SALINITY DISTRIBUTION AND IMPACT IN THE SACRAMENTO VALLEY

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ABSTRACT

In many irrigated regions of the Western United States, management of salinity poses a major challenge. The problem has received significant attention in areas such as the San Joaquin Valley and the Colorado River Basin. Salinity management is also a concern in the generally more dilute Sacramento River Valley watershed. The objective of this study was to combine existing and new data to characterize geographic and temporal patterns of salinity distribution in several irrigation districts along the Sacramento River. The analysis combines weather, water, soil, and crop data in an overview of regional salt distribution and impact. Patterns of salinity, drainage, and crop response were mapped at several points in time, then combined to characterize the problem. A data set relating crop performance to water and soil salinity in the study area was reviewed as a quantitative field indication of rice cropping system sensitivity to salinity. Monitoring results suggest that salinity is quickly elevated to levels that can reduce crop yields when extensive water recycling is practiced for conservation, and that a long-term salinization trend may exist. Field drainage and position within the complex of irrigation and drainage facilities combine to determine the severity of the problem at specific locations. Field data suggest rice is significantly less tolerant of salinity than the literature would suggest, effectively placing more stringent water quality constraints on irrigation in the area. The results suggest that salinity management planning will require refinement of our understanding of salinity distribution and trends, as well as their relationship to crop, soil, and water management, and to crop productivity.

INTRODUCTION

Much of the Sacramento Valley region is irrigated for field crop production. Nearly 60% of this area is flood irrigated rice. At a regional level, salinity generally increases with distance from the water sources (from north to south). At a local level, salinity depends on irrigation management and drainage. When water supplies suffice, salinity is adequately controlled in most of the region through dilution and removal with drainage. However, when water diversions are curtailed due to drought or other (e.g., economic, regulatory) causes, regional salinity begins to concentrate in areas receiving the most saline water supplies (including substitution of groundwater for surface supply) and/or with limited ability to remove salinity in drainage. Because elevated salinity impacts crop production, the principal economic activity throughout much of the region, this constraint to beneficial use of water is significant. This paper provides an overview of salinity patterns in 12 irrigation and reclamation districts within the region. Climatic, soil, water, and crop conditions are

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considered. A rice crop sensitivity study is reviewed, as this is a critical criterion for salt management in the region.

CLIMATE AND SOILS.

Figure 1 shows the extent saline, alkaline, and poorly drained soils in the study area. SSURGO data covers only the Yolo, Sutter, and Placer county portions of the districts. US Bureau of Reclamation (USBR, 1988; CH2M HILL, 1987) data cover the whole study area. Basin soils on both sides of the Sacramento River have widespread drainage limitations, long recognized and generally managed by extensive drainage canal networks in these areas. Many of these areas are historically alkaline, due to basin hydro-geochemical processes favoring sodium carbonate accumulation on basin margins (Whittig and Janitsky, 1963). Saline soils (Soil Survey Staff, 1993) are not observed in the region (USDA-SCS, 1967a, 1967b, 1974, 1988, 1993), but areas with intermediate salinity (mapped as EC_e from 2 to 4 dS/m in Yolo, Sutter, and Sacramento counties) are widespread within and beyond the areas with drainage limitations. US Bureau of Reclamation (1988) samples in Glenn-Colusa Irrigation District (GCID) from 1960 and before were $EC_e < 2$ dS/m. Figure 2 shows widespread salinity increase when the same area was sampled 38 years later (CH2M HILL, 1999), with average EC_e increasing by 0.6 dS/m, to an average level of 0.83 dS/m. While 2 sections exceeded 1 dS/m in 1960, 29 did in 1998, 3 of which also exceeded 2 dS/m. What led to this change? How could it affect crop production? What effects might it have on local and regional irrigation and drainage?

Water supply in this region depends on many factors, including local climate. Local precipitation trends are shown on Figure 3. Droughts in the 1930s, late 1970s, and early 1990s are evident in the 5-year moving averages. Precipitation provides winter flushing of soil salinity and is correlated with upper watershed precipitation, which in turn supplies upstream reservoirs. Water for salt management is thus periodically limited by drought.

Water districts in the northern (upstream) portion of the study area tend to divert relatively fresher water (< 0.3 dS/m) than downstream districts. Return flows from upstream users gradually increases salinity of irrigation water as one moves southward, with diversions up to 1.5 dS/m in the southern Colusa Basin (Scardaci et al., 1995, 1996, 1999). Figure 4 (data from Scardaci et al., 1999; Van Camp, 1999) illustrates lower-basin concentrations over time, measured in the Colusa Basin Drain, which is also a supply canal in this area. The highest concentrations were measured in June and July, when water is retained in fields to maximize herbicide decomposition. Salinity in these areas is highest during years when diversions are reduced, as they were during droughts in the late 1970s and early 1990s. Figure 5 (data from Scardaci et al., 1999) shows how water conservation affected water quality within a series of checks during the 1994 and 1995, increasing by up to 0.6 dS/m during June. The 27 field sites (2 measurement locations each) were in the northern end of the study area (see Figure 1 for locations).

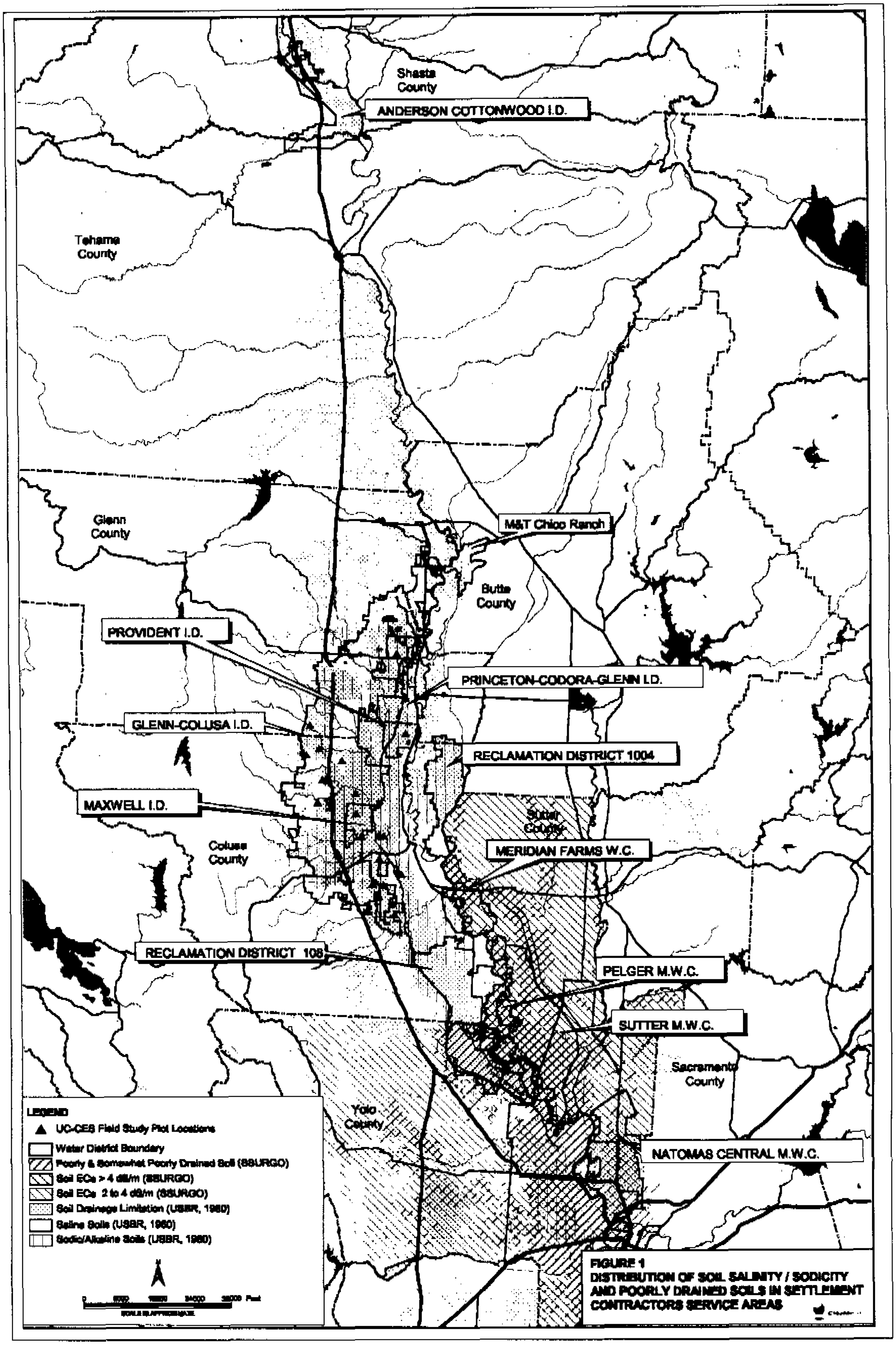

FIGURE 1
DISTRIBUTION OF SOIL SALINITY / SODICITY AND POORLY DRAINED SOILS IN SETTLEMENT CONTRACTORS SERVICE AREAS

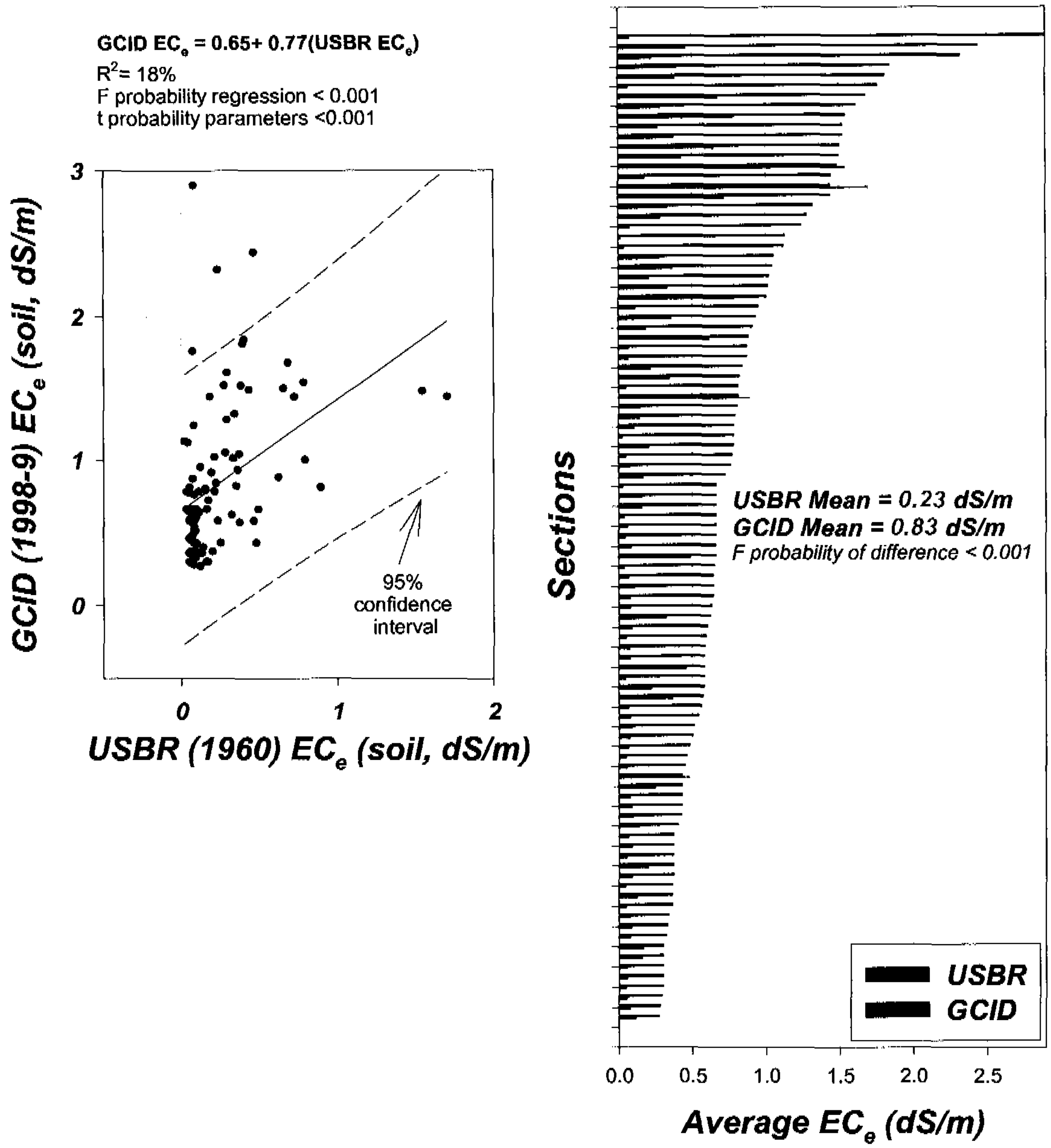

Figure 2. Change in soil salinity between 1960 and 1998 samplings. The shallow (0.77) slope suggests that areas with relatively less initial salinity were affected the most. This is apparent when you compare the length of red (USBR, 1960) and black (GCID, 1999) bars in each pair throughout the range of fields sampled. Sample depth for USBR range from 2 to 12 inches below ground surface. GCID sampled the interval from zero to 6 inches below ground surface.

ATTACHMENT 6

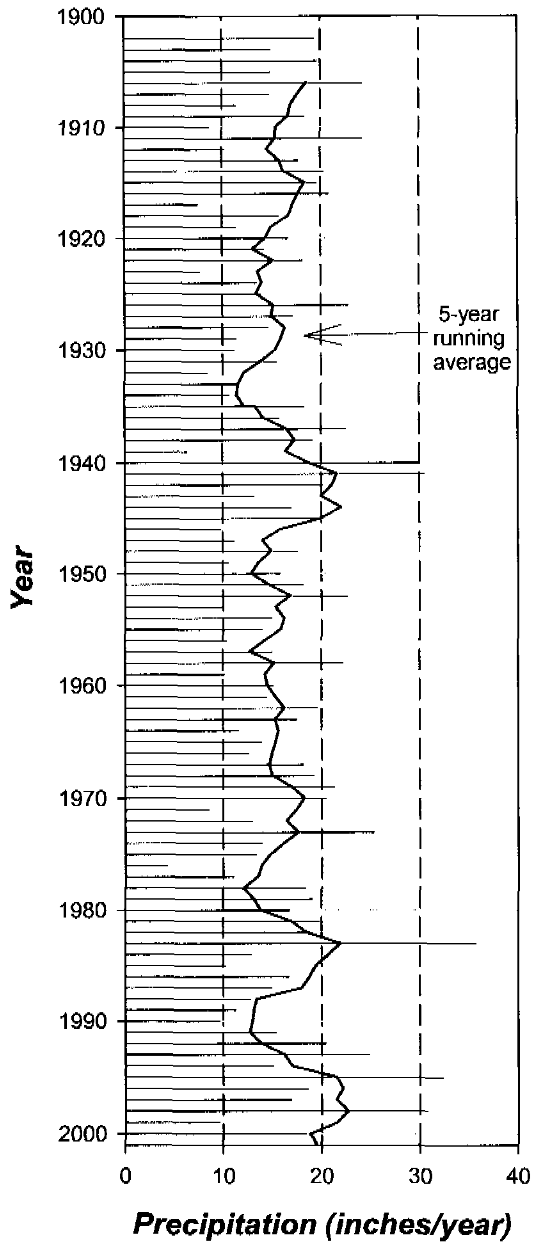

Figure 3. Annual and 5-year moving average precipitation at Colusa. Missing data were estimated from nearby stations.

WATER SUPPLY AND ITS AFFECT ON SOILS.

Exchange between surface and soil water during flood irrigation should cause soil and water salinity to track in parallel. Figure 6 shows the relationship between water and soil salinity within these same fields. With significant scatter, the fitted relationship for the two years of data is nearly 1:1, with a tendency for soils at less saline sites to be concentrated (about 1.5x) relative to irrigation water. Figure 5 shows that soil salinity levels are dynamic from month to month over a season, mirroring patterns in irrigation water salinity.

Recall that soil salinization (Figure 2) presented above was measured in 1998, in the northern (less saline) portion of the study area. This suggests several things.

First, either (1) the effects of water supply salinization on soil salinity, although apparently dynamic in the short term within a field, nevertheless may persist for several years after a period of water supply restriction, and/or (2) increases in soil salinity over time at GCID indicate a steadier, long-term process of general salinization. The widespread nature of salinization in GCID (see Figure 2) would suggest that (2) is true, although (1) may also be.

Second, since GCID's water supply is relatively fresher than water used by downstream irrigators, fields downstream with inadequate flushing flow could exhibit more severe salinization.

Third, curtailment of water supply, with corresponding reductions in flushing flow and increases in water supply salinity, should accelerate salinization trends.

CROP RESPONSE TO SALINITY

Early reports that rice was tolerant of alkali (Adams, 1914) were based on the crop's superior performance to upland small grains (wheat and barley) on alkaline land. How does this square with modern classification of rice as a salt-sensitive crop?

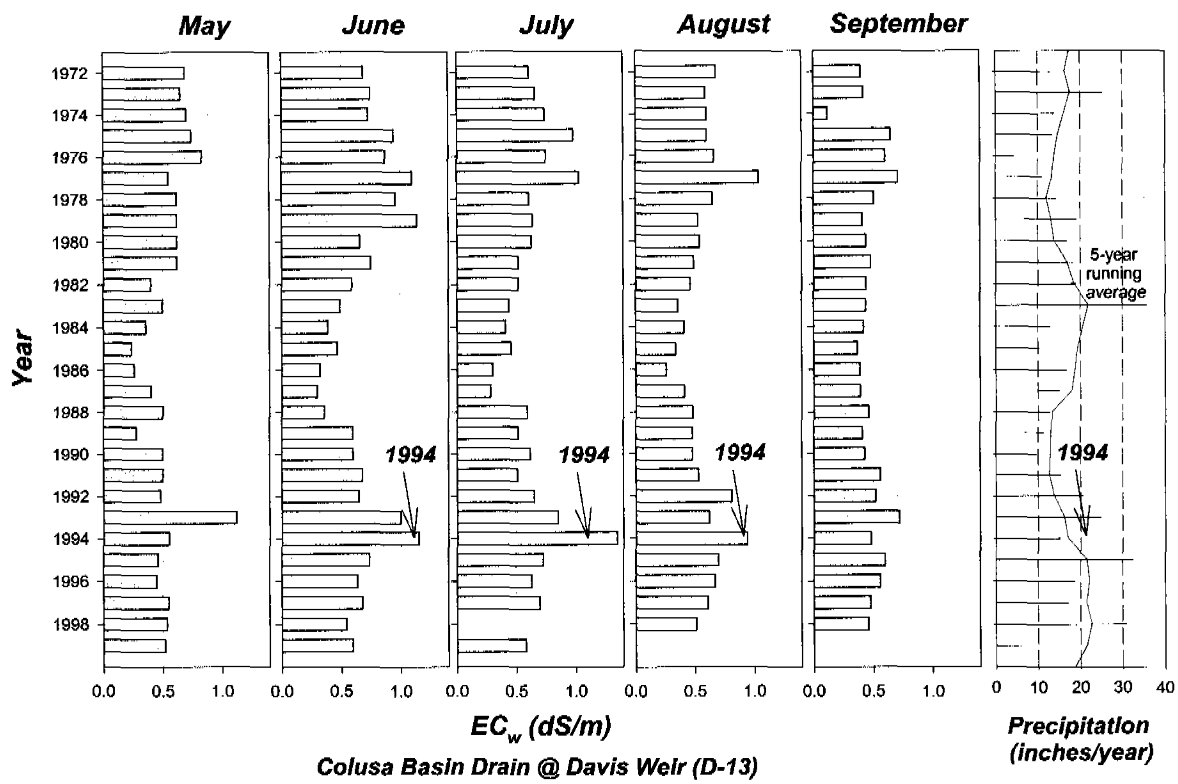

Figure 4. Salinity in the Colusa Basin Drain from 1972 to 1999. In a general sense, this represents the salinity concentrations entering drainage tributaries from surface flow out of lower checks and shallow groundwater seepage. GCID data from Scardaci et al. (1999) through 1997; 1998-9 data from Van Camp (1999).

The observations are reconciled as follows: (1) while alkalinity and salinity co-occur on much land in the region, they are not the same thing; (2) the pH effects of alkalinity, as well as concomitant salinity, can be moderated by tendency to neutral pH and flushing of salts upon flooding. Therefore, it is the flooded rice cropping system that mitigates native alkalinity and salinity, rather than the rice plant as such that is tolerant of alkalinity. Indeed, after some years in rice, historically alkaline land is more readily planted to upland crops that were marginally suitable to the land before reclamation.

Scardaci et al. (1999) summarizes the effects of salinity (EC_w) on rice crops as (1) seedling survival and growth were reduced above 1.85 dS/m in the greenhouse, and above about 2 dS/m in field studies, (2) yields were reduced when season-long salinity was above 1.9 dS/m, and (3) rice salinity response criteria warrant additional refinement.

Figure 7 shows the field-scale yields measured in these studies during 1994 and 1995, plotted together and separately against EC_e, which was a better predictor of yield than EC_w, and is an estimate of average EC_w (see Figure 6). EC_e and EC_w are effectively equated for this discussion. Also, because water recycling requirements and seedling sensitivity to salinity combine to make June the most sensitive period, June EC_e is considered as the independent salinity variable affecting yield..

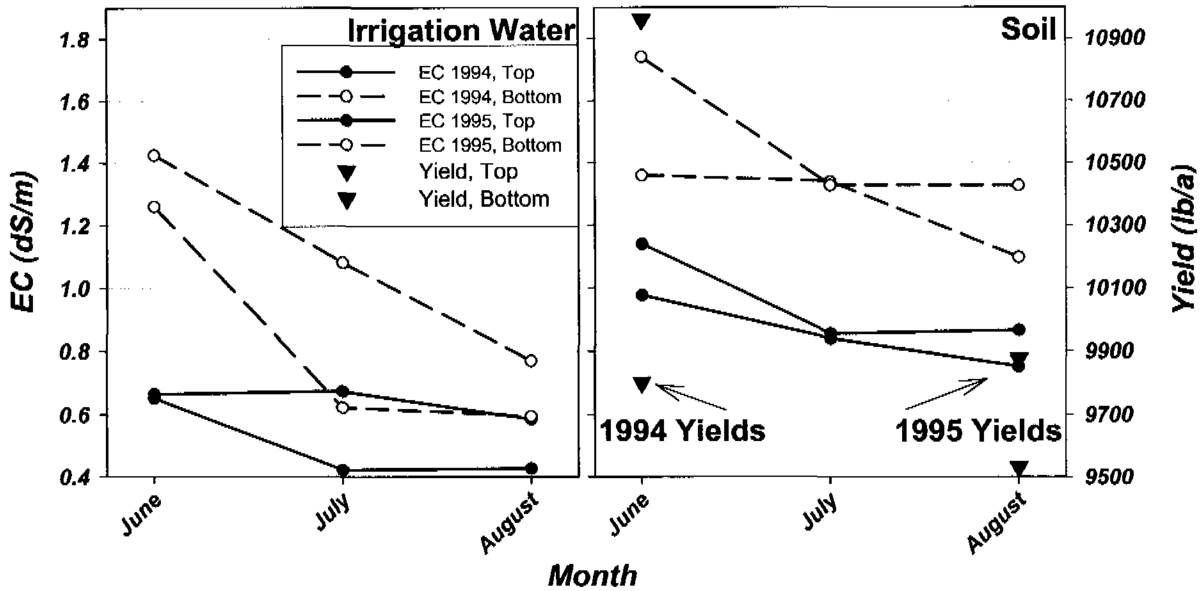

Figure 5. Water and soil electrical conductivity, and rice yield, response to distance from freshwater input to the field. Data from 1994 and 5 (Scardaci, et al., 1999).

Figure 7 shows (1) individual yield measurements in 54 plots located at the top and bottom of 27 fields, (2) average yields for measurements in 0.5 dS/m salinity groupings, (3) a regression line for 1994 yield response to salinity, (4) the yield reduction threshold and slope proposed for rice by Maas (1990; 3 dS/m and 12 (lb/a)/(dS/m)), (5) the yield reduction threshold and slope proposed by Scardaci et al. (1999; reduction from 3 to 1.85 dS/m). Maximum yield levels (before yield reduction by salinity) were defined as average rice yield for each year for locations with June $EC_e<0.05$. This is reasonable, since growing conditions in the absence of salinity stress for each year can be estimated by the performance of these plots.

It is apparent that the model revision proposed by Scardaci et al. is a substantial improvement for rice in these environments. However, an equivalent case could be made from these data for a threshold nearer to $EC_e = 1$ dS/m, and a slope around 8.5 (lb/a)/(dS/m). This line matches the regression shown on the 1994 plot. The significance of this would be to acknowledge a potentially valid, yet more stringent water quality criterion for rice irrigation water, and to retard the estimated rate of yield impact of exceeding the criterion.

CHAIN OF CAUSE AND EFFECT

Evidence in the data reviewed here suggest that, while it is theoretically possible to maintain reclamation and rice productivity, ongoing reclamation is constrained in some areas. In particular, the following "sequence" of causes and effects can be traced conceptually: (1) prolonged drought reduces water available for various beneficial uses, (2) physical, economic, and/or regulatory forces reduce supply of fresh, river water for irrigation, (3) irrigation water is detained within fields, especially during early-season holding periods for herbicide degradation, (4) salinity increases from top to bottom across fields, (5) salinization is further accelerated in drainage impaired areas due to less efficient salt removal, (6) head-gate salt concentrations increase substantially in the lower basin, (7) soil salinity more or less mirrors water salinity in rice fields, (8) rice stand density and growth rate are reduced in the areas where these conditions combine to elevate salinity beyond threshold concentrations, (9) the effects on young rice may translate into a yield reduction, roughly in proportion to the amount by which salinity thresholds are exceeded, (10) seasonal and long-term salinization trends combine to generally increase soil salinity over time, and (11) irrigation districts, farmers, and policy makers sort options to alleviate increasing salinity or its impacts.

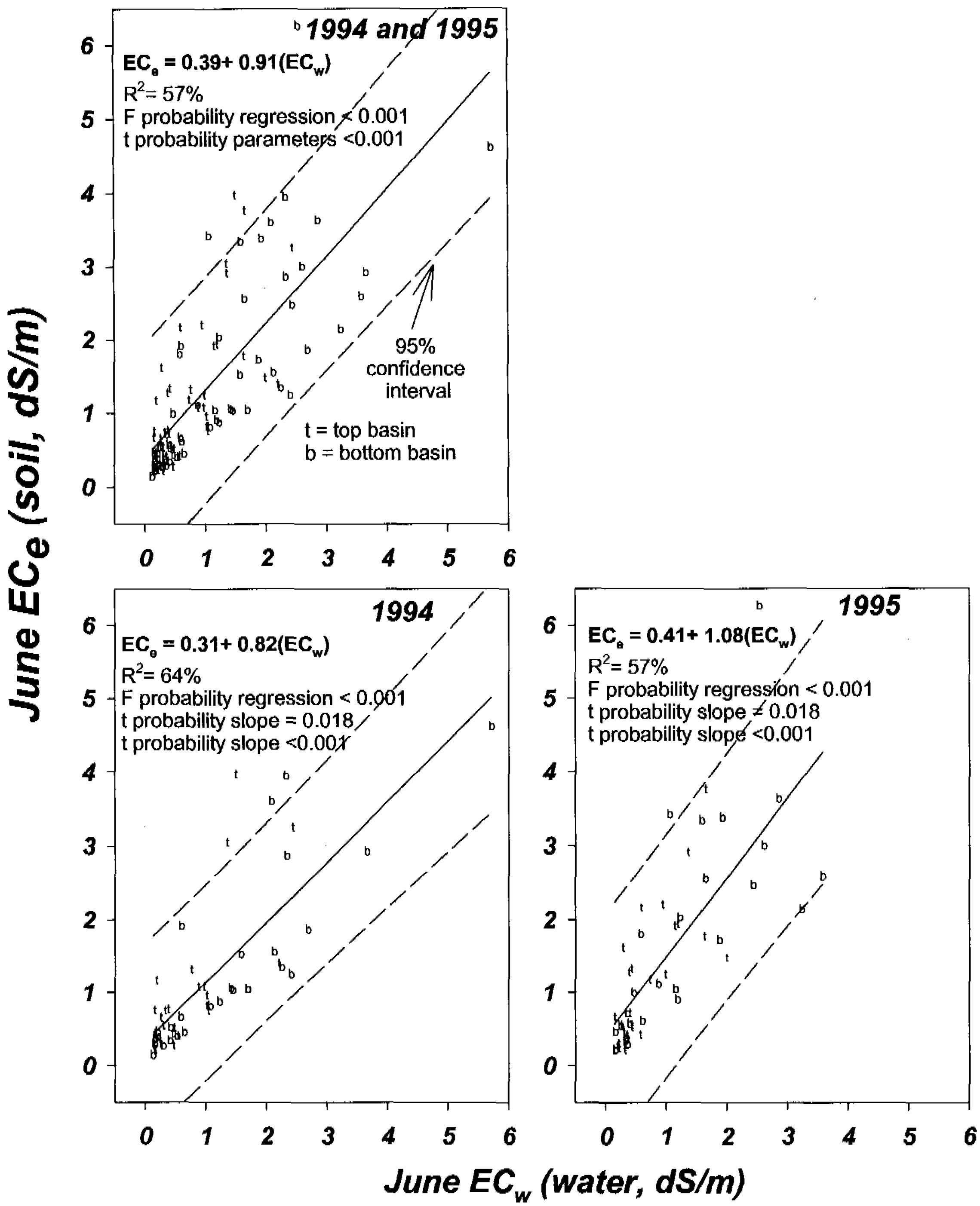

Figure 6. Relationship between water supply salinity and soil salinity in fields sampled in 1994 and 1995 (Scardaci et al., 1999).

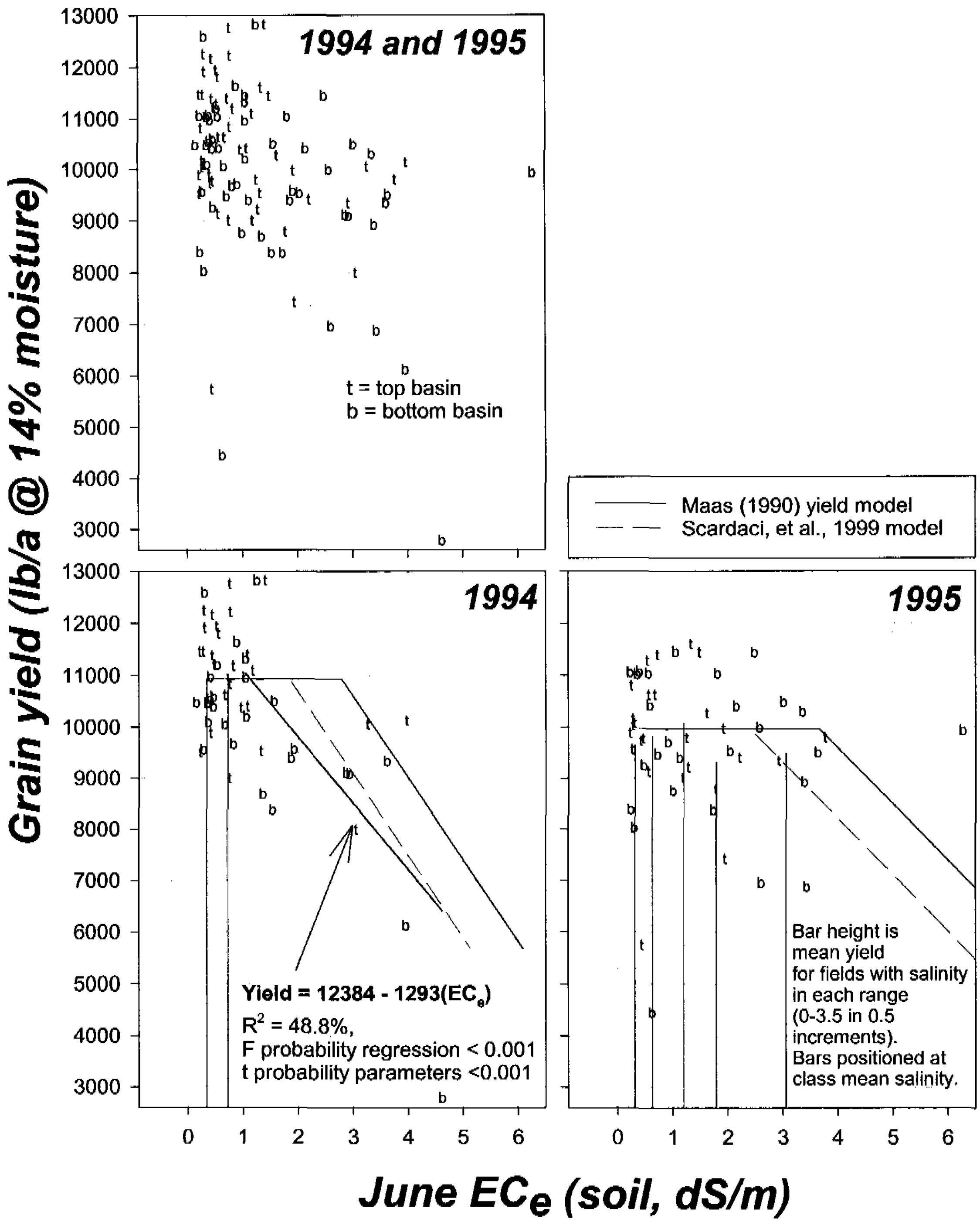

Figure 7. Rice grain yield response to salinity, 1994 and 1995 (data from Scardaci et al., 1999). Note that the EC$_e$ levels shown for the vertical bars are the average EC$_e$ of checks in each 0.5-dS/m increment along the x axis.

CRITICAL DATA NEEDS

The data in Figure 7 represent 54 field-scale plots monitored over 2 seasons. Scardaci et al. also used more controlled greenhouse and microplot studies to arrive at their conclusions. Water policy, farm economic, and water resources engineering decisions will likely be based on the best available crop salt tolerance criteria. Cost implications of these decisions far outweigh the relatively minor effort required to refine rice salt tolerance criteria, as recommended.

There are relatively few extensive surveys of soil salinity in the Sacramento Valley. Focused effort to improve and update salinity mapping, and to monitor trends over time, would refine our understanding of the problem and focus efforts at resolution. Recent advances in ground-based salinity sensing technology could greatly facilitate this work.

The response of soil salinity to various irrigation and drainage regimes over not months, but years and decades, needs to be measured. We must define operating criteria and practice that sustain salt concentrations within ranges favoring planned crop production levels and other beneficial uses. This is true at each level of management, from the individual field to the Sacramento River Basin, and extending across the domains of crop, soil, and water management. Current criteria and practice may be inadequate for this purpose, as significant salinization and associated crop impacts were observed.

Salinity is managed with water. The salt management system is therefore stressed when water supply is curtailed or degraded. Therefore, salt management strategies must explicitly consider the dynamics of water supply quantity and quality.

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