TRAINING TOOL FOR ON-FARM WATER MANAGEMENT USING HEURISTIC SIMULATION SOFTWARE

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ABSTRACT

A modern computer-based simulation tool in the form of a game for on-farm water management has been developed for application in training events for farmers, irrigators, irrigation extension specialists, and students. This training tool can be used to analyze both strategic and operational issues related to the management of on-farm water resources, and automatic analysis of the results to provide feedback to the trainees. It utilizes an interactive framework, thereby allowing the trainee (or player) to develop scenarios and test alternatives in a convenient, risk-free environment. It employs heuristic capabilities in a simulation approach for modeling all of the important aspects of on-farm water management that are essential to effective planning.

The daily soil water balance, crop phenology, root development, and a seven-day weather forecast, can be monitored by the player throughout the simulated growing season. Different crop types, water delivery methods, and irrigation methods are made available to the player. Random events (both favorable and unfavorable) and different strategic decisions are included in the game for more realism and to provide potentially more challenging game play. Scoring and recommendations are provided at the end of the game, based on the management decisions made by the player.

INTRODUCTION

An understanding of agricultural water requirements is critical for resolving water resources issues. Worldwide, agriculture consumes approximately 70 percent of available water resources, with an estimated overall efficiency of only 30-40 percent (Molle and Berkoff 2006). The growing demands on existing water resources necessitates that the agricultural sector improve water management. Much of the emphasis and resources toward dealing with the water scarcity problems in recent years have been dedicated to infrastructure and technological improvements, as well as organizational and institutional changes. These measures alone are not enough to significantly improve water management. An extensive educational program can help improve on-farm water management.

Despite the current availability of abundant information, experience indicates that an educational program is necessary to teach the actors in the field of agricultural water how to manage their water resources in a better way. Very little has been done with regard to

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improved training tools that can be used to promote more complete understanding of the problems faced by farmers and irrigators, and the difficulty of the operational decisions they face with respect to irrigation water management. Simply providing handouts and other written materials to them is insufficient. It may be more effective to teach them in what is called "learning based on experience" through a schematic version of reality, and observing the effects of their management decisions.

Games as Training Tools

Simulations and games have been valuable tools and teaching aids. This includes roles in research, education, and training. Games can be considered as effective decision support tools in which players become decision makers (Ubbels and Verhallen 2000, in Lankford et al. 2004). They can provide means to direct thinking, illustrate complex inter-relationships, adapt to extreme situations, and weigh priorities (Smith 1989; Kos and Prenosilova 1999; Clarke 2004).

Clarke (2004) listed the following elements that must be contained in a game: (1) Relevance: the game must be of interest to the trainee and reflect his/her needs; (2) Simplicity: the game should be presented in a simple and clear format; (3) Realism: the program should produce realistic results and applied recommendations; (4) Interaction: rapid response , different alternatives, and good use of visual effects will attract the player's interest; (5) Flexibility: the ability of the program to modify itself in response to the user needs; (6) Excitement: to be a game, the simulation should be stimulating; and, (7) Discussion: a group de-briefing discussion is recommended once the simulation is completed.

Irrigation Management Games

Several irrigation management games have been developed by different individuals and groups over the past few decades. Although each game has its own unique features, there is some degree of overlap among them. Examples of these games are: The Green Revolution Game, a role-playing game described by Chapman (1982) in Clarke (2004); the Juba Sugar Estate Game, a role-playing game described by Carter (1989); the River Basin Game, a board game described by Lankford et al. (2004); the Wye College Irrigation Game, called "Stop the Breach," which is a mixture of role-playing and computer-based games (Smith 1989); the Irrigation Management Game (classroom version), a role-playing game initiated in 1982 and described by Burton (1994); the Irrigation Management Game, a computer version of the Irrigation Management Game (Clarke 2004); and, Irrigation Management Simulation Game (Irrigame), a computer-based game (Parrish 1982).

Heuristic Simulation Software

There is a new concept regarding heuristic software in what is called "intelligent learning systems," which is defined as an approach to learning from observations. An important goal of many intelligent systems is dynamic personalization and adaptability to the player. Adaptability provides automatic customization of software to the player's needs based on sophisticated user modeling techniques. A system may be trained to recognize the behavior of an expert or novice user, and then it may adjust its dialogue control or help the system automatically match the needs of the current player (Vivou and Jain 2008).

In their book, Vivou and Jain (2008) reported that common approaches for incorporating intelligence in user interfaces include: probabilistic reasoning through Bayesian Networks; machine-learning algorithms; neural networks; case-based reasoning; and, cognitive reasoning or decision-making theories. Ram et al. (2007) discuss three Case-Based Reasoning (CBR) approaches for adaptive games: automatic behavior adaptation for believable characters, drama management and user modeling for interactive stories, and strategic planning behavior for real-time strategy games. Kaukoranta et al. (2010) discussed the use of a pattern recognition approach in the context of computer games and its task to extract relevant information from a game, and to construct concepts to form patterns from this information.

FEATURES OF THE GAME

The methodology of this project describes the design and development of a computer-based training tool in the form of a game that can be used to analyze both strategic and operational issues related to the management of irrigation water resources. It utilizes an interactive framework, thereby allowing the user to develop scenarios and test alternatives in a user-friendly environment. It employs heuristic capabilities in a simulation approach for modeling all of the important aspects of on-farm water management that are essential to effective strategic planning.

The game was developed using the Microsoft Visual Basic .NET programming language. The game has the following target audiences: farmers, irrigators, irrigation extension specialists, and students. Two levels of the software were developed to match different trainee requirements and interests.

The software consists of three models: the technical model, which is considered the "brain" of the game; the scenario-based model, representing the user-computer interface model; and, the scoring and recommendation model which provides an overall evaluation of the decisions taken by the player at the end of a simulated situation (Fig. 1).

The technical-based module uses a database containing the input data (parameters) which are provided to the program (software) by the player in the scenario-based model. The scenario-based module mathematically analyzes the decisions and reactions made by the player, based on the different events, and automatically composes a scenario-based (heuristic) simulation. Random events are generated according to the evaluation of the player by the artificial intelligence method encoded in the program (see heuristic simulation part). Based on the tactical decisions taken as a response to the different random events, a sequence of results is obtained. Processing a comparison between the results obtained from the scenario-based module with that obtained from the technical module (the reference results) enables the scoring and recommendations module to evaluate the decisions made by the player. In terms of results scoring, the player will have a certain set of goals or objectives to meet: maximize profit or maximize on-farm water use efficiency. The scoring results will be based on the achievement of these objectives. After a simulated irrigation season, the program summarizes the overall decision implications (scoring), and makes suggestions for improvement and/or other optimal scenarios.

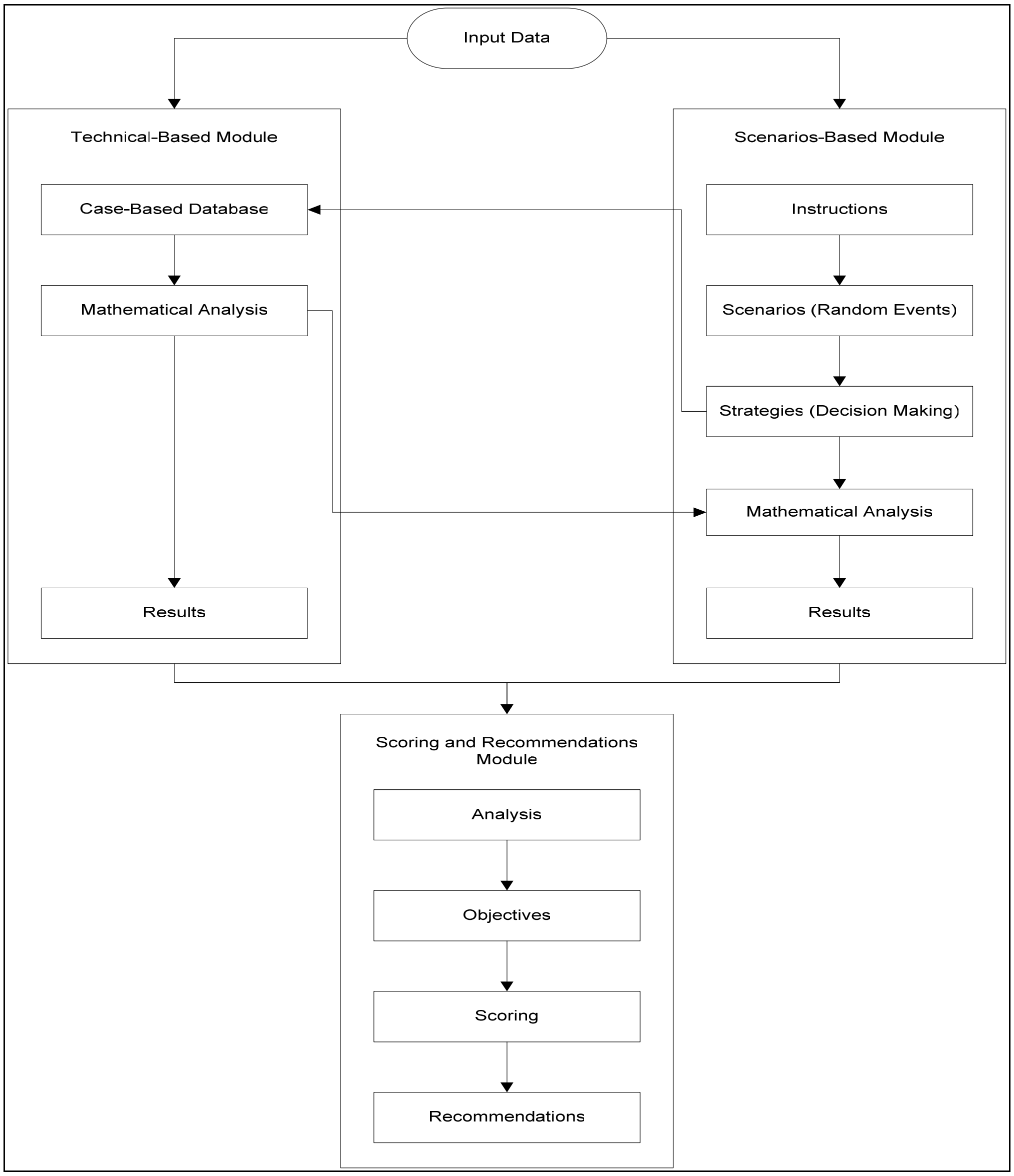

Figure 1. Schematic Diagram of the Simulation Model

Under the technical model (Fig. 2), a comprehensive sub-model has been developed which calculates soil water and salt balances in a crop root zone, and it uses a daily time step. The sub-model is described in detail in the following sections of this paper. The software includes the following options:

1. Distribution system delivery methods: fixed rotation, on-demand, and a modified demand schedule;
2. On-farm irrigation methods: surface, sprinkler, and localized (trickle); and,
3. Irrigation water quality: various salinity levels.

Random events (both favorable and unfavorable) and their effect on crop growth, phenological stage sensitivity, best management practices, and overall agricultural productivity and profitability, are also included in the software. The kinds of random events are: unexpected rain, sudden change in air temperature (weather), canal breaks/breaches, pipe bursts, pump/motor failures (water supply interruptions), unexpected increases in the available water supply (when it was previously constrained), sudden changes in agricultural market conditions (crop prices), sudden failure of the on-farm irrigation system, temporary electrical outages, labor strikes, water theft (effect on quantity and pressure), problems with water drainage, unexpected additional water requirements from non-agricultural sectors, and salinity and other water quality problems.

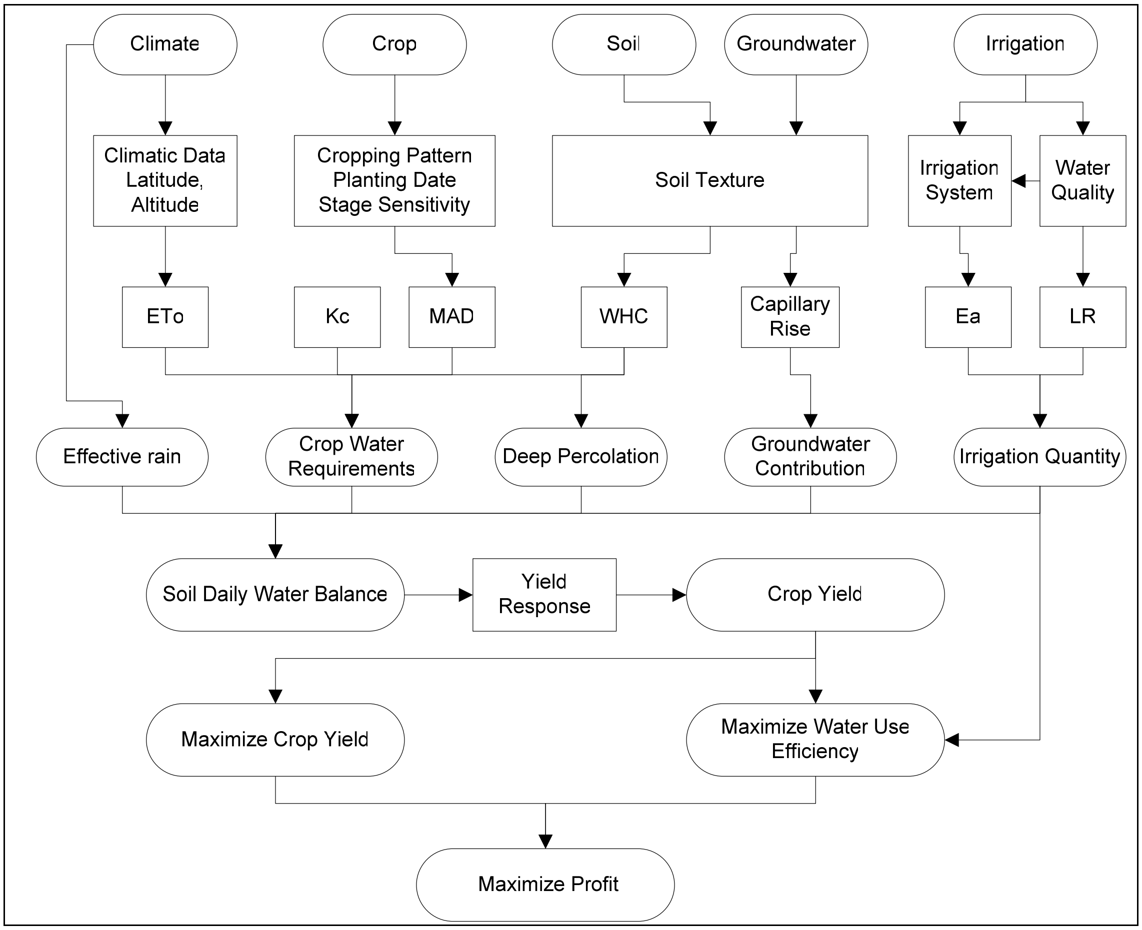

Figure 2. Schematic of the Technical Model

The game has various options for making strategic management decisions. For example, the player can choose to invest in system maintenance, water well development, a better on-farm irrigation method, or a drainage system. The software also gives the player the option to purchase additional water shares (quantity) from other water users, if available, or to sell unused water to other users.

Computer-User Interface

At the beginning of the game, the player is asked to choose one of the two proficiency levels offered by the game: beginner or professional. After this, a new window for data input appears, based on his/her choice.

In the data input window, the player is asked to select the desired climatic zone. The player has the following climatic-zone options based on Keoppen's climate classification (FAO 2010): tropical moist, wet-dry tropical, dry tropical, dry-mid latitude (steppe), Mediterranean, dry-mid latitude (grassland), and moist continental climatic zone.

The planted crop(s) can be chosen from a list of 26 different crop types as found in Doorenbos and Kassam (1979). The player can choose from five different on-farm irrigation methods: furrow, border, basin, solid-set sprinkler, and drip irrigation. The player can also choose from one of three water delivery options: on-demand, modified demand, and fixed rotation. Crop phenology, such as initial and maximum root depths, crop spacing, crop harvesting date, potential productivity (crop yield), market price of the product, and threshold soil water salinity (ECe) are fixed by the program. The cost of the irrigation method, the cost of agronomic inputs and labor, the delivery system flow rate, water table depth, and irrigation supply and groundwater salinities are also set by the program.

In the beginner level, the game allows the player to manage a 40-ha farm consisting of four different fields and a single crop type. The player is allowed to choose one on-farm irrigation method for all four fields. If the player decides to irrigate part of the farm due to water shortage or for any other reason, he/she has the option of choosing which fields are to be irrigated at each potential irrigation event. The player has the option of specifying the planting dates, but the harvest date is set by the game, as mentioned above.

In the professional level, the player will be asked to manage a 200-ha farm, with five different plots. Each plot consists of four different fields. The player has the ability to choose a different on-farm irrigation method for each plot and five different crops for the whole farm, or one crop with different planting dates. Different water sources can be used alternatively during the cropping season with the limitation of one source per irrigation. The player has the option to choose the irrigated plot and to determine the irrigated field within each plot at the beginning of each irrigation event (this option is given in the simulation window).

After completing the data input tasks, the simulation window is displayed in which the computer-player interaction starts and the artificial intelligence coding method is activated, based on the level chosen by the player. In this window, the total available water for the entire season is specified by the program, with the option of increasing/decreasing this quantity by certain random events which may or may not occur. The daily available water quantity for the remainder of the season is schematically made available to the player. A seven-day weather forecast, options for irrigation water quantity, flow rate, and different water source options (with information about the respective salinities) are made available for the player to make management decisions. Random events which are dependent upon the chosen level will appear during the simulation. Evaluation of the player's performance by the game's artificial intelligence system will occur based on the player's reactions to the random events and the management decisions he/she has made. The generation of random events is adjusted dynamically by the program to meet player capabilities. The intelligent system evaluation results in several hints to lead the player toward better management decisions in subsequent simulation events.

A dynamic sketch which shows the daily cropping conditions, based on the decisions taken by the player, is continuously presented in the simulation window. The sketch includes information about daily soil water balance, soil water excess or shortage, daily plant and root growth, plant growth conditions; whether the crop is performing well or shows symptoms of stress; whether the crop is still alive or has died; and so on.

After the end of the planting season, the game will display the final window. In this window, an economic analysis of the cropping season will be processed based on the crop yield, production cost, and on-farm water use indicators. A final score based on the overall consequences of the decisions which were made, in addition to recommendations for management improvements, are presented to the player.

Heuristic Simulation

To be an adaptive game, there are set of rules in the program which capture subtle variations of the user's responses and behavior when face with a specific problem or decision, and these rules are used to modify the game environment. The heuristic features of the program were developed based on a combination of two artificial intelligence approaches: (1) a pattern recognition approach; and, (2) a case-based reasoning approach.

The task of pattern recognition system is to extract information from the game world (management decisions and player actions), group the information into classes of similar patterns, and forward this information to the decision-making system. The pattern recognition part of the program is responsible for developing a player module by clustering the player decisions and classifies them into a pattern class. Based on the forwarded information, the case-based reasoning system, which is the decision-making system, has the responsibility to choose the appropriate action based on the set of possible actions allowed by the game environment.

Water Balance Sub-Model

This sub-model considered the main part of the technical model of the game. It simulates the field soil water and salinity balances on a daily basis and predicts; crop growth, consumptive use, weather conditions, salinity, and relative yield response to irrigation events. Thus, the model monitors the irrigation scheduling program and its effect on crop conditions and productivity.

Various parameters that affect the daily soil and salt water balance are considered, such as: depth of applied irrigation water, depth of precipitation, groundwater contribution, evapotranspiration, deep percolation, and surface runoff.

Calculations of water balance are based on the following equation (Allen et al., 1998):

$$Dr_{EndofDay}(J) = Dr_{BeginningofDay}(J) - P_{net}(J) - I_{net}(J) - GW_{net}(J) + ET_a(J) + DP_a(J) \qquad \text{Eq.(1)}$$

where *J* is the day of the year; $Dr_{EndofDay}(J)$ is the depth of water depletion in the root zone at the end of day *J*; $Dr_{BeginningofDay}(J)$ is the depth of water depletion in the root zone at the beginning of day *J*; $P_{net}(J)$ is the actual amount of precipitation that enters the root zone during day *J*; $I_{net}(J)$ is the amount of irrigation water that infiltrates into the soil during day *J*; $GW_{net}(J)$ is the amount of groundwater contribution in the root zone area during day *J*; $ET_a(J)$ is the actual depth of crop evapotranspiration during day *J*; and, $DP_a(J)$ is the actual depth of water deep-percolated below the root zone during day *J*. All terms in Eq. (1) have units of millimeters.

Simplified assumptions were made to estimate all parameters in Eq. (1). These assumptions are as follows:

- The soil profile is homogeneous (in both texture and structure) throughout the root zone and has only one soil layer. Therefore, soil water content and salt concentration is uniform throughout the depth of the root zone for each 24-h simulation interval.
- Soil water depletion at the beginning of the planting day is assumed to be zero, and the soil water content at this time is at field capacity.
- The depth to the water table is taken to be independent of internal variables such as deep percolation or capillary rise.
- Lateral flow of soil water between adjacent fields is considered to be negligible.
- If irrigation, precipitation, and groundwater contributions all enter the crop root zone in any given day of a simulation, it is assumed that the groundwater contribution occurs first, followed by irrigation, and finally by precipitation.

- One or both of the following variables must be zero in each day of a simulation: net deep percolation from the root zone, and net groundwater contribution to the root zone.

Root depth (R_z): If there is no barrier (e.g. water table or hard pan) within the root zone, the daily root depth is calculated by assuming that the rate of daily root growth is constant and increases linearly from the date of planting. The daily root depth can be calculated using the following equation (Prajamwong et al., 1997):

$$R_z(J) = R_z(J-1) + \frac{(R_z)_{\max} - R_z(J-1)}{J_{full\,cover} - J_{planting}} \qquad \text{Eq.(2)}$$

where $R_z(J-1)$ is the root depth at the previous day, $(R_z)_{\max}$ is the maximum root depth of the specific crop, usually reached at the end of the development growth stage; and, $J_{planting}$ is the planting day.

The sub-model will not allow the root depth to exceed the maximum reported root depth for the specific crop. Also, in calculating the root depth, the sub-model considers the groundwater table. If the bottom of the root zone is at the water table, there will be no root growth during that day. Likewise, there will not be any root growth if the water table is inside the root zone. If any portion of the root zone stays within groundwater table for more than three days, that portion will die.

The sub-model also considers whether the part of the root that atrophied due to saturated soil water conditions will grow back or not based on the crop growth stage. Also, if groundwater table is reached the ground surface for more than three days, the crop will die and there will be no need for further calculations of water and salt balance. The one exception considered herein is that of rice, which can survive fully saturated root-zone conditions.

Actual crop consumptive use (ET_a): The daily actual consumptive use is calculated based on the following equation:

$$ET_a = K_s K_e K_c ET_o \qquad \text{Eq.(3)}$$

where K_s is used to account for the effect of soil water stress due to water shortage in the root zone, K_e is coefficient to reduce ET due to salinity; ET_o is the grass reference evapotranspiration (mm/day), calculated using the Penman-Monteith equation; and, K_c is the crop coefficient, a function of growth stage (Allen et al., 1998).

The climatic data to calculate ET_o are included in the software. The player must choose from one of seven climatic zones. Under each climatic zone, different sets of climatic data are included, and the software will choose one randomly. To estimate K_c on a daily basis, the following equations were used (Allen et al., 1998):

$$K_c(J) = K_{c_{prev}} + \left(K_{c_{next}} - K_{c_{prerv}}\right)\left(\frac{J_c - \sum L_{prev}}{L_{stage}}\right) \qquad \text{Eq.(4)}$$

where J_c is day number within the growing season; $K_{c_{prev}}$ is crop coefficient for the previous growth stage; $K_{c_{next}}$ is crop coefficient for the next growth stage; $\sum L_{prev}$ is sum of the length of all previous stages (days); and, L_{stage} is length of the stage under consideration (days).

The soil water and salinity stress factor, K_s, is calculated using the following equation (Allen et al., 1998):

$$K_s(J) = \left[1 - \frac{b}{100K_y}(EC_e(J) - EC_{threshold})\right]\left[(\frac{TAW(J) - D_r(J)}{TAW(J) - RAW(J)})\right] \qquad \text{Eq.(5)}$$

The first part of the equation represents the effect of the stress due to soil water salinity, while the second part represents the effect of the stress due to water deficit.

TAW is total available water in root zone (mm); *RAW* is readily-available water (mm); *b* is the reduction in crop yield per increase in EC_e $(\%/dSm^{-1})$; $EC_{threshold}$ is the electrical conductivity of the saturation extract at the threshold when crop yield first reduces below the potential crop yield (*dS/m*); and, K_y is a yield response factor.

Ground water contribution (*GW*): The sub-model will check the depth of the groundwater table (*GWT*). If the water table is not inside the root zone, the groundwater contribution can affect the plant only if capillary rise from the groundwater table reaches the bottom of the root zone (Table 1). An average of the values is considered in the model for each textural classification.

Table 1. Capillary rise values for various soil types (FAO 2010).

Soil Texture	Capillary Rise (cm)
Coarse	20 to 50 cm
Medium	50 to 80 cm
Fine	more than 80 cm (up to several meters)

The groundwater contribution is the up-flux due to capillarity from the water table (m/day) and can be calculated based on Darcy's Law (Eching et al., 1994):

$$GW = -K(\theta)\frac{\partial h(\theta)}{\partial Z} = \frac{h(\theta)}{GWT} \qquad \text{Eq.(6)}$$

where $K(\theta)$ is the unsaturated hydraulic conductivity (m/day); *GWT* is the depth to the water table from the ground surface (m); and, *h* is the soil water head (m).

Unsaturated hydraulic conductivity is calculated as follows (Eching et al., 1994):

$$K(\theta) = K_{sat}\left[\frac{\theta(J)-\theta_r}{\theta_s-\theta r}\right]^{0.5}\left[1-(1-\left[\frac{\theta(J)-\theta_r}{\theta_s-\theta_r}\right]^{1/m})^m\right]^2 \qquad \text{Eq.(7)}$$

Where θ_r is residual soil water content (m^3/m^3); θ_s is saturated soil water content (m^3/m^3); K_{sat} is the saturated hydraulic conductivity (m/day); and, *m* is an empirical parameter, defined as follows:

$$m = 1 - \frac{1}{n} \qquad \text{Eq.(8)}$$

where *n* is also an empirical parameter, and is defined in Table 2; and, *h* is soil water head, and is calculated as follows (Raes 2009):

$$h(\theta) = \left(\frac{1}{\alpha}\left[\frac{\theta_s-\theta_r}{\theta(J)-\theta_r}-1\right]^{1/m}\right)^{1/n} \qquad \text{Eq.(9)}$$

Table 2. Class average values of Van Genuchten water retention parameters (Schaap et al., 1999).

Soil Type	***n***	***α*** ***(m^{-1})***	**θ_s(m^3/m^3)**	**θ_r(m^3/m^3)**
Sand	3.18	0.035	0.375	0.053
Loam	1.48	0.0098	0.4	0.062
Clay	1.27	0.011	0.457	0.1

Amount of irrigation water (*Inet*): Based on the chosen on-farm irrigation method, the sub-model calculates the net amount of irrigation water that enters the soil profile. For basin irrigation, the total amount of irrigation water has the potential to enter the soil profile, with no surface runoff losses. The sub-model checks if the amount of total irrigation water is enough to saturate the soil. If it does, it means there will be some extra water, which will be stored on the soil surface as ponded water. The ponded water might take more than one day to infiltrate in the soil. The sub-model accounts for this and calculates the depth (which may be zero) of ponded water on a daily basis.

With furrow, border, sprinkler, and drip irrigation methods, no ponded water is allowed to remain on the soil surface. Also, not all of the irrigation water will infiltrate the soil even if the amount of water is less than the amount required to bring the water content to saturation. Some of the irrigation water will be lost from the field due to runoff. The amount of runoff is estimated as a fraction of the total irrigation water (p). The fraction was decided based on information from Walker (2010) and is presented in Table 3.

Table 3: Fraction of total irrigation water lost as runoff.

Soil Texture	**Irrigation Method**	**p**
Coarse	Furrow	0.1
Coarse	Border	0.1
Coarse	Drip	0.0
Coarse	Sprinkler	0.01
Medium	Furrow	0.2
Medium	Border	0.15
Medium	Drip	0.0
Medium	Sprinkler	0.02
Fine	Furrow	0.3
Fine	Border	0.2
Fine	Drip	0.0
Fine	Sprinkler	0.05

Amount of precipitation water (Pnet): The calculation of the amount of precipitation water follows the same reasoning as the calculation of the net irrigation that enters the soil profile, taking into consideration the irrigation method used. But, instead of taking the runoff quantity as a fraction (percentage) from the total precipitation, the sub-model calculates the effective precipitation by following the FAO-AGLW approach, after adapting it for daily calculations (Smith 1998):

$$P_{eff} = 0.6P_{total} - \frac{10}{30}; P_{total} \leq \frac{70}{30} mm \qquad \text{Eq.(10)}$$

$$P_{eff} = 0.8P_{total} - \frac{25}{30}; P_{total} > \frac{70}{30} mm \qquad \text{Eq.(11)}$$

where P_{eff} is the amount of effective precipitation, which is the amount of precipitation that infiltrates the soil at the surface.

Deep Percolation (*DP*): If the soil water content in the root zone is more than the field capacity there will be some amount of water deep percolated at the bottom of the root zone, and it is considered in the sub-model. The deep percolation potential (*DPp*) is the amount of water that could potentially percolate below the root zone (which includes the soil water content above field capacity and any extra water on the soil surface).

Since only a specific amount of water can percolate below the root zone, according to the soil texture, not all the deep percolation potential can leave the root zone in one day. The sub-model will define the maximum amount of water that can be deep percolated in one day. For the normal range of agricultural soil textures, it will take 1 to 4 days for the extra water (above field capacity) to drain from the root zone due to gravity (Hargreaves and Merkley 1998). The sub-model considers 3 days for heavy soils, 2 days for medium soils, and 1 day for light soil textures.

Due to actual deep percolation of soil water below the root zone, the soil moisture content will change and must be recalculated as follows:

$$\theta(J) = \theta(J) - \frac{DP_a(J)}{1000 R_z(J)} \qquad \text{Eq.(12)}$$

where R_z is in *m*.

Salt Balance Calculation

When large amount of water percolates below root zone, a change in the salt concentration in the soil profile is expected to occur. Therefore, the root-zone salt balance is calculated on a daily basis in order to determine the daily EC_e in the root-zone. The sub-model calculating root-zone salt balance is based on the following concept:

$$S_{today} = S_{yesterday} + \Delta S \qquad \text{Eq.(13)}$$

where ΔS is the change in salt mass in the root zone.

The sub-model will start with an initial value of EC_e on the day of planting. The initial value for soil water salinity, (EC_{sw}) is calculated based on the daily soil moisture content by using the following equation:

$$EC_{sw}(J) = EC_e(J)\frac{\theta_s}{\theta(J)} \qquad \text{Eq.(14)}$$

where θ_s, and $\theta(J)$ are soil water content at saturation and the actual water content, respectively, on a given day.

Accordingly, the salt content in the soil in root zone (*S*) can be calculated as:

$$S(J) = 0.64 EC_e(J) R_z(J) \qquad \text{Eq.(15)}$$

where S is in *kg/m²;* and, EC_e is in *dS/m*. The constant 0.64 is a conversion factor. The calculations are performed for a day other than the planting day, and according to a salt mass balance:

$$S(J) = S(J-1) + \Delta S(J-1) \qquad \text{Eq.(16)}$$

The change in salt mass calculations occurs based on the calculation of the root-zone water balance components; net irrigation water, ground water contribution quantity, or amount of deep percolation, and the salinity of these components as follows:

$$\Delta S(J) = 6.4(10^{-4})\left[I_{net}(J)EC_i(J) + GW_{net}(J)EC_{gw}(J) - DP_a(J)EC_{dp}(J)\right] \qquad \text{Eq.(17)}$$

The constant $6.4(10^{-4})$ is used for conversion of units, and ΔS is in *kg/m²*. The amount of drainage water salinity is calculated, based on the following assumption (Ayers and Westcott 1994):

$$EC_{dp}(J) = 2EC_e(J) \qquad \text{Eq.(18)}$$

Since the calculations are performed on a daily basis, root depth is potentially changing every day. Therefore, the change in root depth should be considered in the salt mass balance equation. The daily salt content is calculated as follows:

$$S(J) = \left(S(J-1) + \Delta S(J-1)\right)\frac{R_z(J)}{R_z(J-1)} \qquad \text{Eq.(19)}$$

And, the average soil saturated extract salinity will be:

$$EC_e(J) = \frac{S(J)}{0.64R_z(J)} \qquad \text{Eq.(20)}$$

Yield Response (Ky): Crop yield is predicted in terms of the relative value with respect to potential crop yield. The relative crop yield is estimated by the sub-model by considering possible yield reduction due to root-zone water deficit and salinity stress. The relative yield reduction can be calculated at the end of the season using the following equation (Stewart et al. 1977):

$$\frac{Y_a}{Y_m} = 1 - K_y\left(1 - \frac{ET_a}{ET_c}\right) \qquad \text{Eq.(21)}$$

where Y_a is the actual harvested yield; Y_m is the maximum potential harvested yield; K_y is a yield response factor; and, ET_c is the maximum evapotranspiration under ideal growing conditions (mm), equal to K_c. ET_o.

SUMMARY AND CONCLUSIONS

A computer-based training tool in the form of a game was developed to be used in training events for farmers and irrigators on irrigation water management. It analyzes both strategic and operational issues related to the management of irrigation water resources. It utilizes an interactive framework, thereby allowing the user to develop scenarios and test alternatives in a user-friendly environment. It employs heuristic capabilities in a simulation approach for modeling all of the important aspects of on-farm water management that are essential to effective strategic planning.

Through intelligent and heuristic simulation tools in the form of a game in which the effect of decisions can be visualized, a great deal of understanding of the parameter and variable interrelationships for a variety of situations can be attained in a much shorter time that it would take by field experience alone. This understanding can lead directly to improvements in on-farm water management.

REFERENCES

Allen R.G., L. S. Pereira, D. Raes, M. Smith. 1998. Crop evapotranspiration: Guidelines for computing crop requirements. Irrigation and Drainage Paper No. 56, FAO, Rome, Italy.
Ayers, R. S. and D. W. Westcot. 1994. Water quality for agriculture. Irrigation and Drainage Paper No.29, FAO, Rome, Italy.

Burton, M. 1994. The Irrigation Management game: A role playing exercise for training in irrigation management. Irrigation and Drainage Systems, 7: 305-318.

Carter. R. 1989. The Juba Sugar Estate Game. Irrigation and Drainage Systems, 3: 229-240.
Clarke. D. 2004. Simulation and role playing for irrigation water management. Tools for Public Participation, Conflict Resolution and Decision-Making in Water Resources Management, Seminar held on 14 October. ICID British Section, London.

Doorenbos, J. and Kassam, A.H. 1979. Yield response to water. FAO Irrigation and Dtainage Paper No. 33, FAO, Rome, Italy. 193 pp.

Eching, S.O, J.W Hopmas, and O. Wendroth. 1994. Unsaturated hydraulic conductivity from transient multistep outflow and soil water pressure data. Soil Sci. Soc. Am. J. 58: 687-695.

FAO-SDRN-Agrometeorology group. World Climates; Keoppen's climate classification. Web page, Jan. 2010. http://www.blueplanetbiomes.org/climate.htm.

FAO-WRMED. 2010. Irrigation water management: Introduction to irrigation. Web Page. March 2010. http://www.fao.org/docrep/R4082E/r4082e03.htm.

Hargreaves, G. H. and G. P. Merkley. 1998. Irrigation Fundamentals, An Applied Technology Text for Teaching Irrigation at the Intermediate level, Water Resources Publications, LLC, Colorado, 182 pp.

Jonoski A, H. Harvey .2004. Aquavoice: prototyping participatory decision making. Tools for Public Participation, Conflict Resolution and Decision-Making in Water Resources Management, Seminar held on 14 October. ICID British Section, London.

Kaukoranta, T., J. Smed, H. Hakonen. Role of pattern recognition in computer games. Web page. March 2010. http://tucs.fi/publications/insight.php?id=pKaSmHa03a.

Kos. Z and E. Prenosilova. 1999. Simulation and gaming in water management in Czech Republic. Simulation & Gaming, Vol. 30 No. 41, pp 476-481.

Lankford. B. Ch. Sokile and D. Yawson. 2004. The river basin game: A role-playing board game for initiating discussions on visions and strategies of water allocation. Tools for Public Participation, Conflict Resolution and Decision-Making in Water Resources Management, Seminar held on 14 October. ICID British Section, London.

Molle, F. and J. Berkoff. 2006. Cities versus agriculture: Revisiting intersectoral water transfers, potential gains and conflicts. Comprehensive Assessment Research Report 10. Colombia, Sri Lanka: Comprehensive Assessment Secretariat.

Parrish, J. 1982. “IRRIGAME” An irrigation management simulation game. M.Sc. Thesis. Biological and Irrigation Department. Utah State University.

Prajamwong, S., G.P.Merkley, and R.G. Allen. 1997. Decision support model for Irrigation water management. Journal of Irrigation and Drainage Engineering. Vol. 123, No. 2.
Raes, D. 2009. UPFLOW: Water movement in a soil profile from a shallow water table to the topsoil (capillary rise), Reference Manual, Version 3.2, Leuven, Belgium, 22 pp.

Ram, A., S. Ontañón, and M. Mehta. 2007. Artificial intelligence for adaptive computer games. Twentieth International FLAIRS Conference on Artificial Intelligence. AAAI.

Schaap, M.G., F.J. Leij and M.Th. Van Genuchten. 1999. Estimation of the soil hydraulic properties. In (Looney and Falt, Editors) Vadose Zone – Science and Technology Solutions. Battelle Press: 501-509.

Smith, M. 1988. Manual for CROPWAT version 5.2. FAO, Rome. 45 pp.

Smith, L. 1989. The Wye college irrigation game, “Stop the breach”. Irrigation and Drainage Systems 3: 255-246.

Stewart, et al. 1977. Optimizing crop production through control of water and salinity levels in the soil. Utah Water Lab. PRWG 151-1, Logan, Utah, p. 91.

Virvou, M. and L.C. Jain. 2008. Intelligent interactive systems in knowledge-based environment: An introduction. Springer-Verlag- Berlin Heidelberg.

Walker, W. 2010. Personal communications