Report for 2002CO6B: Evaluating Strategies to Mitigate Waterlogging and Salinization in Colorado's Lower Arkansas River Valley

- Conference Proceedings:
  - Burkhalter, J.P., T.K. Gates and J.W. Labadie, 2002, Strategies for regional-scale recovery of a salinity-threatened irrigated river valley, in Proc. of Conf. on Energy, Climate, Environment and Water _ Issues and Opportunities for Irrigation and Drainage, USCID and EWRI, San Luis Obispo, California.

Report Follows:

SYNOPSIS

Problem and research objectives

There is growing evidence that the irrigated lands of the lower Arkansas River Valley in Colorado are suffering from severe waterlogging and salinization. Over the last few years, we have conducted scientific investigations with the objectives of accurately diagnosing these problems. This project builds upon on-going studies to apply and refine sound modeling tools, rooted in and calibrated by extensive field data, and founded upon strong working relationships with numerous agencies and with over 80 valley farmers. The goal of the first phase of this project was to build, through application of an existing calibrated model and through comparative economic analysis, a framework for evaluating strategies to support a productive irrigated agriculture in this salinity-threatened valley.

The results of this study will be a proposed set of the most-promising strategies that would both (a) lower the saline high water table leading to lower soil salinity resulting in increased crop yields, and (b) significantly reduce loading of salts and other pollutants to the river. Strategies to be considered will include: increased irrigation efficiency, reduced seepage from irrigation canals, increased pumping rates from existing pumping wells with excess flows (above legal permit) routed through drains to the river, installation of horizontal subsurface drains, lowering of water surface elevation along the river, conversion to more salt-tolerant crop varieties, and combinations of these strategies.

We proposed to pursue this course through the following objectives and general procedures:

(1) Refine the solution strategies listed above through interaction with farmers and agencies, via meetings and information-transfer technologies;
(2) Evaluate the strategies for application in the representative upstream study subregion near La Junta. Data collected by on-going projects in this subregion will be used to refine and support a model for predicting outcomes of implementing the alternative strategies. Cooperation with ongoing projects will allow evaluation of the practical implementation of target strategies, with input from farmers and agencies, at the field scale for selected representative fields in the upstream study subregion;
(3) Refine target strategies and rank their effectiveness according to predefined economic, environmental, and legal/institutional criteria using multicriteria decision analysis; and
(4) Work with farmers and agencies to propose development of organizations and schemes for implementing the most promising alternatives.

Methodology Synopsis

The Groundwater Modeling System (GMS) was applied to simulate impacts of various salinity control strategies in the upstream study subregion. The GMS software package links the MODFLOW groundwater flow model, and the MT3DMS contaminant transport model for solving the flow and transport equations within a spatially-referenced geographic information system (GIS). The original project plan proposed to apply MODFLOW and MT3DMS to conditions of steady flow to explore the comparative order of magnitude of effects to be

expected from scenarios associated with proposed strategies. Instead, it was decided that efforts should be redirected toward calibrating and applying the model in a dynamic framework, using one-week time steps. In addition, an unsaturated zone mass balance model was developed to allow estimation of the impact of considered improvement strategies on root-zone soil salinity. The model was calibrated and validated using historic baseline data for the period April 1999 to October 2001, encompassing three irrigation seasons. The model was used to simulate alternative improvement strategies under the same historic conditions, and predicted results for water table depth, water table salinity, soil salinity, and return flow and salt loading to the river were compared to baseline conditions. Preliminary economic analysis of the alternatives has also been completed.

Principal findings and significance

Extensive field data have been collected from 1999 to the present. This database was used to define baseline conditions for model simulations over the period April 1999 to October 2001. Data collected in 1999 revealed that the average water table depth was less than 2.5 m below ground surface under 43% of the cultivated area. Data from the drier 2000 and 2001 seasons indicated an average water table depth less than 2.5 m below ground surface under 38% and 32% of the cultivated area, respectively. The average measured salinity (as electrical conductivity, EC) of the water table in the study region was about 3.4 dS/m (3025 mg/l) in 1999, 3.3 dS/m (2930 mg/l) in 2000, and 3.1 dS/m (2770 mg/l) in 2001. Soil salinity measured (as electrical conductivity of saturated extract, EC_e) in overlying fields varied from benign to extreme, tending to exceed threshold tolerances for crops when the depth to the saline water table was less than about 2 to 2.6 m. The overall average soil salinity was estimated as 3.0 dS/m (2650 mg/l) in 1999, 3.1 dS/m (2735 mg/l) in 2000, and 3.3 dS/m (2910 mg/L) in 2001.

Numerous improvement strategies have been simulated and evaluated to date. These include boosts in irrigation efficiency to reduce average recharge to the water table by 10 to 90% (in increments of 10%); uniform lining of all irrigation canals to reduce seepage rates by 50%, 70%, and 90%; lining of selected reaches of irrigation canals to reduce seepage by 90%; increases of 25%, 50%, 100%, and 200% in pumping volumes from existing wells; installation of subsurface horizontal drains in poorly drained areas at a depth of 2 m and at spacings of 50 m, 75 m, 100 m, and 150 m; and combinations of these strategies. Predicted impacts on water table depth and salinity, soil salinity, return flows and salt loads to the river, and upflux under fallow fields to nonbeneficial consumptive use are being evaluated. Preliminary assessment indicates that the strategy having the most impact on water table depth and soil salinity would be a combined recharge reduction of 50%, a seepage reduction over all canals of 90%, and sub-surface horizontal drains installed at a spacing of 50 m. The model predicted that if this strategy had been implemented over the historic period, it would have resulted in a reduction in average water table depth of about 2.1 m by the 2001 irrigation season, and a reduction of about 985 mg/L (about 33%) in average soil salinity. Results for all combined strategies generally indicated substantial reduction in salt load to the river, with the largest impact [41% average decrease; 907,324,018 kg (1,000,154 tons) total reduction over the 130-week modeled period] being predicted under a combined strategy of 80% recharge reduction, 90% seepage reduction over all canals, and sub-surface drains installed at a spacing of 50 m.

Preliminary economic analysis indicates average crop yield reduction due to waterlogging and salinity in the upstream study area was about 13% over 1999 – 2001. The associated total value of forgone productivity are estimated to range from approximately $3.1 to $5.4 million annually, averaging around $4.3 million/year or approximately $168/ha. This represents the potential of increasing average annual profits by approximately 39% if the effects of waterlogging and soil salinity were to be removed.

The costs associated with implementing improvement strategies have been identified and the resulting benefits to agricultural productivity within the study area have been estimated. Each strategy evaluated was capable of increasing regional productivity, although the associated costs were typically higher. However, this research indicates that certain strategies appear more promising than others, including improving irrigation efficiency to reduce recharge to the saline shallow water table. Reducing recharge rates by 50% through the universal adoption of gated pipe with surge valve irrigation systems was shown to increase agricultural productivity returns on average by approximately $42.63/ha/year or $1,098,019/year. Although the estimated annual cost of $64.21/acre is higher, this alternative is predicted to reduce salt load to the river by an average quantity of 2,619 tons/week (14.4%) and reduce the quantity of water consumed by non-beneficial upflux under fallow fields by 1234 m^3/week (106 acre-feet/week, or 22%). With these benefits in addition to the productivity gains that offset approximately 66% of the costs, this alternative appears promising. If the additional benefits of reducing non-beneficial upflux are assumed to be zero, the cost of reducing annual salt load using this alternative is approximately $4.10/ton. If future research indicates the value of salt load reduction to exceed $4.10/ton, the total benefits of this alternative would surpass the costs without including the value of reducing non-beneficial upflux. For reference, research by Gardner and Young (1985) estimated the benefits (damages avoided) of salt discharge reduction to be approximately $26/ton in the lower Colorado River Basin.

Work is continuing to refine predicted effects of alternative improvement strategies and the associated economic impacts at the subregional scale. Efforts are also underway to extend the analysis to a representative subregion downstream of John Martin reservoir and to consider basin-scale impacts using a calibrated basin-scale model.