ESTIMATION OF POTENTIAL FOR MANAGEMENT-BASED PRACTICES TO MEET IID ON-FARM WATER CONSERVATION GOALS

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ABSTRACT

The Imperial Irrigation District of Southern California (IID) is embarking on an ambitious program to conserve 303,000 acre-feet per year for transfer to other Colorado River water users in California. Conservation will be achieved through a combination of system and on-farm improvements. On-farm conservation of approximately 200,000 acre-feet of water per year will be achieved through a voluntary program in which participants have the option to choose which conservation measures to implement on individual fields based on incentive offerings.

In 2007, IID completed the Efficiency Conservation Definite Plan (Definite Plan), which identifies likely components of the on-farm program, including expected on-farm conservation measure implementation by participants for varying incentive offerings. Expected increases in irrigation performance, reductions in farm deliveries, and corresponding implementation costs were estimated for each field for each season and compatible conservation measure.

Estimation of delivery changes was accomplished by modeling performance increases as a function of the crop, soil, and irrigation method at the field; the conservation measure selected; and the historical irrigation performance of the field. The model was developed, in part, based on simulations of surface irrigation performance across a range of inflow rates and cutoff times for historical irrigation events monitored by IID.

This paper provides a brief background and overview of the on-farm component of the Efficiency Conservation Definite Plan, describes the evaluation of management-based conservation measures such as irrigation scheduling, and compares conservation estimates for management-based conservation measures to other conservation measures evaluated as part of the Definite Plan.

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BACKGROUND AND OVERVIEW

The Imperial Irrigation District of Southern California (IID) diverts approximately 3.1 million acre-feet of Colorado River water annually to irrigate approximately 475,000 acres of agricultural lands (Figure 1). The top nine crops by water use in IID in recent years are alfalfa, Bermuda hay, Sudan, sugar beets, wheat, carrots, onions, and lettuce. Soils range from heavy, cracking clay to sand but are dominated (> 80%) by cracking and heavy non-cracking clay soils. Primary irrigation methods employed by IID growers are graded border (locally called "flat") and graded furrow (locally called "row"). High distribution uniformity and application efficiency are possible due to the heavy cracking soils for which infiltration is relatively insensitive to intake opportunity time. The primary on-farm loss is tailwater (surface runoff), which flows to the Salton Sea, a saline lake supplied mainly by irrigation drainage.

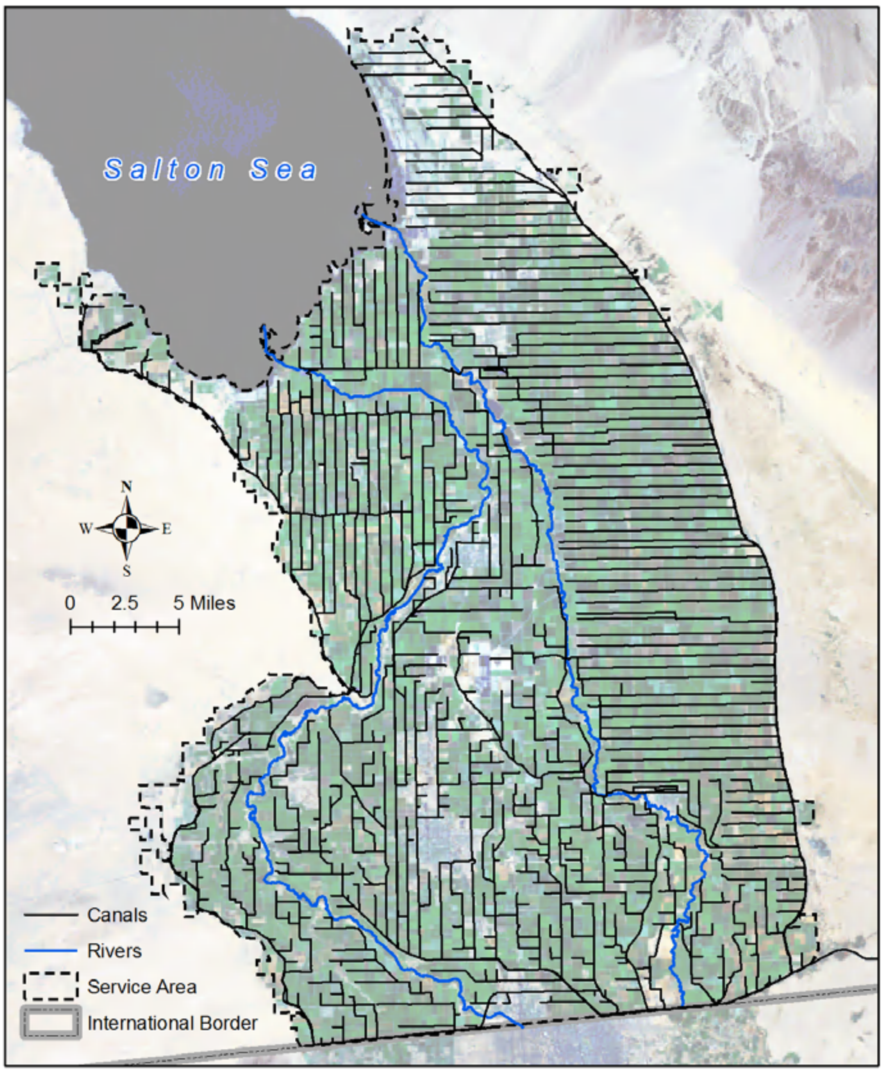


Figure 1. Imperial Irrigation District

In 2003, IID entered the Quantification Settlement Agreement and Related Agreements (QSA), agreeing to the transfer of 303,000 acre-feet annually to other Southern California Colorado River water users through a combination of system and on-farm conservation projects aimed at increasing on-farm irrigation and distribution system efficiency. As a condition of the agreements, at least 130,000 acre-feet must be generated through the implementation of on-farm conservation measures (CMs). The ramp-up schedule of transfer amounts is shown in Figure 2.

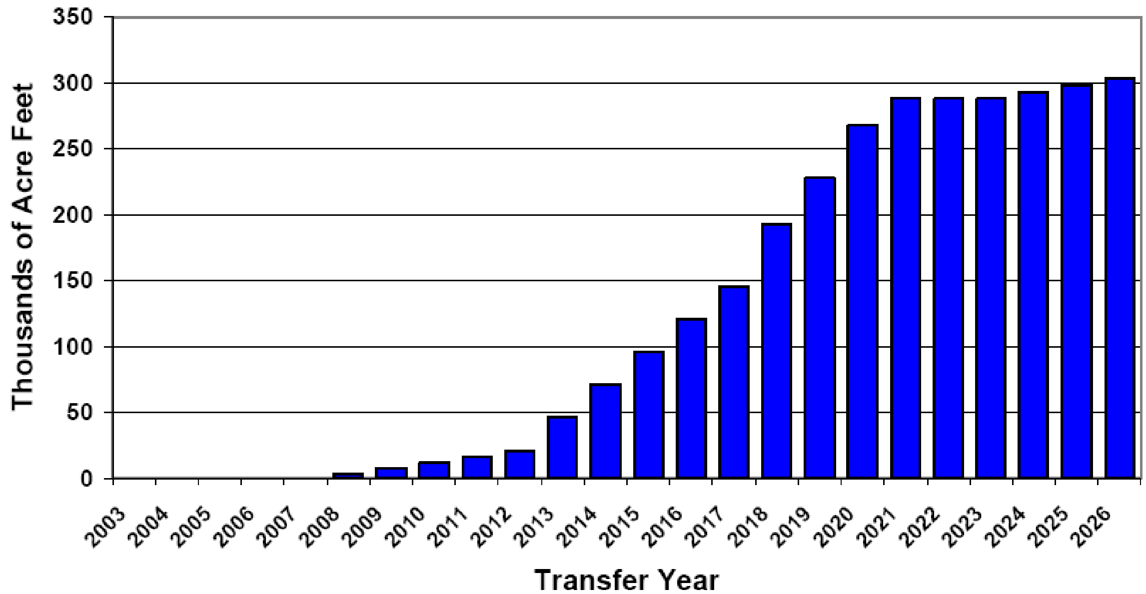


Figure 2. QSA Transfer Schedule

In 2007, IID completed its Efficiency Conservation Definite Plan (Plan), which identifies the most cost effective mix of on-farm and system improvements needed to satisfy transfer obligations while keeping expenditures below available transfer revenues. On-farm participants in the transfer program will be provided incentives to implement CMs to achieve conservation goals. The Plan identified numerous CMs that growers are likely to consider. Among those CMs growers expressed interest in implementing were management-based CMs aimed at increasing irrigation efficiency through decreased tailwater production. CMs evaluated under the Plan are listed in Table 1[5].

In particular, interest was expressed in improving surface irrigation methods through irrigation scheduling and event management. Scientific Irrigation Scheduling (SIS), as evaluated under the Plan, includes decisions made prior to placing irrigation orders for individual fields including the timing, duration, and amount of water aimed at minimizing tailwater production while satisfying crop water requirements. Scientific Event Management (SEM), as evaluated under the Plan, includes decisions made after the start of an irrigation event based on observed advance, infiltration, and runoff aimed at

[5] The CMs evaluated under the Plan were selected to represent the range of costs and efficiency gains generally available to IID growers. In implementation, it is expected that growers will be allowed wide latitude in selecting CMs including but not limited to those considered during planning.

minimizing tailwater production while providing adequate infiltration to meet crop water needs.

Table 1. Conservation Measures Evaluated as Part of the Plan

Conservation Measure	Configurations	Method of Analysis for Conservation Potential
Center Pivot	3 field sizes, 8 crop-irrigation method combinations	Potential application efficiency based on distribution uniformity, results of on-farm demonstrations.
Level Basin	10 basin sizes, flexible and standard delivery schedules, 8 crop-irrigation method combinations	Surface irrigation modeling (SIRMOD)
Micro Irrigation	3 field sizes, with and without reservoir, rental or purchase, 8 crop-irrigation method combinations	Potential application efficiency based on distribution uniformity, results of on-farm demonstrations.
Minor Management and Physical Improvements	3 field sizes, 8 crop-irrigation method combinations	Professional judgement based on results of other conservation measures.
Scientific Irrigation Scheduling	3 field sizes, 8 crop-irrigation method combinations	Surface irrigation modeling (SIRMOD)
Scientific Event Management	3 field sizes, 8 crop-irrigation method combinations	Surface irrigation modeling (SIRMOD)
Sprinkle Irrigation	3 field sizes, with and without reservoir, rental or purchase, 8 crop-irrigation method combinations	Potential application efficiency based on distribution uniformity, results of on-farm demonstrations.
Tailwater Recovery Systems with Reservoirs	3 field sizes, 2 reservoir sizes, 2 pipeline lengths, 8 crop-irrigation method combinations	Operational model of TRS operation for historical irrigation events, results of on-farm demonstrations.
Tailwater Recovery Systems without Reservoirs	3 field sizes, 2 pipeline lengths, rental or purchase, 8 crop-irrigation method combinations	Operational model of TRS operation for historical irrigation events, results of on-farm demonstrations.

Each CM was characterized with respect to potential increases to irrigation performance, defined as the ratio of crop evapotranspiration of delivered water (ET_{dw}) to irrigation deliveries (DW). This ratio is called the Consumptive Use Fraction, or CUF ($CUF = ET_{dw}/DW$). Parameters were developed to estimate increases in the CUF for individual crop-seasons across the range of crops, irrigation methods, and soils in the Valley (Figure 3). Additionally, parameters were estimated for each CM to estimate implementation costs for individual crop seasons (Table 2).

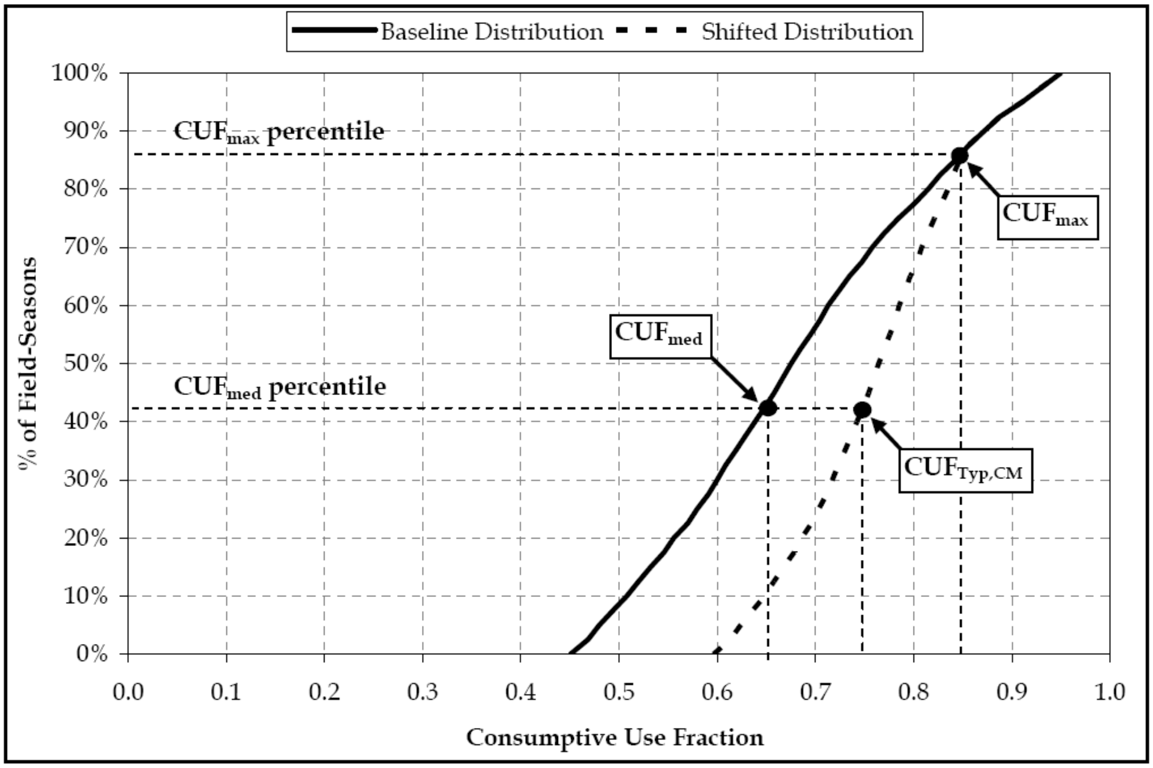


Figure 3. Example Increase in Consumptive Use Fraction Resulting from CM Implementation for a Particular Crop, Soil Type, Irrigation Method, and Conservation Measure.[6]

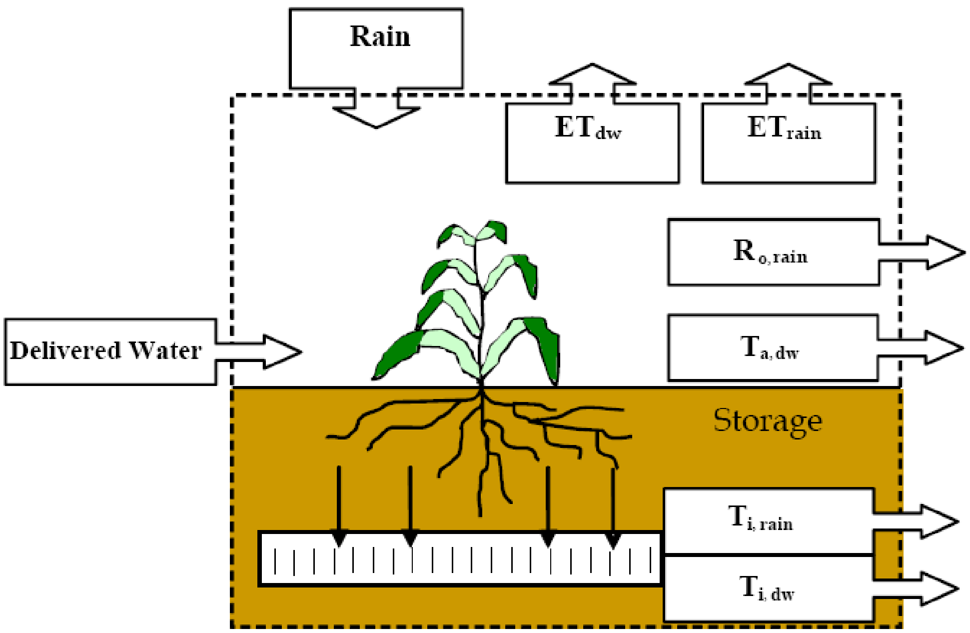
Table 2. CM Cost Characterization Parameters

Annual Capital and Maintenance Cost per Acre
Annual Capital and Maintenance Cost per Field
Seasonal Operations Cost per Acre
Seasonal Operations Cost per Field
Seasonal Additional Benefit per Acre

[6] CUF$_{max}$ percentile – Percentile at which maximum CUF occurs, above which an increase in seasonal CUF would not be expected for a given CM.
CUF$_{max}$ – Representative CUF at the CUF$_{max}$ percentile for a particular crop, soil type, irrigation method, and CM combination.
CUF$_{med}$ percentile – Median percentile for CUF values expected to increase as a result of CM implementation (equal to ½ of CUF$_{max}$ percentile).
CUF$_{med}$ – representative CUF at the CUF$_{med}$ percentile for a particular crop, soil type, and irrigation method.
CUF$_{Typ,CM}$ – representative CUF at the CUF$_{med}$ percentile for a particular crop, soil type, irrigation method, and CM combination.

EVALUATION OF PERFORMANCE INCREASES AND ASSOCIATED DELIVERED WATER REDUCTION FOR MANAGEMENT-BASED CONSERVATION MEASURES

Changes in irrigation performance were estimated by estimating the increase in CUF for each historical crop season (over 103,000 crop seasons were evaluated). Then, the increased CUF was used to update the water balance for each crop season (Figure 4). Changes in deliveries were estimated by assuming little or no change in evapotranspiration of delivered water (ET_{dw}). The deliveries following CM implementation are estimated as the historical ET_{dw} divided by the estimated CUF after CM implementation.



ET_{dw} – Evapotranspiration of delivered water
$T_{i,dw}$ – Tilewater of delivered water
$T_{i,rain}$ – Tilewater of rain
$T_{a,dw}$ – Tailwater of delivered water
ET_{rain} – Evapotranspiration of rain
$R_{o,rain}$ – Runoff of rain

Figure 4. On-Farm Water Balance Conceptual Diagram

Potential CUF increases for irrigation scheduling and event management were estimated using the SIRMOD surface irrigation model developed at Utah State University. SIRMOD simulates advance, recession, infiltration, runoff, and performance indicators for surface irrigation events and can be used for simulation, evaluation, and design (Figure 5). The model was calibrated for 21 historical flat irrigation events and 13 historical row irrigation events. Calibration was accomplished using delivery and tailwater hydrographs collected by IID's Irrigation Management and Monitoring Unit (IMMU) as shown in Figure 6. For each event the model was calibrated to estimate the soil intake characteristics (Figures 7a and 7b for row and flat events, respectively). Light, heavy, and heavy cracking soil classes, shown in Figures 7a and 7b, were preliminarily assigned based on the NRCS soil survey of the Imperial Valley.

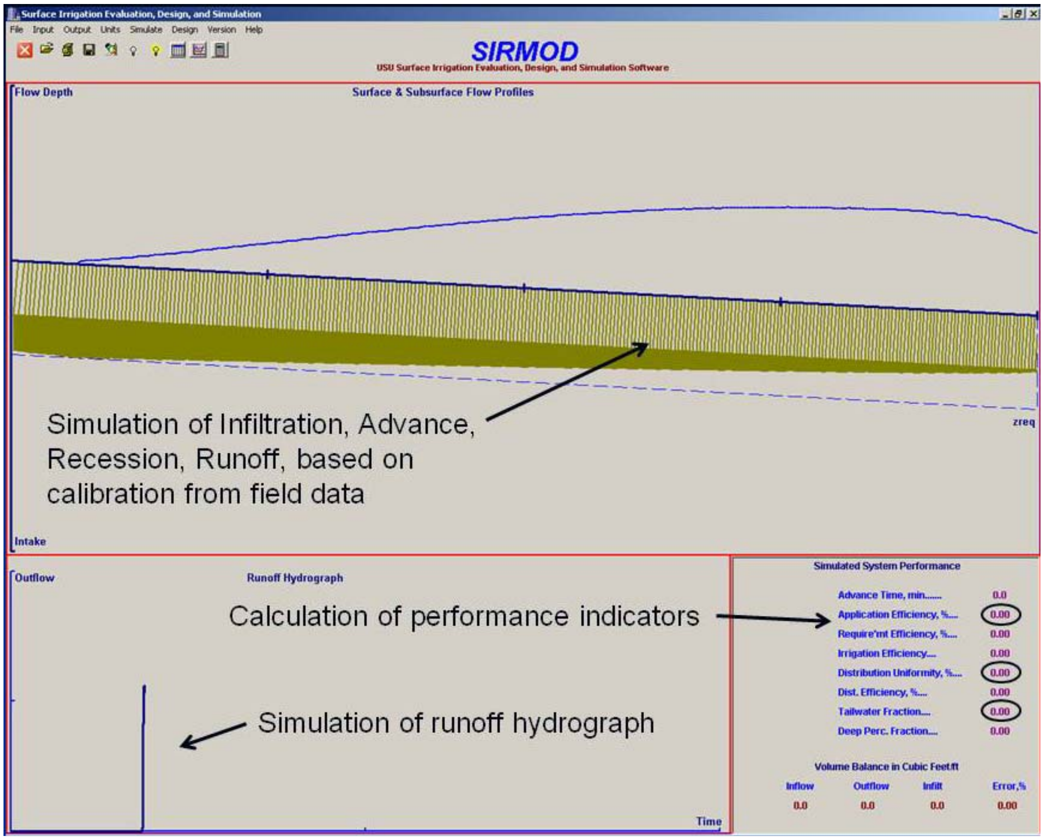


Figure 5. SIRMOD Screen During Event Simulation

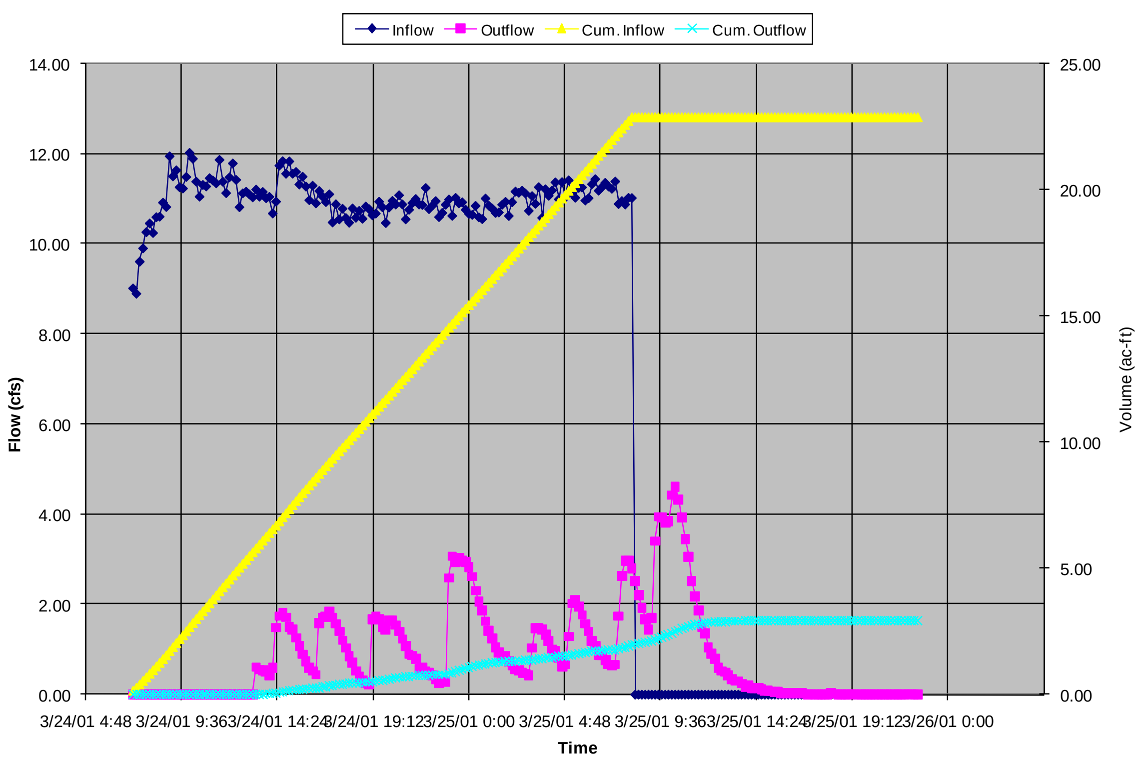


Figure 6. Sample Delivery and Tailwater Hydrograph for a Flat Irrigation Event

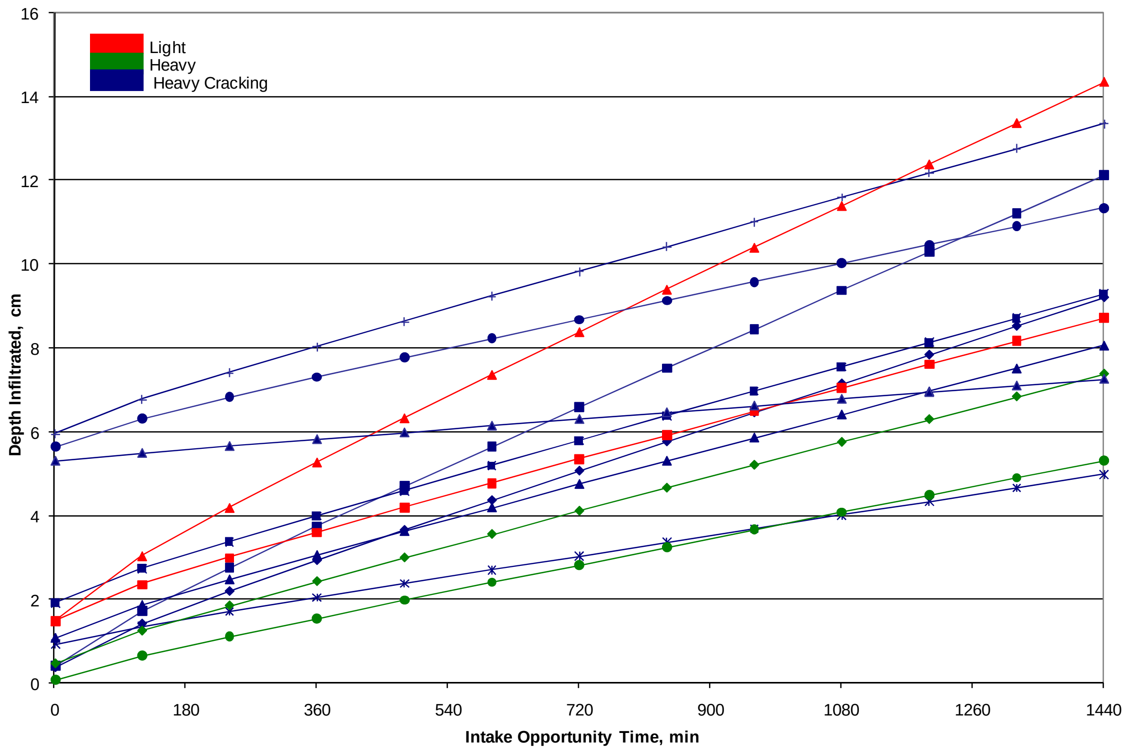


Figure 7a. Calibrated Intake Curves, Row Events

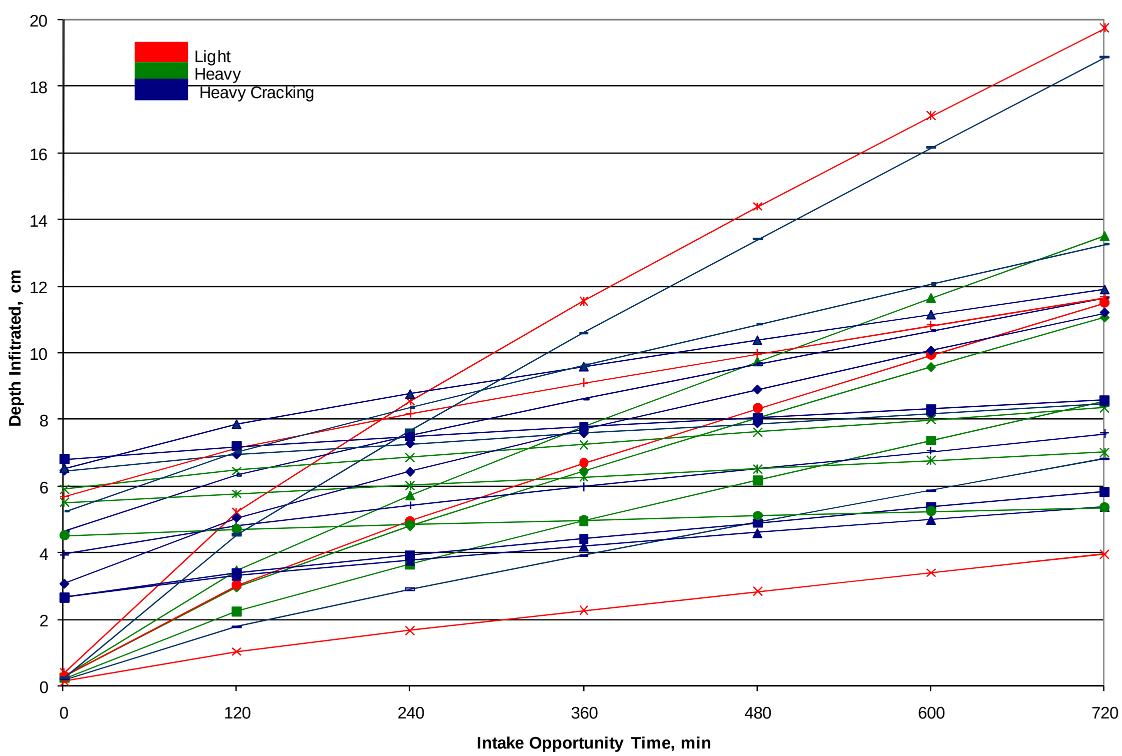


Figure 7b. Calibrated Intake Curves, Flat Events

Following model calibration, potential increases to irrigation performance were estimated for each event by running the SIRMOD model to maintain infiltration and distribution uniformity while increasing application efficiency. For irrigation scheduling, inflow rate was varied and cutoff times were maintained. For event management, both inflow rate and cutoff time were optimized. Application efficiency (AE) cumulative distributions were used as a surrogate for CUF in the SIRMOD analysis and plotted for the calibration and optimized data sets. The water-weighted average application efficiency over the course of a season, when calculated based on the soil moisture deficit prior to irrigation, is equivalent to the CUF. The optimized distributions were “detuned” (adjusted downwards) to account for difficulties in optimizing application efficiency over the course of an irrigation season for each irrigation event due to various uncertainties faced by growers in addition to field non-uniformity. The detuned distributions were used to develop the CUF shift parameters to estimate potential increases in performance Valley-wide (as described previously in Figure 3). The distributions of AE from the SIRMOD runs are shown in Figures 8a and 8b for row and flat events, respectively.

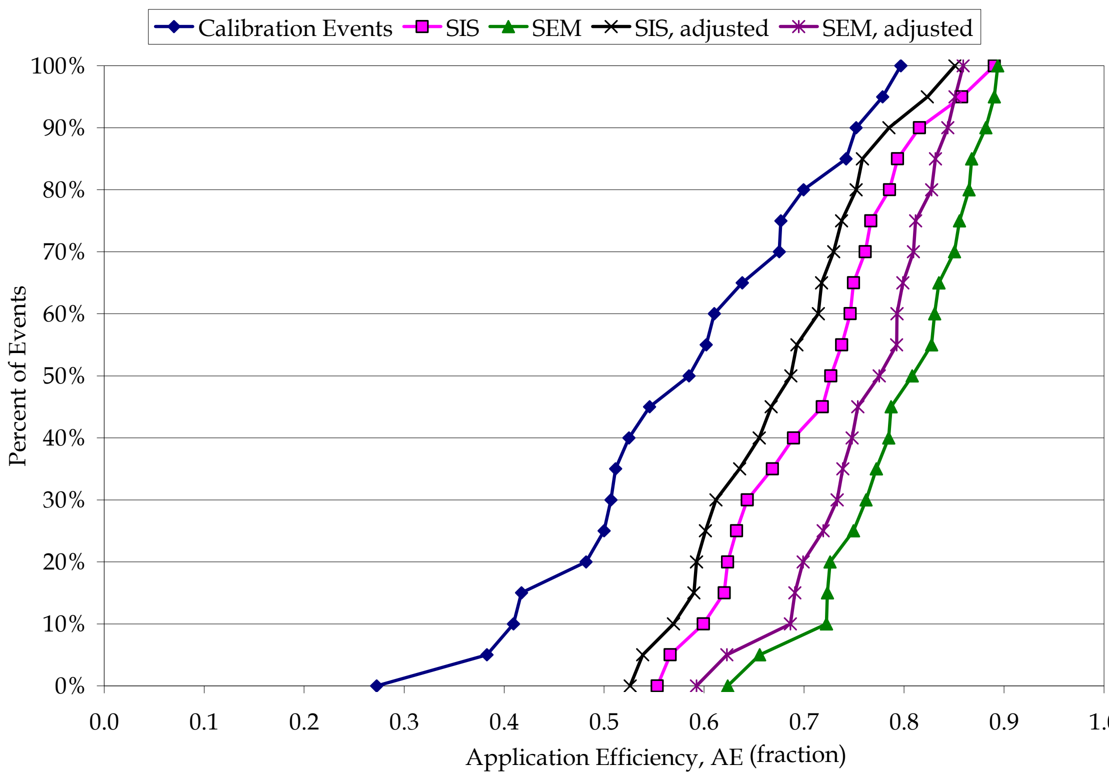


Figure 8a. Cumulative Distributions of Application Efficiency from SIRMOD, Row Irrigation Events

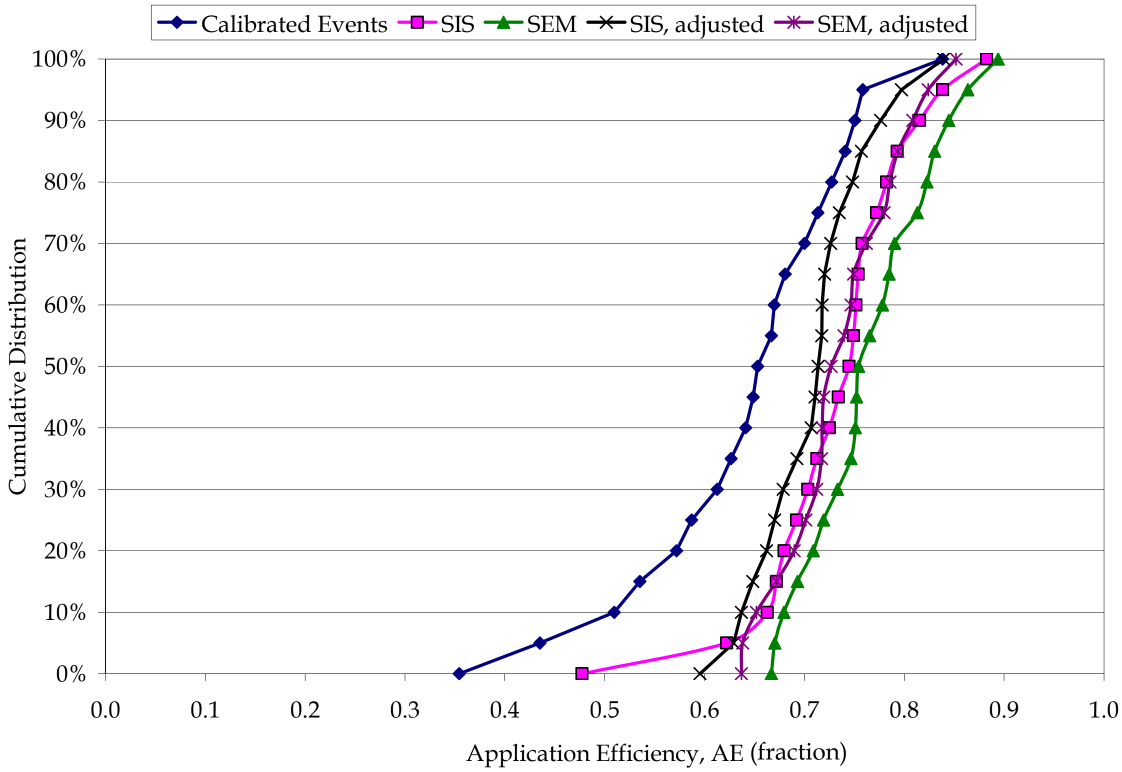


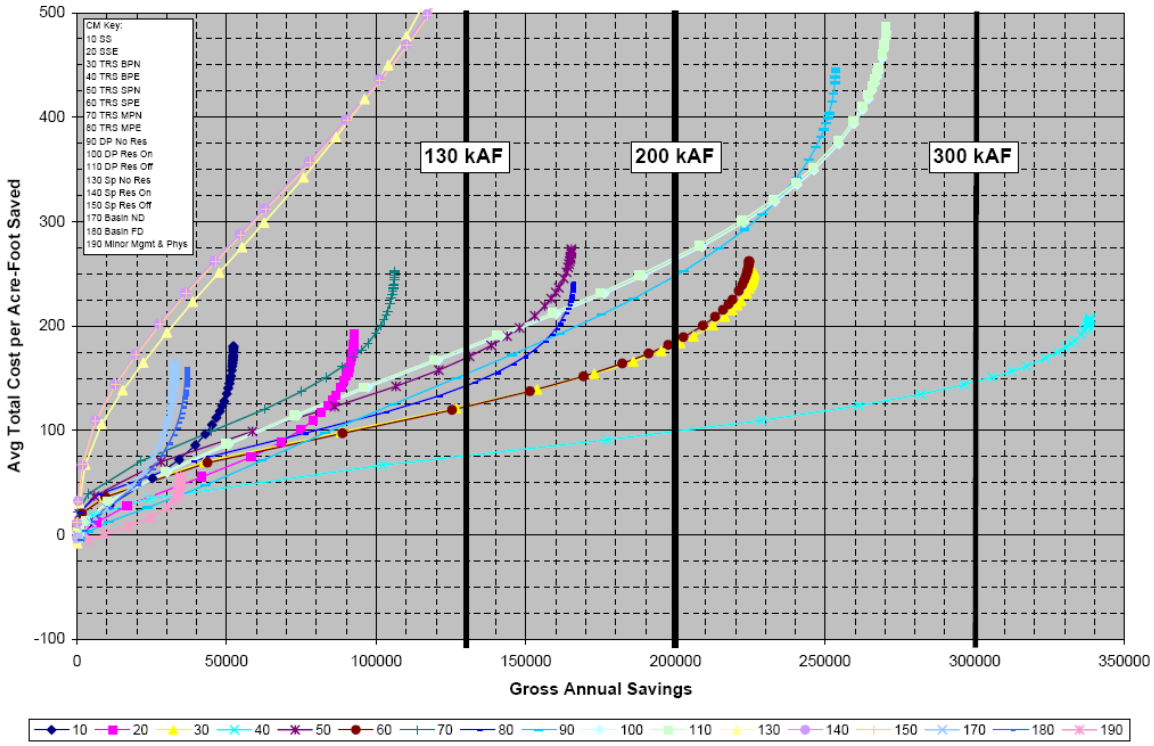
Figure 8b. Cumulative Distributions of Application Efficiency from SIRMOD, Flat Irrigation Events.

COMPARISON OF WATER SAVINGS AND IMPLEMENTATION COST ESTIMATES TO RESULTS FOR OTHER CONSERVATION MEASURES AND PROGRAMMATIC IMPLICATIONS

As described previously, water savings and implementation costs for all CMs evaluated were estimated for over 103,000 historical crop seasons. Typical ranges of water savings and implementation costs are shown in Table 3. Cumulative conservation and average implementation costs were plotted for each CM. The distributions are shown in Figure 9.

Table 3. Typical Savings and Costs by CM

Conservation Measure	Cost Range ($/ac-yr)						Delivered Water Reduction Range (ac-ft/ac-yr)		
Irrigation Scheduling and Event Management	$	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



Series	CM Description	Series	CM Description	Series	CM Description
10	Scientific Irrigation Scheduling	70	TRS, Small Pond, Normal Delivery	140	Sprinkle, Reservoir on System
20	Scientific Event Management	80	TRS, Small Pond, Extended Delivery	150	Sprinkle, Reservoir off System
30	TRS, Big Pond, Normal Delivery	90	Drip, No Reservoir	170	Level Basin, Normal Delivery
40	TRS, Big Pond, Extended Delivery	100	Drip, Reservoir on System	180	Level Basin, Flexible Delivery
50	TRS, Medium Pond, Normal Delivery	110	Drip, Reservoir off System	190	Minor Management and Physical Improvements
60	TRS, Medium Pond, Extended Delivery	130	Sprinkle, No Reservoir		

Figure 9. Average Implementation Cost per Acre-Foot Conserved On-Farm.[7]

Based on the results, it is estimated that a total of approximately 50,000 acre-feet could be conserved annually via irrigation scheduling at an average implementation cost of $150 per acre-foot. Likewise, approximately 90,000 acre-feet could be conserved annually via event management at an average implementation cost of $175 per acre-foot.

In each case (irrigation scheduling and irrigation scheduling combined with event management), total conservation with full implementation fall short of the minimum on-farm conservation amount of 130,000 acre-feet. Based on the Definite Plan evaluation of distribution system conservation opportunities, it is estimated that approximately 200,000 acre-feet will need to be conserved on-farm. Thus, it appears that it will be necessary to implement physical improvements such as tailwater recovery systems and pressurized irrigation in addition to management-based conservation measures in order to achieve program goals.

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[7] In Figure 9, series "10" represents irrigation scheduling and series "20" represents event management. Series 30 through 80 represent various tailwater recovery configurations. Series 90 through 110 represent various microirrigation configurations. Series 130 through 150 represent various sprinkle irrigation configurations. Series 170 and 180 represent level basin configurations. Series 190 represents minor management and physical improvements.

CONCLUSIONS

SIRMOD provides a valuable tool to evaluate potential reductions in on-farm losses through improved surface irrigation management. The application of SIRMOD as part of the Definite Plan provided insights into both the amount of reduction in on-farm losses that could be achieved across a range of fields and into how to achieve those reductions. Future applications of SIRMOD could be used to develop field-specific or more generalized guidelines for improved surface irrigation management tailored to Imperial Valley conditions.

This analysis demonstrates the utility of defining the Consumptive Use Fraction in order to estimate incremental increases in irrigation performance resulting from CM implementation. Parameterization of the increase in CUF for individual fields based on historical performance allows for understanding of the range of costs and delivered water reduction amounts within a population of similar fields.

A wealth of additional information describing SIRMOD and the Definite Plan is provided in the references listed below.

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