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Reusing Saline Drainage Waters for Irrigation: A Strategy to Reduce Salt Loading of Rivers

J.D. Rhoades
U.S. Salinity Laboratory
4500 Glenwood Drive
Riverside, California

INTRODUCTION

The theme of this symposium is salinity control in river systems. Irrigated agriculture is a major contributor to the salinity of our rivers, especially the Colorado River. The agricultural community has a responsibility to protect the quality of our environment and to improve water use efficiency to conserve water. It must also maintain a viable, permanent irrigated agriculture. Irrigated agriculture can not be sustained without adequate leaching and drainage to prevent excessive salination of the soil. But these processes are the ones that contribute to the salt loading of our rivers. Obviously, river salinity could be reduced if this component of its salt loading were eliminated. To protect our water resources against excessive salination, while sustaining agricultural production through irrigation, we need a well thought-out and developed land-water use policy -- a policy that is compatible with high crop production and with maintaining suitable water quality while recognizing the realities of the natural processes involved in the soil-plant-water and associated geohydrological systems.

Several strategies may be identified to cope with increasing levels of salinity in river systems resulting from irrigation. First, irrigation can be eliminated. In some instances this might be appropriate but, in general, this approach is untenable. Second, point sources of drainage return flow can be intercepted and diverted to other outlets and ends. For example, saline drainage water can be desalted before reuse, it can be disposed of by evaporation in a pond or by injection into some isolated appropriate deep-aquifer, or it can be used as a water supply for some application for which such brackish waters are appropriate. Drainage waters contain more salt than does the fresh water supply, but not generally at unacceptable levels for the irrigation of some crops [1]; one use of saline drainage water would be reuse for irrigation. It would reduce the amount of brackish water returned to the river and would reduce the salination of the associated river system; with proper procedures, it could maintain, or even increase, a suitable agricultural water supply and crop production base. Growing tolerant rather than sensitive crops clearly permits use of more saline water. In this paper a strategy of substitution of drainage water for the conventional water for irrigation at certain times is presented that prevents the development of highly saline soils, which can only be used to grow a few salt-tolerant crops, and eliminates the need for special equipment and techniques. Third, the amount of water lost in seepage and deep percolation can be reduced, thus lessening the amount that passes through the soil. Since this deeply percolating water often displaces saline groundwater of higher salinity, or dissolves additional salt from the subsoil, reducing it will reduce the salt load returned to the river (or groundwater) as well as reduce some unrecoverable water loss. The adoption of the "minimized leaching" concept of irrigation should be of appreciable benefit for reducing river salinity, especially in the Colorado River basin, as has been pointed out in detail before [2-5].

The latter two strategies of agricultural management offer considerable potential to reduce salinity in our river systems while maintaining the viability of our irrigated agriculture. In this paper the "cyclic" drainage water reuse strategy is presented in principle. The various engineering, economic, social and political aspects and issues are not discussed - just the technical feasibility of growing crops with such waters.

Irrigated Agriculture and Salinity Management

When plants extract water from the soil they leave most of the salt behind in the remaining water. If such salts are allowed to accumulate in the rootzone, their concentration will increase until crop growth is no longer practical. To sustain irrigated agriculture, extra water must therefore be applied to leach out this salt. This drainage water is unavoidably higher in salts than the applied water. The salt must go somewhere--to either surface water or groundwater. This has often been interpreted as requiring that the amount of salt removed in the drainage water must equal or exceed that brought in with the irrigation water. Such a

simple concept of salt balance requires refinement before it can be applied to field situations. When the concentration of salts in the soil water is low, primary minerals tend to dissolve, adding salt to the soil solution; when the concentration of salts in the soil water increases mineral dissolution stops and certain salts, such as calcite and gypsum, tend to precipitate. As a consequence, the amount of salt discharged in the drainage water can be changed drastically--by as much as 50 percent or more--by reducing the amount of water applied for irrigation and the fraction of it that is passed through the soil [3]. Whether or not this will result in a reduction of salinity in the receiving water varies with the chemistry of the waters involved and the geohydrologic conditions [4,5]. In many geohydrologic situations drainage return "picks up" highly soluble salts from the soil substrata through which the drainage water flows enroute to the river or more saline groundwater is displaced by it into the river. For such situations, reduced leaching will always reduce degradation of the receiving river. An example, is the Colorado River through Grand Valley (many other upper Colorado River basin projects are similar). Here, reduced leaching should reduce the salt load in the river by reducing salt "pick up" during percolation and displacement of the highly saline groundwater out of the cobble aquifer [4].

Thus, there is an excellent opportunity to reduce the salt load contributed by drainage water through better irrigation management, especially through reductions in seepage and deep percolation. Of course, there are practical constraints in the real world which limit such reductions. But the ultimate goal should be to maximize the utilization of an irrigation water supply in a single application with minimum drainage. To the extent that the drainage water still has value for use by a crop of higher salt tolerance, it could be used again for irrigation. This could be achieved by successively irrigating a sequence of crops of increasing salt tolerance. The properties of representative agricultural drainage waters of the western United States have been evaluated and judged generally suitable for irrigation [1, 6]. Such reuse of drainage would reduce the salinity of the river system since the saltload associated with the drainage return would not be added to it.

Frequently, of course, drainage waters are returned by diffuse flow or intentional direct discharge to the water course and automatically "reused" after mixing, a practice that has some advantages [7, 8]. To illustrate, diversions in excess of needs in Utah provide return flows for irrigation downstream in the Colorado River system. The excess diversions relax demands for intensive irrigation management, while the return flows tend to modulate the river flows. However, as pointed out earlier, such return is the mechanism by which much of the salt loading of rivers occurs. Furthermore, the increased river salinity that results often limits the crops which can be grown. Even more important, as will be discussed in more detail later, if the water being returned to the river is so saline that its use for crop production is spent in the first use then diluting it with purer water and using the mix for irrigation downstream of crops of the same or lesser salt-tolerance does not add to or contribute to the usable water supply in the river for crop production. One has, in this process of mixing, simply utilized the river as a combined "delivery-and disposal" system and mixed the usable and unusable waters into one blend which must be separated again during use by the plant. In an irrigated soil, the plant, through evapotranspiration, "distills" out the usable fraction of the mix (expending bio-energy to do so) and the "unusable" fraction passes through the profile again without contributing to evapotranspiration and in the process displaces or "picks up" more salt in the substrata flow path. Greater flexibility and opportunity for crop production results if the drainage water can be intercepted, isolated and kept from being returned to the river. Then the waters can be blended or used separately, as desired, for irrigation or other uses as appropriate to the situation at hand. Once the waters are mixed, these alternatives are lost.

Irrigation With Saline Drainage Water

As discussed above, total salt output is least when leaching is kept to a minimum. But with reduced leaching, the salt concentration in the soil water, as well as drainwater, is increased. Thus, the extent to which leaching can be minimized in practice is limited by the tolerances of crops to increased salinity in the rootzone [9]. As pointed out by Leon Bernstein [10]:

> ...under conditions of maximum efficiency of water use, the drainage water in passing through the rootzone will have had its salt content increased by evapotranspiration to the maximum level possible without unacceptable damage to the crop. Such drainage is spent and can contribute nothing more to the water needs of crops of the same or lower salt tolerance than the crop that it already nourished...

This is so because the plant must expend bio-energy (that would otherwise be used in biomass production) to extract water from the saline (low osmotic potential) soil solution.

The plant removes the "good water" fraction from the mix until the fraction of the mix made up of the excessively saline portion is left. This fraction is just as unusable at this point as it was the first time because it requires more energy to separate the pure water from the low osmotic potential solution than the plant can muster. Thus, diluting spent drainage water with less saline water does not stretch the water supply for crops of the same or lower salt tolerance. This "saline water" component is usable, however, if reused on crops that are more salt-tolerant than those which produced the drainage. Bernstein also indicated that for any succession of crops, the fraction of <u>maximally used</u> drainage water available for reuse could be determined by

$$1 - \frac{\sigma_a}{\sigma_b} \tag{1}$$

where σ values refer to the allowable salinities (expressed in electrical conductivity) in the drainage water for the first crop, a, and the second crop, b. Extremely high irrigation efficiencies are needed to completely utilize most irrigation waters in a single use. For example, for an irrigation water of $\sigma = 1.0$ dS m^{-1}, leaching fractions of 1/45 to 1/15 would be needed for the most salt-tolerant and sensitive crops, respectively. With such efficiencies, 67 percent of the drainage water from the most-sensitive crops would be usable for the most tolerant crops. While new methods are being developed toward this goal, the required efficiencies to maximally use normal irrigation water in a single cycle are rarely attainable with present irrigation methods. A recent Bureau of Reclamation survey of 231 irrigated fields showed that only 44 percent of the water applied was used consumptively [8]. In some cases, drainage water is inadvertently recovered and used for irrigation elsewhere because drainage often returns by diffuse flow to the water supply system [7]. Even though there is uncertainty in the magnitude of available drainage water and in amount recovered, an appreciable amount of water diverted for irrigation becomes wasted drainage water. Furthermore, when the water mixes back with the receiving water it increases its salinity and hence limits its usability for sensitive crops (or certain industrial and domestic uses) as explained above.

The above estimate of the fractional usability of drainage waters is based on the assumption of steady-state conditions and use of but that one water of fixed salinity level for irrigating the crop. The usability will not be the same under non-steady state conditions nor where another water of better quality can be used sequentially with it. But this strategy of use of drainage waters will be discussed in more detail later. Before that, some evidence that waters with salinity levels like those found in typical drainage waters can be used successfully to grow salt-tolerant crops, even with conventional methods, is in order. Since such evidence has been reviewed in detail elsewhere [2, 6], it will not be repeated here. Suffice it to say that experience abroad and in the U.S. indicates that waters of far higher salinities than conventionally classified as suitable can be used effectively for irrigating selected crops. It appears that water quality standards are very much affected by the availability of better quality water supplies. If ample water of low salinity is generally available, waters of relatively low salinity are classified as "unusable", but if such good quality waters are not available, saline waters are judged more usable. The scale is obviously a sliding one, based on the availability of better quality water.

Cyclic Crop/Water Strategy for Using Saline Waters

A way to use brackish waters for irrigation of suitably tolerant crops that should result in little, if any, loss of yield as well as increase the opportunity to use the same land to grow salt sensitive crops without special equipment or techniques has been conceived and is now under test in two field projects. The impetus for the strategy has its origin in the assumption that typical farmers will not voluntarily use drainage (brackish) water for irrigation given access to enough water of lower salinity unless the brackish water can be used to yield a higher income without loss of cropping flexibility or significant change of farming operations. The proposed management strategy which meets such requirements is to substitute the saline (drainage) water for the "good" (river) water when irrigating certain crops in the rotation when they are in a suitably tolerant growth stage; the "good" water is used at the other times. The maximum soil salinity in the rootzone resulting from continuous use of brackish water will not occur when such water is used for only a fraction of the time. The timing and amount of substitution will vary with the quality of the two waters, the cropping pattern, the climate, and the irrigation system. Whatever salt build up occurs in the soil from irrigating with the brackish water can be alleviated in the subsequent cropping period when a more sensitive crop is grown using the normal (low-salinity) water for irrigation. A soil will not generally become unduly saline from use of a saline water for a part of a single irrigation season and often not for several seasons. Furthermore, the yield of the sensitive crop should not be

reduced if proper pre-plant irrigations and careful management are used during germination and seedling establishment to leach salts out of the seed area and shallow soil depths. Subsequent "inseason" irrigations will leach the salts farther down in the profile ahead of the advancing root system and "reclaim" the soil in preparation for the next time when the brackish water will be used again to grow a suitably tolerant crop. This cyclic use of waters of "low" and "high" salinity waters prevents the soil from becoming saline while permitting, over the long period, substitution of the brackish water for a better quality water for a large fraction (>50%) of the irrigation water needs. The farmer would benefit economically because the drainage water costs would be less than the conventional irrigation water. If not, he should be subsidized to use it. Such monies could be made available from the savings accrued from the reduced river salinity and associated damages and costs of alternative control measures.

The suggested strategy for using brackish waters for irrigation is intuitively appealing and has good potential. But it can not be claimed that its validity has been established, because the long-term consequences have not yet been fully evaluated. However, the strategy is under evaluation in three experiments.

One is a forty-acre field experiment which was begun on a cooperators farm in the Imperial Valley, California in January, 1982. Two cropping patterns are under test there. One is a successive-crop-rotation of wheat, sugar beets, and melons. In this rotation Colorado River water (0.9 g L^{-1} TDS) is being used in the preplant and early irrigations of wheat and sugar beets and for all irrigations of melons. The remaining irrigations are with Alamo River (drainage water of 3.5 g L^{-1} TDS). The other is a block rotation of cotton (a salt-tolerant crop) for several years followed by wheat (a crop of intermediate salt tolerance) and then by alfalfa (a more sensitive crop) for a block of several years. Drainage water is being used for all or part of the irrigations of cotton; beginning with the wheat crop only Colorado River water will be used. Wheat should withstand the salinity initially present in the soil achieved from irrigating the cotton with the brackish water and yield well when irrigated with Colorado River water. Sufficient desalination of the soil will occur during its irrigations with Colorado River water to subsequently permit the alfalfa crop to be grown without loss of yield. To date, one wheat crop and one cotton crop have been harvested and the highest yields were actually obtained in both cases with the treatments which received the greatest amount of drainage water substitution for Colorado River water -- 75 and 100 percent, respectively.

A second field experiment has been underway near Lost Hills in the San Joaquin Valley of California for five years. In this case a very saline water (6.0 g L^{-1} TDS) has been used to irrigate cotton following seedling establishment with California aqueduct water (0.3 g L^{-1} TDS), for four consecutive years. Wheat is now being grown with aqueduct water for desalination purposes. Subsequently sugar beets and then cotton will be grown with the "cyclic" strategy. This experiment, upon completion should provide appropriate data to evaluate the long-term effects of the strategy. This is a demanding test since a very saline (>sea water) ground water has existed beneath the test area at a depth varying between 0.4 and 0.9 meters for the last three years, eliminating the opportunity for leaching and causing the soil salinity to increase to abnormally high levels. In spite of these problems, 1982 cotton lint yields were good: 2.8 bales per acre (aqueduct water only) and 2.3 bales per acre (drainage water after seedling establishment).

A new experiment has just been initiated to simulate the two field conditions in a controlled lysimeter facility. A computer model is being developed to predict the chemistry of the soil water with cyclic crop/water use within the rootzone and over time for a variety of cropping situations. It will be tested with the empirical data obtained. The long term consequences of the strategy will then be evaluated for various water quality combinations and cropping situations.

CONCLUSION AND SUMMARY

A strategy to control the salinity of river systems is to intercept drainage returns before they are mixed back in the river and to use them for irrigation by substituting them for the river water normally used for irrigation at certain periods during the irrigation season of certain crops in the rotation. When the drainage water quality is such that its potential for reuse is exhausted then this drainage is discharged to evaporation ponds. This strategy will conserve water, sustain crop production, and minimize the salt loading of rivers that occurs by irrigation return flow. It will also reduce the amount of river water diverted for irrigation. Its primary objectives are to substitute drainage water for some of the river water used for irrigation without significant yield reduction, loss in cropping flexibility, or change in current farming operations. The strategy is to irrigate salt sensitive crops (lettuce, alfalfa, etc.) in the rotation with river water and salt tolerant crops (cotton, sugar beets, wheat,

etc.) with drainage water. For the tolerant crops, the switch to drainage water would usually occur after seedling establishment --preplant irrigations and initial irrigations being made with river water. The feasibility of this strategy is supported by the following: 1) the maximum soil salinity in the rootzone resulting from continuous use of drainage water will not occur when such water is only used for a fraction of the time; 2) substantial alleviation of salt build-up resulting from irrigation of salt tolerant crops with drainage water will occur during the time salt-sensitive crops are irrigated with river water; 3) proper preplant irrigation and careful irrigation management during germination and seedling establishment leaches salts out of the seed area and from shallow soil depths and 4) data obtained in field experiments to date support the credibility of this "cyclic" reuse strategy. That this strategy is valid has yet to be established because the long-term consequences have not yet been fully evaluated.

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