Environmental and Institutional Aspects of Irrigation Agriculture

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ABSTRACT

IRRIGATION agriculture requires drainage, but design options and water management choices impact not only agricultural production. A host of institutional and societal considerations affect the viability of technically feasible alternatives. Drainage, as an integral part of water management, must be viewed within this larger framework and options identified that optimize total resource use.

INTRODUCTION

Much emphasis has recently been given, quite properly, to the mechanics of installing drains and the effectiveness of drainage systems installed by different methods. The purpose of this paper, however, is to place drainage into the context of irrigation agriculture, and its relation to the environment. Design, treated recently elsewhere (van Schilfgaarde, 1978) will not be discussed here.

To maintain a viable agriculture over time, all irrigated land needs drainage. Salt contained in the irrigation water tends to build up in the soil solution as the plants transpire pure water, unless it is removed by drainage. Thus the question is not whether drainage is needed, but how much. Another question concerns disposal of the drainage water. Does it pose an environmental hazard or can it be used beneficially?

The drainage requirement is made up of several components that cannot be fully separated. Drainage must remove the precipitation and irrigation water applied in excess of crop demand to prevent waterlogging; it must remove the salts that accumulate in the rootzone to avoid salination; it must remove "foreign" water, or water that seeps into the area from leaky canals, from excessive irrigation on adjacent land or similar sources separate from the field under consideration; and it is desirable, even if not mandatory, to prevent buildup of a water table from which salts may rise into the rootzone by capillary upward flow. In short, the drainage requirement must provide adequate aeration for plant roots and avoid soil-water salination; it also should permit timely farm operations. Drainage also may need to be provided temporarily for reclamation, i.e., for leaching to remove excessive salt from the rootzone. To meet the drainage requirement, one depends on the natural drainage rate, supplemented as needed by drainage installations. Thus one should distinguish between the (total) drainage requirement and the drainage system design requirement (Bouwer, 1974).

It is the need for salinity control that distinguishes drainage requirements in irrigated areas from those in rainfed areas. Except where substantial amounts of water from extraneous sources need to be removed. the salinity criterion tends to dominate in drainage considerations. Yet, frequently, because of poor irrigation practices, or poor water distribution systems, the actual situation is less clear-cut.

The amount of drainage needed for salinity control is generally expressed in terms of the leaching requirement (L_r), which sets a lower limit on the required leaching fraction (L). L is that fraction of the water applied and retained on the land (rainfall plus irrigation) that percolates below the rootzone. At hydraulic equilibrium, it thus becomes the drainage flux. On the basis of a simple mass balance, it can be expressed to a first approximation in terms of the concentration (C) of dissolved salts in the irrigation (i) and drainage (d) waters, as

$$L = V_d/V_i = C_i/C_d.$$

Here the symbol V represents volume. The concentration is frequently expressed in terms of electrical conductivity, σ, in S m^{-1}. L_r then becomes

$$L_r = \sigma_i/\sigma_d^*,$$

where σ_d^* is the highest salinity of the water draining out of the rootzone acceptable to the crop to be grown. The selection of σ_d^* and the associated L_r is discussed elsewhere (Rhoades, 1974; van Schilfgaarde et al., 1974; van Schilfgaarde and Hoffman, 1977). Suffice it here to recall that crop tolerance data (Maas and Hoffman, 1977) can be used in various ways to arrive at appropriate σ_d^* values, and thus to establish L_r. Of importance in the present context is the general observation that, for most irrigation waters used in the Western USA (< 1000 mg/l dissolved salts), L_r is small, on the order of 0.05, even for relatively salt-sensitive crops.

This leads us to a consideration of irrigation efficiency. With most conventional irrigation systems, neither water distribution nor amount applied can be controlled to an accuracy of 5 percent. To adequately control salinity, therefore, one generally must apply substantially more water to the land than is dictated by L_r. Furthermore, the distribution system may result in canal leakage, spills, or forced overirrigation. Considering water pricing policy and costs of irrigation system improvements and labor, installation of additional drainage facilities often seems to be the most economic management decision. If all costs are taken into account, especially in an era

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of rising energy costs and increasing water scarcity, the conclusion may be different.

Before elaborating on these observations, one additional technical consideration needs to be stated. Not all ions in the soil solution originate in the irrigation water or stay in solution as implied by a simple mass balance. As water percolates through soil, minerals are either selectively dissolved or precipitated, depending primarily on the ionic composition and electrolyte concentration. These reactions, which can be predicted in detail, can be generalized as follows: As the electrolyte concentration of percolating water changes from low to high, the reactions change gradually from significant dissolution to substantial precipitation. The species that dissolve or precipitate are primarily $CaCo_3$ and $CaSO_4$.

With the foregoing as a point of departure, let us now consider, by means of examples, some of the available options and their consequences in managing irrigation and drainage waters.

The Wellton-Mohawk Irrigation and Drainage District in SW Arizona is one of the last units within the US to draw water out of the Colorado River. The District serves about 26,000 ha of irrigated land. Historically, it diverts about 640 x 10^6 m^3/yr through open canals and lifted some 55 m. The area served is a geologically closed valley with roughly 23,000 ha of irrigated land, with the remainder of the irrigated area on the coarse-textured surrounding mesa. About 270 x 10^6 m^3/yr are drained by means of more than 100 wells. In 1973, the drainage water concentration averaged 3600 mg/l. This water is conveyed back to the river in a concrete-lined open drain. Since 1944, an international agreement provides for delivery to Mexico of 18.5 x 10^9 m^3 out of the Colorado system every 10 years. Of this amount, about 1.68 x 10^9 m^3/yr is delivered in the river. With the salt concentration of the river water about 850 mg/l, mixing 0.27 x 10^9 m^3 of W-M drainage water at 3600 mg/l with the river flow would result in a final salinity of 1292 mg/l. Since this level of salinity was unacceptable to Mexico, a number of steps have been taken over the years to reduce the salinity of water delivered, and in 1973, a new international agreement was adopted that guarantees that the water delivered to Mexico in the river shall not exceed by more than 115 mg/l the concentration at Imperial Dam, the last impoundment in the US.

The above summary, although abbreviated, serves to contrast options open to meet the terms of the agreement and to point out some of the implications. In 1973, on-farm irrigation efficiency was estimated to be 56 percent; that is, 56 percent of the water delivered to farms was consumptively used. Total return flows were about 42 percent of total diversions; the 2 percent difference is accounted for by distribution system losses, phreatophyte use, and a number of smaller components of the water budget. Increasing on-farm irrigation efficiencies would have several consequences. It would reduce the amount of water diverted and the amount pumped for drainage, thus saving energy. On the sandy mesa soils, where the efficiencies were well below average, there would be an additional energy savings from reduced loss of fertilizer through leaching. Projections made at that time showed that increasing the on-farm efficiency to an average of 82 percent would reduce the drainage flow from 270 to 116 x 10^6 m^3/yr; these calculations did not consider reductions in system losses, which have been estimated at 60 x 10^6 m^3/yr. The conclusion is that drainage flows can be reduced at least 50 percent by applying off-the-shelf technology to improve on-farm water management; greater reductions should be possible, but only with substantial effort. The agreement with Mexico, then, could be met by spilling 100 x 10^6 m^3/yr of drainage water to the ocean. This loss of water, amounting to ½ percent of the average annual flow in the river, is not negligible, but technically reasonable. Politically, however, it appears to be completely unacceptable.

Alternatively, a desalting plant can be built to desalt the drainage flow, mixing the processed water with the river and spilling the brine stream. This scheme would result in a brine stream of 57 x 10^6 m^3/yr at an annualized cost of about \$30 x 10^6; it would also require 370 x 10^6 kwhr/yr of energy. Other options are possible, including a combination of the two described. Any decrease in drainage volume would reduce the volume needing desalting accordingly. It has been estimated that the benefit-cost ratio for improving irrigation efficiency as compared with the operating cost only of a desalting plant exceeds 5.

I do not wish to belabor the details of these or other options that have been considered, nor the merits of the decisions that have been made. In this instance, careful irrigation management clearly can reduce the drainage volume and thus help solve a downstream water quality problem in a cost-effective manner. But who is the beneficiary and who pays the bill? What is required to implement a program — facility improvement and operational management — that involves approximately 100 farm operators? Implementing a program of on-farm irrigation improvements institutionally is clearly far more complicated than building a desalting plant: varied and changing land ownership and tenure, water pricing policy, water law, contractual repayment provisions for federally financed water conveyance facilities, and federal cost sharing for on-farm improvements are some of the components that must be considered. Notwithstanding these many complications, we must pose the question whether, ultimately, the "easy" solutions are the best ones when we consider the costs and benefits to society as a whole.

As a second example, consider the Palo Verde Irrigation District near Blythe, CA. In this valley, 36,000 ha are irrigated by gravity with Colorado River water. The Palo Verde differs from the Wellton-Mohawk in that neither irrigation nor drainage water is pumped; more importantly, the Valley is hydrologically connected with the river. The on-farm irrigation efficiency in Palo Verde is estimated at 53 percent. Clearly, this efficiency could be raised substantially with current technology, but such a change would have essentially no effect on water use efficiency, would have minimal effect on energy consumption, and would have only a minor effect on the salt concentration of the river downstream from the valley, at least after steady state had been reached. Assuming unrealistically that L could be reduced quickly to 0.1 from the present 0.5, the short-term effect would be a reduction of 45 mg/l at Imperial Dam, below the Palo Verde District, but ultimately the reduction would only be 9 mg/l. This latter reduction would result from carbonate precipitation in the soil profile. Considering the costs, both real and imagined, associated with improved water management in the District, the obtainable benefits are extremely small. In an area where, as a first approximation, no "foreign" salts are involved, efforts to improve irrigation efficiency can only be justified on the basis of increased farm income. Providing adequate drainage, even for relatively sloppy irrigation, is probably cheaper and certainly more readily accepted by the farming community than is improving irrigation efficiency. Neither would such action sacrifice any significant social benefit.

In contrast, consider next the Grand Valley of Colorado, a valley that may well have been studied more than any other in the country. In brief, some 24,000 ha of land are irrigated by gravity, with water supplied through a set of canals that have grown historically into a crazy-quilt pattern. Partly because of the soils, but primarily because of the irrigation systems, diversions are very large relative to consumptive use. Estimates vary, but the valley probably adds about 650,000 t (metric tons) of salt to the Colorado River each year. The valley is underlain by a massive Mancos shale formation. Water spilled from canals or laterals and returned to the river adds no significant salt, but water that seeps from water courses or percolates through the rootzone of agricultural land tends to come to chemical equilibrium with the underlying materials and is ultimately discharged with a salt concentration of about 6500 mg/l. Here, then, is a case of drainage water displacing highly saline ground water. Thus a reduction in water throughput through the soil system will result in an approximately proportional reduction in salt loading. The national objective, spelled out by legislation (PL 93-320), to reduce the salinity of the Colorado River can be aided by reducing this throughput. At the same time, the salination of parts of the lower valley, intensified by high water tables, would be stemmed and reclamation made easier, eliminating or at least reducing the need for additional drainage.

The Grand Valley situation, however,is very complicated, both technically and institutionally. Some of the main questions, oversimplified, are as follows: With considerable uncertainty, it has been estimated that the salt contribution from canal seepage is 245,000 t/yr, from lateral and ditch seepage 254,000 t/yr, and from deep percolation 130,000 t/yr.* Thus canal and lateral lining appears to be an obvious candidate for project improvement. Such a lining project also would be attractive because the largest single canal was built by the Bureau of Reclamation and lining need not interfere with the right (nota bene) to irrigate poorly. Improvement of on-farm irrigation systems and management would be more cost effective, but would require the cooperation of many land owners and operators; because of relatively steep grades and poor infiltration rates, it would also bring technical difficulties, complicated even more by the antiquated delivery system and the customary 24-h or 48-h sets.

Before proceeding, one must consider the appropriate objective function. Do we simply wish to reduce downstream salinity at minimum cost, or do we wish to optimize the total benefits from an amelioration project? How do we measure the benefits, or identify the beneficiaries? Presumably, the most cost-effective way to meet the first objective would be to purchase the water rights to the 24,000 ha and discontinue irrigation, but most of us would reject that option. The path of least resistance towards meeting this objective would be to line the canals and laterals as they are; however, that solution would preclude a number of options for future changes in water management in the valley that might benefit the local community.

Conceptually, a strong case can be made for quite a different approach: replacing the existing distribution system with a single water conduit along the northern perimeter of the valley, which in turn would distribute water through closed conduit laterals. The advantage would be that the same downstream benefits would be realized as from lining the existing system, while in addition, the water would be delivered under pressure at all user points. In principle, such a system would lend itself to demand delivery. It would permit adoption of a wider range of irrigation systems on the farm, depending on the site and crop, available technology, or newly developed techniques. It would provide, in many circumstances, sufficient pressure to operate automation devices, bubbler systems for orchards, or even low-pressure sprinkler systems.

Several disadvantages must also be recognized. Foremost, the cost would no doubt be higher. Since the present plans, combining canal lining and replacement of laterals with closed conduits with a cost-sharing program for on-farm improvements, are estimated to cost $\$160 \times 10^6$, questions of cost may not be overriding. More immediate is probably the question of acceptability. The plan would require consolidation of a number of irrigation and drainage districts, with separate patronage, management and water rights, into single units. It also would likely result in delivery of adequate amounts of water to meet crop needs, but substantially less than established water rights. It would be very difficult to obtain broad public acceptance for such a solution.

Finally, a few words about the Central Valley of California. The importation of water from northern California has increased the potential for irrigation substantially, while also aggravating a drainage disposal problem. Although the need for drainage has long been recognized and is projected to increase, there are serious objections to the construction of a central drain to transport drainage from the closed valley to the Sacramento Delta, the most accessible outlet. Extensive studies have evaluated alternatives, of which we shall consider only one.

As indicated by Rhoades (1977), the concentration of salts in drainage waters often is such that they are still suitable for crop production at essentially full yield if proper management practices are used. Our projections indicate, for example, that irrigation of cotton with a leaching fraction of 0.25 should give full yield if the water has an electrical conductivity of 0.9 S m^{-1} (6300 mg/l). Thus selective use of drainage waters to irrigate appropriate crops, with proper management precautions, offers the potential of reducing to 25 percent the volume of water to be disposed of. Less costly, or less objectionable, options can be found for disposing of this reduced volume. In the example quoted, based on an actual water supply near Bakersfield, CA, the drainage water from the cotton would have a conductivity of 2.5 S m^{-1}. It is possible to carry the concept one step further and to use this water, if it can be collected, once

(Continued on page 350)

*Alleviation of Salt Load in Irrigation Water Return Flow of the Upper Colorado River Basin, Final Report by ARS for USBR, Sept. 1977.

Environmental and Institutional Aspects of Irrigation Agriculture

(Continued from page 346)

again for biomass production. Although currently no crop plants exist that can be grown economically with 2.5 S m^{-1} water, there are halophytes that can be grown as wildlife habitat, or as a source for methane production. Thus plants, whether they be conventional crops or species not now used in agriculture, provide the option to make beneficial use of a resource now considered a waste product.

The above examples illustrate that drainage must be viewed as an integral part of total water management. Frequently the technical problems of drainage design and installation are less difficult than the broader questions that involve an evaluation of total impact of alternatives and a consideration of the institutional implications associated with implementation. This situation, in principle, is not so different from engineering design questions in general, but in practice the restraints as well as the opportunities are especially great when dealing with water resources in the West.

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