SALT MANAGEMENT: A KEY TO IRRIGATION SUSTAINABILITY IN ARID CLIMATES

J.D. Oster[1]
S.R. Kaffka[2]
D. Wichelns[3,4]

ABSTRACT

Salt management is a critical component of irrigated agriculture in arid regions. Successful crop production cannot be sustained without maintaining an acceptable level of salinity in the root zone. This requires drainage and a location to dispose drainage water, particularly, the salts it contains, which degrade the quality of receiving water bodies. Despite the need to generate drainage water to sustain productivity, many irrigation schemes have been designed and constructed with insufficient attention to drainage, to appropriate re-use or disposal of saline drainage water, and to salt disposal in general. To control the negative effects of drainage water disposal, state and federal agencies in several countries now are placing regulations on the discharge of saline drainage water into rivers. As a result, many farmers have implemented irrigation and crop management practices that reduce drainage volumes. Farmers and technical specialists also are examining water treatment schemes to remove salt or dispose of saline drainage water in evaporation basins or in underlying groundwater. We propose that the responsibility for salt management be combined with the irrigation rights of farmers. This approach will focus farmers' attention on salt management and motivate water delivery agencies and farmers to seek efficient methods for reducing the amount of salt needing disposal and to determine methods of disposing salt in ways that are environmentally acceptable.

Keywords: Drainage, Economics, Policy, Salinity, Salt Loads

IRRIGATE NOW – MANAGE SALTS LATER

Irrigation development and planning have become more sophisticated over time. Initially, irrigation developed opportunistically, initiated by individuals and small communities. Commonly, there was minimal planning, except for choosing the route of an irrigation canal, considering how to extract water from rivers, or determining where to drill irrigation wells. In some regions, this remains the extent of planning for irrigation schemes. Where government involvement with irrigation has increased, the planning effort expanded to include technical and economic feasibility analyses of projects involving public expenditures. Other important issues, such as the potential environmental impacts of irrigation, the opportunity costs of limited water resources, and the notion of sustainability have not yet been considered. In some areas where rivers were diverted to provide irrigation water, planners implicitly assumed that these rivers had the assimilative capacity to convey saline return flows to the sea.

[1]J.D. Oster, Univ. of California, 5192 Kendall, Riverside, California. james.oster@ucr.edu
[2]S.R. Kaffka, Dept. of Plant Sciences, Univ. of California, Davis, Calif. 95616. srkaffka@ucdavis.edu
[3]D. Wichelns, Dept. of Economics, Hanover College, Hanover, Indiana 47243. wichelns@hanover.edu
[4]All authors have contributed equally to the preparation of this paper

Planners are concerned primarily with designing adequate infrastructure to provide timely delivery of water supplies, while farmers are concerned with obtaining sufficient water to meet crop water needs, including water for leaching to maintain acceptable levels of salinity in the root zone. Planners have adjusted agricultural water rights to include the water lost to evaporation and crop transpiration, and the additional water required for leaching. Leaching requirements also generated the need to install subsurface drainage systems to control water table depths and prevent the loss of land due to secondary salinization, particularly on low-lying lands in arid regions. In many areas, however, drainage systems are not installed in a timely manner. In California's San Joaquin Valley, for example, the need for on-farm subsurface drainage systems and regional collector systems has long been recognized. Some systems have been installed and others planned, but much of the needed construction has been delayed and shallow water tables have developed. The need for drainage has become critical in those areas.

Only in recent years have planners and others begun appreciating environmental impacts and noting the importance of managing salts in irrigation return flows (van Schilfgaarde, 1994; Murray-Darling Basin Commission, 2001). Beginning in the 1970s, researchers sought ways to reduce the negative environmental impacts of irrigation and drainage in both small (van Schilfgaarde *et al*., 1974; Rhoades, *et al*., 1974; Oster and Rhoades, 1975) and field scale projects (Hoffman, et al., 1984; Rhoades *et al.*, 1988). They provided information that supported the concepts of increased application efficiency, minimum leaching, and salt storage within the soil profile (Rhoades and Suarez, 1977; Hanson and Ayars, 2002). Some of the concepts that were proposed and tested include: 1) serial biological concentration, in which the volume of water containing salt is reduced as much as possible (Rhoades, *et al*., 1988; Cervinka, *et al*., 1999, Kaffka, *et al*., 2002), 2) salt disposal on dedicated portions of irrigation schemes (Quinn *et al*., 1998; Murray-Darling Basin Commission, 2001), and 3) modified drainage system management to enhance crop use of shallow, saline groundwater (Ayars *et al*., 2006) thereby reducing drainage volume. The goals were to identify and demonstrate management strategies that increased the proportion of applied water used by crops, with consequent reductions in drainage water volume and salt loads.

The lack of focus on salt management and delays in constructing adequate drainage systems have contributed to substantial problems of salinity and waterlogging in many irrigated areas (Wichelns and Oster, 2006; National Research Council, 1989). In regions with poor natural drainage conditions, shallow water tables develop, soils become saline, and crop yields are reduced (Hillel and Vlek, 2005; Bouwer, 2000). Declining productivity reduces farm-level income, leaving farmers less able to pay for a drainage project that should have been installed initially. The regional salinity problem becomes more severe as farmers continue irrigating, while public discussion regarding the potential costs and benefits of constructing a regional drainage system continues.

Awareness of the inadequacy of the "irrigate now, manage salts later" approach has increased in recent years, due partly to the rising cost of building and operating irrigation schemes and the environmental impacts of saline drainage water. Public agencies responsible for water quality understand that salts in the drainage waters generated by irrigation often do not leave the region without impact. Rather, salts tend to accumulate in groundwater through deep percolation or they enter surface streams and lakes via surface runoff or from tile drain discharge. In either case, the increasing salinity of surface water and groundwater negatively impact water users located downstream, or those who rely on groundwater now and in the future for municipal or agricultural uses.

Public agencies generally have mandates to protect water quality for current and future generations and are becoming more involved in regulating the potential salinity impacts of irrigation in arid areas, such as in the San Joaquin Valley in California (National Research Council, 1989; Schoups, et al., 2005), the Colorado River Basin (van Schilfgaarde, 1982), and the Murray-Darling River Basin in Australia (Murray-Darling Basin Commission, 2001). Salt management is too expensive to ignore. Not only can environmental costs develop over time while irrigation is taking place, but the cost of retrofitting an irrigation scheme to control or mitigate environmental harm can become very large. In some areas the cost of collecting subsurface drainage water and removing salts and other constituents before discharging the water into rivers and other water bodies can reach levels that exceed the benefits of irrigation (Wichelns and Oster, 2006).

New policies and investments are needed to change the ways farmers irrigate and drain their fields, and dispose or re-use their drainage water. Both the costs and benefits of irrigation must be estimated when devising these policies. Ultimately the decision regarding the portion of the full costs of salt management paid by farmers will be determined through the political process. Planners and other analysts need to estimate the full costs accurately and impartially, and report their estimates in terms that can be understood readily by public officials, farmers, and other interested parties.

WATER RIGHTS AND SALT RESPONSIBILITIES

In the western United States, water is allocated according to a legal system of water rights that are clearly specified, enforced by the state, and sometimes tradable. Water rights are assigned to individuals and districts. Some states require that farmers and others use water in ways that are "reasonable," such as irrigating crops and providing water for livestock. Unreasonable use of water can result in the loss of a water right. The concept of reasonable use allows for some degree of water quality degradation, given that return flows generally are of lower quality than water diverted for irrigation and other uses. However, the discharge of saline drainage water into receiving waters is constrained in some regions by efforts to achieve ambient water quality standards and protect water quality for downstream users.

In many arid areas, the responsibility for salt management is not yet defined or assigned as clearly as are rights to divert and use water in agriculture. At present, salts are managed by a combination of efforts by water delivery agencies, irrigation and drainage districts, and farmers. In the absence of clear responsibilities, many irrigators allow saline drainage water to flow into receiving surface waters or percolate into deep groundwater, while others dispose drainage water in evaporation ponds. Many farmers also re-use drainage water to augment irrigation deliveries or to comply with restrictions on drainage water disposal.

We think that it would be helpful to assign the responsibility for salt management to regional associations of farmers, as a condition of their right to use water for irrigation. This would: 1) enhance awareness of the salt management issue among irrigators, and 2) motivate water delivery agencies and farmers to seek efficient methods for reducing the amount of salt needing disposal and disposing salt in ways that are environmentally acceptable.

Farmers have several options to consider when given the responsibility for salt management. They might direct salt to an on-farm evaporation pond, or join with other farmers in forming a regional drainage district that coordinates salt collection and disposal efforts. Alternatively, farmers might hire contractors who agree to collect and dispose salts in a fee for services agreement. In the absence of surface disposal opportunities, which can occur where the depth to the water table is too deep to intercept drainage water with tile drainage, farmers or local drainage districts could optimize groundwater use to provide regional drainage (Fogg, 1999), allowing groundwater gradually to become more saline. Deep water tables can occur because the irrigated fields are located at the highest elevations of the irrigation scheme, or because groundwater pumping lowers the water table.

The regional aspects of drainage systems – tile drainage, use of groundwater for irrigation, or the combination of the two – would benefit from a coordinated regional program to optimize its duration. The program could include the re-use of moderately saline groundwater and tile drainage water for irrigation of salt tolerant crops (Kaffka et al., 2002; Cervinka et al., 1999). A local drainage district or regional drainage agency could develop and administer the program. A regional agency could build and operate a regional collector system to collect saline drainage water from many farms, with the goal of discharging the water into an evaporation pond, a nearby waterway or inland lake, or the ocean. The plan could also include financial incentives for farmers willing to re-use drainage water for irrigation. Under some circumstances, separating salt from drainage water using reverse osmosis or exchange membranes might be appropriate, although the costs of these options are substantial, and always involve disposal of saline brines in an environmentally acceptable manner.

EXAMPLES OF CURRENT SALT MANAGEMENT EFFORTS

The salinity management strategy for 2001 to 2015 in the Murray-Darling River Basin in southeastern Australia is a continuation of a regional, or watershed, planning process that began in the 1980s (Murray Darling Basin Commission, 2001). The strategy includes land management options to reduce salt loads to the river that originate from both dryland and irrigated agriculture. Engineering options include re-use of low salinity drainage water, conversion of open channels to piped water supplies to reduce seepage, salt interception and disposal schemes to divert groundwater or drainage water to safe disposal sites, and use of relatively non-saline groundwater for irrigation. The goal of maintaining an EC of 0.8 dS/m at least 85% of the time at Morgan, South Australia, located in the lower reach of the Murray River, was nearly achieved in 1999. However, salt stored previously in soils upstream of Morgan complicated efforts to achieve the 85% objective.

The Murray-Darling salinity management strategy recognizes possible impacts on the reliability of water supplies for irrigation. The need for maintaining flows that originate from relatively small areas that receive more than 800 mm of average annual rainfall is recognized, because those flows are particularly important to managing salinity levels in the river. The Murray Darling Basin Commission (2001) addressed this concern as follows:

> "Water supplies and management throughout the Basin have focused historically on ensuring reliable supplies for irrigation, mainly because of the undisputed benefits to regional economics and the Basin as a whole. It is becoming apparent, however, that increased priority must be given to maintaining flows from high rainfall areas and providing for more dilution and environmental flows. Unless this more balanced approach prevails, urban and other water users will have less water of poorer quality, and entire riverine ecosystems will be threatened. Further clarification of water property rights will be helpful in achieving a more balanced approach."

In South Africa the current thinking is to develop watershed management plans (Du Plessis, private communication, 2007). Stakeholders within a watershed would assess the current state of the river and agree on its desired ecological state. They might choose to restore a natural river or maintain an impacted, regulated river. The next step would involve establishing quantity and quality objectives for the river, as the basis for developing a watershed management strategy. Sources of water quality degradation would be determined and remediation costs estimated. For existing systems, salt loads generated along different portions of rivers would be measured or estimated and management plans developed accordingly. For new irrigation developments, predictions of salt loading would be needed, based on the soils and geology of the irrigated region.

The European Commission's Water Framework Directive (WFD), passed in 2000, pertains primarily to water quality issues (Playan, private communication, 2007). The Directive requires that all waterbodies in Europe attain "good ecological status" by 2015, a goal that could have notable implications for salinity control of rivers in Europe, although salinity is not mentioned in the Directive (http://ec.europa.eu/environment/water/water-framework/overview.html) because it is not generally an issue in the EU region. The WFD was reinforced in 2003 and a groundwater directive was added. Many of Europe's aquifers are impacted by pollution from several sources, including nitrogen applications in agriculture.

The assessment of environmental impacts in Europe will require regional coordination. According to the WFD, the price of water for all uses must reflect: 1) the cost of making water available, 2) water scarcity, and 3) the cost of cleaning up all water pollution generated by the user. The WFD approach suggests that water and salt management will be conducted in parallel in semiarid regions. The cost of the program might have substantial impacts on farm-level crop choices. Several Mediterranean governments are implementing agricultural aspects of the WFD somewhat slowly, due to concerns regarding the potential financial impacts on the sector. However, river basin authorities in these areas are giving greater attention to salinity control and management (Playan, private communication, 2007)

AN IRRIGATION AND DRAINAGE PROSPECTIVE

The world has obtained great benefits from irrigated agriculture for thousands of years, both in arid and humid regions. Some might suggest there is little need for proposing a substantive change in the way that irrigation schemes are planned and policies are chosen. We argue that a new approach is needed, particularly in arid regions. The fundamental issues regarding salts and drainage necessary to sustain irrigated agriculture are well known. The environmental impacts are becoming better understood, and the costs of salt disposal are substantial.

Planning for salt management is more complicated than planning for water management. Irrigation water is not the only source of salt in drainage water in arid climates – native salts are present in the soil. The salt content of drainage water varies with how it is collected – the depth and spacing of the tile system (Ayars, 1999), the management of the drainage system (Ayars, 2006) and the depth and spacing of groundwater wells (Quinn, 1991). The salt load in drainage water changes with time as the soil adjusts to the chemical composition of the irrigation water. The amount of drainage water, and to some extent its salt load, varies with irrigation efficiency, the fraction of applied water that is used by the crop. Re-use of drainage water for irrigation reduces the volume requiring management and disposal, but some re-use practices can complicate farm-level efforts to maintain soil salinity within an acceptable range.
Regional efforts to maintain ambient water quality standards in receiving waters will require continual monitoring of drainage water volumes and salt loads by staff members of public agencies. Their efforts, and the associated public costs of maintaining water quality standards, can be reduced by assigning responsibility for salt management to farmers as a condition of their water rights.

Implementing and enforcing responsibility for salt is not easy (Murray Darling Basin Commission, 2001). Compared with relying on regulation, an incentive-based approach can accomplish the same goal at a smaller aggregate cost. Farmers will be motivated to seek methods for reducing the amount of salt needing disposal and determining low-cost methods for disposing salt in an environmentally acceptable manner. A purely regulatory approach will not provide the same motivation to develop less costly disposal technology.

Some observers will suggest that agriculture requires special consideration when discussing environmental goals because farmers use a large volume of water to produce crops of relatively low market value. They may be subject to competition with farmers in other regions where the costs and burdens of salt disposal are ignored. If the "polluter pays" principle is applied to agriculture, irrigation might become non-viable in some areas, and new irrigation schemes might not be developed. This result is particularly likely in arid and semiarid areas where native soils are saline. If society needs the food and fiber produced by irrigated agriculture in such regions, policy makers might need to consider accepting lower water quality standards. Alternatively they might decide to provide financial support of water and salt management practices that minimize environmental impacts. Such considerations will be based on the perceptions of policy makers regarding the present and future benefits irrigation provides, the public value of achieving irrigation sustainability in arid regions, and the public's interest in protecting water quality.

The problems with salt management along the Murray-Darling Basin (Murray Darling Basin Commission, 2001), the Colorado River Basin, and along the west side of the San Joaquin Valley (Wichelns and Oster, 2006) attest to the need to improve planning for salt management. Perhaps there are two approaches the agricultural community might take regarding salt management in the future: 1) Allow policy makers to work through a regulatory process that will mandate changes needed in irrigated agriculture to achieve water quality objectives – a non-engaged approach, or 2) Implement programs that encourage farmers to develop options to optimize both water and salt management, and to propose them to policy makers – a proactive approach. Optimal solutions likely will emerge if policy makers, planners, farmers, and other stakeholders take the opportunity to be part of the planning process.

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