SUMMARY OF MODIFICATIONS OF THE U.S. GEOLOGICAL SURVEY MODULAR, FINITE-DIFFERENCE, GROUND-WATER FLOW MODEL TO READ AND WRITE GEOGRAPHIC INFORMATION SYSTEM FILES

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ABSTRACT: This paper discusses modifications to the U.S. Geological Survey modular, three-dimensional, finite-difference, ground-water flow model, commonly called MODFLOW, so that it can read and write files used by a geographic information system (GIS). The modified model program is called MODFLOWARC.

Simulation programs such as MODFLOW generally require large amounts of input data and produce large amounts of output data. Viewing data graphically, generating head contours, and creating or editing model data arrays such as hydraulic conductivity are examples of tasks that currently are performed either by the use of independent software packages or by tedious manual editing, manipulating, and transferring data. Programs such as GIS programs are commonly used to facilitate preparation of the model input data and analyze model output data. Auxiliary programs are frequently required to translate data between programs, when different programs use different data formats. Thus, the user might use GIS techniques to create model input data, run a translation program to convert input data into a format compatible with the ground-water flow model, run the model, run a translation program to convert the model output into the correct format for GIS, and use GIS to display and analyze this output. MODFLOWARC, avoids the two translation steps and transfers data directly to and from the ground-water-flow model.

This paper describes the design and use of MODFLOWARC and includes instructions for data input/output of the Basic, Block-centered flow, River, Recharge, Well, Drain, Evapotranspiration, General-head boundary, and Streamflow-routing packages. The modification to MODFLOW and the Streamflow-Routing package was minimized.

KEY TERMS: Ground-water; flow model; GIS

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INTRODUCTION

The increased use and importance of ground water as a source of water supply has led to the need for understanding and managing ground-water resources. A three-dimensional, finite-difference ground-water-flow model, developed by McDonald and Harbaugh (1988) and referred to as "MODFLOW", is used extensively by the U.S. Geological Survey (USGS) and others to simulate ground-water flow. Requirements for constructing and operating the model include compiling and manipulating large and unwieldy data sets. The graphic and analytical capabilities of a geographic information system (GIS) facilitate manipulating, editing, viewing data graphically, or generating contours for large input and output array data sets. ARC/INFO software (see Disclaimer) is used in numerous USGS offices and in many other agencies to manage these large spatial and relational data sets.

ARC/INFO software can facilitate the initial preparation of data arrays for a ground-water-flow model. The initial data frequently are derived from a collection of non-grided observations such as well pumpage or hydraulic conductivity. ARC/INFO can be used to process the data into the grided form required for input to the ground-water-flow model. The data can be graphically displayed if desired at any stage of the process.

ARC/INFO software also can be useful for manipulating data during model calibration. The user can graphically display the grided data sets, interactively select areas that need correction, and edit these values. Using this technique, sensitivity analysis of a ground-water-flow model becomes less unwieldy. The results of various simulations can be displayed, and differences can be analyzed.

A two-step approach commonly is required to use data stored in ARC/INFO datafiles in a ground-water-flow model. In the first step, data are rewritten from the binary format used by ARC/INFO software to the American Standard Code for Information Interchange (ASCII) format needed for input to the ground-water-flow model. After running the ground-water flow model, the second step consists of rewriting the output data from the simulation in a format acceptable for input into ARC/INFO datafiles. MODFLOW was modified so that it can directly read and write ARC/INFO data. The modified program, called MODFLOWARC, was developed using FORTRAN subroutines available within the ARC/INFO software to transfer data between the binary format of ARC/INFO datafiles and the ground-water flow model (Orzol and McGrath, 1992). MODFLOWARC performs no data modifications or transformations.

PURPOSE AND SCOPE

The purpose of this paper is to discuss the design and use of MODFLOWARC. MODFLOWARC is designed for individuals who have a working knowledge of the flow model developed by McDonald and Harbaugh (1988). This knowledge of the ground-water flow model must include an understanding of the input data and the initial control records within ASCII files that are used to direct the operation of the flow model.

MODFLOWARC DESIGN

The design of MODFLOWARC parallels the design of the ground-water flow model program MODFLOW. Each hydrologic component in the ground-water flow system is conceptualized into a separate package. Each package consists of a number of computer modules and submodules. The suffix, ARC, was added to the new and modified modules. Modifications to the code of MODFLOW were minimized.

The names of variables, modules, and submodules used to explain the operations of MODFLOWARC were derived from names used in the original ground-water-flow model (McDonald and Harbaugh, 1988). As an example, input data defining the IBOUND array are read by the BAS1RP module within the Basic package. The equivalent module within the MODFLOWARC is called BAS1RPARC and the variable name searched for in the ARC/INFO datafiles is IBOUND. Code that has been added to the original FORTRAN program code of the model will be referred to as an "arc-section."

MODFLOWARC uses FORTRAN subroutines provided as part of ARC/INFO. This set of subroutines, collectively described as a low level, machine independent module (Environmental Systems Research Institute, Inc., 1989), opens, closes, sorts, and performs various other functions on ARC/INFO files. A significant advantage of the subroutines is that the item names of data stored in ARC/INFO files (the names for the arrays of values of input/output data) and their individual formats are easily obtainable. The item names adopted within the new modules or submodules of MODFLOWARC match the variable names used by the flow model. To read ARC/INFO data, MODFLOWARC opens an ARC/INFO file and the item names are retrieved and verified for the matching ground-water, flow-model, program-variable name. The matched item's format is also retrieved. In this manner the user does not need to supply the format. When writing ARC/INFO data, MODFLOWARC specifies formats. A limitation is that ARC/INFO software does not support scientific notation.

INSTALLATION AND OPERATION OF MODFLOWARC

MODFLOWARC should work on any computer that has ARC/INFO software (version 5.01 or higher). It has been tested on a Prime computer and a Data General Aviion computer. The MODFLOWARC modules use FORTRAN library subroutines within ARC/INFO software (ISP module). These library subroutines are available from ESRI (Environment Systems Research Institute) and must be installed on the system along with the necessary software to compile and load FORTRAN programs. The ARC/INFO libraries are usually found on a Prime computer system under an ARC50>LIB directory or on a computer using UNIX under an /ARC50/LIB/ directory.

Installation involves two steps: (1) compiling the modules of MODFLOWARC and (2) linking the compiled modules of MODFLOWARC with the computer system libraries, if needed, and ARC/INFO libraries to produce an executable program.

Operation of MODFLOWARC follows a three-step process: (1) user activates the ARC/INFO software by issuing the "arc" command; (2) user runs the AML program MODFLOWARC.AML within the ARC/INFO software by next issuing the command "&r modflowarc filename_argument" (filename_argument is discussed below); and (3) the AML program, MODFLOWARC.AML, passes program control to MODFLOWARC.F77.

The user supplies a filename_argument when running MODFLOWARC.AML at the "arc" prompt. The filename_argument consists of an ASCII file containing unit numbers and filenames of the files that must be opened for a model simulation. Each line in this filename_argument file is a unit number followed by the associated filename in free format with the filename surrounded by single quotes such as 'modflow.list'. The user builds this file in a definite order. The first record consists of the unit number and filename for the Basic (BAS) package input. The last record is the unit number and filename where all printer output is directed. All remaining unit numbers and filenames are included in any order between these two entries. If unformatted files are used for a model simulation, the user specifies the unit numbers of these files as negative. For an example, if the starting heads were recorded in an unformatted file in a previous simulation, then the user sets the unit number for the file containing the starting heads data as negative for the next simulation.

INSTRUCTIONS FOR INPUT AND OUTPUT DATA FOR MODFLOWARC

During the data input phase, MODFLOWARC reads array control records similar to the original control records of the ground-water flow model, except that an additional variable follows either the ITMP variable for the Drain, Well, River, and General-head boundary packages; or the IPRN print variable for Basic, Block-centered, Recharge, and Evapotranspiration packages; or the print variable

IPTFLG for Streamflow-routing package (Prudic, 1988). This additional variable is a complete path to the file within the ARC/INFO database containing the input data to be read. This specified path is dependent on the computer in use. If this additional input variable is blank, then the module operates exactly in the manner of the "original" module.

The input data within each ARC/INFO file is organized by items and each item has a user defined data format. MODFLOWARC uses the names of these items to locate and read input arrays. The names of the items are preset within MODFLOWARC and are described in the following input examples for each package of the ground-water flow model. For example, the Basic (BAS) package of MODFLOWARC reads in the IBOUND array values using the root name IBOUND_ and attaches a suffix representing the layer number such as IBOUND_1 for the IBOUND array values for layer 1. The user defines the data format within each ARC/INFO file for input arrays as either integer, floating point, or numeric. MODFLOWARC uses the complete path supplied by the user to locate the directory and file containing the input data; then retrieves the array values using the preset item names. One record within the specified ARC/INFO file is needed for each model cell for two and three-dimensional arrays. However, for one-dimensional arrays one record is needed for each model layer. For example, the three-dimensional IBOUND array will need a record for each cell and the one-dimensional TRPY array will need a record for each layer.

The input for the Streamflow-routing package (Prudic, 1988) is slightly different than the input to the packages in the original model. The original Streamflow-routing package reads input data for streams, diversions, and tributaries from one file. ARC/INFO datafiles are not easily constructed to store these data in such a form. MODFLOWARC needs these data separated into one ARC/INFO datafile for stream data, one for diversion data, if needed, and one for tributaries data, if needed. The user must add a suffix to the names of the ARC/INFO datafiles containing these data, such as STREAMS**_1** for stream data. The suffix identifies the stress period during which these stream data are read. The under-score preceding the stress period is **mandatory**. The user formulates the filenames for the ARC/INFO datafiles containing tributary and diversion data by adding this suffix to the root TRIB_ for tributary data and DIV_ for diversion data. For example, stream data for the stress period 1 is stored in an ARC/INFO datafile, STREAMS_1, while, the tributary and diversion data are stored in two ARC/INFO datafiles called TRIB_1 and DIV_1. MODFLOWARC reads the path to the data (specified after the print flag IPTFLG) and uses the suffix to identify and read the ARC/INFO data.

When recording output data from MODFLOWARC, the user sets package record/print flags such as IWELCB for the Well (WEL) package, the head and drawdown output flag, IHEDFL, and the cell_by_cell flow-term flag, ICBCFL, like the original output operations of MODFLOW and the Streamflow-routing package. To record cell_by_cell budget data in unformatted files or ARC/INFO files, the user sets the individual package record/print flag such as IWELCB for the Well (WEL) package greater than 0. In the original model, these record/print flags are set to unit numbers for recording output data and to less than 0 to print output data. Also, the user sets ICBCFL to greater than 0 to record output data to unformatted files and to less than 0 to record output data to ARC/INFO files. To record heads and drawdown output data, the user sets the head and drawdown output flag, IHEDFL, to greater than 0 to record output data to unformatted files and to less than 0 to record output data to ARC/INFO files.

However, the user must supply an additional variable, OUTPATH, to the control record for **each** of the output control modules BAS1RPARC and BAS1OCARC. BAS1RPARC module reads the print formats and unit numbers for the head and drawdown output data: IHEDFM, IDDNFM, IHEDUN, and IDDNUN. OUTPATH is a path name to the directory where output head and drawdown data from the ground-water flow model are recorded. If IHDDFL is set to less than 0 for head and drawdown output arrays, the OUTPATH variable immediately follows after the unit number for drawdown, IDDNUN. BAS1OCARC module reads the head/drawdown output code, the output flag for head/drawdown data, the budget print flag, and the cell_by_cell flow-term flag: INCODE, IHHDFL, IBUDFL, and ICBCFL. If the cell-by-cell flow-term flag, ICBCFL, is set to less than 0, then the OUTPATH variable immediately follows the ICBCFL. This additional variable is a path name to the directory where output budget data from the ground-water-flow model are recorded.

Specific Arc/Info output file names for the individual packages within the ground-water-flow model are created by the MODFLOWARC modules. MODFLOWARC formulates filenames from a root name derived from the package name, e.g. WELBUD from the Well (WEL) package, and then appends a suffix. This suffix is composed of the stress period and the time step within the stress period when data was recorded. The stress period and time step are appended together in this order and are separated by underscores. For example, the root name WELBUD is used for well output budget data and is appended by stress period 1 and time step 2 and output data is recorded in an ARC/INFO file named WELBUD_1_2.

With MODFLOWARC the output for the Streamflow-routing package (Prudic, 1988) has been enhanced; however, the user can still record output data for stream outflow and leakage separately. To record stream outflow and leakage data, the user sets stream record/print flags, ISTCB1 and ISTCB2, to greater than 0. If the cell-by-cell flow-term flag, ICBCFL, is greater than 0, stream output data are recorded in two unformatted files, and if the ICBCFL is less than 0, stream output data are recorded in two separate ARC/INFO files, LKGBUD_i_j (stream leakage) and FLOBUD_i_j (stream outflow) (stress period i and time step j). These data are recorded for each cell and not by stream segment or reach within each segment (see Prudic (1988) for discussion of stream segment and reaches). However, input data for the streamflow-routing package is grouped by stream segment and reach. During model calibration, the user may wish to calibrate streamflow output data by stream segment and reach. An additional module is incorporated into MODFLOWARC to record streamflow output data by stream segment and reach in an ARC/INFO file. For example, streamflow output data by stream segment and reach are recorded to ARC/INFO file, STRSEG_1_2, for stress period 1 and time step 2. This additional module is called STR1SRARC. The user sets the streamflow print flag, IPTFLG, to less than 0 and cell_by_cell flow-term flag, ICBCFL, to less than 0 to record streamflow output data by stream segment and reach to an ARC/INFO file.

USE AND TESTING OF MODFLOWARC

In regional or local studies of ground-water flow systems, large amounts of data are prepared and analyzed. MODFLOW, a ground-water flow model, is typically used to simulate the flow of ground water. GIS programs facilitate preparation and analysis of input and output data, but auxiliary programs are required to translate data between MODFLOW and GIS programs. MODFLOWARC saves the user time by directly transferring data between a ground-water-flow and GIS. MODFLOWARC was developed and tested to study and investigate the ground-water flow system in a regional study conducted by USGS in Oregon and Washington.

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