MODFLOW DATA READER

A PROCESSOR FOR IMPORTING MODFLOW DATA SETS INTO ARCVIEW®

VERSION 1.0

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The development of the **MODFLOW Data Reader** arose from the need to have a utility that can easily import a MODFLOW data set without requiring experienced personnel. The MODFLOW Data Reader code and user’s manual are authored by M. Clay Brown of HSI GeoTrans. Contributions were made by Charles R. Faust and Jeffrey J. Benegar of HSI GeoTrans, including coding, testing, bench marking and verification, documentation review and editing. Other contributions were made by the following HSI GeoTrans staff: Jerry Amann, Ellen Barr, Robert Barr, Scott Garrity, Steve Lindsay, Christina Paugh, P. Srinivasan, Jacqueline Stanfill, and Tracy Wisenburg. Also, thanks goes to James Mercer for appropriating the internal Research and Development funds necessary to complete this software.

TABLE OF CONTENTS

Page

CHAPTER 1

INTRODUCTION

MODFLOW is a public domain groundwater flow model developed by the U.S. Geological Survey (McDonald and Harbaugh, 1988). MODFLOW can simulate steady and non-steady flow using a uniform or variably spaced model grid (three-dimensional finite-difference). The model layers can be confined, unconfined, or a combination of confined and unconfined. Flow from external stresses, such as flow to wells, areal recharge, evapotranspiration, flow to drains, and flow through river beds, can be simulated. Hydraulic conductivities or transmissivities for any layer may differ spatially and be anisotropic, and the storage coefficient may be heterogeneous. Flow between model layers is simulated by using the ratio of vertical hydraulic conductivity to distance between vertically adjacent block centers. Specified head, specified flux boundaries, and head dependent flux can be simulated across the model's outer boundary. MODFLOW is currently the most used numerical model in the U.S. Geological Survey and among groundwater professionals for groundwater flow problems.

ArcView® is a desktop geographical information system (GIS) developed by Environmental Systems Research Institute, Inc. (ESRI) of Redlands, CA. It is a powerful tool that can aid in performing all types of geographical and spatial analysis. ArcView can also be used to easily and quickly create layouts. Key features include editing, thematic mapping, symbolization, labeling and customization capabilities, and loading tabular data from databases, as well as enhancing ArcView with add-on programs that provide specialized GIS functionality. These add-on programs are called extensions.

The MODFLOW Data Reader (MDR) is an ArcView extension that imports MODFLOW input data sets into the ArcView data model called a shape file. The optional version of the MDR can contour MODFLOW output data into lines and/or shaded model grid cells. The shape files created by MDR are available for further processing in the ArcView environment.

CHAPTER 2

INSTALLATION

Installation of the software is simple. It can only be installed on a computer running the Microsoft® Windows® 95, Windows® 98, or Windows NT® operating system, with a local installation of ArcView 3.1. Place the CD into the computer and use “Windows Explorer” to view the contents on the CD. Invoke the installation software by double clicking on “Setup.exe”. A four page menu will appear on the screen. Page 1 is an introduction describing the extension. The second page is the licensing agreement. On the third page, you must select, by double clicking, the location of the root directory of ArcView (for example, C:\ESRI\AV_GIS30). If you do not know the location of this directory, contact your system administrator. On page 4, you will see the location of the installation path for the MODFLOW Data Reader as well as the path for the sample problems and user’s guide. Verify that the correct paths are displayed in the menu. Click “Finish” to install the MODFLOW Data Reader ArcView extension. After a successful installation, the extension will be available for use the next time you start up ArcView.

To uninstall the software, place the CD into the computer and use “Windows Explorer” to view the contents on the CD. Invoke the software uninstall by double clicking on “uninstall.exe”. A one page menu will appear. Select, by double clicking, the location of the root directory of ArcView (for example, C:\ESRI\AV_GIS30). If you do not know the location of this directory, contact your system administrator. Click “Finish” to uninstall the MODFLOW Data Reader ArcView extension.

CHAPTER 3

OVERVIEW AND OPERATION

The typical steps involved in processing MODFLOW data sets using the MDR is shown in the following schematic:

MODFLOW input data sets (*.BAS, *.BCF, *.WEL, *.DRN, *.RIV, *.EVT, *.GHB, *.RCH) and output data sets (SAVE FILES) are verified and generated by executing MODFLOW.

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MODFLOW Data reader, an ArcView extension, translates MODFLOW data sets into ArcView shape files (*.SHP, *.SHX, *.DBF).

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ArcView shape files, derived from MODFLOW input and output data sets, are available for processing (printing, analysis, etc.) in the ArcView environment.

The MDR extension must be activated before it can be used. The extension is selected in the same manner as other extensions. From the ArcView main menu and under the menu tab “File”, select “Extensions”. Find the extension labeled “MODFLOW Data Reader”, place a check in the box next to it and select “OK”. To invoke MDR, open a view and a new menu tab on the ArcView main menu called “MODFLOW” will appear. Select “MODFLOW Input Data Reader” and you are ready to begin.

There are two available functions within the MODFLOW Data Reader. The "MODFLOW Input Data Reader" module translates input data sets into ArcView shape files. The *.BAS, *.BCF, *.WEL, *.DRN, *.RIV, *.EVT, *.GHB, and *.RCH are model input data files written in MODFLOW format. The MDR will only read formatted ASCII file types. Additional shape files (model grid columns and rows, model grid extent, and model grid centers) are created that describe the model grid geometry. An optional module, the "MODFLOW Output Data Reader", translates output data sets into ArcView shape files. The output data, created by MODFLOW, can be free ASCII formatted or true binary file types. After executing either module, the resultant shape files are available for processing in a ArcView view, table, or layout.

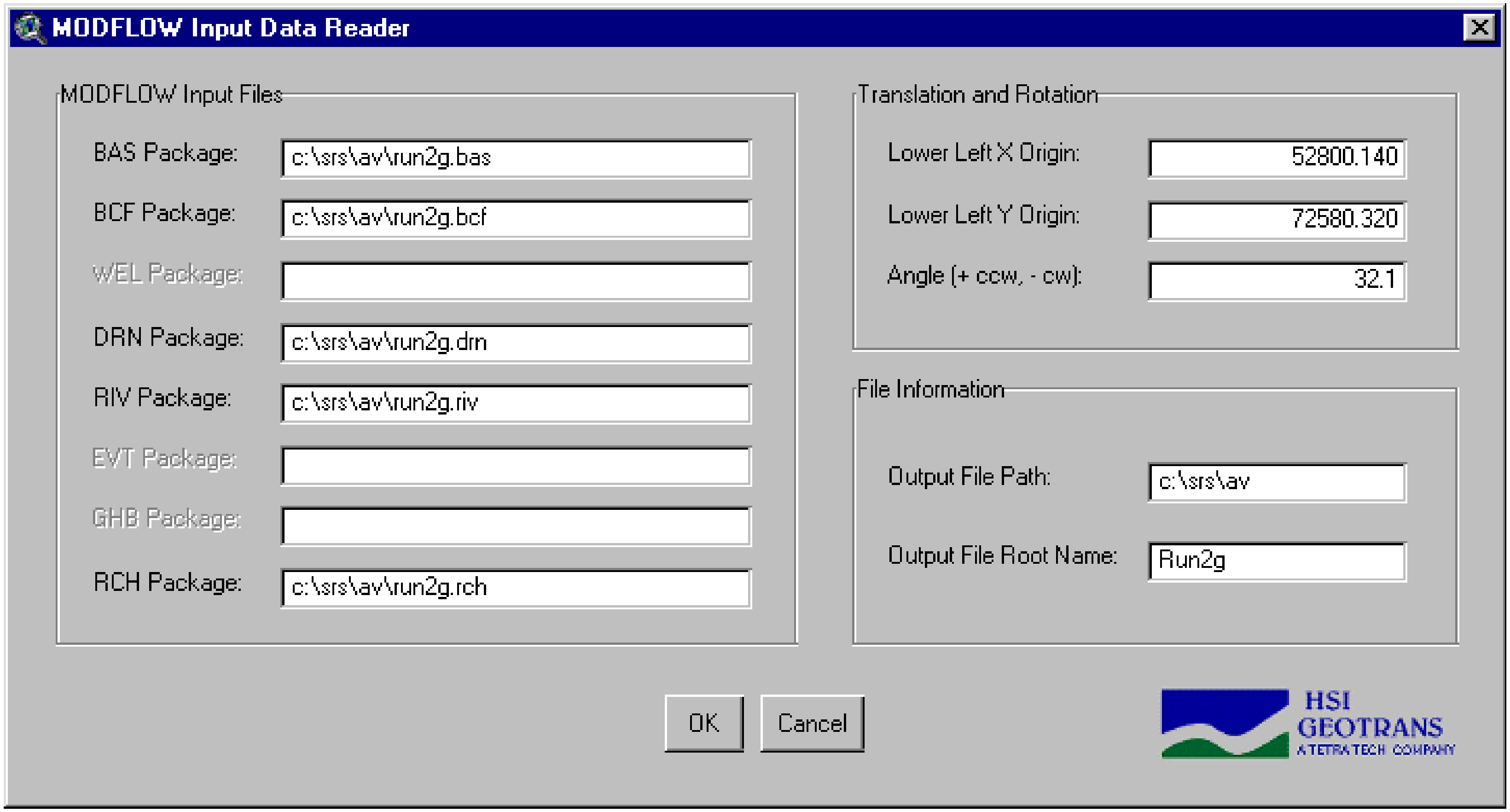
CHAPTER 4

MODFLOW INPUT READER DATA GUIDE

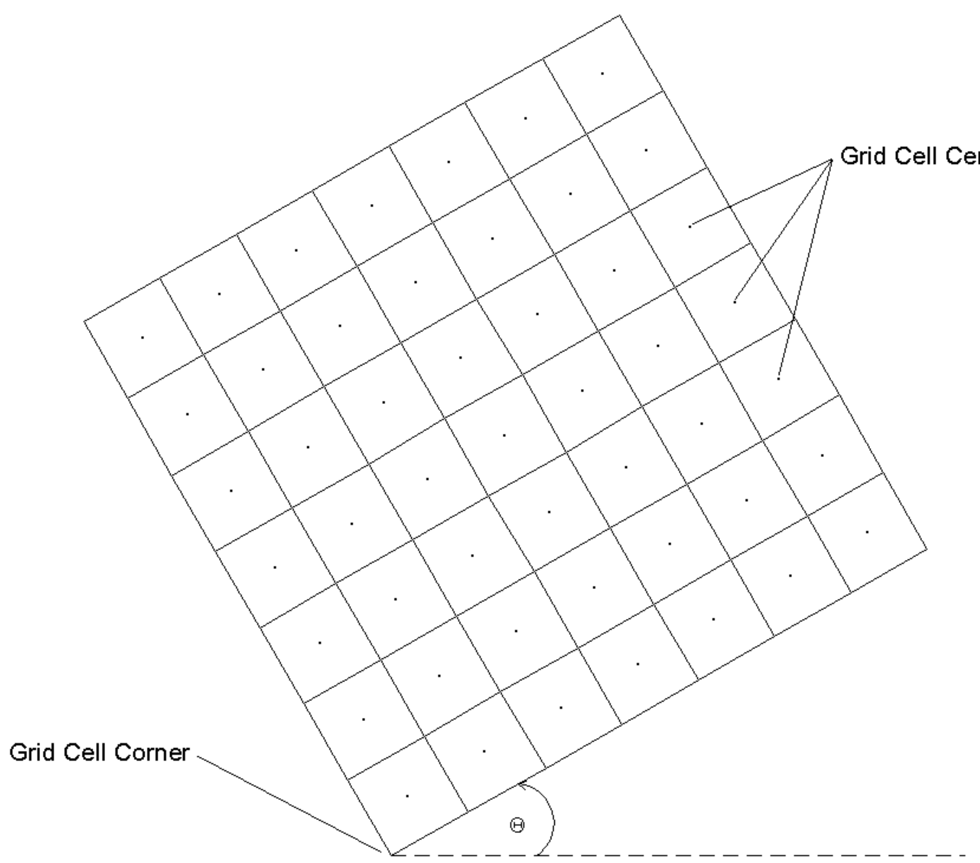
The input for the MDR is simple. From the MODFLOW Input Files section, select the MODFLOW Basic package (*.bas) to import. The available packages for the selected Basic package will activate accordingly. Then, select the MODFLOW packages to import. The table below indicates the convention used by the MDR to select model data files. Note that your file extensions may differ from the convention used by the MDR.

MODFLOW Package	File suffix
Basic Package	*.BAS
Block Centered Flow Package	*.BCF
Well Package	*.WEL
Drain Package	*.DRN
River Package	*.RIV
Evapotranspiration Package	*.EVT
General Head Boundary Package	*.GHB
Recharge (RCH) Package	*.RCH

Below is a screen capture of the MDR menu that imports MODFLOW data sets.



The MDR has the ability to translate and rotate the model grid. In the Translation and Rotation section of the MDR menu, enter the lower left grid cell corner of the X and Y coordinate offsets. This offset occurs about the lower left corner of the model grid. Note that this location is specified as the “grid cell corner” not the “grid cell center”. Enter the angle of rotation about the lower left corner where counter clockwise is positive (+) and clockwise is negative (-). Note that the angle of rotation uses the “Right Hand Rule” convention. The angle must be between –360 and +360 degrees.



Up to eight resultant shape files are created by the MDR. In order to make an automated and universal naming convention, each shape file has a root name entered by the user and an automatically generated descriptive suffix. From the File Information section, enter the desired output directory. Then, enter a root name for the output shape files. Below are the names and descriptions of the output shape files.

Shape File	Shape Type	Description
root-bnd.shp	Polygon	Model grid boundary
root-lin.shp	Line	Model grid columns and rows
root-pnt.shp	Point	Model grid centers
root-mat.shp	Polygon	Model grid cells (polygons) with all matrix data (i.e. hydraulic conductivity, recharge, etc.) from the MODFLOW data sets
root-wel.shp	Polygon	Model grid cells with well data
root-drn.shp	Polygon	Model grid cells with drain data
root-riv.shp	Polygon	Model grid cells with river data
root-ghb.shp	Polygon	Model grid cells with general head boundary data

The output shape files have unique fields for each MODFLOW parameter. The field naming conventions for matrix based data are listed in the following table. All field names in italic are integer numbers indicating layer number or stress period.

Shape file	MODFLOW Package	MODFLOW Parameter	Field Name
root-mat.shp	*.BAS	IBOUND	ibo-*layer*
root-mat.shp	*.BAS	Starting head	she-*layer*
root-mat.shp	*.BCF	Primary storage coefficient	sf1-*layer*
root-mat.shp	*.BCF	Transmissivity	tra-*layer*
root-mat.shp	*.BCF	Hydraulic conductivity	hyc-*layer*
root-mat.shp	*.BCF	Bottom	bot-*layer*
root-mat.shp	*.BCF	Vertical hydraulic conductivity	vcn-*layer*
root-mat.shp	*.BCF	Secondary storage coefficient	sf2-*layer*
root-mat.shp	*.BCF	Wetting threshold	wet-*layer*
root-mat.shp	*.BCF	Top	top-*layer*
root-mat.shp	*.EVT	Elevation of the ET surface	sur-*stress period*

root-mat.shp	*.EVT	Maximum ET rate	evt-*stress period*
root-mat.shp	*.EVT	ET extinction depth	exd-*stress period*
root-mat.shp	*.EVT	Layer indicator array	iet-*stress period*
root-mat.shp	*.RCH	Recharge flux	rch-*stress period*
root-mat.shp	*.RCH	Layer number array	irh-*stress period*

The field naming conventions for list based parameters are listed in the following table. All field names in italic are integer numbers indicating layer number and stress period.

Shape file	MODFLOW Package	MODFLOW Parameter	Field Name
root-wel.shp	*.WEL	Volumetric rate (Q)	Q*layer*-P*stress period*
root-drn.shp	*.DRN	Elevation	E*layer*-P*stress period*
root-drn.shp	*.DRN	Hydraulic conductance	C*layer*-P*stress period*
root-riv.shp	*.RIV	Stage	S*layer*-P*stress period*
root-riv.shp	*.RIV	Elevation of riverbed bottom	R*layer*-P*stress period*
root-riv.shp	*.RIV	Riverbed hydraulic cond.	C*layer*-P*stress period*
root-ghb.shp	*.GHB	Boundary head	B*layer*-P*stress period*
root-ghb.shp	*.GHB	Hydraulic conductance	C*layer*-P*stress period*

Once the appropriate MODFLOW files have been selected, the translation and rotation have been entered, and output files have been set, then select “OK”. After the import is complete, the shape files can be added to the current view.

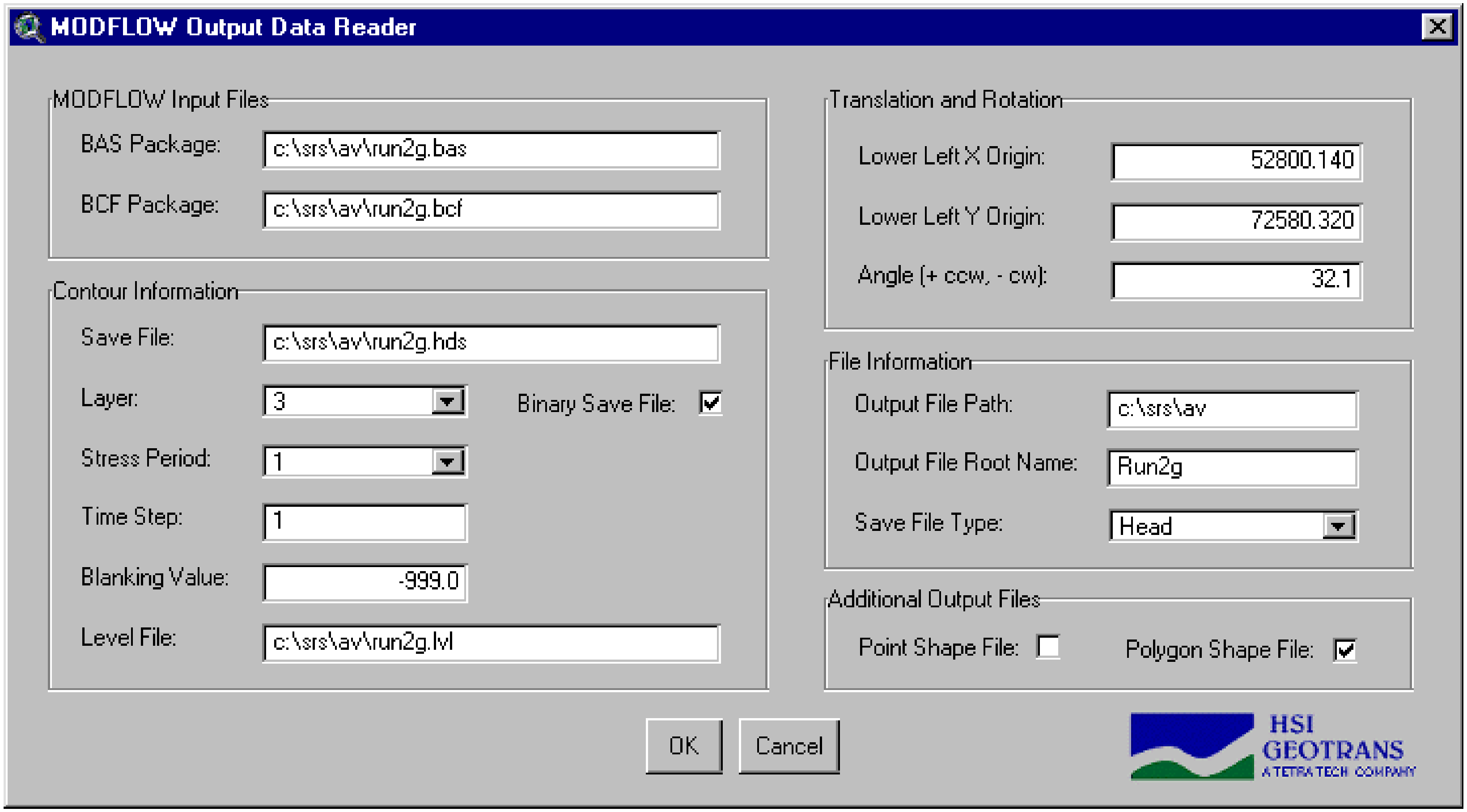
Depending on the size of the MODFLOW model, number of stress periods, packages used and the machine CPU, importing could take some time. Another factor in determining the time to import a model is whether the process is being performed on a local disk or on a network disk. If the data are being imported on a network disk, factors such as network speed, traffic, and number of users will determine processing time. Below is a table with CPU times.

Model Dimensions (C x R x L)	CPU	Time
86 x 64 x 4 with 44 stress periods	200 MHZ, 196 RAM (local)	14 seconds
Same model	Same as above (network)	20 minutes
86 x 64 x 4 with 44 stress periods	450 MHZ, 196 RAM (local)	11 seconds
159 x 138 x 5 with 2 stress periods	450 MHZ, 196 RAM (local)	43 seconds

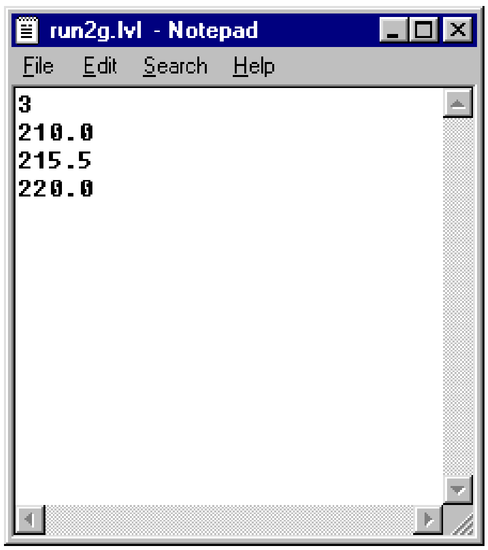
CHAPTER 5

MODFLOW OUTPUT READER DATA GUIDE (OPTIONAL MODULE)

This module can contour output data into contour lines and/or shaded model grid cells. The contouring algorithm in the MDR uses linear interpolation between model grid cells. There is no kriging or smoothing in this algorithm. Importing model data output is performed by selecting the option "MODFLOW Output Data Reader". As shown below, a simple menu will appear that looks similar to the "MODFLOW Input Data Reader" menu. From the MODFLOW Input Files section, select the desired Basic package (*.bas) and Block Centered Flow package (*.bcf).



In the Contour Information section, select a MODFLOW output save file. The save file can be a MODFLOW head save file (*.hds) or drawdown save file (*.ddn). Concentration save files (*.cnc) from MODFLOWT, MT3D, or other transport models can be read by MDR as long as the save file uses the identical save format as MODFLOW. The format of the save file is specified in the MODFLOW documentation. Place a check the binary save file box if the file was written out in true binary format (leave unchecked for an ASCII formatted file). If MODFLOWT was used, make sure the concentration save file unit number is >0 and < 100. If MT3D was used, the utility "UNF2BIN" will need to be executed to convert the concentration save file from Lahey binary to true binary. Indicate the desired layer, stress period, and time step that is to be contoured. Specify a blanking value, this is typically the "HNOFLOW" value listed in the MODFLOW basic package. Select the appropriate level file (*.lvl). A level file is a simple ASCII file, created using Microsoft Notepad or Excel, that specifies the number of contour intervals and the intervals to be contoured. An example is shown below.



The Translation and Rotation section are, as in the "MODFLOW Input Data Reader" menu, located at the lower left grid cell corner. The File Information section is similar to the "MODFLOW Data Reader" menu. Enter the desired output directory and a root name for the output shape file. The File Information section has an additional pull down scroll bar indicating the type of data to import: head, drawdown, or concentration. The output shape files have unique names similar to the files created with the "MODFLOW Input Data Reader" menu. An additional descriptor indicating line, point, or polygon is appended to the file name. The table below describes the naming convention.

Shape File	Shape Type	Description
root-parameter-lin.shp	Line	Contoured data
root-parameter-pnt.shp	Point	Model grid centered points
root-parameter-mat.shp	Polygon	Model grid cells

For example, if the output file root name is "run9" and the save file type is "concentration", the resulting contoured data ArcView file name would be "run9-cnc-lin.shp".

Additional shape files can also be created by checking the appropriate boxes in the Additional Output Files section. A point shape file can be created with the model grid centers and save file data. For example, the grid center point data can be used to post simulated data and observed data. Also, a polygon shape file can be created with the model grid cells and save file data. For example, the polygon shape file can be used for displaying shaded model grid cell zones of either simulated groundwater elevation or concentration.

For more advanced users, any MODFLOW data input set can also be contoured. Copy the desired matrix, such as initial head, hydraulic conductivity or transmissivity, into a new file. The matrix of numbers should be space delimited because the output data reader reads the file in free ASCII format. The file should also have a header with the following written in free format: 2 integer numbers (KSTPFT, KPERFT), 2 real numbers (PERTIM, TOTIM), text string (TEXT), and 3 integer numbers (NXFT, NYFT, KFT). Consult the MODFLOW documentation for description of a save file and header variables. Once the header and matrix data are correctly input, the file is ready to be imported.

Advanced users can also compute a contaminant's mass in place. Model layer elevations, if not specified in the Block Centered Flow package, and porosity for each model layer should be read into shape files using the procedure described in the previous paragraph. The simulated groundwater elevations and concentrations (both are model output save files) should be imported into shape files for all layers at the desired stress period and time step. At this point, you will have several shape files. In order to simplify the mass in place calculation, combine all tables into a single table using the field "Cell-id" as the field to join. The "Cell-id" is a unique descriptor for each grid cell. The saturated thickness for each layer should be calculated using the model layer elevations and the simulated groundwater elevations. The simulated concentration units must be consistent with the model's units (for example, concentration units of mg/L may be converted to pounds/ft^3). Create a series of new fields called "mass-in-place-*N*", for layers 1 to the total numbers of layers (*N*). For the mass in place field for each layer, multiply the simulated concentration (with the proper units), porosity and saturated thickness (called pore volume), and the grid cell area. In order to get a mass in place for a particular layer, sum all values in the field "mass-in-place-*N*".

CHAPTER 6

LIMITATIONS

The MDR is configured to import an ASCII MODFLOW data set using MODFLOW-88 format. It is the user's responsibility to ensure that the data sets are in the proper format and that the model properly executes. It is also assumed that the user has some experience using MODFLOW and ArcView 3.1. The MDR will not import MODFLOW '96 free format files.

The MDR cannot read external data files. For example, the matrices for hydraulic conductivity and transmissivity may be stored as external file instead of storing them in the block centered flow (*.BCF) package. Before executing the MDR, all matrix data must be contained within the appropriate MODFLOW package and not read as an external file. This was done to minimize data input and make the MDR's operation as simple as possible.

The MDR can only have one list-based feature for each model grid cell. For example, more than one well may be assigned to a unique model grid cell. For the well package, the MDR will sum the flow rates for each unique model grid cell. However, for the other list-based packages (river, drain, and general head boundary) there is no provision for multiple entities within a unique model grid cell. The MDR currently assigns the last unique entity for stress period to the model grid cell. For example, within the MODFLOW river package (*.RIV) a riverbed conductance of 10.0 is assigned to row 34, column 10, and layer 1. Further down the data input file, in the same stress period, a riverbed conductance of 22.0 is assigned to same row, column, and layer. MDR will assign a riverbed conductance of 22.0 at row 34, column 10, and layer 1.

The MDR's display format of matrix and list data with real numbers is limited to 32 spaces wide and 16 decimal spaces (xxxxxxxxxxxxxxx . xxxxxxxxxxxxxxxx) and all integer data are limited to 10 spaces wide (xxxxxxxxxx). MODFLOW is able to read list and matrix data in most any format. ArcView's database component, dBase, is limited because it does not have an E format specification and only a field width and number of decimal places can be specified when the database is constructed. A related limitation occurs when either the matrix or list data is displayed (i.e., using "Graduated Value" or "Unique Value"). The data range displays three or less decimal places even if the values are much smaller. This is a limitation of ArcView. The value from the MODFLOW data set is preserved and can be verified by using the "Info Tool".

There are no limitations for importing a model based on the number of layers, rows, columns, or stress periods. However, the field headings in an ArcView's database component, dBase, have a fixed width of 10 spaces. This may be problematic if a well package in a model has several layers and stress periods. For example, the flow rate in the well package for layer 1 stress period 1 is stored in a field called "Q1-1" containing four spaces. If the same model has 100 layers and 100,000 stress periods, the field will be called "Q100-10000" containing 10 spaces and omitting the last zero. However, in practical experience, it is doubtful that this limitation will be reached.

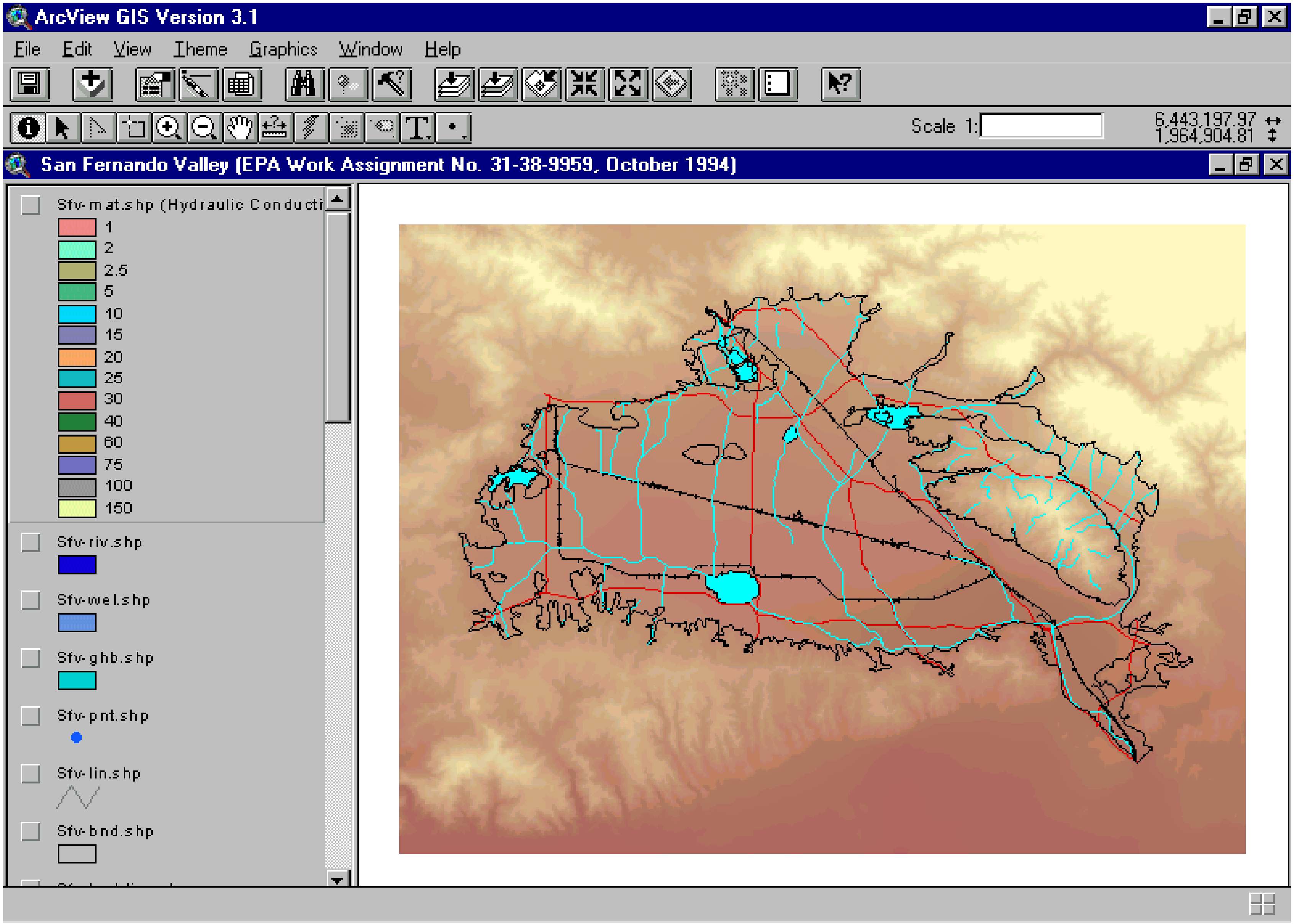
CHAPTER 7

SAMPLE DATA

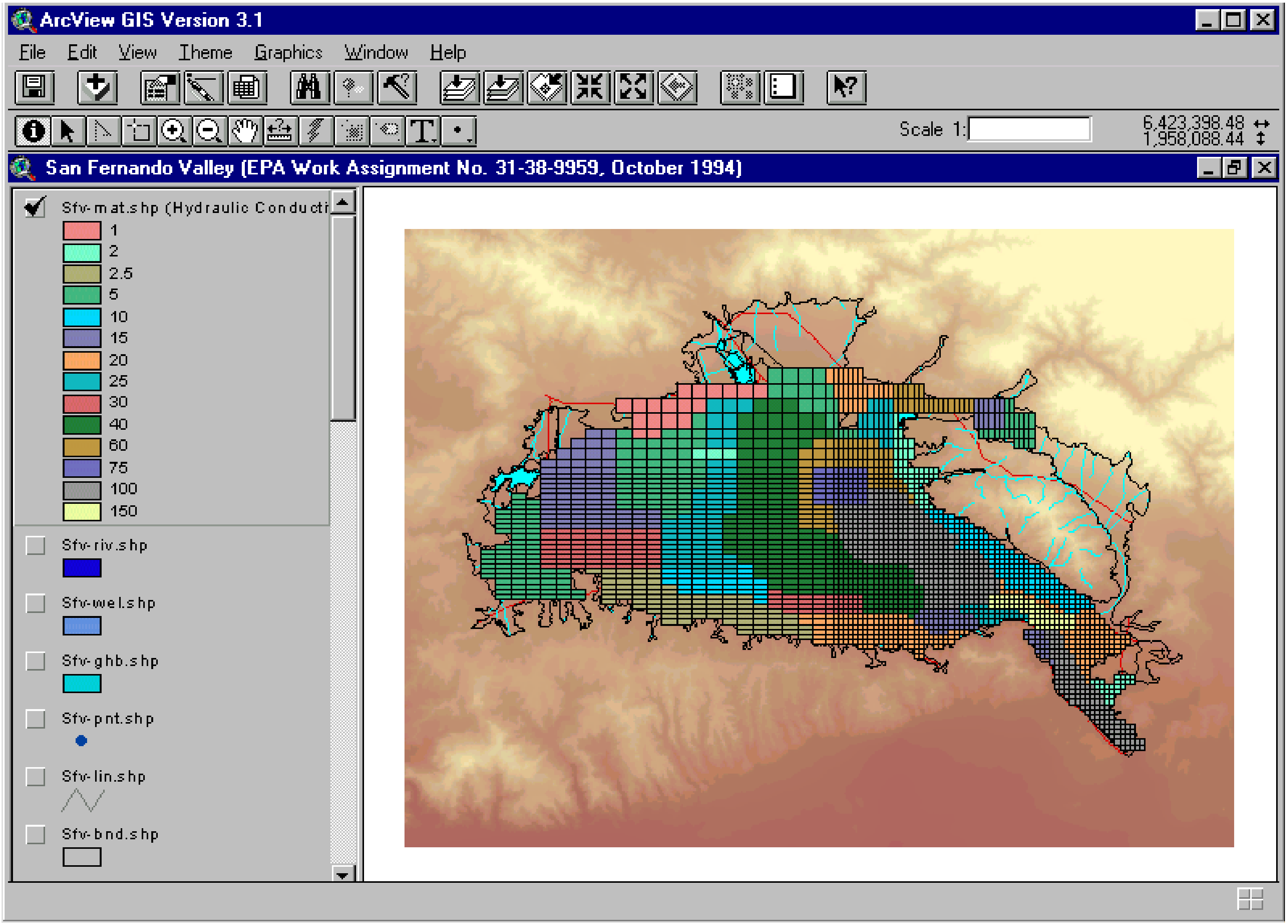
A sample data set is provided to illustrate the power of an integrated GIS and groundwater model. All data in the sample directory, located in *install path*/mdr1_0/samples, are in the public domain. The groundwater model and all site features were obtained from the EPA Region 9 (www.epa.gov/region09) and the San Fernando Groundwater Model Documentation (EPA Work Assignment No. 31-38-9959, October 1994). The digital elevation model (DEM) was obtained from the U.S. Geological Survey (www.usgs.gov). For additional information on the sample files, read *install path*/mdr1_0/samples/readme.txt.

The site is the San Fernando Valley located in Southern California. The project file, sfv.apr, contains all site features including the groundwater model. If desired, the user can re-import the MODFLOW data sets (see *install path*/mdr1_0/samples/readme.txt for coordinate information). The shape file, sfv-mat.shp, contains all model matrix data (i.e. transmissivity, recharge, etc.). Shape files for the River, Well, and General Head Boundary list based packages are called sfv-riv.shp, sfv-wel.shp, and sfv-ghb.shp, respectively. Features of the model grid such as model grid centered points, column and row lines, and the model grid extent (or boundary) are in the shape files sfv-pnt.shp, sfv-lin.shp, and sfv-bnd.shp, respectively.

The DEM and site features are shown below.



Below are the hydraulic conductivities for model layer 1.



The simulated heads for layer 1, stress period 44, and time step 5 are in the view in a shape file called sfv-hed-line.shp. The user can re-create the simulated heads, if the contouring option was purchased. The simulated groundwater elevations are shown below.