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Salinization of Irrigated Soils and Associated Waters: A Major Colorado Problem

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Introduction

Irrigated agriculture is a major contributor to crop production. It is presently practiced on about 15 percent of the nation's cropland but contributes about 40 percent of the crop value. The dependency on irrigation in this regard is expected to increase over the period of the next thirty years. The growth in the expansion of world-wide irrigation has dramatically slowed over the past decade or two to a present rate that is inadequate to keep up with the projected expanding food requirements. At the same time, many presently developed irrigated lands and associated water resources have become substantially degraded through salinization caused by irrigation and drainage activities. In Colorado, this degradation appears to be on the increase in the Lower South Platte River and Arkansas River Valleys.

Soil and Water Degradation by Irrigation/Drainage

Irrigation water infiltrated into the soil in excess of that used by the crops becomes drainage water once it passes through the rootzone. This drainage water becomes salinized as the salt in the applied water is concentrated in the reduced drainage volume. This drainage water, together with that percolating downward from canal seepage, often gains additional salts from the dissolution of mineral-salts and the weathering of silicate minerals present in the soil and underlying substrata (especially those of marine origin). This salt-laden drainage and seepage water generally flows into lower-lying landscapes or is transported into receiving waters. Lower-lying fields become waterlogged when the water tables become shallow in depth; they become salinized when the salt-laden groundwaters are "wicked up" into the soils and the salts are accumulated in the topsoil by evaporation. Receiving waters, especially rivers, become salinized when salt-laden drainage "returns" are discharged into them. The above-described combined processes of salt mobilization, redistribution and localization associated with drainage/seepage flows are the most prevalent causes of waterlogging and of the degradation by salinization of irrigated lands and associated water supplies.

Extensive areas of irrigated land in Colorado have become salinized in the above-described manner, and their associated water supplies have become similarly degraded. The Arkansas River is well known for the degree of its progressive downstream salinization; only in relatively recent few years has it been recognized that the Lower South Platte River and associated irrigated lands are becoming increasingly salt-affected.

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Substantial programs have not been implemented to rejuvenate the irrigated lands in Colorado that have become degraded by salinity. Programs have been implemented to reduce salinization of the Colorado River with some success, but not of the Arkansas or South Platte Rivers.

Some Guiding Principles of Salinity Control

There is usually no "single--way" to achieve salinity control in irrigated lands and associated waters. Many different approaches and practices can be combined into satisfactory control systems; the appropriate combination depends upon economic, climatic, social, as well as edaphic and geohydrologic situations. However, some important principles and strategies of salinity management exist that should be understood and used to develop appropriate "packages" of management for purposes of increasing water use efficiency in irrigation, reducing the drainage discharges which cause waterlogging and soil/water salinization and optimizing the usability of irrigation water supplies. These principles and strategies will now be briefly reviewed in terms of four important management element-objectives; they are discussed more fully elsewhere[2].

1. Deliver Water Uniformly to Fields in Correct Amounts and Timing

A key element of salinity control is efficient irrigation. This requires that consumable water must be applied uniformly, without undue excess, to fields to provide the individual plants with water as needed to meet evapotranspiration requirements and to avoid salinity stress. Thus, careful control of irrigation timing, of application uniformity and of amount of water applied and stored in the rootzone are prerequisites in this regard. This calls, optimally, for water delivery to the field on demand, which, in turn, requires close coordination between the irrigator and the organization that delivers the water. It also calls for measurement of water flow (rates and volumes), feedback devices that measure the status of water and salinity in the soil, ways to predict or measure the content of available soil moisture, ways to detect or predict the onset of plant stress, and ways to control of volume delivered to each field and its distribution within it. It also calls for the prevention of seepage from the distribution and drainage-discharge canals.

2. Minimize Deep Percolation and the Need for Drainage

To prevent the excessive accumulation of salt in the crop rootzone from irrigation, a relatively small amount of extra water (or rainfall) must, over the long term, be applied in excess of that needed for evapotranspiration (ET) and this excess must pass through the rootzone in a minimum net amount. This amount, in fractional terms, is referred to as the "leaching requirement" (L_r, the fraction of infiltrated water that must pass through the rootzone to keep salinity within acceptable levels for crop production). In fields irrigated

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[2] Rhoades, J.D., A. Kandiah, and A. M. Mashali. 1992. The Use of Saline Waters for Irrigation. FAO Irrigation and Drainage Paper No. 48, Food and Agricultural Organization of the United Nations, Rome, Italy and Rhoades, J.D. 1999. Use of saline drainage water for irrigation. Drainage Monograph, Amer. Soc. Agron. (in press).

with conventional irrigation management, the salt concentration of the soil water is essentially uniform near the soil surface regardless of the leaching fraction (L, the fraction of infiltrated water that actually passes through the rootzone) but increases with depth as L decreases. Likewise, average rootzone salinity increases as L decreases; crop yield is decreased when tolerable levels of average salinity are exceeded. Once the soil solution has reached the maximum salinity level compatible with the crop tolerance, at least as much soluble salt as is brought in with additional irrigations must be removed from the rootzone; a process called "maintaining salt balance". Without net leaching, such as occurs by the abandonment of irrigation and by the USDA's WRP and CRP set-aside programs, moderately saline soils may become extremely salinized, especially if the water table remains at a shallow depth (~<6 feet).

In most irrigation projects, the currently used leaching fractions (and resulting drainage volumes) are excessive (L is typically about 0.4). They can be reduced appreciably without harming crops or soils; they should be minimized because the resulting excesses in leaching and drainage volumes are the major, fundamental causes of both soil and water salinization, for the reasons explained previously. Minimized leaching reduces drainage volume and the associated problems of waterlogging; it also reduces salinization in three ways. Less salt is discharged with reduced leaching because less irrigation water, and hence less salt, is applied. Reduced leaching reduces the discharged salt-load still more because the fraction of applied salt that precipitates as minerals (such as calcite and gypsum) in the rootzone of the soil increases. A further benefit of reduced leaching is that less additional "geologic" salts are "picked-up" by the percolating water from the weathering and dissolution of soil and substrata minerals, because the through–put of drainage water is reduced and the "solvent" capacity of the more saline water resulting from low leaching is likewise reduced. Thus, as compared to high leaching, minimized leaching reduces the amount of salt added to soils and discharged from irrigated rootzones because it maximizes the precipitation of applied Ca, HCO_3 and SO_4 salts as carbonate and gypsum minerals in the soil, and it minimizes the application of salts and the "pick–up" of weathered and dissolved salts from the soil and substrata. The extent to which leaching and drainage can be minimized is limited in theory by the salt tolerances of the crops being grown, but in practice it is limited more by the application efficiency of the irrigation system and by the variability in soil infiltration rates existing within the field.

To prevent waterlogging and secondary salinization, drainage must remove the precipitation and irrigation water infiltrated into the soil that is in excess of crop demand and any other excessive water (surface or subsurface) that flows into the irrigated soils; it must provide an outlet for the removal of salts that accumulate in the rootzone in order to avoid excessive soil salinization, and it must keep the water table sufficiently deep to permit adequate root development, to prevent the net flow of salt–laden groundwater up into the rootzone by capillary forces and to permit the movement and operations of farm implements in the fields without excessive compaction. Artificial drainage systems should be provided in the absence of adequate natural drainage. The water table depth required in order to prevent a net upward flow of groundwater and salt into the rootzone is dependent on irrigation management, as well as on soil hydraulic properties.

Therefore, a proper relation between irrigation management and drainage must be maintained in order to prevent irrigated lands from becoming salt affected and waterlogged. The amount of water applied should be sufficient to supply the crop and satisfy the leaching requirement but not enough to overload the drainage system. It is important to recognize that inefficient irrigation is the major cause of salinity and shallow water tables in most irrigation projects of Colorado, and of the world for that matter, and that the need for drainage can be reduced through improvements in irrigation management and through reuse of drainage water for irrigation. Ways to improve irrigation efficiency and to enhance drainage water reuse should usually be sought first before the drainage capacity is increased.

Where the drainage waters can be intercepted before being returned to lower lying lands or to surface or groundwaters, this should be done to prevent them from salinizing these precious resources. Intercepted saline drainage water can be desalted and reused, disposed of by pond evaporation or by injection into some isolated deep aquifer, or it can be used as a water supply where use of saline water is appropriate. The latter approach offers many advantages, as discussed next.

3. Intercept, Isolate and Reuse Drainage Water for Irrigation

Agricultural drainage usually finds its way naturally into fresh-water supplies, but sometimes by design with the intent to conserve water, to increase water use efficiency or to gain additional water to enable the expansion of irrigation. Such "blending" occurs repeatedly in the Arkansas and South Platte River systems and, though it enhances river flows, is probably counter productive. The return of saline waters to good-quality water supplies, even when sufficient dilution occurs to keep the salinity of the mixture within apparently safe quality-limits, reduces the quantity of the total water supply that can be used in consumptive processes (such as the growth of salt–sensitive crops) that are limited by salt concentration. More consumptive use (hence, crop production) can generally be obtained from the two waters by keeping them separated. A strategy for such "non-blended" use is described later. Those who advocate blending should consider the potential deleterious effect it can have upon the usability of the total water supply, not just what effect it has on the volume of available water.

The ultimate goal of irrigation/drainage management should be to minimize the amount of water unnecessarily extracted from the projects good–quality water supply and to maximize the utilization of the extracted portion during irrigation use, so that as much of it as possible is consumed in transpiration (hence producing biomass) and as little as possible is wasted and discharged as drainage. Towards this goal, to the extent that the drainage water from a field or project still has value for transpirational use by a crop (i.e., the crop is sufficiently salt-tolerant to be able to extract the water from the saline solution at a rate fast enough to meet its transpirational requirement), it should be intercepted and used again for irrigation before ultimate disposal. This will reduce drainage and the associated potential for salinization, as well as increase the available supply of water for irrigation. It will also reduce the waterlogging and overall amount of soil salinity degradation in the associated region.

There are essentially five alternative strategies for reusing drainage waters for irrigation: i) using the drainage water as a sole supply for irrigation, ii) using a blend of drainage and "fresh" water supplies, iii) using the two water supplies separately and sequentially in the so-called "serial/cyclic" method, iv) using the drainage water directly from the shallow water table by means of deficit irrigation, and v) using the drainage water from the shallow water table by means of a combination subsurface irrigation/drainage system, which controls the water table depth to optimize its use by the crop. Each of these strategies has its own advantages and disadvantages. These strategies are reviewed elsewhere[3].

The most generally preferred method is the serial/cyclic method. In this strategy, sensitive crops (such as alfalfa, beans, melons, etc.) in the rotation are irrigated with "low salinity" water (usually the developed water supply of the irrigation project), and salt-tolerant crops (such as barley, sugar beets, etc.) are irrigated with the saline water (such as drainage water generated in the project). For the salt-tolerant crops, the switch to saline water is usually made after seedling establishment; preplant and initial irrigations being made with the low-salinity water. The secondary drainage resulting from such reuse is also collected/isolated and used successively (serially) elsewhere for even more salt-tolerant crops (including eventually halophytes). The ultimate unusable drainage water should be disposed of to some non-polluting outlet or treatment plant.

The feasibility and utility of this serial/cyclic strategy has been supported by conceptual, modeling and experimental studies. The strategy, along with its advantages and disadvantages, are described more fully elsewhere[2]. Suffice it to say that better and more sustainable yields can generally be obtained by this strategy than can be obtained by using the saline water either solely for irrigation or after blending with low-salinity water. The next most appealing strategy is that of withholding irrigations in the latter part of the season to promote the extraction of water from the shallow groundwater; early season irrigations are managed to promote deep rooting.

Blending is not generally advocated as a means to facilitate the reuse of saline drainage waters because, as compared to the serial/cyclic strategy, it reduces the absolute amount of water that can be consumed in transpiration (hence crop production) and it increases the salinity level in the soil during the most sensitive seedling-establishment period. An important principle to be understood in this matter is the following one: if a drainage (waste) water is too saline to be solely usable for the crop in mind, then no additional consumptive-use benefit can be gained from it by blending it with a low-salinity water. But a loss can occur in the amount of such benefit that could have been achieved from the sole use of the low-salinity water for crop production.

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[3] J.D.Rhoades.1998. Use of saline and brackish waters for irrigation: implications and role in increasing food production, conserving water, sustaining irrigation and controlling soil and water degradation. pp 261-308, In R. Ragab and G. Pearce (eds.), Proc. Int l Workshop on Use of Saline and Brackish Water for Irrigation, July 23-24, 1998, Bali, Indonesia.

4. Monitor Soil Salinity to Evaluate Irrigation/Drainage Appropriateness

For reasons given elsewhere[4], I conclude that the effectiveness of irrigation/drainage design and management and of water-table/salinity control can not be achieved using traditional leaching requirement and salt balance concepts. Direct monitoring of rootzone salinity levels and distributions across fields needs to be undertaken periodically in order to evaluate the effectiveness of salinity, irrigation and drainage management programs, especially those involving drainage water reuse.

Indeed, in my opinion, the proper management of soil and water salinity requires the following: 1) an adequate knowledge of the level, extent, magnitude and distribution of rootzone soil salinity in the fields of the irrigation project (a suitable inventory of conditions); 2) the ability to be able to detect changes and trends in the status of soil salinity over time and the ability to determine the impact of management changes upon the conditions (a suitable monitoring program); 3) the ability to identify salinity problems and their underlying/inherent causes, both natural and management-induced (a suitable means of detecting & diagnosing problems and identifying their causes); 4) a means to evaluate the adequacy and effectiveness of on-going irrigation and drainage systems, operations and practices with respect to controlling soil salinity, conserving water supplies and protecting water quality from excessive salinization (a suitable means of evaluating management practices), and 5) the ability to determine the areas in fields and in irrigation projects where excessive deep percolation is occurring, i.e., where the water- and salt-loading contributions to the underlying groundwater are coming from (a suitable means of determining areal sources of pollution). I refer to the above set of measurement-related techniques and methods as "salinity assessment". Theory, equipment and practical technology has been developed for this purpose. It is described in a book to be published very soon[5]. I recommend that salinity assessment programs based on this technology, which provide the kind of required information described above in a timely and efficient way, should be implemented in Colorado.

Conclusions

The seriousness of the increasing salinity problems in Colorado needs to be fully grasped by the responsible leaders and agricultural and water resource managers in the state and appropriate policies and effective programs need to be developed and implemented to deal with this most serious matter. The effectiveness of irrigation needs to be enhanced, the return of drainage waters to fresh-water supplies needs to be curtailed and drainage waters need to be isolated and reused for irrigation to help meet the future water-supply/food production needs and to reduce the degradation of Colorado's soil and water

[4] Rhoades, J. D., et al., 1997. Assessing irrigation/drainage/salinity management using spatially referenced salinity measurements. Agr. Water Mgt. 35:147-165.
[5] Rhoades, J. D., et al., 1999. Soil Salinity Assessment: Methods of Electrical Conductivity Measurement and Interpretation, Food and Agriculture Organization of the United Nations, Rome, Italy.

resources. Strategies/management for such purposes exist, but are not being fully utilized.

An integrated holistic approach to irrigation/drainage management and monitoring is needed to sustain irrigation, to conserve water, to prevent soil salinization and waterlogging and to protect the associated water supplies, environment and ecology. Firstly, source control through the implementation of more efficient irrigation systems and practices should be undertaken to minimize water application and to reduce deep percolation. Unavoidable drainage waters should be intercepted, isolated and reused to irrigate a succession of crops of increasing salt tolerance, possibly including halophytes, so as to further reduce drainage water volumes and to conserve water and minimize pollution, while producing useful biomass and habitat. Conjunctive use of saline groundwater and surface water should also be undertaken to aid in lowering water table elevations, hence to reduce the need for drainage and its disposal, and to conserve water. Various means should be used to reclaim or to dispose of the ultimate unusable final drainage effluent. Unusable drainage waters should never be discharged into good quality water supplies. Soil salinity needs to be monitored to assess the adequacy and appropriateness of irrigation and drainage practices and to improve and refine management. Presently degraded lands need to be rejuvenated.