delivery system**: A management technique used for community irrigation water delivery systems in which water deliveries are rotated among water users often at a predetermined frequency and for a fixed duration.

**runoff percentage (irrigation)**: The ratio of the volume of irrigation runoff water to the volume of irrigation water applied, expressed as a percent.

**saline-sodic soil**: Soil containing sufficient exchangeable sodium to interfere with the growth of most crops and containing appreciable quantities of soluble salts. The exchangeable-sodium-percentage is greater than 15, and the electrical conductivity of the saturation extract is greater than 4 mS/cm (0.01 mho/in.).

**saline soil**: Nonsodic soil containing soluble salts in such quantities that they interfere with the growth of most crops. The electrical conductivity of the saturation extract is greater than 4 dS/m, and the exchangeable-sodium-percentage is less than 15 %.

**Saline sodic soil**: A soil containing excess salts and sodium. The electrical conductivity of the saturation extract is greater than 4 dS/m and exchangeable sodium percentage greater than 15%.

**salinity**: The concentration of dissolved mineral salt in water and soil on a unit volume or mass basis. May be harmful or non-harmful for the intended use of the water.

**set time (irrigation)**: Elapsed time between the beginning and end of water application to an irrigation set.

**SI units**: An international metric system developed by General Conference on Weights and Measures (CGPM, Confe´ rence Ge´ ne´ rale des Poids et Mesures). This system provides for an established single unit that applies for each physical quantity. Units for all other mechanical quantities are derived from these basic units. Also called International System of Units.

**siphon tube**: Relatively short, light-weight, curved tube used to convey water over ditch banks to irrigate furrows or borders.

**sodic soil**: A nonsaline soil containing sufficient exchangeable sodium to adversely affect crop production and soil structure. The exchangeable-sodium- percentage is greater than 15 % and the electrical conductivity of the saturation extract is less than 4 dS/m.

**sodium adsorption ratio, SAR**: The proportion of soluble sodium ions in relation to the soluble calcium and magnesium ions in the soil water extract or water expressed in $(mmol/L)^{0.5}$ or $(meq/L)^{0.5}$. SAR can be used to predict the exchangeable sodium percentage.

**sodium adsorption ratio, adjusted**: The sodium adsorption ratio of a water adjusted for the precipitation or dissolution of $Ca^{+2}$ and $Mg^{+2}$ that is expected to occur where a water reacts with alkaline earth carbonates within a soil. Numerically, it is obtained by multiplying the sodium adsorption ratio by the value (1+8.4-pHc*), where pHc is the theoretical calculation of the pH of water in contact with lime and in equilibrium with soil $CO_2$.

**sodium percentage**: Percentage of total cations that is sodium in water or soil solution.

**soil**: The unconsolidated minerals and material on the immediate surface of the earth that serves as a natural medium for the growth of plants.

**soil horizon**: A layer of soil differing from adjacent genetically related layers in physical, chemical, and biological properties or characteristics.

**soil moisture**: (See soil water.)

**soil moisture (available)**: Water in the root zone that can be extracted by plants. The available soil moisture is the difference between field capacity and wilting point.

**soil moisture (unavailable)**: Water in the root zone that is held so firmly by various forces that it usually cannot be absorbed by plants.

**soil organic matter**: Organic fraction of the soil, including plant and animal residues in various stages of decomposition, cells and tissues of soil organisms, and substances synthesized by the soil population.

**soil profile**: Vertical section of the soil from the surface through all its horizons into the parent material.

**soil series**: The lowest category of U.S. system of soil taxonomy. A conceptualized class of soil bodies having similar characteristics and arrangement in the soil profile.

**soil structure**: The combination or arrangement of primary soil particles, into secondary particles, units, or peds that make up the soil mass. These secondary units may be, but usually are not, arranged in the profile in such a manner as to give a distinctive characteristic pattern. The principal types of soil structure are platy, prismatic, columnar, blocky, and granular.

**soil texture**: Classification of soil by the relative proportions of sand, silt, and clay present in the soil.

**soil water**: All water stored in the soil (see water holding capacity).

**soil-water characteristic curve**: Soil-specific relationship between the soil-water matric potential and soil-water content.

**soil-water content**: The mass or volume of water in a given volume of soil.

**soil-water deficit**: Amount of water required to raise the soil-water content of the crop root zone to field capacity. It is measured in mm (inches) of water. Also called soil-water depletion.

**soil-water tension**: A measure of the tenacity with which water is retained in the soil. It is the force per unit area that must be exerted to remove water from the soil and is usually measured in bars, or atmospheres. It is a measure of the effort required by plant roots to extract water from the soil.

**solar radiation ($R_s$ )**: Radiation from the sun that passes through the atmosphere and reaches the combined crop and soil surface. The energy is generally in a waveband width of 0.1 to 5 microns. Net $R_s$ is incoming minus reflected radiation from a surface.

**spile**: Conduit, made of lath, pipe, or hose, placed through ditch banks to transfer water from an irrigation ditch to a field.

**spray irrigation**: The application of water by a small spray or mist to the soil surface, where travel through the air becomes instrumental in the distribution of water.

**sprinkle irrigation**: (See sprinkler irrigation.)

**sprinkler application rate**: The rate at which water is applied to a given area by a sprinkler system, usually expressed as depth (volume per unit area) per unit time, mm per hr (inches per hour).

**sprinkler distribution pattern**: Water depth-distance relationship measured from a single sprinkler head.

**sprinkler head**: A device for distributing water under pressure.

**sprinkler irrigation**: Method of irrigation in which the water is sprayed, or sprinkled, through the air to the ground surface.

**sprinkler irrigation systems**:

- boom: An elevated, cantilevered sprinkler(s) mounted on a central stand. The sprinkler boom rotates about a central pivot.
- center pivot: An automated irrigation system consisting of a sprinkler line rotating about a pivot point and supported by a number of self-propelled towers. The water is supplied at the pivot point and flows outward through the line supplying the individual outlets.
- corner pivot: An additional span or other equipment attached to the end of a center pivot irrigation system that allows the overall radius to increase or decrease in relation to the field boundaries.
- lateral move: An automated irrigation machine consisting of a sprinkler line supported by a number of self-propelled towers. The entire unit moves in a generally straight path and irrigates a basically rectangular area. Sometimes called a ‘‘linear move’’.
- permanent: Underground piping with risers and sprinklers.
- portable (hand move): Sprinkler system which is moved by uncoupling and picking up the pipes manually, requiring no special tools.
- side-move sprinkler: A sprinkler system with the supply pipe supported on carriages and towing small diameter trailing pipelines, each fitted with several sprinkler heads.
- side-roll sprinkler: The supply pipe is usually mounted on wheels with the pipe as the axle and where the system is moved across the field by rotating the pipeline by engine power.
- solid set: System which covers the complete field with pipes and sprinklers in such a manner that all the field can be irrigated without moving any of the system.
- towed sprinkler: System where lateral lines are mounted on wheels, sleds, or skids, and are pulled or towed in a direction approximately parallel to the lateral.

**subirrigation**: Application of irrigation water below the ground surface by raising the water table to within or near the root zone.

**subsurface drain**: Subsurface conduits used primarily to remove subsurface water from soil. Classifications of subsurface drains include pipe drains, tile drains, and blind drains.

**subsurface drip irrigation**: Application of water below the soil surface through emitters, with discharge rates generally in the same range as drip irrigation. This method of water application is different from and not to be confused with subirrigation where the root zone is irrigated by water table control.

**surface irrigation**: Broad class of irrigation methods in which water is distributed over the soil surface by gravity flow.

**surge irrigation**: A surface irrigation technique wherein flow is applied to furrows (or less commonly, borders) intermittently during a single irrigation set.

**surge irrigation cycle time**: The time required to complete a full on-time and off-time cycle.

**surge irrigation on-time**: The time when water is flowing into an irrigation furrow.

**surge irrigation off-time**: The time when water is not flowing into an irrigation furrow.

**tailwater**:
- Water, in a stream or canal, immediately downstream from a structure;
- Excess irrigation water which reaches the lower end of a field.

**tile drain**: Drain constructed by laying drain tile with unsealed joints in the bottom of a trench which is then refilled. Tile is usually constructed of clay or concrete.

**tile joint**: Opening between two drain tiles through which water from the surrounding soil flows (compare with crack width).

**total dissolved solids (TDS)**: The total dissolved mineral constituents of water, often expressed in parts per million (ppm) or milligrams per liter (mg/L).

**transpiration**: The process by which water in plants in transferred as water vapor to the atmosphere.

**trickle irrigation**: (See drip irrigation.)

**unavailable soilwater**: That portion of water in a soil held so tightly by adhesion and other soil forces that it cannot be absorbed by plants rapidly enough to sustain growth. Soil water at permanent wilting point.

**unconfined aquifer**: An aquifer whose upper boundary consists of relatively porous natural material that transmits water readily and does not confine water. The water level in the aquifer is the water table.

**uniformity coefficient**:
- irrigation: A characterization of the aerial distribution of water in a field as the result of an irrigation.

**wasteway**: Channel for conveying or discharging excess water from a canal to a river.

**water application efficiency**: Ratio of the average depth of water infiltrated and stored in the root zone to the average depth of water applied.

**water conveyance efficiency**: Ratio of the volume of irrigation water delivered by a distribution system to the water introduced into the system.

**water holding capacity**: Total amount of water held in a freely drained soil per increment of depth. It is the amount of water held between field capacity and oven dry moisture level, expressed in cm/cm (in/in), cm/m (in/ft), or total centimeters (in) for a specific soil depth. Sometimes called total water holding capacity (see available water capacity).

**water rights**: Legal rights to use water supplies derived from common law, court decisions, or statutory enactments.

**water use**: Application of a resource such as water to a particular purpose.

beneficial use: Application of a resource to a purpose that produces economic or other benefits, tangible, or intangible, economic or otherwise, such as employment of water for domestic supply, irrigation, industrial supply, power generation or recreation.

conjunctive irrigation use: That portion of water applied to irrigation that is absorbed by the crop and used to build plant tissue or transpired, together with that lost from the cropped area by evaporation.

consumptive water use: Employment of water in a manner that makes it unavailable for other application because of absorption, evaporation, transpiration, incorporation in manufactured product or changes in quality.

domestic use: Employment of water for the purposes of the home, including drinking, cooking, bathing, laundry, cooling, lawns, washing cars and swimming pools.

multiple use: Management of resources to satisfy two or more function purposes.

non-beneficial consumptive irrigation use: That portion of water withdrawn for irrigation that is neither used directly in crop production nor returned to the stream, but rather is lost in transmission, by evaporation or otherwise.

non-consumptive water use: Employment of water in a manner that does not reduce the amount of suitable water available for other purposes, including both on-site uses of the flow.

on-site water use: Employment of water in a manner that does not require diversion or flow of water, chiefly recreation uses and retention and temporary storage of excess water to prevent flood damage downstream.

**water use efficiency**:

- Dry matter or harvested portion of crop produced per unit of water consumed;
- Ratio of water beneficially used to the water delivered to the area being irrigated.

**wilting point**: (Synonymous with permanent wilting point.)

**CURRICULUM VITAE OF AUTHORS**

**PREPARED BY THE WAC**

**FOR THE**

**COACHELLA VALLEY WATER DISTRICT**

**JAMES R. GILLEY, P.E.**
Agricultural Engineer
Professor
Biological & Agricultural Engineering Department
Texas A&M University, College Station, Texas

## EDUCATION

| Degree | Institution | Major Field of Study | Dates of Degree |
|---|---|---|---|
| Ph.D. | University of Minnesota | Agricultural Engineering | 12/71 |
| M.S. | Colorado State University | Agricultural Engineering | 6/68 |
| B.S. | Colorado State University | Agricultural Engineering | 6/66 |
| | Pueblo College | Engineering | |

## PROFESSIONAL EXPERIENCE

| Employer | Position | Nature of Position | Location | Dates of Employment |
|---|---|---|---|---|
| Texas A&M | Professor | Research/Teaching | College Station, TX | 1/02- |
| Texas A&M | Professor & Head | Administration/Research | College Station, TX | 1/94 - 1/02 |
| IA State Univ. | Professor & Head | Administration/Research | Ames, IA | 11/88-1/94 |
| Univ. of NE | Interim Head | Administration/Research | Lincoln, NE | 2/88-11/88 |
| Univ. of NE | Professor | Research/Teaching | Lincoln, NE | 7/81-2/88 |
| Univ. of NE | Associate Professor | Research/Teaching | Lincoln, NE | 1/75-7/81 |
| Univ. of MN | Assistant Professor | Teaching/Research | St. Paul, MN | 1/72-1/75 |
| Univ. of MN | Instructor | Teaching/Research | St. Paul, MN | 9/68-1/72 |
| CO State Univ. | Research Fellow | Research | Fort Collins, CO | 6/66-9/68 |

## PROFESSIONAL REGISTRATION

Registered Professional Agricultural Engineer in Texas and Nebraska.

## PROFESSIONAL AND SCIENTIFIC ORGANIZATIONS

American Society of Agricultural Engineers
Irrigation Association
Sigma Xi, Phi Kappa Phi, Sigma Tau, Alpha Epsilon, Gamma Sigma Delta, Alpha Zeta, and Phi Theta Kappa

## HONORS

Awarded the ASAE Massey-Ferguson Education Award - July, 1998
Elected to the grade of Fellow of ASAE - 1993
ASAE Honor Paper Award - 1978
Who's Who in Engineering - 1980, 1982
Who's Who in the Midwest - 1979, 1983
Who's Who in Technology Today - 1979
Member of Seven Honor Societies

## INTERNATIONAL ACTIVITIES

Participated in research and teaching programs in Australia, China, Malaysia, Israel, Romania, Republic of South Africa, Egypt, Morocco, Tunisia, Thailand, Indonesia, Russia, USSR, Ukraine, Belgium, Great Britain, Germany, Netherlands, Norway and Portugal.

2002 Faculty Development Leave with the Catholic University of Leuven, Belgium. Feb 19 – Aug 13.

2001 Traveled to China and visited the Chinese Agricultural University in Beijing, the Chinese Academy of Agricultural Sciences in Beijing and toured the three gorges project. May 28 - June 9. Discussed potential joint research and teaching projects.

2000 Traveled to Australia, New Zealand, Malaysia and Belgium. Attended the Agricultural Engineering Conference in Adelaide, Australia; visited agricultural production practices in New Zealand; served as the external reviewer for the Agricultural and Biological Engineering Department at the University of Putra, Malaysia; and visited the research laboratories at the Catholic University of Leuven, Belgium. March 23 - May 2.

1999 Traveled to China and visited the Chinese Agricultural University in Beijing, the Chinese Academy of Agricultural Sciences in Beijing and toured the three gorges project. October 6-16.

1999 Served as the external reviewer for the Agricultural and Biological Engineering Department at the University of Putra, Malaysia November 13-24.

1998 Attended the 1998 meeting of EURO AGENG meeting in Oslo, Norway and traveled trough portions of Norway. August, 1998.

1998 Traveled to the Agricultural University of Bogor, Indonesia and served as an overseas visiting scholar, February 9-23, 1998.

1997 Traveled to Belgium to establish a new exchange agreement between the Catholic University of Leuven, Belgium and Texas A&M University, May 15-31, 1997.

1997 Invited to participate in a 6 person delegation from the U.S. to discuss redirection of Russian undergraduate education system for the BS degree in Agricultural Engineering curricula. Moscow, Russia from April 19-26.

1997 Invited to participate in a 5 person scientific team from the U.S. to provide review and recommendations for research proposals under the Foods Crops Component of the Agricultural Technology Utilization and Transfer Project (ATUT) for the country of Egypt. The project was funded by the Agency for International Development and administered by the U.S. Department of Agriculture, Foreign Agricultural Service. Cairo, Egypt from January 3-10.

1995 Participated in International Symposium on the “Direction of Agro-Industry in Thailand Globalization Effort” in Bangkok Thailand, November 25-December 5, 1995.

1994 Presented a paper at the NATO Advanced Research Workshop "Sustainability of Irrigated Agriculture," Vimeiro, Portugal, March 21-26.

1993 Traveled to Belgium to establish a new exchange agreement between the Catholic university of Leuven, Belgium and Iowa State University, October 30-November 9.

1993 Traveled to Belgium to continue cooperative research grant with J. Feyen, Catholic University of Leuven, Jan 29-Feb 6.

1992 Presented a paper at the International Conference "Advances in Planning, Design, and Management of Irrigation Systems as Related to Sustainable Land Use," Leuven, Belgium, September 14-17.

1992 Visiting Professor at the Faculty of Agricultural Sciences, Center for Land and Water Management and Center for Irrigation Engineering, Catholic University of Belgium, Leuven, Belgium, Feb 28 - March 27.

1991 Continued research program at the Catholic University of Leuven, Belgium, May 19-25 and Nov 16-20.

1990 Participated in the ISU-USSR exchange. Visited Moscow, Kiev and Yalta and many state and cooperative farms. Presented a paper on Energy Conservation and Efficiency in Agriculture at a joint symposium, Oct 1-13.

1990 Traveled to Belgium to continue joint research project at the Catholic University of Leuven, May 6-16 and Oct 13-17.

1989 Invited participant to develop irrigation scheduling models. Sponsored by FAO. Meeting held in Leuven, Belgium, Feb. 26-March 6.

1989 Participated in Exchange program with the USSR Research Academy. Visited the Agriphysics Institute in Leningrad, Nov 4-11.

1988 Traveled to Belgium to participate in NATO Research Grant with J. Feyen and prepare NATO research proposal with Louis Pereira of Portugal, April 26-May 11.

1988 Received a renewal of the NATO Collaborative Research Grant to support travel between the U.S. and Belgium for J. Gilley and J. Feyen. Traveled to Belgium to continue cooperative research grant with J. Feyen Catholic University of Leuven, Sept 26-Oct 1.

1988-93 Served as the Technical Advisor to a NATO sponsored Science for Stability Project on irrigation research in Portugal, Technical University of Lisbon. Professor Luis S. Pereira was the project director. Traveled to Portugal to participate in project activities on nine separate occasions: Oct 1-9, 1988; May 27-June 12, 1989; Nov 11-Nov 19, 1989; May 26-June 7, 1990; May 11-19,1991; Nov 5-16, 1991; June 8-19, 1992; Jan 15-29, 1993; October 20-30, 1993.

1987 Received a NATO Collaborative Research Grant to support travel between the U.S. and Belgium for J.R. Gilley and J. Feyen (Catholic University of Belgium). To support cooperative research in irrigation optimization. Traveled to Belgium, May 1-15.

1986 Member of an US-AID review team for the Tunisia Farming Systems Research, Tunis and surrounding area project, June 14-25.

1984 Visited AID-Morocco dryland farming project, Settat, May 1-7.

1984 Visiting Professor at the Faculty of Agricultural Sciences, Irrigation Engineering, Catholic University of Belgium, Leuven, Belgium, March 1 - September 1 (Sabbatical Leave).

1983 Selected by ASAE to present a week of seminars on Irrigation Technology with three other ASAE members, also visited new irrigation project developments in Egypt. Cairo, Egypt, January.

1981 Visiting Professor at the Faculty of Agricultural Sciences, Irrigation Engineering, Catholic University of Belgium, Leuven, Belgium, October 17 - November 19.

1981 Host Professor for Dr. Ioan Paltineanu, Exchange scientist from Romania, August 15-October 5.

1981 Presented an invited paper at the South African Irrigation Institute, Johannesburg, South Africa and visited irrigation research facilities, February 2-11.

1980 Participated in the Romania-Nebraska Scientist Exchange Program, Bucharest, and other cities, Romania, May 19-July 1.

1979 Presented a paper at the International Conference on Operations Research in Agriculture and Water Resources, Jerusalem, Israel, November.

**CONSULTING**

Served as a technical consultant to several irrigation companies, state and federal agencies including the following:

| | |
|---|---|
| 1996-present | Consultant for Coachella Valley Water District involving irrigation water management practices, feasibility and conservation. |
| 1987-92 | Preparation of a chapter on irrigation water requirements for the National Engineering Handbook, USDA-SCS. |
| 1985 | Valmont Industries, Economic Feasibility of Stirling Engine. |
| 1984 | USDA, Alternative Irrigation Power Study - Stirling Engine Analysis. |
| 1982-84 | Nebraska State Energy Office, Wind Energy Analysis. |
| 1982-83 | Presented Irrigation Seminars for Latin Americans (New Orleans, November 1982; Miami, November 1983). |
| 1982 | COMSAT, Advanced Irrigation Scheduling Methods. |
| 1982-present | Expert witness in irrigation engineering. |
| 1980-81 | DOE Contract on Energy Saving Procedures in Irrigation. (Received recognition as one of the top 10 projects in the U.S.). |
| 1979-80 | Joint USDA-DOE Contract on the Economic Analysis of Wind Energy for Irrigation. |
| 1979 | EPA Contract for Training Workshops on Land Treatment of Municipal Wastes, February. |
| 1979 | Presented Technical Workshop for Carborundum Irrigation Co., Mexico City, January. |
| 1978-present | Consultant for Irrigation Equipment Manufacturers. |
| 1977-1984 | Irrigation Association Short Courses. |

**PEER-REVIEWED PUBLICATIONS**
**TOTAL CAREER: 55; TOTAL 1988-present: 21**; **TECHNICAL PAPERS AND PRESENTATIONS: over 80**

Dierckx, J., J.R. Gilley, J. Feyen and C. Belmans. 1988. Simulations of soil-water dynamics and corn yields under deficit irrigation. Irrigation Science 9:105-125.

Gilley, J.R. 1989. Discussion of “Friction correction factor for center pivot irrigation systems” by J. M. Reddy and H. Apolayo. Journal of Irrigation and Drainage Engineering, ASCE 115(4): 769-770.

Martin, D.L., J.R. Gilley and R.J. Supalla. 1989. Evaluation of irrigation planning decisions. Journal of the Irrigation and Drainage Engineering, ASCE 115(1): 58-77.

Leander, W.S., Jr., D. L. Martin and J. R. Gilley. 1991. Performance of seedigated and conventionally planted crops. Applied Engineering in Agriculture 7(2): 170-176.

Gilley, J. R., C. A. Hackbart, L. E. Stetson and J. Feyen. 1991. Energy Management. In Management of Farm Irrigation Systems (G. J. Hoffman, T. A. Howell and K. H. Solomon, eds). p 719-746.

Martin. D. L., J. R. Gilley and R. W. Skaggs. 1991. Soil water balance and management. In Managing Nitrogen for Groundwater Quality and Farm Profitability (R.F. Follett, D.R. Keeney and R.M. Cruse, eds). Soil Science Society of America. p 199-235.

Munir, H.M., D.E. Eisenhauer and J.R. Gilley. 1992. Performance of chemigation backflow prevention assemblies. Applied Engineering in Agriculture 8(2): 211-219.

Thompson, A.L., J.R. Gilley and J.M. Norman. 1993. A sprinkler water droplet evaporation and plant canopy model: I. model development. Transactions of the ASAE 36(3):735-741.

Thompson, A.L., J.R. Gilley and J.M. Norman. 1993. A sprinkler water droplet evaporation and plant canopy model: II. model application. Transactions of the ASAE 36(3):743-750.

Martin, D.L. and J.R. Gilley. 1993. Irrigation water requirements. Chapter 2, Part 623 (Section 15, Irrigation), National Engineering Handbook. United States Department of Agriculture, Soil Conservation Service. 284 p.

Pereira, L.S., R.A. Feddes, J.R. Gilley and B. Lesaffre. 1996. Sustainablitiy of Irrigated Agriculture (Editors). NATO Advanced Science Institutes Series. Kluwer Academic Publishers. 631 p.

Gilley, J. R. 1996. Sprinkler Irrigation Systems. In Sustainability of Irrigated Agriculture (L.S. Pereira, R.A. Feddes, J.R. Gilley, and B. Lesaffre, eds). NATO Advanced Science Institutes Series. Kluwer Academic Publishers. pp. 291-307.

Pereira, L.S., J.R. Gilley and M.E. Jensen. 1996. Research agenda on sustainability of irrigated agriculture. Journal of Irrigation and Drainage Engineering, ASCE 122 (3): 172-177.

Xevi, E., J. Gilley, and J. Feyen. 1996. Comparative study of two crop yield simulation models. Agricultural Water Management 30: 155-173.

Thompson, A.L., D.L. Martin, J.M. Norman, J.A. Tolk, T.A. Howell, J.R. Gilley and A.D. Schneider. 1997. Testing of a water loss distribution model for moving sprinkler systems. Transactions of the ASAE 40(1): 81-88.

**ROBERT W. HILL**
Irrigation Engineer
Professor and Extension Specialist
Biological and Irrigation Engineering Department
Utah State University, Logan, UT

**EDUCATION**

| Degree | Institution | Major Field of Study | Dates of Degree |
|---|---|---|---|
| Ph.D. | Utah State University | Civil Engineering (Water Resources) | 1973 |
| M.C.E. | Brigham Young University | Civil Engineering (Water Resources) | 1969 |
| B.E.S. | Brigham Young University | Civil Engineering | 1967 |

**PROFESSIONAL EXPERIENCE**

| Employer | Position | Location | Dates |
|---|---|---|---|
| Utah State Univ | Extension Irrigation Engineering Specialist | Logan, UT | 1985 |
| Utah State Univ | Professor of Ag & Irrig. Engr. Department | Logan, UT | 1983 |
| Utah State Univ | Associate Professor, Ag. & Irrig. Engineering Dept | Logan, UT | 1977-83 |

**PROFESSIONAL REGISTRATION**

Registered Professional Agricultural Engineer, Utah..

**EXTENSION PROGRAMS**

Irrigation Specialist for Utah State University since 1985: Provide technical assistance and training to farmers, irrigation companies, and state and federal agencies in all areas of irrigation and water resource management. Develop programs in field irrigation system performance and scheduling, crop water use and yield effects. Develop microcomputer programs for irrigation scheduling and project crop water requirements.

**RESEARCH**

Principal Investigator on many research projects including: field plot studies of crop water use and yield, irrigation delivery and conveyance systems operation; hydrologic, crop yield and irrigation scheduling model studies and river basin and state-wide crop water requirements.

**CONSULTING**

Expert witness in Western U.S. Water rights and irrigation-related litigation. Feasibility and hydrology studies for Southwest U.S. Irrigation Projects. Irrigation and crop water requirements aspects of Environmental Impact Statements. Development and use of computer programs in irrigation scheduling, hydraulics, hydrology and water resource engineering applications.

**SPECIALTY SUBJECTS**

Irrigation, Agricultural Hydrology, Agro-Meteorology, Crop Water Requirements, Crop Yield and Irrigation Scheduling Models, Soil-Water-Plant Management Research, Water Resource Systems Simulation and Computerized Hydraulics Design

**RELATED PUBLICATIONS**

Hill, R.W. and Keller Engineering, Logan, Utah. 1979. Water Requirements Carson River Valley, California/Nevada. United States vs. Alpine Land and Reservoir Company, Civil No. D-183 BRT, USDC, Nevada. U.S. Justice Department. May. 100+ pp.

Hill, R.W. 1980. Historical Water Requirements for the Newlands Reclamation Project. Draft for EIS document. U.S. Department of Interior. August.

Fapohunda, H.O. and R.W. Hill. 1981. River Basin Hydro-Salinity - Economic Modeling. Journal of Irrigation and Drainage Division, ASCE. Vol. 107, No. IR1, Proceedings Paper 16145. March. pp. 53-69.

Hill, R.W., E.L. Johns and D.K. Frevert. 1983. Comparison of Equations Used for Estimating Agricultural Crop Evapotranspiration. Water Utilization Section, Hydrology Branch, Division of Plan. Technical Services, USBR Engineering and Research Center, Denver, Colorado. October. 260 pp.

Hill, R.W., R.J. Hanks and J.L. Wright. 1984. Crop Yield Models Adapted to Irrigation Scheduling Programs. Final Report USDA-SEA/AR Cooperative Research No. 58-9AHZ-9-440. Utah Agricultural Experiment Station Research Report No. 99. (User Manual is Research Report No. 100), Utah State University, Logan, Utah.

Hill, R.W., C.E. Brockway, R.D. Burman, L.N. Allen and C.W. Robison. 1989. Duty of Water Under the Bear River Compact: Field Verification of Empirical Methods for Estimating Depletion. Final Report. Utah Agriculture Experiment Station Research Report No. 125. Utah State University, Logan, Utah. January.

Abu-Awwad, A.M. and R.W. Hill. 1991. Tomato Production and Soil Salt Distribution under Line-Source Trickle Irrigation. Journal of Agronomy and Crop Science 167:188-195

Hill, R.W. 1991. Irrigation Scheduling. Chapter 21. In Modeling Plant and Soil Systems, pp. 491-509. John Hanks and J. T. Ritchie (Eds.). American Society of Agronomy, Inc.; Crop Science Society of America, Inc.; Soil Science Society of American, Inc., Publishers. Madison, Wisconsin. 545 p.

Allen, R.G., J. Prueger and R.W. Hill. 1992. Evapotranspiration from isolated stands of hydropytes: cattail and bulrush. Trans. ASAE 35(4) :1191-1198.

Hill, R. W. 1993. Crop Water Use Estimates for the Silver Creek Area of Northeastern Arizona. Exhibit No. USA-0352, Little Colorado Adjudication, Silver Creek Objections. Expert Report. Prepared for Natural Resources Consulting Engineers, Inc. Berkeley, California. Logan, UT. January

Hill, R.W. 1994. Consumptive Use of Irrigated Crops in Utah. Utah Agr. Exp. Stn. Res. Report No. 145, Utah State University, Logan, UT. Oct. 370 pp. Revised and reprinted Feb. 1998

Ley, T.W., R.W. Hill and D.T. Jensen. 1994. Errors in Penman-Wright Alfalfa Reference Evapo-transpiration Estimates: I. Model Sensitivity Analyses. Transactions ASAE. 37(6) 1853-1861.

Ley, T.W., R.W. Hill and D.T. Jensen. 1994. Errors in Penman-Wright Alfalfa Reference Evapotranspiration Estimates: II. Effects of Weather Sensor Measurement Variability. Transactions ASAE. 37(6) 1863-1870.

Hill, R.W. and R.G. Allen. 1996. Simple Irrigation Scheduling Calendars. Journal Irrigation and Drainage Division. ASCE, Vol. 122, No. 2, March/April

Hill, R.W., A. Gonzalez-Meza, L.N. Allen and R. Oldham. 1996. Turfgrass Water Use for an Intermountain Golf Course. ASAE Intrl. Evapotranspiration and Irrg. Scheduling Conf. Nov. 3-6. San Antonio, TX.

Hill, R.W. and A. Gonzalez-Meza. 1997. Water Use of an Intensive Managed Dairy Pasture. Presented, ASAE PNW Regional Mtg., Sept. 18-20. Boise, ID. Paper No. PNW 97-109 ASAE.

Ramalan, A.A. and R.W. Hill. 2000. Strategies for Water Management in Gravity Sprinkle Irrigation Systems. Agricultural Water Management Vol 43:51-57.

Hill, R.W. and T.W. Ley. 2002. Crop Water Use Estimates for the Arkansas River Basin in Southeastern Colorado. Kansas v. Colorado Expert Report. (No. 105 Original - DE 1409). Prepared for Colorado State Engineer. Denver, CO. April

Hill, R.W. 2003. Procedures for Estimating Depletion in the Lower Bear River Basin in Idaho. (Revised) Prepared for PacifiCorp. Logan, UT. January.

**SUMMARY**

Dr. Hill has extensive practical hands-on experience with field irrigation in addition to his 36 years of professional experience in water resources engineering and irrigation system design. Fifteen years of the practical experience was obtained on the family farm in eastern Idaho and included various gravity and sprinkler irrigation systems on potatoes, small grains, alfalfa and pasture. His professional experience includes university teaching, extension and research, consulting, engineering design and short term training of developing country scientists and engineers. He has provided more than 25 technical assistance TDY's in 14 countries, most recently in Uganda, India, Pakistan, Dominican Republic, Egypt and Armenia. He is currently conducting research in Utah relating to irrigation scheduling, irrigation system performance, crop water use and yields, and water resources.

Dr. Hill has conducted two multi-year field studies of meadow hay and golf course turf water use plus several other research plot studies of wetland and vegetable evapotranspiration utilizing 53 lysimeters since 1983. He has performed five linesource sprinkler field research crop water use and yield response studies on alfalfa, beans, corn, pasture (currently), potatoes and wheat. Numerous other farm field crop water use and irrigation scheduling research and demonstration projects using neutron probes have been conducted throughout central and northern Utah by students and technicians under his direction. He has been instrumental in establishing an electronic weather station ag-met network and directly operates and maintains 14 units. He also installed electronic weather stations in Somalia, Yemen A.R., Dominican Republic, Egypt, and Armenia and trained technicians in their operation and maintenance. Recently he has supervised the use of Bowen Ratio systems in estimating lake evaporation (Bear Lake) and evapotranspiration of pasture and onions in northern Utah farm fields.

Dr. Hill has written major computer programs for river basin hydrologic simulation, pipe network design, center pivot nozzling, irrigation scheduling and crop water requirements, crop yield models, economic evaluation of agricultural investments and an irrigation management game. He is presently a Professor in the Biological and Irrigation Engineering Department and Extension Irrigation Specialist at Utah State University, Logan, Utah. Dr. Hill has authored over 90 technical publications, 13 reports, one book, and has supervised 46 graduate students.

**Charles V. Moore**
Senior Research Agricultural Economist
University of California, Davis, California

## EDUCATION

| Degree | Institution | Major Field of Study | Dates |
|---|---|---|---|
| Ph.D. | Ohio State University | Agricultural Economics | 1956 - 59 |
| MSc | Ohio State University | Agricultural Economics | 1955 - 56 |
| BS | Ohio State University | Agriculture | 1950 - 53 |
| | Otterbein College | | 1949 - 50 |

## MILITARY EXPERIENCE

U.S. Navy 1953 - 55 -- Communications Officer, Destroyer, Pacific Fleet

## PROFESSIONAL EXPERIENCE

| Employer | Position | Location | Dates of Employment |
|---|---|---|---|
| University of California | Lecturer in International Agricultural Development | Davis, CA | 1990 to present |
| University of California | Consulting Economist, Center for Cooperatives | Davis, CA | 1990 - 94 |
| Rice Growers Ass of California | Director Research and Planning | CA | 1986 - 89 |
| U.S. Department of Agriculture | Agricultural Economist | Davis, CA | 1972 -1986 |
| Saudi Arabian Government | Senior Agricultural Economist Stanford Research Institute Central Planning Organization | | 1972 - (7 months) |
| U.S. Department of Agriculture | Agricultural Economist | Davis, CA | 1967 - 72 |
| Agricultural University | Ass Professor, Ohio State University/AID Contract | Punjab, India | 1965 - 67 |
| U.S. Department of Agriculture | Agricultural Economist | Davis, CA | 1962 - 65 |
| University of California | Post Doctoral Agricultural Economist | Davis, CA | 1959-62 |

## TEACHING EXPERIENCE

Basic Farm Management
Resource Economics
Managerial Accounting
Regional Planning
Agricultural Financial Management
International Agricultural Development

## AWARDS AND HONORS

Administrators Special Merit Award for Outstanding Research, (USDA)
Vice President, Western Agricultural Economics Association,
Board of Directors, Freedom from Hunger Foundation, 1983-Present
Gamma Sigma Delta (honors)
Navy E for outstanding leadership in Communications

## CONSULTING

U.S. Atomic Energy Commission, Oak Ridge, Tennessee

Stanford Research Institute, Central Planning Organization, Saudi Arabia

FAO - General Water Authority of Libya

City of San Jose, California

Boeing Computer Corporation

Sonoma County Board of Supervisors

U.S. Department of The Interior, Bureau of Reclamation

U.S. Department of Justice

California Department of Water Resources

World Bank

U.S. AID

Lost Hills Water District

Westlands Water District

General Electric - Capital

Ernst and Young

Coachella Valley Water District

**LIST OF PUBLICATIONS**

1. Moore, Charles V., Credit and Repayment Plans for Selected Central Ohio Farms, M.S. Thesis, 1956

2. Moore, Charles V., "Purchase of Feeder Pigs," Timely Economic Information Ohio State University Circular, March , 1959

3. Sitterly, J.H., E.T. Shaudys and C.V. Moore, Cost of Hay Conditioning for Faster Field Curing, Ohio Agric. Expt. Sta.. Res.. Bul, 854, May, 1959

4. Moore, Charles V., Evaluation of Farm Accounting Systems as Aids to Management of Commercial Farms , Ph.D. dissertation, June, 1959

5. Moore, Charles V., Costs of Storing and Feeding Chopped and Baled Hay, Ohio Agric. Expt. Sta. Res. Bul, 854, July, 1960

6. Moore, Charles V., "Irrigation Pumping Plant Characteristics in the San Joaquin Valley," California Agriculture, Vol. 14, No. 10. October, 1960, pp. 2-3

7. Hedges, T.R. and C.V. Moore, "Irrigation Costs of Pumping in the San Joaquin Valley, " California Agriculture, Vol. 14, No. 10, October, 1960, pp. 3-4

8. Hedges, T.R. and C.V. Moore, " Surface Irrigation Water Deliveries and Costs in the San Joaquin Valley Cotton Area," San Joaquin Valley Cotton Area," California Agriculture, Vol. 15, No.3 March, 1961, pp. 7-8

9. Moore, Charles V., "A General Analytical Framework for Estimating the Production Function for Crops Using Irrigation Water," Journal of Frarm Economics, Vol. 43, No. 3, July, 1962, pp. 89-94

10. Caton, D.D. and C.V. Moore, "Cost, Size and Income Relations on Cotton Famrs," Agricultural Economics Research, Vol. 14, No. 3, July, 1962, pp.89-94

11. Moore, Charles V., "Economics of Water Demand in Commercialized Agriculture, "Journal of American Water Works Association, Vol. 54. No. 8, August, 1962 , pp. 913-920

12. Hedges, T.R. and C.V. Moore, Some Characteristics of Farm Irrigation Water Supplies in the San Joaquin Valley, Giannini Foundatrion Res. Rpt. No. 258, September, 1962, pp. 42

13. Hedges, T.R. and C.V. Moore, Economics of On-Farm Irrigation Water Availability and Costs and Related Farm Adjustment. 1. Enterprise Choices, Resource Allocations and Earnings on 640-Acre General Crop Farms on the San Joaquin Valley Eastside, 1962, pp. 86

14. Hedges, T.R. and C.V. Moore, Economics of On-Farm Irrigation Water Availability and Costs and Related Farm Adjustments. 2. Farm Size in Relation to Resource Use, Earnings and Adjustments on the San Joaquin Valley Eastside, Giannini Foundation Res. Rpt. No. 263, June, 1963, pp. 79

15. Hedges, T.R. and C.V. Moore, Economics of On-Farm Irrigation Water Availability and Costs and Related Farm Adjustments. 3. Some Aggregate Aspects of Farmer Demand for Irrigation Water and Production Response on the San Joaquin Valley Eastside, Giannini Foundation Res. Rpt. No. 261, March, 1963, pp. 40

16. Moore, Charles V., "Value of Storing Stream Runoff for Irrigation Use," Natural Resources Journal, Vol. 3, No. 1, May 1963, pp. 98-103

17. Moore, Charles V., "A Method for Estimating the Demand for Irrigation Water," Agricultural Economics Research, Vol. 15, No. 4, October, 1963, pp. 131-136.

18. Moore, Charles V., "A Method of Selecting Least-Cost Irrigation Water Distribution Systems,: Journal of Farm Economics, Vol. XLV, No.5, December, 1963, pp. 1238-1242.

19. Moore, Charles V., Guides to Selecting an Economical Surface Irrigation Distribution System, University pf California, Agric. Exten. Serv. Circ., AXT 161, August, 1964, pp. 14

20. Moore, C.V. and J.H. Snyder, "Pump Irrigation, Cost Increases in Salinas Valley," California Agriculture, Vol. 19, No. 8, August, 1965, pp. 14-15.

21. Moore, Charles V., "Income Variability and Farm Size," Agricultural Economics Research, Vol. XVII, No.4, October, 1965, pp. 108-115

22. Moore, C.V. and J.H. Snyder, "Irrigation Pumping Lifts in the San Joaquin Valley,," California Agriiculture, Vol. 19, No. 9, October, 1965, pp. 14-15

23. Moore, Charles V., Economies Associated with Size, Fresno County Cotton Farms, Berkeley: University of California, Agricultural Experiment Station, Giannini Foundation Research Report No. 285, November, 1965, pp. 49

24. Hedges, Trimble, R. and Charles V. Moore, Economics of On-Farm Irrigation Water Availability and Cost, and Related Farm Adjustments. 4. Intravallley Variations in Relation to Resource Use, Earnings, and Adjustments in the San Joaquin Valley Cotton Area, Berkeley: University of California, Agricultural Experiment Station, Giannini Foundation Research Report No. 286, December, 1965, pp. 72

See No. 22. Moore Charles V., "Income Variability and Farm Size," Agriculture Economics Research, Vol. 17, No.4, October, 1965, pp. 108-115

Rev: "Report of Study by Charles V. Moore on Income Variability and Farm Size," L.T. Wallace, Farm Management, Agricultue Extension Service, University of California in cooperation with the U.S. Department of Agriculture, January, 1966

25. Moore, Charles V., "The Role of Technology," Dynamics of Punjab Agriculture, Punjab Agricultural University Press, Punjab Agricultural University, Ludhiana, unnumber monograph, January, 1967, pp. 37-51

26. Moore, C.V., An Analysis of the Expected Shifts in Cropping Pattern of the Punjab (India) Resulting from the Introduction of High-Yielding Varieties of Crops, (unnumbered bulletin), Department of Economics, Punjab Agricultural University, 1967, pp. 161

27. Moore, Charles V., The Role of Agriculture in India's Economic Development, Proceedings, Seminar on Economic Development, University of Rajasthan, Jodhpur, Department of Economics, 1965, (Also in J. Nehru, Memorial Volume, Papers on Economic Development, 1968).

28. Mann, K.S., Johl, S.S. and Moore, C.V., "Projections of Shifts in the Cropping Pattern of Punjab, " Indian Journal of Agricultural Economics, 1968

29. Mann, K.S., Johl, S.S. and Moore, C.V., Projected Normative Cropping Patterns in Punjab, Proceedings, All India Seminar on Cropping Patterns, New Delhi, 1968

30. Mann, K.S., Johl, S.S. and Moore, C.V., "Estimates of Potential Effects of New Technology on Agriculture in Punjab, India, " American Journal of Agricultural Economics, Vol.50, No. 2, May, 1968

31. Moore, C.V. and Snyder, J.H., Some Welfare Implications on Sea Water Intrusion--A Case Study of Groundwater Managementt, Proceedings Water Resource Committee, W.A.E.R.C., San Franscisco, Decvember, 1967

32. Moore, C.V. and Snyder, J.H. "Some Legal and Economic Implications of Sea Water Intrusion--A Case Study of Groundwater Management,: Natural Resources Journal, Vol. 9, No.3, July, 1969, pp. 401-419

33. Moore, C.V. and Snyder, J.H., Risk and Uncertainty in Lettuce Production in Salinas Valley, Berkely: University of California, Agricultural Experiment Station, Giannini Foundation Research Report No. 300, January, 1969, pp. 59

34. Moore, C.V. and Snyder, J.H., "Lettuce: Risk in Eden,"The Fam Index, ERS, USDA, May, 1969, pp. 3-4

35. Moore, C.V. and Snyder, J.H., "Crop Selection in High Risk Agriculture, " Agricultural Economics Research, Vol. 21, No. 4, October, 1969, pp. 8 9-98

36. Moore, Charles V., Water and Western Destiny: From Conflicts to Cooperation, Alternative Water Policies for an Arid Region, Proceedings, Third Western Interstate Water Conference, Fort Collins, Colorado, 1969, pp. 63-67

37. Johl, S.S. and Moore, C.V., Essentials of Farm Financial Management, Today and Tomorrow Publishers, New Delhi, 1970, pp. 152

38. Moore, C.V. and Snyder, J.H., "Corporate Farming in California," California Agriculture, Vol. 24, No.3 March, 1970, pp. 6-8

39. "Corporate Farms in California:Extend Boundaries; Expand Sales," The Farm Index, ERS, USDA, May, 2970, p. 5

40. Moore, C.V., Economies of Water Quality Control, Proceedings 43rd Annual Meeting Western Agricultural Economics Association, Tucson, Arizona, July, 1970, pp. 288-294

41. Moore, C.V., "Timely Tale of an Ancient Culture," Farm Index. ERS. , USDA. Vol. 9, No. 11, November, 1970, pp. 4-5

42. Isyar, Yuskel, Moore, C.V. and G.W.Dean, Financial Analysis of Potential Agricultural Development on San Joaquin Valley Westside, Berkeley: University of California, Agricultural Experiment Station, Giannini Foundation Research Report No. 316, July, 1971, pp. 55

43. Moore, C.V., "Can Economists Internalize Agricultures Environmental Enternalities? American Journal of Agricultural Economics, Vol. 53, No. 5, December, 1971, pp. 861-863

44. Moore, C.V., and Dean, G.W., "Industrialized Farming," Size, Structure and Future Farms, Iowa State Press, 1972, Chapter 12, pp. 214- 231

45. Lane, Sylvia and Moore, Charles V., "San Joaquin Valley Study of Insolvent Farmers," California Agriculture, Vol 26, No.2, February, 1972, pp. 6-7

46. Moore , C.V., "on The Necessary and Sufficient Conditions for a Long-Term Irrigated Agriculture, "Water Resources Bulletin, Vol. 8, No. 4, August, 1972, pp. 802-812

47. Moore, C.V. and Lane, Sylvia, An Analysis of Bankrupt and Debtor Arrangements Among San Joaquin Valley Cotton Growers, Proceedings, WAEA, Logan, Utah, 1972, pp. 233-245

48. Carter, H.O., Dean, G.W., Isyar, Yuksel and Moore, C.V., "Programming Model for Evaluating Ecomomic and Financial Feasibility of Irrigation Projects with Extended Development Periods," Water Resources Research, Vol. 9, No. 3, June, 1973, pp. 546-555

49. Moore,C.V, Snyder, J.H., Howitt, R.E. and Moore, S.F., The evaluation of Changes in Recreation Quality:: A "Systems Dynamics" Formulations Approach, Presented to the Western Regional Science Association, Monterey, California, Februaru, 1973.

54. Butcher, Walter R., Anderson., Jay C., Hagen, Robert, Johnston, Warren and Moore, Charles, Review and Critique: "Agricultural and Water Policies and Evironment," in Economics of Natural Resource Development in the West: Current Problems in Natural Resource Use, Report No. 4, Western Agricultural Economics ResearchCouncil, Committee on the Economics of Natural Resources Development, 1973, pp. 56-81

55. Lin, William, Carman, H.F., Moore, C.V. and Dean, G.W., "Producer Response to Income Taxes: An Empirical Test Within a Risk Framework," {Giannini Foundation Research Paper No. 368}.

56. Lin, W., Dean, G.W. and Moore, C.V., "An Empircal Test of Utility vs. Profit Maximization in Agricultural Production," American Journal of Agricultural Economics, Vol 56., No. 3, August, 1974, pp. 497-508

57. Bessler, D.A. and Moore, C.V., "Risk Transfer, Information and Production Contracts: A Suggested Analytical Methodoloogy," Presented at AAEA Meetings, Columbus, Ohio, August, 1975, pp.14

58. Howitt, R.E. and Moore, C.V., "Internalyzing Health Effects of Pesticides, " Presented at AAEA Meetings, Columbus, Ohio, August, 1975, pp.14

59. Noel J., Moore, C.V., Robinson, F. and Snyder, J.H., "Effect of Water Quality and Irrigation Frequency on Farm Income in the Imperial Valley," California Agriculture, Vol.29, No.11, November, 1975, pp. 12-13

60. Seifert, W., Bakr, M. and Kettani, M., eds., Moore, C.V., Book Review: "Energy and Development, A Case Study," in Annals of Regional Science, Vol. 8, No. 3, October, 1974, pp. 155-157

61. Howitt, R.E. and Moore, C.V., "Pesticide Injury Report: One Study," Economic and Social Issues, Cooperative Extension, University of California, August-September, 1975.

62 Sarhan, M., Howitt, R.E. and Moore, C.V., "An Economic Analysis of Mosquito Abatement In California and Chemical Industry's Investment in Narrow Spectrum Pesticides," Paper Presented at California Mosquito Control Workshop, March 15, 1976, Davis, California, 6 pp.

63. Moore, C.V., "Some Observations on Tax Loss Farming," Paper Presented to California Assembly Subcommittee on Food and Agricultural Economy, April 2, 1976, Sacramento, 13 pp.

64. Moore, Charles V., 1977, "Water Conservation Perspective: Economics," Proceedings, Agricultural Water Conservation Conference, University of California, Davis, June 23-24, Department of Water Resources, Sacramento, pp. 47-50.

65. Reimund, Donn A., Charles V. Moore and J. Rod Martin, July, 1977, "Factors Affecting Structural Change in Agricultural Subsectors: Implications for Research," Southern Journal of Agricultural Economics, Vol. 9, No. 1, pp. 11-19.

66. Moore, Charles, V., September, 1977, ERS Roles, Functions, and Services, Looking Forward: Research Issues Facing Agriculture and Rural America, Economic Research Service, Washington, D.C., pp. 392-400.

67. Moore, Charles, October, 1977, Statement Presented to Joint Hearings, House Subcommittee on Family Farm, Obstacles to Strengthening Family Farm System, Hearings before the Subcommittee on Family Farms, Rural Development and Special Studies, 95th Congress, First Session, Sacramento, California, October 28, House, U.S. Congress, Washington, pp. 411-416.

68, Moore, Charles V., July, 1977, Effect of Tax Shelters on Agriculture, Presented to California Assembly Committee on Agriculture, July 27, 1977, 6 pp.

69. Moore, Charles V., July 1977, "Industrialization of Agriculture, California Style: PROTOTYPE?" Presented to the Meeting of Agricultural Economists, Federal Reserve System, San Francisco, California, July 28, 1977, 7 pp.

70. Moore, Charles V., July, 1977, "Effects of Tax Shelters on Agriculture, How Limited Partnerships May Affect California Agriculture: Transcript of Joint Hearing," California Legislature, Assembly committee on Agriculture and State Board of Food and Agriculture, Subcommittee on Land Acquisitions, Sacramento, July 27, 1977, pp. 39-60.

71. Moore, C.V., October, 1977, "External Equity Capital in Production Agriculture," Presented to Joint Hearing, House Subcommittee on Family Farm Assembly Committee on Agriculture, October 28, 1977, Sacramento, California, 6 pp.

72. Horner, Gerald and Charles Moore (Members of a Team) January, 1978, The U.S. Department of The Interior's Proposed Rules for Enforcement of the Reclamation Act of 1902: An Economic Impact Analysis: A Staff Reort Prepared by a Team, Economics, Statistics and Cooperatives Service, U.S. Department of Agriculture, Washington, 61 pp.

73. Moore, Charles V., January, 1977, "Water and the Agricultural Economy Presented to Superior California Water Assocaition," Red Bluff, California, January 14, 1977, 5 pp.

74. Reimund, Donn A., Charles V. Moore and J. Rod Martin, February, 1977, "Factors Affecting Structural Change in Agricultural Subsectors: Implications for Research," Presented at the Southern Agricultural Economics Association Meeting in Atlanta, Georgia, February 8, 1977, 20+ pp.

75. Moore, Charles V., July, 1977, "Industrialization of Agriculture, California Style: PROTOTYPE?" Presented to the Meeting of Agricultural Economists, Federal Reserve System, San Francisco, California, July 28, 1977, 7 pp.

76. Moore, Charles V., September, 1976, "Where Do We Go From Here?: Panel Discussion," Proceedings of the Conference on Salt and Salinity Management, Santa Barbara, September 23-24, pp. 151-152, Davis, California Water Resources Center Report No. 38, December, 1976.

77. Moore, Charles V., January, 1977, "Effects of Federal Programs and Policies on the Structure of Agriculture," National Economic Analysis Division Working Paper, Economic Research Service, Washington, D.C., 31 pp.

78. Moore, Charles V., January, 1977, "Water and the Agricultural Economy," Presented to Superior California Water Association, Red Bluff, California, January 14, 1977, 5 pp.

79. Moore, Charles V., March, 1977, "Roles, Functins and Services of ERS in 1986, " ERS Forward Look: Emerging Issues and Research Implications, Washington, D.C., Economic Research Service, USDA, pp. 454-469.

80. Snyder, J. Herbert, Richard G. Rohde, Charles V. Moore, Gerald L. Horner and Richard E. Howitt, May, 1977, "Can Water Pricing Encourage Conservation? Some Principles and Some Problems, " California Agriculture, Vol. 31, No. 5, pp. 11-12.

81. Sarhan, Mohamed E., Howitt, Richard E. and Moore, Charles V., Pesticide Resistance Externalities and Optimal Mosquito Management, Journal of Environmental Economics and Management, Vol. 6, No. 1, March, 1979, p. 69-84, G.F. Paper 525.

82. Lin, William W. and Moore, Charles V., February, 1978, "Bernoullian Utility Functions: Alternative Uses and Estimating Procedures," Paper Presented at the W-149 Regional Research Project Meeting on Market Risk, February 2, 1978, in San Diego, California, 27 pp.

83. Moore, Charles (Member of a Team) January, 1978, The U.S. Department of The Interior's Proposed Rules for Enforcement of the Reclamation Act of 1902: An Economic Impact Anlysis: A Staff Report prepared by a Team, Economics, Statistics and Cooperatives Service, U.S. Department of Agriculture, Washington, 61 pp.

84. Bessler, David A. and Moore, Charles V., "Use of Probability Assessments and Scoring Rules for Agricultural Forecasts," Agricultural Economics Research, Vol. 31, No. 4, October, 1979, p. 44-47.

85. Moore, Charles V., "Interim Report, Acreage Limitation: Apendix III - Agricultural Economics: Farm Viability and Efficiency," Washington, D.C., U.S. Water and Power Resources Service, Department of the Interior, March, 1980, 32 p.

86. Moore, Charles V., "External Equity Capital in Production Agriculture," Agricultural Finance Review, Vol. 39, November, 1979, p. 72-82.

87. Moore, Charles V. (Co-preparer) "Acreage Limitation, Draft Environmental Impact Report," U.S. Department of The Interior, January, 1981.

88. Sarhan, M.E., R. E. Howitt, C.V. More and C.J. Mitchell, "Economic Evaluation of Mosquito Control Programs," California Agriculture, Univeristy of California, Division of Agric. Sciences, November-December, 1980, vol. 34, Nos. 11 and 12, pp. 20-24.

89. Moore, Charles V., "Impact of Increasing Energy Costs on Pump Irrigated Agriculture," California Agriculture, University of California, Division of Agric. Sciences, Vol. 35, January-February, 1981, pp. 23-25.

90. Noel, J.E., B.D. Gardner and C.V. Moore, "Optimal Regional Conjunctive Water Management,." AJAE, Vol. 62, No. 3, August, 1980, pp. 489-507.

91. Reimund, D.A., J.R. Martin and C.V. Moore, "Structural Change in Agriculture," ESCS, USDA, Technical Bulletin No. 1648, April, 1981 pp. 73.

92. Moore, C.V., "Issues in California Water Resource Management," Paper Presented to University of California Extension Economic Outlook Conference, Davis, July 16, 1981, pp. 10.

93. M.E. Sarhan, R.E. Howitt, C.V. Moore and C.J. Mitchell, Economic Evaluation of Mosquito Control and Narrow Spectrum Mosquotocide Development in California, Giannini Foundation Research Report No. 330, August, 1981, pp. 90.

94. Moore, Charles, V., Economic Evaluation of Irrigation with Saline Water Within the Framework of a Farm, Methodology and Empirical Findings: A Case Study of Imperial Valley, California, Chapter 7, Salinity in Irrigation and Water Resources by Dan Yaron, editor, New York, Marcel Dekker, Inc., January, 1981, pp. 159-172.

95. Lane, Sylvia and Charles V. Moore, Analysis of Attributes of Insolvent Farmers in San Joaquin Valley, California Agriculture, Vol. 26, No. 2, February, 1972, pp. 6-7.

96. Moore, C.V. and J. Herbert Snyder, Management of Saline Water, Report No. 29, Water Resources Center, University of California, Davis, California, March, 1974, 19 pp.

97. Moore, Charles V., On the Necessary and Sufficient Conditions for a Long-Term Irrigated Agriculture, Reprinted from Water Resources Bulletin, Vol. 8, No. 4, August, 1972, pp. 802-812, in a set of papers supporting the theme of the proposed nineteenth annual New Mexico Water Conference, New Mexico Water Resources Research Institute, Las Cruces, New Mexico, June, 1974, pp. 139-153.

98. Moore, Charles V., David L. Wilson, and Thomas C. Hatch, Structure and Performance of Western Irrigated Agriculture: With Wpecial Reference to U.S. Department of the Interior's Acreage Limitation Policy, Staff Report, NED, ERS, USDA, December 1981, 261 pp.

99. Moore, Charles V., "Long-run Demand for Irrigation Water", Paper presented to California Irrigation Institute, January 27, 1882, Fresno, 9 p.

100. Moore, Charles V., "Pricing Water in California", Paper presented to Water Task Force, February 17, 1982, Fresno, 5 p.

101. Moore, Charles V., "Demand for Water in California", Paper presented to Water Conservation Advisory Committee, April 27, 1982, Sacramento, 9 p.

102. Moore, Charles V., "Inefficiencies in California's Water Rights System", Paper presented to Agricultural Leadership Class XI, May 14, 1982, Davis, 6 p.

103. Moore, Charles V., Daniel L. Wilson and Thomas C. Hatch, Structure and Performance of Western Irrigated Agricultural with Special Reference to the Acreage Limitation Policy of the U.S. Department of the Interior, Giannini Foundation Information Series 82:2, Bulletin 1905, Division of Agricultural Sciences, University of California, Sept. 1982. 63 pp.

104. Moore, Charles V., David L. Wilson and Thomas C. Hatch. Appendix to Structure and Performance of Western Irrigated Agriculture, Giannini Foundation Information Series 82:2, Bulletin 1905, Division of Agricultural Science, Univerity of California, September 1982, 243 pp.

105. Wallace, H., Charles V. Moore and Raymond Coppock, Chapter XI, "An Overview: The conflicts and the Questions" in Competition for Calfornia Water. Univerity of Calfornia Press, Berkeley, 1982.

106. Moore, Charles V., "Farm and Local/Regional Impacts of Competition for Irrigation Water: Discussion," Paper presented to Conference on Impacts of Limited Water for Agriculture in the Arid West, Asilomar, California, September 28, 1982, 6 pp.

107. Moore, Charles V., "Impact of Federal Acreage Limitation Policy on Western Irrigated agriculture," WJAE, Vol. 7, No. 2, December 1982, pp. 301-316.

108. Moore, Charles V., "An Economic Analysis of Plant Improvement Strategies for Saline Conditions, " Paper presented to Conference on Plant Improvement for Irrigated Crop Production Under Increasing Saline Conditions, Bellogio, Italy, October 15-22, 1982, 27 pp.

109. Moore, Charles V., "The Reclamation Reform Act--P.E.S.T. or Pesticide," Paper presented at WAEA Meeings, Laramie, Wyoming, July 10-12, 1983, 20 pp.

110. Moore, Charles V. and H.W. Carter, "Methodological and Empirical issues in Economics of Size Studies," Paper presented to Workshop on Economics of Size, August 3-4, 1983, Purdue Univeristy, 18 pp.

111. Moore, Charles V., Effects of Federal Programs and Policies on the Structure of Agriculture, NEAD, ERS, USDA Working Paper, January 1977, pp. 31.

112. Moore, Charles V., G.L. Horner and R.E. Howitt, A New Source of Water fo the San Joaquin Valley by Conserving On-Farm Irrigation Water, Dept. of Agricultural Economics, Univerity California, Davis, June, 1984.

113. Moore, Charles V., J.R. Martin and Donn Riemund, A Theory of Structural Change in Agriculture, NEAD Working Paper, ERS, USDA, May, 1983, 16 pp.

114. Moore, C.V., R.E. Howitt, Water Issues in California, Paper presented to Western Agricultural Economics Assoc., July, 1984, 13 pp.

115. Moore, C.V. and T. W. Gossard, Benefits and Costs of a Through Delta Facility to Kern County, Working Paper #84-6, Department of Agricultural Economics, U.C. Davis, December, 1984, 15 pp.

116. Moore, Charles V., Defining Resource Conservation, Paper Presented to Soil Conservation Society, Sacramento, Feb., 1984, 8 pp.

117. Moore, C.V., Water Marketing, Paper presented to California Assembly Committee on Water, April, 1982, 6 pp.

118. Moore, Charles V., "An Economic Analysis of Plant Improvement Strategies for Saline Conditions" in Salinity Tolerance in Plants: Strategies for Crop Improvement, Edited by R.C. Staples, Wiley and Son, 1984, pp. 381-397.

119. Moore, Charles V., Groundwater Overdraft Management: Some Suggested Guidelines, Giannini Foundation Information Series No. 81-1, Feb., 1984, pp. 12.

120. Moore, Charles V., Salinity Management in California, Paper Presented to Workshop on "Arid Lands Development and Desert Location Control, Islamabad, Pakistan, Jan., 1986, pp. 13.

121. Moore, Charles V., Report on the Economic Impact of Section 203(b) of PL 97-293. Paper presented to Bureau of Reclamation, U.S. Dept. Interior, May, 1985, pp. 26.

122. Zering K.D., C.O. McCorkle, C.V. Moore, "The Utility of All-Risk Crop Insurance for Irrigated Mutiple-Crop Agriculture," WJAE, December, 1985, pp. 24.

123. Moore, C.V. with M.D. Rosen, Water Transfers from Imperial Valley to Metropolitan Water District of Southern California, Working Paper, Dept. Agricultural Economics, U.C. Davis, January, 1985, pp. 56.

124. Moore, Charles V., Karen Klonsky, Determining Irrigation System Replacement Costs. Report to Soil Conservation Service, USDA, June, 1985, pp. 24.

125. Hardesty, S.D., H.F. Carman, C.V. Moore, Dynamic Analysis of Income Tax Provisions on Farm Firm Decision Making, AJAE, August, 1987.

126. Moore, Charles V., K.D. Olson, Migael A. Marino, "On-Farm Economics of Reclaimed Wastewater Irrigation" in, Irrigation with Reclaimed Municipal Wastewater - A Guidance Manual, Edited by Pettygrove and Asano Lewis Publishers, chelsea Mi, p. 9-1, 9-29, 1985.

127. Moore, Charles V., Richard E. Howitt, "The Central Valley of California", The World Resources Institute, Cambridge Univeristy Press, 1987, pp. 85-125.

128. Moore, C. V. and S. D. Hardesty, Base Capital Plan, Center For Cooperatives, University of California, Working Paper Series No. 6-A, p. 12, March, 1991.

129. Howitt, R.E. and C. V. Moore, "Water Management," in California Policy Choices, Vol. nine, Edited by J. Kirlin and J.I. Chapman, University of Southern California, School of Public Administration, Sacramento, 1994, pp. 115-140

130. Moore, C.V. , "Starting an Agricultural Marketing Cooperative" Center for Cooperatives, University of California, Research Series, p 56,, October 1994

131. Moore, C. V., and J. E. Noel, "Valuation of Transferable Delivery Rights For Marketing Cooperatives" Journal of Cooperation, Vol 10, p.17, National Council for Farmer Cooperatives, 1995

132. Moore, C. V. and D. Villarejo, “A Review of Economic Models Used to Assess the Impact of Cancelling Pesticide Registrations”, California Institute for Rural Studies, Davis, CA, p. 43, 1996

133. Moore, C.V. and D. Villarejo, A Critique of the Reoport, “Economic Impact of Methyl Bromide”, California Institute for Rural Studies, Davis, 1996, p.13

**BOOK REVIEWS**

1. Moore, Charles V., October, 1974, Review of, "Energy and Development, A Case Study," by William W. Siefert, Mohammed Bakr and M. Ali Kettani, Annals of Regional Science, Vol. 8, No. 3, pp. 155-157.

2. Moore, Charles V., July, 1976, "Production Conditions in Indian Agriculture: A Study Based on Farm Management Surveys," by Krishna Bharadwaj, Reviewed in Annals of Regional Science, Vol. 10, No. 2, pp. 133-135.

3. Moore, Charles V., July, 1977, Book Review: "International Trade Policy: Agriculture and Development," by Vernon L. Sorenson, Michigan State University International Business and Economic Studies, East Lansing, 1975, Annals of Regional Science, Vol. 11, No. 2, pp. 134-135.

4. Hexem, R.W. and Heady, E.O., Book Review: Water Production Functions for Irrigated Agriculture, Ames, Iowa State Univeristy Press, 1978, Reviewed by Charles V. Moore, American Journal of Agricultural Economics, Vol. 61, No. 2, May, 1979, p. 384-385.

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**EDUCATION**

| Degree | Institution | Major Field of Study | Dates |
|---|---|---|---|
| Ph.D. | Michigan State Univ | Agr. Engineering | 1966 |
| M.S. | North Dakota State Univ | Agr. Engineering | 1961 |
| B.S. | North Dakota State Univ | Agr. Engineering | 1959 |

**PROFESSIONAL EXPERIENCE**

| Employer | Position | Nature of Position | Location | Dates of Employment |
|---|---|---|---|---|
| ND State Univ. | Professor and Chair | Administration | Fargo, ND | 1/91- |
| ND State Univ. | Professor | Research/Teaching | Fargo, ND | 7/74-12/90 |
| ND State Univ. | Associate Professor | Research.Teaching | Fargo, ND | 7/68-6/74 |
| ND State Univ. | Assistant Professor | Research,Teaching | Fargo, ND | 1/66-6/68 |
| Mich. State Univ. | Grad. Research Assistant | Research | E. Lansing, MI | 7/63-12/65 |
| Mich. State Univ. | Instructor | Teaching | E. Lansing, MI | 9/60-6/63 |
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**PROFESSIONAL AND SCIENTIFIC ORGANIZATIONS**

Member ASAE
Member ASEE

**HONORS**

ASAE Outstanding Paper (1993)
ASAE Recognition, Assoc. Editor of Soil and Water Division (1991)
Researcher of Year, NDSU College of Engineering and Architecture (1988)
ASAE Outstanding Paper (1977)
Alpha Epsilon (1972)
Sigma Xi (1968)
B. S. degree with Honor (1959)
Phi Kappa Phi (1958)
Tau Beta Pi (1958)

**RESEARCH INTERESTS**

Irrigation engineering, evapotranspiration, irrigation scheduling/management.

**BACKGROUND**

Dr. Stegman has been a faculty member of North Dakota State University since 1966. He has conducted and supervised a research program that was focused on irrigation management methods. He has authored over 90 scientific papers and publications, two of which received outstanding paper recognitions from the American Society of Agricultural Engineers (ASAE). He co-developed an irrigation scheduling method that was widely used by irrigators in North Dakota and surrounding states. He senior authored the water management chapter in the first comprehensive monograph on irrigation systems by ASAE in 1980. He subsequently authored additional irrigation management chapters in monographs of the American Society of Agronomy. His paper presentations include invited presentations at several national/international irrigation symposia.

His teaching program emphasis has been in irrigation engineering and related water resources management. Following a sabbatic leave to Colorado State University in 1989-90, he was appointed chairman of the Agricultural Engineering Department in 1991. Accomplishments include a department name and curriculum change to agricultural and biosystems engineering, a curriculum and name change of the agricultural mechanization degree to agricultural systems management, and a recent approval to offer a Ph.D. degree in agricultural and biosystems engineering. As Chair, he has given leadership to the department's program focus areas in agricultural production systems, biological materials handling/processing, and environmental resources management and protection.

## SELECTED PUBLICATIONS

### CHAPTERS IN BOOKS


Martin, D. L., E. C. Stegman and E. Fereres. 1990. Irrigation Scheduling Principles. Chapt. 7. In: Management of Farm Irrigation Systems.( G. Hoffman, T. Howell, K.Solomon; eds.). ASAE Monograph. St. Joseph, MI. p155-199.

Heermann, D. F., D. L. Martin, R. D. Jackson and E. C. Stegman. 1990. Irrigation scheduling controls and Techniques. Chapt. 17. In: Irrigation of Agricultural Crops. (B. Stewart et al., eds) American Society of Agron. Monograph No. 30. Madison, WI. p. 509-535.

Stegman, E.C. 1983. Irrigation Scheduling: Applied Timing Criteria. In: Advances in Irrigation (D. Hillel, ed.). Academic Press. New York. Vol. 2:1-30.

Stegman, E.C. 1983. Irrigation Options to Avoid Critical Stress/Applied Irrigation Scheduling Concepts. Chapter 10. In: Efficient Water Use Crop Production. H.M. Taylor and W. Jordan (eds.). American Society of Agron. Monograph. Madison, WI. pp. 499-505.

Stegman, E.C., J.T. Musick, and J.I. Stewart. 1981. Irrigation Water Management. In: Design and Operation of Farm Irrigation Systems. (M.E. Jensen). American Society of Agricultural Engineering Monograph No. 3. St. Joseph, MI. pp. 763-816.


### JOURNAL ARTICLES/PAPERS


F.X.M. Casey, N. Derby, R. Knighton, D. D. Steele, and E. Stegman. 2002. Initiation of irrigation and the long term impacts and trends of subsurface water quality. Vadose Zone J.1 (2): 300-309

R.E. Knighton, W.L. Albus, N.E. Derby, D.D. Steele, E.C. Stegman. 2000. Integrated irrigation and nitrogen management impacts on ground water quality in southeastern North Dakota. In Proc. Fourth Decennial NationalIrrigation Symposium, eds. R.G. Evans, B.L. Benham, and T.P. Trooien. pp. 153-160. St. Joseph, Michigan: Amer. Soc. Agric. Engrs. 14-16 November

Steele, D.D., E.C. Stegman and R. E. Knighton. 2000. Irrigation management for corn in the Northern Great Plains. USA. Irrig. Sci. 19:107-114

Stegman, E.C. and W. Burbank. 1997. Overview and Background of the Oakes Test Area - Garrison Diversion Unit. In Proc. USCID Conference on Best Management Practices for Irrigated Agriculture and the Environment, eds. L. Stephens,pp Fargo, ND 16-19 July.

Steele, D. D. and E. C. Stegman. 1997. Irrigation management in the northern Great Plains. In Proc. 1997 Water Management Conference, Eds. J. Schaack, A.W. Freitag, and S.S. Anderson, 129-143/ Denver. Colorado: U.S. Committee on Irrigation and Drainage

Steele, D. D., R.E. Knighton, B. Mahoney, and E. C. Stegman.1997. Modeling crop growth, water balance, and nitrogen fate for irrigated corn. In Proc. 1997 Water Management Conference, Eds. J. Schaack, A. W. Freitag, and S. S. Anderson, 13-27. Denver, Colorado: U.S. Committee on Irrigation and Drainage.

Knighton, R. E., D. D. Steele, N.E. Derby, and E. C. Stegman. 1997. Crop responses and leachate losses under best management practices. Presented at the USCID Conf. Best Management Practices for Irrigated Agriculture and the Environment, Fargo, ND 16-19.

Steele, D. D., T.F. Scherer, L. D. Prunty. and E.C. Stegman. 1997. Water balance irrigation scheduling: Comparing crop curve accuracies and determining the frequency of corrections to soil moisture estimates. Appl. Engr. Agric. 13(5):593-599.

Steele, D. D., E. C. Stegman, and B. L. Gregor. 1994. Field Comparison of irrigation scheduling methods for corn. Trans. of ASAE 37(4):1197-1203

Stegman E. C. and M. G. Soderlund. 1992. Irrigation scheduling of spring wheat using infrared thermometry. TRANSACTIONS OF ASAE 35(1):143-152

Stegman, E. C. and D. F. Heermann. 1990. Ceres-maize applications to irrigation scheduling. ASAE paper No. 90- 2585. St. Joseph, MI.

Stegman, E. C., B. G. Schatz and J. C. Gardner. 1990. Yield sensitivities of short-season soybean cultivars to irrigation water management. Irrig. Sci. 11:111-119.

Stegman, E. C. 1989. Soybean yields as influenced by timing of ET deficits. Transactions of ASAE 32(2):551-557.

Stegman, E.C. 1988. Corn Crop curve comparisons for the Central and Northern Great Plains of the U.S. APPLIED ENGINEERING IN AGRICULTURE, ASAE 4(3):226-233.

Stegman, E.C. 1988. Water Management. In: Best Management Practices Manual: 5000 Acre Irrigated Test Site (H.M. Olson, ed.). Garrison Diversion Conservancy District-Dept. of Interior, USBR. Bismarck, ND. p.76-105.

Lundstrom, D.R. and E.C. Stegman. 1988. Irrigation scheduling by the checkbook method. North Dakota State Univ. Extension Serv., AE-792 (Revised). 15 p.

Montgomery, B.R., L. Prunty, A.E. Mathison, E.C. Stegman, and W. Albus. 1988. Nitrate and pesticide concentrations in shallow aquifers underlying coarse textured soils of E.C. North Dakota. p. 361-387. In: Agricultural Impacts on Ground Water, Conference Proceedings. Des Moines, IA. 21-23 March. National Water Well assoc., Dublin, OH.

Stegman, E.C. 1986. Efficient irrigation timing methods for corn production. Trans. of ASAE 29(1):203-210.

Stegman, E.C. 1985. Efficient water scheduling regimes for corn production. In: Proceedings of ICID Crop Water Requirements Conf., Paris, France. Sept. 11-14. pp. 635-648.

Stegman, E.C. 1983. Corn and sunflower yield vs. management of leaf xylem pressures. TRANSACTIONS OF ASAE 26(5):1362-1368 and 1374.

Lundstrom, D.R. and E.C. Stegman. 1983. Irrigation scheduling by the checkbook method. North Dakota Coop. Ext. Serv., Fargo, ND. Circular, AE-762. p. 15.

Stegman, E.C. 1981. Corn grain yield as influenced by timing of ET deficits. Irrigation Science 3:75-87.
Stegman, E.C. and G.W. Lemert. 1981. Sunflower yield vs. water deficits in major growth periods. TRANSACTIONS OF ASAE 24(6):1533-38, 45.

**Kenneth K. Tanji**

Soil and Water Chemist

Professor Emeritus in Hydrology
Department of Land, Air and Water Resources
University of California, Davis, CA

**EDUCATION**

| Degree | Institution | Major Field of Study | Location | Dates of Degree |
|---|---|---|---|---|
| Sc.D. | Kyoto University | Agricultural Science | Japan | 1997 |
| M.S. | University of California | Soil Science | Davis, CA | 1961 |
| B.S. | University of California | Soil Science | Davis, CA | 1958 |
| B.A. | University of Hawaii | Chemistry | Honolulu, HI | 1954 |

**PROFESSIONAL EXPERIENCE**

- Forty-five years of research experience dealing with water quality aspects of irrigation and drainage.
- Nationally and internationally recognized authority on the chemistry and management of soil salinity.
- Author/editor of major publications on soil salinity and salinity management.
- Served on numerous technical and advisory panels and committees on salinity problems in the U.S. and abroad.

**HONORS**

- Fellow, American Institute of Chemists, 1977; Fellow, Soil Science Society of America, 1982; Fellow, American Society of Agronomy, 1982.
- Benchmark Paper in Soil Science, Chemistry of Irrigated Soils, International Soil Science Society, 1984; Benchmark Paper in Soil Science, Chemistry of Soil Solutions, International Soil Science Society, 1986.
- Tree planted in honor of Tanji as a Distinguished Scientist, Central Soil Salinity Research Institute, Karnal, India, 1989.
- Award of Distinction, College of Agricultural & Environmental Sciences, UC Davis, 1990.
- Royce J. Tipton Award**,** American Society of Civil Engineers, 1993.
- Outstanding Practice Paper Award, ASCE Journal of Irrigation and Drainage Engineering, 1994
- Distinguished Public Service Award, University of California, Davis, 1995.
- Person of the Year, California Irrigation Institute, 1997.

**UNIVERSITY AND OTHER COURSES TAUGHT RELATED TO SALINITY AND WATER QUALITY**

- Chemistry of the Hydrosphere, University of California, Davis, 1972-2001
- Hydrochemical Models**,** University of California, Davis, 1972-2000
- Agricultural Water Quality and Salinity, University of California, Davis, 1976, 1993-95.
- Water Quality Aspects of Irrigation and Drainage, Kyoto University, 1984, 1990, 1996.
- Simulation Modeling on Agricultural Salinity Problems, Central Soil Salinity Research Institute, India, 1989.
- Salinity and Sodicity, Chinese Academy of Sciences, Institute of Geography, Changchun, China, 1999.
- Use of Marginal Quality Waters in Irrigated Agriculture, International Center for Agricultural Research in the Dry Areas, Aleppo, Syria, 2000.

**OTHER UNIVERSITY OF CALIFORNIA POSITIONS HELD RELATED TO SALINITY AND WATER QUALITY**

- Director, UC Salinity/Drainage Program, Division of Agriculture and Natural Resources, University of California, 1985-92.

- Assistant Director, Soil and Water, Agricultural Experiment Station, Division of Agriculture and Natural Resources, University of California, 1985-92.

**SELECTED LIST OF BOOKS ON IRRIGATION AND SALINITY**

- Tanji, K.K., Editor 1990. Agricultural Salinity Assessment and Management. ASCE Manual and Reports No. 71, American Society of Civil Engineers, 619 pages.
- Tanji, K.K. and B. Yaron, Editors. 1994. Management of Water Use in Agriculture, Springer-Verlag Publishers, 320 pages.
- Tanji, K.K. and N.C. Kielen. 2002. Agricultural Drainage Water Management in Arid and Semi-Arid Areas. Irrigation and Drainage Paper 61, UN Food and Agriculture Organization, Rome, Italy, 188 pages.

**SELECTED LIST OF BOOK CHAPTERS ON IRRIGATION AND SALINITY**

- Tanji, K.K. 2002. Salinity in the soil environment. Chapter 2, pages 21-51, IN Salinity: Environment-Plants-Molecules, Kluwer Academic Publishers.
- Ayars, J.E., and K.K. Tanji, 2000. Effects of drainage on water quality in arid and semi-arid irrigated lands. Chapter 25, pages 831-867, IN Drainage Monograph, American Society of Agronomy.
- Tanji, K.K., and B.R. Hanson, 1990. Drainage and return flows in relation to irrigation management. Chapter 35, pages 1057-1088, IN Irrigation of Agricultural Crops, Agronomy Monograph, American Society of Agronomy.
- Tanji, K.K., L.D. Doneen, G.V. Ferry and R.S. Ayers. 1986. 1972 paper on Computer simulation analysis on reclamation of salt-affected soils in San Joaquin Valley, California, pages 346-352, IN Benchmark Papers in Soil Science, Chemistry of Soil Solutions, International Society of Soil Science .
- Tanji, K.K., L.D. Doneen, G.V. Ferry and R.S. Ayers. 1984. 1972 paper on Computer simulation analysis on reclamation of salt-affected soils in San Joaquin Valley, California, pages 369-375, IN Benchmark Papers in Soil Science, Chemistry of Irrigated Soils, International Society of Soil Science.
- Tanji, K.K. 1981. River basin hydrosalinity modeling. Pages 207-225, IN Land and Stream Salinity, Developments in Agricultural Engineering, 2. Elsevier Scientific Pub. Co.

**SELECTED LIST OF JOURNAL AND CONFERENCE PAPERS RELATED TO SALINITY**

- Dutt, G.R., and K.K. Tanji. 1962. Predicting concentrations of solutes in water percolated through a column of soil. Journal of Geophysical Research 67(9): 3437-3439.
- Paul, J.L., K.K. Tanji and W.D. Anderson. 1966. Estimating soil and saturation extract composition by a computer method. Soil Science Society of America Proceedings 30: 15-17.
- 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 analysis. Hilgardia 38(9): 319-353.
- Tanji, K.K. 1969. Solubility of gypsum in aqueous electrolytes as affected by ion association and ionic strengths up to 0.15M and 25$^{o}$C. Environmental Science and Technology 3: 656-661.
- Tanji, K.K., D.W. Henderson, and S.K. Gupta. 1975. Water and salt transfers in Sutter Basin, California. Transactions, American Society of Agricultural Engineers 18(1): 111-115, 121.
- Tanji, K.K. 1977. A conceptual hydrosalinity model for predicting salt load in irrigation return flows. Pages 49-70, IN Proceedings of the International Salinity Conference, Lubbock, Texas.
- Tanji, K.K. 1981. California irrigation return flows vary. ASCE Journal of Irrigation and Drainage Engineering 107(IR2): 209-220.
- Oster, J.D., and K.K. Tanji. 1985. Chemical reactions within rootzone of arid soils. ASCE Journal of Irrigation and Drainage Engineering 111(3): 207-217.
- Tanji, K.K., and F.F. Karajeh. 1993. Saline drainage water reuse in agroforestry systems. ASCE Journal of Irrigation and Drainage Engineering 19: 170-180 (Selected as Best Practice Paper by Editorial Committee).
- Tanji, KK. 1997. Irrigation with marginal quality waters: Issues. ASCE Journal of Irrigation and Drainage Engineering 123(3): 165-169.

- Tanji, K.K., W.W. Wallender, and L.T. Rollins. 2002. San Joaquin Valley Case Study: Irrigation drainage water management options. IN, Proceedings 17th World Congress, International Union of Soil Science, Bangkok, Thailand, August, 2002.
- Tanji, K.K., and C.G. Keyes, Jr. 2002 Water quality aspects of the Irrigation and Drainage Division: Past history and future challenges for civil engineers. ASCE 150-year Anniversary Paper. ASCE Journal of Irrigation and Drainage Engineering 128: 1-9

**SELECTED LIST OF TECHNICAL REVIEWS AND ADVICE RELATED TO SALINITY AND WATER QUALITY**

- Technical Consultant on Agricultural Salinity and Water Quality, UN Food and Agriculture Organization, 1977, 1998, 2000 to present; Federal-State San Joaquin Valley Drainage Program, 1985-90; San Joaquin Valley Drainage Implementation Program, California Department of Water Resources, 1998 to present.
- Member, Technical Review Panel on the Research Plan of US Salinity Laboratory, US Department of Agriculture, 2001; Committee on Planning and Remediation of Irrigation – Induced Water Quality Problems, National Research Council, National Academy of Engineering, 1990-95; Advisor, Secretariat for The Third World Water Forum held in Kyoto, Japan, 2002-03.
- Editor, Paddy and Water Environment Journal, 2002 to present; Editorial Advisory Board, Journal on Recent Advancements in Soil Science, 1996 to present; Associate Editor, Soil Science Society of America Journal, 1981-84.
- Member, Agricultural Water Quality and Drainage Technical Committee, ASCE (EWRI), 1977 to present; Technical Services Committee, US Committee of Irrigation and Drainage, 1997 to present.

**WESLEY W. WALLENDER**
Agricultural Engineer
Professor
Departments of Land, Air and Water Resources (Hydrology Program) and
Biological and Agricultural Engineering
University of California, Davis, Ca

## EDUCATION

| Degree | Institution | Major Field of Study | Dates of Degree |
|---|---|---|---|
| Ph.D. | Utah State University | Engineering | June 1982 |
| M.S. | University of California Davis | Water Science | June 1978 |
| B.S. | Utah State University | Agricultural and Irrigation Engineering | September 1981 |
| B.S. | Oregon State University | Agricultural Engineering Technology | June 1976 |
| EIT | | Engineer-in-Training Exam | May 1979 |
| PE | | Professional Engineer, California | 1987 |

## PROFESSIONAL EXPERIENCE

| Employer | Position | Location | Dates of Employment |
|---|---|---|---|
| Univ of California | Assistant-82-88, Associate-88-92 and Full-Professor-92-present | Davis, Ca | 1982-present |

Research includes modeling and measurement of precipitation- and irrigation-driven watersheds from submeter to kilometer scales. Specific subject matter interest includes water, energy and chemical transport for sustainable agroecosystems. Teach undergraduate courses in Geographic Information Systems (GIS) and spatial analysis; transport of momentum, heat and chemicals; and irrigation system design and graduate courses in continuum mechanics as well as surface irrigation hydraulics. Supervise four Ph.D. and two M.S. students. Funding in excess of $7 million supporting the completion of 27 graduate student theses.

Univ of California Salinity/Drainage Research Program Director Davis, Ca 1992-3

Administered the development, interpretation, and dissemination of research knowledge addressing critical environmental problems on salinity, drainage, selenium, and other toxic elements in the San Joaquin Valley. Initiated a long term study on the sustainability of irrigated agroecosystems within environmental constraints.

Consultant to Keller Engineering Logan, UT 1980-2

Measure and analyzed mine waste water disposal. Conducted infiltration tests to design pressurized irrigation systems.

Registered Profession Engineering Consultant 1987-present

Advise watershed entities in California. Advice and consulting to governments of France, Egypt, Oman, Mexico, Morocco, China, Brazil, and India and to the International Rice Research Institute (Philippines) and the International Water Management Institute (Sri Lanka).

## PROFESSIONAL, SCIENTIFIC AND HONORARY SOCIETIES AND AWARDS

American Geophysical Union
American Society of Agricultural Engineers
American Society of Civil Engineers
Phi Kappa Phi
Sigma Xi
Alpha Zeta
Tau Beta Pi
Blue Key
Who's Who in California
American Society of Civil Engineers, Best Practices Paper Award, 2002.
American Society of Civil Engineers, Best Research Paper Award, 2003.
American Society of Agricultural Engineers, Technical Reviewer Special Recognition, 2001, 2002

## MEMBERSHIP ON COMMITTEES AND EDITORIAL BOARDS

Associate Editor, Soil and Water Division, American Society of Agricultural Engineers, Developed and implemented procedures for an electronic journal, 1991-present

Member, Advisory Board, International Journal of Water Resources Engineering, 1991-present.

Member, Editorial Board, Irrigation Science, Springer Verlag, 1994-present

Member, Technical Advisory Committee on Forest Geology, State of California Mining and Geology Board, 2002

Member, Challenge Program Consortium, Global Challenge Program on Food and Water, Consultative Group on International Agricultural Research, 2001-present

Member, Integrated Basin Water Management Systems (Research) Workgroup, Global Challenge Program on Food and Water, Consultative Group on International Agricultural Research, 2001-present

### RECENT PRESENTATIONS

Poster presentation, Regional Water Use of Winter Crops Using GIS. American Geophysical Union Fall Meeting, San Francisco, CA Dec. 13-17, 1999.

Poster presentation,"Numerical simulation of water and solute transport to tile drains under heterogeneous soil and crop conditions" American Geophysical Union Fall Meeting, San Francisco, CA Dec. 13-17, 1999.

Poster presentation, "Significance of specific storage in modeling variably saturated flow" American Geophysical Union Fall Meeting, San Francisco, CA Dec. 13-17, 1999.

Poster presentation, "Quantifying dormant spray pesticide runoff in a prune orchard" American Geophysical Union Fall Meeting, San Francisco, CA Dec. 13-17, 1999.

Invited lectures, "Hydrology: a continuum science" Holmes Junior High School, Davis, CA May 1, 2000.

Poster presentation, "Quantifying dormant spray pesticide runoff in a prune orchard" Toxic Substances Research and Teaching Program 13th Annual Research Symposium, San Diego, CA. April 28, 2000.

Presentation, Land retirement option and retired land management, Environmental and Water Resources Institutes of the American Society of Civil Engineers, Watershed Management 2000 Symposium, Fort Collins, CO, June 22, 2000.

Poster presentation, "Quantifying dormant spray pesticide runoff in a prune orchard" Toxic Substance Research and Teaching Program, Granlibakken, CA April 20, 2001.

Invited Lecture "Tensors and Continuum Mechanics" HYD 210, UC Davis, June 6, 2001.

Invited presentation, International Union of Soil Scientists, Groundwater: Context for Agriculture, Environment and Economics, Riverside California, June 26, 2001.

Invited presentation, XI Internation Congress of Irrigation and Drainage and the 4th Inter-Regional Conference on Environment Water, Irrigation Hydrology, Fortaleza, Brazil, 29 August 2001.

Invited debater, XI International Congress of Irrigation and Drainage and the 4th Inter-Regional Conference on Environment Water, Remote Sensing of Evapotranspiration, Fortaleza, Brazil, 30 August 2001.

Invited seminar, Federal Rural University, Irrigation Hydrology and Sampling, Recife, Brazil, 3 September 2001.

Invited seminar, Federal University, Irrigation Hydrology and Uniformity, Vicosa, Brazil, 6 September 2001.

Presentation, Water and Land Management in Irrigated Ecosystems, University of California Salinity Drainage Program, Sacramento, CA, March 26, 2002.

Invited presentation, Irrigated-Land Retirement, The Future of the West Side, UC Berkeley's College of Natural Resources & Center for Sustainable Resources Development Conference, Parlier, CA, March 22, 2002.

Invited presentation, Integrated Water Resources Management, Research Planning Conference, International Water Management Institute, Colombo, Sri Lanka, May 16, 2002.

Invited presentation, Irrigation Hydrology Crossing Scales, Conference on Energy, Climate, Environment and Water Issues and Opportunities for Irrigation and Drainage, Sponsored by the US Committee on Irrigation and Drainage and the American Society of Civil Engineers, San Luis Obispo, California, July 10-13, 2002.

**RECENT REFEREED PUBLICATIONS**


103. Angermann, T., W.W. Wallender, J.D. Henderson, G.H. Oliveira, B.W. Wilson, I. Werner, L.A. Deanovic, D.E. Hinton, P. Osterli, W. Krueger, M.N. Oliver and F. G. Zalom. 2002. Runoff from orchard floors—micro-plot field experiments and modeling. Journal of Hydrology. 254(2002):178-194.
102. Tarboton, K.C., N.S. Raghuwanshi and W.W. Wallender. 2002. 2-D Saturated-unsaturated zone irrigation and drainage model: Sensitivity analysis. Transactions of the American Society of Agricultural Engineer. 45(5):1365-1374.
101. Tarboton, K.C., W.W. Wallender and N.S. Raghuwanshi. 2002. 2-D Saturated-unsaturated zone irrigation and drainage model: Theory. Transactions of the American Society of Agricultural Engineer. 45(5):1353-1363.
100. Wallender, W.W. and M.E. Grismer. 2002. Irrigation hydrology-Crossing scales. J. of Irrigation and Drainage Engineering ASCE. 1284:203-211.
99. Young, C.A. and W. W. Wallender. 2002. Spatially distributed irrigation hydrology: water balance. Transactions of the American Society of Agricultural Engineer 45(3):609-618.
98. Kumar, M., N.S. Raghuwanshi, R. Singh, W.W. Wallender, and W.O. Pruitt. 2002. Estimating evapotranspiration using artificial neural networks . J. of Irrigation and Drainage Engineering ASCE 128(4:224-233).
97. Buyuktas, D. and W.W. Wallender. 2002. Enhanced subsurface irrigation hydrology model. J. of Irrigation and Drainage Engineering ASCE. 128(3):168-174.
96. Buyuktas, D. and W.W. Wallender. 2002. Numerical simulation of water and solute transport to tile drains. J. of Irrigation and Drainage Engineering ASCE. 128(1):49-56.
95. George, B.A., B.R.S. Reddy, N.S. Raghuwanshi and W.W. Wallender. 2002. Decision support system for estimating reference evapotranspiration. J. of Irrigation and Drainage Engineering ASCE. 128(1):1-10.
94. Joyce, B., W. W. Wallender, J.R. Mitchell, L.M. Huyck, S.R. Temple, P.N. Brostrom, T.C. Hsiao. 2002. Infiltration and soil water storage with winter cover cropping. Transactions of the American Society of Agricultural Engineer. 45(2):315-326.
93. Werner, I., L.A. Deanovic, D.E. Hinton, J.D. Henderson, G.H. Oliveira, B.W. Wilson, W. Krueger, W.W. Wallender, M.N. Oliver, F. G. Zalom. 2002. Toxicity of stormwater runoff after dormant spray application of Diazinon and Esfenvalerate (Asana) in a French prune orchard Glenn County, California, USA. Bulletin of Environmental Contamination and Toxicology. 68:29-36.
92. Wallender, W.W. 2001. Irrigation Hydrology. Ed. A.A. Soares and H.M. Helvecio. 2001. Competitive Use and Conservation Strategies for Water and Natural Resources. International Congress of Irrigation and Drainage. The Brazilian Association on Irrigation and Drainage. Banco do Nordeste Press. Brazilia, Brazil. Published as a CD.
91. Purkey, D.R. and W.W. Wallender. 2000. Habitat restoration and agricultural production under land retirement. J. of Irrigation and Drainage Engineering ASCE 127(4):240-245.
90. Purkey, D.R. and W.W. Wallender. 2000. Drainage reduction under land retirement over shallow water table. J. of Irrigation and Drainage Engineering ASCE 127(1):1-7.
89. Renault, D. and W.W. Wallender. 2000. Nutritional water productivity and diets. Agricultural Water Management. 45(2000):275-296.
88. Schwankl L.J., N.S. Raghuwanshi and W.W. Wallender. 2000. Furrow irrigation performance under spatially varying conditions. J. of Irrigation and Drainage Engineering ASCE.
87. Schwankl L.J., N.S. Raghuwanshi and W.W. Wallender. 2000. Time series modeling for predicting spatially variable infiltration. J. of Irrigation and Drainage Engineering ASCE.
86. Mateos, L., C.A. Young, W.W. Wallender and H.L. Carlson. 2000. High spatial resolution for irrigation district water and salt balance. J. of Irrigation and Drainage Engineering ASCE 126 (5):288-295.
85. Colla, G. J.P. Mitchell, B.A. Joyce, L.M. Huyck, W.W. Wallender, S.R. Temple, T.C. Hsiao, and D.D. Poudel. 2000. Soil physical properties and tomato yield and quality in alternative cropping systems. Agron. J. 92:924-932
84. Tarboton, K.C. and W.W. Wallender. 2000. Finite-element grid configuration for drains. 2000. J. of Irrigation and Drainage Engineering ASCE 126(4):243-249.

83. Raghuwanshi, N., and W. W. Wallender. 2000. Forecasting daily evapotranspiration for a grass reference crop. Agricultural Engineering Journal 9(1):1-16.

**RELATED REFEREED PUBLICATIONS**

81. Wallender, W.W. and T. Fernandes. 1999. Drainage penalty and economic irrigation technologies and crops. Applied Engineering in Agriculture 15(5):457-464.
80. Raghuwanshi, N., and W. W. Wallender. 1999. Forecasting and optimization of furrow irrigation management decision variables. Irrigation Science 19:1-6.
78. Ito, H., N. Raghuwanshi, and W. W. Wallender. 1999. Economics of furrow irrigation under partial infiltration information. J. of Irrigation and Drainage Engineering ASCE 125(3):105-111.
77. Raghuwanshi, N., and W. W. Wallender. 1998. Effects of input variability on mean and variance of simulated evapotranspiration. Agricultural Engineering Journal 7(2):109-122.
76. Raghuwanshi, N., and W. W. Wallender. 1998. Converting from pan evaporation to evapotranspiration. J. of Irrigation and Drainage Engineering ASCE 124(5):275-277.
75. Raghuwanshi, N., and W. W. Wallender. 1998. Optimal furrow irrigation scheduling under heterogeneous conditions. Agricultural Systems 58(1): 39-55.
73. Raghuwanshi, N., and W. W. Wallender. 1997. Optimization of furrow irrigation schedules , designs and net return to water to water. Agricultural Water Management 35(1998):209-226.
72. Renault, D., and W. W. Wallender. 1997. Surface storage in furrow irrigation evaluation. J. of Irrigation and Drainage Engineering ASCE 123(6):415-422.
71. Raghuwanshi, N., and W. W. Wallender. 1997. Economic optimization of furrow irrigation. J. of Irrigation and Drainage Engineering, ASCE 123(5): 377-385.
70. Wind, B., and W. W. Wallender. 1997. Fossil fuel carbon emission control in irrigated maize production. Energy: The International Journal 22(8):827-846.
69. Raghuwanshi, N., and W. W. Wallender. 1997. Field-measured evapotranspiration as a stochastic process. *Agricultural Water Management* 32(1997):111-129.
67. Renault, D., and W. W. Wallender. 1996. Initial-inflow-variation impacts on furrow irrigation evaluation. J. of Irrigation and Drainage Engineering, ASCE 122(1):7-14.
66. Raghuwanshi, N., and W. W. Wallender. 1996. Modeling of seasonal furrow irrigation. *J. of Irrigation and Drainage Engineering, ASCE* 122(4):235-242.
62. Purkey, D. R., and W. W. Wallender. 1994. A review of irrigation performance assessment in California. *Irrigation and Drainage Systems* 8:233-249.
61. Eching, S. O., J. W. Hopmans, W. W. Wallender, J. L. MacIntyre, and D. Peters. 1994. Estimation of local and regional components of drain flow from an irrigated field. Irrigation Science 15:153-157.
59. Lamacq, Sophie and W. W. Wallender. 1994. Soil water model for evaluating water delivery flexibility. J. of Irrigation and Drainage Engineering, ASCE, 120(4):756-774.
58. Renault, D. and W. W. Wallender. 1994. Furrow advance-rate solution for stochastic infiltration properites. J. of Irrigation and Drainage Engineering, ASCE, 120(3):617-633.
56. Waller, P. M. and W. W. Wallender. 1993. Changes in cracking, water content and bulk density of salinized swelling clay field soils. Soil Science, 156(6):414-423.
55. Bautista, E. and W. W. Wallender. 1993. Optimal management strategies for cutback furrow irrigation. J. of Irrigation and Drainage Engineering, ASCE, 119(6):1099-1114.
54. Bautista, E. and W. W. Wallender. 1993. Reliability of optimized furrow infiltration parameters. J. of Irrigation and Drainage Engineering, ASCE, 119(5):784-800.
53. Bautista, E. and W. W. Wallender. 1993. Numerical calculation of infiltration in furrow irrigation simulation models. J. of Irrigation and Drainage Engineering, ASCE, 119(2):286-294.
52. Bautista, E. and W. W. Wallender. 1993. Identification of furrow infiltration parameters from advance times and rates. J. of Irrigation and Drainage Engineering, ASCE, 119(2):295-311.
51. Childs, J. C., W. W. Wallender, and J. W. Hopmans. 1993 Spatial and seasonal variation of infiltration under surface irrigation. J. of Irrigation and Drainage Engineering, ASCE, 119(1):74-90.
49. Shepard, J. S., W. W. Wallender, and J. W. Hopmans. 1993. One-point method for estimating furrow infiltration. Transactions of the American Society of Agricultural Engineers, 36(2):395-404.

47. Xanthoulis, D. and W. W. Wallender. 1992. Furrow infiltration and design with cannery wastewater. Transactions of the American Society of Agricultural Engineers, 34(6):2390-2396.
46. Bautista, E. and W. W. Wallender. 1992. Hydrodynamic furrow irrigation model with specified space steps. *J. of Irrigation and Drainage Engineering, ASCE,* 118(3):450-465.
45. Renault, D. and W. W. Wallender. 1992. "ALIVE" Advance LInear VElocity: Surface Irrigation Rate Balance Theory. *J. of Irrigation and Drainage Engineering, ASCE*, 118((1):138-155.
43. Renault, D. and W. W. Wallender. 1991. "ALIVE" Advance Linear Velocity: Horton Infiltration Law from Field Water Advance Rate. *Transactions of the ASAE*, 34(4):1706-1714.
42. Waller, P. M. and W. W. Wallender. 1991. Infiltration in surface irrigated swelling soils. *Irrigation and Drainage Systems*, 5:249-266
41. Tod, I. C., M. E. Grismer, and W. W. Wallender. 1991. Measurement of irrigation flows through irrigation turnouts. *J. of Irrigation and Drainage Engineering, ASCE* 117(4):596-599.
37. Wallender, W. W. and Junji Yokokura. 1991. Space solution of kinematic-wave model by time iteration. Journal of Irrigation and Drainage Engineering 117(1):140-144.
38. Wallender, W. W. 1990. Economic surface irrigation within environmental constraints. In: Irrigation theory and practice. J. R. Rydzewski and C. F. Ward (eds.), Pentech Press, London. pp. 507-513.
35. Wallender, W. W., S. Ardila, and M. Rayej. 1990. Irrigation optimization with variable water quality and nonuniform soil. Transactions of the American Society of Agricultural Engineers 33(5):1605-1611. September-October.
33. Tod, Ian C., Wesley W. Wallender, Delbert W. Henderson, and Johannes J. DeVries. 1990. Considerations for sizing water delivery systems. Irrigation and Drainage Systems 4:171-179.
30. Tarboton, Kenneth C. and W. W. Wallender. 1989. Field-wide furrow infiltration variability. Transactions of the American Society of Agricultural Engineers 32(3):913-918. May-June.
29. Purkey, D. R. and W. W. Wallender. 1989. Surge flow infiltration variability. Transactions of the American Society of Agricultural Engineers 32(3):894-900. May-June.
28. Sirjani, Fariba and W. W. Wallender. 1989. Stochastic infiltration from advance in furrows. Transactions of the American Society of Agricultural Engineers 32(2):649-654. March-April.
26. Wallender, W. W. and Mohammad Rayej. 1989. Runoff recovery and evaporation pond system on nonuniform soil. Transactions of the American Society of Agricultural Engineers 32(2):621-625.
25. Rayej, Mohammad and W. W. Wallender. 1988. Time solution of kinematic-wave model with stochastic infiltration. American Society of Civil Engineers, Journal of Irrigation and Drainage Engineering 114(4):605-621. November.
24. Schwankl, L. J. and W. W. Wallender. 1988. Zero inertia furrow modeling with variable infiltration and hydraulic characteristics. Transactions of the American Society of Agricultural Engineers 31(5):1470-1475.
20. Wallender, W. W. and Mohammad Rayej. 1987. Economic optimization of furrow irrigation with uniform and nonuniform soil. Transactions of the American Society of Agricultural Engineers 30(5):1425-1429.
19. Rayej, Mohammad and W. W. Wallender. 1987. Furrow model with specified space intervals. American Society of Civil Engineers, Journal of Irrigation and Drainage Engineering 113(4):536-548.
16. Rayej, Mohammad and W. W. Wallender. 1987. Runoff recovery and evaporation pond optimization model. Transactions of the American Society of Agricultural Engineers 30(4):1031-1037, 1042.
14. Bali, Khaled and W. W. Wallender. 1987. Water application under varying soil and intake opportunity time. Transactions of the American Society of Agricultural Engineers 30(2):442-448.
12. Wallender, W. W. 1986. Furrow model with spatially varying infiltration. Transactions of the American Society of Agricultural Engineers 29(4):1012-1016.
9. Bautista, E. and W. W. Wallender. 1985. Spatial variability of infiltration in furrows. Transactions of the American Society of Agricultural Engineers 28(6):1846-1851, 1855.
8. Izadi, Behzad and W. W. Wallender. 1985. Furrow hydraulic characteristics and infiltration. Transactions of the American Society of Agricultural Engineers 28(6):1901-1908.
7. Wallender, W. W. and M. Rayej. 1985. Zero-inertia surge model with wet-dry advance. Transactions of the American Society of Agri-cultural Engineers 28(5):1530-1534.
5. Rayej, M. and W. W. Wallender. 1985. Furrow irrigation simulation time reduction. Journal of the Irrigation and Drainage Division, American Society of Civil Engineers 111(2):134-146. June.

1. Wallender, W. W., D. W. Grimes, D. W. Henderson, and L. K. Stromberg. 1979. Estimating the contribution of a perched water table to the seasonal evapotranspiration of cotton. Agronomy Journal 71:1056-1060.

**Joseph M. Lord Jr.**
**Professional Engineer**
**President and Chief Operating Officer**
**JMLord, Inc., Fresno, CA**

## EDUCATION

B.S., Civil Engineering, State University of Iowa, 1962

## PROFESSIONAL REGISTRATION AND AFFILIATION

Agricultural Engineer: California
Civil Engineer: California, Arizona, Nevada, Colorado, Oregon and Texas
American Society of Agricultural Engineers
American Society of Civil Engineers
U.S. Committee on Irrigation, Drainage, and Flood Control
California Irrigation Institute

## HONORS

Recipient of "Irrigation Person of the Year" Award Presented by the California Irrigation Institute, February 1998
Past President of the California Irrigation Institute
Past Advisor to the Office of Water Conservation, Department of Water Resources, State of California

## EXPERIENCE

Mr. Lord has been operating his own consulting firm since 1979. This firm provides a broad spectrum of professional services to agricultural water users and operates a complete agricultural laboratory. JMLord, Inc. has clients throughout the United States, as well as internationally. A list of major projects that Mr. Lord personally participated in are as follows:

- Directed an investigation and authored a comprehensive report on the agricultural assets of a 9,100 acre property in Kern County, California.
- Selected as a member of a five-person panel of experts to review existing information and develop a comprehensive report on Colorado River water use by Coachella Valley Water District and Imperial Irrigation District.
- Designed and directed a "Water Needs Assessment" for several water districts in support of their Contract Renewal Negotiations and Conservation Plans.
- Principal in charge of performing a detail survey of soil salinity conditions of a 90,000 acre water district, and preparation of a report for management of irrigations to address the agricultural salinity hazards.
- Principal in charge of feasibility studies for developing a conjunctive use and water supply improvement program in Mokelumne River Basin.
- Project manager for a two-year study and report for inventory and evaluation of 21,000 acre drainage district on west side of San Joaquin Valley. This study produced a master plan that was accepted by district directors.
- Directed a three-year demonstration project that developed controlled drainage concepts in groundwater management for production agriculture in the San Joaquin Valley.
- Directed a statewide study and report of Water Districts in California for Department of Water Resources to evaluate factors affecting their water delivery flexibility.

- Directed a two year investigation for the ERDA to identify and quantify energy use and potential savings with on-farm water management in irrigated agriculture.

- Conducted a soil survey of 25,000 acres of reservation lands for the Fort Yuma Indians.

**WORK HISTORY**

1973 - 1979 Harza Agricultural Services, Fresno, California
President and Manager. Directed water and fertility management programs, providing consulting services in the San Joaquin Valley of California. Engaged in contracts for irrigation and drainage system design, and topographic and soil mapping.

1971 - 1973 U.S. Bureau of Reclamation, Denver, Colorado
Coordinator of the Irrigation Management Services program. Responsible for developing the applied research program for improving irrigation efficiencies with on-farm water management.

1967 - 1971 U.S. Bureau of Reclamation, Bangkok, Thailand
Drainage Engineer in charge of drainage investigations for the PaMong Project and other projects in Laos and Thailand.

1964 - 1967 U.S. Bureau of Reclamation, Denver, Colorado
Hydraulic Engineer in the Water Utilization Section.

Prior to 1964 Boeing Company, Seattle, Washington
Flight Test Engineer on the Minuteman Missile and Scientific Programmer.

**AREAS OF SPECIAL EXPERIENCE**

Irrigation District Management and Operations

United States Bureau of Reclamation Project Planning and Design Procedures

Discharge Permits and Regional Water Quality Control Board Monitoring Procedures

Selection, Performance, Management, and Evaluation of On-farm Irrigation Systems

Effects of Water Management, Drainage, and Salinity on Agricultural Production

Groundwater Hydrology, Monitoring, and Well Design, Construction and Development

**CASES WHERE A TECHNICAL OPINION WAS EXPRESSED**

California vs. Arizona - U.S. Supreme Court

Golden Crops vs. AquaNova

F & L Farm Company, et al. vs. Lindsay Olive Growers and City of Lindsay

**PUBLICATIONS**

*"Where Has The Drainage Gone?"* November, 1996. Prepared for ASAE Magazine, Resource, January 1997.

*"Evaluating Performance,"* Chapter 21. October, 1996. Design and Operation of Farm Irrigation Systems, 2nd Edition, ASAE Manual.

*"San Joaquin Valley Drainage."* April, 1996. Presented to Westland Water District.

*"Scheduling Irrigations."* February, 1995. Prepared for JMLord, Inc. newsletter, AgINFORMER.

*"Water Use Assessment, Coachella Valley Water District and Imperial Irrigation District,"* Phase I Report. January, 1994. Prepared by Technical Work Group: S. Jones, C. Burt, A. Clemmens, M. Jensen, J. Lord, and K. Solomon.

*"Coachella Valley Water District Soil Salinity Survey - 1993."* Prepared for Coachella Valley Water District, Coachella, California.

*"The Lower Mokelumne River Area Crop, Soil, and Water Use Assessment for a Ground Water Storage/Conjunctive Use Study."* July, 1991.

*"Information Systems and Irrigation Institutions,"* Chapter 24, pp. 901-913. M. E. Jensen, J. M. Lord, Jr. American Society of Agricultural Engineers, Management of Farm Irrigation Systems , 1990. Hoffman, G.J., T.A. Howell, K.H. Solomon, editors.

*"Study of Innovative Techniques to Reduce Subsurface Drainage Flows."* Phases I, II and III Reports. 1989. The San Joaquin Valley Drainage Program. Contract No. 7-CS-20-05160.

*"Distribution System Improvement to Facilitate Water Deliveries. Case Study of Three Irrigation Districts."* May, 1982.

*"Demand Theory and Application in Irrigation District Operation."* Co-authored with C.M. Burt. Presented at ASAE Irrigation Scheduling Conference, Chicago, Illinois, December, 1981.

*"Irrigation Scheduling an Essential Component of Optimum Water Management."* Co-author with M.E. Jensen, presented at the Ninth Congress of ICID, 1975.

*"Irrigation Scheduling: Painless Way to Green Parks and Lower Water Bills."* Article in manual published by State of California - Community Water Management for the Drought and Beyond.

**FOREIGN ASSIGNMENTS**

Republic of Sudan, January 24, 1985 - February 7, 1985, for World Water Foundation.

Arab Republic of Egypt, January 10, 1982 - January 17, 1982, for American Society of Consulting Engineers.

Peoples Republic of China and Inner Mongolia, November 22, 1979 - December 7, 1979, Caterpillar Far East.

Hashmite Kingdom of Jordan, September 1977 and January 1978, Jordan Valley Water Authority.

Iran, November 30, 1975 - December 12, 1975, for Harza Engineering, Colorado.

Thailand and Laos, January 1967 to February 1971 for USAID/Bureau of Reclamation.