A DECISION SUPPORT SYSTEM FOR FIELD DRAINAGE MANAGEMENT

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ABSTRACT

The Colorado State University Irrigation and Drainage model (CSUID) is a decision support system (DSS) that helps design and/or manage irrigation and drainage systems, which maintain crop productivity while controlling drainage return flows. CSUID includes components for irrigation scheduling; root growth calculations; flow and transport in unsaturated and saturated zones; drain discharge; and crop yield estimates. The DSS runs on a PC with Windows 95/NT. Data for the model is currently being collected from four fields in Colorado's Arkansas River Basin.

INTRODUCTION

About 30 percent of the land in the western United States has the potential for moderate to severe salinity problems (Nation Research Council, 1996). In communities where salinity problems occur, sustainable agriculture is threatened (Western Water Policy Review Commission, 1997). Sustainable agriculture is defined as being productive and profitable while also conserving resources, protecting the environment and enhancing the health and safety of the public (O'Connell, 1991).

While the agricultural community has addressed salinity problems for many years, the inability to achieve sustainability in areas prone to salinity reflects a lack of an integrated/holistic approach to solving the problem (Water Environment Federation, 1992). As concerns about possible long-term environmental damage from downward percolating waters and the disposal of saline drainage water have increased, it has become more difficult to reach the goal of maintaining sustainable crop production in areas of high salinity (Wiley,

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1986; Gates and Grismer, 1989). Furthermore, the discharge of highly saline drainage effluents with high loads of trace elements from the irrigation-drainage system can induce water quality problems in downstream surface water systems (NRC, 1989).

Consumptive use from human activities significantly increases salt concentration. Consumptive use alone causes a seven-fold increase in the salt concentration in the Arkansas River (USGS, 1997). Evaporation from reservoirs, canals, high water table areas and from cropland receiving excessive or poorly timed irrigation are important consumptive uses. Evapotranspiration from crops and weeds and from phreatophytes in wastewater areas also occurs.

Crop yields are being reduced, and in some areas, cropland is being lost because of waterlogging and high salinity levels. To combat waterlogging problems, agricultural producers need a complete management package that blends information about irrigation practices, crop types, capabilities for improving yield, economic returns, and water quantity and quality.

Traditional irrigation systems have been designed based on a purely agronomic objective: sustain crop productivity on lands subject to saline high water tables. Growing concerns about the impacts of drainage return flows on water quality in downstream systems require the formulation of designs and innovative management strategies for both irrigation and drainage

Irrigation and drainage systems often have been designed separately. Frequently, the drainage system is designed only after the impacts of waterlogging and salinity are observed. The practice of designing each component separately has generated extensive reference work in each discipline but produced only weak links between irrigation and drainage design. In reality, the two disciplines are inextricably linked, especially in arid and semi-arid irrigated areas. First, irrigation inputs are controllable, as opposed to the random inputs due to rainfall in humid regions. Thus, the quantity of drainage water is controllable. Second, drainage requirements often change after a system has been designed because irrigation practices change. Third, disposal options for drainage effluents are directly affected by the on-farm design. The quality, quantity and timing of these discharges impact downstream users of the receiving stream.

This paper describes CSUID, a comprehensive irrigation and drainage system design and management DSS.

SYSTEM DESCRIPTION

CSUID (IDS, 1994) is a DSS that will be used in the Arkansas River Basin in Colorado to help in the design and/or management of irrigation and drainage systems that maintain crop productivity while controlling contaminant loads in

drainage return flows. It includes irrigation scheduling, root growth calculations, flow and transport in unsaturated and saturated zones, drain discharge and salinity of the effluent, and crop yield estimates (Garcia et al., 1995). The components of the DSS have been verified using field data, and the results are presented in Manguerra and Garcia (1995 and 1997).

The drainage modules are based on the numerical implementation of a quasi three-dimensional finite difference model that solves the Richards' equation. The advective-dispersive transport equation is solved for one-dimensional vertical flow and salt transport in the variably saturated zone. The saturated zone is modeled using three dimensional flow and salt transport equations. The Newton-Raphson method is used to handle non-linearities in the numerical solution. The resulting tridiagonal matrices for one-dimensional flow and transport are then solved by the Thomas algorithm. A strongly implicit procedure is used to solve the pentadiagonal matrices that result from the finite difference formulation of the governing equations in the fully saturated zone.

CSUID allows users to manipulate the large amounts of spatial information that are required to manage irrigation and drainage systems. The user can study the spatial variability of data and the impacts of design and management decisions on irrigation and drainage systems. CSUID significantly reduces the amount of effort involved in the creation and/or debugging of input data and improves the understanding of the output.

The Colorado State University Irrigation and Drainage DSS: CSUID

Design and analysis of irrigation and drainage systems using decision support tools is not yet common practice. However, computer models allow consideration of more complicated scenarios, reflecting the complex concerns surrounding both on-farm and regional management. While models are numerous, few include both irrigation and drainage components and even fewer have the capabilities needed to make them useful decision support tools for arid and semi-arid irrigated regions. To date, most models have not been sophisticated enough to simulate water and salt transport in both the unsaturated and saturated zones, taking into account three-dimensional mixing in the saturated zone. This level of sophistication is needed to adequately study the effects of irrigation and drainage design on the quantity and quality of the drain effluent.

The numerical formulation of the computer simulation model is based on a modified linked finite difference implementation of the governing flow and salt transport equations. The modified linked approach evolved from the standard formulations because of the shift in the design and management of irrigation-drainage systems from a primarily agricultural focus to an approach that takes into account both agricultural and environmental concerns. Because of its computational economy, the standard linked approach is normally used for

modeling traditional systems that have the main objective of maintaining crop yield despite the presence of a highly saline shallow water table. However, more rigorous models that adopt the continuous approach are required to handle adequately both the agricultural and environmental components of the system being modeled. The modified linked approach is an attractive alternative to the continuous formulation because it couples computational economy with accuracy.

The current CSUID DSS allows users to simulate such complex systems. The model is supported by an interactive Graphical User Interface (GUI).

Graphical User Interface

The GUI for CSUID is a combination of window, menu, and icon selections designed to allow quick and easy movement through the model. The GUI makes the tasks of data entry, editing, and viewing easier by providing editing tools that allow the user to graphically specify the data. Different irrigation and drainage scenarios (drain spacing, depth from the ground surface, irrigation rate, irrigation duration, and irrigation frequency) can be formulated for sensitivity analysis.

The model currently works on a PC running Windows 95/NT. The GUI was developed in C^{++} using OpenGL for the graphics.

The GUI provides the capability to discretize the system being modeled into a row-column-layer finite difference grid network. The location of drains, collectors, irrigation canals and no flow boundaries are graphically specified. Any number of basins can be included, and a different irrigation schedule can be specified for each basin. Some of the input parameters required to perform a simulation are bedrock elevation, vertical hydraulic conductivity, horizontal hydraulic conductivity, specific yield, initial root depth, maximum root depth, date of planting, and various crop coefficients.

Spatial crop and aquifer properties can be specified using the drawing area. Space-invariant parameters such as simulation control flags and coefficients of equations can be edited through a series of pop-up windows. These parameters include simulation parameters, pressure-saturation functions, root growth functions, root extraction functions, crop yield functions, ET functions, K-weighting method, equation type, and initial conditions.

The behavior of the hydraulic conductivity and saturation with pressure head can be defined by empirically-based nonlinear functions. The user can select from the following relationships: Brooks and Corey (1964), van Genuchten (1980), and Haverkamp et al. (1977).

In addition, different plant water uptake functions developed by van Genuchten (1987), Molz and Remson (1970), Hillel et al. (1976), Feddes et al. (1974),

Gardner (1964), Whisler et al. (1968), and Herkelrath et al. (1977) are provided in the DSS. Root growth functions included are Rasmussen and Hanks (1978), Ferreres et al. (1981), Hank and Hill (1980), Borg and Grimes (1987) and Schouwenaars (1988). At present, the user can enter a crop yield model or use the crop yield model by Doorenbos and Kassam (1979). The model also provides different methods for calculating interblock hydraulic conductivities, including upstream weighting, and geometric, arithmetic and harmonic means.

The results can be displayed both spatially and temporally. Maps of soil moisture, salt concentration, flow vectors, and relative yield can be displayed. Cross-sectional profiles of parameters varying with depth can also be generated.

Field Application

The DSS will be validated at and applied to four field sites in the Arkansas River Valley, a semi-arid irrigated area where waterlogging and high salinity levels threaten both crop production and ground water, surface water and soil water quality. Intensive sampling at each field site will provide input data for the simulations and show the ability of the DSS to model existing conditions as well as changes in the system under different irrigation and drainage options. The DSS will help determine how well the proposed management options meet water quality objectives, while maintaining crop productivity and production.

Irrigation and Drainage Strategies

Traditionally, irrigation is scheduled based on soil moisture depletion to prevent or minimize matric stress. However, in areas with shallow water tables, water is continuously available for crop water use. Irrigation, however, needs to be scheduled whenever the average root zone salinity has exceeded a selected threshold level to prevent or minimize osmotic stress. Thus, for an extended period of time, a favorable crop root zone environment can be maintained without the use of artificial drains through the adoption of controlled irrigation using low salinity water combined with the use of the shallow water table as a supplemental source of water (Wallender et al. 1979; Campbell et al., 1960). When the groundwater contribution is included in the soil moisture budget, the estimated rate at which water is depleted from stored soil water is reduced, and the interval between irrigation events is increased, reducing the total number of irrigations (Ayars and Hutmacher, 1994).

Current State of Salinity in the Arkansas River Basin

Salinity levels in the Arkansas River in Colorado increase from 300 mg/l to 4000 mg/l over the 150-mile stretch from Pueblo to the Kansas Border. It is estimated that consumptive use alone causes a sevenfold increase in salinity in the river (USGS, 1997; Malinski, 1990). Crop yields are being reduced, and in some areas,

cropland is being lost due to irrigation with highly saline water. In a recent study by Timothy Gates and John Labadie at Colorado State University, salinity levels were measured at 50 points (on average) in each of 30 fields, in the Arkansas River Basin, using an EM-38 probe. In the late summer, median salinity levels for 27 of these 30 fields were found to be at least 1,200 mg/L. Corn yield reductions occur when salinity is above this level. These results are consistent with the results obtained by Luis Garcia in four field studies presently being conducted in the same area. The combination of high on-farm salinity levels, high river salinity levels and highly variable seasonal river flows makes the Arkansas River Valley an ideal location for this project.

With time, the evapotranspiration processes will eventually cause the salinity of the shallower layers to increase so that irrigation becomes more frequent, and waterlogging becomes inevitable. As this stage approaches, the flows in the river should be evaluated to determine when the next drainage cycle should occur. Both on-farm crop requirements and flow and water quality requirements in the river determine the end of the no-drainage cycle.

Field Investigation and Data Collection Activities

Currently four experimental sites with different depths to water table and/or salinity levels have been selected for data collection. For each of the fields the following data are being collected:

- Weekly water table depth and salinity measurements from wells. In each of the fields between seven and eleven observation wells have been installed using a Giddings Rig, and their position and elevation has been recorded with a differential GPS receiver. In 10 of these wells continuous water table recorders have been installed measuring water table every hour. Figure 1 shows the hourly and weekly values of depth to water table for one of the observation wells.

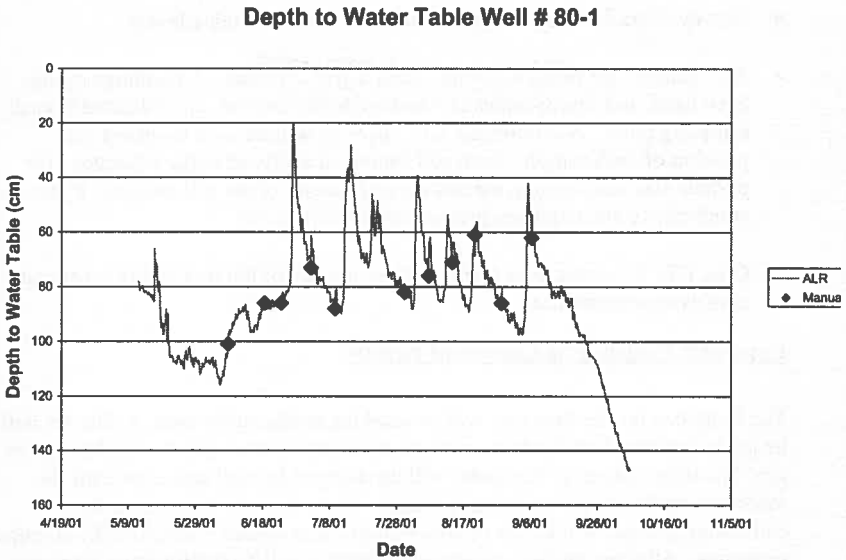**Depth to Water Table Well # 80-1**

Figure 1. Hourly and Weekly Values of Depth to Water Table for Well 17-7.

- Average root zone soil salinity (as electrical conductivity of saturated extract, EC_e measured using an EM-38 probe). The sampling was done using a grid approach and determining the location of each sample using a differential GPS unit. Figure 2 shows the spatial variation in soil salinity in one of the fields being studied.
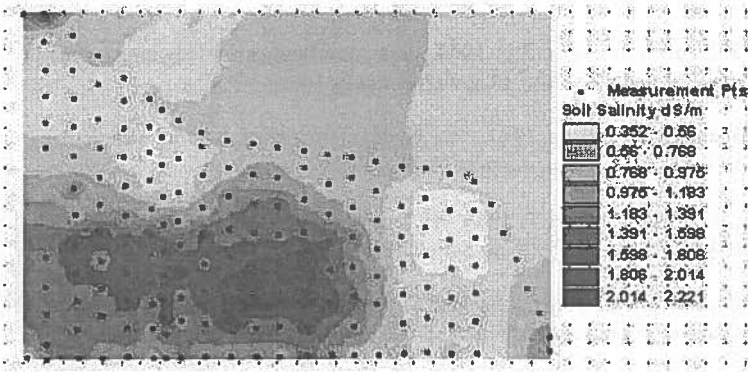

Figure 2. Soil Salinity for One of the Fields

- Survey of surface elevations, boundaries, and water table levels.

- Soil samples are being collected using a grid approach. A Giddings rig has been used, and four samples at one-foot depth intervals are collected at each sampling point. A differential GPS receiver will be used to record the position of each sample. Each soil sample is analyzed in the laboratory for particle size distribution, electrical conductivity of the soil solution, hydraulic conductivity and capillary-pressure saturation curves.

- Crop ET. ET gages have been installed at each of the four fields to estimate crop evapotranspiration.

Computer Modeling and Expected Results

The field data for the first year will be used for model calibration. A data set will be generated based on the best estimate of the parameters, and the model will be run. The input values of the model will be changed by trial and error until the modeled results match the measured ones. The criteria for success of the calibration process will be the minimum root mean square error (RMSE) in output estimates. After the model has been calibrated, it will be run for other scenarios using the data gathered during the remainder of the project time. The final evaluation of the model will be conducted by looking at the model's performance over the entire length of the project.

The DSS will be used to test suitable, alternative drain designs and management schemes, and if possible adjustments will be made in the current field management to verify the model's predicted results.

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