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The SWMS 2D code with a user-friendly interface-in a windows environment

J. Ŝimůnek, M. Sejna, M. Th. van Genuchten and D. L. Suarez

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THE SWMS_2D CODE WITH A USER-FRIENDLY INTERFACE IN A WINDOWS ENVIRONMENT

J. Simunek[1], M. Sejna[2], M. Th. van Genuchten[1], and D. L. Suarez[1]

ABSTRACT

A new version (2.1) of the SWMS_2D code simulating water flow and solute transport in two-dimensional variably saturated media was developed. The code was made more effective by implementing an interactive graphics-based user interface which includes data pre-processing and graphical presentation of the output results in a MS Windows 3.1 environment. Data pre-processing involves specification of the flow region having an arbitrary continuous shape bounded by polylines, arcs and splines, discretization of domain boundaries, and subsequent automatic generation of an unstructured finite element mesh. The method used for generating the mesh was based on a Delaunay criterion. We also incorporated an alternative. structured mesh generator for relatively simple quadrilateral domains. A small catalog of soil hydraulic properties was made part of the user-friendly interface. Graphical presentation of the output results consists of simple two-dimensional x-y plots, as well as contour and spectral maps, velocity vectors, and animation of both contour and spectral maps. Graphs along any cross-section are also readily obtained. The versatility of the SWMS_2D code is illustrated by means of an example simulating the two-dimensional infiltration of water and solute from a furrow into a tile-drained soil profile.
Keywords: Solute transport, Water flow, User-friendly interface, Mesh generation.

INTRODUCTION

The past several decades has seen considerable progress in the conceptual understanding and mathematical description of water flow and solute transport processes in the unsaturated zone. A variety of multi-dimensional numerical models based on the Richards' equation for variably saturated flow and the Fickian-based convection-dispersion equation for solute transport are now available to predict water and/or solute transfer processes between the soil surface and the groundwater table. These models have proven to be useful for (1) predicting water and solute movement in the vadose zone, (2) analyzing specific laboratory or field experiments involving unsaturated water flow and/or solute transport, and (3) extrapolating information from a limited number of field experiments to different soil, crop and climatic conditions, as well as to different tillage and water management schemes.

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1 U.S. Salinity Laboratory, USDA-ARS, Riverside, CA.

2 PC Progress, Prague, Czech Republic.

Even with well-documented multi-dimensional numerical computer models available. one major problem which often prevents the use of such codes is the extensive work required for data preparation, finite element grid design, and graphical presentation of output results. Hence. a more widespread use of multi-dimensional models requires techniques which make it easier to create, manipulate and display large data files, and which facilitate interactive data management. Introducing such techniques will free users from cumbersome manual data processing. and should enhance the efficiency in which programs are implemented for a particular example. To avoid or simplify the preparation and management of relatively complex input data files for two-dimensional applications, and to graphically display final simulation results, we developed an interactive graphics-based user-friendly interface for the MS Windows 3.1 environment. The interface is connected to the SWMS_2D code (Simunek et al., 1994) which simulates two-dimensional variably-saturated water flow and solute transport in a porous medium. Details of the SWMS_2D finite element code are given in the user manual, and are not further discussed here.

AN INTERACTIVE GRAPHICS-BASED USER INTERFACE

The new version 2.1 of SWMS_2D consists of an interactive graphics-based user interface, and the computational FORTRAN application itself. The user interface includes five modules and one dynamic linked library (DLL). All modules except the Fortran application are written in c++.

Brief Description of Particular Modules

SWMS_2D (Fig. 1) is the main program unit defining the overall computational environment of the system. This module controls execution of the program and determines which other optional modules are necessary for a particular application. The module contains both the pre-processing and post-processing units. The pre-processing unit includes specification of all necessary parameters to successfully run the SWMS_WIN Fortran code, a grid generator for relatively simple rectangular transport domains, and a small catalog of soil hydraulic properties. The post-processing unit consists of simple x-y graphics for graphical presentation of soil hydraulic properties, as well as such output as time changes of a particular variable at selected observation points in the domain, and actual or cumulative water and solute fluxes across boundaries of a particular type.

A project manager, POSITION (DLL) (Fig. 1) is used to manage data of existing projects, and helps to locate, open, copy, delete and/or rename the desired projects, or their input or output data.

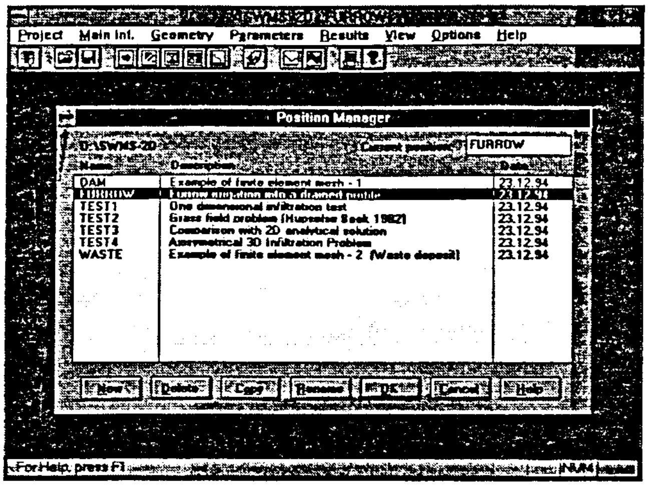

Figure 1. The main window of the SWMS_2D module, including the project manager.

The module GEOMETRY (Sejna et al., 1994) may be used to design boundary curves of virtually any two-dimensional computational domain in a Windows environment. Boundary curves can consist of any number of poly-lines, arcs, circles or cubical splines. The module permits one to specify internal boundaries (e.g., drains, wells, impermeable objects), as well as internal curves. The consistency of the invoked geometry is also checked by this module. Boundary curves can be entered from a keyboard or with a mouse, or by reading an ASCII file.

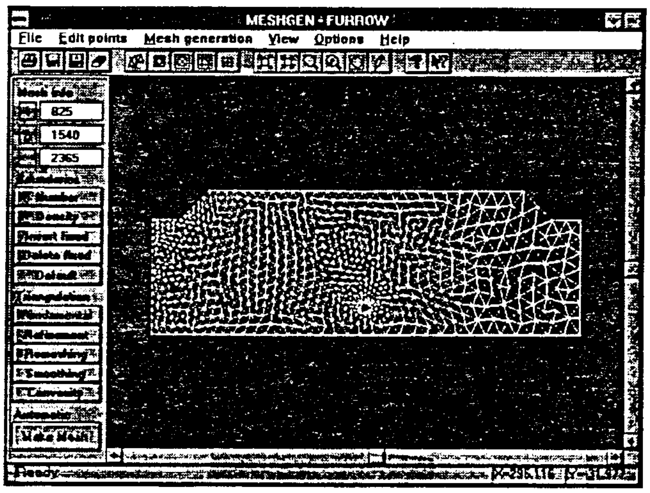

Figure 2. The main window of the MESHGEN module.

The MESHGEN (Fig. 2) (Sejna et al., 1994) module may be used to discretize a two-dimensional flow region into an unstructured triangular mesh. The algorithm used for this purpose is general and can be applied to virtually any two-dimensional computational domain. The first step of the mesh generation process is discretization of the boundary curves, while the second step involves the generation of the unstructured triangular mesh. The second step consists of five operations: (1) discretization of the flow domain into triangles with vertices in a given boundary nodes (fundamental triangulation), (2) inserting new points in all triangles which do not fulfill a certain smoothness criterion (mesh refinement), (3) implementation of Delaunay retriangulation for the purpose of eliminating all nodes surrounded by more than six triangles, as well as all extreme angles (remeshing), (4) smoothing of the mesh by solving a set of coupled elliptic equations in a recursive algorithm (smoothing), and (5) correction of possible errors which may appear during smoothing of the finite element mesh (convexity check). Operations 2 through 5 are repeated until a prescribed smoothness of the mesh has been achieved.

The BOUNDARY module helps a user in the specification of boundary and initial conditions, as well as the definition of the spatial distribution of other parameters characterizing the flow domain (e.g., spatial distribution of soil materials, scaling factors, root water uptake parameter, and possible hydraulic anisotropy) and/or observation nodes. All parameters in this module are specified in a graphical environment with the help of a mouse.

The SWMS_2D system further involves the FORTRAN application SWMS_WIN which simulates water and solute movement in a two-dimensional variably saturated medium. The SWMS_WIN program numerically solves the Richards' equation for saturated-unsaturated water flow and the convection-dispersion equation for solute transport. The flow equation incorporates a sink term to account for water uptake by plant roots. The solute transport equation includes provisions for linear equilibrium adsorption, zero-order production, and first-order degradation. The flow region itself may be composed of nonuniform soils having an arbitrary degree of local anisotropy. Flow and transport can occur in the vertical plane, the horizontal plane, or in a three-dimensional region exhibiting radial symmetry about a vertical axis. The water flow part of the model considers prescribed head and flux boundaries, as well as boundaries controlled by atmospheric conditions.

The governing flow and transport equations are solved numerically using Gale&in-type linear finite element schemes. Depending upon the size of the problem, the matrix equations resulting from discretization of the governing equations are solved using either Gaussian elimination for banded matrices, or the conjugate gradient method for symmetric matrices and the ORTHOMIN method for asymmetric matrices.

An external module GRAPHICS (Fig. 3) may be used to present results of the simulation by means of contour maps, isolines, spectral maps, velocity vectors, and animation of both contour and spectral maps. Contour and spectral maps may be drawn for the pressure head, water content and/or concentration. Animation of all three variables is also possible. Graphs of all variables at the boundaries, as well as along any selected cross-section, can be readily obtained.

EXAMPLE

Figures 1, 2 and 3 show the main windows of three different modules when the program is used to simulate furrow irrigation in a tile-drained soil profile. Calculations were carried out for a period of 100 days. The soil profile was assumed to be initially free of any solute. Every other furrow was flooded with water to a level of 12 cm. The irrigation water contained solute of unit concentration for the first 50 days. Neither root water extraction nor other soil-atmosphere interactions were considered in this example.

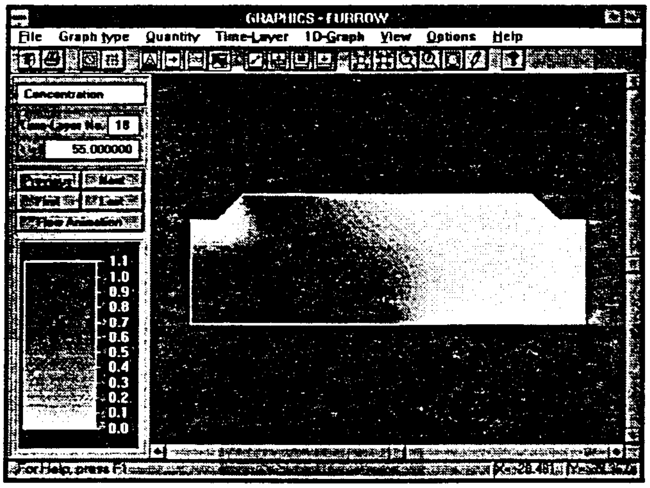

Figure 3. The main window of the GRAPHICS module.

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Fact Sheet -- SWMS-2D

An Interactive Graphics-Based User Interface for the SWMS-2D Code

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Developer J. Simúnek[1], M. Sejna[2], and M. Th. van Genuchten'
[1] U.S. Salinity Laboratory, U.S. Department of Agriculture, Agriculture Research Service, Riverside, CA.
[2] PC Progress, Prague, Czech Repub1ic.U.S. Salinity Laboratory

Description

An interactive graphics-based user interface was developed in support of the computer model SWMS_2D. SWMS 2D may be used to simulate two-dimensional water flow and solute transport in variably-saturated soils. The code also considers three-dimensional exhibiting radial symmetry about a vertical axis. SWMS_2D uses the Richards' equation for simulating variably-saturated flow and the Fickian-based convection-dispersion equation for solute transport. The user interface includes data pre-processing and graphical presentation of the output results in a Microsoft Windows 3.1 environment. Data pre-processing involves specification of the flow region having an arbitrary continuous shape bounded by poly-lines, arcs and splines, discretization of domain boundaries, and subsequent automatic generation of an unstructured finite element mesh. We also incorporated an alternative structured mesh generator for a simple quadrilateral domains. An unstructured triangular mesh is generated based on a Delaunay criterion. A small catalog of soil hydraulic properties was made part of the user-friendly interface. Graphical presentation of the output results consists of simple two-dimensional x-y plots, as well as contour and spectral maps, velocity vectors, and animation of both contour and spectral maps. Graphs along any cross-section can be readily obtained.

Water Quality Application

The model may be used to predict water and/or solute transfer processes between the soil surface and the groundwater table. The model may be an especially useful tool for (1) predicting water and solute movement in the vadose zone, (2) analyzing specific laboratory or field experiments involving unsaturated water flow and/or solute transport, and (3) extrapolating information from a limited number of field experiments to different soil, crop and climatic conditions, as well as to different tillage and water management schemes etc.

Features

A Microsoft Windows 3.1 interactive graphics-based user interface (GUI) was developed to facilitate data input and interpretation of model results. The interface was written in C++ using the Microsoft Visual C/C++ compiler. The GUI consists of five modules, and a **dynamic** linked library as follows:

S WMS_2D

Main program unit and overall computational environment of the system. This module controls execution of the program and determines which other optional modules are necessary for a particular application.

POSITION

Dynamically linked library to manage data of existing projects, and to help locate, open, copy, delete and/or rename the desired projects, or their input or output data.

GEOMETRY

Windows application to design boundary curves of virtually any two-dimensional computational domain. Boundary curves can consist of any number of poly-lines, arcs, circles or cubical splines. The module allows one to specify internal boundaries (drains, wells, impermeable objects), as well as internal curves.

MESHGEN

Discretizes the two-dimensional flow region into an unstructured triangular mesh. The method used for generating the unstructured triangular mesh is based on a Delaunay criterion

BOUNDARY

Specifies the boundary and initial conditions, as well as spatial distribution of parameters describing the properties of the flow domain (materials, scaling factors, root water uptake, anisotropy tensor), and/or observation nodes.

GRAPHICS

Presents results of the simulation by means of contour maps, isolines, spectral maps, velocity vectors, and animation of both contour and spectral maps.

SWMS **WIN**

The actual FORTRAN model simulating water and solute movement in two-dimensional variably saturated media. Relevant features of SWMS_WlN are:

- Numerically solves the Richards' equation for saturated-unsaturated water flow and the convection-dispersion equation for solute transport.
- The flow equation incorporates a sink term to account for water uptake by plant roots.
- The solute transport equation includes provisions for linear equilibrium adsorption, zero-order production, and first-order degradation.

- The program may be used to analyze water and solute movement in unsaturated, partially saturated, or fully saturated porous media.
- The program can handle flow domains delineated by irregular boundaries.
- The flow region itself may be composed of nonuniform soils having an arbitrary degree of local anisotropy.
- Flow and transport can occur in the vertical plane, the horizontal plane, or in a three-dimensional region exhibiting radial symmetry about a vertical axis.
- The water flow part of the model considers prescribed head and flux boundaries, as well as boundaries controlled by atmospheric conditions.
- The program implements a simplified representation of nodal drains using results of electric analog experiments.
- The code implements a scaling procedure designed to simplify the Description of the spatial variability in the unsaturated soil hydraulic properties in the flow domain.
- Three stabilizing options are used to avoid oscillations in the numerical solution of the solute transport equation: upstream weighting, artificial dispersion, and performance indexing.
- The governing flow and transport equations are solved numerically using Galerkin-type linear finite element schemes.
- The matrix equations resulting from discretization of the governing equations are solved using: (1) Gaussian elimination for banded matrices, (2) the conjugate gradient method for symmetric matrices, or (3) the ORTHOMIN method for asymmetric matrices.

Limitations The interface operates only under a Microsoft Windows environment. SWMS_2D does not handle preferential flow. SWMS_2D may fail for extremely nonlinear problems. Numerical instabilities may develop for convection-dominated transport problems when no stabilizing options are used. The effect of air phase on water flow is neglected. The spatial distribution of the root water uptake is constant with time.

support Distribution diskettes are available through the U.S. Salinity Laboratory, 450 Box Springs, Riverside, CA 92 507

Resource Requirements The SWMS-2D package requires a MS-DOS compatible system (386 with a mathematical co-processor, or better) running Microsoft Windows 3.1 (or later), 4 Mb of RAM memory, VGA (SVGA is recommended), and at least 10 Mb of available disk space.