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Field Studies of Irrigation Efficiency in the Imperial Valley

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ABSTRACT

Irrigation return flows to the Salton Sea originating from on-farm and conveyance losses are potential water sources that could be used by the Imperial Irrigation District (IID) to increase the irrigated area in the Imperial Valley or by other California users of Colorado River water. An on-farm irrigation study conducted by USDA-ARS and IID between 1977 and 1981 provided estimates of on-farm return flows originating from runoff and drainage, as well as crop water and leaching requirements. Recovery of all runoff water without any change in cropping practices would yield about 0.4 km^3/y. All but 0.1 km^3/y of this runoff water would be needed on-farm, if irrigation practices were changed so that crop water and leaching requirements were fully met without recycling drainage water for irrigation. If drainage water were recycled, only 0.1 km^3/y would be needed, leaving 0.3 km^3/y which could be used elsewhere. Combining these estimates of recoverable water with those for recoverable conveyance losses from IID operations of 0.3 km^3/y results in a total which ranges from 0.4 to 0.6 km^3/y. This brackets the maximum reduction in Colorado River water available to California after full implementation of the Central Arizona Project.

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Field Studies of Irrigation Efficiency in the Imperial Valley[1]

INTRODUCTION

WATER DIVERSION FROM the Colorado River by the Imperial Irrigation District (IID) during 1975-1979 averaged 3.4 km^3/y for irrigation of 186,000 ha in the Imperial Valley (California Department of Water Resources, Southern District 1981). On-farm deliveries and return flows to the Salton Sea were estimated at 3.1 and 1.1 km^3/y, respectively. The return flow value required estimation of subsurface flows which discharge directly into the Salton Sea and correction of gauged flows of the Alamo and New rivers for contributions originating from Mexico, storm runoff, and conveyance losses. Data obtained in a joint Agriculture Research Service–IID study (1977-1981) of on-farm irrigation efficiency provided an alternative means to assess on-farm return flows originating from runoff and drainage, water required for evapotranspiration and leaching, and amount of recoverable water.

Flows originating from on-farm and conveyance losses may be a source of recoverable water that could be used by the IID to increase the irrigated area in the Imperial Valley or by other California water users of Colorado River water. The Central Arizona Project, which began to divert water in late 1985, will eventually result in a 0.5 km^3/y reduction in Colorado River water available to California. A related issue is the legal action (California Department of Water Resources, Southern District 1981) stemming from high-water levels in the Salton Sea which was partially based on the claim that tailwater from on-farm operations has not been beneficial or is excessive.

EXPERIMENTAL METHODS

Field selection criteria. The nine selected fields were distributed throughout the valley (fig. 1). The soil type distribution for the 444 ha included in this study (table 1) was similar to that of the lacustrine basin soils (266,000 ha) in Imperial County (Zimmerman 1981). For both, the order in decreasing area was Imperial-Glenbar silty clay loam > Imperial silty clay > Holtville silty clay. Although the relative distributions for both areas are similar (table 1), a more detailed comparison is subject to question because the area of lacustrine basins soils included in a Soil Conservation Service (SCS) soil survey exceeds the irrigated area of IID (186,000 ha).

Eight fields had separate artificial drainage systems with outlets that could be instrumented to measure the drainage volume. All fields had a suitable irrigation inlet for installation of an impeller-actuated flow meter and suitable sites to measure tailwater. The cooperators determined all the cultural practices; the crops grown and management sequences are summarized in table 2 and figure 2. The distribution of the cropped area was similar to that for the Imperial Valley (table 3) during 1977-1979.

Water measurements. In all but 39 measurements, applied water was measured by one of two methods, flow meter (V_m) or difference in water height over a rectangular

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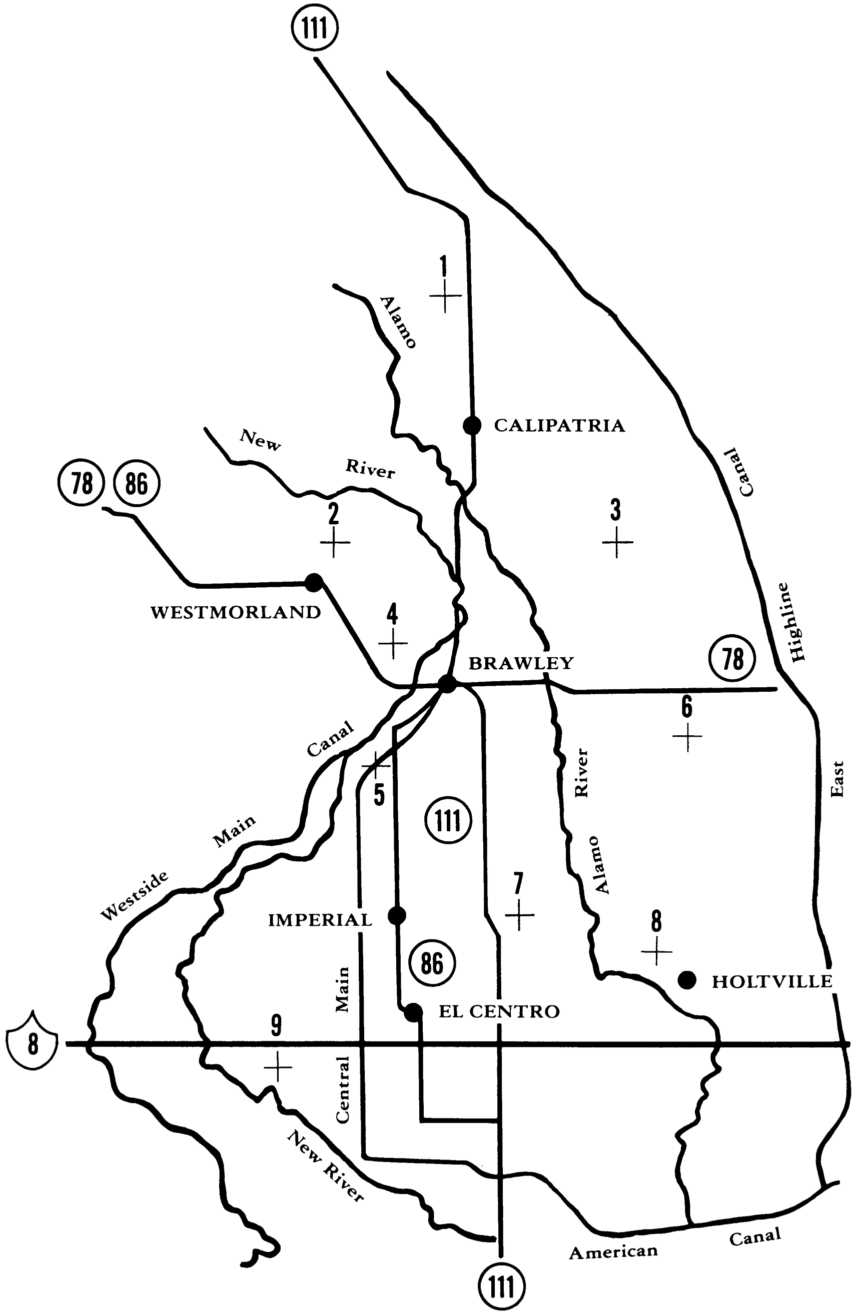

Fig. 1. Location of fields for the ARS-IID irrigation efficiency study (1977-1981) in the Imperial Valley.

submerged orifice (V_k). The latter is the common method used by IID throughout the district. The relationship between the two methods for the 39 paired measurements was $V_k = -0.002 + 1.02\ V_m$ ($r^2 = 0.77$). Consequently, both sets of applied water data were merged into a single set for the analysis reported here. Tailwater was measured with a Parshall flume equipped with a stage recorder. Drain water was measured with a similarly equipped slotted tube (Larson and Hermsmeier 1958). Calibration, using a bucket and stopwatch, was conducted about every fourth irrigation.

Annual rainfall, which averaged 104 mm for 1977-1981 at Brawley and Imperial, was not included in the applied water records; the minimum was 66 mm in 1981 and the maximum was 144 mm in 1977. The average rainfall corresponds to 0.19 km^3/y or about 6 percent of the on-farm water deliveries.

Pan evaporation. Daily measurements were made with a U.S. Weather Bureau Class A pan located at the Irrigation Desert Research Station (USDA-ARS) about 2 miles southwest of Brawley, California. It was located inside a fenced, grassed area (9×9 m) on an open 10-cm-high wood platform to allow air circulation between the pan and the ground surface. Farm roadways surrounded the fenced area. Beyond the roads, within a distance of 0.5 km, were machine yards and buildings (north), laboratory buildings (east), roads and fields (south), and experimental fields (west). The prevailing wind direction is from the west and northwest from September to June; during

TABLE 1. FIELD AREAS AND ASSOCIATED DISTRIBUTION OF SOIL TYPES FOR THIS STUDY AND FOR IMPERIAL VALLEY LACUSTRINE BASIN SOILS

Field no.	Area (*ha*)	Soil type index*						
		106	109-110	114	115	117-118	122	142
					(%)			
1	64	0	0	15	72	0	13	0
2	31	12	28	0	50	0	0	10
3	53	0	0	77	23	0	0	0
4	61	0	77	0	0	23	0	0
5	32	0	20	0	50	30	0	0
6	64	0	0	85	15	0	0	0
7	60	0	0	50	50	0	0	0
8	53	0	0	3	97	0	0	0
9	26	0	20	0	80	0	0	0
TOTAL	444	1	15	31	45	5	2	1
Lacustrine basin soils	266,000	1	13	18	31	3	6	4

SOURCE: R. P. Zimmerman 1981.

* 106 Glenbar clay loam
109-110 Holtville silty clay
114 Imperial silty clay
115 Imperial-Glenbar silty clay loams
117-118 Indio loam
122 Meloland very fine sandy loam
142 Vint loamy very fine sand

TABLE 2. CROP HISTORY BY FIELD*

Fields	1977	1978	1979	1980	1981
Alfalfa					
Field 3	A	A			A
Field 5		B	B	B	B
Field 6	A		B	A	A
Field 8	A	A	A	A	
Field 9	B	B	B		
Barley					
Field 1				A	
Bermudagrass					
Field 1				A	A
Broccoli					
Field 4	B	B			
Cantaloupe					
Field 8					A
Cotton					
Field 1	A	A	A		
Field 2		A	B		A
Field 5	B				
Cucumber					
Field 5	B				
Lettuce					
Field 2	A	A		A	B
Field 4	B	B			
Onion					
Field 2		B	B		
Field 7					B
Sorghum					
Field 4		A			

Continued

July and August winds from the southeast and south are common. Considering these factors the average pan evaporation of 2.86 m/y (minimum of 2.79 m in 1979; maximum of 3.03 m in 1978) may be somewhat higher than would be obtained from a pan installed according to standard guidelines.

Data analysis. Several difficulties were encountered. Field 5 did not have an artificial drainage system, and canal seepage confounded the drainage data obtained from field 9. Runoff or drainage, or both, were not measured for each irrigation because of equipment malfunctions. Multiple crops were grown at the same time on fields 2 and 4 during a portion of the study period.

The data were assembled into different subsets for analysis (table 4). Crop and field effects on irrigation efficiency ([applied water—runoff—drainage]/applied water) were evaluated using the smallest subset (N = 279); applied water, drainage, and runoff were measured for each irrigation on fields with single crops. IID water budget estimates—total on-farm delivery, drainage, and runoff—were based on all available data. All applied water records (N = 591) were used to estimate on-farm water delivery. Runoff (16 percent) was calculated from total runoff and corresponding total applied

TABLE 2.—*Continued*

Fields	1977	1978	1979	1980	1981
Soybeans					
Field 2			B		
Sudangrass					
Field 9		B	B		
Sugarbeets					
Field 2	B				
Field 3		A	A	A	
Field 7	A	A	A	A	
Field 8	A				
Field 9	B	B			
Tomato					
Field 5	B				
Wheat					
Field 2				A	
Field 4	B				
Field 5	B	B			
Field 6	A	A	A		
Field 7	A		A		A
Field 8					A
Fallow					
Field 1	B	B			
Field 2				B	
Field 3		B	B	B	B
Field 5					B
Field 6		B	B		
Field 7		A	A	A	A

*Data sets which include drainage and runoff for a single crop are represented by the letter A; B represents all other data sets.

water for 485 irrigations; similarly, drainage (8 percent) was calculated from the total drainage and corresponding total applied water for 399 irrigations for fields 1 through 8. The complete set of data, approximately 20 pages, is available from the senior author.

RESULTS AND DISCUSSION

Crops and fields. Irrigation efficiency, drainage, and runoff by crop (excluding field 9) are listed in order of decreasing efficiency in table 5. Efficiency equals or exceeds 70 percent for barley, alfalfa, wheat, cotton, and sorghum. Excluding sorghum, the higher efficiencies for barley, alfalfa, wheat, and cotton were partially the result of lower drainage. Sorghum was excluded because irrigation efficiency could only be determined for two irrigations. The low efficiencies for lettuce and cantaloupe resulted, in part, from the high drainage percentages, 29 and 42 percent, respectively. Soil type may have been a factor in the drainage data obtained from lettuce: the data were obtained on field 2 for which about one-tenth is mapped (Zimmerman 1981) as Vint

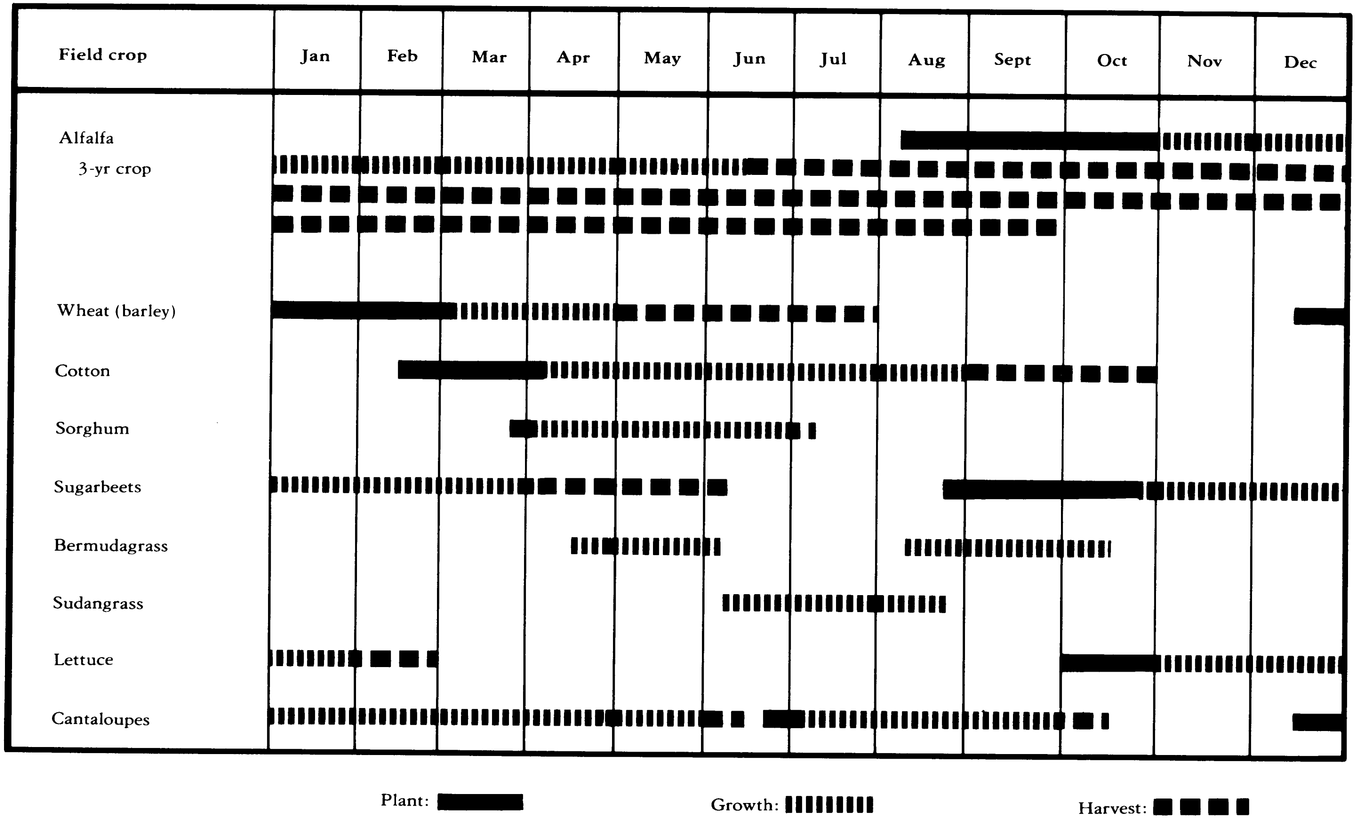

Fig. 2. Typical planting, growth, and harvest schedules for crops grown in the Imperial Valley.

TABLE 3. TOTAL CROPPED AREA, POTENTIAL EVAPOTRANSPIRATION, AND ASSOCIATED AREAL CROP DISTRIBUTION OF THE SURVEYED FIELDS.* THE CORRESPONDING CROP DISTRIBUTION FOR THE IMPERIAL IRRIGATION DISTRICT DURING 1977-1979 IS GIVEN IN COLUMN 5.

Crop	Area *(ha)*	ET *(m)*	Fields studied (%)	Valley (%)
Alfalfa	833	2.01	33	35
Barley	64	0.55	2	1
Cotton	380	1.03	15	18
Lettuce	185	0.43†	7	8
Sorghum	61	0.53	2	2
Sugarbeets	336	1.16	13	9
Wheat	485	0.64	19	19
Bermudagrass	128	0.85‡	5	0
Sudangrass	26	0.53§	1	0
Total ARS-IID	2,498			
Total cropped area-IID	210,700			

SOURCE: R. La Mert, private communication.

*Except for lettuce, bermudagrass, and sudangrass, crop ET was determined at the Irrigation Desert Research Station near Brawley with a weighting lysimeter.

†Erie, French, and Harris 1965.

‡Letey et al. 1983.

§Assumed to equal ET of sorghum.

TABLE 4. NUMBER OF DRAINAGE, RUNOFF, AND APPLIED WATER MEASUREMENTS BY FIELD*

Field	Drainage		Runoff	Water applied
1	70	55	62	78
2	67	25	54	77
3	63	41	49	68
4	11	2	29	34
5	0	0	71	82
6	57	40	47	63
7	48	39	46	51
8	83	77	80	85
9	51	45	47	53
Total	450 (399)†	324 (279)†	485	591

*Total number of drainage measurements for each field are given in the second column. The number of drainage measurements where runoff was also measured is given in the third column.

†Excludes data for field 9; see text.

loamy very fine sand. Runoff also contributed to the low efficiencies for bermudagrass, lettuce, and cantaloupe.

Runoff for furrow-irrigated crops tended to be higher than for border-strip irrigated crops. The weighted average runoff for cantaloups, lettuce, sugarbeets, and cotton was 25 percent compared with 17 percent for barley, wheat, sorghum, alfalfa, and bermudagrass, and to 16 percent if bermudagrass were excluded.

Crop effects on irrigation efficiency were greater than field effects. Variation among crops ranged from 20 to 79 percent (table 5), whereas that for fields, excluding field 9, ranged from 69 to 78 percent (table 6). Similar trends were evident among crops for the same field. For field 2, efficiency ranged from 44 percent for lettuce to 87 percent for wheat; for field 8, it ranged from 20 percent for cantaloupe to 80 percent for alfalfa. The range was smaller among fields for the same crop: 65 to 78 percent for sugarbeets, 70 to 80 percent for alfalfa, and 58 to 87 percent for wheat. Drainage and runoff variation was also greater among crops than fields.

A comparison of our drainage results to the leaching fraction data, reported by Lonkerd, Ehlig, and Donovan (1979), indicates the crop and soil effects are somewhat different for the two studies. They calculated the leaching fraction from the soil water chloride concentrations, in soil samples obtained from cropped fields, and irrigation water for four different soil series in the Imperial Valley: (1) For the Holtville and Indio soils, leaching fractions for lettuce, sugarbeets, and wheat ranged from 12 to 28 percent as compared to a range of 4 to 9 percent for alfalfa and cotton. (2) For the Imperial silty clay, the range in leaching fractions for the same five crops was from 4 to 8 percent. In our study, the predominate soil series for fields 3, 6, 7, and 8 was also Imperial silty clay, where drainage accounted for 5 to 42 percent of the applied water, depending on the crop. The larger crop effects we obtained could be the consequence of the different methods of measurement. The Lonkerd data were obtained using standard soil sampling and analytical methods for identifiable soils within a field. The results reported here integrate whatever spatial variation of water infiltration occurred for the entire field.

TABLE 5. AVERAGES AND STANDARD DEVIATIONS FOR RUNOFF, DRAINAGE, AND IRRIGATION EFFICIENCY BY CROP

Crop	N	Runoff Ave	Runoff SD	Drainage Ave	Drainage SD	Irrigation efficiency Ave	Irrigation efficiency SD
				(%)			
Barley	5	19	9	2	2	79	9
Alfalfa	190	15	10	9	8	76	20
Wheat	45	17	9	7	9	75	15
Sugarbeets	44	21	9	6	4	73	24
Cotton	46	26	17	4	6	70	18
Sorghum	2	7	4	22	10	71	5
Bermudagrass	16	30	11	5	5	64	16
Lettuce	5	26	10	29	7	44	11
Cantaloupe	7	38	14	42	13	20	24

The annual depth of applied water by field varied considerably (table 7) because of changes in cropping history. Excluding the data for fields 4 and 9, the pooled standard deviation for a two-way analysis of variance (year × field) was 43 cm. The overall average was 142 cm. Consequently, the coefficient of variation was about 30 percent. Differences among fields were significant ($P<0.05$), as were differences between years ($P<0.01$). Applied water for fields 1 and 7 was consistently low, reflecting the absence of alfalfa in the crop rotation (table 2). Annual applied water for fields 5 and 9 was the highest for the opposite reason; alfalfa was grown 4 out of 5 years. In most cases where applied water was <100 cm, the crop rotation included fallow during summer months. Fallow also contributed to the unusually low average applied water for 1981 (82 cm): Field 2 was fallow after cotton, September through December; field 5 was fallow from August through December, and field 7 was fallow during the summer, between wheat and onion, May through October.

TABLE 6. AVERAGES AND STANDARD DEVIATIONS FOR RUNOFF, DRAINAGE, AND IRRIGATION EFFICIENCY BY FIELD

Field	N	Runoff Ave	Runoff SD	Drainage Ave	Drainage SD	Irrigation efficiency Ave	Irrigation efficiency SD
				(%)			
1	55	27	11	3	3	70	13
2	25	19	21	11	12	69	27
3	41	23	13	7	6	70	15
4	2	7	6	22	10	71	5
6	40	19	8	11	7	71	13
7	39	20	8	2	2	78	9
8	77	14	13	13	13	72	23
9	45	14	7	41	27	45	28

TABLE 7. WATER APPLIED BY FIELD AND YEAR

Field	Water applied 1977	1978	1979	1980	1981
			(cm)		
1	79	183	150	101	53
2	148	148	232	163	77
3	193	148	151	64	103
4	156	149	—*	—*	—*
5	226	136	231	244	94
6	147	68	123	205	96
7	129	82	164	81	42
8	131	220	239	205	107
9	188	188	237	—*	—*
AVERAGE	155	147	191	152	82

*Indicates no data available.

Water budget, table 8. This section addresses two questions. What were the applied, runoff, drainage, and evapotranspiration components of the IID water budget for 1977-1981? And what were the water needs for crop evapotranspiration (ET), and leaching? Answers to the first question are based on the applied water data obtained in this study. Two estimates of applied water were calculated because of the small amount of water applied in 1981: the average for 1977 through 1980, 1.61 m/y, and that for 1977 through 1981, 1.45 m/y. Runoff and drainage were 16 and 8 percent, respectively, of the applied water (see data analysis section) and crop ET was obtained by difference (table 8).

Answers to the second question are based on crop ET requirements measured in southwestern Arizona and the Imperial Valley. The ET was estimated for each field crop combination. Except for lettuce, bermudagrass, and sudangrass, the selected crop ET requirements (table 3) were measured at the Irrigation Desert Research Station near Brawley with a weighing lysimeter (R. Lemert, private communication). The ET value for lettuce was reported by Erie, French, and Harris (1965); ET for bermudagrass was assumed to equal that for improved pasture (Letey et al. 1983) and the ET for sudangrass was assumed to equal that for sorghum. Monthly crop ET requirements were used (MacGillivray 1980) whenever the crop was grown for only a portion of the year. The resulting average crop ET, 1.36 m/y (column 5, table 8), exceeds both ET estimates, 1.21 and 1.10 m/y (columns 4 and 5, table 8), based on total applied water. This indicates insufficient water infiltrated to meet crop ET.

Underirrigation of alfalfa may account for 0.14 m/y. This estimate was made as follows: Applied water to alfalfa fields and corresponding pan evaporation were tabulated, provided both could be determined for the same interval. The resulting totals for applied and evaporated water were 2.57 and 3.54 m. The annual applied water to alfalfa, 2.08 m, was estimated by multiplying the applied water, 2.57 m, by the ratio, 2.86/3.54, where 2.86 m is the average annual pan evaporation. Correcting for 15 percent runoff and 9 percent drainage (alfalfa, table 5) results in an ET estimate of 1.58 m/y. This is 0.43 m/y, or 21 percent, less than the annual ET requirement for alfalfa of 2.01 m (table 3). Adjusting for the fraction of total area cropped to alfalfa, 0.33 (table 3), results in an annual underirrigation of 0.14 m.

Water budget estimates for IID based on our data (table 9) necessarily assume the cropping history, including double cropping, and water management of the surveyed fields are representative. Based on the spatial distribution of these fields within the valley (fig. 1) and the distribution of the crops grown (table 2), we believe water budget estimates have sufficient validity to report them and to compare them to previous estimates. The volume numbers in columns 6 through 8 of table 10 are based on the product of the corresponding depths in columns 3 through 5 and an irrigated area of 186,000 ha.

Our ET estimates, with one exception, are higher than that reported by the California Department of Water Resources (DWR). (See table 8, column 9.) However, in all cases, the sums of runoff and drainage are less. The DWR numbers were based on a hydrologic assessment:

(1) Measured on-farm deliveries by IID during 1975-1979 averaged 3.07 km^3/y.

(2) Gauged flows of the Alamo and New rivers, 1.02 km^3/y, were corrected for flows originating from Mexico, storm runoff, canal seepage, and canal spills.

(3) Crop ET, 2.05 km^3/y, equaled the difference between on-farm deliveries and return flows.

TABLE 8. ESTIMATES OF WATER BUDGET COMPONENTS—ET, RUNOFF, AND DRAINAGE—BASED ON FIELD DATA OBTAINED IN THIS STUDY AND ON EVAPOTRANSPIRATION (ET) REQUIREMENTS FOR MAXIMUM CROP GROWTH (TABLE 9)

		EQUIVALENT DEPTH			WATER VOLUME				
		Applied water			Applied water				
Component	Total applied water	High	Low	ET	High	Low	ET		DWR*
	(%)		(m/y)				(km^3/y)		
ET	76	1.22	1.10	1.36†	2.27	2.05	2.53		2.05
Runoff	16	0.26	0.23	0.29	0.48	0.43	0.54	0.80	1.02
Drainage	8	0.13	0.12	0.14	0.24	0.22	0.26		
Total	100	1.61†	1.45†	1.79	2.99	2.70	3.33		3.07‡

*California Department of Water Resources, Southern District 1981.
†Estimated quantity used as the base to calculate other numbers in the same column.
‡Corrected for canal spills.

TABLE 9. WATER REQUIREMENTS FOR IMPERIAL IRRIGATION DISTRICT

	WATER VOLUME	
Component	Without recycling drainage water	With recycling drainage water
	(km^3/y)	
ET	2.53	2.53
Runoff (5% of total)	0.15	0.14
Drainage (LR = 12)*	0.33	0.14
Total	3.01	2.81

*Leaching requirement expressed as percent of total infiltrated water; runoff is not included.

Agreement between this ET estimate and that calculated from individual crop areas and crop water requirements was achieved by reducing the alfalfa area by 20 percent (MacGillivray 1980). In effect, this allocates all the underirrigation to alfalfa which generally agrees with our conclusion as discussed above. Kaddah and Rhoades (1976) also made a similar adjustment in their estimate of 1973 crop ET, 2.29 km^3/y. They reduced alfalfa ET by 12 percent; without this adjustment their total crop ET would have been 2.38 km^3/y. Our higher estimate of crop ET, 2.53 km^3/y, reflects the increased area of alfalfa in 1977-1979, 70,600 ha, compared with 58,700 ha in 1973.

Underirrigation of alfalfa results in an economic loss. Twenty percent underirrigation reduces alfalfa yield about 30 percent (Donovan and Meek 1983). It is difficult to correct. The challenge is to apply sufficient water between April and September to shrinking and swelling soils, with high initial infiltration rates but low saturated hydraulic conductivities, to meet the high alfalfa water requirements between July and September. Irrigating more than twice per cutting during summer is limited by a cutting schedule of once every 28 days, and the need for dry soil conditions for haying operations. Consequently, if underirrigation during July through September cannot be corrected by increasing the number of irrigations or applying more water per irrigation, one alternative is to overirrigate before June in an attempt to increase the amount of stored water available for plant growth. Another alternative currently under study is to increase infiltration using control traffic lanes to reduce compaction (B. D. Meek, private communication).

IMPLICATIONS AND CONCLUSION

Drainage. Our estimates may be low. Several studies (Chang et al. 1983; Hermsmeier 1973; Robinson and Luthin 1968) have shown that as much drainage water may move downward past subsurface drains as is removed by subsurface drains. If the drainage values we report are only one-half of the actual value, the implications are: underirrigation would be increased by about 0.13 m (or 0.24 km^3/y) to a total of 0.26 m (0.48 km^3/y), and if on-farm deliveries were sufficient to meet full crop ET and runoff continues unchanged, the required on-farm deliveries would increase from 3.30 km^3/y to 3.57 km^3/y. This volume exceeds that (3.45 km^3/y) entering the valley at drop one.

Water requirements, IID. Estimated water requirements (table 9) consider two alternatives: full ET with and without recycling drainage water for irrigation. Both include a runoff component of 5 percent and a leaching requirement that corresponds to a no-yield reduction due to salinity. Without recycling drainage water, the leaching requirement was estimated following the methods proposed by Rhoades (1982) for infrequent irrigation using threshold salinities for each crop (Maas and Hoffman 1977). The resulting required drainage depth was 0.18 m (0.33 km^3/y) when weighted for individual crop acreage. This corresponds to a leaching requirement of 12 percent and at a steady state, a drainage water with a salinity of 9 dS/m (Oster and Rhoades 1975).

Blending this water with an appropriate amount of Colorado River water could result in 0.50 km^3/y of irrigation water with a salinity of about 6 dS/m. In principle this water could be used to irrigate cotton, barley, sugarbeets, and wheat without causing a yield loss, provided the leaching requirement of 30 percent could be achieved. The final drainage volume would be about 0.14 km^3/y. Although the practicality of achieving such a recycling strategy is questionable, it results in the lowest estimate of the required water (2.81 km^3/y) which, in principle, would be achievable without yield loss due to excessive levels of soil salinity.

Recoverable water. The volume of runoff water in columns 6 and 7 of table 8, 0.43-0.48 km^3/y, represents one estimate of recoverable water. It assumes recovery of all runoff water, continuation of underirrigation practices and areal cropping distribution (table 3) existing in 1977-1979, and no change in drainage volume. Other estimates, based on meeting crop ET and leaching requirements, are lower. Assuming an on-farm delivery of 3.00 km^3/y and 5 percent runoff, recoverable water ranges from −0.01 to 0.19 km^3/y without and with recycling drainage water. The corresponding numbers for no runoff component would be 0.14 and 0.33 km^3/y. Runoff could be reduced to zero, in principle, if each field had a pumpback system. Cost estimates of pumpback systems range from \$6 to \$20 per 100 m^3 (California Department of Water Resources, Southern District 1981). Since water costs are currently about \$6 per 1000 m^3, current economic incentives to install pumpback systems are small.

Other recoverable losses (California Department of Water Resources, Southern District 1981) include canal spills (0.06 km^3/y), seepage (0.04 km^3/y), and canal lining (0.14 km^3/y). Including these sources and assuming 5 percent runoff and the 1977-1979 areal crop distribution, the total potential recoverable water from IID operations within the Imperial Valley would range from 0.23 to about 0.43 km^3/y. Without runoff the corresponding numbers would be 0.38 and 0.57 km^3/y. These numbers bracket the eventual reduction in Colorado River water available to California, 0.5 km^3/y. Consequently, the results from this study indicate water savings from both on-farm and IID operations would be required to offset water diversions by the Central Arizona Project.

Potential users of saved water. An irrigatable area of 40,000 ha exists on the west mesa of the Imperial Valley with a water requirement of about 0.60 km^3/y. Coachella Valley could use 0.21 km^3/y to irrigate an additional 15,000 ha. Both the Coachella and Imperial valleys have the same water rights to the Colorado River, and these are higher in priority than those assigned to coastal southern California.

A water exchange between IID and the Metropolitan Water District (MWD) may be legal (Stavins 1983) and is currently the subject of negotiation. Electrical capacity and energy represent the major portion of delivery costs by MWD from either the Colorado River or northern California. The energy required to deliver Colorado River water is about 1000 kilowatt hours less per 100 m^3 than that for northern California water (Stavins 1983).

Public law 96-375, passed in 1980, authorizes the Secretary of the Interior to determine the feasibility of obtaining 0.12 km^3/y "for existing and potential domestic water users along the Colorado River who do not hold water rights or whose rights are insufficient to meet their requirements (e.g., City of Needles)."

In summary the age of unlimited Colorado River water is slowly coming to an end. Although the current irrigation efficiency of IID is above average (Bureau of Reclamation, Lower Colorado Region 1983), there is room for improvement. In principle, potential water savings in IID during 1977-1979 resulting from reduced on-farm runoff and reduced conveyance losses could have equaled the maximum reduction in Colorado River diversion by California ($\sim$0.5 km^3/y) which will result when the Central Arizona Project is fully implemented.

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LITERATURE CITED

BUREAU OF RECLAMATION, LOWER COLORADO REGION
1983. Water conservation opportunities, Imperial Irrigation District, California. Hearing testimony. California Water Resource Control Board, Imperial Irrigation District Auditorium, El Centro, CA. Sept. 27-29.

CALIFORNIA DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT
1981. Use of water by Imperial Irrigation District. 209 pp. P.O. Box 6598, Los Angeles, CA 90055.

CHANG, A. C., R. W. SKAGGS, L. F. HERMSMEIER, and W. R. JOHNSTON
1983. Evaluation of a water management model for irrigated agriculture. Trans. ASAE 26:412-18, 422.

DONOVAN, T. J., and B. D. MEEK.
1983. Alfalfa response to irrigation treatment and environment. Agron. J. 75:461-64.

ERIE, L. J., O. F. French, and K. HARRIS
1965. Consumptive use of water by crops in Arizona. Univ. Ariz. Agric. Exp. Stn. Tech. Bull. No. 169, 44 pp.

HERMSMEIER, L. F.
1973. Shallow drain performance in a heavy soil. Trans. ASAE 16:92-94, 96.

KADDAH, M. T., and J. D. RHOADES
1976. Salt and water balance in Imperial Valley, California. Soil Sci. Soc. Am. J. 40:93-100.

LARSON, C. L., and L. F. HERMSMEIER
1958. Device for measuring pipe effluent. Agr. Eng. 39(5) 282-85, 287.

LETEY, J., H. J. VAUX, JR., M. YITAYEW, E. FEINERMAN, D. HANDLEY, and P. HASH
1983. An evaluation of water duties for California Agriculture. Project report, Agreement 2-043-0300-0. California State Water Resources.

LONKERD, W. E., C. F. EHLIG, and T. J. DONOVAN
1979. Salinity profiles and leaching fractions for slowly permeable irrigated field soils. Soil Sci. Soc. Am. J. 43:287-89.

MAAS, E. V., and G. J. HOFFMAN
1977. Crop salt tolerance—current assessment. J. Irrig. and Drainage Div. ASCE 103 (IR2):115-34.

MacGILLIVRAY, N. A.
1980. Estimated crop evapotranspiration in the Imperial Valley, California. Appendix A in Inouye, D. (undated), Crop water requirements, Imperial Valley. Draft Technical Information. Record Study Code No. 1489-23-D-1. California State Water Resources, Southern District Planning Branch.

OSTER, J. D., and J. D. RHOADES
1975. Calculated drainage water compositions and salt burdens resulting from irrigation with river waters in the western United States. J. Environ. Qual. 4:73-79.

RHOADES, J. D.
1982. Reclamation and management of salt-affected soils after drainage. Proc. of the First Annual Western Provincial Conf. Rationalization of Water and Soil Res. and Management. Lethbridge, Alberta, Canada, Nov. 29-Dec. 2.

ROBINSON, F. E., and J. N. LUTHIN
1968. Comparison of three commercial drain tiles in a heavy clay soil of the Imperial Valley. Calif. Agric. Vol. 22, 8:10-11.

STAVINS, R.
1983. Trading conservation investments for water: A proposal for the Metropolitan Water District of Southern California to obtain additional Colorado River water by financing water conservation investments for the Imperial Irrigation District. Environmental Defense Fund, Inc., 2606 Dwight Way, Berkeley, CA 94704. 198 pp.

ZIMMERMAN, R. P.
1981. Soil survey of Imperial County, California, Imperial Valley area. USDA Soil Cons. Serv. in cooperation with Univ. of Calif. Agric. Exp. Stn. and IID.

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