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An Introduction to Using MODFLOW The USGS Modular Finite-Difference Ground-Water Computer Modeling System

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MASTER'S THESIS

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TABLE OF CONTENTS

INTRODUCTION

MODFLOW is the U.S. Geological Survey (U.S.G.S.) Modular Finite-Difference Ground-Water computer modeling system. This program incorporates basic concepts derived from previous computer groundwater modeling programs. MODFLOW improves upon these programs because it is easy to modify, simple to use and maintain, can be executed on a variety of computers with minimal changes, and is relatively efficient with respect to computer memory and execution time (McDonald and Harbaugh, 1988).

The model simulates three dimensional ground water flow using a block-centered finite-difference approach. The following explanation of the finite-difference approach is taken from the McDonald and Harbaugh (1988) MODFLOW manual:

> *... the continuous system described by equation (1) is replaced by a finite set of discrete points in space and time, and the partial derivatives are replaced by terms calculated from the differences in head values at these points. The process leads to systems of simultaneous linear algebraic difference equations; their solution yields values of head at specific points and times. These values constitute an approximation to the time-varying head distribution that would be given by an analytical solution of the partial-difference equation of flow.*

Equation 1 Three-dimensional movement of ground-water of constant density through porous earth material can be described by this partial differential equation (McDonald and Harbaugh, 1988).

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

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})
Ss is the specific storage of the porous material (L^{-1})
t is time

The modular structure of the computer program consists of a Main Program and several independent subroutines called modules. Modules are grouped into packages. Packaging of the modules allows specific hydrologic features of the model to be examined and modified without changing other subroutines (McDonald and Harbaugh, 1988). MODFLOW packages and a brief description of each is listed in Appendix A. The Basic Package is always required for a simulation and other packages are optional depending upon the model.

The purpose of this paper is to supply information and resources useful to new users of MODFLOW.

MODFLOW PREFACE

The following prerequisites apply to the beginning MODFLOW user:

- Knowledge of Fortran programming
- Understanding of your computer operating system
- Fundamental knowledge of ground-water concepts

Knowing the Fortran programming language is an advantage because MODFLOW and its input files are written in Fortran. If a particular modeling problem cannot be solved, MODFLOW's code can be modified by the user to accommodate the problem. Trouble shooting is more efficient as data entry errors within input text files are more obvious to Fortran programmers. Understanding the computer's operating system is essential to manipulating MODFLOW files and running the program. MODFLOW documentation assumes the user understands basic ground-water concepts.

Self taught MODFLOW users should have technical support people available to answer questions. Users can contact the Water Resources Division of U.S.G.S. for technical support.

The Internet is a useful reference for MODFLOW related questions. Three Internet addresses have extensive information regarding ground-water modeling software:

1. http://www.et.byu.edu/~geos/staff/owens/groundwater.html
2. http://gwrp.cciw.ca/internet/survey.txt
3. http://igwmc.mines.colorado.edu:3851/

To save time learning MODFLOW there are courses offered by research institutes and other agencies for different levels of MODFLOW users. Short courses are a good way to make time spent on MODFLOW more effective. See Appendix B for details on three courses offered this year.

MODFLOW is designed to run on various types of computers. There are versions for both UNIX based systems and personal computers. The PC version has a compiled executable file that allows MODFLOW to run without a Fortran 77 compiler. MODFLOW requires a computer with a math co-processor because the program uses iterative mathematics.

MODFLOW SAMPLE PROBLEM

A good initial introduction to MODFLOW is through the sample problem that comes on the MODFLOW diskette. The MODFLOW sample problem is a particular aquifer environment that uses the following packages: Basic, Block Centered Flow, Recharge, Strongly Implicit Procedure, Drain, and Well. This is a good problem to use because it exposes the user to many of the different packages.

Parameters for the sample problem is as follows:

- The aquifer has three layers, each separated with a confining layer.
- The aquifer is a square, 75,000 feet on each side, and divided into a grid of 15 rows and 15 columns.
- Flow into the system is infiltration from precipitation.
- Flow out of the system is to buried drain tubes, discharging wells, and a lake which is represented by a constant-head boundary (McDonald and Harbaugh, 1988).

The sample problem is described in greater detail in the MODFLOW manual.

Input and output files from an actual sample problem run are in Appendices D and E. The sample problem was run on a 486 DX 66 personal computer. It is possible that numbers in the output will be unlike those in the manual. The output file in Appendix F has numbers that do not correspond with the manual. Computers vary in the way they store and calculate real numbers. In each computer, values will differ due to the size of the problem and the number of iterations required. The difference in values should not be significant except in the "IN - OUT" line, which may vary up to a factor of three depending on computer type.

After running the sample problem the user should manipulate the data in order to learn how the model responds to changes. For additional practice using MODFLOW, sample problems developed by the EPA are available (Anderson, 1993). In the EPA sample problems is a package used by MODFLOW called "Output Control." It is not listed in the manual as a package. See Appendix C for IGWMC's address to order the EPA's manual of instructional problems for MODFLOW.

MODFLOW STEP BY STEP

- Copy MODFLOW to the hard drive (in this case the hard drive is named 'p').
- Go to MS-DOS Prompt.
- "C:\WINUSERS>" type `P:\` to change the drive address
- "P:\" type `cd MODFLOW` to call up the MODFLOW drive address
- "P:\ MODFLOW" type `MODFLOW` to activate the executable file
- "Enter the name for the BAS input file" type `TEST1.BAS`
- "Enter the name for the output file <Enter LPT1 to go directly to the printer>" Never send it to the printer. Make up a simple name for the output file and use the extention .OUT, for example `TEST.OUT`.
- "Enter the name for the BCF input file" type `TEST1.BCF`
- "Enter the name for the WEL input file" type `TEST1.WEL`
- "Enter the name for the DRN input file" type `TEST1.DRN`
- "Enter the name for the RCH input file" type `TEST1.RCH`
- "Enter the name for the SIP input file" type `TEST1.SIP`
- "Stop - Program Terminated." This means MODFLOW has run and the output file has the solution to the sample problem. Go to the DOS Editor and open the output file.
- "run-time error..." This means MODFLOW was not able to run the entire program. There is an error in the input of file names or a problem with an input file. Go to the DOS Editor and note the last input file processed. The problem is probably after that.
- type `EDIT` to get into the DOS Editor
- Open the output file using the "File" pull-down. This file should look like the output file in Appendix F.

ASSOCIATED SOFTWARE

Several software programs have been developed specifically to work with MODFLOW. Further research on the software packages should be done in order to purchase the one that best fits the modeling needs. Information on associated software is in Appendices C and D.

The data input computer program (MFI) for MODFLOW reduces the time it takes to enter data into the model by building ASCII input tables. With MFI the user is guided logically through the data entry process. MFI checks the data for validity and help information is available within MFI to reduce frequent referral to the manual (Harbaugh, 1994).

The ANNIE Interactive Development Environment (AIDE) is required to make MFI operational. It is obtained by written request to the Center of Exposure Assessment Modeling (CEAM). Refer to Appendix C for CEAM's address. They have a diskette exchange policy where the person requesting the software sends a 3.5" HD diskette to CEAM and they send back the software on that disk. Another way to receive AIDE software is through file transfer on the worldwide Internet network. The ftp address for AIDE is in Appendix D.

The GMS MODFLOW interface also saves data entry time. It is structured after MODFLOW's package concept for organizing computational subroutines and input files. Menu commands and a dialogs for MODFLOW packages reduces referencing manuals. All information associated with a MODFLOW package can be edited with the package dialog.

Visual Modflow is a pre-processor and post-processor for MODFLOW. It allows the user to easily input data, run MODFLOW, and visualize the output results in a Windows type environment. A demo program is available, however, it has some problems. It does not save the grid information before or after continuing on to properties. There are also detail oriented functions that don't work. A requirement for this system is a video card that will support 256 colors. Visual MODFLOW runs under DOS, under a Windows DOS session, and under an OS/2 DOS session. This program does not require the user to know Fortran.

ACKNOWLEDGMENTS

Thanks to Arnold Hansen from the Water Resources Division of U.S.G.S. for his knowledgeable assistance running the MODFLOW sample problem. Thanks to Dr. Richard Berg of Western Washington University for loaning the software and reading material to set up and learn MODFLOW. Thanks to Dr. William Hotchkiss of the U.S.G.S. for assistance with set up and research of MODFLOW.

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Anderson, Peter F. 1993. A Manual of Instructional Problems for the U.S.G.S. MODFLOW Model. Ada, Oklahoma: U.S. Environmental Protection Agency.

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Harbaugh, Arlen W. 1994. A Data Input Program (MFI) for the U.S. Geological Survey Modular Finite-Difference Ground-Water Flow Model. Reston, Virginia: U.S. Geological Survey. Open File Report 94-468.

International Ground Water Modeling Center. Colorado School of Mines. Internet. 1995.

McDonald, Michael G. and Harbaugh, Arlen W. 1988. A Modular Three-Dimensional Finite-Difference Ground-Water Flow Model. Washington, D.C.: Techniques of Water Resources Investigations of the United States Geological Survey. Book 6, Chapter A1.

Waterloo Hydrogeologic, Inc. April 17, 1995. personal letter/communication.

APPENDICES

APPENDIX A

LIST OF MODFLOW PACKAGES *

PACKAGE NAME	ABBREVIATION	PACKAGE DESCRIPTION
Basic	BAS	Handles those tasks that are part of the model as a whole. Among those tasks are specification of boundaries, determination of time-step length, establishment of initial conditions, and printing of results.
Block-Centered Flow	BCF	Calculates terms of finite-difference equations which represent flow within porous medium; specifically, flow from cell to cell and flow into storage.
Well	WEL	Adds terms representing flow to wells to the finite-difference equations.
Recharge	RCH	Adds terms representing areally distributed recharge to the finite-difference equations.
River	RIV	Adds terms representing flow to rivers to the finite-difference equations.
Drain	DRN	Adds terms representing flow to drains to the finite-difference equations.
Evapotranspiration	EVT	Adds terms representing ET to the finite-difference equations.
General-Head Boundaries	GHB	Adds terms representing general-head boundaries to the finite-difference equations.
Strongly Implicit Procedure	SIP	Iteratively solves the system of finite-difference equations using the Strongly Implicit Procedure.
Slice-Successive Overrelaxation	SOR	Iteratively solves the system of finite-difference equations using Slice-Successive Overrelaxation.

* This list was taken from the McDonald and Harbaugh (1988) MODFLOW manual.

APPENDIX B
MODFLOW EDUCATIONAL COURSES 1995

JULY 24-26
Brigham Young University offers a short course on the use of the Department of Defense Groundwater Modeling System (GMS). Attendees should be familiar with the MODFLOW model and have a basic understanding of ground-water modeling. "The course instruction will consist of a combination of classroom lectures and demonstrations and "hands-on" training at a computer terminal. The computer sessions will be conducted on high performance Hewlett Packard UNIX workstations (The interface to the UNIX version of GMS is identical to the PC version. UNIX experience is not required)" (Internet site). Instructors are Dr. Norman L. Jones, Rus Berrett, and R. Jeffrey Davis. The cost of this short course is $750 per person. For more information contact Molly Broadbent at The Engineering Computer Graphics Lab, 300 Clyde Building, Brigham Young University, Provo, Utah 84602, telephone (801) 378-2812, fax (801) 378-2478, or e-mail: MMBROADB@ucs.byu.edu.

AUGUST 7-11
Oklahoma State University offers a course called "RCRA Ground Water Monitoring System Design and Plume Characterization." "This course is designed to familiarize the hydrogeologist/environmental professional with the EPA's hazardous waste ground water monitoring program. Participants will apply RCRA regulations and TEGD guidance, as well as use ground water flow transport models, to design a fully compliant ground water monitoring system. Software models which will be used to complete this objective are MODFLOW, ModelCad, SURFER, PATH3D, and MT3D."

OCTOBER 17-21
The International Ground Water Modeling Center offers a short course from October 17-21, 1995 entitled "The MODFLOW Groundwater Flow Modeling System." Instructors are Peter F. Anderson and Robert M. Greenwald of Geo Trans, Inc. For more information contact IGWMC at Colorado School of Mines, Golden, Colorado, 80401-18887, telephone (303) 273-3103 or (800) 446-9488. "This course focuses on the use of the USGS Three-Dimensional Finite-Difference Ground-Water Flow Model MODFLOW and its accompanying programs. Lectures on the principles of ground-water flow modeling and the use of MODFLOW will be complemented by hands-on computer sessions during which participants will work through a series of real world problems." This course was advertised in the July, 1995 "GSA Today" (vol 5, No.7).

APPENDIX C
SOFTWARE AND SOFTWARE AGENCIES

MODFLOW and MFI	U.S. Geological Survey, WRD National Water Information System 437 National Center 12201 Sunrise Valley Drive Reston, Virginia 22092 phone: (703) 648-6978
	Books and Open-File Reports Section U.S. Geological Survey Federal Center, Box 25425 Denver, Colorado 80225 phone: (303) 236-7476
MODFLOW and OTHER MODELS	International Ground Water Modeling Center (IGWMC) Institute for Ground-Water Research and Education Colorado School of Mines Golden, Colorado 80401-1887 phone: (303) 273-3103
AIDE (for Data General workstations and Sun Sparcstations)	U.S. Geological Survey Hydrologic Analysis Support Section 415 National Center Reston, Virginia 22092
(for IBM compatible personal computers)	U.S. Environmental Protection Agency Center for Exposure Assessment Modeling 960 College Station Road Athens, Georgia 30613
(Documentation)	National Technical Information Service (NTIS) 5285 Port Royal Road Springfield, Virginia 22161 phone: (703)487-4650
GMS from ECGL	Engineering Computer Graphics Lab 300 Clyde Building Brigham Young University Provo, Utah 84602
VISUAL MODFLOW	Waterloo Hydrogeologic, Inc. 200 Candlewood Crescent Waterloo, Ontario Canada N2L 5Y9 phone: (519) 746-1798

APPENDIX D
SOFTWARE PRICE INFORMATION

Software	Agency	Price*	Additional Cost Information
MODFLOW	Intn'l Ground Water Modeling Center	$350	$75 for sample problem set
MFI	U.S. Geological Survey	$45	must be used with AIDE
AIDE	U.S. Geological Survey	$0	ftp at earth1.epa.gov or send one 3.5" diskette, requires Fortran 77 compiler, documentation ordered separately
GMS	Engineering Computer Graphics Lab	$1,050 - $3,000	educational and quantity discounts available; ftp demo available
VISUAL MODFLOW	Waterloo Hydrogeologic, Inc.	$1,395	free demo upon request

* Price information was taken from price lists on the Internet (MODFLOW, GMS) and order forms from the above agencies(AIDE, VISUAL MODFLOW, MFI).

APPENDIX E

SAMPLE PROBLEM INPUT

BASIC PACKAGE: (Lower case text is explanation of input.)

```
SAMPLE----3 LAYERS, 15 ROWS, 15 COLUMNS; STEADY STATE; CONSTANT HEADS COLUMN 1,
LAYERS 1 AND 2; RECHARGE, WELLS AND DRAINS
    3     15     15     1     1   (3 layers, 15 rows, 15 columns, 1 stress period, time unit is seconds)
 11 12 13  0  0  0  0 18 19  0  0 00   (assigning IUNIT locations for BCF, WEL, DRN, RIV, EVT, GHB,
                                  RCH, SIP, SOR, OUTPUT CONTROL  i.e. BCF has been assigned to
                                  IUNIT 11 and so on,  zero means the option is not used.)
   0      0   IAPART,ISTRT       (array BUFF is shared with array RHS; starting heads not saved)
    60      1(15I3)           3  IBOUND-1  (control record for IBOUND array layer 1)
 -1 1 1 1 1 1 1 1 1 1 1 1 1 1 1             (IBOUND codes:  < 0  constant head
 -1 1 1 1 1 1 1 1 1 1 1 1 1 1 1                             = 0  no flow
 -1 1 1 1 1 1 1 1 1 1 1 1 1 1 1                             > 0  variable head)
 -1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 -1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 -1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 -1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 -1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 -1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 -1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 -1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 -1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 -1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 -1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 -1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
    60      1(15I3)           3  IBOUND-2  (control record for IBOUND array layer 2)
 -1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 -1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 -1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 -1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 -1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 -1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 -1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 -1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 -1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 -1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 -1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 -1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 -1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 -1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 -1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
    0      1                    IBOUND-3  (control record for IBOUND array layer 3)
  999.99                                  (value of head to be assigned to all inactive cells throughout
                                           simulation)
    0     0.                    HEAD-1    (head values at beginning of simulation)
    0     0.                    HEAD-2
    0     0.                    HEAD-3
  86400.     1     1.   PERLEN,NSTP,TSMULT  (stress period length, # time steps, multiplier)
```

BLOCK CENTERED FLOW PACKAGE:

```
     1      0   1.E30      0       0        0        0 ISS,IBCFBD   (steady state flag, flag and unit #)
1 0 0
     0     1.                        TRPY  (one-dimensional array containing an anisotropy factor for each layer)
     0    5000.                      DELR  (cell width along rows)
     0    5000.                      DELC  (cell width along columns)
     0    .001                       HY-1  (hydraulic conductivity along rows)
     0    -150.                      BOT-1 (elevation of aquifer bottom)
     0    2.E-8                      VHY/THICK-1
     0     .01                       T-2
     0    1.E-8                      VHY/THICK-2
     0     .02                       T-3
```

RECHARGE PACKAGE:

```
     1      0   NRCHOP,IRCHBD  (recharge to only the top grid layer, flag and unit #)
     1         INRECH              (recharge read flag)
     0    3.E-8                     RECH-1   (array of recharge fluxes)
```

STRONGLY IMPLICIT PROCEDURE PACKAGE:

```
    50      5     MXITER,NPARM  (maximum times through the iteration loop in one time step in an attempt
                                 to solve the system of finite-difference equations, # of iteration
                                 parameters to be used)
    1.    .001      0    .001      1 ACCL,ERR,IPCALC,WSEED  (acceleration parameter, flag, seed for
                                                              calculating iteration parameters)
```

DRAIN PACKAGE:

```
     9      0   MXDRAI,IDRNBD  (maximum # of drain cells active at one time, flag and unit #)
     9         NDRAIN          (# of drains)
     1      8     2      0.    1.E00  (first drain: layer, row, column, elevation, cond)
     1      8     3      0.    1.E00
     1      8     4     10.    1.E00
     1      8     5     20.    1.E00
     1      8     6     30.    1.E00
     1      8     7     50.    1.E00
     1      8     8     70.    1.E00
     1      8     9     90.    1.E00
     1      8    10    100.    1.E00  (nineth drain)
```

WELL PACKAGE:

```
15     0   MXWELL,IWELBD   (maximum # of wells used at any time, flag and unit #)
15         ITMP (NWELLS)   (flag and counter)
 3     5    11    -5.      (first well:  layer, row, column, Q)
 2     4     6    -5.
 2     6    12    -5.
 1     9     8    -5.
 1     9    10    -5.
 1     9    12    -5.
 1     9    14    -5.
 1    11     8    -5.
 1    11    10    -5.
 1    11    12    -5.
 1    11    14    -5.
 1    13     8    -5.
 1    13    10    -5.
 1    13    12    -5.
 1    13    14    -5.      (fifteenth well)
```

APPENDIX F

OUTPUT FROM SAMPLE PROBLEM

```
U.S. GEOLOGICAL SURVEY MODULAR FINITE-DIFFERENCE GROUND-WATER MODEL
SAMPLE----3 LAYERS, 15 ROWS, 15 COLUMNS; STEADY STATE; CONSTANT HEADS COLUMN 1,
LAYERS 1 AND 2; RECHARGE, WELLS AND DRAINS
  3 LAYERS      15 ROWS      15 COLUMNS
 1 STRESS PERIOD(S) IN SIMULATION
 MODEL TIME UNIT IS SECONDS
I/O UNITS:
 ELEMENT OF IUNIT: 1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
          I/O UNIT: 11 12 13 0  0  0  0 18 19 0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
BAS1 -- BASIC MODEL PACKAGE, VERSION 1, 9/1/87 INPUT READ FROM UNIT 60
 ARRAYS RHS AND BUFF WILL SHARE MEMORY.
 START HEAD WILL NOT BE SAVED -- DRAWDOWN CANNOT BE CALCULATED
   5892 ELEMENTS IN X ARRAY ARE USED BY BAS
   5892 ELEMENTS OF X ARRAY USED OUT OF  50000
BCF3 -- BLOCK-CENTERED FLOW PACKAGE, VERSION 3, 7/9/92 INPUT READ FROM UNIT 11
 STEADY-STATE SIMULATION
 HEAD AT CELLS THAT CONVERT TO DRY=  .10000E+31
 WETTING CAPABILITY IS NOT ACTIVE
    LAYER  AQUIFER TYPE   INTERBLOCK T
    -------------------------------------
      1      1      0-HARMONIC
      2      0      0-HARMONIC
      3      0      0-HARMONIC
    453 ELEMENTS IN X ARRAY ARE USED BY BCF
   6345 ELEMENTS OF X ARRAY USED OUT OF  50000
WEL1 -- WELL PACKAGE, VERSION 1, 9/1/87 INPUT READ FROM 12
 MAXIMUM OF  15 WELLS
     60 ELEMENTS IN X ARRAY ARE USED FOR WELLS
   6405 ELEMENTS OF X ARRAY USED OUT OF  50000
DRN1 -- DRAIN PACKAGE, VERSION 1, 9/1/87 INPUT READ FROM UNIT 13
 MAXIMUM OF   9 DRAINS
     45 ELEMENTS IN X ARRAY ARE USED FOR DRAINS
   6450 ELEMENTS OF X ARRAY USED OUT OF  50000
```

```
RCH1 -- RECHARGE PACKAGE, VERSION 1, 9/1/87 INPUT READ FROM UNIT 18
 OPTION 1 -- RECHARGE TO TOP LAYER
     225 ELEMENTS OF X ARRAY USED FOR RECHARGE
    6675 ELEMENTS OF X ARRAY USED OUT OF   50000
SIP1 -- STRONGLY IMPLICIT PROCEDURE SOLUTION PACKAGE, VERSION 1, 9/1/87
INPUT READ FROM UNIT 19
 MAXIMUM OF  50 ITERATIONS ALLOWED FOR CLOSURE
  5 ITERATION PARAMETERS
    2905 ELEMENTS IN X ARRAY ARE USED BY SIP
    9580 ELEMENTS OF X ARRAY USED OUT OF   50000
```

1SAMPLE----3 LAYERS, 15 ROWS, 15 COLUMNS; STEADY STATE; CONSTANT HEADS
COLUMN 1, LAYERS 1 AND 2; RECHARGE, WELLS AND DRAINS

BOUNDARY ARRAY FOR LAYER 1 WILL BE READ ON UNIT 60 USING FORMAT: (15I3)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
4	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
5	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
6	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
7	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
8	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
9	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
11	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
12	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
13	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
14	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
15	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

BOUNDARY ARRAY FOR LAYER 2 WILL BE READ ON UNIT 60 USING FORMAT: (15I3)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
4	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
5	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
6	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
7	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
8	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
9	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
11	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
12	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
13	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
14	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
15	-1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

```
                    BOUNDARY ARRAY =          1 FOR LAYER 3
AQUIFER HEAD WILL BE SET TO 999.99    AT ALL NO-FLOW NODES (IBOUND=0).
                    INITIAL HEAD = .0000000    FOR LAYER 1
                    INITIAL HEAD = .0000000    FOR LAYER 2
                    INITIAL HEAD = .0000000    FOR LAYER 3
DEFAULT OUTPUT CONTROL -- THE FOLLOWING OUTPUT COMES AT THE END OF
EACH STRESS PERIOD:
 TOTAL VOLUMETRIC BUDGET
    HEAD
            COLUMN TO ROW ANISOTROPY = 1.000000
                             DELR = 5000.000
                             DELC = 5000.000
        HYD. COND. ALONG ROWS = .1000000E-02 FOR LAYER 1
                    BOTTOM = -150.0000    FOR LAYER 1
     VERT HYD COND /THICKNESS = .2000000E-07 FOR LAYER 1
       TRANSMIS. ALONG ROWS = .1000000E-01 FOR LAYER 2
     VERT HYD COND /THICKNESS = .1000000E-07 FOR LAYER 2
       TRANSMIS. ALONG ROWS = .2000000E-01 FOR LAYER 3


            SOLUTION BY THE STRONGLY IMPLICIT PROCEDURE
             ------------------------------------------
         MAXIMUM ITERATIONS ALLOWED FOR CLOSURE =      50
               ACCELERATION PARAMETER =    1.0000
         HEAD CHANGE CRITERION FOR CLOSURE =    .10000E-02
            SIP HEAD CHANGE PRINTOUT INTERVAL =      1

5 ITERATION PARAMETERS CALCULATED FROM SPECIFIED WSEED = .00100000:

  .0000000E+00 .8221720E+00 .9683772E+00 .9943766E+00 .9990000E+00
```

STRESS PERIOD NO. 1, LENGTH = 86400.00

NUMBER OF TIME STEPS = 1

MULTIPLIER FOR DELT = 1.000

INITIAL TIME STEP SIZE = 86400.00

15 WELLS

LAYER	ROW	COL	STRESS RATE	WELL NO.
3	5	11	-5.0000	1
2	4	6	-5.0000	2
2	6	12	-5.0000	3
1	9	8	-5.0000	4
1	9	10	-5.0000	5
1	9	12	-5.0000	6
1	9	14	-5.0000	7
1	11	8	-5.0000	8
1	11	10	-5.0000	9
1	11	12	-5.0000	10
1	11	14	-5.0000	11
1	13	8	-5.0000	12
1	13	10	-5.0000	13
1	13	12	-5.0000	14
1	13	14	-5.0000	15

9 DRAINS

LAYER	ROW	COL	ELEVATION	CONDUCTANCE	DRAIN NO.
1	8	2	.0000	1.000	1
1	8	3	.0000	1.000	2
1	8	4	10.00	1.000	3
1	8	5	20.00	1.000	4
1	8	6	30.00	1.000	5
1	8	7	50.00	1.000	6
1	8	8	70.00	1.000	7
1	8	9	90.00	1.000	8
1	8	10	100.0	1.000	9

RECHARGE = .3000000E-07

31 ITERATIONS FOR TIME STEP 1 IN STRESS PERIOD 1
MAXIMUM HEAD CHANGE FOR EACH ITERATION:
HEAD CHANGE (LAYER,ROW,COL) HEAD CHANGE (LAYER,ROW,COL) HEAD CHANGE (LAYER,ROW,COL) HEAD CHANGE (LAYER,ROW,COL) HEAD CHANGE (LAYER,ROW,COL)

```
-------------------------------------------------------------------------------------------------------------------
 -22.41   ( 3, 5, 11)  12.48   ( 1, 1, 15)  13.39   ( 3, 1, 14)  48.21   ( 1, 1, 15)  35.91
( 3, 1, 13)
 2.482   ( 1, 9, 14)  1.430   ( 3, 10, 13)  6.214   ( 1, 12, 14)  7.411   ( 3, 11, 14)  13.66
( 1, 15, 15)
 .5503   ( 3, 8, 7)  .4821   ( 2, 6, 9)  .4711   ( 3, 5, 10)  2.019   ( 1, 11, 14)  2.302   (
3, 5, 13)
 .1108   ( 1, 13, 12)  .7059E-01 ( 3, 12, 11)  .2819   ( 1, 14, 14)  .3141   ( 3, 13, 14)
.3320   ( 1, 15, 15)
 .7853E-02 ( 1, 13, 12)  .1586E-01 ( 2, 11, 11)  .1777E-01 ( 3, 11, 10)  .7910E-01 ( 1, 14,
14)  .8499E-01 ( 3, 7, 14)
 .4169E-02 ( 1, 13, 14)  .2555E-02 ( 3, 14, 15)  .9769E-02 ( 1, 14, 14)  .1082E-01 ( 3, 13,
14)  .1030E-01 ( 1, 15, 15)
 .2430E-03 ( 1, 13, 12)
```

```
           HEAD IN LAYER  1 AT END OF TIME STEP  1 IN STRESS PERIOD  1
      -----------------------------------------------------------------------
       1       2       3       4       5       6       7       8       9
 10   11      12      13      14      15
 ..............................................................................................
 0 1  .0000   24.94   44.01   59.26   71.82   82.52   91.91   100.0   106.9
 112.6   117.4   121.3   124.3   126.4   127.4
 0 2  .0000   24.45   43.10   57.98   70.17   80.57   90.12   98.40   105.3
 111.0   115.7   119.6   122.7   124.9   126.1
 0 3  .0000   23.45   41.30   55.43   66.78   76.21   86.51   95.20   102.2
 107.6   112.0   116.1   119.6   122.1   123.4
 0 4  .0000   21.92   38.61   51.75   61.79   68.03   81.34   90.75   97.64
 102.5   106.1   110.7   114.9   117.9   119.4
 0 5  .0000   19.73   34.92   47.32   57.69   66.74   77.09   85.76   92.22
 96.15   97.29   103.1   108.8   112.5   114.3
 0 6  .0000   16.51   29.50   40.90   51.30   61.21   71.19   79.85   86.47
 90.82   93.03   94.23   102.1   106.4   108.4
 0 7  .0000   11.55   21.10   31.21   41.40   51.84   63.08   72.68   79.95
 84.92   88.60   91.66   96.43   99.82   101.8
 0 8  .0000   3.483   6.832   16.25   26.30   36.97   52.59   64.31   72.52
 77.25   81.99   85.00   89.27   91.72   94.33
 0 9  .0000   10.54   19.11   28.12   36.92   45.27   52.95   55.38   65.15
 66.07   73.93   73.79   80.84   80.17   86.49
 0 10  .0000   14.62   25.86   35.38   43.49   50.11   54.93   57.55   62.95
 65.55   70.39   72.44   76.72   78.26   81.79
 0 11  .0000   17.11   29.96   40.01   47.78   53.24   55.81   53.33   60.27
 59.29   66.43   65.45   72.22   71.04   77.62
 0 12  .0000   18.68   32.56   43.07   50.81   55.92   58.33   58.47   61.93
 63.18   67.12   68.50   72.29   73.46   76.85
 0 13  .0000   19.67   34.24   45.14   53.01   58.04   59.91   56.75   62.59
 60.91   67.22   65.75   71.90   70.35   76.48
 0 14  .0000   20.27   35.27   46.48   54.61   60.08   63.17   64.52   67.25
 68.79   71.64   73.18   75.84   77.03   79.09
 0 15  .0000   20.56   35.78   47.16   55.48   61.26   65.02   67.52   69.94
 72.01   74.29   76.22   78.22   79.66   80.82
```

HEAD IN LAYER 2 AT END OF TIME STEP 1 IN STRESS PERIOD 1

```
        ------------------------------------------------------------------
          1        2        3        4        5        6        7        8        9
 10        11       12       13       14       15
 ........................................................................................
 0 1  .0000    24.66    43.73    59.02    71.61    82.32    91.72    99.86    106.7
 112.5  117.2    121.1    124.1    126.2    127.3
 0 2  .0000    24.17    42.83    57.74    69.95    80.36    89.93    98.22    105.1
 110.8  115.5    119.4    122.6    124.8    125.9
 0 3  .0000    23.17    41.03    55.19    66.53    75.77    86.29    95.02    102.0
 107.4  111.8    116.0    119.5    121.9    123.2
 0 4  .0000    21.65    38.34    51.50    61.35    60.17    80.90    90.55    97.45
 102.3  105.4    110.4    114.8    117.7    119.2
 0 5  .0000    19.48    34.65    47.07    57.44    66.30    76.85    85.57    92.00
 95.41  91.09    102.1    108.6    112.4    114.2
 0 6  .0000    16.27    29.24    40.65    51.07    60.98    70.98    79.65    86.28
 90.54  92.06    86.23    101.7    106.2    108.3
 0 7  .0000    11.38    20.95    31.05    41.25    51.70    62.90    72.48    79.76
 84.73  88.35    91.24    96.22    99.65    101.6
 0 8  .0000    4.209    8.330    17.58    27.58    38.25    52.94    64.19    72.34
 77.12  81.81    84.86    89.10    91.59    94.17
 0 9  .0000    10.38    18.96    27.98    36.79    45.16    52.86    56.13    65.08
 66.79  73.87    74.48    80.77    80.84    86.38
 0 10  .0000   14.40    25.61    35.15    43.27    49.91    54.76    57.48    62.79
 65.49  70.24    72.37    76.57    78.20    81.64
 0 11  .0000   16.87    29.70    39.78    47.56    53.05    55.68    54.09    60.20
 60.04  66.37    66.18    72.16    71.75    77.51
 0 12  .0000   18.43    32.31    42.85    50.60    55.73    58.16    58.41    61.78
 63.12  66.98    68.44    72.15    73.40    76.69
 0 13  .0000   19.42    33.98    44.91    52.80    57.85    59.78    57.50    62.53
 61.65  67.16    66.48    71.84    71.06    76.37
 0 14  .0000   20.02    35.02    46.26    54.41    59.88    62.99    64.39    67.08
 68.66  71.48    73.06    75.68    76.91    78.93
 0 15  .0000   20.30    35.52    46.94    55.28    61.07    64.84    67.34    69.76
 71.84  74.11    76.04    78.04    79.49    80.65
```

HEAD IN LAYER 3 AT END OF TIME STEP 1 IN STRESS PERIOD 1

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0 1	1.800	24.34	43.36	58.70	71.33	82.06	91.48	99.63	106.5	112.3	117.0	120.9	123.9	126.0	127.1
0 2	1.764	23.85	42.46	57.42	69.66	80.07	89.68	97.99	104.9	110.6	115.3	119.2	122.4	124.6	125.7
0 3	1.691	22.86	40.67	54.87	66.20	75.28	85.98	94.77	101.7	107.2	111.5	115.7	119.3	121.7	123.0
0 4	1.578	21.35	37.98	51.17	60.85	62.69	80.41	90.28	97.19	101.9	104.1	110.0	114.5	117.5	119.0
0 5	1.415	19.18	34.30	46.75	57.10	65.80	76.54	85.30	91.67	94.17	77.46	100.7	108.2	112.1	114.0
0 6	1.176	15.99	28.91	40.33	50.76	60.67	70.70	79.38	86.01	90.12	90.60	88.55	101.2	106.0	108.0
0 7	.8273	11.21	20.79	30.88	41.09	51.55	62.67	72.22	79.50	84.46	87.98	90.77	95.94	99.41	101.4
0 8	.4331	5.131	10.19	19.27	29.19	39.84	53.40	64.07	72.11	76.95	81.58	84.68	88.88	91.44	93.95
0 9	.7543	10.22	18.82	27.84	36.66	45.06	52.78	57.03	65.02	67.64	73.81	75.31	80.72	81.64	86.24
0 10	1.039	14.13	25.29	34.85	42.99	49.65	54.54	57.44	62.61	65.44	70.05	72.33	76.39	78.15	81.43
0 11	1.224	16.59	29.37	39.47	47.28	52.79	55.53	55.01	60.16	60.94	66.33	67.06	72.13	72.60	77.38
0 12	1.341	18.15	31.97	42.54	50.32	55.47	57.94	58.37	61.60	63.08	66.80	68.41	71.97	73.36	76.49
0 13	1.415	19.14	33.65	44.61	52.53	57.60	59.63	58.39	62.48	62.54	67.12	67.35	71.80	71.90	76.24
0 14	1.460	19.73	34.68	45.96	54.13	59.63	62.76	64.24	66.87	68.52	71.27	72.91	75.47	76.77	78.71
0 15	1.481	20.01	35.18	46.63	55.00	60.81	64.59	67.11	69.52	71.61	73.87	75.82	77.81	79.27	80.42

```
VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP 1 IN STRESS PERIOD 1
                  ----------------------------------------------------------------------------
CUMULATIVE VOLUMES      L**3              RATES FOR THIS TIME STEP      L**3/T
          ------------------                    ------------------------

       IN:                                   IN:
       ---                                   ---
        STORAGE =    .00000                        STORAGE =    .00000
    CONSTANT HEAD =    .00000                 CONSTANT HEAD = .00000
          WELLS =    .00000                          WELLS =    .00000
         DRAINS =    .00000                         DRAINS =    .00000
       RECHARGE =    .13608E+08                   RECHARGE = 157.50
       TOTAL IN =   .13608E+08                     TOTAL IN =    157.50
      OUT:                                   OUT:
      ----                                   ----
        STORAGE =    .00000                        STORAGE =    .00000
    CONSTANT HEAD =    .43265E+07             CONSTANT HEAD = 50.075
          WELLS =   .64800E+07                       WELLS =    75.000
         DRAINS =   .28011E+07                      DRAINS =    32.420
       RECHARGE =    .00000                       RECHARGE =    .00000
      TOTAL OUT =    .13608E+08                  TOTAL OUT = 157.50
       IN - OUT =   397.00                        IN - OUT =    .45929E-02
PERCENT DISCREPANCY =     .00              PERCENT DISCREPANCY =    .00


     TIME SUMMARY AT END OF TIME STEP 1 IN STRESS PERIOD 1
                  SECONDS      MINUTES       HOURS        DAYS        YEARS
                  ---------------------------------------------------------------------------
TIME STEP LENGTH      86400.0      1440.00      24.0000      1.00000     .273785E-02
STRESS PERIOD TIME    86400.0      1440.00      24.0000      1.00000     .273785E-02
TOTAL SIMULATION TIME 86400.0      1440.00      24.0000      1.00000 .273785E-02
```