Irrigation and drainage strategies in salinity problem areas

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Uniform irrigation systems are essential

Long-term reduction of saline high water tables that cause problems in the western San Joaquin Valley requires simultaneous irrigation and drainage management. Sufficient water must be supplied for crop needs and leaching of salts, while drainage is required to remove water leached from the crop root zone. Water table levels must be deep enough to minimize waterlogging and upward flow of salts to the root zone.

One means of determining optimal irrigation and drainage strategies is to find the approach that yields the greatest economic return to growers in the region. Regional management strategies are important because variability in soil properties and water management practices in a large area may need to be taken into account. Regional planning permits incorporation of variability into appropriate analyses of benefits and costs. For example, it has been suggested that regional evaporation ponds could provide more economical disposal of drainage water than numerous on-farm ponds. To plan and design such facilities, estimates of regional drainage volumes are needed. Results from a regional analysis can also provide direction in selecting economical water management methods at the farm level.

Our purpose in this report is to describe a simulation model used to determine optimal irrigation and drainage strategies in a hypothetical region of the San Joaquin Valley. We also consider possible field methods and operations necessary to address the best regional water management strategy.

Simulation model

Our conceptual model is for a region of irrigated agriculture underlain by a shallow, saline, perched water table (fig. 1). The water table is recharged from excess irrigation water leaching and draining the root zone and may supply a part of the crop needs by upward flow. The water table may also be affected by discharge from subsurface drains, lateral flows across its thickness, and leakage to deeper aquifers. The crop root zone interacts with the water table through leaching and upward flow. Other components of the root-zone water balance are irrigation, precipitation, and evapotranspiration.

Mathematical models were used to simulate the processes shown in figure 1. Processes associated with water and salt flows in the root zone were described by semi-empirical and mass-balance equations. Flow processes in the saturated zone below the water table were described by more sophisticated models, which incorporated variability in soil properties as well as groundwater salinity. Formulation and selection of particular models were based on simplicity of computation and the level of accuracy necessary for regional planning. When assembled, the simulation model accounts for the major processes governing behavior of shallow water tables in salinity-affected regions of irrigated agriculture.

In calculating the salt and water balance in the root zone, we considered flows of water and salt entering or leaving the zone. Flows entering included irrigation water, precipitation, and upward flow from the water table. Flows leaving the root zone were evapotranspiration and leaching water. A specified level of salinity was assigned to irrigation water, upward flow, and leaching water. Changes in soil water storage and salinity were accommodated in the overall mass balance. We also included potential soil salt dissolution as a source of salinity in the root zone. Table 1 summarizes information related to determination of root-zone water balance parameters.

Saline high water tables affect crop yield by inhibiting soil aeration so that root growth is stunted, and by increasing soil salinity, which limits availability of root-extractable soil water and may cause ion toxicity to the plant. Thus our model of crop yield took water table depth and salinity into consideration. Generally, as salinity increases or water table depth decreases, crop yield may drop, reducing monetary return to the grower.

Production costs related to water management in this model include the costs of irrigation water, the irrigation and drainage systems, and disposal of saline drain water. We did not include costs for land, farm management, and property taxes.

When crop yield and the associated economic analysis are included, the complete integrated model describes variability of shallow water table depth and salinity, soil salinity, crop yield conditions, and net economic returns to growers in the region for a specified irrigation and drainage management strategy. The management strategy was mathematically represented by the regional average irrigation and drainage

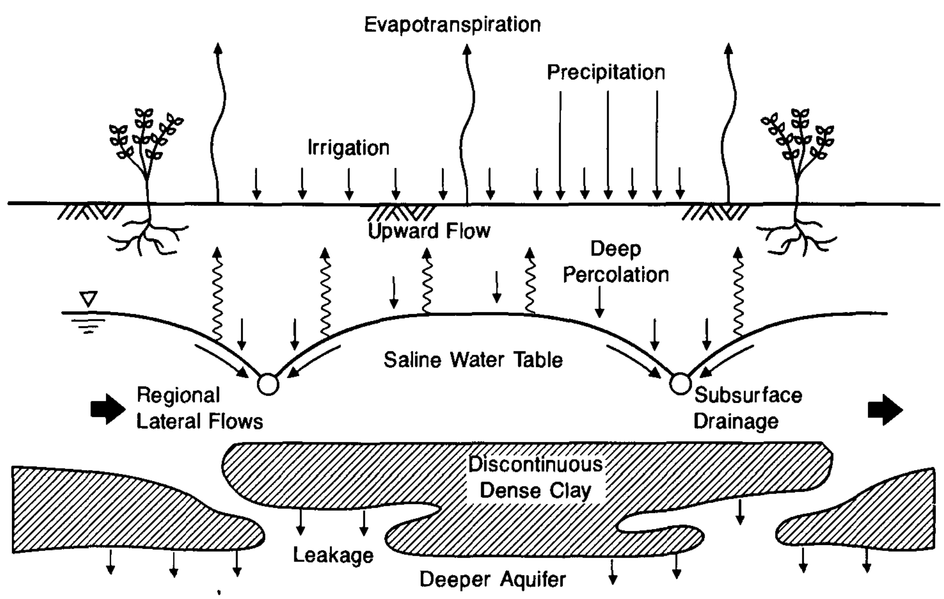

Fig. 1. Cross-section of a hypothetical tile-drained field with a shallow water table, showing water pathways into and out of the crop root zone.

efficiencies. Irrigation efficiency is the fraction of the average depth of applied water in the region used to satisfy crop needs, and drainage efficiency is the fraction of deep percolation water removed by the subsurface drains. By systematically varying irrigation and drainage efficiencies, it is possible to determine which management combination yields the greatest economic return. Such a combination represents the "optimum" or target irrigation and drainage management planning strategy for the region.

Model response and sensitivity

We analyzed data from several field studies in the Delta-Mendota and Panoche fan areas to obtain all parameter values necessary to run the model. These studies included examination of cotton water use, data on soil properties, crop yields, rootzone leaching, and expenses of irrigation, drainage, and cotton production. This information has been summarized by Gates (Ph.D. dissertation, UC Davis).

From the collected information, we constructed a hypothetical 5,000-acre region consisting of 60 independently managed cotton fields for which we determined optimal irrigation and drainage management strategies. We varied key parameters (table 2) to determine their impact on the optimal management strategy.

For conditions given in table 2, the greatest average net benefit to growers in the hypothetical region occurred when irrigation and drainage efficiencies were 78 and 85 percent, respectively. When considering smaller values of average soil permeability in the region, we found that the average net benefits to growers declined substantially at the optimum management strategy. Increasing the rate of soil salt dissolution also reduced average net benefits over the region.

In addition to varying soil parameters, it is possible to examine the effect of different initial water table and soil salinities on the optimal management strategy and associated net benefits. As initial water table salinity and soil salinity changed from 15,000 to 11,000 and 12,000 to 8,000 mg/L, respectively, optimal irrigation efficiencies remained constant at 78 percent, optimal drainage efficiencies decreased from 93 to 79 percent, and average net benefits to growers nearly tripled.

Increasing preirrigation in the model (table 3) resulted in higher irrigation efficiencies, since with greater leaching of soil salts during the preirrigation season, less leaching would be required during the irrigation season. Corresponding decreases in drainage efficiency indicated that more upward flow of salts from the water table can be tolerated when leaching from preirrigation is greater.

Expected annual net benefits increased with increasing depth of preirrigation over the range of values considered. Amounts of drainage water and accompanying salts requiring disposal were similar for the optimal management strategies determined for each alternative depth of preirrigation. Had the management strategy been fixed at a particular combination of irrigation and drainage efficiencies, decreasing preplant irrigation would have reduced drain water volume. A decrease in preplant depths would also have resulted in smaller net benefits, because the fixed strategy would no longer have been the optimal combination of irrigation and drainage efficiency.

Increasing fixed costs of drain water disposal decreased regional net benefits, but there was little effect on the optimal management strategy over disposal costs ranging from $120 to $370 per acre-foot. The lack of effect suggests that, for regional planning purposes, the optimal water management strategy is largely dictated by the responses of the crop, root zone, and water table system to irrigation and drainage.

The modeling studies indicate that economically optimal water management strategies typically occur at regional irrigation efficiencies between 75 and 80 percent. Conceivably, such efficiencies may be achieved with surface irrigation methods. If so, it may not be economical to invest the capital necessary to upgrade surface systems to pressurized systems for low-frequency irrigations subject to water delivery schedules. We also found that it is not necessary for field drainage systems to extract all of the expected deep percolation. Rather, it may be advantageous to allow the fraction of deep percolation water not collected to contribute to water table storage and crop use by upward flow.

Research on drain-water reduction with surface irrigation systems has indicated that reducing the irrigation set time and furrow run length to a quarter mile will decrease deep percolation losses. Surge irrigation methods may also minimize deep percolation losses and increase irrigation efficiency.

Under low-frequency irrigation, large reductions in deep percolation flows are limited by the need to control excess soil salinity resulting from upward-flowing saline groundwater. Soil salinization due to upward flow may be reduced or eliminated by high-frequency water applications with highly uniform, pressurized irrigation systems. The costs of installing pressurized irrigation systems must be balanced against those associated with yield losses from excess salinity and with drain-water disposal.

TABLE 1. Rootzone water balance components

Flow process and origin	How flow was quantified	How salinity was quantified
Precipitation	rainfall data	assumed zero
Irrigation	input data (variable)	input data (constant)
Upward flow from water table	empirical equation*	saturated zone model
Cotton evapotranspiration	input data	assumed zero
Rootzone drainage	water balance	empirical equation†

* M.E. Grismer and T.K. Gates, 1988. Calif. Agric. 42 (2):23-4.
† H. Bouwer. 1969. ASCE J. of Irrig. and Drain. 95:153-70.

TABLE 2. Values of physical parameters used in the model analysis

Parameter	Value
Initial conditions*	
Water table depth	5.6 ft
Water table salinity	13,000 mg/L
Soil water salinity	11,000 mg/L
Soil salt dissolution	0
Irrigation water salinity	250 mg/L
Average permeability of soil, K_h*	0.16 ft/day
Vertical permeability of perching layer*	K_h/100,000
Depth of preplant irrigation	7.1 inches
Cost of drain water disposal	$250/acre-ft
Planning period	20 years

* CH_2M Hill. 1985. Report to Westlands Water District.

TABLE 3. Effects of preplant irrigation depths on the optimal management strategy and drainage

Preplant irrigation depth	E_I*	E_D*	Expected annual drainwater: Depths	Salts
inches			inches	tons/acre
5.9	0.75	0.90	2.72	3.12
7.1	0.78	0.85	2.68	3.08
7.5	0.79	0.85	2.68	3.08
8.3	0.80	0.81	2.87	3.28

* Efficiency of irrigation (E_I) and drainage (E_D)

Conclusions

Our modeling efforts suggest that the primary processes affecting crop yield and economic return to growers are water application efficiency, salinity control in the root zone, and soil permeability. Of particular importance in salinity control is upward flow from the saline water table.

Model results also indicated that, when water delivery schedules result in relatively infrequent applications, surface irrigation systems operated at efficiencies near 80 percent can yield the greatest net benefits to growers in salinity problem areas. Where water delivery schedules are not a limitation, salinity control and a reduction in drainage water may be achieved by very frequent water applications with highly uniform irrigation systems.

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