



LINKAGE OF ARCVIEW GIS WITH THE RZWQM

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ABSTRACT: The Root Zone Water Quality Model (RZWQM) is a one-dimensional, lumped field-scale model. It can simulate major physical, chemical, and biological processes in an agricultural crop production system. While its reliability has been verified by several researchers, because of its lumped structure RZWQM could not account for the soil heterogeneity and the associated nonuniformity of management practices across the field. Neglecting the variability may result in misleading simulation results. On the other hand, the variability can be accurately characterized by using a geographic information system (GIS), especially ArcView GIS, the most widely used desktop mapping and geographic analysis system. Linked with ArcView GIS, RZWQM will have a quasi-distributed structure, which makes it possible to incorporate the field variability into the simulation. The linkage is realized by a series of interfaces and dialogue boxes developed in Avenue and Microsoft Visual Basic computer programming languages. The user can develop and execute such a coupled model by employing an easily-used main interface, the interfaces for preparing the input data files and displaying the simulation results, and the associated dialogue boxes. Undoubtedly, the linkage will facilitate and enhance the use of RZWQM.

(KEY TERMS: geographic Information System; quasi-distributed mathematical modeling; RZWQM; spatial variability; field management; water quality modeling; model integration.)

INTRODUCTION

Root Zone Water Quality Model (RZWQM), developed by the U.S. Department of Agriculture (USDA) Agricultural Research Service (ARS), is a one-dimensional (vertical in the soil profile), process-based field-scale model that simulates major physical,

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chemical, and biological processes in an agricultural crop production system (USDA – ARS, 1992). These processes include plant growth and the movement of water, nutrients, and agrochemicals over, within, and below the crop root zone of a unit area of an agricultural cropping system under a range of common management practices or strategies (Ahuja et al., 1996; Azevedo et al., 1997; Ma et al., 1995, 2000). The primary use of RZWQM is as a tool for assessing environmental impacts of alternative agricultural management strategies on subsurface environments. The management strategies that can be evaluated using RZWQM include 1) conservation plans on a field-by-field basis; 2) tillage and residue practices; 3) crop rotations; 4) planting date and density; 5) irrigation-, fertilizer-, and pesticide-scheduling (method of application, amounts, and timing); and 6) tile drainage. The accuracy and efficiency of RZWQM to simulate these practices have been evaluated and presented by Ahuja et al. (1996), Azevedo et al. (1997), Ma et al. (1995, 2000), Kumar et al. (1997), and Singh et al. (1996). In RZWQM, these strategies are simulated by six major scientific modules called physical processes, plant growth processes, soil chemical processes, nutrient processes, pesticide processes, and management processes. These modules are quantitatively described by six sets of parameters classified as environmental parameters, soil system configuration and properties, macropore and infiltration, potential evaporation, soil chemistry (pesticide), and management parameters (USDA-ARS, 1992). The environmental parameters define the geography and topography of the study field, whereas the potential evaporation specifies the parameters of heat transfer between the sunshine and the field. In field scale, the variations of these two classes of parameters are minor, and thus assumption of uniformity will result in a negligible effect on simulation results. Moreover, the parameters of soil chemistry are inherent attributes of the pesticides to be applied to the field. Therefore, the parameters defining the field – environmental, potential evaporation, and soil chemistry – can be assumed invariant across the field without affecting the model accuracy. However, the other three classes of parameters, including soil system configuration and properties, macropore and infiltration, and management practices, in general, have a spatial variability significantly affecting the model accuracy (Ma et al., 1998; Martin and Watts, 1999). The simulation results based on a model neglecting the spatial variability of these parameters may be

misleading. Thus, to be an effective tool, it is important for RZWQM to be able to account for the spatial variability of these three classes of parameters. Unfortunately, RZWQM was designed to have a lumped structure, which makes this consideration very difficult. On the other hand, the spatial variability can be easily and accurately characterized by using a geographic information system (GIS). Coupled with GIS, RZWQM will have a quasi-distributed model structure, which allows the user to take into account the field spatial variability (Wang, 2001).

ArcView GIS, developed by the Environmental Systems Research Institute (ESRI) to be used primarily for desktop mapping and geographic data analysis and display, is perhaps the most widely used GIS software in the current marketplace. With an estimated 500,000 copies in use worldwide, ArcView provides users intuitive, easy-to-use, point-and-click interfaces for manipulating, querying, analyzing, modeling, and visualizing data from many different sources (Reference). It contains task wizards and customized programs such as Dialog Designer that allow users to quickly develop customized, enterprise-level applications and interfaces by adding standardized functions and operations, deleting and adding buttons, and attaching a script to automate a process. The interfaces can be developed in Avenue and Microsoft Visual Basic computer programming languages and then employed to link ArcView GIS and other application software packages such as RZWQM. Also, ArcView GIS contains customized modules, called Extensions, for enhancing the process of modeling, visualization, and mining of data. For example, as advanced extensions, the Spatial Analyst Extension and the 3D Analyst Extension, when used with ArcView, provide even more powerful functions and tools to analyze and solve real-world problems. The 3D Analyst Extension provides a suite of tools and functions to create three-dimensional surface models, model real-world surfaces and subsurface features, and perform interactive visualization of data. In particular, the Spatial Analyst Extension provides needed capabilities and functions that allow users to 1) create, query, and analyze cell-based data; 2) perform integrated vector-raster analysis using feature- and grid-based functions; and 3) construct grid-based spatial models through the use of ModelBuilder. It also contains functions that allow users to 1) create continuous surfaces from point features; 2) perform discrete cell-by-cell analysis;

3) conduct local, zonal, or global analysis on point data to, for example, generate input data or terrain attributes such as aspect and slope, which are needed by RZWQM; 4) perform hydrologic analysis using cell-level digital elevation models; and 5) display basic and derived data in various formats. Other ArcView Extensions include Network Analyst, StreetMap, Business Analyst, Image Analyst, Tracking Analyst, and Internet Map Server for publishing dynamic maps on the World Wide Web.

This paper presents the linkage of ArcView GIS with the RZWQM model. The linkage is realized by a series of interfaces and dialogue boxes developed in Avenue and Microsoft Visual Basic computer programming languages. The following section describes the main interface, followed by the interfaces for preparing RZWQM input files and for displaying its simulation results.

MAIN INTERFACE

The main interface linking the RZWQM and ArcView GIS is shown in Figure 1. The dialogue box, titled Environmental Modeling by RZWQM, consists of five frames captioned *Parameters*, *Modeling*, *Output Reports*, *End Modeling*, and *Edit Databases and Common Data Files*. In *Parameters*, the **Initialize Project** button is designed to bring out the dialogue box used to specify the soil coverage of the study field and the working directory, where all of the input and output data files to run RZWQM will be stored; whereas the other two buttons, **Prepare RZINIT.DAT** and **Prepare RZWQM.DAT**, are designed to prepare two of the RZWQM input data files, RZINIT.DAT and RZWQM.DAT. The parameters defined by the data of these two files are described by USDA-ARS (1992). The initial values of the RZWQM parameters at the starting time of simulation are provided by RZINIT.DAT and extracted from the soil coverage. The RZWQM.DAT, including the values of the field- and soil-specific parameters, is generated by querying the database created and modified by clicking the command button of **Soil, Crop, and Management** in the frame of *Edit Databases and Common Data Files*. The configurations controlling a RZWQM run, included in the input file of CNTRL.DAT, are specified by clicking the button **Control Datafile:CNTRL.DAT**. The other two buttons of this frame, **Rainfall**

Datafile:BRKPNT.DAT and **Mete. Datafile:DAYMET.DAT**, are used to generate the rainfall and metrological data files, BRKPNT.DAT and DAYMET.DAT, respectively. By completing these operations, the user has developed a cell-based RZWQM model incorporating the field spatial variability. The size of the cells, each of which is a smaller homogeneous area of the study field, is determined using an optimal discretization algorithm developed by Wang (2001).

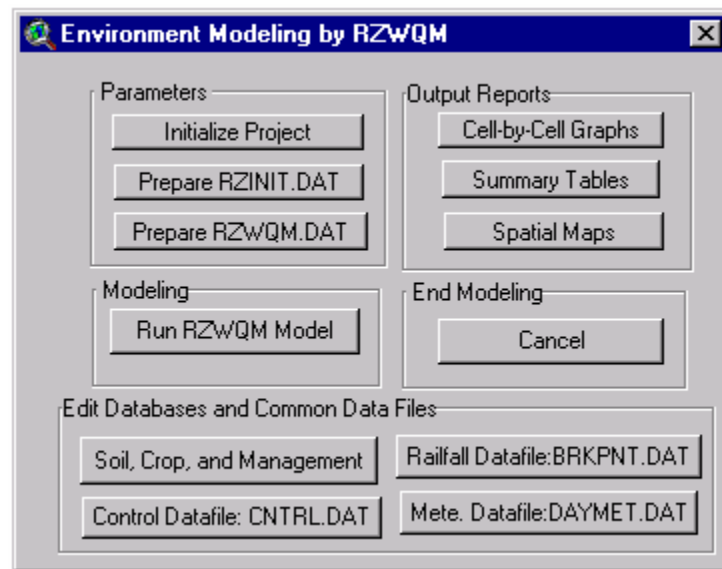


Figure 1. The Main Interface.

The cell-based RZWQM model is executed by clicking **Run RZWQM Model**, the only command button in the frame of *Modeling*. The simulation results can be displayed in three formats, including graphs, summary tables, and spatial maps. The **Cell-by-Cell Graphs** button initiates the generation of graphs using the simulation results from cell to cell. And the **Summary Tables** button displays the simulation results in tables summarized by cells, simulation days, or statistics of the simulated parameters. Taking the summations of the simulated values for each of the interested parameters, such as INFILSEEP, the **Spatial Maps** will generate maps showing their spatial patterns. The execution can be canceled or terminated by clicking on **Cancel**, the only button in the *End Modeling* frame.

INTERFACES FOR PREPARING INPUT FILES

RZWQM requires several input files, including BRKPNT.DAT, DAYMET.DAT, CNTRL.DAT, RZINIT.DAT, and RZWQM.DAT. As aforementioned, the first three files can be created using the buttons in the frame of *Edit Databases and Common Data Files* of the main interface (Figure 1). The parameters specified in these files are assumed uniform across the study field. Thus, these three files are just prepared in the field level. However, the last two files include both field- and soil-specific parameters, and thus need to be prepared for each of the smaller cells. Preparing these two files involves using the buttons of **Initialize Project**, **Prepare RZINIT.DAT**, and **Prepare RZWQM.DAT** of the main interface.

Initialize Project will bring out the dialogue box shown in Figure 2. In this dialogue box, in addition to specifying the working directory where all of the input and output files will be stored, the user needs to load the soil coverage and plot coverage. Both of these coverages are in the format of the ArcView shape file. The soil coverage defines the soil composition of the study field with the associated soil properties, including soil type, soil texture, mean soil moisture, bulk density, saturated hydraulic conductivity, and so on. For each of the soil types, besides the number of horizons to be modeled by RZWQM, the values of these soil properties for each of the horizons are provided in the attribute table of the soil coverage. And the interested field extent, i.e. the field area to be modeled and simulated, is defined by the plot coverage. With these data, the script, written in Avenue and attached to the **Ok** button, will subdivide the field into the appropriate amount of smaller cells, with cell size determined by the optimal discretization algorithm developed by Wang (2001). Moreover, this script will create one RZINIT.DAT input file for each of the smaller cells by extracting values from the soil coverage clipped by the plot coverage. The blocks, called by USDA-ARS (1992) Water and Temperature Section, Soil Chemistry Section, Nutrient Section, and Pesticide Section, to be included in these RZINIT.DAT files, can be specified by checking and/or unchecking the boxes in the dialogue box shown in Figure 3, titled Prepare Input Block for RZINIT.DAT File. These RZINIT.DAT files can later be recreated and modified by clicking Prepare RZINIT.DAT button in Figure 1.

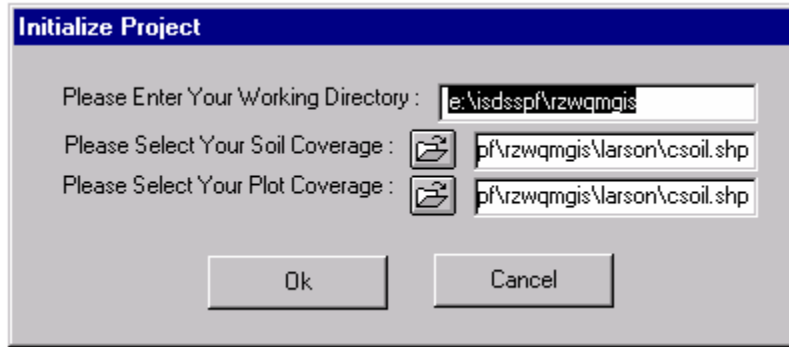


Figure 2. Initialize Project Dialog Box.

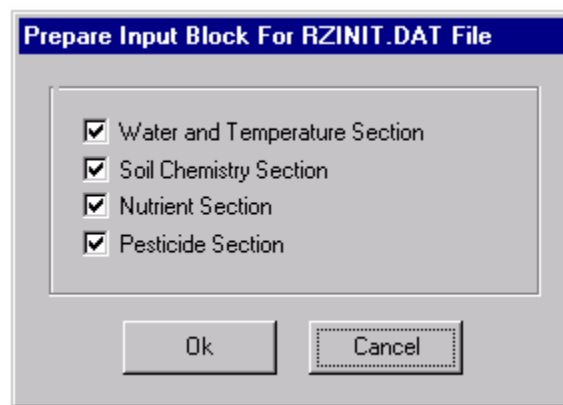


Figure 3. Prepare RZINIT.DAT File Dialog Box.

Prepare RZWQM.DAT button in Figure 1, used to prepare another input file of RZWQM.DAT, will bring out the dialog box shown in Figure 4. This dialog box includes six command buttons called **Environmental Parameters**, **Soil System Configuration and Properties**, **Macropore and Infiltration**, **Potential Evaporation**, **Soil Chemistry-Pesticide**, and **Management Parameters**. **Environmental Parameters** will bring out the dialog box shown in Figure 5. Through this dialog box, the user can input the field elevation, latitude, aspect, and slope. And the values for the parameters used by RZWQM to compute potential evaporation from the field are input through the dialog box shown in Figure 7. These parameters include albedo of the dry soil surface, albedo of the wet soil surface, albedo of the crop at maturity, albedo of fresh residue, height at which wind measurements are taken, average sunshine fraction for a day, and pan coefficient. The input dialog box is activated by clicking the **Potential Evaporation** button in Figure 4. The data used to configure the root zone, such as

number of the horizons and soil saturated hydraulic conductivity, is extracted from the soil coverage by clicking **Soil System Configuration and Properties**. These data can be further modified using the dialogue box shown in Figure 6, brought out by clicking the **Macropore and Infiltration** button in Figure 4. In addition, the parameters relevant to drain tiles, including depth from surface to tile drains, drain spacing, and radius of drains, can be defined in this dialogue box.

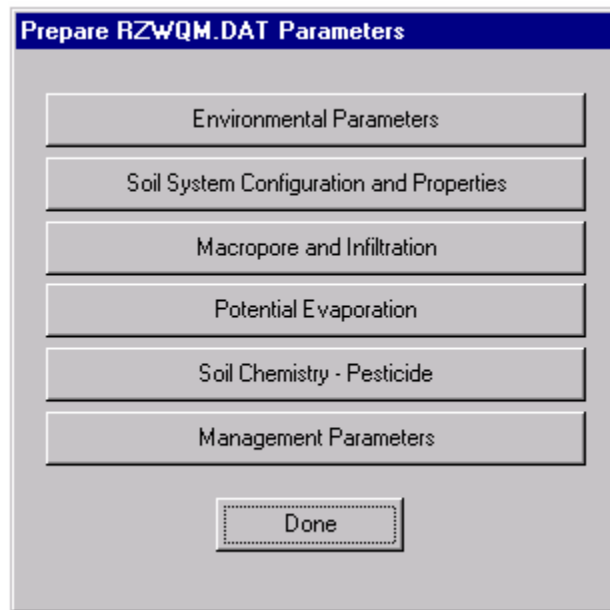


Figure 4. Prepare RZWQM.DAT File Dialogue Box.

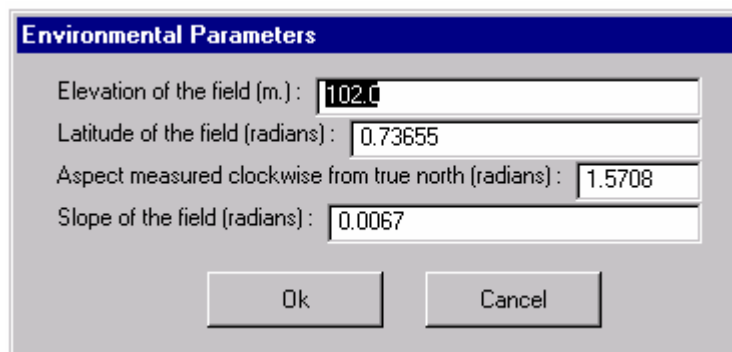


Figure 5. Environmental Parameters Input Dialogue Box.

Macropore and Infiltration

Macropore and Infiltration Parameters

Select the name for soil type : Okoboji

Surface crust present? Yes No

Crust Hydraulic Conductivity 0.0

Macropore present? Yes No

Bottom boundary condition : constant head boundary

Value of leakage rate (cm/hr) 0.0

Field saturation factor (theta-s) 0.9

Management Cutoff Threshold for Soil Moisture Content (0--1) 0.95

High water table present? Yes No

Depth from surface to tile drains (cm) 120

Drain spacing (cm) 3000 Radius of drains (cm) 10

Unit Gradient Flow During Infiltration Events? Yes No

Use Horizon Microporosity Data as Given? Yes No

Const A of Non-uniform Mixing Equation: $\text{mixing} = Ae^{(-Bx)}$ 1.0




Const B of Non-uniform Mixing Equation: $\text{mixing} = Ae^{(-Bx)}$ 4.4

Sorptivity factor control for lateral G-A infil 0.5

Ok Cancel

Figure 6. Macropore and Infiltration Configuration Dialogue Box.

Figure 7. Potential Evaporation Parameters Input Dialogue Box.

As part of RZWQM.DAT, the data describing the properties of pesticides to be applied to the study field is entered through the dialogue box shown in Figure 8, brought out by clicking the **Soil Chemistry-Pesticide** button in Figure 4. In this dialogue box, the user needs to select the pesticide whose parameters will be defined from the combo box of Select Pesticide. The values defining its physiochemical properties, wash-off parameters, and equilibrium coefficients can be input using the corresponding text boxes followed by the Save icon  located at the right-bottom corner in Figure 8. More than one pesticide can be selected and defined by repeating this operation. The list of pesticides to be applied to the field is made by selecting the ones from the combo box of Select Pesticide, followed by clicking the  icon, and adding the selected pesticides into the combo box just right of this icon. Reversely, any of the selected pesticides to be applied can be deleted from the list by selecting the pesticide from the right combo box and then clicking  icon.

The data for the management parameters included in RZWQM.DAT is extracted from the soil coverage as well. They are classified as parameters to describe the field management practices of surface residue, plant growth, manure, fertilizer, pesticide, tillage, irrigation, and others. These management practices are documented by USDA-ARS (1992). The practices to be simulated by RZWQM will be selected by checking

and/or unchecking the corresponding boxes in the Management Parameters dialogue box shown in Figure 9. This dialogue box can be activated by clicking the **Management Parameters** button in Figure 4.

Figure 8. Pesticides Parameters Input Dialogue Box.

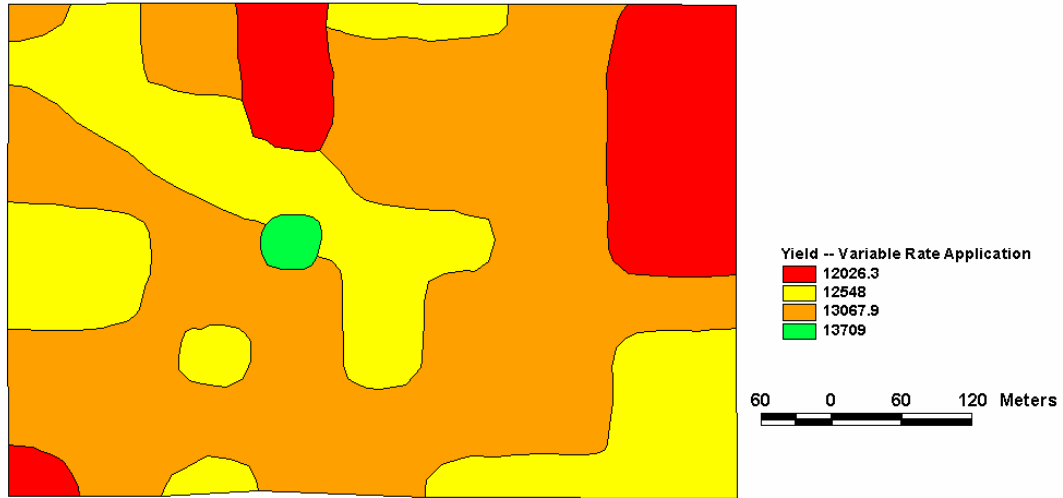
Figure 9. Management Practices Configuration Dialogue Boxes.

INTERFACES FOR DISPLAYING SIMULATION RESULTS

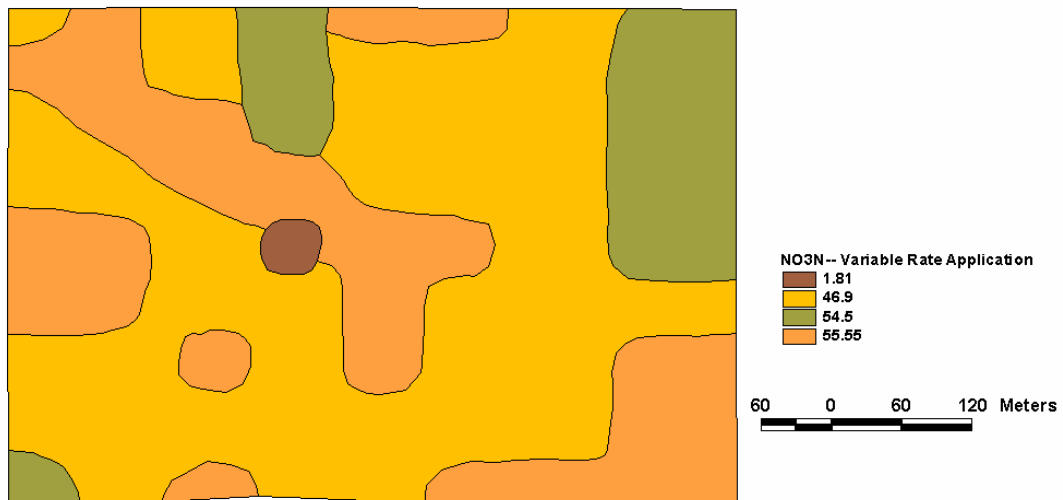
The cell-based simulation is accomplished by clicking the **Run RZWQM Model** button in Figure 1. As a result, a suite of output files storing the simulation results, called *accwat.out*, *cleach.out*, *manage.out*, *daily.plt*, and *layer.plt*, will be generated for each of the smaller cells. These results can be displayed as graphs that are made using the Output Report Generator coming with the RZWQM software package (USDA-ARS, 1992). The total number of graphs to be displayed is equal to the multiplication of the number of parameters by the numbers of cells. In comparison with these cell-by-cell graphs, spatial maps can be generated with the summation of the simulated values of the parameters throughout the simulation period. These maps show the spatial patterns of the displayed parameters. Figure 10 provides examples of these maps showing the simulated corn yield and nitrate-nitrogen leaching for a 25-ha field located in Central Iowa. The graphs are generated by clicking the **Cell-by-Cell Graphs** button and the spatial maps by clicking the **Spatial Maps** button in Figure 1, respectively.

Alternatively, the simulation results can be displayed in summary tables. The results can be either summarized by cells or simulation days. The tables summarized by cells will display the time-series values simulated for the parameters, whereas the ones summarized by simulation days show the simulated values of the parameters for all of the cells, summed throughout the simulation period. In addition, statistical summary tables can be created to display the statistics, including minimum, maximum, mean, and standard deviation, of the simulated values of the parameters categorized by the cells and the simulation days. Figure 11a is a typical example of the tables summarized by cells, and Figure 11b of the statistical summary tables. These summary tables are created through the dialogue boxes shown in Figure 11, brought out by clicking the button of **Summary Tables** in Figure 1. The parameters to be summarized depend upon which of the radio options box found in the *Information Source* frame in Figure 11, labeled as *Accwat.out*, *Cleach.out*, *Manage.out*, *Daily.plt*, and *Layer.plt* and representing the five output files mentioned above, will be checked. For example, when the option box of *Accwat.out* is checked, the water-budget parameters, including *STOR*, *RAIN*, *IRR*,

RUNOFF, AET, SEEPAGE, DRAIN, MACRO, INFIL, and INFILSEEP, will be displayed in the summary tables.

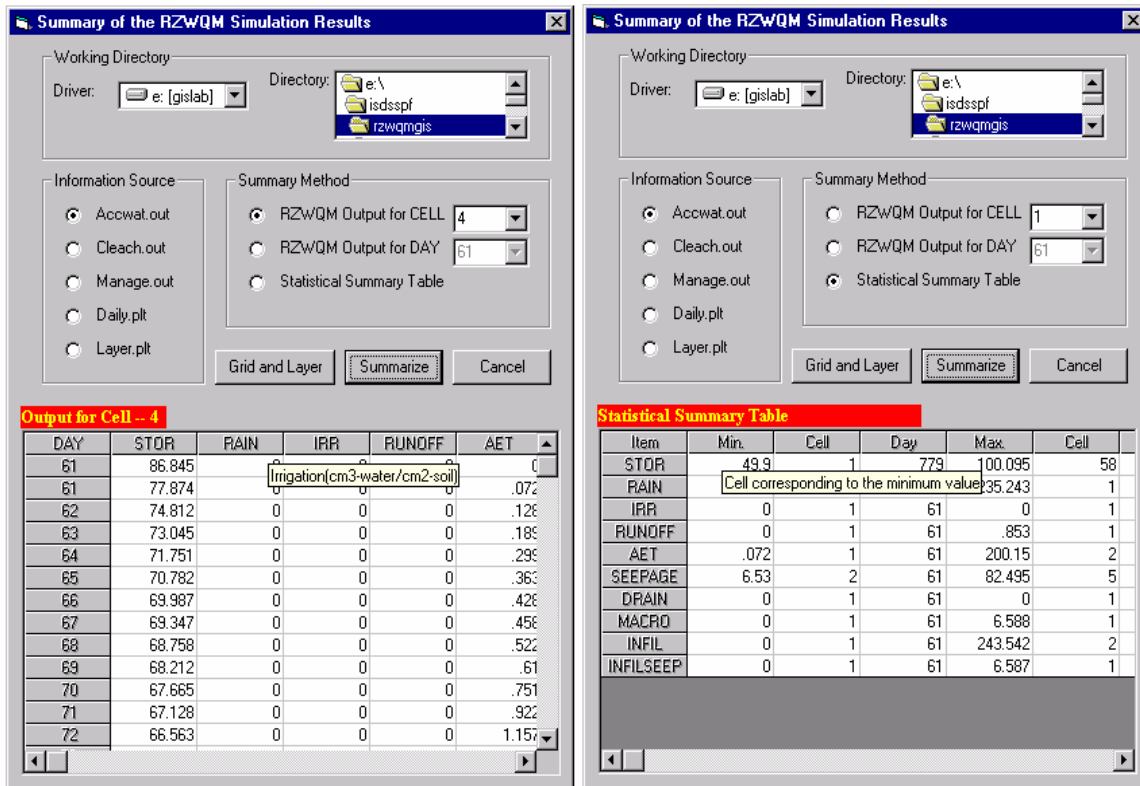


(a) The Simulated Corn Yield Map (kg/ha)



(b) The Simulated Nitrate-nitrogen Leaching (kg/ha)

Figure 10. Examples of Spatial Maps for a 25 ha Field in the Central Iowa



(a) Table Summarized by Cells

(b) Statistical Summary Table

Figure 11. Examples of Summary Tables

CONCLUSIONS

RZWQM is a physically based, lumped, and field-scale model that simulates important physical, chemical, biological, physiological, and management processes of an agricultural system. Its reliability has been established in a number of applications documented by Ma et al. (2000). However, due to its lumped structure, RZWQM could not be used to study spatially distributed agricultural systems, which are general situations for farmlands in practice. Linked with the widely used ArcView GIS, a desktop mapping and geographic analysis system, through a series of interfaces and dialogue boxes, RZWQM has a quasi-distributed structure and can be executed cell-by-cell. Each of the cells is a smaller homogeneous area of the study field. The spatial variability of an agricultural system, such as soil heterogeneity and its resulting nonuniformity of field

management practices, will be accounted for by specifying different values for the parameters from cell to cell. The cell size is determined by on an optimal discretization algorithm developed by Wang (2001). The values for the parameters are extracted from the soil coverage with a format of ArcView shape file or entered and modified through the associated dialogue boxes that were designed using Avenue and Microsoft Visual Basic computer programming languages. The execution of the cell-based RZWQM model will generate a suite of output files storing the simulation results for each of the cells. These simulation results can be displayed in graphs, spatial maps, and summary tables. The graphs display the results for each of the cells as a time series, whereas the spatial maps show the spatial patterns of the simulated parameters. Also, the results can be presented as tables summarized by cells, simulation days, or even the statistics of the simulated parameters categorized by cells and simulation days. The linkage of ArcView GIS and the RZWQM model, presented in this paper, will undoubtedly facilitate and enhance the use of RZWQM.

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