DWR - 22

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Establishing Salinity Water Standards that are Protective for Agricultural Crop Production

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Introduction

The decision by the State Water Resources Control Board to set the south delta salinity requirement at an electroconductivity (EC) of 0.7 dS/m was greatly influenced by the steady-state analysis described by Ayers and Westcot (1985) in FAO Paper 29. The steady-state condition assumes that water flows continuously through the soil and that the soil solution concentration at any point in the root zone is constant at all times. These conditions do not accurately represent the field condition and therefore, the conclusions drawn from the theory are subject to error.

A greater understanding of the dynamic interaction between soil-water, salinity, and plant response has been achieved in recent years. My report will (1) provide a general description of salinity-plant interactions, (2) reproduce portions of the Ayers and Westcot steady-state analysis, (3) identify deficiencies in the analysis, (4) describe an alternative approach to the steady-state analysis, (5) identify the rainfall contribution to partially mitigate the impact of water salinity on crop productivity, and (6) conclude that an EC standard of 1.0 dS/m is protective of agricultural production in the south delta.

General Salinity—Plant Interactions

The fact that salts (commonly referred to as salinity) or total dissolved solutes (TDS) in the water can be damaging to crop production has been known for centuries. Furthermore, it is well known that crops have different degrees of tolerance to TDS. The TDS in water is most quickly and easily quantified by measuring the electro-conductivity (EC) of the water. Therefore, the TDS or salinity of the water is usually reported as the EC of the water. For most waters the EC of 1 dS/m is equivalent to a TDS concentration of 640 mg/L. The following symbols will be used in this report. EC_{iw} is the EC of the irrigation water. EC_{sw} is the EC of the water in the soil. EC_e is the EC of the water in the soil when it is saturated with distilled water in the laboratory and extracted for measurement. EC_{sw} is approximately equal to 2 EC_e.

An index that reflects the sensitivity of a given crop to EC is important. Eugene Maas and Glenn Hoffman, scientists at the USDA Salinity Laboratory, found that research reports on crop growth related to EC_e could approximately be characterized by two straight lines as illustrated in Figure 1.

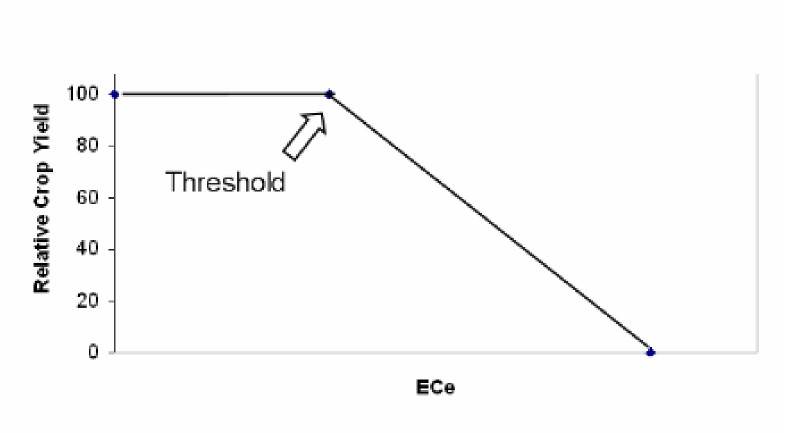


Figure 1. General relationship between relative crop yield and soil salinity.

One line is flat at maximum crop growth at all salinities up to a "threshold" number, but increasing the EC_e beyond this threshold causes a linear decrease in crop growth. The coefficients that would characterize crop tolerance to EC_e are the threshold value and the slope of the curve at values greater than the threshold value. These coefficients have been referred to as the Maas–Hoffmann coefficients and have been reported for numerous crops in various publications. The Maas-Hoffman coefficients for a few selected crops are presented in Table 1. The threshold EC_e of 1.0 dS/m reported for beans represents the lowest threshold EC_e of any vegetable or field crop that have been evaluated.

Table 1. Maas-Hoffman coefficients for some selected crops.

Crop	Threshold ECe dS/m	Slope % per dS/m
Alfalfa	2.0	7.3
Almonds	1.5	19.0
Asparagus	4.1	2.0
Beans	1.0	19.0
Corn	1.7	12.0
Cotton	7.7	5.2
Grapes	1.5	9.6
Tomatoes	2.5	9.9

All irrigation waters add salts as well as water to the soil. The plants extract water and leave most of the salts behind which concentrate in the soil solution. If the EC concentration exceeds the threshold value, some reduction in crop growth will occur. "Extra" water is applied to leach salts from the root zone to prevent their accumulation to detrimental concentrations. Typically the amount of water required depends on the crop tolerance to salinity and the EC of the irrigation water (EC_{iw}). This is the simple straightforward approach to the matter, and these general principles have been successfully used for years. However the quantitative assessment of irrigating with saline waters introduces some complex relationships between the plant and soil-water dynamics.

The long-term water balance equation is

$$AW = ET + DP$$

where AW is the applied water including precipitation that infiltrates the soil, ET is evapotranspiration, and DP is deep percolation (the water that moves below the root zone). The LF (leaching fraction) is defined as deep percolation divided by the applied water. I once assumed that if saline water was applied at amounts less than the amount of evapotranspiration, then there would be no deep percolation to wash the salts out of the root zone, and they would accumulate until they killed the plant. That would be a conclusion readily adopted from the water balance equation. However, I had overlooked another relationship that has been well-supported by research, and that is that evapotranspiration is not only a function of the climate, but also linearly related to plant growth. This reaction sets up a dynamic interaction between the crop and the soil-water system that affects the yield.

If the soil salinity reaches a level that reduces water uptake to a level less than potential transpiration, the leaf stomata close. Closure of the stomata decreases transpiration and preserves water in the leaf to prevent dehydration. Carbon dioxide which is essential for photosynthesis and plant production passes from the atmosphere through the stomata to the cell where photosynthesis occurs. Closure of the stomata decreases carbon dioxide supply to the leaf and consequently reduces photosynthesis and plant growth. This process represents a two-fold mechanism for plant survival. The plant reduces water loss and stops growing and thus reduces the transpiration demand that would occur with larger leaf surface area.

When evapotranspiration is reduced, deep percolation is increased, and the increased deep percolation leaches more salt from the root zone. This is one of nature’s additional protective mechanisms. During the crop-growing season, with irrigation and precipitation, the salt distribution is continuously changing with time and depth in the root zone. The plant naturally integrates all of these dynamic processes and provides “feedback” to the soil-water systems based on the plant growth as described above. This feedback, in turn, modifies the reactions occurring in the soil. The point is that some very complex interactions are occurring which impact the relationships between irrigating with saline waters and crop yield, and some of these relationships can be counter-intuitive.

The crop responds to the salinity in the soil-water surrounding the root (EC_{sw}), and the challenge is to relate EC_{sw} to the EC of the irrigation water (EC_i). The Maas-Hoffman coefficients are used to determine EC_{sw} thresholds for individual crops. (Note that the Maas-Hoffman coefficients are usually reported on EC_e rather than EC_{sw}.) If a reliable approach to relating EC_i to EC_{sw} or EC_e is developed, then the maximum EC in the irrigation water that will not result in a yield reduction can be established for specific crops based upon the Maas-Hoffman coefficients for that specific crop.

Ayers and Westcot Steady-State Analysis

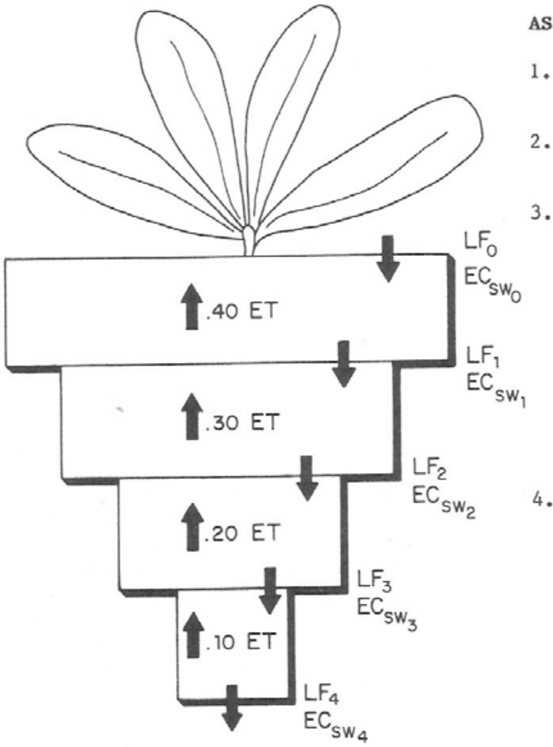
Ayers and Westcot (1985) published a procedure for relating EC_i to EC_{sw} assuming steady-state conditions. Their approach was created based on the knowledge available at the time. The approach has been useful for providing general guidelines, but, as I will point out later, has some technical deficiencies in providing a quantitative analysis. The initial South Delta salinity objectives were largely based on the model presented by Ayers and Westcot and therefore are subject to reevaluation.

Portions of the Ayers and Westcot (1985) report which describe the determination of the average root zone salinity are reproduced as part of this report so that the deficiencies can be identified for the purposes of setting quantitative irrigation water salinity objectives.

Ayers and Westcot assumed steady-state conditions. In other words, water is assumed to flow continuously through the soil, and the soil solution concentration at any point in the root zone is assumed to be constant at all times. Neither of these conditions exists in the field. They assumed that the root water uptake is distributed as follows: 40, 30, 20, and 10% in the first through fourth quarter sections of the root zone, respectively. Pages 16 and 17, referred to as Example 2 of their report, provide the detailed procedures they used to determine the average root zone salinity. Page 18 of their report provides a table relating the concentration factor for converting EC_{iw} to EC_e for various leaching fractions. The distribution of salts within the root zone for various leaching fractions are also illustrated on this page. These pages are reproduced on the following pages of this report.

EXAMPLE 2 - DETERMINATION OF AVERAGE ROOT ZONE SALINITY

The average root zone salinity can be calculated using the average of five points in the rooting depth. The following procedure can be used to estimate the average root zone salinity to which the crop responds.



ASSUMPTIONS

1. Applied water salinity (EC_w) = 1 dS/m.

2. Crop water demand (ET) = 1000 mm/season.

3. The crop water use pattern is 40-30-20-10. This means the crop will get 40 percent of its ET demand from the upper quarter of the root zone, 30 percent from the next quarter, 20 percent from the next, and 10 percent from the lowest quarter. Crop water use will increase the concentration of the soil-water which drains into the next quarter (EC_{sw}) of the root zone.

4. Desired leaching fraction (LF) = 0.15. The leaching fraction of 0.15 means that 15 percent of the applied irrigation water entering the surface percolates below the root zone and 85 percent replaces water used by the crop to meet its ET demand and water lost by surface evaporation.

EXPLANATION

1. Five points in the root zone are used to determine the average root zone salinity. These five points are soil-water salinity at (1) the soil surface, (ECsw0); (2) bottom of the upper quarter of the root zone, (ECsw1); (3) bottom of the second quarter depth, (ECsw2); (4) bottom of the third quarter, (ECsw3) and (5) bottom of the fourth quarter or the soil-water draining from the root zone (ECsw4) which is equivalent to the salinity of the drainage water (ECdw).

2. With a LF of 0.15, the applied water (AW) needed to meet both the crop ET and the LF is determined from the following equation:

$$AW = \frac{ET}{1 - LF} = 1176 \text{ mm of water} \qquad (7)$$

3. Since essentially all the applied water enters and leaches through the soil surface, effectively removing any accumulated salts, the salinity of the soil water at the surface (ECsw0) must be very close to the salinity of the applied water as shown using equation (3) and assuming LF0 = 1.0.

$$EC_{dw_0} = EC_{sw_0} = \frac{EC_w}{LF_0} = \frac{1}{1} = 1 \text{ dS/m} \qquad (3)$$

4. The salinity of the soil-water draining from the bottom of each root zone quarter is found by determining the leaching fraction for that quarter using equation (2) and then determining the soil-water salinity using equation (3).

$$LF = \frac{\text{Water leached}}{\text{Water applied}} \qquad EC_{sw} = \frac{EC_w}{LF}$$

For the bottom of the first quarter:

$$LF_1 = \frac{1176-.40(1000)}{1176} = 0.66 \qquad EC_{sw_1} = \frac{EC_w}{LF_1} = 1.5 \text{ dS/m}$$

--- at the bottom of the second quarter:

$$LF_2 = \frac{1176-.40(1000)-.30(1000)}{1176} = 0.40 \qquad EC_{sw_2} = \frac{EC_w}{LF_2} = 2.5 \text{ dS/m}$$

--- at the bottom of the third quarter:

$$LF_3 = \frac{1176-.40(1000)-.30(1000)-.20(1000)}{1176} = 0.23 \qquad EC_{sw_3} = \frac{EC_w}{LF_3} = 4.3 \text{ dS/m}$$

--- at the bottom of the root zone (fourth quarter):

$$LF_4 = \frac{1176-.40(1000)-.30(1000)-.20(1000)-.10(1000)}{1176} = 0.15 \quad EC_{sw_4} = \frac{EC_w}{LF_4} = 6.7 \text{ dS/m}$$

This is salinity at bottom of root zo

5. The average soil-water salinity of the root zone is found by taking the average of the five root zone salinities found above:

$$EC_{sw} = \frac{EC_{sw_0} + EC_{sw_1} + EC_{sw_2} + EC_{sw_3} + EC_{sw_4}}{5}$$

$$EC_{sw} = \frac{1.0 + 1.5 + 2.5 + 4.3 + 6.7}{5} = 3.2 \text{ dS/m}$$

6. This calculation shows that the soil-water draining below the root zone will be 3.2 times as concentrated as the applied water.

This is average root zone salinity – not salinity leaving root zone.

Table 3 CONCENTRATION FACTORS (X) FOR PREDICTING SOIL SALINITY (ECe)[1] FROM IRRIGATION WATER SALINITY (ECw) AND THE LEACHING FRACTION (LF)

Leaching Fraction (LF)	Applied Water Needed (Percent of ET)	Concentration Factor[2] (X)
0.05	105.3	3.2
0.10	111.1	2.1
0.15	117.6	1.6
0.20	125.0	1.3
0.25	133.3	1.2
0.30	142.9	1.0
0.40	166.7	0.9
0.50	200.0	0.8
0.60	250.0	0.7
0.70	333.3	0.6
0.80	500.0	0.6

[1] The equation for predicting the soil salinity expected after several years of irrigation with water of salinity ECw is:

$$EC_e \text{ (dS/m)} = EC_w \text{ (dS/m)} \cdot X \qquad (8)$$

[2] The concentration factor is found by using a crop water use pattern of 40-30-20-10. The procedure is shown in example 2.

(From Ayers and Westcot, 1985)

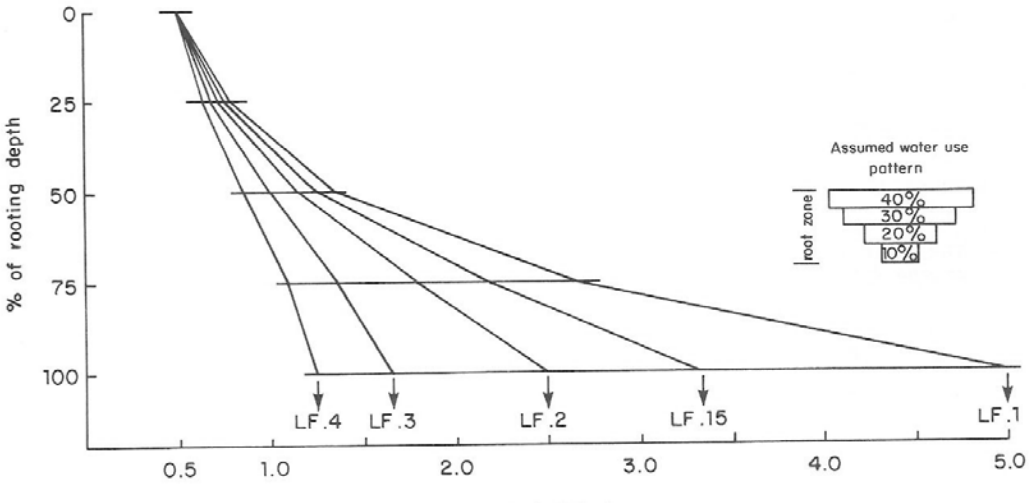


Fig. 2 Salinity profile expected to develop after long-term use of water of EC_w = 1.0 dS/m at various leaching fractions (LF)

(From Ayers and Westcot, 1985)

The equations used in Ayers and Westcot's Example 2 are basic mass balance equations assuming no salt dissolution or precipitation. They calculated an average EC_{sw} by taking the concentrations at each of the nodes and dividing by the number of nodes. They concluded that with a 15% leaching fraction, the irrigation water salinity was increased three-fold within the root zone, or EC_{sw} is equal to 3 EC_i.

The assumption that the irrigation water salinity is increased three-fold in the root zone was a major factor in establishing the 0.7 dS/m standard for the South Delta salinity requirement. If an irrigation water salinity of 0.7 dS/m was applied, with a 15% leaching fraction, the average soil-water salinity, EC_{sw}, was tripled to 2.1 dS/m. Because EC_{sw} was assumed to be 2 EC_e, the resultant EC_e is 2.1 divided by 2 or 1.05 dS/m. Thus irrigation with a water of 0.7 dS/m could be used to irrigate crops with a Maas-Hoffman threshold value of 1.05 or greater. The Maas-Hoffman threshold EC_e for the most sensitive crops grown in the delta is 1.0 dS/m. Therefore an irrigation water of 0.7 dS/m was calculated to be protective of the most salt-sensitive crops.

Deficiencies in Ayers and Westcot Steady-State Approach

One major deficiency in this approach from a crop response point of view is that equal weight was attributed to the 10% of roots at the lower part of the root zone as to the 40% of the roots in the upper quarter of the root zone. By weighting each portion of the root zone's EC contribution by the percentages shown in the diagram, one can calculate the weighted soil-water salinity more accurately. In this case, the root-weighted average EC_{sw} is 2.33 dS/m. This is significantly less than 3 and, in principle, would more accurately represent the impacts on the crop.

However, there is another major deficiency with the Ayers and Westcot analysis. Following the procedures of Ayers and Westcot to calculate the water distribution, the soil water content is found to decrease with depth. Assuming the soil surface to be saturated with a volumetric water content of 0.50, the distribution of volumetric water content at successively lower nodes decrease as follows: 0.33, 0.20, 0.115, and 0.075 at the bottom of the root zone as depicted in my Figure 2. In other words, the bottom of the root zone is extremely dry. This water distribution as calculated from the steady-state approach differs drastically from the typical water distribution found in the field and is not realistic.

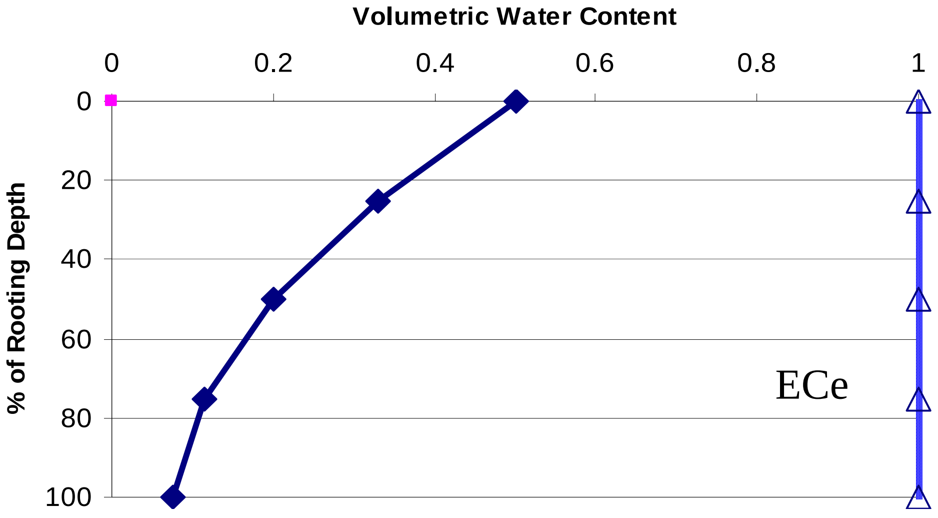


Figure 2. The distribution of water content and accurately calculated EC_e for steady-state condition of Ayers and Westcot for 15% leaching fraction and irrigation with a water salinity of 1.0 dS/m.

Ayers and Westcot made the usual assumption that EC_{sw} equals 2 EC_e in converting EC_{sw} to the EC_e values that are reported in their Table 3. This commonly used relationship is recognized as being a very useful approximation, but it lacks rigor when a quantitative analysis is required. This relationship assumes that at water contents that soils are commonly collected in the field, an equal amount of distilled water must be applied to saturate the soil from which a solution can readily be extracted and analyzed. This isn't necessarily true. Therefore, for an accurate quantitative analysis, one must measure the soil water content of each sample as well as the amount of distilled water applied to each sample, and then calculate the appropriate dilution factor. This would give the true quantitative relationship between EC_{sw} and EC_e of each sample.

Using the salt distributions reported in the Ayers and Westcot Figure 2 and the soil-water content distributions in my Figure 2, and adding sufficient distilled water to bring the soils to saturation, results in an EC of the saturated extract (EC_e) equal to 1.0 dS/m at each depth as illustrated in Figure 2. For the steady-state case, the accurate EC_e at each depth is equal to EC_i. Therefore, the average root zone EC_e is equal to EC_i, and *not* 3/2 EC_i as computed by Ayers and Westcot. One could then conclude that an irrigation water salinity of 1.0 dS/m would be protective of the most salt-sensitive crops.

In conclusion, the steady-state analysis as proposed by Ayers and Westcot clearly has scientific deficiencies from a quantitative point of view. The assumed steady-state condition does not represent conditions in the field. Therefore, an alternative approach is required to establish a better relationship between the irrigation water salinity and the salinity in the root zone to which the crop responds.

An Alternative to Steady-State Approach

Ayers and Westcot (1985) readily recognized that the natural soil-water system reacts differently than their simplified analysis. They state, “As the soil dries, the plant is also exposed to a continually changing water availability in each portion of the rooting depth since the soil-water content and soil water salinity are both changing as the plant uses water between irrigations. The plant absorbs water, but most of the salt is excluded and left behind in the root zone in a shrinking volume of soil water. Figure 4 shows that following an irrigation, the soil salinity is not constant with depth. (Their Figure 4 is reproduced in this report). Following each irrigation, the soil-water content at each depth in the root zone is near maximum, and the concentration of dissolved salts near the minimum. Each changes, however, as water is used by the crop between irrigations.” Figure 4 depicts the measured soil-water salinity at the 40- and 80-cm depths as a function of time for irrigated alfalfa as reported by Rhoades. As described by Ayers and Westcot, the salinity at a given depth increases with time as the crop extracts the water. The irrigation leaches the accumulated salts out of the zone so that the soil salinity starts out at the same concentration after each irrigation, particularly in the upper part of the root zone where most of the roots are.

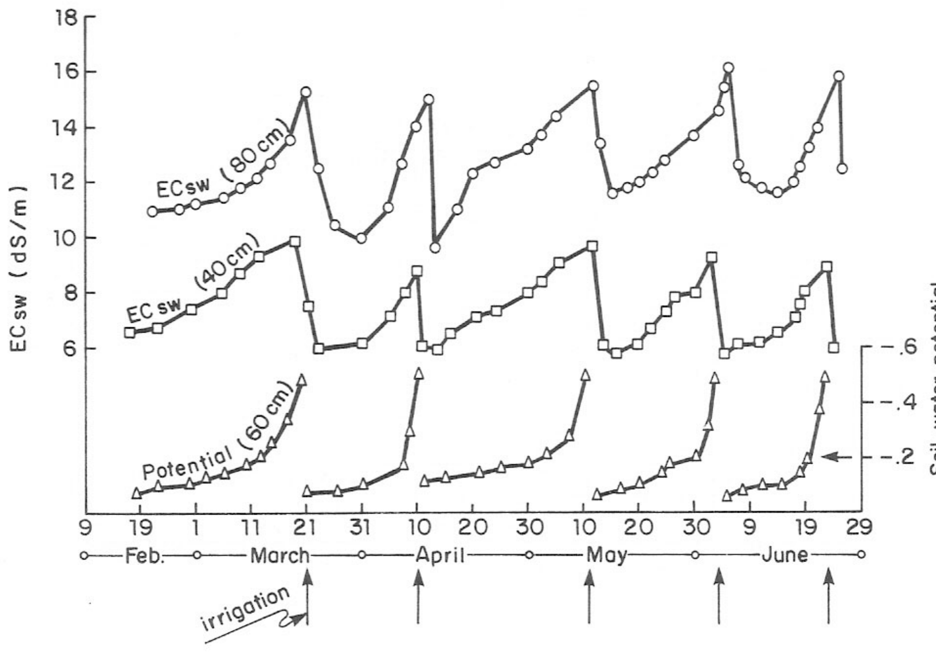


Fig. 4 Change in salinity of soil-water (EC_{sw}) between irrigations of alfalfa due to ET use of stored water (Rhoades 1972)

The magnitude of the salt concentration from immediately after irrigation to immediately before the next irrigation depends on the volumetric water content immediately after and before irrigation. The law of mass conservation dictates that the salt concentrates proportionately to the change in volumetric soil water content when there is no salt dissolution or precipitation. The change in volumetric water content between irrigation depends on the soil-water retention characteristics. For most soil types the volumetric soil water would decrease by less than half between irrigations. Consequently, the soil salinity would concentrate less than two times between irrigations. Therefore, it is logical that if one applies water at one-half the threshold value, the soil-water salinity will not concentrate beyond the threshold value before the next irrigation. For the example in Figure 4, the soil water salinity at the 40-cm depth increased in concentration by a factor of 1.7 between irrigations, which would be expected for many soils.

I would not recommend choosing 1.7 as the concentrating factor for two reasons. First, it leaves no margin for possibly having a soil with more extreme soil-water holding characteristics. Second, the salt transport is assumed to be completely efficient with no bypass. In other words, the soil solution will not be exactly the concentration of the irrigation water, thus a factor of two would be a more conservative approach. Using a factor of 3 as suggested by Ayers and Westcot, steady-state analysis is not justified based on the dynamics of soil water flow, salt transport mechanisms, and plant interaction with soil water.

By coincidence computing the irrigation water salinity that can be used to grow a crop with a given Maas-Hoffman threshold salinity is simple. The concentration of salts in the soil water increases by a factor of approximately two between irrigations. The Maas-Hoffman coefficients are based on the salinity of the saturated soil extract, or EC_e, which is approximately equal to ½ of the salinity of the soil-water, or EC_{sw}. Therefore, the irrigation water salinity that can be tolerated is equal to the Maas-Hoffman threshold value when they are reported as EC_e.

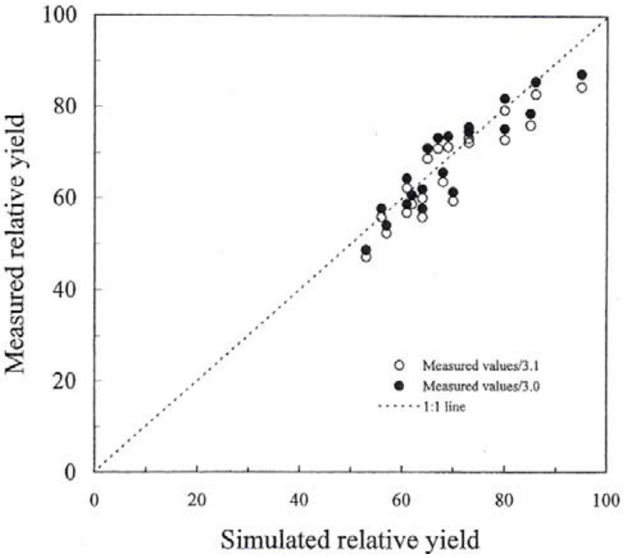
The most salt-sensitive crop grown in the area of interest is beans. The Maas-Hoffman threshold EC_e for beans is 1.0 dS/m. Therefore, an irrigation water as high as this value could be used without reduction in yield.

Contribution of rainfall toward reducing salinity effect

The analysis reported above neglected the effects of rainfall. Rain is almost pure water and therefore provides salt-free water to satisfy a portion of the crop need. The challenge is to quantify the contribution of rain towards partially mitigating the impacts of saline irrigation water.

I developed a model in 1985 (Letey et al. 1985) which allowed the computation of relative crop yield and amount of deep percolation based upon the amount and salinity of the applied irrigation water, crop tolerance to salinity, and the potential ET for a nonstressed crop. A comparison of model simulated results to experimental values was reported by Letey and Dinar (1986). One comparison was done with results from an experiment conducted in Utah, where snow and rain contributed to the crop water supply. The computed yields agreed quite well with the experimental yields when the weighted average EC of the rain and irrigation waters was used in the computations. Based on this, the contribution of rain can be estimated based on the weighted average EC of the combined rain and irrigation water.

Although the original seasonal model has great utility, it is limited to conditions where the same irrigation management and crop are continuously followed. Subsequently, I was involved in developing a transient-state model that allows incorporating the time, amount, and salinity of irrigation water applied. This model tracks the soil water content and water salinity as a function of depth and time and allows computation of relative crop yield and deep water percolation (Cardon and Letey, 1992; Pang and Letey, 1998). This model has much greater flexibility to simulate the consequences of a wide array of management practices. Excellent agreement between simulated relative yield and the measured relative yield for an experiment conducted on corn in Israel was achieved (Feng et al. 2003). Figure 3 of the Feng et al. (2003) publication which illustrates the agreement between measured and simulated relative yields is reproduced below to document the validity of the model.



Comparison of measured and simulated relative yields assuming unstressed yield equal to 3.0 and 3.1 Mg ha^{-1}. (Feng et al. 2003).

The transient-state model can be used to simulate the effect of various cyclic and blending strategies for using non-saline and saline waters for irrigation (Bradford and Letey, 1993). In one case, the model was used to simulate mixing waters before irrigation or intermittently using waters of different qualities for the irrigation of the perennial crop alfalfa. The intermittent applications of saline and non-saline waters were done on alternate irrigations. The periods of use for each type of water varied, and the longest simulation was an annual use of non-saline water followed by an annual use of saline water. The same total amount of water and salts were added to the system in all simulations.

The main finding was that no significant difference in simulated yields occurred whether the waters were mixed prior to application, or were intermittently applied for different lengths of time. In other words, the crop response was to the integrated average EC of the waters regardless of when or how long the individual waters were applied. This result is consistent with Meiri et al. (1986) who conducted a three-year study in Israel to compare crop performance under mixing irrigation waters or intermittently applying them to the soil. They concluded that the crops responded to the weighted mean water salinity regardless of the blending method.

Therefore, both experimental evidence and theoretical model analyses come to the same conclusion. The crop responds to the weighted mean water salinity between rainfall and irrigation water. The amounts and concentrations of irrigation and rainwater that contribute to crop production, including the off-season water penetrating the soil, in addition to the in-season applications, must be included in the analysis such as was done in all of the reported studies.

With this information as background, one can now make quantitative estimates of the contribution of rain to partially mitigate the effects of salinity in the irrigation water in the area of interest. The weighted mean water salinity is calculated by equation 1

[1] $$C_a = \frac{C_i A_i}{A_i + A_r} \qquad or \qquad C_i = \frac{C_a (A_i + A_r)}{A_i}$$

where C_a is the weighted mean water salinity, C_i is the irrigation water salinity, A_r is the amount of rainfall, and A_i is the amount of irrigation.

The main uncertainty in making this computation is in properly accounting for the amount of rainfall that contributes to the crop water supply. As previously stated, rainfall during the off-season recharges the soil profile, leaches salts, and therefore contributes to the welfare of the crop.

Based on the factors stated above, I will now compute the contribution of rainfall towards the production of beans in the area of interest for three assumptions on the effective amount of precipitation. The assumptions are 25, 50, or 75% of the total precipitation contributed to the crop production.

The crop ET was calculated by multiplying the ET_o value from the nearest CIMIS station by the appropriate crop coefficient (K_{cr}). The numbers reported in Table 2 are for dry beans or large limas grown from May 1 to August 28. The average annual precipitation at the Tracy Pumping Plant based on a 55-year period of record is 12.24 inches. I will assume that 10% more water than crop ET is applied through a combination of irrigation and rain to accommodate some leaching. Thus, the ET times 1.1 equals 28.4 inches. The amount of irrigation (A_i) will equal 28.4 inches minus the effective precipitation, which will be calculated for 25, 50, and 75% times the total precipitation of 12.24 inches.

The results of these computations are presented in Table 3 for the three assumptions on the effective precipitation. The computed C_a value in the table represents the weighted average EC when the irrigation water salinity is 1.0 dS/m. The C_i number in the table represents the concentration of the irrigation water that could be used if the weighted average EC of the water equal to 1.0 dS/m is protective for producing beans. These calculations were done to illustrate that rainfall can significantly mitigate the impact of irrigation water salinity. If only 25% of the precipitation was effective, an irrigation water salinity of 1.12 rather than 1.0 dS/m could be used without impacting the most salt-sensitive crop.

Table 2. Computed crop ET for beans

	K_{cr}	ET_o in/mo	ET in/mo
May	0.40	6.45	2.58
June	0.97	7.45	7.23
July	1.15	8.02	9.22
Aug	0.96	7.11	6.82
Total			25.85

Table 3. Computed contributions of rainfall to partially mitigating the effects of salty irrigation water.

$A_i + A_r$	A_r	A_i	C_a[1]	C_i[2]
28.4	3.1	25.3	0.89	1.12
28.4	6.1	22.3	0.78	1.28
28.4	9.2	19.2	0.68	1.47

1. Calculation of C_a from equation 1 if C_i is 1.0 dS/m.
2. Calculation of C_i from equation 1 of C_a equal to 1 was adequate crop protection.

Experimental results and the results from theoretical model analyses all come to the same conclusion--that irrigation water with an EC of 1.0 dS/m or slightly higher would be sufficiently protective for the most salt-sensitive crops. Nevertheless, the conclusion should be compared as much as possible to what is actually happening under real farming operations. Equally salt-sensitive crops are being successfully grown in the Coachella and Imperial Valleys of California when irrigated with Colorado River water. The EC of the Colorado River water is approximately 1.25 dS/m. Furthermore, precipitation contributes almost nothing to the crop water demand in these valleys.

Based on all of this documented evidence, I confidently conclude that an irrigation water concentration of 1.0 dS/m is sufficiently protective for even the most salt-sensitive crops grown in the area of interest.

Comments on the “PROTEST-APPLICATION” to Change 0.7 EC to 1.0 EC

In the South Delta Water Agency Protest of the Department of Water Resources and the U.S. Bureau of Reclamation’s Petition to change the 0.7 EC, each of the farm protestants claim that they would be damaged by not enforcing the 0.7 EC standard currently in effect and they provide exhibits G, H, and I to support their claim.

Exhibits G and H provide some laboratory analyses indicating high chloride concentrations in walnut leaves. However, the source of the chloride is not identified. Chloride and salinity are not synonymous terms. Chloride is one chemical component which contributes to TDS. The difference in chloride concentration between waters of 0.7 and 1.0 EC would be relatively small and could not contribute to the very high chloride analysis of the walnut leaves which were measured.

The testimony of William Salmon (Exhibit H) states “To address this problem over the years, I have applied soil amendments such as gypsum and have flooded the fields in the winter to attempt to flush out the salts. However, the soil pH in combination with the salty water binds the chlorides and prevents leaching.” The latter statement is chemically incorrect. Chlorides are very mobile and easily transported by water. Salty water does not bind chlorides and prevent their leaching. In my professional judgment, if chlorides are causing crop damage, the damage is not associated with the irrigation water having an EC of 1 rather than 0.7 dS/m. It definitely is not a result of the chlorides being prevented from leaching by the salinity.

The reported decrease in walnut production between 1999 and 2002 by Salmon are far greater than can be attributed to irrigation water salinity. Indeed, I do not see any evidence that the irrigation water salinity was higher in 2002 than in 1999. And if there was a difference, the difference would be very small and could not be responsible for these large yield reductions. As a matter of fact, it is stated that the orchard would have had to be removed eventually due to a virus. These decreases were likely due to virus infection, rather than salinity.

Exhibit I is a report prepared by Dr. G. T. Orlob in 1987. His Equation 2, which relates the yield reductions to the Maas-Hoffman coefficients and leaching fraction, is based upon the steady-state analysis of Ayers and Westcot. As noted above, the steady-state analysis does not accurately represent field conditions, and indeed a quantitative error is introduced by improperly calculating EC_e. I also pointed out that Westcot and Ayers provided a more accurate description of the dynamics in the soil-water-salinity interactions than the steady-state analysis. However, the steady-state analysis allows developing equations for doing calculations as was done by Orlob. However, since these equations are all based on an erroneous starting point, none of the results can be considered as being quantitatively valid.

Conclusions

The most salt-sensitive crops have a threshold salinity of 1.0 dS/m. Based on the dynamics of water flow, salt transport, and crop-soil water interactions, an irrigation water with an EC of 1.0 dS/m is sufficiently protective of salt-sensitive crops and can be used to irrigate these crops without yield reduction. The contribution of rainfall provides an added margin of safety to this conclusion. Finally, this conclusion is consistent with experience in the Imperial and Coachella Valleys of California, where the salt sensitive crops are being successfully irrigated with Colorado River water with an EC of approximately 1.25 dS/m.

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