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IMPERIAL IRRIGATION DISTRICT EFFICIENCY CONSERVATION DEFINITE PLAN: ON-FARM CONSERVATION OPPORTUNITIES AND COSTS

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ABSTRACT

Water use in the West is changing, and nowhere is that being felt more acutely than in the Imperial Irrigation District (IID), a 450,000-acre district in Southern California where longstanding agricultural water users are under intense pressure to transfer water to the region's ever-thirsty and ever-expanding urban areas. Four years ago, the District agreed to launch a massive conservation program that would free up roughly 10 percent of its water for transfer to San Diego and others. The heart of the agreement called for IID to generate more than 300,000 acre-feet annually through a combination of District and voluntary on-farm efficiency conservation savings. In 2007, IID completed their Efficiency Conservation Definite Plan (Definite Plan) that outlined strategies for both delivery system and on-farm water savings. This paper, one of seven in this conference detailing the findings of the Definite Plan, addresses on-farm conservation.

On-farm conservation opportunities were evaluated by defining conservation families, which are made up of individual seasons for unique fields with similar crops, soils, and irrigation methods. Members of each conservation family are expected to respond similarly when incentives for conservation are offered. Sets of applicable conservation measures were identified for each conservation family. Incremental costs of implementing conservation measures were estimated for each field and crop season uniquely. The change in water deliveries resulting from implementation of each applicable conservation measure for each field and crop season was estimated based on the characteristics of the measure and the historical potentially conservable water. The resulting set of applicable conservation measures, projected costs, and estimated water savings for each field and season were used to simulate grower responses to a variety of incentive offerings under a voluntary conservation program.

Over 100,000 unique field-seasons from the 1998 to 2005 water years were evaluated. Typical net implementation costs ranged from $35 per acre per year for management based conservation measures to more than $800 per acre per year for capital-intensive

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conservation measures with pressurized irrigation. Typical savings ranged from zero acre-feet per acre per year for field-seasons with historically high performance to more than 1.5 acre-feet per acre per year for capital-intensive conservation measures on fields with historically low performance. The substantial variability in implementation costs and water savings among field-seasons results in a wide range of implementation costs per acre-foot conserved, which has important implications on the design of incentives for on-farm conservation.

OVERVIEW

Water use in the West is changing, and nowhere is that being felt more acutely than in the Imperial Irrigation District, a 450,000-acre district in Southern California where longstanding agricultural water users are under intense pressure to transfer water to the region's ever-thirsty and ever-expanding urban areas. Four years ago, the District agreed to launch a massive conservation program that would conserve about 10 percent of its water for transfer to San Diego and others. The heart of the agreement called for the District to generate more than 300,000 acre-feet annually through a combination of District and voluntary on-farm efficiency conservation savings. In 2007, IID completed their Efficiency Conservation Definite Plan (Definite Plan) that outlined strategies for both delivery system and on-farm water savings. This paper, one of seven detailing the findings of the Definite Plan, addresses on-farm conservation.

On-farm water conservation, along with conservation from improvements to the delivery system and its operation, will represent a major component of the water conserved as part of the Definite Plan. Imperial Valley growers will need to collectively conserve at least 130,000 acre-feet and potentially a much larger share of the total needed to satisfy the transfer agreement. Conserved water will be generated through implementation of conservation measures rather than through decreased consumptive use (fallowing), with the net effect of maintaining or increasing agricultural production.

Historical cropping and water use data were compiled and used to evaluate on-farm conservation opportunities and costs. The period of analysis was selected as water years (WY) 1998 through 2005 to provide a baseline data set. A "water year" consists of the period from October 1 through September 30. Because the dataset evaluated contained some information for crops planted prior to October 1998 or harvested after September 2005, the dataset represents approximately 8.3 water years.

On-farm conservation opportunities were evaluated by first defining conservation families, which are made up of individual seasons for unique fields with similar crops, soils, and irrigation methods. Members of each conservation family are expected to respond similarly when incentives for conservation are offered. Water delivery and calculated crop evapotranspiration (ET) were used to estimate the portion of applied water not consumed and potentially conservable for each field and season in each conservation family. The applied water not consumed as ET was further divided into quantities leaving the field as tailwater (surface runoff) and tilewater (deep percolation).

Sets of applicable conservation measures were identified for each conservation family. Incremental costs of implementing conservation measures were estimated uniquely for each field and crop season based primarily on the field size, crop, and season length. The projected change in water deliveries resulting from implementation of each applicable conservation measure for each field and crop season was estimated based on the characteristics of the measure and the historical potentially conservable water. The resulting set of applicable conservation measures, projected costs, and estimated water savings for each field and season were used to simulate grower responses to a variety of incentive offerings under a voluntary conservation program.

CONSERVATION FAMILIES

As described previously, conservation families consisting of individual seasons for unique fields were developed based on similar crops, soils, and irrigation methods, based on the expectation that similar field-crop seasons will respond similarly when offered conservation incentives. This section describes the development of irrigation method families, soil families, and crop families. The combination of these families into conservation families is also discussed.

Irrigation Method Families

The most common irrigation methods used in IID are flat (graded border), row (furrow), sprinkle, drip, and gated pipe. A very small number of fields are also irrigated using level basins. For a given field and season, more than one irrigation method may be used. For example, many crops are established using sprinkle irrigation, which is then followed by surface irrigation methods (row or flat).

For purposes of defining the irrigation method families, five primary irrigation methods were defined: Flat (F), Row (R), Sprinkle (S), Drip (D), and Combination (C). The combination method is used to classify the irrigation method for field-seasons where between 10% and 70% of the seasonal volume applied is applied with sprinklers and between 30% and 90% is applied using row irrigation or gated pipe. The drip irrigation method family includes all forms of micro irrigation. The row method family includes gated pipe in addition to conventional furrow irrigation.

The total acre-feet of deliveries and percentage of water delivered over the period of analysis for each irrigation method family are provided in Table 1.

Table 1. Summary of Total Deliveries by Irrigation Method Family (1998 through 2005).

Method Code	Method Description	Total Deliveries	
		Ac-Ft	%
C	Combination of Sprinkle and Row	1,294,255	6.2%
D	Drip	208,494	1.0%
F	Flat (Graded Border)	12,551,601	59.9%
R	Row (graded Furrow)	6,637,836	31.7%
S	Sprinkle	257,655	1.2%
	Total	20,949,841	100.0%

Soil Families

Irrigation performance and management opportunities for a given crop and method vary in part due to differences in soil physical characteristics. Based on a review of available soils data and discussions with local growers, Imperial Valley soils were grouped into three classes (or families). The classes were based on permeability (saturated hydraulic conductivity) and cracking potential (linear extensibility percentage). The three classes are light soils (L), heavy soils (H), and heavy-cracking soils (C). Soil characteristics were quantified based on the Natural Resources Conservation Service State Soil Survey Geographic Database (SSURGO), which contains detailed spatial and tabular data describing the soils of the Imperial Valley as well as many other regions.

Soils are believed to have a strong influence on the absolute and relative magnitude of tailwater and tilewater production, impacting irrigation performance and the potential for water conservation. On light soils, infiltration continues at substantial rates after ponding and deep percolation losses may occur. On heavy non-cracking soils, infiltration is limited by low permeability and by the lack of cracks that could otherwise result in preferential flow. On heavy-cracking soils, infiltration occurs primarily through surface cracks that seal shortly after ponding. The choice of appropriate conservation measures and the resulting impact on losses varies substantially among soil families.

The total acre-feet of deliveries and percentages of the total water delivered over the period of analysis for each soil family are provided in Table 2.

Table 2. Summary of Total Deliveries by Soil Family (1998 through 2005).

Soil Code	Soil Type Description	Total Deliveries	
		Ac-Ft	%
C	Heavy-Cracking	15,797,127	75.4%
H	Heavy Non-Cracking	2,445,900	11.7%
L	Light Non-Cracking	2,706,814	12.9%
	Total	20,949,841	100.0%

Crop Families

A diverse mix of crops is grown in the Imperial Valley including alfalfa, Bermuda grass (for hay), Sudan, sugar beets, and wheat as well as a variety of truck and horticultural crops including carrots, onions, lettuce, asparagus, broccoli, cantaloupes, sweet corn, lemons, grapefruit, and date palms to name a few. The Imperial Irrigation District maintains a list of over 170 unique codes used to track cropping and other water uses such as leaching of salts from the root zone.

IID crops were grouped into nine general families based on anticipated responses to conservation incentives. Except as influenced by soil and irrigation methods, growers of crops within a crop family are expected to incur similar production costs, exhibit similar water ordering behaviors, and produce similar fractions of tailwater and tile water for any given level of performance. The nine crop families and corresponding total deliveries over the period of analysis are listed in Table 3.

Table 3. Summary of Total Deliveries by Crop Family (1998 through 2005).

Crop Code	Crop Type Description	Total Deliveries	
		Ac-Ft	%
AM	Alfalfa, Mature	5,789,195	27.6%
AN	Alfalfa, New (1st year)	3,299,804	15.8%
BM	Bermuda, Mature	2,458,997	11.7%
BN	Bermuda, New (1st year)	723,757	3.5%
FD	Field Crops	2,070,956	9.9%
LG	Leaching (to remove salinity)	1,511,651	7.2%
SB	Sugar Beets	1,140,703	5.4%
VG	Truck and Horticultural Crops	2,817,148	13.4%
WT	Wheat	1,137,630	5.4%
	Total	20,949,841	100.0%

Note that although sugar beets and wheat may be considered field crops, they are grown extensively enough in the Imperial Valley that they were assigned to unique crop families. The field crops family consists primarily of Sudan and cotton.

Conservation Families

Conservation families were formed from unique combinations of irrigation method soil, and crop families. Based on the 5 method families, 3 soil families, and 9 crop families, there are 135 (5 x 3 x 9) unique possibilities.

Conservation families are formed to create groups of crop season data representing existing fields and recent past conditions in the Imperial Valley. Some combinations of method, soil, and crop are not typically or have never been observed in the Imperial Valley. Thus, for example, a conservation family was not created for sprinkle-irrigated Bermuda on either light, heavy, or cracking soils. Following the implementation of conservation measures in the future, there may be a substantial number of sprinkle-irrigated Bermuda fields; however, historically there have been very few such fields in the Valley.

Based on observed patterns of cropping with respect to soils and irrigation methods, 54 unique conservation families were formed for analysis including 21 flat-irrigated families, 18 row-irrigated families, and 15 combination-, drip-, and sprinkle-irrigated families. The top-twenty conservation families based on total deliveries during the period of analysis are listed in Table 4. The water delivered to these twenty families represents more than 83% of all recorded agricultural water deliveries during the period of analysis.

Table 4. Summary of Deliveries for Top-Twenty Conservation Families (1998 through 2005).

Rank	Family Code	Family Description	Total Deliveries	
			Ac-Ft	%[1]
1	FCAM	Flat-Irrigated Mature Alfalfa on Cracking Soils	2,599,789	12.4%
2	FCBM	Flat-Irrigated Mature Bermuda on Cracking Soils	2,250,048	10.7%
3	RCAM	Row-Irrigated Mature Alfalfa on Cracking Soils	1,833,863	8.8%
4	FCAN	Flat-Irrigated New Alfalfa on Cracking Soils	1,290,091	6.2%
5	FCFD	Flat-Irrigated Field Crops on Cracking Soils	1,167,775	5.6%
6	RCAN	Row-Irrigated New Alfalfa on Cracking Soils	1,121,197	5.4%
7	RCSB	Row-Irrigated Sugar Beets on Cracking Soils	1,016,674	4.9%
8	FCWT	Flat-Irrigated Wheat on Cracking Soils	897,764	4.3%
9	FCLG	Flat-Irrigated Leaching on Cracking Soils	851,663	4.1%
10	RCVG	Row-Irrigated Truck Crops on Cracking Soils	720,301	3.4%
11	CCVG	Combination-Irrigated Truck Crops on Cracking Soils	676,271	3.2%
12	FCBN	Flat-Irrigated New Bermuda on Cracking Soils	576,328	2.8%
13	FLAM	Flat-Irrigated Mature Alfalfa on Light Soils	408,256	1.9%
14	FHAM	Flat-Irrigated Mature Alfalfa on Heavy Soils	373,858	1.8%
15	RCFD	Row-Irrigated Field Crops on Cracking Soils	324,348	1.5%
16	RLVG	Row-Irrigated Truck Crops on Light Soils	314,183	1.5%
17	CLVG	Combination-Irrigated Truck Crops on Light Soils	308,276	1.5%
18	RHAM	Row-Irrigated Mature Alfalfa on Heavy Soils	250,386	1.2%
19	FLFD	Flat-Irrigated Field Crops on Light Soils	238,592	1.1%
20	FLLG	Flat-Irrigated Leaching on Light Soils	222,591	1.1%
Total			17,442,254	83.3%

1. Refers to percent of total deliveries (20,949,841 ac-ft) during study period.

HISTORICAL ON-FARM WATER USE AND POTENTIALLY CONSERVABLE WATER

A major element of the Definite Plan on-farm analyses involved assessing the potential water savings that could be achieved if conservation measures were adopted by growers in response to financial incentives to conserve water. This was approached through the development of water balances for individual fields and crop seasons, or "field-seasons," which enabled characterization of historical water delivery, crop water use, and water discharged as tailwater and tilewater. Historical field-season water balances over the analysis period established baseline water use, providing a basis for estimating potential water savings, field by field, and season by season.

Figure 1 shows the primary flow paths used for the field-season water balances, which were delivered water, precipitation, crop evapotranspiration (ET), surface runoff (tailwater), and deep percolation (tilewater). As shown in Figure 1, the effects of rain were accounted for in the water balance for each field-season. As a result, the analysis focused on characterizing the destination of delivered water only, quantifying the ET, tailwater, and tilewater derived from irrigation deliveries. Rainfall was accounted for using a daily root zone water balance model based on daily weather data along with crop and soil information for each field-season. Field seasons were parameterized in the model based on crop, planting and harvest dates, and soil type.

Delivered Water

Historical water delivery data were obtained from databases maintained by IID and summed for each field-season. Field-seasons were limited to 365 days in length, so that a given field could have a series of field-seasons for the same crop across years—for example in the case of perennial crops such as citrus or alfalfa.

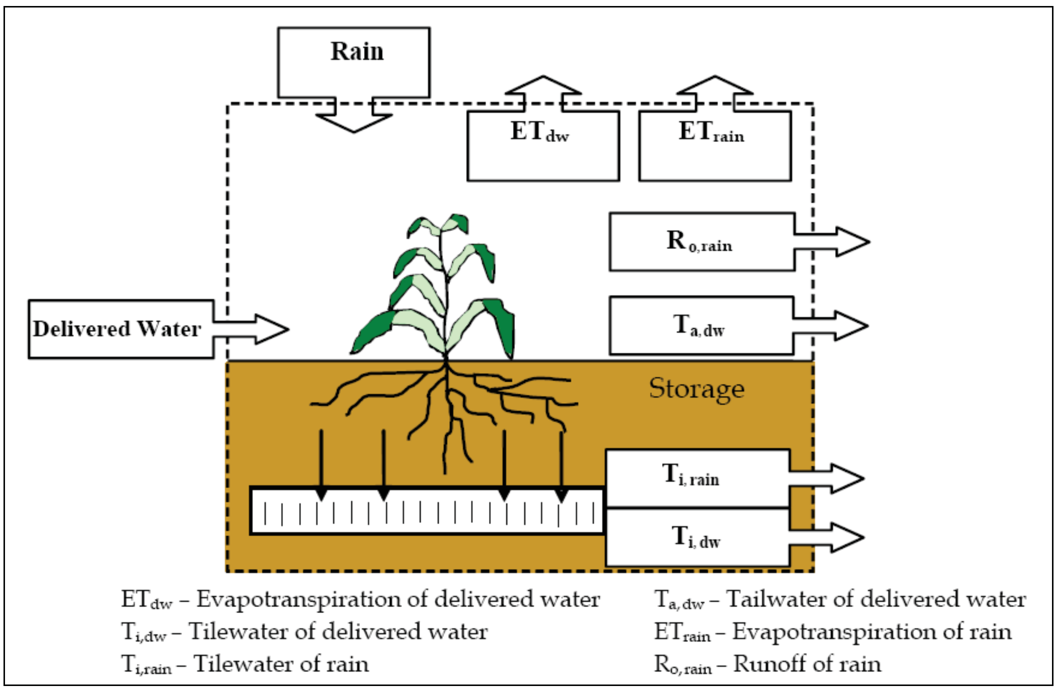


Figure 1. Conceptual Diagram of On-Farm Flow Paths.

Crop Evapotranspiration

Crop evapotranspiration (ET) is typically the largest outflow path in the field-season water balance. Crop ET was estimated by applying the daily water balance model to estimated potential ET (ET_p) based on the dual crop coefficient approach described in

FAO Irrigation and Drainage Paper No. 56 (Allen et al, 1998). Based on the daily model, total ET_p was disaggregated into ET derived from delivered water and ET derived from precipitation.

Estimates of ET_p are representative of ideal or nearly ideal growing conditions and may lead to overestimates of actual crop ET. In order to evaluate differences between actual ET under field conditions and potential ET from the crop coefficient approach, an independent analysis of ET was performed using the Surface Energy Balance Algorithm for Land (SEBAL®) on a monthly time step for the 1998 water year. The SEBAL model calculated actual ET (ET_a) based on information contained in LandSat Satellite imagery for each approximately ¼-acre image pixel (30 m by 30 m) in IID. The results of the SEBAL analysis were compared to potential ET from the FAO56 approach, and adjustment factors were developed to correct estimated ET_p to ET_a under Imperial Valley conditions. The resulting "inference factors" are the ratio of ET_a to ET_p for individual conservation families as presented in Table 5. Note that where the second letter of the family code is "A," the results represent the combination of all soil types for a particular crop and irrigation method combination.

SEBAL ET results were validated by an independent water balance performed by Keller-Bliesner Engineering (2007). Total inflows and outflows for IID were quantified for the 1998 water year (excluding ET), and used to solve for ET as a closure term. Total crop ET was estimated as the total consumptive use minus the sum of canal evaporation; municipal and industrial consumption; and ET from other sources including drains, rivers and other non-ag land. For the cropped area, the total ET estimated using SEBAL was 1,838.6 thousand acre-feet (kaf) compared to 1,827.0 kaf based on water balance results, agreeing within 1%. The SEBAL results fell well within the water balance 95 percent confidence interval for crop ET of 5.1%.

Consumptive Use Fraction

The Consumptive Use Fraction (CUF) was calculated for each field-season in the period of analysis based on the estimated actual crop ET, net of precipitation, divided by the total IID recorded deliveries during the season. The CUF provides a means of normalizing water conservation potential among field-seasons. Within a given conservation family, a field-season with a low CUF will have relatively more potential for conservation than a field-season with a high CUF if the same conservation measure is implemented on both fields.

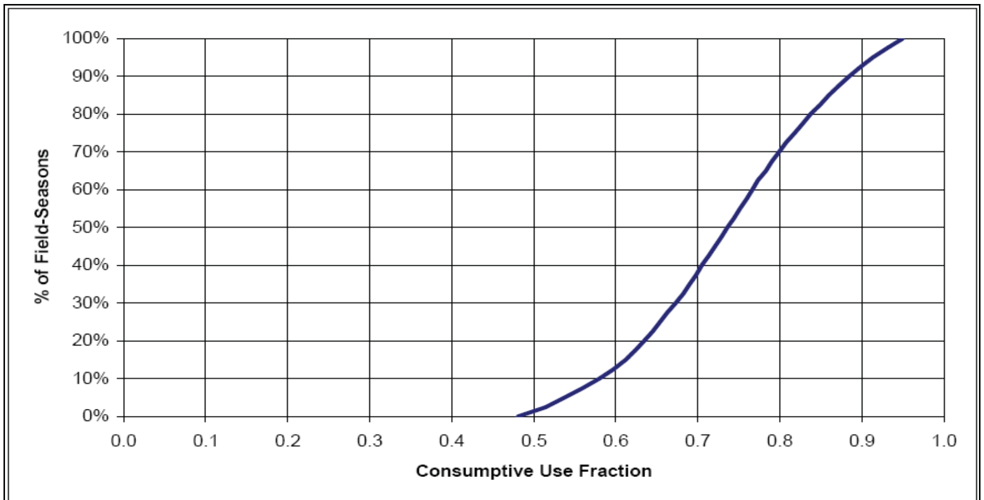
Table 5. Inference Factors Used to Estimate Actual ET from Potential ET.

Family Code	Field-Seasons	Season-Acres	ET, Acre-Feet SEBAL (ET_a)	FAO56 (ET_p)	Inference Factor, f
CAVG	76	5,108	5,589	7,751	0.72
DAVG	12	858	1,127	1,624	0.69
FABM	185	16,268	67,244	85,206	0.79
FABN	58	5,038	9,242	10,203	0.91
FAWT	283	23,789	37,260	44,013	0.85
FCAM	356	24,902	105,075	124,873	0.84
FCAN	147	10,440	7,024	8,308	0.85
FCFD	125	9,455	20,358	19,347	1.05
FHAM	51	3,050	12,338	14,308	0.86
FHAN	23	1,309	1,136	1,372	0.83
FHFD	16	1,067	2,821	2,638	1.07
FLAM	60	3,263	12,461	14,650	0.85
FLAN	27	1,386	887	1,175	0.75
FLFD	23	1,193	2,716	2,533	1.07
RAAM	184	17,007	68,660	78,584	0.87
RAAN	43	3,991	2,540	3,120	0.81
RAFD	51	3,778	6,324	6,989	0.90
RASB	143	13,066	22,943	25,866	0.89
RCVG	73	5,147	9,551	11,513	0.83
RHVG	14	705	1,282	1,429	0.90
RLVG	23	1,083	1,253	1,535	0.82
SAAN	88	8,884	6,520	7,341	0.89
SAVG	60	4,889	4,069	5,397	0.75
All	2121	165,676	408,420	479,775	0.85

When CUF values for each field-season were calculated from available delivery data, it was found that some field-seasons had values that appeared to be greater than or less than practical bounds. For example, a CUF value greater than one indicates that more water was returned to the atmosphere as ET than was delivered to the field. Additionally, a CUF value less than 0.25 suggests that the amount of water delivered to the field was in excess of four times that amount used by the crop. In order to reduce potential inaccuracies, a series of quality control checks was applied when computing the CUF values. These included a filter to eliminate abnormally short or long seasons and a filter to eliminate fields where more than one field is served by a single gate, which presents challenges to the District in accurately accounting for delivered water. Finally, a set of practical bounds was established for CUF values of each family to identify field-seasons with an abnormally low or high CUF.

Based on the quality control procedures, a set of field-seasons passing the checks was identified for each conservation family. These field-seasons were then used to develop representative CUF distributions for the population of field seasons within each family.

As an example, the resulting cumulative CUF distribution for flat-irrigated mature alfalfa on cracking soils (FCAM) is provided in Figure 2.



number of field seasons:	6931	mean CUF:	0.73
minimum CUF:	0.48	median CUF:	0.74
maximum CUF:	0.95	standard deviation:	0.11

Figure 2. Cumulative CUF Distribution and Summary Statistics for Conservation Family FCAM (Flat-Irrigated Mature Alfalfa on Cracking Soils) (1998 through 2005).

The remaining field seasons not passing the quality control checks were randomly assigned a CUF value so that they would fall within the representative distribution. Then, the ET associated with the field-season was recalculated based on the delivered water records and the CUF values to maintain closure of the water balance. Delivered water values were not adjusted because of the reliance of other quality control analyses related to the IID distribution system on the delivered water records for individual field-seasons.

Tailwater (Surface Runoff) Production

Tailwater production for individual field-seasons was estimated by developing empirical relationships between CUF values and tailwater fractions (ratio of tailwater production to total delivered water) developed from a database of irrigation events. These included a total of more than 1,300 irrigation events during which tailwater production amounts were measured along with the water delivery to the field.

For each unique combination of surface irrigation method family (flat and row) and soil family (light, heavy, and heavy-cracking), the distribution of tailwater fractions was assembled from the monitored events. Additionally, the distribution of CUF values for each method-soil family was generated from the set of fields used to develop the ET inference factors for the 1998 water year. It was assumed that fields within a soil-method family with the least tailwater production tend to have the greatest CUF, and vice-versa. Then, relationships between tailwater fraction and CUF were developed by pairing the 90th percentile CUF with the 10th percentile tailwater fraction, the 80th percentile CUF with the 20th percentile tailwater fraction, and so on. Relationships developed for flat- and row-irrigated soil-method families are presented in Figures 3.a and 3.b, respectively.

The relationship for row-irrigated fields on heavy soils was developed based on the results for flat-irrigated fields on heavy soils due to only a limited set of empirical data for row-irrigated fields on heavy soils.

Similar relationships were developed for sprinkle- and combination-irrigated families based on collective professional judgment by the project team. It was assumed that drip irrigation produces no tailwater.

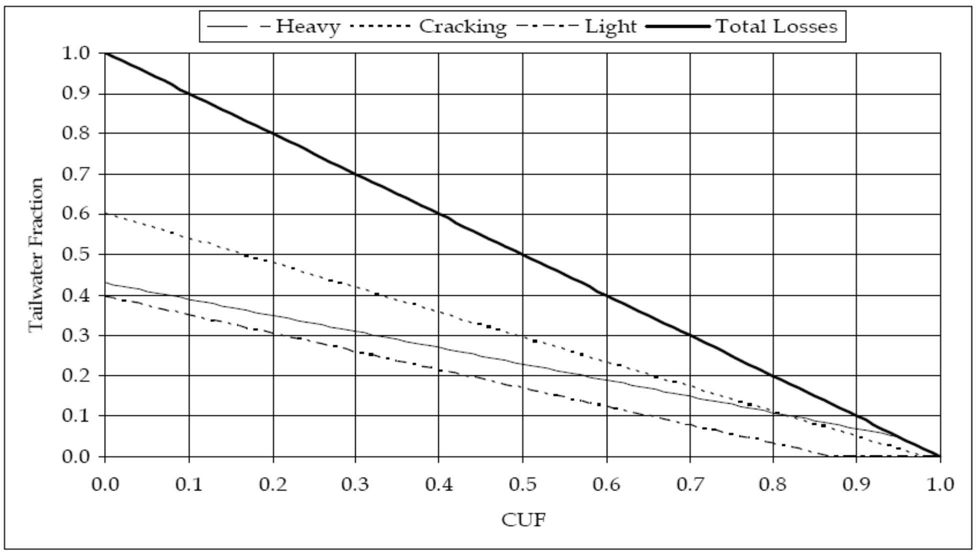


Figure 3.a. Relationship of Tailwater Fraction to CUF for Flat-Irrigated Soil-Method Families.

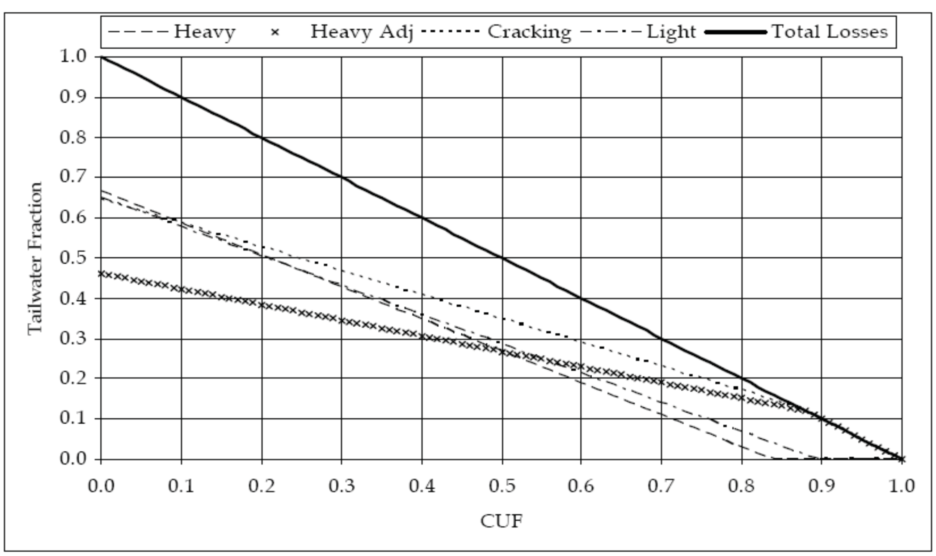


Figure 3.b. Relationship of Tailwater Fraction to CUF for Row-Irrigated Soil-Method Families.

Tilewater (Deep Percolation) Production

Tilewater production as a fraction of deliveries was estimated for each soil-method family based on the CUF-tailwater relationships developed from the tailwater monitoring data. It was assumed that both the head ditch seepage and evaporation are relatively small on-farm flow paths, and the change in soil moisture storage is relatively small across the season. Therefore, the fraction of deliveries that leaves the field as tailwater and tilewater must equal the fraction of deliveries that are not consumed by crop ET. Thus, the tilewater fraction is expressed by:

$$f_{Ti} = 1 - (CUF + f_{Ta}) \qquad [1]$$

where f_{Ti} is the tilewater fraction and f_{Ta} is the tailwater fraction. The volumetric tilewater production is simply the delivered water volume multiplied by the tilewater fraction.

Summary

The on-farm water balance construct (Figure 1) was used in conjunction with available data and models to develop estimates of delivered water, crop evapotranspiration, tailwater, and tilewater for more than 100,000 individual field-seasons within the period of analysis. These water balances provide a basis for estimating the impacts of implementing conservation measures at the field-scale. A summary of the results of the historical on-farm water use analysis for the top twenty conservation families is provided in Table 6.

ON-FARM CONSERVATION MEASURES AND COSTS

Conservation measures (CMs) likely to be considered when water conservation incentives are offered were identified through consultation with Imperial Valley growers. The range of potential measures identified includes measures that are currently in use in the Valley as well as those that may be considered in the future. A subset of CMs was selected for detailed characterization of costs and water savings. CMs were selected to provide a representative set for analysis. The selection was made based on grower interest, applicability, cost, potential water savings, and delivery system impacts. In program implementation, the expectation is that growers will be allowed wide latitude in selecting the most cost effective measures for their operations. A list of the conservation measures included in the analysis is provided in Table 7.

The applicability of a given CM to a given conservation family requires that the CM be compatible with the irrigation method, soil, and crop present. The applicability of each CM to each conservation family was evaluated by considering any constraints limiting the ability to implement the measure or its effectiveness.

Table 6. Summary of Historical Delivered Water, Crop ET, Tailwater, and Tilwater for Top Twenty Conservation Families (1998 through 2005).

Family Code	Total Deliveries (Ac-Ft)	Crop Water Use (ET_{aw}) Total (Ac-Ft)	Crop Water Use (ET_{aw}) Fraction of Deliveries	Tailwater Total (Ac-Ft)	Tailwater Fraction of Deliveries	Tilewater Total (Ac-Ft)	Tilewater Fraction of Deliveries
FCAM	2,599,789	1,896,599	0.73	400,073	0.15	303,117	0.12
FCBM	2,250,048	1,582,827	0.70	382,223	0.17	284,998	0.13
RCAM	1,833,863	1,360,257	0.74	373,330	0.20	100,276	0.05
FCAN	1,290,091	965,706	0.75	183,461	0.14	140,924	0.11
FCFD	1,167,775	790,237	0.68	217,547	0.19	159,991	0.14
RCAN	1,121,197	829,908	0.74	229,459	0.20	61,830	0.06
RCSB	1,016,674	734,380	0.72	219,076	0.22	63,218	0.06
FCWT	897,764	613,563	0.68	163,539	0.18	120,662	0.13
FCLG	851,663	237,252	0.28	42,583	0.05	571,828	0.67
RCVG	676,271	420,919	0.62	214,878	0.32	40,474	0.06
FCBN	651,274	460,464	0.71	109,212	0.17	81,598	0.13
CCVG	576,328	438,701	0.76	53,346	0.09	84,281	0.15
FLAM	576,328	369,522	0.64	60,967	0.11	145,839	0.25
FHAM	408,256	296,358	0.73	56,758	0.14	55,140	0.14
RCFD	324,348	216,195	0.67	80,639	0.25	27,514	0.08
RLVG	314,183	167,201	0.53	82,586	0.26	64,396	0.20
CLVG	308,276	192,569	0.62	28,836	0.09	86,871	0.28
RHAM	250,386	177,889	0.71	55,812	0.22	16,685	0.07
FLFD	238,592	157,048	0.66	23,405	0.10	58,139	0.24
FLLG	222,591	33,322	0.15	11,130	0.05	178,139	0.80
Total[1]	17,575,697	11,940,917	0.68	2,988,860	0.17	2,645,920	0.15
Total[2]	20,949,841	13,880,037	0.66	3,439,026	0.16	3,630,778	0.17

1. Corresponds to top twenty families only.
2. Corresponds to all families

Table 7. Potential Conservation Measures Included Explicitly in Analyses.

Conservation Measure	CM Code
Center Pivot Irrigation	CPI
Level Basin Irrigation	LVL
Micro Irrigation	DRP
Minor Management and Physical Improvements	MNR
Scientific Irrigation Scheduling	SIS
Scientific Irrigation Scheduling and Event Management	SEM
Sprinkle Irrigation	SPR
Tailwater Recovery Systems with Reservoirs	TRS
Tailwater Recovery Systems without Reservoirs	TRP

Incremental Implementation Costs

The net on-farm costs of implementing selected CMs were estimated by considering capital costs, maintenance costs, and operations costs as well as additional costs and benefits of CM adoption. In all cases, the cost of CM adoption was estimated as an incremental cost above existing irrigation costs. Incremental costs were calculated as the difference between the total implementation cost and the current cost of irrigation, including consideration of additional management time needed to implement each CM. Cost estimates were developed through consultation with irrigation equipment suppliers, on-farm construction contractors, and Imperial Valley growers. On-farm CM demonstrations provided a valuable source of input from growers regarding actual implementation costs. Additional information describing the studies may be found in Brooks et al. (2008). Budgets were developed across a range of field sizes and crop types to develop cost functions for estimating unique costs for individual combinations of CM, conservation family, and field size. Each cost function consists of annual capital and maintenance costs, expressed as a base cost per field plus an additional cost per acre along with seasonal operating costs, expressed as a base cost per field plus an additional cost per acre.

Example cost functions for scientific irrigation scheduling and tailwater recovery systems with reservoirs are shown in Figures 4 and 5, respectively. In the case of irrigation scheduling, the costs are shown as seasonal operating costs for different crops, which vary due to differences in irrigation practices and season length. For tailwater recovery systems, the costs are shown as annual capital and maintenance costs that vary for different reservoir sizes.

The point costs in Figure 5 represent individual budgets developed for alterative tailwater recovery system (TRS) configurations. In all, a total of 145 unique CM implementation budgets were developed and used to estimate the CM cost functions.

Additional costs and benefits of CM adoption included yield changes, fertilizer cost savings, and reduced water costs. The cost (or benefit) of yield changes was estimated based on anticipated changes in crop ET either due to changes in the cropped area (i.e.,

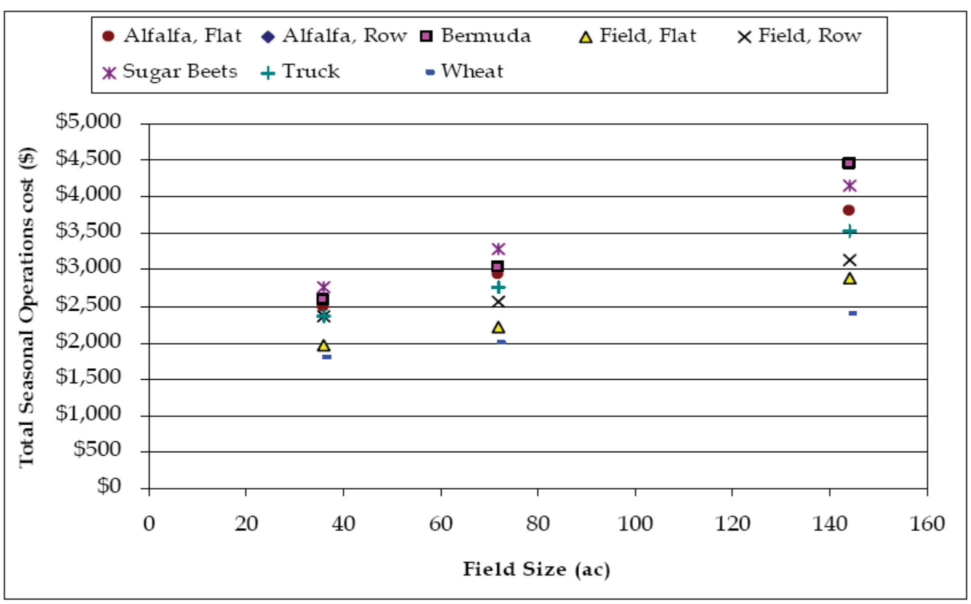


Figure 4. Operations Costs by Crop Type and Field Size for Scientific Irrigation Scheduling.

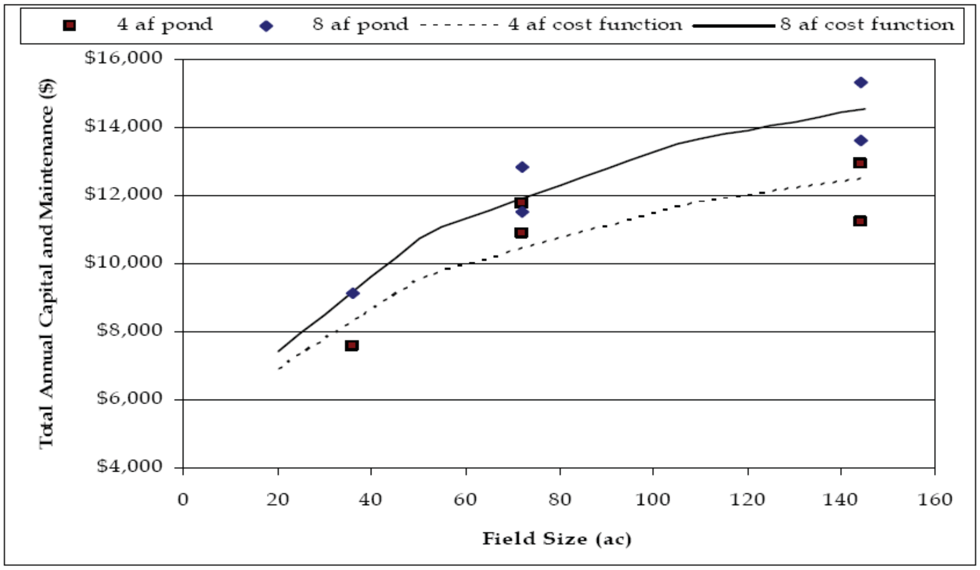


Figure 5. Capital and Maintenance Costs for Tailwater Recovery Systems with Reservoirs.

crop area lost for installation of a reservoir) or due to changes in crop vigor (i.e., resulting from more uniform irrigation). The change in crop ET was translated into a change in returns, net of harvest costs, estimated from Imperial Valley Agricultural Commissioner crop reports and Cooperative Extension cost and return studies. For drip and sprinkle irrigation, potential yield increases were estimated empirically based on historical drip and sprinkle adoption rates in the Imperial Valley.

Fertilizer savings for each CM-conservation family combination were estimated on a seasonal basis from aggregate water savings estimates, and in-season fertilizer cost estimates were made from Cooperative Extension cost-return studies. It was assumed that reductions in losses (tailwater and tilewater) following CM adoption would result in proportional reductions in fertilizer losses for in-season applications.

Reduced water costs for each field-season were calculated as the product of the water rate (estimated to be $17 per acre-foot) and the estimated decrease in delivered water.

POTENTIAL ON-FARM WATER SAVINGS

Flow Path Impacts and Water Savings Characterization Framework

The IID water balance reveals that the main opportunity to save water on-farm is to reduce tailwater. For the large majority of IID soils, deep percolation (tilewater) is not excessively above leaching requirements. Exceptions include the roughly 10 percent of the irrigable area with light texture soils where deep percolation can easily occur or cracking soils where preferential flow through cracks below the root zone can occur.

Delivered water savings were estimated by developing estimates of the impact of CM adoption on the consumptive use fraction (CUF). Implementation of CMs by all members of a given conservation family would be expected to increase the overall CUF for the family by incrementally increasing the CUF of each field-season within the family. Additionally, members of a family would be expected to maintain rank following CM adoptions, so that a field-season with a relatively low CUF initially would remain a relatively low (though increased) CUF field following implementation. Finally, field-seasons with historically low performance are expected to experience increases in performance relative to the total potential for conservation that are less than for fields with historically greater performance. These assumptions were used to develop a rationale to estimate the increase in performance for individual field-seasons.

The change in the baseline CUF distribution for a conservation family resulting from implementation of an individual CM is based on two parameters. The first parameter, CUF_{max}, is the maximum expected baseline CUF for which a CM is expected to result in water savings. Field seasons that have a CUF above CUF_{max} prior to CM implementation are expected to have no change in the CUF following implementation. The second parameter, $CUF_{Typ,CM}$, is the estimated post-implementation median CUF for field-seasons with an initial CUF less than CUF_{max}. CUF values for individual field-seasons implementing a CM are estimated by shifting the baseline CUF value according to:

If: $CUF_{Base} \geq CUF_{max}$, then,

$$CUF_{CM} = CUF_{Base} \qquad [2.a]$$

Otherwise,

$$CUF_{CM} = CUF_{Base} + \left(\frac{CUF_{Typ,CM} - CUF_{med}}{CUF_{\max} - CUF_{med}} \right)^{\left(\frac{CUF_{med}}{CUF_{Base}} \right)} \left(CUF_{\max} - CUF_{Base} \right) \qquad [2.b]$$

Where: CUF_{CM} is the estimated field-season CUF following CM implementation; CUF_{Base} is the field-season CUF prior to CM implementation; and CUF_{med} is the median CUF for field-seasons with values below CUF_{max} prior to CM implementation.

Equation 2 was applied to each unique combination of field-season and applicable CM to estimate potential changes to the CUF (and delivered water) resulting from CM implementation.

The curve-shift parameters and resulting shifted CUF distribution are depicted graphically in Figure 6.

Water savings resulting from CM implementation were further partitioned into savings resulting from reduced water orders and savings resulting from adjustment of orders after the start of delivery. For adjustments made after the start of delivery, water turned back to the distribution system must be stored, or another destination must be found to deliver the water in order to prevent it from spilling from the system. Interactions between on-farm conservation and the delivery system are discussed in detail in Thoreson et al. (2008).

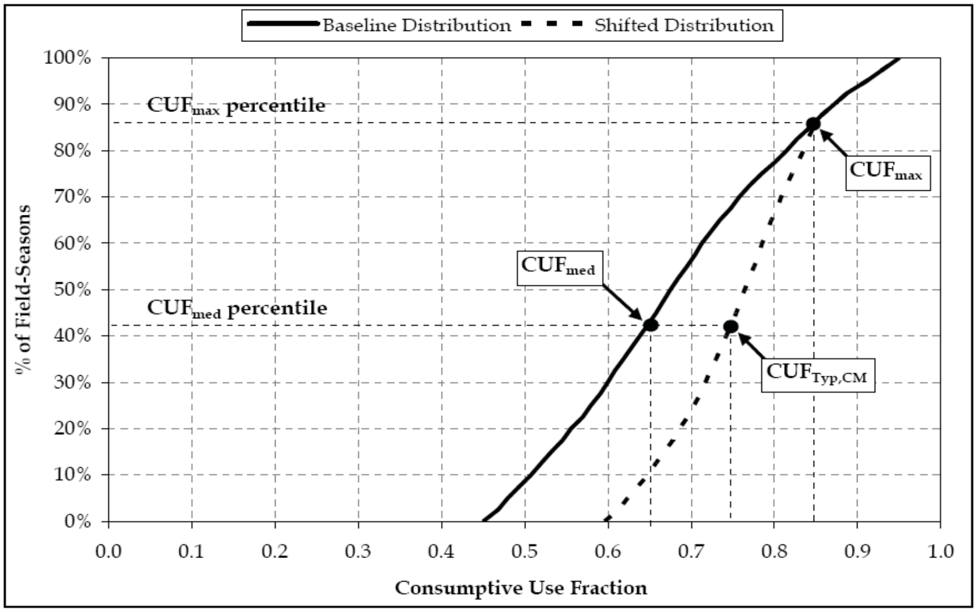


Figure 6. Example CUF Shift Parameters and Resulting Shift.

SUMMARY

Over 100,000 unique field-seasons from the 1998 to 2005 water years were assigned to conservation families based on expected similar response to incentives for adoption of conservation measures. For each field-season, a water balance was performed to estimate the amount of delivered water leaving the field as crop ET, tailwater, or tilewater. A performance indicator called the consumptive use fraction (CUF) was calculated for each field and used as a relative measure of conservation potential.

A set of representative conservation measures likely to be considered by growers under an incentive-based conservation program was identified. Each conservation measure was characterized with respect to its expected implementation costs and water savings. Implementation costs were calculated as the net cost of adoption, considering capital, maintenance, and operations costs along with incidental costs (or benefits) due to yield changes, fertilizer savings, and delivered water savings. Water savings for each unique combination of field-season and applicable CM were estimated by first estimating a change in the CUF resulting from its adoption, and then estimating the change in delivered water (after considering possible ET impacts).

A summary of the estimated typical range of costs and water savings for selected CMs on an annual basis is provided in Table 8. Cumulative distributions of the net implementation cost per acre-foot conserved for selected CMs are shown in Figure 7 for selected CMs.

Table 8. Estimated Ranges of Net Implementation Costs and Water Savings for Selected Conservation Measures.

Conservation Measure	Cost Range ($/acre)			Savings Range (acre-feet/acre)		
Scientific Irrigation Scheduling	$ 35	to	$ 135	0	to	0.5
Drip Irrigation	$ 395	to	$ 625	0	to	1.7
Sprinkle Irrigation	$ 624	to	$ 812	0	to	1.4
Tailwater Recovery Systems	$ 145	to	$ 442	0	to	1.5
Level Basin Irrigation	$ 180	to	$ 312	0	to	1.4

As shown in Figure 7, there is substantial variability in the implementation cost per acre-foot conserved among different field-seasons. This variability is due to differences in water savings and implementation costs among fields. As water savings approach zero, the unit cost of conservation skyrockets. The variability in implementation costs and water savings among field-seasons for different CMs has important implications to the design of incentives for on-farm conservation. The development of incentive approaches is discussed in detail in Hatchett et al. (2008).

The results of the on-farm analyses completed for the Definite Plan provide a data set of possible choices that could be made by growers for individual field-seasons when offered incentives for on-farm conservation. This data set allowed for the evaluation of alternative incentive structures as part of the planning process. Full documentation of the Definite Plan is available from the Imperial Irrigation District website at www.iid.com/Water/EfficiencyConservationProgram.

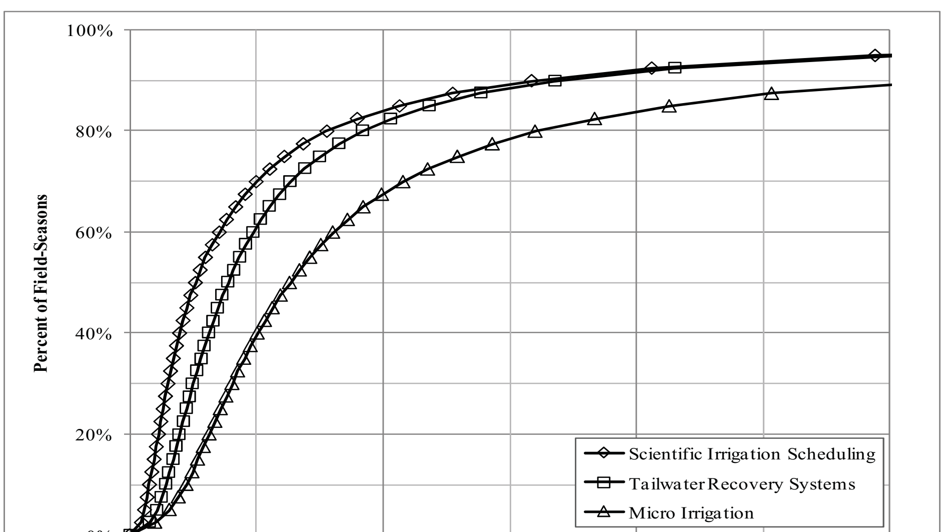


Figure 7. Cumulative Distributions of Costs per Acre-Foot Conserved for Selected Conservation Measures.

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