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A MANUAL OF INSTRUCTIONAL PROBLEMS FOR THE U.S.G.S. MODFLOW MODEL

by

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INTRODUCTION

A recent report by the United States Environmental Protection Agency Groundwater Modeling Policy Study Group (van der Heijde and Park, 1986) offered several approaches to training Agency staff in the application of groundwater modeling. They identified the problem that current training efforts tend to be of short duration (one week or less) with a lack of in-house programs to reinforce training received in a formal setting. The study group suggested, among other things, the alternative of self-study coupled with obtaining experience under the guidance of a senior modeling specialist.

In order for groundwater modeling self study to be viable, a curriculum must exist that allows the student to have hands-on experience with the practical application of models. Available resources do not meet this need. Current groundwater modeling texts deal primarily with the mathematics or theory of modeling. Code documentations usually discuss the programming aspects and performance standards of particular models. They usually include one or two test problems for verification purposes. Journal articles or U.S. Geological Survey publications best fit the need for learning about the practical application of models. However, these sources either do not give enough information to reproduce results or involve data setup that is too complicated to allow a student to efficiently have hands-on experience with the model.

This manual is intended to meet the need described above. Twenty documented problems, complete with problem statements, input data sets, and discussion of results are presented. The problems are designed to cover modeling principles, specifics of input/output options available to the modeler, rules of thumb, and common modeling mistakes.

Data set preparation time and execution time have been minimized by simplifying the problems to small size and to focus only on the aspect that is under consideration. Model grids are generally smaller and more homogeneous than would be used in practice, however, the intent and result of each exercise are not compromised by the simplification.

This manual is developed for the U.S. Geological Survey modular groundwater model (MODFLOW) by McDonald and Harbaugh (1988). MODFLOW is perhaps the most popular groundwater flow model used by government agencies and consulting fins. MODFLOW solves the partial differential equation describing the three-dimensional movement of groundwater of constant density through porous material:

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right) - W = S_s\frac{\partial h}{\partial t} \qquad (1.1)$$

EPA 600/R 93/010

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where:

K_{xx}, K_{yy}, and K_{zz}	are values of hydraulic conductivity along the x, y, and z coordinate axes, which are assumed to be parallel to the major axes of hydraulic conductivity (LT^{-1});
h	is the potentiometric head (L);
W	is a volumetric flux per unit volume and represents sources and/or sinks of water (T^{-1});
S_s	is the specific storage of the porous material (L^{-1}); and
t	is time (T).

S_s, K_{xx}, K_{yy}, K_{zz}, may be functions of space and W may be a function of space and time. This equation, combined with specification of boundary and initial conditions, is a mathematical expression of a groundwater flow system. MODFLOW uses the finite difference method to obtain an approximate solution to this equation. Hydrogeologic layers can be simulated as confined, unconfined, or a combination of confined and unconfined. External stresses such as wells, areal recharge, evapotranspiration, drains and streams can also be simulated. Boundary conditions include specified head, specified flux, and head-dependent flux. Two iterative solution techniques, the Strongly Implicit Procedure and Slice Successive Over Relaxation, we contained within MODFLOW to solve the finite difference equations (McDonald and Harbaugh, 1988).

The user of this manual should attempt to solve the problems as described in the problem statement portion of each exercise. The model setup can be checked in the data set listing given in the model input section of each problem. Results can be checked by the pertinent portions given in the model output section. Some training on the structure and input of MODFLOW as well as some training on the theory of groundwater modeling is assumed. The user will need to refer to the MODFLOW manual on some occasions. The abbreviated input instructions given in the MODFLOW manual are included as Appendix A to this manual.

A secondary function of this manual is for verification purposes. Although the MODFLOW code has been extensively applied, very little documentation of its testing and verification is available in the literature. To address this situation, where possible, model generated results are compared to analytical solutions, results of other models, or to simulations with alternative boundary conditions or configurations. In addition to providing an informal benchmarking of MODFLOW, these problems can be used to verify the correct installation of the code on a particular computer system or to verify that certain user modifications have not altered the integrity of the program. The results of the simulations may vary slightly (approximately ±0.02 ft or m) from one computer to another. The results obtained here were with a 386 microcomputer. Table 1 shows the problems that were run and what types of verification were performed.

All the packages of MODFLOW have been utilized at least twice in this series of problems. Table 2 is a matrix showing which packages were utilized in individual problems. Several parts exist to each problem. Input and output files are included on the attached diskette for the data sets listed in the manual. Minor modifications, as described in the model input section of each problem are not included as separate data sets. The diskettes included with this document do not include a copy of MODFLOW. It is assumed the reader has obtained a copy of MODFLOW and has the necessary computer hardware to execute the program.

The problems given in the manual are intended to be useful without changes or additions. However, the problems may also be useful as a stepping stone to more detailed analysis. Rather than creating new data sets, the analyst can modify existing data sets to fill a particular need.

Table 1. Verification of MODFLOW results

Problem No.	Title	Analytical or Semianalytical Solution	Numerical Model	Alternate Boundary Condition or Model Configuration
1	Theis solution	X		
2	Anisotropy	X		
3	Artesian-water table conversion	X		
4	Steady State			X
5	Mass balance			X
6	Similarity solutions in model calibration			
7	Superposition			X
8	Grid and time stepping considerations	X	X	
9	Calibration and prediction			
10	Transient calibration			
11	Representation of aquitards			
12	Leaky aquifers	X	X	
13	Solution techniques and convergence			
14	Head dependent boundary conditions			X
15	Drains			X
16	Evapotranspiration		X	
17	Wells			
18	Cross-sectional simulations			
19	Application to a water supply problem		X	
20	Application to a hazardous waste site		X	