# PLUMAN

## A Decision Support System for Optimal Groundwater Contaminant Plume Management

User's Manual
Version 1.0

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## A Decision Support System for Optimal Groundwater Contaminant Plume Management

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by

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# NOTICE

The authors do not warrant PLUMAN for any specific purpose and do not assume any liability resulting from use of the software. PLUMAN includes new software as well as public-domain tested algorithms for simulating and/or optimizing groundwater contaminant plume capture.

This User's Manual might contain misprints, and the PLUMAN software could contain errors. We will appreciate your bringing these to our attention. Changes will be periodically incorporated into the software and released in new versions.

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LIST OF SYMBOLS AND ACRONYMS

| Symbol/ Acronym | Definition | Units |
|---|---|---|
| a | integer number used to generate random numbers | |
| AQMAN | linear and quadratic programming matrix generator using two-dimensional ground-water flow simulation for AQuifer MANagement modeling | |
| $b_{\bar{e},k}$ | recharge rate at cell ē, during stress period k | $L^3/T$ |
| c | increment used to generate random numbers | |
| $C_v$ | coefficient of variation | |
| $d_{\bar{e},k}$ | drawdown at cell ē, during stress period k | L |
| DSS | decision support system | |
| EDP | electronic data processing | |
| ê, ē | super- or subscripts designating excitation wells and cells, respectively, considered for optimization | |
| $g_{\bar{e},k}$ | groundwater withdrawal rate at cell ē, during stress period k | $L^3/T$ |
| $G_{\bar{o}_{1,2},k}$ | hydraulic gradient between a pair of control cells $\bar{o}_1$ and $\bar{o}_2$, during stress period k | L/L |
| $h_{\bar{e},k}$ | hydraulic head at cell ē, during stress period k | L |
| $h^{non}$ | nonoptimal hydraulic head | L |
| $\Delta h_{\bar{o}_{1,2},k}$ | head difference between a pair of control cells $\bar{o}_1$ and $\bar{o}_2$, during stress period k | L/L |
| J | hydraulic conductivity | L/T |
| j | integer number used to generate random | |

| | | |
|---|---|---|
| | numbers | |
| K | total number of stress periods | |
| L | distance between cells | L |
| m | parameter used to generate random number with uniform distribution | |
| $M^{\bar{e}}$ | total number of pumping cells | |
| MACMAN | a generally applicable model for optimizing groundwater hydraulic management | |
| MINOS | Modular In-core Nonlinear Optimization System | |
| MIS | management information system | |
| MOC | method of characteristics solute transport model | |
| MODFLOW | quasi-three-dimensional groundwater flow simulation model | |
| MODFLOW+STR | groundwater flow simulation model with streamflow-routing package | |
| MPS | Mathematical Programming Systems | |
| $\hat{o}$, $\bar{o}$ | super- or subscripts designating observation wells and cells, respectively, considered for optimization | |
| p | random number sequence term | |
| pdf | probability density function | |
| PLUMAN | a decision support system for optimal groundwater contaminant plume management | |
| $q_j^{un}$ | unit pumping or pumping rate used to compute influence coefficients describing the effect of pumping at cell j | $L^3/T$ |
| Q | sink or source term | L/T |
| r | radius of influence from the well | L |
| $r_d$ | cell width | L |
| $r_e$ | radius of hypothetical well | L |
| $r_n$ | random number | |
| $R_f$ | retardation factor | --- |

| | | |
|---|---|---|
| $s_{i,N}$ | well drawdown at point i at the end of period N | |
| S | storage coefficient | |
| SURFER | contouring software developed and sold by Golden Software, Inc. | |
| t | time | T |
| T | transmissivity | $L^2/T$ |
| UNITQ | unit stress | $L^3/T$ |
| v | seed number | |
| $V_{\bar{o}_{1,2},k}$ | seepage velocity between control cells $\bar{o}_1$ and $\bar{o}_2$, during stress period k | L/T |
| $V^{retarded}$ | retarded seepage velocity | L/T |
| $V^{unretarded}$ | unretarded seepage velocity | L/T |
| x | random variable with lognormal distribution | |
| $X_n$ | $n^{th}$ term of a random number sequence | |
| Z | objective function | |
| z | standard normal variate | |
| W(u) | well function | |
| $\theta$ | effective porosity | |
| $\delta_{i,j,N-k+1}$ | influence coefficient describing head response at point i by end of period N, resulting from a unit pumping at point j, during stress period k | |
| $\mu_x$ | expected value of variable x | |
| $\sigma_x$ | standard deviation for variable x | |
| $\sigma_x^2$ | variance of variable x | |
| $\sigma_{\bar{o},k}$ | river stage at observation cell $\bar{o}$, during stress period k | L |

# INTRODUCTION

This manual describes PLUMAN, a decision support system (DSS) that provides easy and efficient use of three groundwater models:

- a modified version of the Method of Characteristics (MOC) model for simulating saturated zone solute transport (Konikow and Bredehoeft, 1984);
- a modified version of MODFLOW+STR (McDonald and Harbaugh, 1988), updated with the streamflow-routing package (Prudic, 1988), for simulating saturated flow and stream-aquifer interaction;
- MACMAN for computing optimal pumping strategies for specified management objectives. This is a combination of modified version of AQMAN (Lefkoff and Gorelick, 1987) and MODFLOW+STR.

PLUMAN also has the following features:

- capability to draw contour or three-dimensional maps of potentiometric surface or contaminant concentrations, using SURFER[1] (Golden Software, 1991);
- easy viewing of output files of the models;
- optional preparation of the MOC input data file using templates. It uses the modified MODFLOW+STR to create boundary fluxes for a selected subsystem that will be modelled by MOC;
- optional automatic cycling to develop optimal strategies for nonlinear aquifers, even when using superposition;
- statistical generation of multiple aquifer realizations.

MACMAN is a model that simulates and optimizes groundwater pumping and head management. It is appropriate for optimizing plume capture. It computes hydraulic head in a multilayer aquifer or

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[1] SURFER is a registered trademark of Golden Software, Inc.

streamflow-routing system under steady or unsteady state. The model solves the flow equation written as:

$$\frac{\partial}{\partial x} J_x \frac{\partial h}{\partial x} + \frac{\partial}{\partial y} J_y \frac{\partial h}{\partial y} + \frac{\partial}{\partial z} J_z \frac{\partial h}{\partial z} - S \frac{\partial h}{\partial t} + Q \quad (1)$$

where

$h$ = hydraulic head [L];
$J_x$ = hydraulic conductivity in x-direction [L/T];
$S$ = storage coefficient [dimensionless];
$t$ = time [T];
$Q$ = sink or source term [$LT^{-1}$].

**Overview of MACMAN processing**

The definition of some terms used to describe the MACMAN processing are given below.

**Unmanaged or nonoptimal head** refers to the potentiometric surface, with unmanaged wells, recharges, and discharges, without imposition of an optimal groundwater pumping strategy.

**Constraint** refers to limitations imposed on aquifer system response to optimal pumping strategy. These represent needs to be satisfied at a certain times and locations. Those constraints can be on hydraulic gradients, velocity gradients, heads, stream stages, and on pumpings (extraction or injection). In general, constraints affect the objective result, and the problem may even be infeasible if the limitations cannot be satisfied.

**Manageable drawdown** refers to the optimization model's workable head interval. It is determined by subtracting the constraints from the unmanaged heads. For example, if unmanaged head is 10 m and acceptable drawdown is 4 m, the workable head (manageable drawdown) is from 10 to 6 meters (upper and lower bounds on head).

First, MACMAN determines the unmanaged head for a given scenario. Subtracting the constraints from the unmanaged heads, the manageable drawdowns are obtained for each control location.

These are written in the RHS (right-hand side) of an MPS (Mathematical Programming Systems) format file.

Next, MACMAN computes manageable heads for each potential well, using a specified unit withdrawal or recharge. Subtracting these heads from the unmanaged heads, the drawdown response is obtained for each control location. These influence coefficients become entries in a response matrix, which are written in the column section of the MPS format. An influence coefficient is the change in head that results with time at point i, in response to a unit pumping at point j.

MACMAN uses the response matrix method. It generates influence coefficients describing head response to a unit withdrawal or recharge at desired control points. River stage response to a unit withdrawal or recharge is valid as long as: the optimal pumping strategy does not cause a change from saturated to unsaturated streamflow-routing, or vice versa, and system response at a point is in a nearly linear portion of the stage discharge relation for that point.

A superposition equation describing drawdown is given by (Peralta, 1991)

$$s_{i,N} = \sum_{k=1}^{N} \delta_{i,j,N-k+1} \frac{q_{j,k}}{q_j^{un}} \tag{2}$$

where

$$\delta_{i,j,N-k+1} = \frac{1}{4\pi T} \left[ W\left( \frac{r^2 S}{4T\,(N-k+1)} \right) - W\left( \frac{r^2 S}{4T\,(N-k)} \right) \right] \tag{3}$$

where

$s_{i,N}$ = drawdown at point i at the end of period N [L];

$\delta_{i,j,N-k+1}$ = influence coefficient describing head response at point i by end of period N, resulting from a unit pumping at point j, during stress period k [T/L$^2$];

$q_{j,k}$ = pumping at point j, in period k [L$^3$/T];

$q_j^{un}$ = unit pumping or pumping rate used to compute influence coefficients describing the effect of pumping at well j [$L^3/T$];

T = transmissivity [$L^2/T$];

r = radius of influence [L];

S = storage coefficient [dimensionless].

The following sink/source terms can be considered in the MODFLOW+STR simulation model: wells (withdrawal or recharge), drainage, streamflow-routing, evapotranspiration, bedrock recharge, ground-surface recharges (rainfall, irrigation).

**Cycling Process**

MACMAN utilizes linear influence coefficients and linear superposition to compute optimal strategies. Unconfined aquifers are not linear, since transmissivity changes with head. This difficulty is overcome by the process of cycling: (1) computing influence coefficients using a unit pumping, (2) computing optimal strategy, (3) simulating system head response to optimal strategy using MODFLOW+STR, (4) computing influence coefficients using optimal pumping, computed in step 2, as unit pumping, (5) repeating steps 2 and 3 and comparing heads and pumping values based on appropriate criterion, and (6) repeating steps 4 to 5 if necessary. A new cycle begins at step 1 or step 4. The cycling process was applied to DEMO1. The largest difference in heads and pumping values between these of the end of step 3 (the first cycle) and these of the end of step 5 (the second cycle) were 1/1000 m and 1.8 percent, respectively.

# MODEL FORMULATION

## Objective Function

MACMAN is capable of optimizing problems having linear constraints and a linear objective function of the form:

Minimize

$$Z = \sum_{k=1}^{K} \sum_{\bar{e}=1}^{M^{\bar{e}}} C_{\bar{e},k} \left( g_{\bar{e},k} + b_{\bar{e},k} \right) \tag{4}$$

where

$b_{\bar{e},k}$ = recharge rate at cell $\bar{e}$ during period k, (+) $[L^3/T]$;

$C_{\bar{e},k}$ = cost or weight coefficient for cell $\bar{e}$ in period k $[\$T/L^3$ or dimensionless];

$\hat{e}$, $\bar{e}$ = super- or subscript designating excitation well and cells, respectively;

$g_{\bar{e},k}$ = withdrawal rate at cell $\bar{e}$ during period k,(-) $[L^3/T]$;

K = total number of stress periods;

$M_{\bar{e}}$ = total number of pumping cells;

$\hat{o}$, $\bar{o}$ = super- or subscript designating observation well and cells, respectively;

Z = objective function.

## Constraints

Constraints refer to restrictions of 1) withdrawal or recharge values, 2) hydraulic head and streamflow stage, or 3) other useful and measurable characteristics such as velocity or hydraulic gradient. The hydraulic gradient can be considered between two points located in the same or different layers.

Some of the constraints are entered as input to MACMAN (hydraulic head, streamflow stage, hydraulic gradient, seepage velocity, and pumping). Other constraints (demand, capacity, and balance constraint) have to be edited manually into the MPS file.

### Constraints on Hydraulic Heads and Streamflow Stage

These constraints establish limits on the maximum or minimum hydraulic heads or streamflow stage that are allowed or desired at control points. For example,

$$h_{1,k} \leq 50 \qquad h_{2,k} \leq 25 \qquad \sigma_{\bar{o},k} \leq 16$$

where

$h_{1,k}$ and $h_{2,k}$ = hydraulic heads at cells 1 and 2, during stress period k [L];

$\sigma_{\bar{o},k}$ = river stage at observation cell $\bar{o}$, during stress period k.

### Constraints on Head Difference, Hydraulic Gradients and Seepage Velocities

These constraints represent limitations on the head difference, gradient or the seepage velocity that can occur between two control locations. It is positive if head decreases from point 1 to point 2 in the same or different layers. The head difference between a pair of control cells is:

$$\Delta h_{\bar{o}_{1,2},k} = h_{1,k} - h_{2,k} \tag{5}$$

where

$\Delta h_{\bar{o}_{1,2}}$ = head difference between control cells $\bar{o}_1$ and $\bar{o}_2$, during stress period k [L];

An example of a head difference constraint is:

$$\Delta h_{\bar{o}_{1,2},k} \geq 0.01$$

The hydraulic gradient between a pair of control cells is:

$$G_{\bar{o}_{1,2},k} = \frac{h_{1,k} - h_{2,k}}{L} \tag{6}$$

where

$G_{\bar{o}_{1,2},k}$ = hydraulic gradient between control cells $\bar{o}_1$ and $\bar{o}_2$, during stress period k [L/L];

L = distance between cells $\bar{o}_1$ and $\bar{o}_2$ [L].

An example of a gradient constraint is:

$$G_{\bar{o}_{1,2},k} \geq 0.01$$

The hydraulic head at each cell is equal to the difference between nonoptimal head, $h^{non}$, and the drawdown, d.

$$h_{1,k} = h_{1,k}^{non} - d_{1,k} \qquad (7)$$

$$h_{2,k} = h_{2,k}^{non} - d_{2,k} \qquad (8)$$

Substituting Eqs. 4 and 5 into Eq. 3 gives:

$$d_{1,k} - d_{2,k} \leq h_{1,k}^{non} - h_{2,k}^{non} - 0.01\ (\ L\ ) \qquad (9)$$

The seepage velocity between a pair of control points is:

$$V_{\bar{o}_{1,2},k} = \frac{J\ (h_{1,k} - h_{2,k})}{\Theta\ L} \qquad (10)$$

where

$V_{\bar{o}_{1,2},k}$ = seepage velocity between control cells $\bar{o}_1$ and $\bar{o}_2$, during stress period k [L/T];

J = hydraulic conductivity within cells $\bar{o}_1$ and $\bar{o}_2$ [L/T];

$\theta$ = effective porosity.

An example of a velocity constraint is:

$$V_{\bar{o}_{1,2},k} \geq 0.01$$

or

$$d_{1,k} - d_{2,k} \leq h_{1,k}^{non} - h_{2,k}^{non} - 0.01 \left( \frac{\Theta L}{J} \right) \tag{11}$$

The values of the left and right sides of Eqs. 6 and 8 are written in the column and RHS sections, respectively, of the MPS file. Both values can take either a positive or negative sign.

**Retarded Velocities**

Contaminants that are carried by the groundwater might not flow as quickly as the water. In this case, a retardation factor, $R_f$, is used in determining the velocity of the contaminant.

$$R_f = \frac{V^{unretarded}}{V^{retarded}} \tag{12}$$

or

$$V^{retarded} = \frac{V^{unretarded}}{R_f} = \frac{J\ (h_{1,k} - h_{2,k})}{R_f\ \Theta\ L} \tag{13}$$

**Constraints on Withdrawal and Recharge**

These constraints can be applied directly to the decision variables. Termed "bounds," these limit the range of acceptable values of individual withdrawal or recharge rates. For example,

$$(g_{1,1}) \leq 15$$
$$(b_{1,1}) \leq 15$$

**Demand Constraint**

This limits the total withdrawal during a stress period k to satisfy some demand. For example,

$$\sum_{\bar{e}=1}^{M^{\bar{e}}} g_{\bar{e},k} \geq 40.0 \frac{l}{s} \qquad \text{for } k \in K.$$

**Capacity Constraint**

This limits the total withdrawal or recharge rate during a stress period k. For example,

$$\sum_{\bar{e}=1}^{M^{\bar{e}}} ( g_{\bar{e},k} + b_{\bar{e},k} ) \leq 25.0 \frac{l}{s} \qquad \text{for } k \in K.$$

**Balance Constraint**

This establishes that the total withdrawal equals or exceeds the total artificial recharge during a stress period k:

$$\sum_{\bar{e}=1}^{M^{\bar{e}}} g_{\bar{e},k} - \sum_{\bar{e}=1}^{M^{\bar{e}}} b_{\bar{e},k} \geq 0.0 \qquad \text{for } k \in K.$$

# GETTING STARTED

The PLUMAN software has been written for an IBM[2] compatible MS-DOS[3] 386 microcomputer systems with at least 1 MB RAM memory. The FTN77/386[4] FORTRAN compiler was used for the MACMAN model and Microsoft C[5] version 6.0 for the Decision Support System. A math co-processor chip is desirable for speeding the computational part of the software.

PLUMAN software can be easily installed. Loading the system requires the steps found below. In essence, the user has to create a directory for the DSS. This directory will contain the execution and batch files required by the DSS. Next, the user will create three subdirectories under the DSS directory. Each subdirectory will be loaded with input files for MACMAN, MODFLOW and MOC, respectively.

For example, if the user wants to create a directory DSS in drive C, follow the steps below (DOS prompt is written in **bold** and user's instructions are written in *italic*):

| | |
|---|---|
| **C:>** *MD DSS* | (and hit RETURN or ENTER key) |

To create the subdirectories MACDSS, MODDSS and MOCDSS follow the steps below:

| | |
|---|---|
| **C:>** *CD DSS* | (and hit RETURN or ENTER key) |
| **C:\DSS>** *MD MACDSS* | (and hit RETURN or ENTER key) |
| **C:\DSS>** *MD MODDSS* | (and hit RETURN or ENTER key) |
| **C:\DSS>** *MD MOCDSS* | (and hit RETURN or ENTER key) |

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[2] IBM is a registered trademark of International Business Machines, Inc.

[3] MS-DOS is a trademark of Microsoft Corporation.

[4] FTN77/386 is a trademark of University of Salford, England.

[5] Microsoft C is a trademark of Microsoft Corporation.

To load files into the DSS directory, put the diskette in drive A and follow the steps below:

**C:>** *CD DSS* (and hit RETURN or ENTER key)
**C:\DSS>** *COPY A:\DSS*.** (and hit RETURN or ENTER key)

Continue by loading the groundwater model files into the subdirectories, using the steps bellow:

**C:\DSS>** *CD MACDSS* (and hit RETURN or ENTER key)
**C:\DSS\MACDSS>** *COPY A:\MACDSS*.**
(and hit RETURN or ENTER key)

Return to DSS directory by typing:

**C:\DSS>** *CD..* (and hit RETURN or ENTER key)

Repeat the last three steps (substituting MODDSS or MOCDSS for MACDSS) to load MODFLOW and MOC files in MODDSS and MOCDSS subdirectories, respectively.

After loading, the following files, supplied for the Decision Support System, should be in C:\DSS:

| Execution or batch files | Definition |
| --- | --- |
| CYCLE.BAT | Batch file for cycling MACMAN. |
| DBOS.EXE | Memory resident program required to execute files compiled using FTN77/386. |
| DSS.EXE | Decision support system execution file. |
| DSSG.H | Global variables, header file for DSS. |
| DSSP.H | Function prototypes, header file for DSS. |
| EDITOR.BAT | Batch file for user's preferred text editor. |
| MACMINOS.BAT | Batch file to run MACMAN. |
| MOCBAT.BAT | Batch file to run MOC. |
| MOCSURF.BAT | Batch file to create 3-D concentration |

| | |
|---|---|
| | maps using SURFER. |
| MOCTOPO.BAT | Batch file to create contour concentration maps using SURFER. |
| MODBAT.BAT | Batch file to run MODFLOW+STR and copy files to MOCDSS. |
| MODMOC.BAT | Batch file to create semiautomatically MOC input file. |
| MODSURF.BAT | Batch file to create 3-D potentiometric surface maps using SURFER. |
| MODTOPO.BAT | Batch file to create contour maps using SURFER. |
| VIEWMAC.BAT | Batch file to view MACMAN optimal pumping strategy output file. |
| VIEWMOC.BAT | Batch file to view MOC general output file. |
| VIEWMOD.BAT | Batch file to view MODFLOW+STR general output file. |

---

The file names with extension BAT (batch files) should not be changed by the users. Changes in the batch file name, will require model edition with the new name and subsequent model compilation.

The DBOS must be loaded before using the models. DBOS can be run automatically from the AUTOEXEC.BAT, making it easier to use PLUMAN. The directory that contains the DBOS.EXE file, C:\DSS, should be in the path in the AUTOEXEC.BAT file.

Three sample problem data sets DEMO1, DEMO2 and DEMO3 are supplied in the diskettes, in their respective subdirectories. The following files are supplied for MACMAN for each sample problem, except the MACMAN.EXE. These files should be in directory C:\DSS\MACDSS:

| Execution or input files | Definition |
|---|---|
| CYCLE.EXE | Cycling execution file. |
| MACMAN.EXE | Execution file of MACMAN. |
| MACFNAM1.DAT | Data file with unit number and file names. |
| MACFNAM2.DAT | Data file with unit number and file names. |
| STRBAS.DAT | Input data file for basic package. |
| STRBCF.DAT | Input data file for bock-centered package. |
| STROC.DAT | Input data file for output control. |
| STRRCH.DAT | Input data file for recharge package. |
| STRSIP.DAT | Input data file for strong implicit procedure package. |
| STRSTR.DAT | Input data file for streamflow routing package. |
| FOR013.DAT | Input data file with optimization parameter information. |
| FOR014.DAT | Input data file with gradient constraint information. |
| FOR004 | Optimization specification data file. |

For example, if the user wants to load the sample problem DEMO1, insert the diskette in drive B and follow the steps below (DOS prompt is written in **bold** and user's instructions are written in *italic*)

**B:>** *CD DEMO1*
**B:\DEMO1>** *CD MAC*
**B:\DEMO1\MAC>** *COPY *.* C:\MACDSS*

The following files are supplied for MOC for each sample problem, except MOC.EXE. These files should be in directory C:\DSS\MOCDSS:

| Execution or input files | Definition |
|---|---|
| FORMOC.DAT | Subsystem hydraulic head and boundary fluxes data file created by MODFLOW+STR, and used by MDMCLNK. |
| IGV.H | Global variables and parameter definition, header file for MDMCLNK. |
| LOCWELL.DAT | Well location data file created by MODFLOW+STR, and used by MDMCLNK. |
| MDMCLNK.EXE | Program that semiautomatically writes MOC input data file. |
| MOC.EXE | MOC execution file. |
| MOCFNAME.DAT | Data file with unit number and file names. |
| MPROT.H | Function prototypes, header file for MDMCLNK. |
| PGV.H | Include and structures header file for MDMCLNK. |
| TE1.DAT | General input data file. |

The following files are supplied for MODFLOW+STR for each sample problem, except MODSTR.EXE. These files should be in directory C:\DSS\MODDSS:

| Execution or input files | Definition |
| --- | --- |
| MODSTR.EXE | MODFLOW+STR execution file. |
| MODFNAME.DAT | Data file with unit number and file names. |
| STRBAS.DAT | |
| STRBCF.DAT | |
| STROC.DAT | |
| STRRCH.DAT | |
| STRSIP.DAT | |
| STRSTR.DAT | |
| STRWEL.DAT | Input data file for well package. |

The user should not change the names of MACNAM1.DAT, MACNAM2.DAT, MOCFNAME.DAT, and MODFNAME.DAT files. Change in these file names will require editing and recompiling the model.

Sample problem DEMO1 is presented and explained thoroughly in the example section. The objective and constraints for all three sample problems are described below. Sample problems are for steady state, but transient is also possible.

- DEMO1 minimizes total pumping (withdrawal or recharge) at the upper unconfined aquifer layer of a two-layer system, to optimally capture a conservative contaminant plume. In this scenario, the user is interested only in capturing the plume (preventing its movement and extracting it). It uses gradient constraints surrounding the plume. Contamination of the bottom layer can occur due to flow from upper to lower layer;
- DEMO2 minimizes pumping from layer 1 and maximizes withdrawal for water supply from layer 2. As in DEMO1, containment prevents plume movement. An additional constraint prevents downward contaminant movement by controlling heads in both layers;
- DEMO3 adds to DEMO2 a head constraint on river stage in a nearby river.

# MAIN MENU

Once the files are loaded into a DSS directory, the software is executed by entering the appropriate directory and then typing DSS followed by the RETURN or ENTER key. For example, if the user has chosen DSS as the Directory name in drive C, one should follow the steps below (DOS prompt is written in **bold** and user's instructions are written in *italic*).

| | |
|---|---|
| **C:>** *CD DSS* | (and hit RETURN or ENTER key) |
| **C:\DSS>** *DSS* | (and hit RETURN or ENTER key) |

Fig. 1 will appear showing the pull-down Menu of the Decision Support System. The user can select one of five Submenus, using the right and left arrow keys: (1) QUIT, (2) DATA FILES, (3) RUN MODELS, (4) VIEW RESULTS, and (5) HELP.

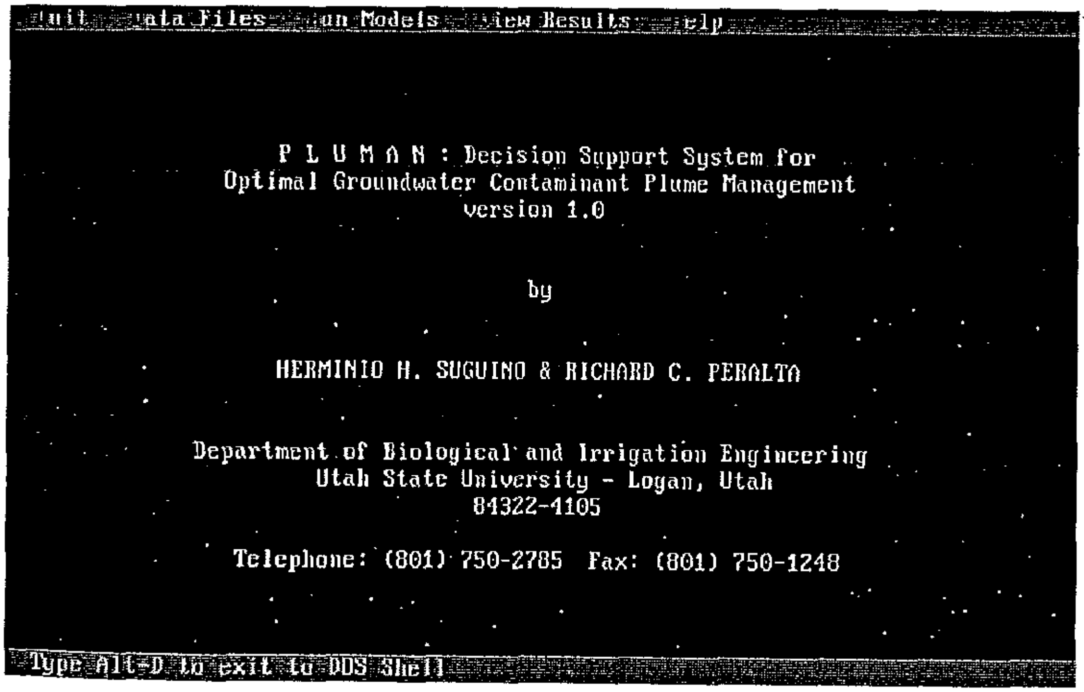


FIGURE 1. Main Menu of Decision Support System.

# Quit

The QUIT submenu, has four options (Fig. 2):

1- Exit : quits the software and returns the user to the DOS prompt;

2- Text editor: connects to the user preferred editor software. The execution file of the editor should be edited in a batch file EDITOR.BAT;

3- Quick DOS : connects to Quick Dos software, if loaded on the PC;

4- Shell to DOS: brings the user to DOS, without leaving the DSS environment. To subsequently return to the DSS, type EXIT at the DOS prompt. Another way to access DOS from the DSS is to type ALT+D.

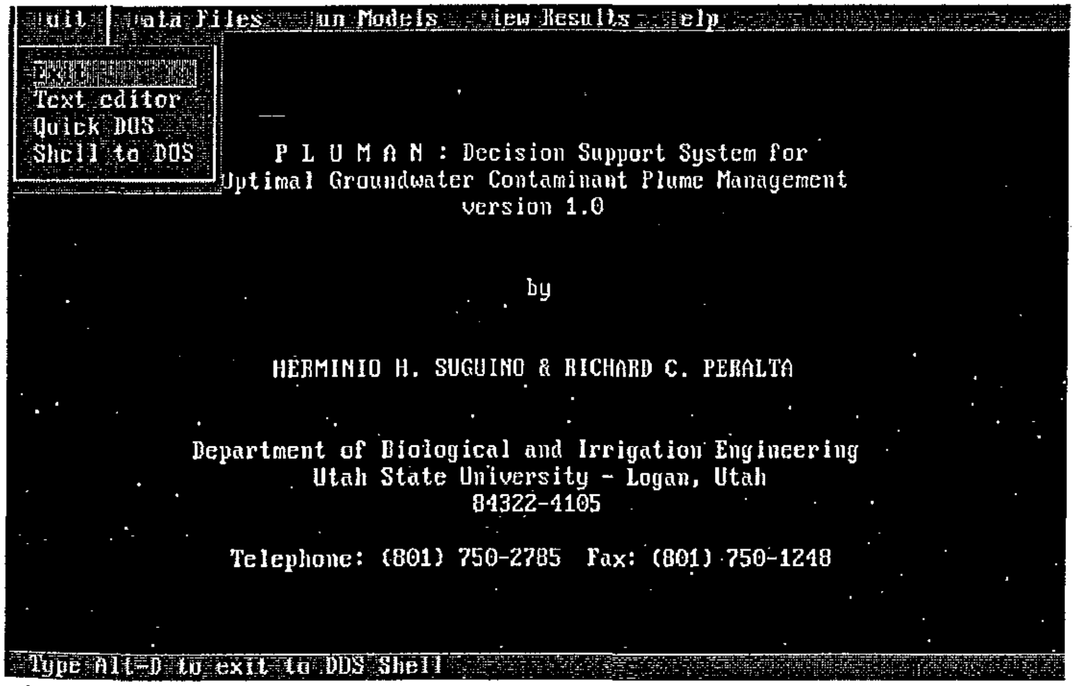


FIGURE 2. Quit Submenu of PLUMAN.

# Data Files

The user must come to this submenu before running any of the models. The DATA FILES submenu permits the user to edit existing data files or create new ones. DATA FILES has three options (Fig. 3).

**1- Help:** contains general information for the models MACMAN, MODFLOW+STR and MOC.

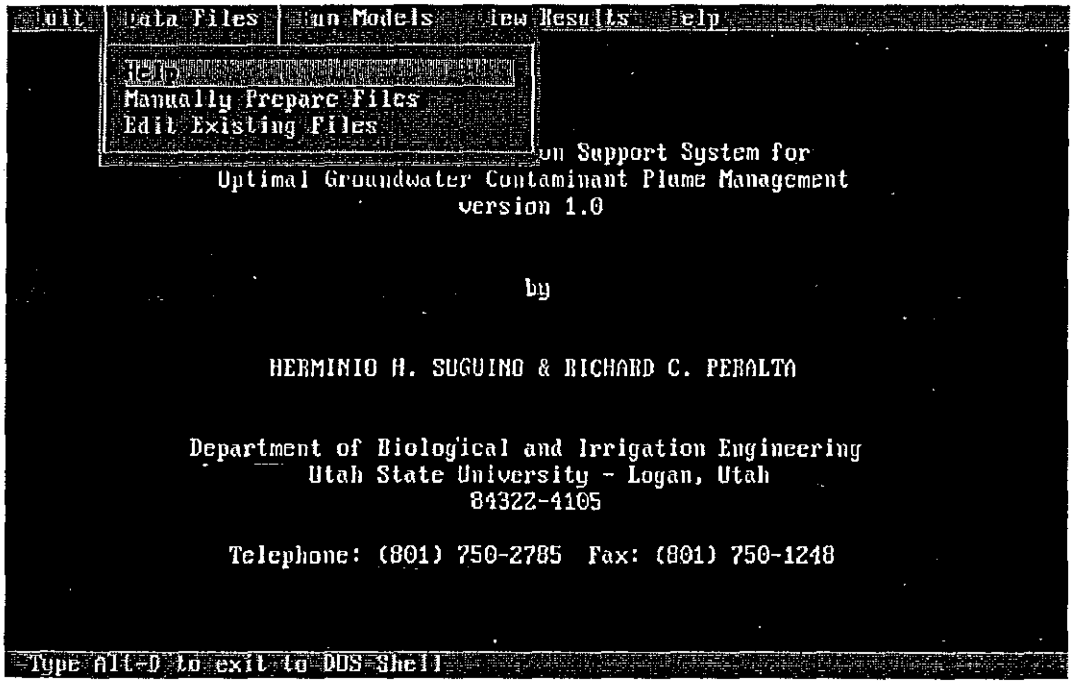


FIGURE 3. Data Files Submenu of PLUMAN.

**2- Manually prepare files:**

This option places the user within his preferred text editor. There, the user can create necessary data files.

**MODFLOW+STR model:**

Input data requirements for groundwater potentiometric surface simulation using MODFLOW+STR are listed in Appendix K. With minor exception they are the same as the data files used by MODFLOW. Changes, made only in the Basic Package Input, are as follow:

1. To use the Streamflow-Routing Package (Prudic, 1988) the user has to write a unit number in the Iunit Location number 13 of Data number 4.
2. A new feature was added to the original MODFLOW. This is useful when the user wants to simulate contaminant transport for a portion (subsystem) of the entire gridded system used by MODFLOW. The subsystem must be rectangular in shape. Within the subsystem all rows must be of equal height and all columns must be of equal width (a characteristic MOC). This option allows MODFLOW to write, in a file, the hydraulic heads within the subsystem and boundary fluxes for that subsystem. This file is subsequently used while semiautomatically preparing MOC input data file. This new feature requires that one create a Data number 10 with parameters IBEG, JBEG, IEND, JEND. The first four are row and column numbers within the full system. They define the beginning and ending rows and columns of the subsystem.

**MACMAN model :**

For the simulation/optimization MACMAN model, the input data requirements are listed in Appendix L. The MACMAN model requires all data normally required by AQMAN (Lefkoff and Gorelick, 1987) and the MODFLOW+STR input data files, except the Iunit number 15 and Well Package used in the original AQMAN and MODFLOW+STR, respectively. Iunit number 15 is not required because the Trescott et al. (1976) simulation model was replaced by MODFLOW+STR. Iunit number 15 was used to supply data for the Trescott et al. (1976) model. The Well Package used in the original MODFLOW+STR is no longer needed, because the required well data is supplied by MACMAN. The following changes were made in the original input data files required by AQMAN and MODFLOW+STR, in order to meet MACMAN requirements.

1. Modification in Data number 3 of MODFLOW Basic Package Input involves including flags for ITHIEM and ITHEISS. The flags allow the user to estimate

heads outside well casings (rather than merely in the center of cells) The wells are assumed to be located in the center of cells. These approaches use the Thiem or Theis equation while simulating and building the MPS (Mathematical Programming Systems) file.

2. Changes in the original AQMAN input data file Unit 13. These changes are required if the simulation/optimization process involves constraints between heads located in different layers. Data Set 2 is created in Unit 13, and consequently the former number 2 becomes Data Set 3. In Data Set 2, the parameters ILOCLY(I), JLOCLY(I), LTOP(I) and LBOT(I) are found in columns 1-10, 11-20, 21-30, and 31-40, respectively.
3. Changes in the original AQMAN input data file Unit 14. These changes are needed in case one wishes to use constraints relating heads located in different layers or limit river stage.
   - In Data Set 2, LGRAD, KSTR, NWBOUND and IRLN are needed in columns 51-55, 56-60, 61-65 and 66-70, respectively.
   - In Data Set 6, LLOCW(I) and KWBOUND(I) are included in columns 51-60 and 61-70, respectively.
   - In Data Set 7, KLAY(I) and KRIV(I) are included in columns 51-60 and 61-70, respectively.
4. Create a new input data file Unit 12, if IRLN flag is set. This data file is required to supply data for each realization.

   For input data format refer to page L-5.

The MPS and SPEC (specification) files are used by MINOS (Modular In-Core Nonlinear Optimization System) (Murtagh and Saunders, 1987) to compute an optimal pumping strategy. The MPS and SPEC files should be further edited according to the user's desired objective function. The SPECS file format is in Appendix L (pages L-9 to L-11).

**MOC model :**

For the contaminant transport MOC model, the input data requirements are listed in Appendix M. These include upgrades that account for contaminant decay (Konikow, 1985). If the user wants to consider the contaminant decay option, a flag for NREACT is required in columns 69-72 of Card image number 2. A new Card image number 4, is created for parameters DK, RHOB and THALF. Because free format is used values are separated by a blank space.

**3- Edit existing files:** permits the user to edit selected files or create new ones, and has four options (Fig. 4):

1- Editor : connects to the user preferred editor for editing files.

2- DOS path : allows the user to specify the directory path where data files can be found.

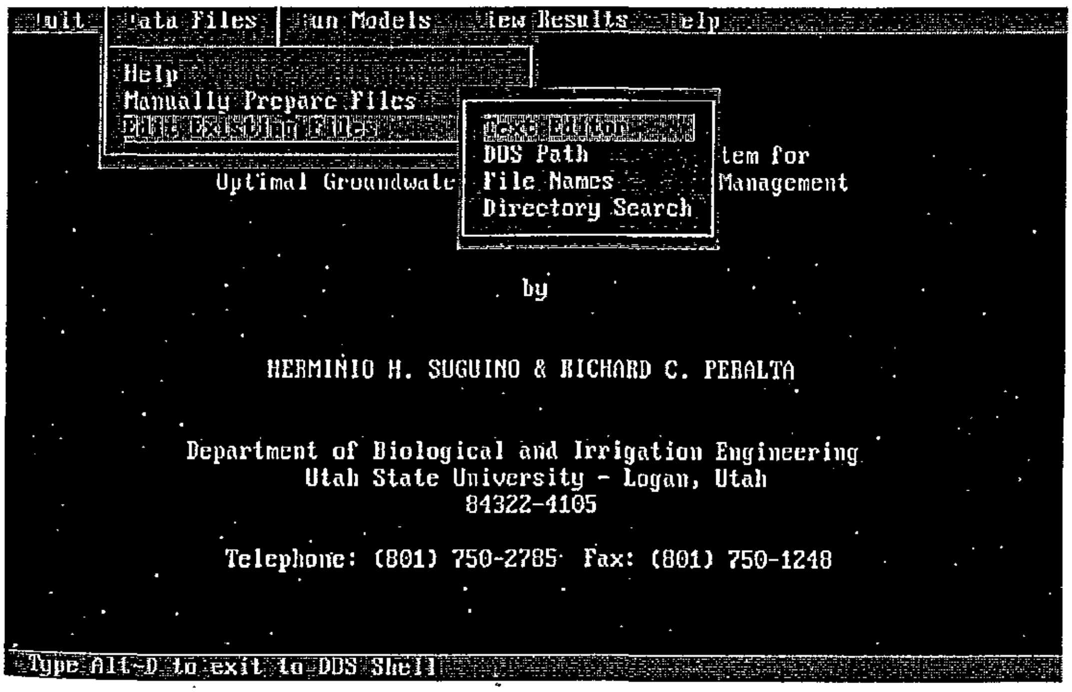


FIGURE 4. Options of Edit Existing files.

3- File names : allows the user to specify data files to be listed in option 4 (Directory Search). For example, the user may want to look only for filenames beginning with MOD. By typing MOD*.* option 4 will locate and list all the files that start with MOD.

4- Directory search : permits the user to select desired data files listed according to the direction given in the previous option. Selected file names with their respective unit numbers are saved in MACFNAM1.DAT, MACFNAM2.DAT, MOCFNAME.DAT, or MODFNAME.-DAT. A unit number is required for each file. Those numbers are referred to by the model, while reading or writing from or into input or output files, respectively.

Instead of using options 2, 3 and 4 above, the user can just connect to the text editor and edit the files. In this case the user should know the input and output file names with their respective unit numbers.

**Generation of Multiple Realizations Using a Lognormal Distribution**

To address uncertain knowledge of hydraulic conductivity, MACMAN can generate different realizations of hydraulic conductivity and can create appropriate constraint sets for each system realization. This permits running an optimization model which might constrain heads and gradients for many different realizations simultaneously, an approach described by Gorelick et al. (1990).

Here, a system realization consists of a set of spatially distributed statistically generated cell realization. For example, a single n-cell system realization of hydraulic conductivity has n distinct conductivity values.

To use this option, one must select the number of realizations desired in the IRLN flag. An extra data file, Unit 12, (page L-5 of the User's Manual) must be created to supply seed numbers, standard deviation, unit number, and file name for each realization. These data are used to compute for each realization, a random lognormally distributed hydraulic conductivity value. This process is repeated for all cells. The file name and unit number of Unit 12 have to be written in the 4th row of MACFNAM1.DAT file. MACMAN generates as many realizations as are specified in the IRLN flag and writes the MPS file for each realization in a specific output file name supplied in the Unit 12 data file. Before running the optimization package, all the MPS files for each realization have to be merged manually into one larger MPS file. In this process, many data rows and variables need to be renamed. Each realization must represent one set of constraints in the resulting MPS file.

Although there might be other approaches, the method used here requires conversion of the statistical moments of lognormally distributed field data into a normal distribution. The method and an example application are presented below for hydraulic conductivity.

If field data is lognormally distributed, ln(field data) is normally distributed. Pertinent relations between lognormal and normal distributions are shown below. There, the expected value and variance of a lognormally distributed variate x are expressed using the statistical moments of an equivalent normal distribution (Naylor et al., 1966; and Haan, 1977):

$$\mu_x = \exp\left( \mu_y + \frac{\sigma_y^2}{2} \right) \tag{14}$$

$$\sigma_x^2 = ( \mu_x )^2 \left[ \exp ( \sigma_y^2 ) - 1 \right] \tag{15}$$

where

$\mu_x$ = expected value of a lognormally distr. variate x;
$\sigma_x^2$ = variance of a lognormally distributed variate x;
$\mu_y$ = expected value of a normally distributed variate y;
$\sigma_y^2$ = variance of a normally distributed variate y.

Since, field conductivity values follow a lognormal distribution, this approach requires conversion into an equivalent normal distribution. The first step is to rearrange Eqs. 14 and 15 and solve for $\mu_y$ and $\sigma_y{}^2$.

$$\mu_y = \ln ( \mu_x ) - \frac{1}{2} \ln [ \frac{\sigma_x^2}{( \mu_x )^2} + 1 ] \tag{16}$$

or

$$\mu_y = \frac{1}{2} \ln [ \frac{( \mu_x )^2}{C_v^2 + 1} ] \tag{17}$$

and

$$\sigma_y^2 = \ln [ \frac{\sigma_x}{( \mu_x )^2} + 1 ] \tag{18}$$

or

$$\sigma_y^2 = \ln ( C_v^2 + 1 ) \tag{19}$$

where

$C_v$ = coefficient of variation;

$$C_v = \frac{\sigma_x}{\mu_x} \tag{20}$$

$\sigma_x$ = standard deviation for variable x;

The standard normal variate z is defined as:

$$z = \frac{\ln x - \mu_y}{\sigma_y} \tag{21}$$

x = random parameter with lognormal distribution.

Solving Eq. 21 for x gives:

$$x = \exp ( \mu_y + \sigma_y z ) \tag{22}$$

where

$$z = \sqrt{-2 \ln ( r_1 )} \cos ( 2 \pi r_2 ) \tag{23}$$

where

$r_1$ and $r_2$ are random numbers, and are created to be representative of a uniform distribution over the interval from 0 to 1.

Random numbers $r_1$ and $r_2$ are determined using seed numbers and Eqs. 24 and 25 (Torres, 1980):

$$r_n = \frac{p}{m} \tag{24}$$

$$p = I - \text{integer}\left( \frac{I}{m} \right) m \tag{25}$$

where

p = random number sequence term;

$I = a\,v + c$;

$a = 8j \pm 3$; j is any integer;

v = seed number;

c = increment;

int(I/m) is the integer part of a quotient I/m;

m = parameter = $2^{\alpha}$.

For binary computer systems, parameter m is determined by considering a base equal to 2 and $\alpha$ = 8, 10, 12, 16, or 20.

When parameter c = 0, the procedure is called the multiplicative congruence method; when $c \neq 0$, it is termed the mixed congruence method.

The j values are selected such that a (which equals 8j $\pm$ 3) is close in value to $2^{\alpha/2}$. This requirement links the j values with particular values of $\alpha$. For example the j values for $\alpha$ = 8, 10, 12, 16, and 20 equal 3, 3, 11, 29, and 131, respectively. In MACMAN, the following are always used a = 8j + 3, j = 3, c = 0, and $\alpha$ = 10.

Seed numbers, v, for binary and decimal computer system are any odd integer number and any odd integer which is not a multiple of 5, respectively. The user inputs these, as well as $\mu_x$ and $\sigma_x$, for each realization computed using MACMAN. The initial v value generates a sequence of numbers that are randomly considered, varying from 0 and $2^{\alpha}$-1. The FORTRAN statement ifix(v) is used to get the random nunmbers.

To illustrate the generation of a realization using a lognormal distribution, consider the following data:

seed numbers v = 15 and 33

$\mu_x$ = 5.208e-04 m/s (mean value of lognormally distributed field values of hydraulic conductivity)

$\sigma_x$ = 0.0001 m/s,

Using Eq. 20 gives:

$C_v$ = 0.0001/5.208e-04 = 0.192.

The $\mu_y$ and $\sigma_y$ moments of an equivalent normal distribution are given by Eqs. 17 and 19:

$$\mu_y = \frac{1}{2} \ln \left[ \frac{(5.208E-04)^2}{(0.192)^2 + 1} \right] = -7.5782$$

$\sigma_y$ = sqrt [ ln ( $0.192^2$ + 1 ) ] = 0.1903.

The first random number is determined by using the first seed number and Eq. 25:

I = a v + c = 27 * 15 + 0 = 405

where, a = 8*3 + 3 = 27

m = $2^{10}$ = 1024

I/m = 405/1024 = 0.3955078 and int(I/m)m = 0

p = 405 - 0 = 405.

Then, a random number from a uniform distribution between 0 and 1 is computed using Eq. 24:

$r_1 = 405/1024 = 0.3955078.$

Similarly, if $v = 33$, $r_2 = 0.8701171.$

The standard normal variate z is given by using Eq. 23:

$$z = \text{sqrt}\ [\ -2 \ln (r_1)\ ] \cos (2 \pi r_2) = 0.933115$$

Finally, using Eq. 22 we find the random parameter with lognormal distribution:

$$x = \exp(-7.5782 + 0.1903*0.933115) = 0.0006108.$$

In a hypothetical example problem (Chapter 6), two realizations are considered to derive constraints in the optimization model. It is assumed that the standard deviation is the same for both realizations. Seed numbers are 15, 33 and 55, 97 for realizations 1 and 2, respectively. The resulting total optimal pumping is 3.28E-02 $m^3/s$, about 2 percent smaller than the value obtained using only mean conductivity values, i.e., 3.358E-02 $m^3/s$ (DEMO1 strategy is shown on page F-7 of the User's Manual). PLUMAN selected the same pumping wells in DEMO1 as in this 2-realization run. However, pumping rates changed. Tight gradient constraints remained unchanged. In another tested 2-realizations run, pumping was about 2 percent larger than that of DEMO1. Normally, one would expect that the more realizations employed, the greater the likelihood that total pumping will exceed that from a deterministic run (like DEMO1).

**Well Head Correction Using Thiem or Theis Equation**

The hydraulic head in the center of a pumping cell can be modified using either the Thiem or Theis equation to compute head just outside the casing of a well existing at the center of a pumping cell. This is important because average cell heads or drawdowns do not adequately represent values at a pumping well casing. This optional operation is performed via a flag in the input data file for MACMAN (Appendix L of the User's Manual).

The Thiem equation is used for steady state simulation. For a confined aquifer it is expressed as (Trescott et al., 1976),

$$h_{\hat{o}} = h_{\bar{o},k} - \frac{g_{\hat{o},k}}{2 \pi T_{\bar{o}}} \ln \left( \frac{r_e}{r_{\hat{o}}} \right) \qquad (26)$$

where

$$r_e = \frac{r_d}{4.81} \qquad (27)$$

$h_{\hat{o}}$ = hydraulic head at well ô [L];
$h_{\bar{o},k}$ = head at cell ō at time period k [L];
$g_{\hat{o},k}$ = withdrawal at well ô at time period k [$L^3/T$];
$T_{\bar{o}}$ = transmissivity in cell ō [$L^2/T$];
$r_e$ = radius of a hypothetical well for which the cell averaged head applies [L];
$r_d$ = average cell side length [L];
for square cell $r_d = \Delta x = \Delta y$
for rectangular cell $r_d = (\Delta x + \Delta y)/2$
$r_{\hat{o}}$ = well radius [L].

The derivation of Eq. 27 considers the Darcy and Thiem equations. Considering only one-quarter of the cell, the discharge is

$$\frac{g_{\hat{o},k}}{4} = \Delta x \, T_{\bar{o}} \frac{\Delta h}{\Delta y} \qquad (28)$$

From the Thiem equation,

$$\frac{g_{\hat{o},k}}{4} = \frac{\pi \, T_{\hat{o}}}{2} \frac{\Delta h}{\ln \left( \frac{r_d}{r_e} \right)} \qquad (29)$$

Equating Eqs. 28 and 29, gives Eq. 27.

Eq. 26 assumes (1) flow in the cell, which contains the well, is described by a steady state equation; (2) no source term other than well withdrawal or recharge; (3) isotropic and homogeneous aquifer within in the cell; (4) laminar flow; (5) well fully penetrates the aquifer and only one well is allowed within the cell; (6) negligible well loss; and (7) only one well, located at center of the cell.

For an unconfined aquifer, the Thiem equation is given by

$$H_{\hat{o}} = \sqrt{H^2_{\bar{o},k} - \frac{g_{\hat{o},k}}{\pi J_{\bar{o}}} \ln\left(\frac{r_e}{r_{\hat{o}}}\right)} \quad (30)$$

where

$H_{\hat{o}}$ = saturated thickness at the well ô [L];

$H_{\bar{o},k}$ = saturated thickness of the aquifer at radius $r_e$ [L];

$J_{\bar{o}}$ = hydraulic conductivity in cell ō [L/T].

The Theis equation is used for transient simulation (Bear, 1979)

$$s = \frac{g}{4 \pi T} W(u) \quad (31)$$

$$u = \frac{r^2 S}{4 T t} \quad (32)$$

$$W(u) = -0.5772 - \ln u + u - u^2/2 \times 2! + u^3/3 \times 3! - u^4/4 \times 4! + \ldots.. \quad (33)$$

where

s = drawdown at well ô [L];

r = radius from the well [L];

S = storage coefficient [dimensionless];

t = time [T];

W (u) = well function.

Drawdown response to unit pumping rates are considered to be influence coefficients. MACMAN will, upon request, substitute well influence coefficients for cell influence coefficients in the MPS file. In this case the s computed at the pumping well, will be substituted for average cell drawdown and written in the MPS file. The inherent assumption for this substitution is that there is only one well pumping in the center of a cell specified for substitution.

# Run Models

This menu allows the user to select which of three models to run (Fig. 5) MODFLOW+STR, MOC or MACMAN. Fig. 6 presents a general view of possible operations with the models. Data files required by the models have to be in their respective subdirectories as described in pages 19 to 21. A model is selected by moving the cursor using UP or DOWN arrows and pressing the ENTER or RETURN key.

Input data for running MOC for a subsystem of an area addressed by MACMAN can be prepared using templates (Figs. 7 to 10). In this option a template guides the user to input parameter

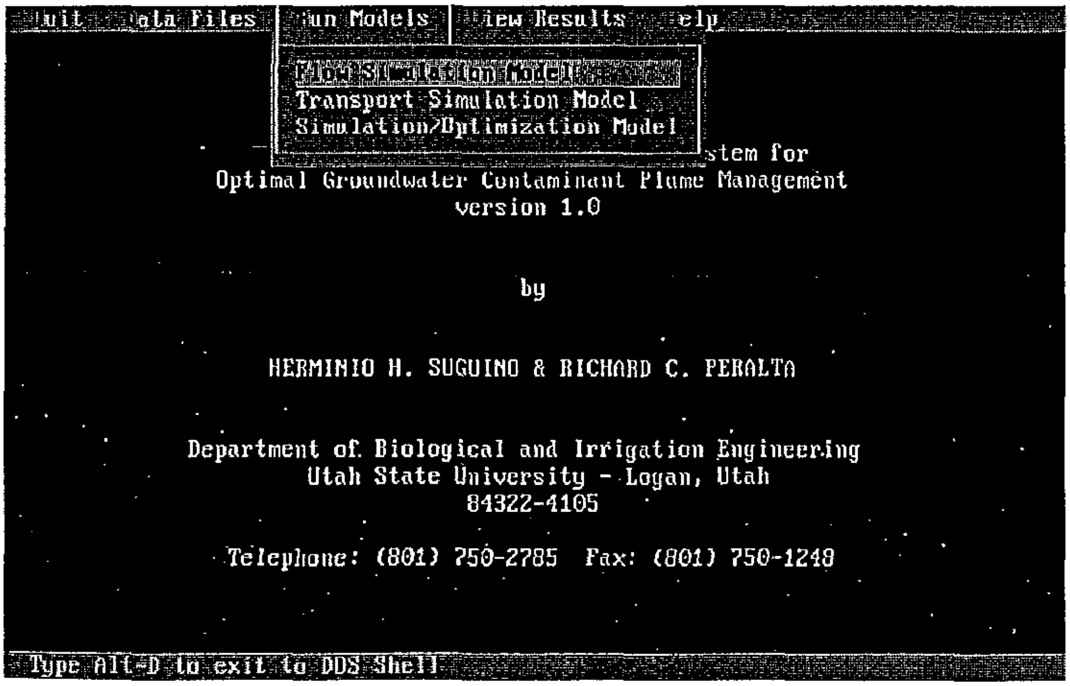


FIGURE 5. Run Models Submenu of PLUMAN.

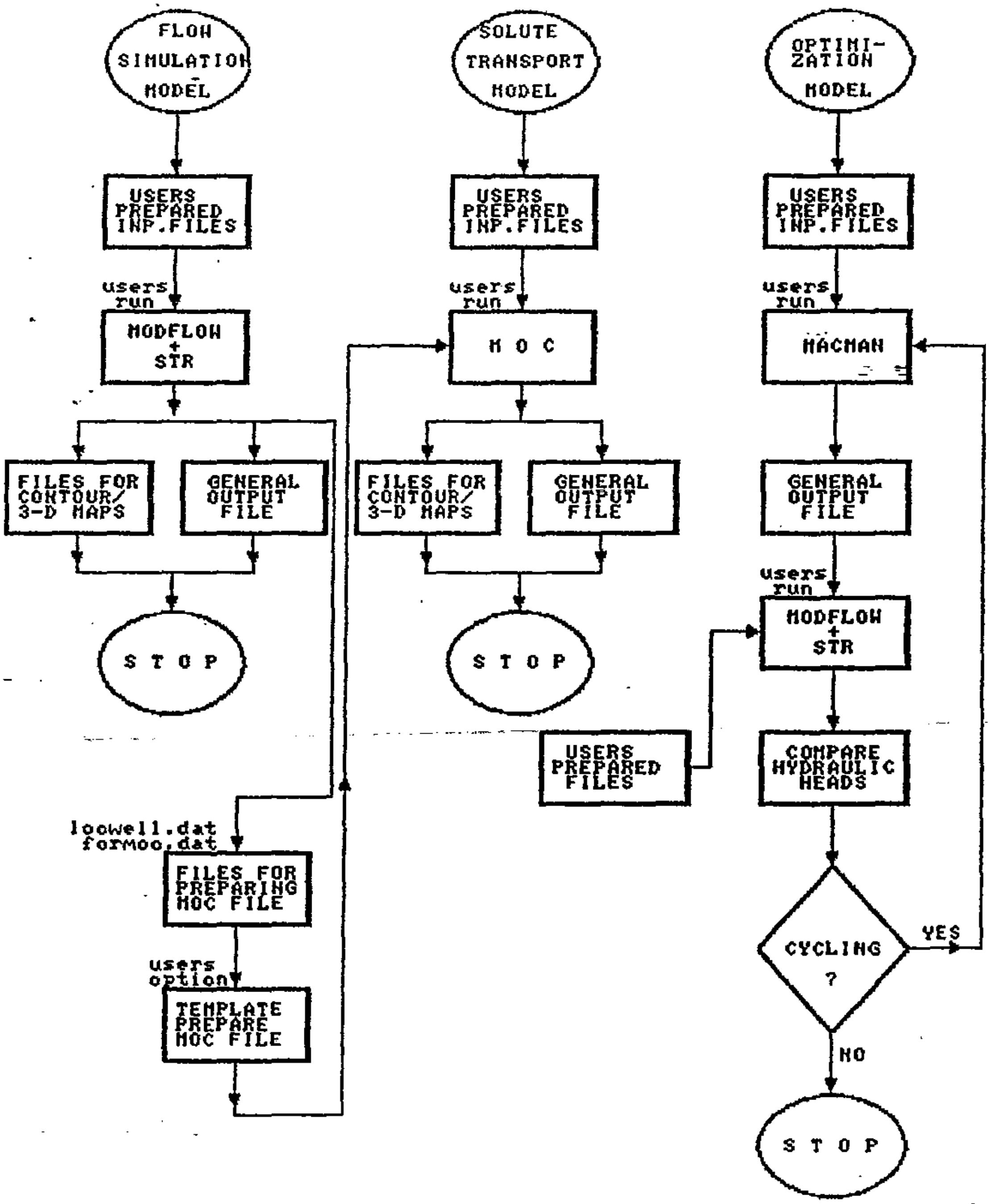


FIGURE 6. General View of Simulation and Optimization Options.

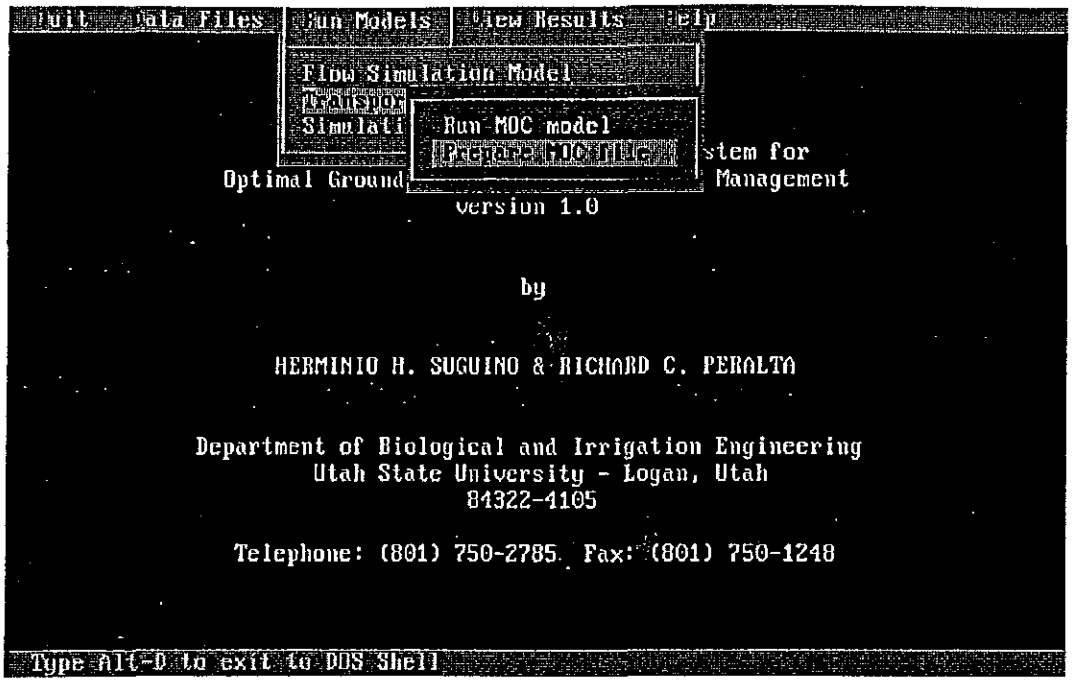


FIGURE 7. Options for Transport Simulation Model.

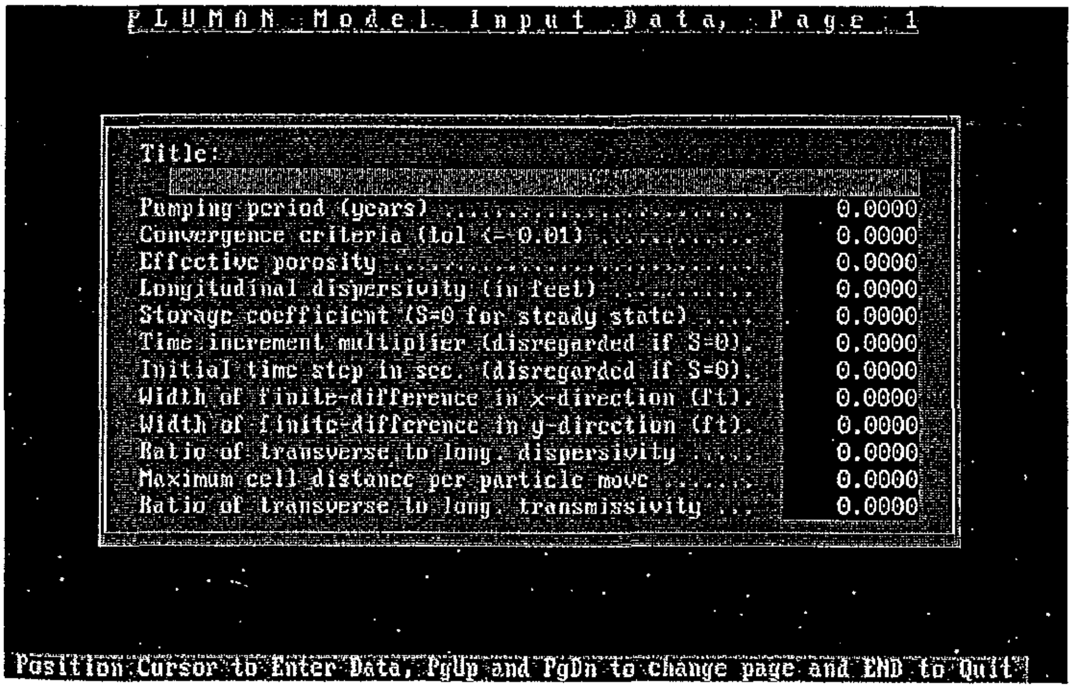


FIGURE 8. Page 1 of Prepare MOC File Option.

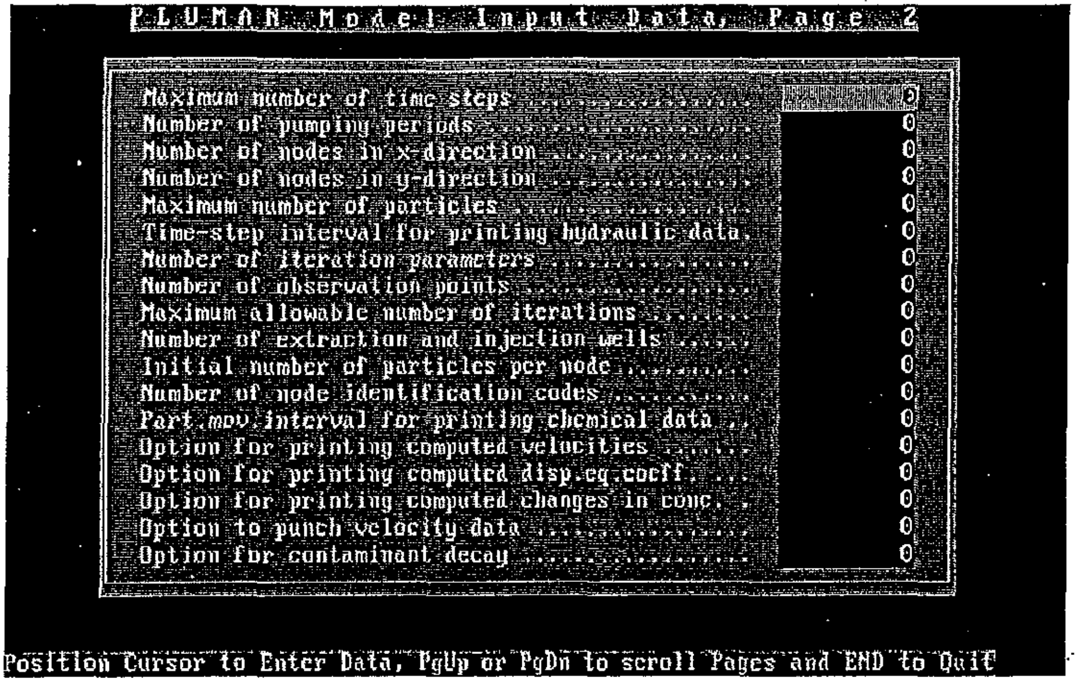


FIGURE 9. Page 2 of Prepare MOC File Option.

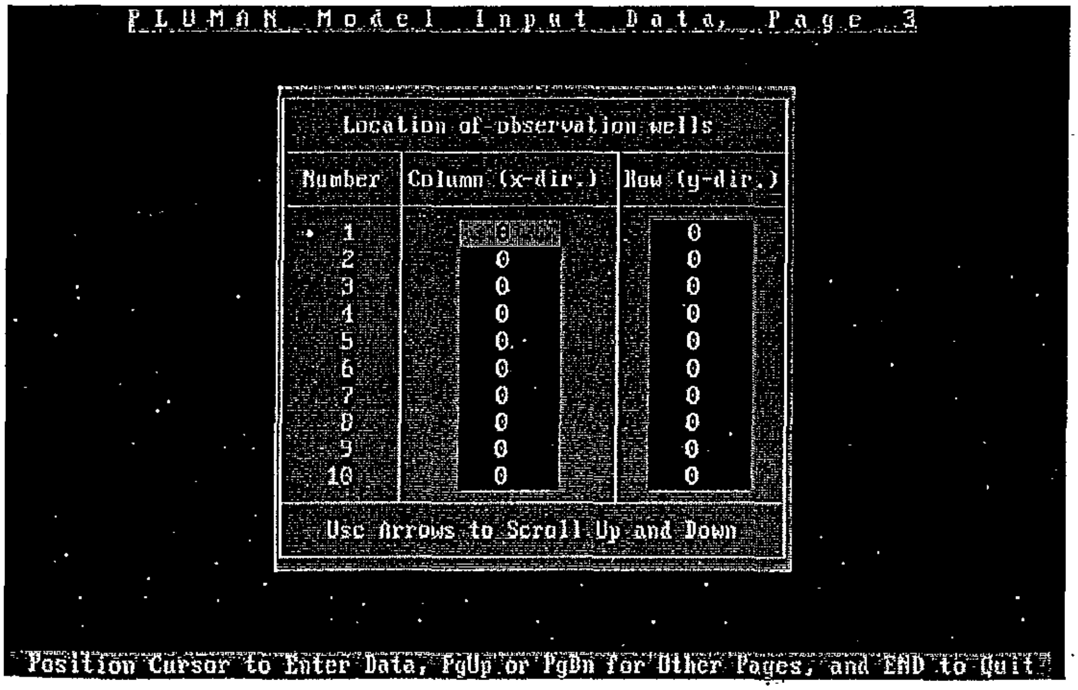


FIGURE 10. Page 3 of Prepare MOC File Option.

information. Data provided by the user and data from the output file generated by MODFLOW+STR, are used to semiautomatically prepare MOC input data file.

A convenient option permits automatic input data file preparation option for MACMAN (Fig. 11). This option takes the optimal pumping strategy generated by MACMAN and prepares a new input data file that can be used for cycling. This option is convenient for checking head convergence when addressing unconfined aquifers.

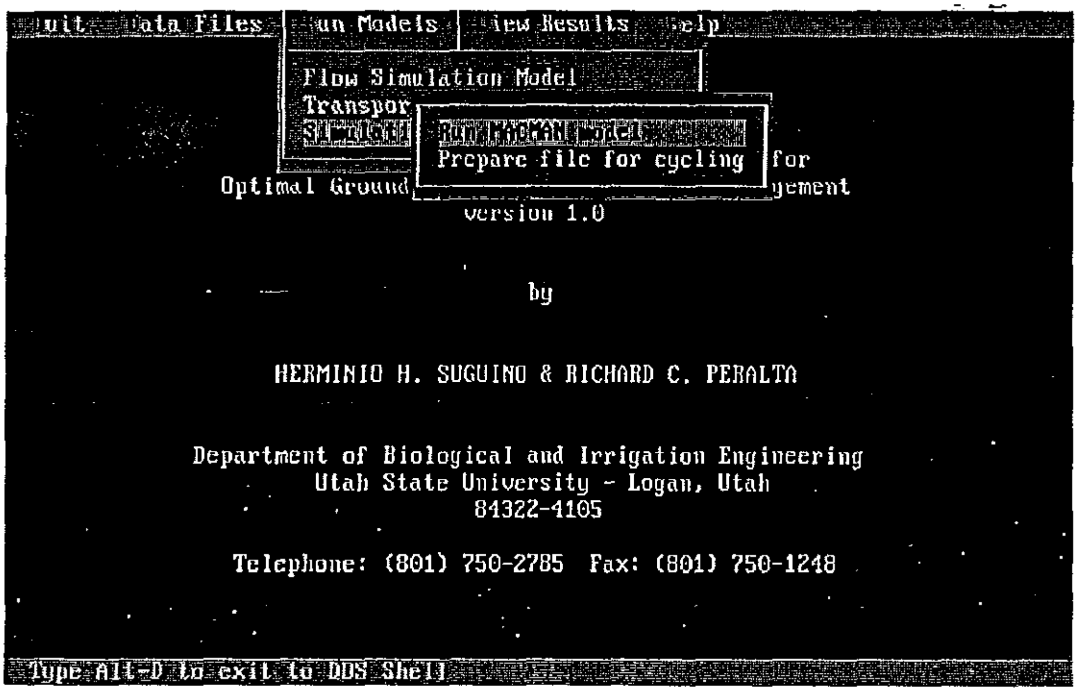


FIGURE 11. Options for Simulation/Optimization Model.

# View Results

Allows the user to view output listings from all three models or contour or 3-D plots of output from MODFLOW+STR and MOC. These plots are generated using SURFER software (Figs. 12 and 13).

All output files (listings, data and graphic) are written automatically in the respective model subdirectory. Thus the user can find all related input and output files of a model in one subdirectory.

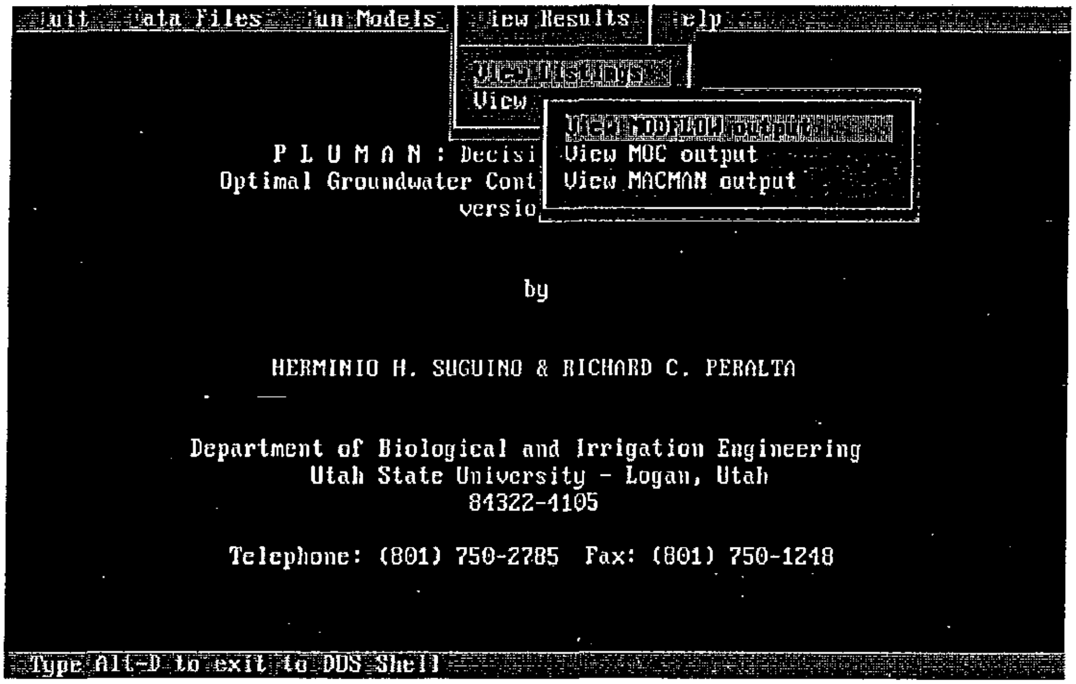


FIGURE 12. Options for View Listing.

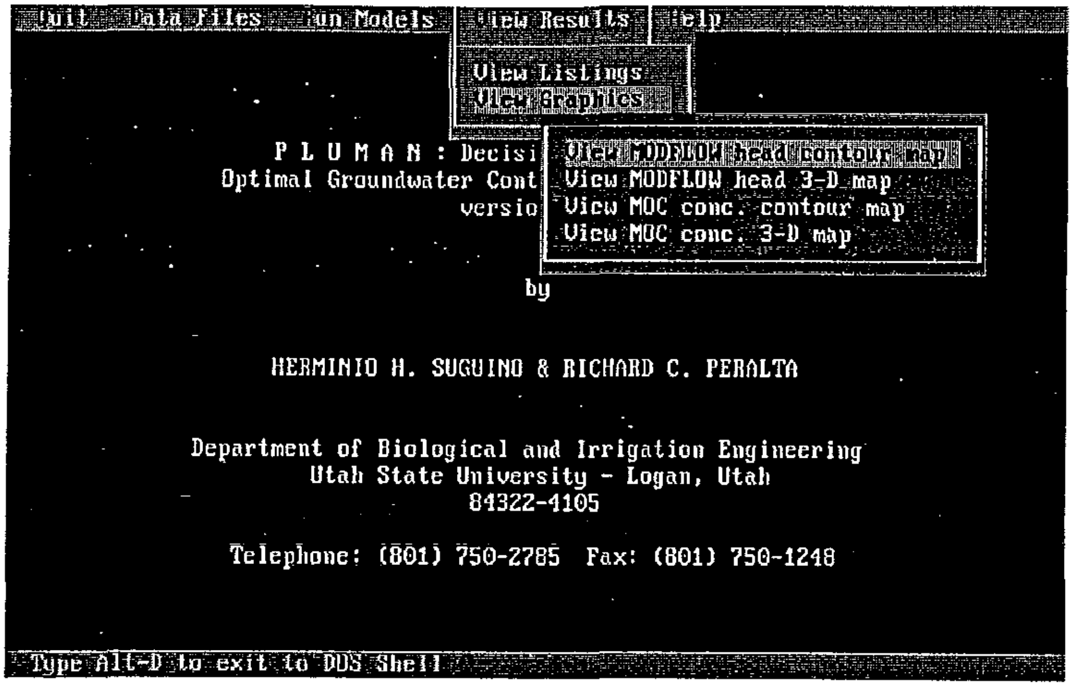


FIGURE 13. Options for View Graphics.

The flow simulation model (MODFLOW+STR) generates five output files:

1. MODSTR.OUT is the general output of the model;
2. MOD.DAT contains hydraulic head information for the entire grid system. This information is used by SURFER to automatically plot a contour or a 3-D potentiometric surface map;
3. MODSUBSY.DAT contains hydraulic head information of the subsystem. This information is used by SURFER to plot a contour or a 3-D potentiometric surface map;
4. LOCWELL.DAT contains well location information used to build a MOC input data file;

5. FORMOC.DAT contains subsystem hydraulic head and fluxes information. This is used to semiautomatically build a MOC input data file.

If the user desires to use different names for MODFLOW+STR output files, the file names have to be specified in MODFNAME.DAT file, using a text editor.

The simulation/optimization MACMAN model generates six output files:

1. FOR010.DAT contains the influence coefficients in a MPS format;
2. FOR017.DAT contains unmanaged (nonoptimal) hydraulic heads for control points and input data used by MACMAN. This output file can be easily checked to verify whether MACMAN is reading input data appropriately for the posed problem;
3. MODSTR.OUT is the general simulation output file;
4. FOR009 is the general optimization output file;
5. MOPTSTG.OUT contains the optimal pumping strategy. This information is used to automatically build part of a MACMAN input data file (FOR014.DAT), which is used to cycle for transient unconfined (nonlinear) conditions;
6. MACPXY.OUT contains coordinates of well locations. This information is also used to automatically build MACMAN input data file (FOR014.DAT) for cycling.

The transport simulation model (MOC) generates two output files:

1. TE1.OUT is the general output file;
2. MOCSURF.DAT contains information to plot a contour or a 3-D contaminant concentration map using SURFER.

# Help

Contains information about the PLUMAN and MACMAN software (Fig. 14). This information helps the user utilize the software without frequent reference to the manual.

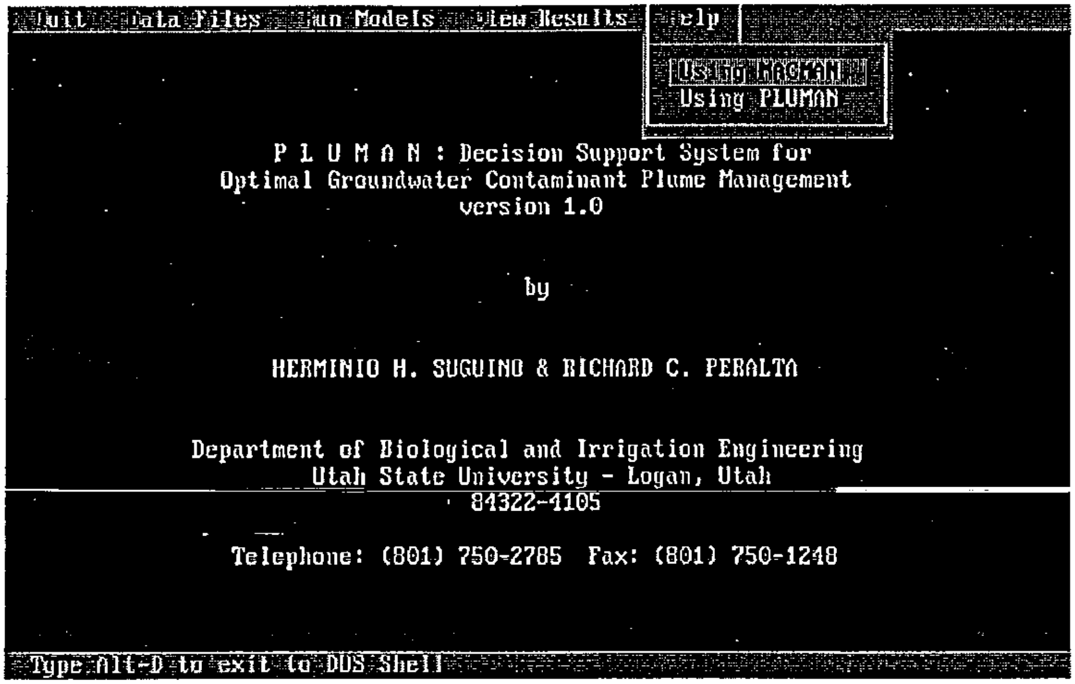


FIGURE 14. Help Submenu of PLUMAN.

# EXAMPLE

MACMAN was applied to three hypothetical sample problems, for optimal steady state groundwater management.

A comprehensive explanation of sample problem DEMO1_A and the steps used to solve it, are given below. In scenario DEMO1_B, a pumping constraint, making total extraction equal to total injection, was added to DEMO1_A. In both scenarios, DEMO1_A and DEMO1_B, the objective function is to minimize the total extraction and injection on the top layer, needed to capture the contaminant plume.

In sample problem DEMO_2, a head difference constraint on heads located in different layers and three additional potential extraction wells on the second layer were added to the scenario of DEMO_1. In sample problem DEMO3, a stream stage constraint is added to the scenario of DEMO2. The objective function for DEMO2 and DEMO3, simultaneously minimizes total extraction and injection at the top layer, and maximizes total extraction from the bottom layer. The water from the bottom layer is used for drinking water.

For the purpose of checking head resulting from implementing the optimal pumping strategy, the following were used: (1) a modified groundwater flow simulation MODFLOW model (McDonald and Harbaugh, 1988), with streamflow-routing package (STR) (Prudic, 1989), called MODFLOW+STR, and (2) a transport simulation MOC model (Konikow and Bredehoeft, 1984).

**Sample Problem - DEMO1_A**

This problem illustrates optimal management of a groundwater contaminant plume in an unconfined aquifer. The area (Fig. 15) is bounded on the north by a large salt water body, on the south, east, and northwest by impermeable material and on the west by a lake. A river transects the area from south to north.

The plume originates from a spill of a nonreactive contaminant upgradient of drinking and irrigation supply wells. This spill is treated

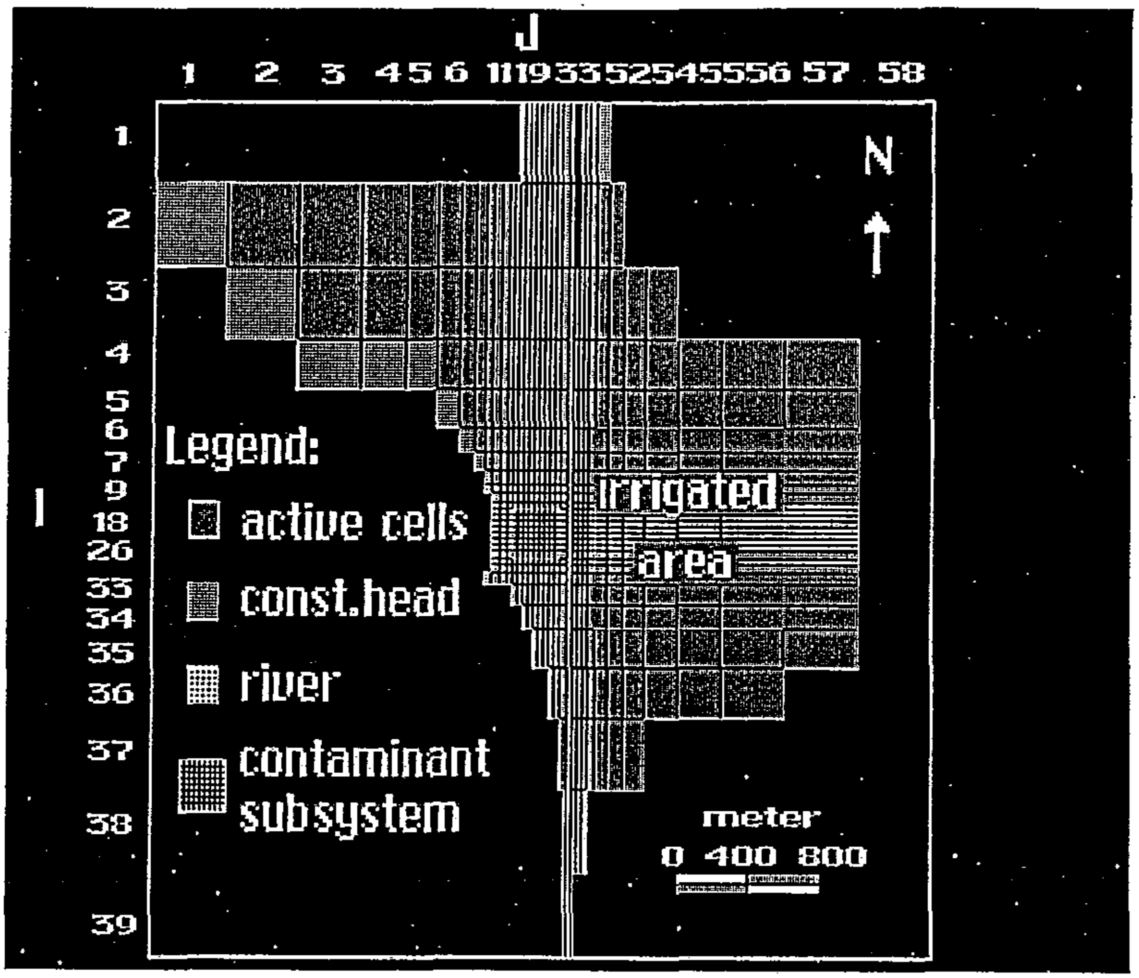


FIGURE 15. Finite-Difference Grid for Sample Problem DEMO1_A.

as a continuous source in the problem. Between lake and river the hydraulic gradient is from west to east, ie., toward the river. The aquifer is recharged by deep percolation from rainfall and irrigation.

The preliminary goal is to minimize the pumping needed to capture the plume. Pumping can include withdrawal and recharge. Capture is assumed to be achieved when hydraulic gradients, just outside the plume boundary, all point toward the plume interior. Here, this is intended as a steady state problem. First, data will be presented, then the solution process will be explained.

The greatest dimensions of the irregularly shaped area measure 4,314 m by 4,135 m. The area is discretized into 58 columns and 39 rows in a block-centered finite-difference grid (Fig. 15). Spacing between nodes ranges from 3 to 400 m.

Fig. 16 shows the time scale of DEMO1_A sample problem. At time zero, the contaminant reaches the water table and starts to pollute the groundwater. The optimal pumping management is assumed to start at day 60. The potential well locations were determined by considering the contaminant distribution that would result after 60 days, if nothing new occurred (i.e. if a steady surface was maintained by a steady pumping from existing well). At day 90, all the head difference constraints are achieved. At day 240, the concentration is checked and verified that all the contaminant is contained. A subsystem is specified to contain the plume area. To permit modelling with MOC, the subsystem grid spacing must be uniform. Fig. 17 illustrates the subsystem discretization into 17 rows and 20 columns, with a fixed spacing of 15.2 m (50 ft). Fig. 18 shows locations of subsystem head difference constraints, which are placed to enclose the contaminant plume. Utilized aquifer parameters for the study area, were obtained from ranges reported by Todd (1980).

Top unconfined layer:

Hydraulic conductivity:

1st zone: 45 m/day (coarse sand) from lake to contaminant spill area (columns 1 to 36 and 57 to 58);

2nd zone: 30 m/day (medium sand) in irrigated area (columns 51 to 56);

3rd zone: 450 m/day (fine gravel) in contaminant spill area (columns 37 to 50).

```
aquifer  optimal  all head differ.                    check of
contam.  pumping  constraints                         cont.conc.
         begins    achieved

I---------I---------I------------------------------I

0         60        90                             240   days
```

FIGURE 16. Time Scale of the Sample Problem.

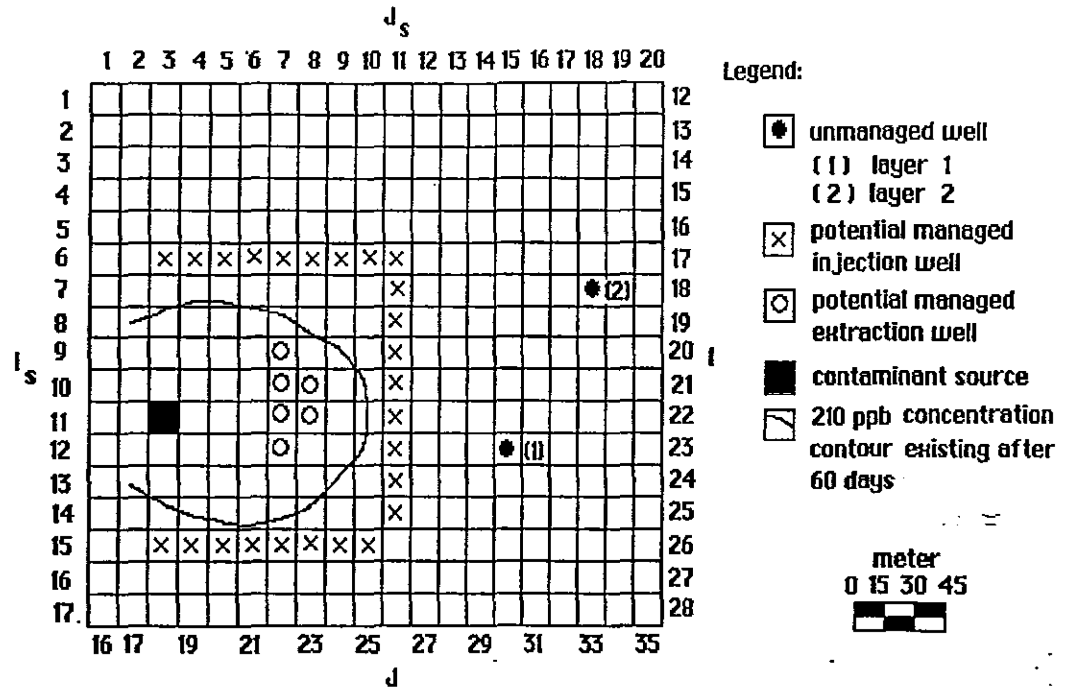


FIGURE 17. Finite-Difference Grid for the Subsystem.

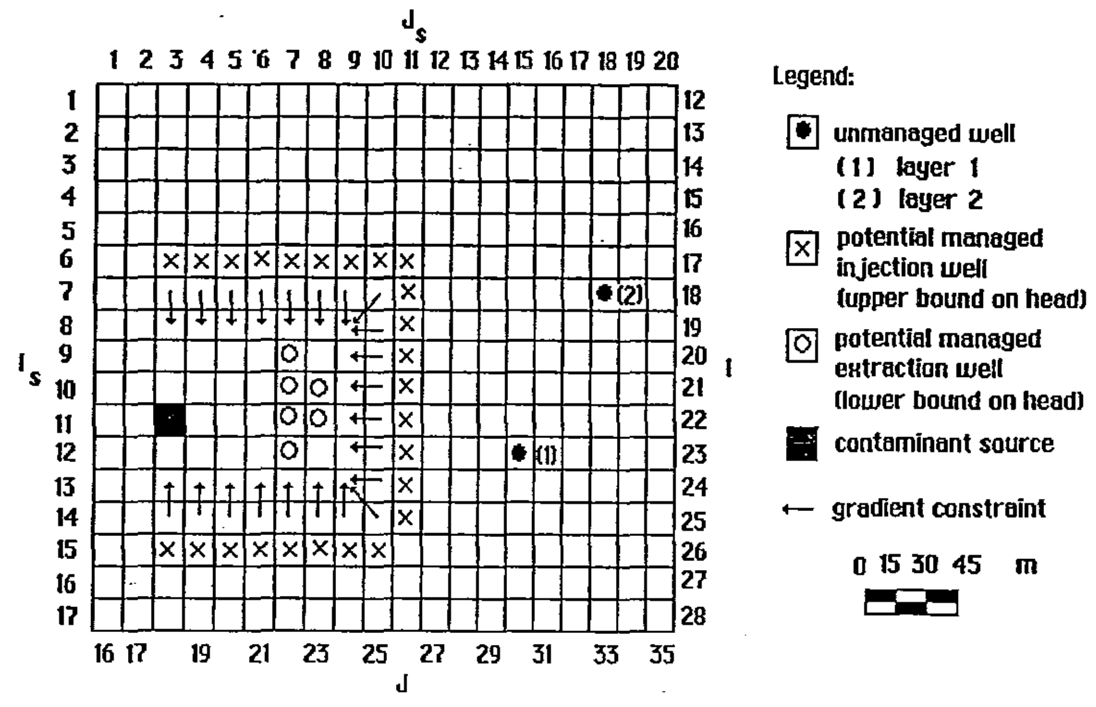


FIGURE 18. Head Difference Constraint Locations in the Subsystem.

Specific yield:

1st zone: 0.27 (coarse sand);

2nd zone: 0.28 (medium sand);

3rd zone: 0.25 (fine gravel).Recharge by deep percolation and/or irrigation:

: $1.167 \times 10^{-8}$ m/s in non-irrigated area;

: $1.928 \times 10^{-8}$ m/s in irrigated area.

Bottom confined layer:

Transmissivity for confined bottom layer: 0.1564 $m^2/s$;

Storage coefficient: 0.0001; Saturated thickness: 30.0 m.

**Problem Formulation**

The objective is to minimize the total withdrawal and recharge needed to capture the contaminant plume.

Objective function

$$\text{Minimize} \sum_{\bar{e}=1}^{M^{\bar{e}}} ( g_{\bar{e}} + b_{\bar{e}} )$$

where

$g_{\bar{e}}$ = extraction rate at well in center of cell $\bar{e}$, $[L^3/T]$;

$b_{\bar{e}}$ = injection rate at well in center of cell $\bar{e}$, $[L^3/T]$;

$M^{\bar{e}}$ = total number of pumping cells.

Head difference constraint $\Delta h_{\bar{o}}$, between cells $\bar{o}_1$ and $\bar{o}_2$. The head difference between two control locations, should be greater than or equal to 0.01.

$$\Delta h_{\bar{o}_{1,2}} \leq 0.01 \qquad \text{for } \bar{o}_{1,2} = 1..22$$

Hydraulic head h, constraint on withdrawal well ê. Head drawdown at extraction well is limited to about 10 percent of the unmanaged saturated thickness.

$$h_{\hat{e}} \geq 15.0 \qquad \text{for } \hat{e} = 1 .. 6$$

Hydraulic head h, constraint on recharge well ê. Head at recharge well should not rise above the ground surface elevation (25.0 m), which is measured above the base of top layer.

$h_{\hat{e}} \leq 25.0$ for $\hat{e} = 1 .. 25$

**Determine Nonoptimal Potentiometric Surface (Step 1)**

The nonoptimal potentiometric surface refers to the current hydraulic surface without any groundwater management. It considers all the existing conditions (extraction and injection wells, recharges, and discharges) that affect nonoptimal groundwater flow.

The optimal potentiometric surface evolves from the current nonoptimal potentiometric surface due to the implementation of an optimal pumping strategy, designed to achieve a certain objective.

Steps 1 and 2 involve determining the contaminant plume movement with time if no optimal strategy is implemented (i.e. continuing current steady pumping for water supply and maintaining current nonoptimal potentiometric surface). Fig. 19 illustrates the general procedure required for steps 1 and 2.

First, load (page 22 of the manual) the required input data file (Appendix A). MODFLOW+STR was used to compute the steady state potentiometric surface resulting from current (nonoptimal) management. The model automatically writes the hydraulic heads and fluxes for the selected subsystem in an output file. Appendix B contains the subsystem output file, which contains data for 15 rows and 20 columns. The model writes zeros in the first and last value of each row to represent the noflow boundary required by MOC.

This process is to run the modified MODFLOW+STR and subsequently, SURFER. To eliminate spurious contour lines that might appear outside the study area, manually set HNOFLO value (Appendix K) approximately equal to the boundary head of the study area. The resulting potentiometric surface for the entire study area and for the subsystem are presented in Figs. 20, and 21, respectively.

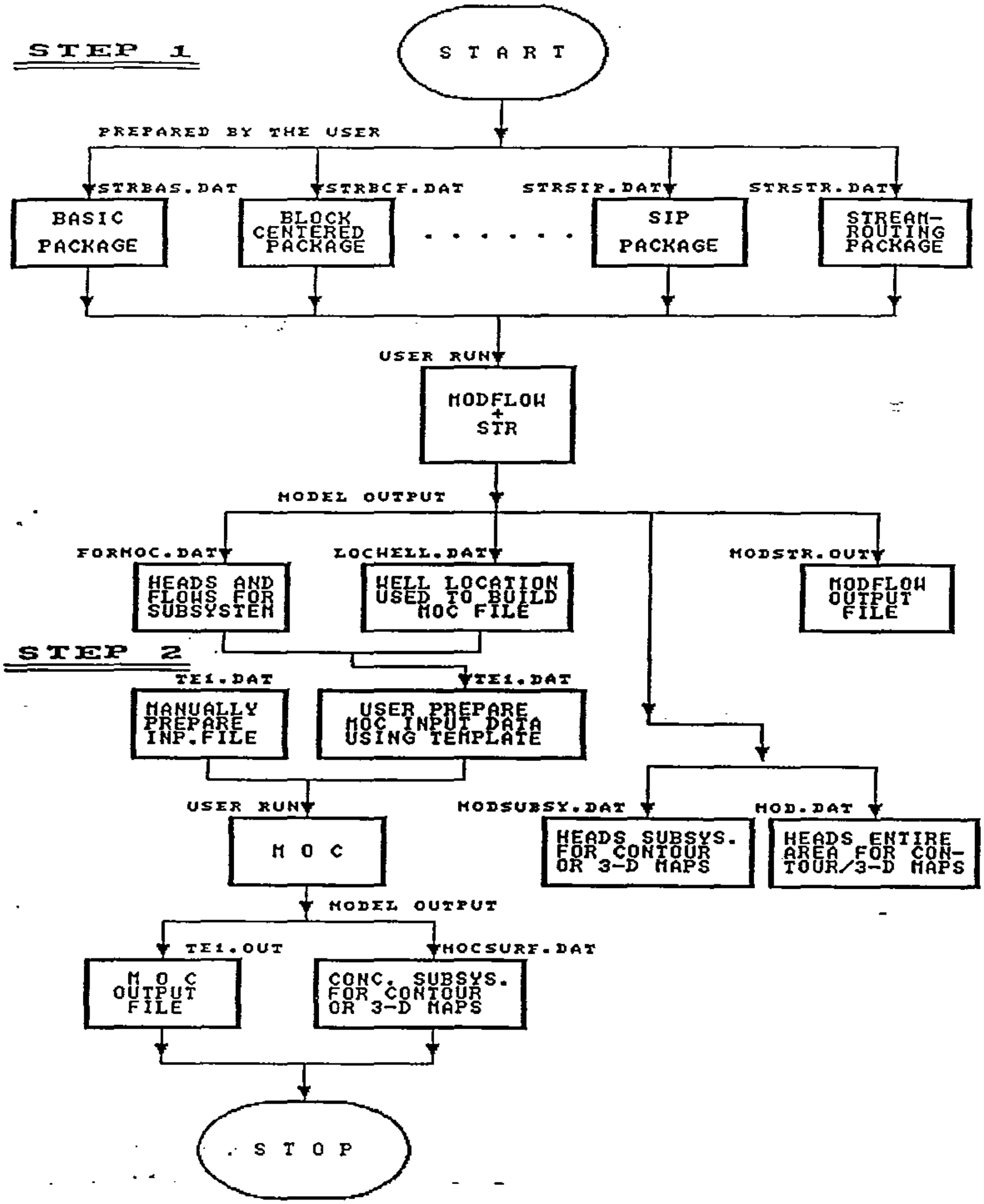


FIGURE 19. Flowchart of Steps 1 and 2.

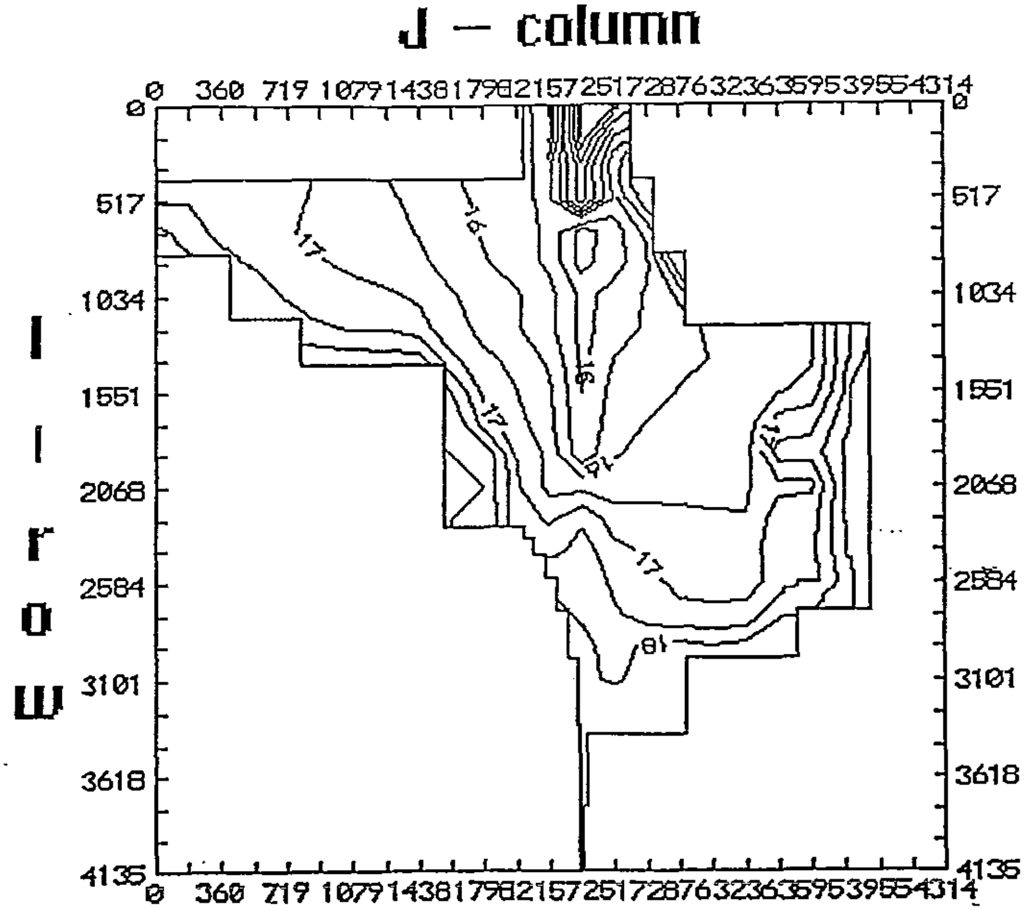


FIGURE 20. Nonoptimal Potentiometric Surface Contour Map for the Entire Study Area (m above MSL).

**Compute Contaminant Transport for Nonoptimal Scenario (Step 2)**

Fig. 19 presents a flowchart for this step. First, load (page 21 of the manual) MOC input date file (Appendix C). Run MOC to compute the potentiometric surface and transport resulting in the subsystem for the nonoptimal scenario. Appendix D illustrates the MOC output file generated in this step.

Steady state potentiometric surfaces computed by MODFLOW+STR and MOC (in steps 1 and 2, respectively) are almost identical, with the greatest error in 1/100 meter. This demonstrates that fluxes along the subsystem boundary are computed correctly and subsystem data is transferred to MOC properly. The contaminant is

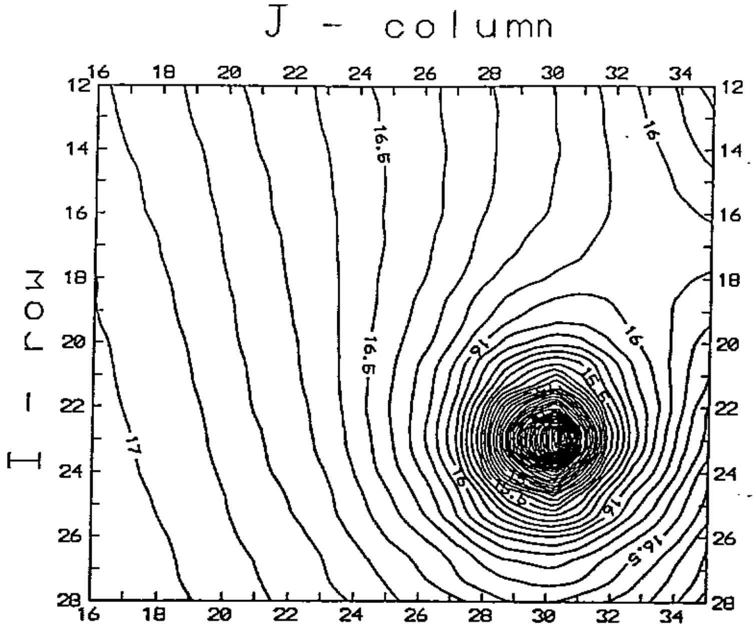


FIGURE 21. Nonoptimal Potentiometric Surface Contour Map for the Subsystem Area (m above MSL).

assumedly spilled in cell ($11_s$,$3_s$) and begins migrating toward drinking wells located in cells ($12_s$,$15_s$) and ($7_s$,$18_s$) (Fig. 18). The subscript $_s$ after a cells' row and column indices indicates that the cell is in the subsystem. If current (nonoptimal) pumping continues, the contaminant concentration in the cell containing the drinking well ($12_s$,$15_s$) reaches 317 ppb 8 months after the spill. It is assumed, that this concentration level is higher than the minimum acceptable for human consumption.

**Define the Management Objective and Compute an Optimal Pumping Strategy (Step 3)**

A flowchart for this step is presented in Fig. 22.

Assume that decision makers wish to determine how best to protect the wells using a system of pumping (withdrawal and recharge) wells. They decide to place head difference constraints around the contaminant plume that will exist after 60 days (Fig. 17).

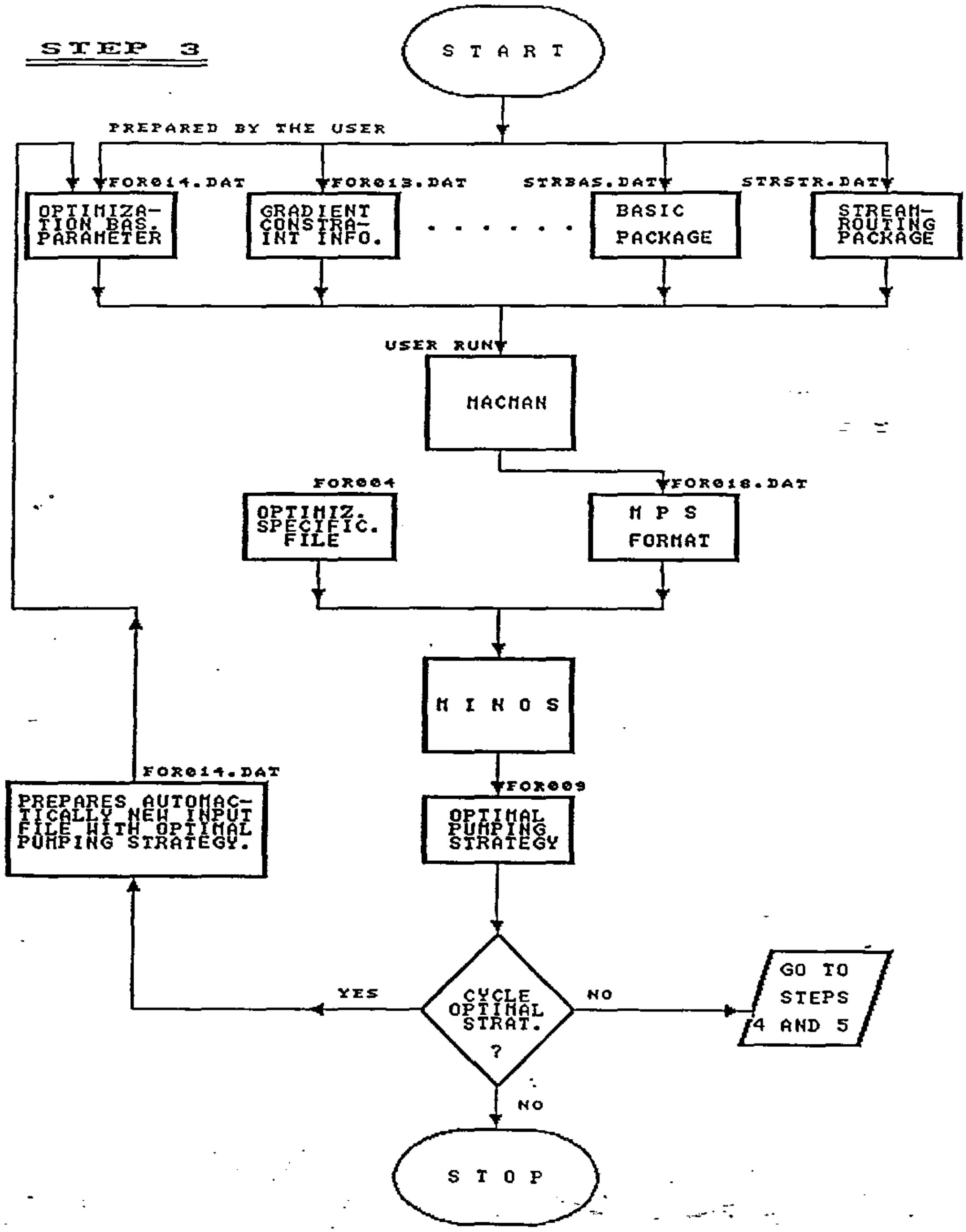


FIGURE 22. Flowchart of Step 3.

It is assumed that recharge wells might be located in up to 29 cells outside of the contaminant plume. Withdrawal wells might be located in up to 6 cells, within the contaminant plume (Fig. 18). Selection of injection well location is based on the direction of the regional groundwater flux and closeness to the head difference constraint cell. The closer the well to the head difference cell, the less withdrawal or recharge will be needed to satisfy the head difference constraint. Load (page 20 of the manual) required input data. Run MACMAN for the entire area to compute the influence coefficients and obtain the optimal contaminant capture pumping strategy. MACMAN input and output files are in appendices E and F, respectively. Here, the Thiem equation is used to adjust cell heads to well heads, for all potential extraction and injection wells .

Fig. 23 shows the locations of well that will pump, and the head difference constraint that will be tight under the optimal strategy. No heads at extraction or injection wells are tight.

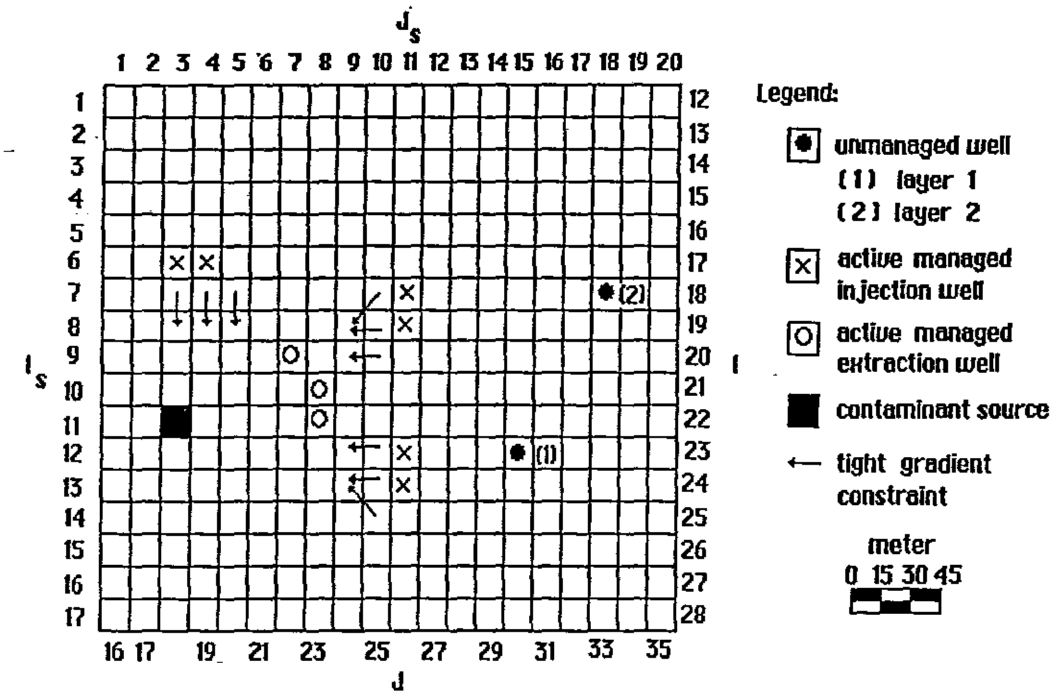


FIGURE 23. Location of Optimal Well Location and Tight Constrained Head Difference Location.

**Calculate Subsystem Potentiometric Surface Area after Resulting from Implementing Optimal Pumping Strategy (Step 4)**

This step involves verifying that the optimal pumping strategy accomplishes its goal (Fig. 24).

Perform transient flow simulation using MODFLOW+STR. Input data files must be created by user, utilizing the optimal pumping strategy generated in the previous step (Fig. 22). The user should edit STRBAS.DAT, STRBCF.DAT, and STRWEL.DAT (Appendix G). Arbitrarily, a period of 6 months was chosen for this transient simulation. Analyzing the resulting potentiometric surface (page H-10), the head difference constraint is achieved around the contaminant plume. Figs. 25 and 26 show the subsystem potentiometric surface contour and three-dimensional maps, respectively. Incidentally, the head difference constraints are all achieved by 180 days after beginning optimal pumping.

**Compute Subsystem Contaminant Concentrations Resulting from Implementing the Optimal Pumping Strategy (Step 5)**

Edit MOC input data file (Appendix I) to include the optimal pumping strategy. Resulting boundary heads and fluxes generated by MODFLOW+STR in Step 4, are used to semiautomatically build MOC input data file.

Perform transient flow and transport simulation using MOC. Fig. 27 illustrates a three-dimensional concentration map for the subsystem.

Based on Appendix J and Fig. 26, the contaminant plume is captured. Note that the well numbers in Fig. 26 do not correspond to these in the data or output files. For example, well number 3 in Fig. 26 is well number 1 (card image 1, column value Q011001 in page F-11). (Recall that extraction wells are placed first in the input data file). Hydraulic heads resulting from Steps 4 and 5 are similar, demonstrating that both models are computing heads properly (compare pages H-11 and J-4).

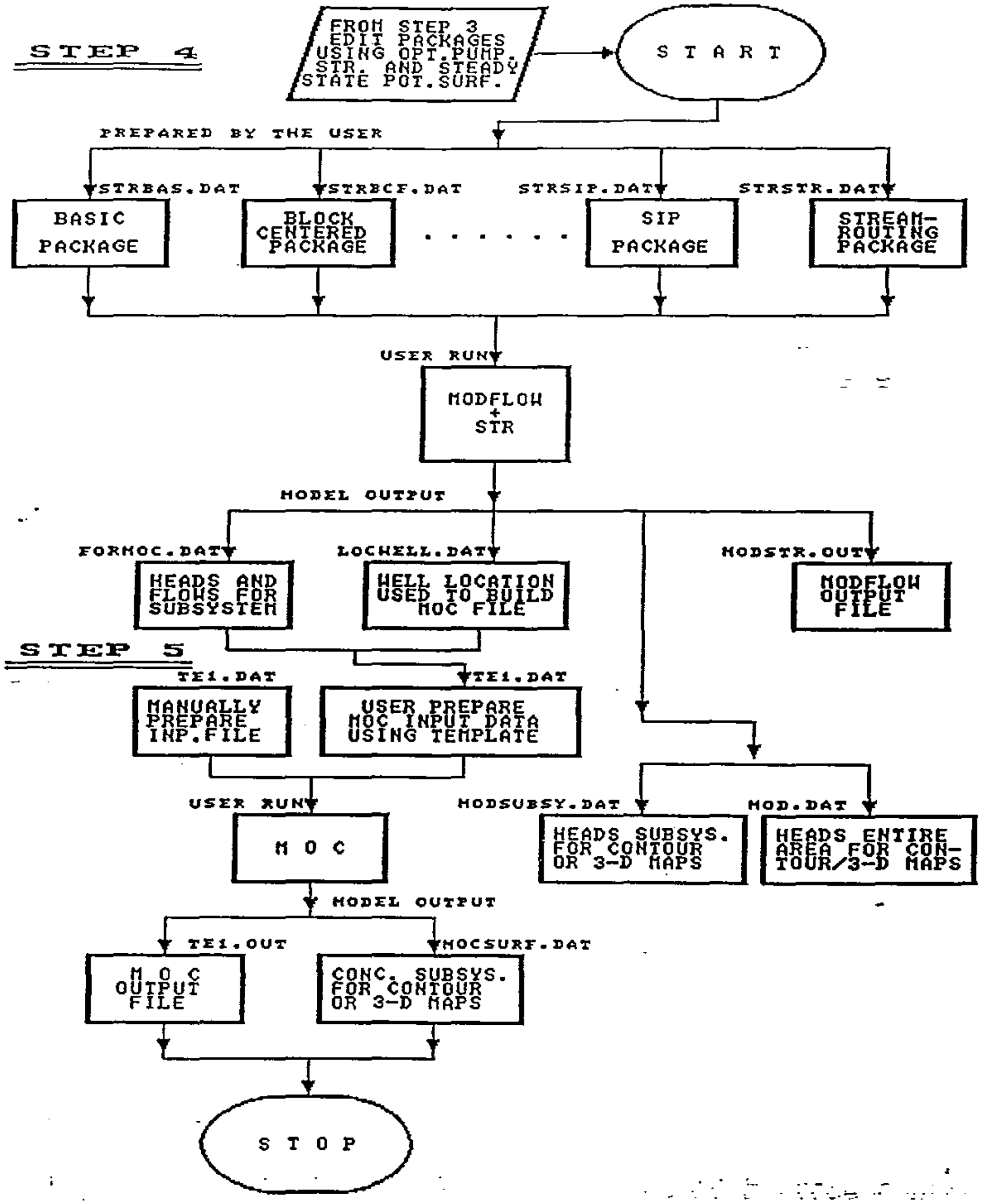


FIGURE 24. Flowchart of Steps 4 and 5.

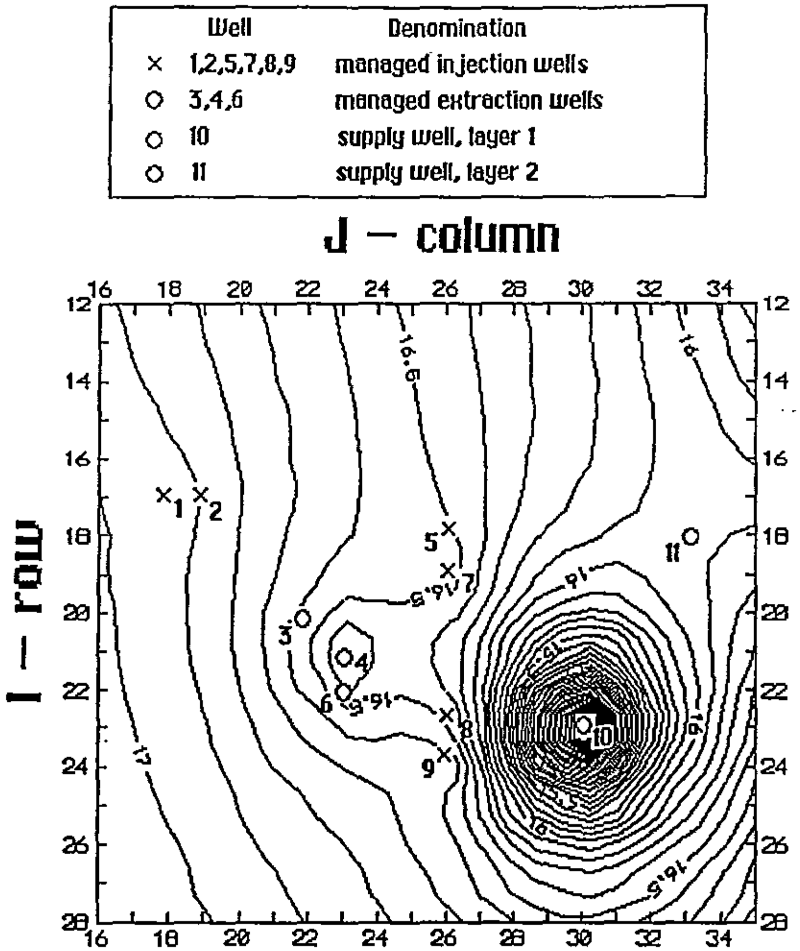


FIGURE 25. Potentiometric Surface Contour Map for the Subsystem Using Optimal Pumping Strategy (m above MSL). I and J are Row and Column of the Entire Study Area.

**Time Needed to Run the Models**

Table 1 shows the time required to run each part of DEMO1_A sample problem on a micro-computer 386/33 Mhz, IBM compatible 4 Mbyte RAM memory.

TABLE 1. Time Required to Run each Part of DEMO1_A.

| Step | Software used | Time (min) |
|---|---|---|
| 1 | MODFLOW+STR(compute nonoptimal head) ...... | 5.0 |
| 2 | MOC (predict solute transport in a non-optimal potent. surface) ............. | 35.0 |
| 3 | MACMAN (compute influence coefficients, formulate management model and determine optimal pumping strategy) ........ | 150.0 |
| 4 | MODFLOW+STR (compute transient head response to optimal pumping) ............ | 1.3 |
| 5 | MOC (compute head and solute transport response to optimal pumping) .... ..... | 8.0 |

| Well | lps | gpm | Well | lps | gpm |
|---|---|---|---|---|---|
| 1 | 1.36 | 21.56 | 6 | −3.09 | −49.02 |
| 2 | 0.62 | 9.89 | 7 | 5.02 | 79.58 |
| 3 | −0.60 | −9.49 | 8 | 4.46 | 70.67 |
| 4 | −9.69 | −153.55 | 9 | 7.88 | 124.96 |
| 5 | 0.85 | 13.46 | 10 | −100.00 | −1584.82 |

(+) recharge (−) withdrawal

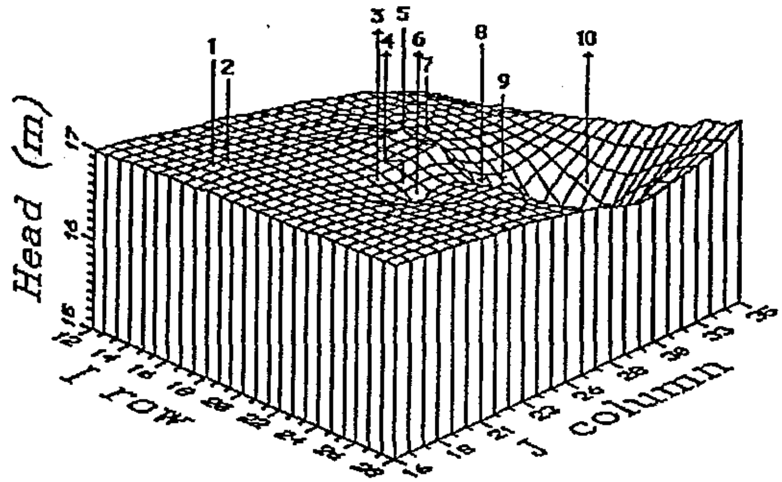


FIGURE 26. Potentiometric Surface Resulting in the Subsystem after Implementing the Optimal Pumping Strategy for 6 Months (m above MSL). I and J are Row and Column of the Entire Study Area.

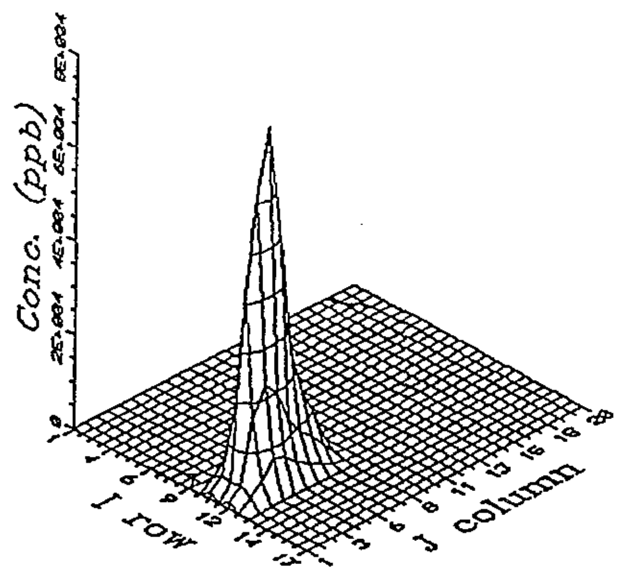


FIGURE 27. Contaminant Conc. Resulting in the Subsystem after Implementing the Optimal Pumping Strategy for 6 Months (m above MSL).

**Results**

Well numbering in the output of Appendix F corresponds to the order in which managed wells are written in the input data in Appendix E. The optimal pumping strategy can be found in the column section of MINOS output (page F-11). For example, pumping well number one will extract at a rate of 0.000599 $m^3/s$; pumping well number three at a rate of 0.0096886 $m^3/s$, and so on. Those values are computed by multiplying the activity value by the object gradient value.

The head difference constraint information is found in the row section of MINOS output (pages F-8 to F-10). The head difference is tight in nine pairs of cells: cell pairs one, two, three, eight, nine, 10, 13, 14, and 15. These heads are shown on page H-11, in which heads of tight head difference constraint cell pairs are shown in **bold**.

Hydraulic heads of head difference constrained cells are written in **bold** in page H-10. For example, to check the accomplishment of the head difference constraint, consider the pair of cells (7,3) and (8,3) (Fig. 18). The constraint restricting the head difference, between these two cells is tight. Hydraulic heads of these cells are 16.937 m and 16.928 m, respectively , showing an inward head difference toward the contaminant source cell (11,3) of 0.01 m. All other head difference control cell pairs show a gradient toward the plume, thus capturing it.

The optimal pumping strategy includes 3 extraction and 6 injection wells. The total amount of extraction and injection are 0.01338 and 0.02020 $m^3/s$ or 212.05 and 320.13 gpm, respectively.

DEMO1_B optimal pumping shows an increase of about 1.4 percent, compared to the results of DEMO1_A. The optimal pumping strategy includes 2 extraction and 6 injection wells. The total amount of extraction, that is equal to the total amount of injection, is 0.0170 $m^3/s$ or 269.74 gpm.

**Sample Problem DEMO2**

Fig. 28 shows the head difference and potential location of injection and extraction wells. Compared to the previous sample problem, 3 new potential extraction well locations were added to the second layer, i.e. at cells (19,25), (20,25), and (21,25).

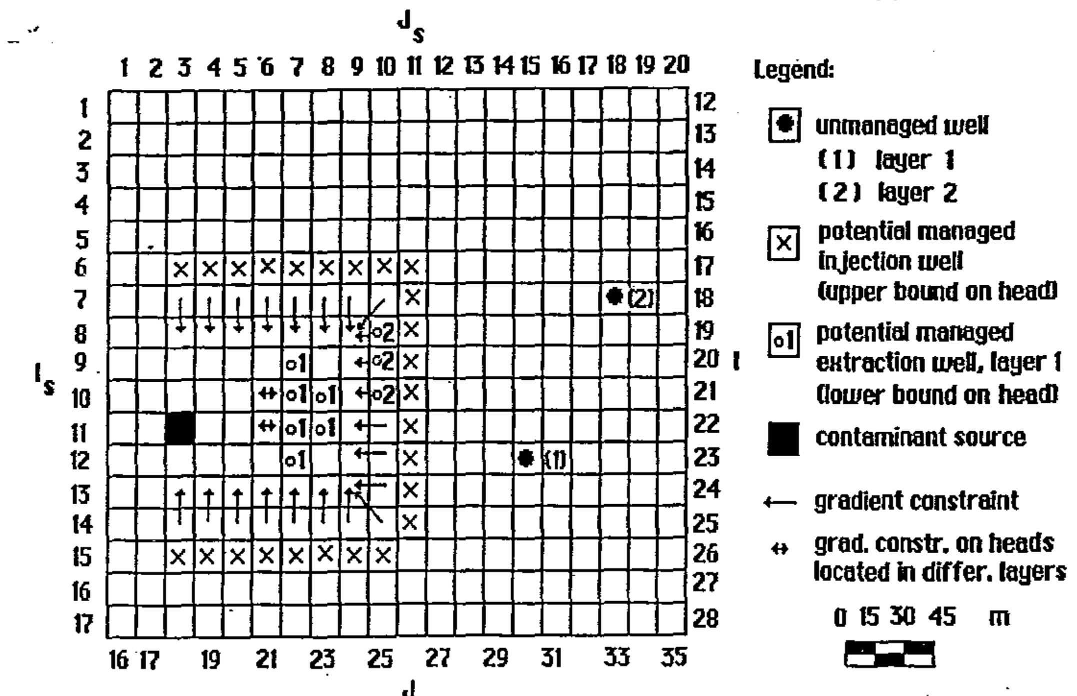


FIGURE 28. Head Difference and Potential Well Locations.

Also added were 2 head difference constraint locations, constraining flow between the two layers (cells 21,21 and 22,21). This constraint on heads allows the user to maintain the upward flow from the lower to upper layer. This will prevent contamination of the lower layer, in those cells.

**Problem Formulation**

The objective is two fold: (1) to maximize the amount of drinking water that can be extracted, without reversing the flow to a downward direction at the control locations; (2) to minimize extraction and injection in the top layer, needed to capture the contaminant plume. Objective function

$$\text{Minimize} \sum_{\bar{e}=1}^{M^{\bar{e}}} (g_{\bar{e}} + b_{\bar{e}})_{1^{st}layer} - (g_{\bar{e}})_{2^{nd}layer}$$

Head difference constraint (heads located on the same or different layer)

$$\Delta h_{\bar{o}_{1,2}} \leq 0.01 \qquad \text{for } \bar{o}_{1,2} = 1..22$$

Hydraulic head constraint at well in center of withdrawal cell

$$h_{\hat{e}} \geq 15.0 \qquad \text{for } \hat{e} = 1..6$$

Hydraulic head constraint at well in center of recharge cell

$$h_{\hat{e}} \leq 25.0 \qquad \text{for } \hat{e} = 1..25$$

**Results**

Fig. 29 shows the optimal injection and extraction wells, and tight head difference constraint locations. The optimal pumping strategy includes, 7 extraction and 14 injections wells. The total amount of extraction and injection are 0.00629 and 0.03786 $m^3/s$ or 99.68 and 600.01 gpm, respectively. Most of the cells near the plume, in which the head difference between layers are not controlled, show downward flow. This illustrates the importance of controlling heads located in different layers.

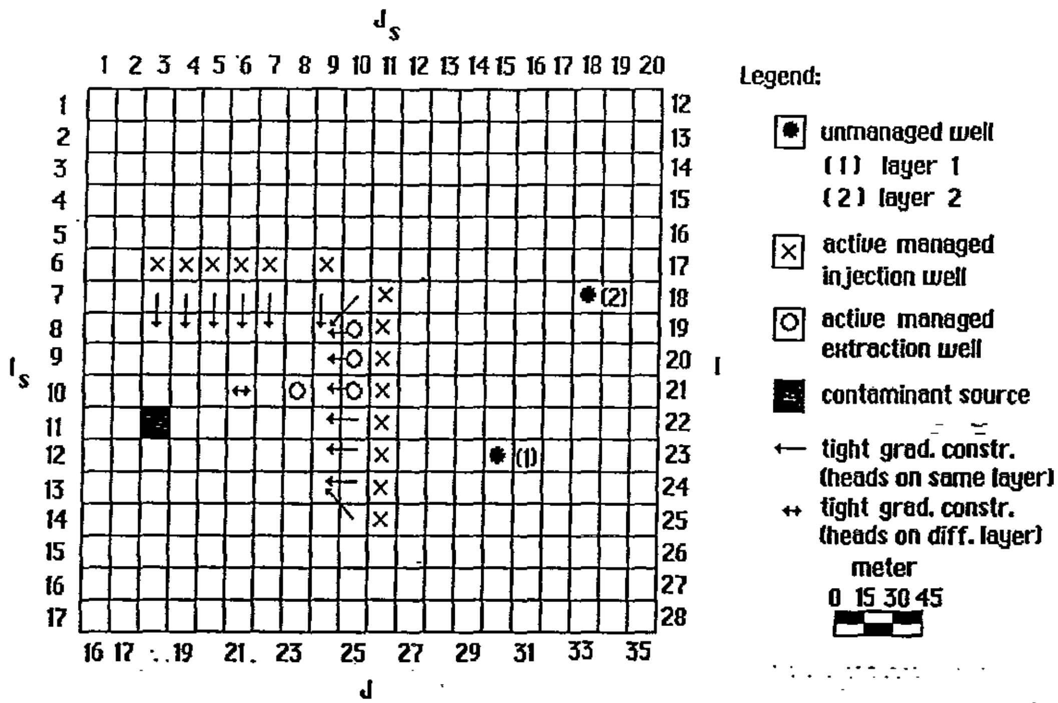


FIGURE 29. Optimal Well and Tight Head Difference Locations.

**Sample Problem DEMO3**

Two stream stage constraints were added to the scenario of sample problem DEMO2, on cells (22,39), and (23,39). All the head difference constraints, injection and extraction potential well locations are the same as sample problem DEMO2 (Fig. 28).

**Problem Formulation**

The objective function is identical to the sample problem DEMO2.

Objective function

$$\text{Minimize} \sum_{\bar{e}=1}^{M^{\bar{e}}} (g_{\bar{e}} + b_{\bar{e}})_{1^{st}layer} - (g_{\bar{e}})_{2^{nd}layer}$$

Head difference constraint (heads located on the same or different layer)

$$\Delta h_{\bar{o}_{1,2}} \leq 0.01 \qquad \text{for } \bar{o}_{1,2} = 1..22$$

Hydraulic head constraint at cell in center of withdrawal cell

$$h_{\hat{e}} \geq 15.0 \qquad \text{for } \hat{e} = 1 .. 6$$

Hydraulic head constraint at well in center of recharge cell

$$h_{\hat{e}} \leq 25.0 \qquad \text{for } \hat{e} = 1 .. 25$$

Stream stage constraint

$$h_{\bar{e}} \geq 16.5748 \qquad \text{for } \bar{e}\ (22,39)$$

$$h_{\bar{e}} \geq 16.6747 \qquad \text{for } \bar{e}\ (23,39)$$

**Results**

Fig. 30 shows the optimal extraction well, and tight head difference constraint locations. Stream stage on cell (23,39) is also tight constraint. The optimal pumping includes 2 extraction and 13 injections wells. The amount of extraction and injection are 0.04093 and 0.08131 $m^3/s$, or 648.67 and 1288.62 gpm, respectively.

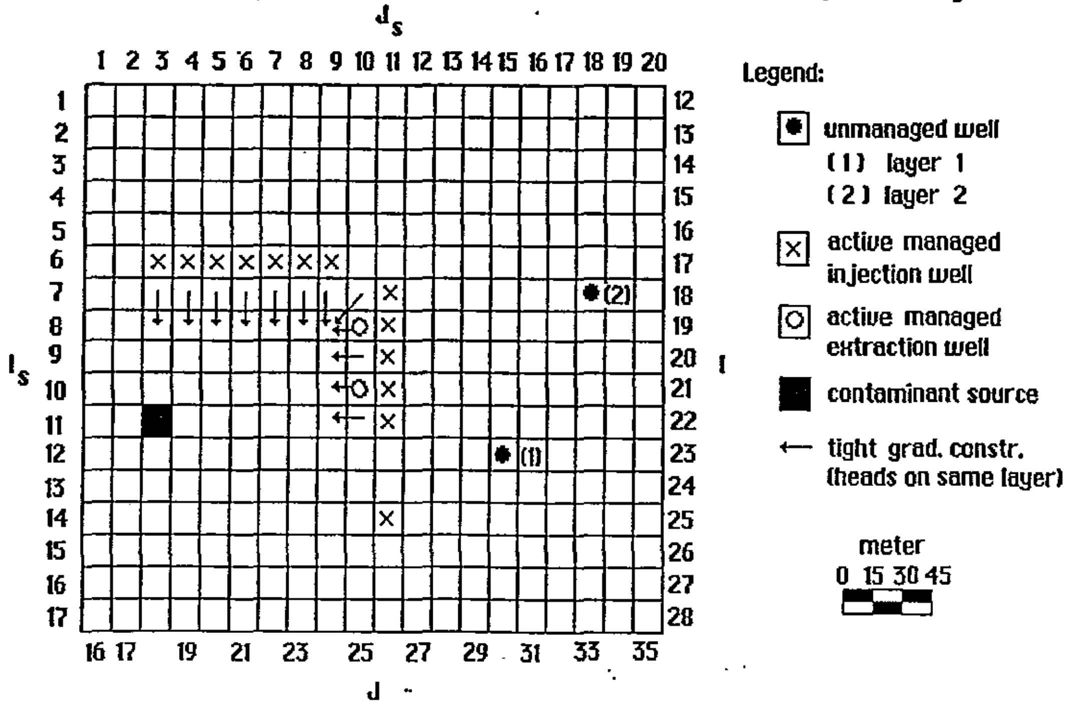


FIGURE 30. Optimal Well and Tight Head Difference Locations.

## Summary of the Results

Table 2 shows a summary of the three sample problems. Comparing the results of the three scenarios, an increase in constraints is followed by an increase in the total pumping amount.

Adding a pumping constraint on sample problem DEMO1_A, (forcing total extraction to equal total injection), increased the total pumping by 1.4 percent. The total number of optimal well locations decreased, from 9 to 8 wells.

The DEMO2 problem differs from DEMO1_A by maximizing extraction on lower layer, while minimizing extraction and injection on upper layer, and adding a head difference constraint on heads located in different layers. This increased total pumping by about 31.5 percent compared to DEMO1_A.

The DEMO3 problem is found by considering the same objective function as DEMO_2 and adding a stream stage constraint. Because stream stage was forced to rise, injection was increased. Total pumping increased by 176.9 percent compared to DEMO2.

Table 3 shows the number of managed wells for each scenario. An increase in the total pumping does not always mean an increase in the total number of wells. In DEMO1_B, compared to DEMO1_A, there is an increase of about 1.4 percent in the total pumping, but the number of wells decreased by one. In DEMO3, compared to DEMO2,

TABLE 2. Pumping Results for the Sample Problems.

| Scenario | Constraints | g(extr.) | | b(inj.) | (g+b) total |
|---|---|---|---|---|---|
| | | 1st layer | 2nd layer | | $m^3/s$ (gpm) |
| DEMO1_A | Head difference constraints on heads within the same layer, head constraint at injections and extraction wells. | .01338 | --- | 02020 | .03358 |
| | | (212.05) | --- | (320.13) | (532.18) |
| DEMO1_B | Added pumping constraint: total extraction = total injection. | .01702 | --- | .01702 | .03404 |
| | | (269.74) | --- | (269.74) | (539.48) |
| DEMO2 | Head difference constraint on heads within the same and different layers, head constraint at injec. and extrac. wells. | .00300 | .00329 | .03786 | .04415 |
| | | (47.54) | (52.14) | (600.03) | (699.69) |
| DEMO3 | Head difference constraint on heads within the same and different layers, head constraint on injection and extraction wells, stream stage constraint. | --- | .04093 | .08131 | .12224 |
| | | --- | (648.67) | (1288.62) | (1937.29) |

TABLE 3. Number of Optimal Pumping Wells for the Sample Problems.

| Scenario | g(extr.) | | b(inj.) | (g+b) total |
|---|---|---|---|---|
| | 1[st] layer | 2[nd] layer | | |
| DEMO1_A | 3 | --- | 6 | 9 |
| DEMO1_B | 2 | --- | 6 | 8 |
| DEMO2 | 4 | 3 | 14 | 21 |
| DEMO3 | --- | 2 | 13 | 15 |

there is an increase of about 176.9 percent in the total pumping, but the total number of wells decreased by six.

Table 4 shows stream flow and stage at control cells (23,39), and (22,39), for the three sample problems. Both cells are losing reaches, i.e. the river is supplying water to the aquifer. The units are given in m and $m^3/s$ for stage and flow in the stream reach, respectively.

In DEMO3 we show how to inject water to raise stream stage at a nearby location, so that water can be diverted or pumped from the river at that point. Table 4 shows how, in that scenario, pumping affects river flow into cells (23,39). Note that streamflow at the cell is 0.012 $m^3/s$ greater than in the nonoptimal scenario. This exceeds inflow rates in the other scenarios. This was achievable only by injecting water. The model showed how to minimize the amount of injection necessary.

TABLE 4. Stream Flow and Stage at Control Locations.

| Scenario | Cell (23,39) | | | | Cell (22,39) | | | |
|---|---|---|---|---|---|---|---|---|
| | Head (m) | Flow into cell ($m^3/s$) | Flow from cell ($m^3/s$) | Flow into aquifer ($m^3/s$) | Head (m) | Flow into cell ($m^3/s$) | Flow from cell ($m^3/s$) | Flow into aquifer ($m^3/s$) |
| Nonoptimal | 16.67 | .706 | .699 | .00697 | 16.57 | .699 | .693 | .00607 |
| Demo1_A | 16.67 | .708 | .701 | .00688 | 16.57 | .701 | .695 | .00597 |
| Demo1_B | 16.67 | .706 | .699 | .00694 | 16.57 | .699 | .693 | .00603 |
| Demo2 | 16.67 | .713 | .707 | .00667 | 16.57 | .707 | .701 | .00576 |
| Demo3 | 16.68 | .718 | .711 | .00652 | 16.58 | .711 | .706 | .00563 |

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## APPENDICES

(A-J are from sample problem DEMO1;
K-M are general guidelines; and
N is Fortran compiler error messages)

# APPENDIX A

## MODFLOW+STR input data files for total area.

Input data STRBAS.DAT

```
Scen. 8.1,meandering river with diversion,smaller grid sys. Nov. 29, 1991.
-- steady state, constant head, rech.two layers, stream stage,lower lake level
        2          39          58          1          1
  7  4                     8 13        14 15
        0          1
        1          1 (58I3)                       -1
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
-1  0  0  0  0  0  0  0  0  0  0  0  0 -1 -1 -1 -1  0  0  0  0  0  0  0
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  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  0  0  0  0  0  0 -1 -1  1  1  1  1  1  0  0  0  0  0  0
  0 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  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  0  0  0
  0  0 -1 -1 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
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
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                               ibeg,jbeg,iend,jend,imult
                               variables for sub-system.
```

Input data STRBCF.DAT

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        7 5.208E-04  (58F5.0)               -1  hy.cond. - layer 1
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10.  10.  10.  10.  10.  10.  10.  10. .666 .666 .666 .666 .666 .666 .666   1.   1.
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10.  10.  10.  10.  10.  10.  10.  10.  10. .666 .666 .666 .666 .666 .666   1.   1.
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 1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.  10.  10.  10.  10.  10.  10.
10.  10.  10.  10.  10.  10.  10.  10.  10. .666 .666 .666 .666 .666 .666   1.   1.
  1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
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10.  10.  10.  10.  10.  10.  10.  10.  10. .666 .666 .666 .666 .666 .666   1.   1.
  1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
 1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.  10.  10.  10.  10.  10.
10.  10.  10.  10.  10.  10.  10.  10.  10. .666 .666 .666 .666 .666 .666   1.   1.
  1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
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10.  10.  10.  10.  10.  10.  10.  10.  10. .666 .666 .666 .666 .666 .666   1.   1.
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10.  10.  10.  10.  10.  10.  10.  10.  10. .666 .666 .666 .666 .666 .666   1.   1.
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 1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.  10.  10.  10.  10.  10.
10.  10.  10.  10.  10.  10.  10.  10.  10. .666 .666 .666 .666 .666 .666   1.   1.
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10.  10.  10.  10.  10.  10.  10.  10.  10. .666 .666 .666 .666 .666 .666   1.   1.
  1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
 1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.  10.  10.  10.  10.  10.
10.  10.  10.  10.  10.  10.  10.  10.  10. .666 .666 .666 .666 .666 .666   1.   1.
  1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
 1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.  10.  10.  10.  10.  10.
10.  10.  10.  10.  10.  10.  10.  10.  10. .666 .666 .666 .666 .666 .666   1.   1.
         0       0.0                                  bottom layer 1
         0  5.00E-06                                  vert.hy.cond/thick layer 1
         0   0.15624                                  trans. - layer 2
```

Input data STROC.DAT

```
      12          12          0          0
       0           1          1          1      time step 1   S.P. 1
       1           0          0          0
```

Input data STRRCH.DAT

```
             1         0
             1
             8 1.176E-08 (58F5.0)                    -1
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1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1
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1    1    1    1    1    1    1    1    1    11.6521.6521.6521.6521.6521.652    1    1
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1    1    1    1    1    1    1    1    1    11.6521.6521.6521.6521.6521.652    1    1
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1    1    1    1    1    1    1    1    1    11.6521.6521.6521.6521.6521.652    1    1
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1    1    1    1    1    1    1    1    1    11.6521.6521.6521.6521.6521.652    1    1
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```

```
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```

Input data STRSTR.DAT

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 41 | | 3 | | 1 | 1 | 1 | 1.000 | -1 | 0 |
| | 41 | | 0 | | 0 | | | | | |
| 1 | 39 | 40 | 1 | 1 | | 1.14 | 19.5 | 1.00 | 17.5 | 18.0 |
| 1 | 38 | 40 | 1 | 2 | | | 19.4 | 1.00 | 17.4 | 17.9 |
| 1 | 37 | 41 | 1 | 3 | | | 19.3 | 1.00 | 17.3 | 17.8 |
| 1 | 36 | 42 | 1 | 4 | | | 19.2 | 1.00 | 17.2 | 17.7 |
| 1 | 35 | 43 | 1 | 5 | | | 19.1 | 1.00 | 17.1 | 17.6 |
| 1 | 34 | 43 | 1 | 6 | | | 19.0 | 1.00 | 17.0 | 17.5 |
| 1 | 33 | 43 | 1 | 7 | | | 18.9 | 1.00 | 16.9 | 17.4 |
| 1 | 32 | 43 | 1 | 8 | | | 18.8 | 1.00 | 16.8 | 17.3 |
| 1 | 31 | 42 | 1 | 9 | | | 18.7 | 1.00 | 16.7 | 17.2 |
| 1 | 30 | 41 | 1 | 10 | | | 18.6 | 1.00 | 16.6 | 17.1 |
| 1 | 29 | 40 | 1 | 11 | | | 18.5 | 1.00 | 16.5 | 17.0 |
| 1 | 28 | 39 | 1 | 12 | | | 18.4 | 1.00 | 16.4 | 16.9 |
| 1 | 27 | 39 | 1 | 13 | | | 18.3 | 1.00 | 16.3 | 16.8 |
| 1 | 26 | 39 | 1 | 14 | | | 18.2 | 1.00 | 16.2 | 16.7 |
| 1 | 25 | 39 | 1 | 15 | | | 18.1 | 1.00 | 16.1 | 16.6 |
| 1 | 24 | 39 | 1 | 16 | | | 18.0 | 1.00 | 16.0 | 16.5 |
| 1 | 23 | 39 | 1 | 17 | | | 17.9 | 1.00 | 15.9 | 16.4 |
| 1 | 22 | 39 | 1 | 18 | | | 17.8 | 1.00 | 15.8 | 16.3 |
| 1 | 21 | 39 | 1 | 19 | | | 17.7 | 1.00 | 15.7 | 16.2 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 20 | 39 | 1 | 20 | | 17.6 | 1.00 | 15.6 | 16.1 |
| 1 | 19 | 39 | 1 | 21 | | 17.5 | 1.00 | 15.5 | 16.0 |
| 1 | 18 | 40 | 1 | 22 | | 17.4 | 1.00 | 15.4 | 15.9 |
| 1 | 17 | 41 | 1 | 23 | | 17.3 | 1.00 | 15.3 | 15.8 |
| 1 | 16 | 42 | 1 | 24 | | 17.2 | 1.00 | 15.2 | 15.7 |
| 1 | 15 | 43 | 1 | 25 | | 17.1 | 1.00 | 15.1 | 15.6 |
| 1 | 14 | 43 | 1 | 26 | | 17.0 | 1.00 | 15.0 | 15.5 |
| 1 | 13 | 43 | 1 | 27 | | 16.9 | 1.00 | 14.9 | 15.4 |
| 1 | 12 | 43 | 1 | 28 | | 16.8 | 1.00 | 14.8 | 15.3 |
| 1 | 11 | 40 | 1 | 29 | | 16.7 | 1.00 | 14.7 | 15.2 |
| 1 | 10 | 40 | 1 | 30 | | 16.6 | 1.00 | 14.6 | 15.1 |
| 1 | 10 | 40 | 2 | 1 | 0.20 | 16.6 | 1.00 | 14.6 | 15.1 |
| 1 | 10 | 41 | 2 | 2 | | 16.5 | 1.00 | 14.5 | 15.0 |
| 1 | 10 | 42 | 2 | 3 | | 16.4 | 1.00 | 14.4 | 14.9 |
| 1 | 10 | 43 | 2 | 4 | | 16.3 | 1.00 | 14.3 | 14.8 |
| 1 | 10 | 40 | 3 | 1 | -1.0 | 16.6 | 1.00 | 14.6 | 15.1 |
| 1 | 9 | 40 | 3 | 2 | | 16.5 | 1.00 | 14.5 | 15.0 |
| 1 | 8 | 40 | 3 | 3 | | 16.4 | 1.00 | 14.4 | 14.9 |
| 1 | 7 | 41 | 3 | 4 | | 16.3 | 1.00 | 14.3 | 14.8 |
| 1 | 6 | 42 | 3 | 5 | | 16.2 | 1.00 | 14.2 | 14.7 |
| 1 | 5 | 42 | 3 | 6 | | 16.1 | 1.00 | 14.1 | 14.6 |
| 1 | 4 | 42 | 3 | 7 | | 16.0 | 1.00 | 14.0 | 14.5 |

| | | |
|---|---|---|
| 3. | 0.007 | 0.030 |
| 3. | 0.007 | 0.030 |
| 3. | 0.002 | 0.022 |
| 3. | 0.002 | 0.022 |
| 3. | 0.002 | 0.022 |
| 3. | 0.004 | 0.030 |
| 3. | 0.005 | 0.030 |
| 3. | 0.005 | 0.030 |
| 3. | 0.005 | 0.030 |
| 3. | 0.005 | 0.025 |
| 3. | 0.005 | 0.022 |
| 3. | 0.005 | 0.020 |
| 3. | 0.006 | 0.025 |
| 3. | 0.007 | 0.030 |
| 3. | 0.007 | 0.030 |
| 3. | 0.002 | 0.022 |
| 3. | 0.002 | 0.022 |
| 3. | 0.002 | 0.022 |
| 3. | 0.004 | 0.030 |
| 3. | 0.005 | 0.030 |
| 3. | 0.005 | 0.030 |
| 3. | 0.005 | 0.030 |
| 3. | 0.005 | 0.025 |
| 3. | 0.005 | 0.022 |
| 3. | 0.005 | 0.020 |
| 3. | 0.006 | 0.025 |
| 3. | 0.007 | 0.030 |
| 3. | 0.007 | 0.030 |
| 3. | 0.002 | 0.022 |
| 3. | 0.002 | 0.022 |
| 3. | 0.002 | 0.022 |
| 3. | 0.004 | 0.030 |
| 3. | 0.005 | 0.030 |
| 3. | 0.005 | 0.030 |
| 3. | 0.005 | 0.030 |
| 3. | 0.005 | 0.025 |
| 3. | 0.005 | 0.022 |
| 3. | 0.005 | 0.020 |
| 3. | 0.006 | 0.025 |
| 3. | 0.007 | 0.030 |
| 3. | 0.007 | 0.030 |

| | | |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 0 | 0 |
| 1 | 0 | 0 |
| | 0 | |
| | 1 | |
| | 0 | |

Input data STRWEL.DAT

| | | | |
|---|---|---|---|
| 4 | 0 | | |
| 4 | | | |
| 1 | 15 | 51 | -0.11 |
| 2 | 18 | 33 | -0.12 |
| 1 | 23 | 30 | -0.10 |
| 1 | 22 | 181.53e-05 | |

Input data STRSIP.DAT

| | | | | |
|---|---|---|---|---|
| 790 | 5 | | | |
| 0.1 | 1.0E-03 | 1 | 0 | 0 |

# APPENDIX B

MODFLOW+STR output data for the subsystem.

```
------ Hydraulic heads in meter ------
     0. 16.888 16.839 16.789 16.738 16.687 16.636 16.584 16.532 16.479 16.426 16.372 16.317 16.261
16.204 16.143 16.077 15.999 15.903      0.
     0. 16.904 16.854 16.804 16.753 16.701 16.649 16.596 16.542 16.487 16.431 16.375 16.319 16.263
16.207 16.150 16.090 16.024 15.945      0.
     0. 16.918 16.869 16.818 16.767 16.714 16.661 16.606 16.549 16.492 16.433 16.374 16.315 16.257
16.202 16.149 16.098 16.045 15.985      0.
     0. 16.932 16.883 16.832 16.780 16.726 16.671 16.614 16.555 16.493 16.430 16.365 16.301 16.241
16.186 16.138 16.096 16.059 16.023      0.
     0. 16.945 16.896 16.845 16.792 16.738 16.681 16.621 16.558 16.490 16.419 16.346 16.274 16.207
16.151 16.110 16.081 16.063 16.057      0.
     0. 16.957 16.908 16.858 16.805 16.749 16.690 16.626 16.557 16.482 16.399 16.312 16.224 16.144
16.085 16.055 16.048 16.057 16.088      0.
     0. 16.968 16.920 16.870 16.817 16.760 16.699 16.631 16.555 16.468 16.369 16.257 16.140 16.032
15.963 15.956 15.992 16.049 16.121      0.
     0. 16.980 16.933 16.883 16.829 16.772 16.708 16.636 16.552 16.451 16.328 16.178 16.006 15.834
15.727 15.772 15.889 16.019 16.146      0.
     0. 16.991 16.945 16.896 16.842 16.784 16.719 16.643 16.551 16.434 16.281 16.077 15.807 15.487
15.246 15.439 15.720 15.965 16.164      0.
     0. 17.002 16.958 16.909 16.857 16.799 16.733 16.654 16.556 16.427 16.246 15.976 15.558 14.910
14.117 14.875 15.498 15.906 16.187      0.
     0. 17.013 16.970 16.923 16.872 16.816 16.751 16.673 16.574 16.441 16.247 15.939 15.386 14.189
10.453 14.165 15.350 15.905 16.238      0.
     0. 17.024 16.982 16.938 16.889 16.835 16.773 16.699 16.606 16.482 16.307 16.045 15.636 15.000
14.224 14.989 15.621 16.041 16.338      0.
     0. 17.035 16.996 16.954 16.908 16.857 16.800 16.732 16.649 16.543 16.403 16.212 15.959 15.659
15.442 15.657 15.961 16.232 16.464      0.
     0. 17.046 17.009 16.970 16.927 16.881 16.829 16.769 16.699 16.613 16.507 16.378 16.228 16.084
16.009 16.089 16.244 16.418 16.594      0.
     0. 17.056 17.022 16.986 16.947 16.905 16.859 16.807 16.749 16.682 16.604 16.518 16.429 16.356
16.327 16.366 16.456 16.575 16.713      0.

------ Hydraulic heads in feet ------
   0.   55.41   55.25   55.08   54.92   54.75   54.58   54.41   54.24   54.07   53.89   53.72   53.54
53.35   53.16   52.97   52.75   52.49   52.18    0.
   0.   55.46   55.30   55.13   54.97   54.80   54.63   54.45   54.27   54.09   53.91   53.73   53.54
53.36   53.17   52.99   52.79   52.58   52.32    0.
   0.   55.51   55.35   55.18   55.01   54.84   54.66   54.48   54.30   54.11   53.92   53.72   53.53
53.34   53.16   52.99   52.82   52.64   52.45    0.
   0.   55.55   55.39   55.23   55.05   54.88   54.70   54.51   54.32   54.11   53.91   53.69   53.48
53.29   53.11   52.95   52.81   52.69   52.57    0.
   0.   55.60   55.43   55.27   55.10   54.92   54.73   54.53   54.33   54.10   53.87   53.63   53.39
53.18   52.99   52.86   52.76   52.70   52.68    0.
   0.   55.64   55.48   55.31   55.14   54.95   54.76   54.55   54.32   54.08   53.81   53.52   53.23
52.97   52.78   52.68   52.65   52.68   52.79    0.
   0.   55.67   55.52   55.35   55.18   54.99   54.79   54.57   54.32   54.03   53.71   53.34   52.95
52.60   52.37   52.35   52.47   52.66   52.89    0.
   0.   55.71   55.56   55.39   55.22   55.03   54.82   54.58   54.31   53.97   53.57   53.08   52.51
51.95   51.60   51.75   52.13   52.56   52.97    0.
   0.   55.75   55.60   55.43   55.26   55.07   54.85   54.61   54.30   53.92   53.42   52.75   51.86
50.81   50.02   50.66   51.58   52.38   53.04    0.
   0.   55.78   55.64   55.48   55.31   55.12   54.90   54.64   54.32   53.90   53.30   52.42   51.05
48.92   46.32   48.80   50.85   52.19   53.11    0.
   0.   55.82   55.68   55.52   55.36   55.17   54.96   54.70   54.38   53.94   53.31   52.29   50.48
46.55   34.30   46.48   50.36   52.18   53.28    0.
   0.   55.85   55.72   55.57   55.41   55.24   55.03   54.79   54.48   54.08   53.50   52.64   51.30
49.22   46.67   49.18   51.25   52.63   53.60    0.
   0.   55.89   55.76   55.62   55.47   55.31   55.12   54.90   54.63   54.28   53.82   53.19   52.36
51.38   50.67   51.37   52.37   53.26   54.02    0.
   0.   55.93   55.81   55.68   55.54   55.39   55.22   55.02   54.79   54.51   54.16   53.73   53.24
52.77   52.53   52.79   53.30   53.87   54.44    0.
   0.   55.96   55.85   55.73   55.60   55.46   55.31   55.15   54.95   54.73   54.48   54.20   53.90
53.66   53.57   53.70   53.99   54.38   54.83    0.
```

Upward, boundary flows

```
     0.   0.0298-0.0134-0.0131-0.0126-0.0118-0.0108-0.0095-0.0080-0.0063-0.0045-0.0027-0.0012-0.0002
0.0000-0.0007-0.0026-0.0058-0.1143      0.
     0. 0.0446 0.0012 0.0011 0.0011 0.0012 0.0015 0.0018 0.0023 0.0029 0.0036 0.0043 0.0051 0.0059
0.0069 0.0082 0.0104 0.0141-0.0645      0.
     0. 0.0445 0.0014 0.0013 0.0013 0.0015 0.0019 0.0024 0.0031 0.0039 0.0048 0.0057 0.0066 0.0073
0.0077 0.0081 0.0089 0.0109-0.0475      0.
     0. 0.0442 0.0016 0.0015 0.0016 0.0019 0.0024 0.0032 0.0041 0.0053 0.0066 0.0080 0.0092 0.0099
0.0098 0.0088 0.0073 0.0067-0.0272      0.
     0. 0.0438 0.0018 0.0018 0.0019 0.0024 0.0031 0.0041 0.0055 0.0073 0.0094 0.0117 0.0136 0.0147
0.0142 0.0113 0.0059-0.0005-0.0029      0.
     0. 0.0433 0.0020 0.0020 0.0023 0.0029 0.0039 0.0053 0.0074 0.0100 0.0134 0.0172 0.0209 0.0234
0.0229 0.0178 0.0064-0.0183 0.0255      0.
     0. 0.0426 0.0022 0.0022 0.0027 0.0035 0.0048 0.0067 0.0096 0.0135 0.0188 0.0254 0.0325 0.0383
0.0395 0.0332 0.0211 0.0069 0.0657      0.
     0. 0.0417 0.0023 0.0025 0.0030 0.0040 0.0057 0.0082 0.0120 0.0177 0.0257 0.0366 0.0500 0.0634
0.0696 0.0591 0.0410 0.0229 0.1119      0.
     0. 0.0407 0.0024 0.0026 0.0033 0.0045 0.0064 0.0096 0.0144 0.0219 0.0334 0.0506 0.0752 0.1056
0.1276 0.1017 0.0670 0.0376 0.1634      0.
     0. 0.0394 0.0025 0.0028 0.0035 0.0048 0.0070 0.0106 0.0162 0.0254 0.0402 0.0649 0.1064 0.1740
0.2585 0.1702 0.0982 0.0513 0.2113      0.
     0. 0.0380 0.0026 0.0028 0.0035 0.0049 0.0072 0.0109 0.0169 0.0267 0.0433 0.0726 0.1295 0.2590
0.6746 0.2552 0.1208 0.0579 0.2378      0.
     0. 0.0365 0.0026 0.0028 0.0035 0.0048 0.0070 0.0105 0.0162 0.0253 0.0401 0.0647 0.1059 0.1730
0.2566 0.1687 0.0966 0.0489 0.2267      0.
     0. 0.0346 0.0025 0.0027 0.0033 0.0045 0.0064 0.0095 0.0143 0.0218 0.0331 0.0502 0.0745 0.1044
0.1259 0.0999 0.0647 0.0337 0.1938      0.
     0. 0.0326 0.0024 0.0025 0.0030 0.0040 0.0056 0.0081 0.0119 0.0174 0.0253 0.0360 0.0493 0.0623
0.0682 0.0576 0.0391 0.0191 0.1595      0.
     0. 0.0398 0.0138 0.0165 0.0200 0.0247 0.0309 0.0395 0.0514 0.0682 0.0914 0.1218 0.1579 0.1921
0.2084 0.1916 0.1563 0.1177 0.2226      0.
```

# APPENDIX C

## MOC input data file for the subsystem.

```
MOC concentration (steady state, unmanaged heads)    Dec. 2nd, 1991.
  12   1  20  176400   1   7   2 100   2   9   0   0   1   0   0   0
  2.0 .001  0.3  10.  0.0  0.0  0.0  50.  50.  0.3  0.5   1.
17 9
19 9
1512  3.5310                (+):extraction;  (-):injection
 311-.000541 583000.
1.005606412              Trans. Factor=5.208e-04*10.765 (m/s*ft^2/m^2) FORMAT(20G7.3)
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
  0.     0.     0.     0.     0.     0.
     0. 16.888 16.839 16.789 16.738 16.687 16.636 16.584 16.532 16.479 16.426 16.372 16.317 16.261
16.204 16.143 16.077 15.999 15.903     0.
     0. 16.904 16.854 16.804 16.753 16.701 16.649 16.596 16.542 16.487 16.431 16.375 16.319 16.263
16.207 16.150 16.090 16.024 15.945     0.
     0. 16.918 16.869 16.818 16.767 16.714 16.661 16.606 16.549 16.492 16.433 16.374 16.315 16.257
16.202 16.149 16.098 16.045 15.985     0.
     0. 16.932 16.883 16.832 16.780 16.726 16.671 16.614 16.555 16.493 16.430 16.365 16.301 16.241
16.186 16.138 16.096 16.059 16.023     0.
     0. 16.945 16.896 16.845 16.792 16.738 16.681 16.621 16.558 16.490 16.419 16.346 16.274 16.207
16.151 16.110 16.081 16.063 16.057     0.
     0. 16.957 16.908 16.858 16.805 16.749 16.690 16.626 16.557 16.482 16.399 16.312 16.224 16.144
16.085 16.055 16.048 16.057 16.088     0.
     0. 16.968 16.920 16.870 16.817 16.760 16.699 16.631 16.555 16.468 16.369 16.257 16.140 16.032
15.963 15.956 15.992 16.049 16.121     0.
     0. 16.980 16.933 16.883 16.829 16.772 16.708 16.636 16.552 16.451 16.328 16.178 16.006 15.834
15.727 15.772 15.889 16.019 16.146     0.
     0. 16.991 16.945 16.896 16.842 16.784 16.719 16.643 16.551 16.434 16.281 16.077 15.807 15.487
15.246 15.439 15.720 15.965 16.164     0.
     0. 17.002 16.958 16.909 16.857 16.799 16.733 16.654 16.556 16.427 16.246 15.976 15.558 14.910
14.117 14.875 15.498 15.906 16.187     0.
     0. 17.013 16.970 16.923 16.872 16.816 16.751 16.673 16.574 16.441 16.247 15.939 15.386 14.189
10.453 14.165 15.350 15.905 16.238     0.
     0. 17.024 16.982 16.938 16.889 16.835 16.773 16.699 16.606 16.482 16.307 16.045 15.636 15.000
14.224 14.989 15.621 16.041 16.338     0.
     0. 17.035 16.996 16.954 16.908 16.857 16.800 16.732 16.649 16.543 16.403 16.212 15.959 15.659
15.442 15.657 15.961 16.232 16.464     0.
     0. 17.046 17.009 16.970 16.927 16.881 16.829 16.769 16.699 16.613 16.507 16.378 16.228 16.084
16.009 16.089 16.244 16.418 16.594     0.
     0. 17.056 17.022 16.986 16.947 16.905 16.859 16.807 16.749 16.682 16.604 16.518 16.429 16.356
16.327 16.366 16.456 16.575 16.713     0.
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
  0.     0.     0.     0.     0.     0.
1     3.281           Thickness values  factor=3.281 ft/m. Format (20g7.3)
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
  0.     0.     0.     0.     0.     0.
     0. 16.888 16.839 16.789 16.738 16.687 16.636 16.584 16.532 16.479 16.426 16.372 16.317 16.261
16.204 16.143 16.077 15.999 15.903     0.
     0. 16.904 16.854 16.804 16.753 16.701 16.649 16.596 16.542 16.487 16.431 16.375 16.319 16.263
16.207 16.150 16.090 16.024 15.945     0.
     0. 16.918 16.869 16.818 16.767 16.714 16.661 16.606 16.549 16.492 16.433 16.374 16.315 16.257
16.202 16.149 16.098 16.045 15.985     0.
     0. 16.932 16.883 16.832 16.780 16.726 16.671 16.614 16.555 16.493 16.430 16.365 16.301 16.241
16.186 16.138 16.096 16.059 16.023     0.
     0. 16.945 16.896 16.845 16.792 16.738 16.681 16.621 16.558 16.490 16.419 16.346 16.274 16.207
16.151 16.110 16.081 16.063 16.057     0.
     0. 16.957 16.908 16.858 16.805 16.749 16.690 16.626 16.557 16.482 16.399 16.312 16.224 16.144
16.085 16.055 16.048 16.057 16.088     0.
     0. 16.968 16.920 16.870 16.817 16.760 16.699 16.631 16.555 16.468 16.369 16.257 16.140 16.032
15.963 15.956 15.992 16.049 16.121     0.
     0. 16.980 16.933 16.883 16.829 16.772 16.708 16.636 16.552 16.451 16.328 16.178 16.006 15.834
```

```
15.727 15.772 15.889 16.019 16.146      0.
     0. 16.991 16.945 16.896 16.842 16.784 16.719 16.643 16.551 16.434 16.281 16.077 15.807 15.487
15.246 15.439 15.720 15.965 16.164      0.
     0. 17.002 16.958 16.909 16.857 16.799 16.733 16.654 16.556 16.427 16.246 15.976 15.558 14.910
14.117 14.875 15.498 15.906 16.187      0.
     0. 17.013 16.970 16.923 16.872 16.816 16.751 16.673 16.574 16.441 16.247 15.939 15.386 14.189
10.453 14.165 15.350 15.905 16.238      0.
     0. 17.024 16.982 16.938 16.889 16.835 16.773 16.699 16.606 16.482 16.307 16.045 15.636 15.000
14.224 14.989 15.621 16.041 16.338      0.
     0. 17.035 16.996 16.954 16.908 16.857 16.800 16.732 16.649 16.543 16.403 16.212 15.959 15.659
15.442 15.657 15.961 16.232 16.464      0.
     0. 17.046 17.009 16.970 16.927 16.881 16.829 16.769 16.699 16.613 16.507 16.378 16.228 16.084
16.009 16.089 16.244 16.418 16.594      0.
     0. 17.056 17.022 16.986 16.947 16.905 16.859 16.807 16.749 16.682 16.604 16.518 16.429 16.356
16.327 16.366 16.456 16.575 16.713      0.
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
     0.     0.     0.     0.     0.     0.
1-1.412e-04          Recharge Factor=35.31/2500*e-02 (ft^3/m^3/ft^2) (-):inflow
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
     0.     0.     0.     0.     0.     0.
     0. 0.0298-0.0134-0.0131-0.0126-0.0118-0.0108-0.0095-0.0080-0.0063-0.0045-0.0027-0.0012-0.0002
0.0000-0.0007-0.0026-0.0058-0.1143      0.
     0. 0.0446 0.0012 0.0011 0.0011 0.0012 0.0015 0.0018 0.0023 0.0029 0.0036 0.0043 0.0051 0.0059
0.0069 0.0082 0.0104 0.0141-0.0645      0.
     0. 0.0445 0.0014 0.0013 0.0013 0.0015 0.0019 0.0024 0.0031 0.0039 0.0048 0.0057 0.0066 0.0073
0.0077 0.0081 0.0089 0.0109-0.0475      0.
     0. 0.0442 0.0016 0.0015 0.0016 0.0019 0.0024 0.0032 0.0041 0.0053 0.0066 0.0080 0.0092 0.0099
0.0098 0.0088 0.0073 0.0067-0.0272      0.
     0. 0.0438 0.0018 0.0018 0.0019 0.0024 0.0031 0.0041 0.0055 0.0073 0.0094 0.0117 0.0136 0.0147
0.0142 0.0113 0.0059-0.0005-0.0029      0.
     0. 0.0433 0.0020 0.0020 0.0023 0.0029 0.0039 0.0053 0.0074 0.0100 0.0134 0.0172 0.0209 0.0234
0.0229 0.0178 0.0064-0.0183 0.0255      0.
     0. 0.0426 0.0022 0.0022 0.0027 0.0035 0.0048 0.0067 0.0096 0.0135 0.0188 0.0254 0.0325 0.0383
0.0395 0.0332 0.0211 0.0069 0.0657      0.
     0. 0.0417 0.0023 0.0025 0.0030 0.0040 0.0057 0.0082 0.0120 0.0177 0.0257 0.0366 0.0500 0.0634
0.0696 0.0591 0.0410 0.0229 0.1119      0.
     0. 0.0407 0.0024 0.0026 0.0033 0.0045 0.0064 0.0096 0.0144 0.0219 0.0334 0.0506 0.0752 0.1056
0.1276 0.1017 0.0670 0.0376 0.1634      0.
     0. 0.0394 0.0025 0.0028 0.0035 0.0048 0.0070 0.0106 0.0162 0.0254 0.0402 0.0649 0.1064 0.1740
0.2585 0.1702 0.0982 0.0513 0.2113      0.
     0. 0.0380 0.0026 0.0028 0.0035 0.0049 0.0072 0.0109 0.0169 0.0267 0.0433 0.0726 0.1295 0.2590
0.6746 0.2552 0.1208 0.0579 0.2378      0.
     0. 0.0365 0.0026 0.0028 0.0035 0.0048 0.0070 0.0105 0.0162 0.0253 0.0401 0.0647 0.1059 0.1730
0.2566 0.1687 0.0966 0.0489 0.2267      0.
     0. 0.0346 0.0025 0.0027 0.0033 0.0045 0.0064 0.0095 0.0143 0.0218 0.0331 0.0502 0.0745 0.1044
0.1259 0.0999 0.0647 0.0337 0.1938      0.
     0. 0.0326 0.0024 0.0025 0.0030 0.0040 0.0056 0.0081 0.0119 0.0174 0.0253 0.0360 0.0493 0.0623
0.0682 0.0576 0.0391 0.0191 0.1595      0.
     0. 0.0398 0.0138 0.0165 0.0200 0.0247 0.0309 0.0395 0.0514 0.0682 0.0914 0.1218 0.1579 0.1921
0.2084 0.1916 0.1563 0.1177 0.2226      0.
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
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1     3.281        20(G7.3)                  initial unmanaged heads
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   0.     0.     0.     0.     0.     0.
     0. 16.888 16.839 16.789 16.738 16.687 16.636 16.584 16.532 16.479 16.426 16.372 16.317 16.261
16.204 16.143 16.077 15.999 15.903     0.
     0. 16.904 16.854 16.804 16.753 16.701 16.649 16.596 16.542 16.487 16.431 16.375 16.319 16.263
16.207 16.150 16.090 16.024 15.945     0.
     0. 16.918 16.869 16.818 16.767 16.714 16.661 16.606 16.549 16.492 16.433 16.374 16.315 16.257
16.202 16.149 16.098 16.045 15.985     0.
     0. 16.932 16.883 16.832 16.780 16.726 16.671 16.614 16.555 16.493 16.430 16.365 16.301 16.241
16.186 16.138 16.096 16.059 16.023     0.
     0. 16.945 16.896 16.845 16.792 16.738 16.681 16.621 16.558 16.490 16.419 16.346 16.274 16.207
16.151 16.110 16.081 16.063 16.057     0.
     0. 16.957 16.908 16.858 16.805 16.749 16.690 16.626 16.557 16.482 16.399 16.312 16.224 16.144
16.085 16.055 16.048 16.057 16.088     0.
     0. 16.968 16.920 16.870 16.817 16.760 16.699 16.631 16.555 16.468 16.369 16.257 16.140 16.032
15.963 15.956 15.992 16.049 16.121     0.
     0. 16.980 16.933 16.883 16.829 16.772 16.708 16.636 16.552 16.451 16.328 16.178 16.006 15.834
15.727 15.772 15.889 16.019 16.146     0.
     0. 16.991 16.945 16.896 16.842 16.784 16.719 16.643 16.551 16.434 16.281 16.077 15.807 15.487
15.246 15.439 15.720 15.965 16.164     0.
     0. 17.002 16.958 16.909 16.857 16.799 16.733 16.654 16.556 16.427 16.246 15.976 15.558 14.910
14.117 14.875 15.498 15.906 16.187     0.
     0. 17.013 16.970 16.923 16.872 16.816 16.751 16.673 16.574 16.441 16.247 15.939 15.386 14.189
10.453 14.165 15.350 15.905 16.238     0.
     0. 17.024 16.982 16.938 16.889 16.835 16.773 16.699 16.606 16.482 16.307 16.045 15.636 15.000
14.224 14.989 15.621 16.041 16.338     0.
     0. 17.035 16.996 16.954 16.908 16.857 16.800 16.732 16.649 16.543 16.403 16.212 15.959 15.659
15.442 15.657 15.961 16.232 16.464     0.
     0. 17.046 17.009 16.970 16.927 16.881 16.829 16.769 16.699 16.613 16.507 16.378 16.228 16.084
16.009 16.089 16.244 16.418 16.594     0.
     0. 17.056 17.022 16.986 16.947 16.905 16.859 16.807 16.749 16.682 16.604 16.518 16.429 16.356
16.327 16.366 16.456 16.575 16.713     0.
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
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```

# APPENDIX D

## Selected parts of MOC output file from the subsystem.

```
1                    INTERNATIONAL GROUND WATER MODELING CENTER
                              INDIANAPOLIS, INDIANA, USA
                                  MOC VERSION  2.2
0U.S.G.S. METHOD-OF-CHARACTERISTICS MODEL FOR SOLUTE TRANSPORT IN GROUND WATER
0MOC concentration (steady state, unmanaged heads)    Dec. 2nd, 1991.

0                      I N P U T     D A T A
0                        GRID DESCRIPTORS

             NX    (NUMBER OF COLUMNS)  =    20
             NY    (NUMBER OF ROWS)     =    17
             XDEL  (X-DISTANCE IN FEET) =    50.0
             YDEL  (Y-DISTANCE IN FEET) =    50.0
0                        TIME  PARAMETERS

             NTIM   (MAX. NO. OF TIME STEPS)       =      12
             NPMP   (NO. OF PUMPING PERIODS)       =      1
             PINT   (PUMPING PERIOD IN YEARS)      =      2.000
             TIMX   (TIME INCREMENT MULTIPLIER)    =      0.00
             TINIT  (INITIAL TIME STEP IN SEC.)    =      0.
0               HYDROLOGIC AND CHEMICAL PARAMETERS

             S       (STORAGE COEFFICIENT)       =      0.000000
             POROS   (EFFECTIVE POROSITY)        =      0.300
             BETA    (LONGITUDINAL DISPERSIVITY) =     10.0
             DLTRAT  (RATIO OF TRANSVERSE TO
                     LONGITUDINAL DISPERSIVITY)  =      0.30
             ANFCTR  (RATIO OF T-YY TO T-XX)     =      1.000000
0                      EXECUTION PARAMETERS

             NITP   (NO. OF ITERATION PARAMETERS) =    7
             TOL    (CONVERGENCE CRITERIA - ADIP) =    0.0010
             ITMAX  (MAX.NO.OF ITERATIONS - ADIP) =  100
             CELDIS (MAX.CELL DISTANCE PER MOVE
                        OF PARTICLES - M.O.C.)    =    0.500
             NPMAX  (MAX. NO. OF PARTICLES)       = 6400
             NPTPND (NO. PARTICLES PER NODE)      =     9
1
0                        PROGRAM OPTIONS

             NPNT   (TIME STEP INTERVAL FOR
                     COMPLETE PRINTOUT)       =     1
             NPNTMV (MOVE INTERVAL FOR CHEM.
                     CONCENTRATION PRINTOUT)  =     0
             NPNTVL (PRINT OPTION-VELOCITY
                     0=NO; 1=FIRST TIME STEP;
                     2=ALL TIME STEPS)        =     1
             NPNTD  (PRINT OPTION-DISP.COEF.
                     0=NO; 1=FIRST TIME STEP;
                     2=ALL TIME STEPS)        =     0
             NUMOBS (NO. OF OBSERVATION WELLS
                     FOR HYDROGRAPH PRINTOUT) =     2
             NREC   (NO. OF PUMPING WELLS)    =     2
             NCODES (FOR NODE IDENT.)         =     0
             NPNCHV (PUNCH VELOCITIES)        =     0
             NPDELC (PRINT OPT.-CONC. CHANGE) =     0
0                        REACTION TERMS
             DK      (DISTRIBUTION COEFFICIENT) =  0.00000E+00
             RHOB    (BULK DENSITY OF SOLIDS)   =  0.00000E+00
             RF      (RETARDATION FACTOR)       =  0.10000E+01
             THALF   (HALF LIFE OF DECAY,IN SEC)=  0.00000E+00
```

DECAY (DECAY CONSTANT=LN 2/THALF)= 0.00000E+00

1 STEADY-STATE FLOW

TIME INTERVAL (IN SEC) FOR SOLUTE-TRANSPORT SIMULATION = 0.52596E+07

0 LOCATION OF OBSERVATION WELLS

| NO. | X | Y |
|---|---|---|
| 1 | 17 | 9 |
| 2 | 19 | 9 |

0 LOCATION OF PUMPING WELLS

| X | Y | RATE(IN CFS) | CONC. |
|---|---|---|---|
| 15 | 12 | 3.531000 | 0.000000E+00 |
| 3 | 11 | -0.000541 | 0.583000E+06 |

0 AREA OF ONE CELL = 2500.

0 X-Y SPACING:
50.000
50.000

1HEAD DISTRIBUTION - ROW
NUMBER OF TIME STEPS = 4
TIME(SECONDS) = 0.21038E+08
TIME(DAYS) = 0.24350E+03
TIME(YEARS) = 0.66667E+00

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| * | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| * | 0.00 | 55.42 | 55.25 | 55.09 | 54.92 | 54.76 | 54.59 | 54.42 | 54.25 | 54.08 |
| | 53.90 | 53.72 | 53.54 | 53.36 | 53.17 | 52.98 | 52.76 | 52.50 | 52.19 | 0.00 |
| * | 0.00 | 55.47 | 55.30 | 55.14 | 54.97 | 54.80 | 54.63 | 54.46 | 54.28 | 54.10 |
| | 53.92 | 53.74 | 53.55 | 53.37 | 53.18 | 53.00 | 52.80 | 52.59 | 52.33 | 0.00 |
| * | 0.00 | 55.51 | 55.35 | 55.19 | 55.02 | 54.85 | 54.67 | 54.49 | 54.31 | 54.12 |
| | 53.92 | 53.73 | 53.54 | 53.35 | 53.17 | 53.00 | 52.83 | 52.65 | 52.46 | 0.00 |
| * | 0.00 | 55.56 | 55.40 | 55.23 | 55.06 | 54.89 | 54.70 | 54.52 | 54.32 | 54.12 |
| | 53.91 | 53.70 | 53.49 | 53.30 | 53.12 | 52.96 | 52.82 | 52.70 | 52.58 | 0.00 |
| * | 0.00 | 55.60 | 55.44 | 55.27 | 55.10 | 54.92 | 54.74 | 54.54 | 54.33 | 54.11 |
| | 53.88 | 53.64 | 53.40 | 53.18 | 53.00 | 52.87 | 52.77 | 52.71 | 52.69 | 0.00 |
| * | 0.00 | 55.64 | 55.48 | 55.32 | 55.14 | 54.96 | 54.77 | 54.56 | 54.33 | 54.08 |
| | 53.81 | 53.53 | 53.24 | 52.98 | 52.79 | 52.69 | 52.66 | 52.69 | 52.80 | 0.00 |
| * | 0.00 | 55.68 | 55.52 | 55.36 | 55.18 | 55.00 | 54.79 | 54.57 | 54.32 | 54.04 |
| | 53.71 | 53.35 | 52.96 | 52.61 | 52.38 | 52.36 | 52.48 | 52.67 | 52.90 | 0.00 |
| * | 0.00 | 55.72 | 55.56 | 55.40 | 55.22 | 55.03 | 54.83 | 54.59 | 54.31 | 53.98 |
| | 53.58 | 53.09 | 52.52 | 51.96 | 51.61 | 51.76 | 52.14 | 52.57 | 52.99 | 0.00 |
| * | 0.00 | 55.75 | 55.60 | 55.44 | 55.27 | 55.08 | 54.86 | 54.61 | 54.31 | 53.93 |
| | 53.43 | 52.76 | 51.87 | 50.82 | 50.03 | 50.67 | 51.59 | 52.39 | 53.05 | 0.00 |
| * | 0.00 | 55.79 | 55.64 | 55.48 | 55.31 | 55.12 | 54.91 | 54.65 | 54.33 | 53.90 |
| | 53.31 | 52.43 | 51.05 | 48.93 | 46.33 | 48.82 | 50.86 | 52.20 | 53.12 | 0.00 |
| * | 0.00 | 55.82 | 55.68 | 55.53 | 55.36 | 55.18 | 54.97 | 54.71 | 54.39 | 53.95 |
| | 53.31 | 52.30 | 50.49 | 46.56 | 34.31 | 46.49 | 50.37 | 52.19 | 53.29 | 0.00 |
| * | 0.00 | 55.86 | 55.73 | 55.58 | 55.42 | 55.24 | 55.04 | 54.80 | 54.49 | 54.08 |
| | 53.51 | 52.65 | 51.31 | 49.22 | 46.68 | 49.19 | 51.26 | 52.64 | 53.61 | 0.00 |
| * | 0.00 | 55.90 | 55.77 | 55.63 | 55.48 | 55.31 | 55.13 | 54.90 | 54.63 | 54.29 |
| | 53.82 | 53.20 | 52.37 | 51.39 | 50.68 | 51.38 | 52.38 | 53.27 | 54.03 | 0.00 |
| * | 0.00 | 55.93 | 55.81 | 55.68 | 55.54 | 55.39 | 55.22 | 55.03 | 54.80 | 54.51 |
| | 54.17 | 53.74 | 53.25 | 52.78 | 52.54 | 52.80 | 53.31 | 53.88 | 54.45 | 0.00 |
| * | 0.00 | 55.97 | 55.86 | 55.74 | 55.61 | 55.47 | 55.32 | 55.15 | 54.96 | 54.74 |

```
 54.49  54.20  53.91  53.67  53.58  53.71  54.00  54.39  54.84   0.00

*  0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
```

1CONCENTRATION

```
 NUMBER OF TIME STEPS =      4
       DELTA T        =  0.52596E+07
       TIME(SECONDS)  =  0.21038E+08
   CHEM.TIME(SECONDS) =  0.21039E+08
   CHEM.TIME(DAYS)    =  0.24350E+03
       TIME(YEARS)    =  0.66667E+00
   CHEM.TIME(YEARS)   =  0.66667E+00
  NO. MOVES COMPLETED =    297
```

| | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| * | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| * | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| * | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| * | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| * | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| * | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 2 | 3 | 3 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| * | 0 | 0 | 0 | 0 | 1 | 5 | 11 | 17 | 24 | 26 | 27 | 8 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| * | 0 | 0 | 0 | 7 | 34 | 84 | 130 | 182 | 218 | 223 | 163 | 55 | 10 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| * | 0 | 1 | 53 | 249 | 638 | 1037 | 1286 | 1410 | 1424 | 1324 | 545 | 399 | 109 | 14 | 1 | 0 | 0 | 0 | 0 | 0 |
| * | 0 | 203 | 1940 | 5103 | 7247 | 7928 | 7817 | 7366 | 6792 | 4953 | 3832 | 1567 | 577 | 101 | 12 | 3 | 1 | 0 | 0 | 0 |
| * | 0 | 79064981548634398913103024124196611535811696 | | | | | | | | | 8296 | 5639 | 2695 | 1007 | 86 | 11 | 2 | 0 | 0 | 0 |
| * | 0 | 1284 | 3491 | 6478 | 7696 | 7663 | 6702 | 4294 | 2836 | 2156 | 1676 | 1164 | 1796 | 868 | 317 | 37 | 4 | 0 | 0 | 0 |
| * | 0 | 135 | 314 | 715 | 1151 | 1235 | 844 | 403 | 184 | 161 | 176 | 138 | 101 | 106 | 35 | 7 | 1 | 0 | 0 | 0 |
| * | 0 | 13 | 30 | 75 | 143 | 144 | 54 | 14 | 14 | 15 | 15 | 11 | 10 | 7 | 6 | 2 | 0 | 0 | 0 | 0 |
| * | 0 | 1 | 3 | 7 | 16 | 14 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| * | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| * | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

CHEMICAL MASS BALANCE

```
       MASS IN BOUNDARIES     =  0.00000E+00
       MASS OUT BOUNDARIES    =  0.00000E+00
       MASS PUMPED IN         =  0.17460E+11
       MASS PUMPED OUT        = -0.50112E+10
       MASS LOST BY DECAY     =  0.00000E+00
       MASS ADSORBED ON SOLIDS=  0.00000E+00
       INITIAL MASS ADSORBED  =  0.00000E+00
       INFLOW MINUS OUTFLOW   =  0.12449E+11
       INITIAL MASS DISSOLVED =  0.00000E+00
       PRESENT MASS DISSOLVED =  0.15876E+11
       CHANGE MASS DISSOLVED  =  0.15876E+11
       CHANGE TOTL.MASS STORED=  0.15876E+11
     COMPARE RESIDUAL WITH NET FLUX AND MASS ACCUMULATION:
       MASS BALANCE RESIDUAL  = -0.34271E+10
       ERROR  (AS PERCENT)    = -0.19628E+02
```

# APPENDIX E

## MACMAN input data file for total area.

Input data FOR014.DAT.

```
LINE  Scenario 8.1: Manag.farm irrig. system with streamflow constraints.
      35         75          1        22    0    0    0    1
       4
      15         51       0.30         1                   1
  -0.110
      18         33       0.30         1                   2
  -0.120
      23         30       0.30         1                   1
  -0.100
      22         18       0.30         1                   1
1.53e-05
      20         22       0.30              -0.010         1
      21         22       0.30              -0.010         1
      21         23       0.30              -0.010         1
      22         22       0.30              -0.010         1
      22         23       0.30              -0.010         1
      23         22       0.30              -0.010         1
      17         18       0.30               0.010         1
      17         19       0.30               0.010         1
      17         20       0.30               0.010         1
      17         21       0.30               0.010         1
      17         22       0.30               0.010         1
      17         23       0.30               0.010         1
      17         24       0.30               0.010         1
      17         25       0.30               0.010         1
      17         26       0.30               0.010         1
      18         26       0.30               0.010         1
      19         26       0.30               0.010         1
      20         26       0.30               0.010         1
      21         26       0.30               0.010         1
      22         26       0.30               0.010         1
      23         26       0.30               0.010         1
      24         26       0.30               0.010         1
      25         26       0.30               0.010         1
      26         25       0.30               0.010         1
      26         24       0.30               0.010         1
      26         23       0.30               0.010         1
      26         22       0.30               0.010         1
      26         21       0.30               0.010         1
      26         20       0.30               0.010         1
      26         19       0.30               0.010         1
      26         18       0.30               0.010         1
      20         22          1
      21         22          1
      21         23          1
      22         22          1
      22         23          1
      23         22          1
      17         18          1
      17         19          1
      17         20          1
      17         21          1
      17         22          1
      17         23          1
      17         24          1
      17         25          1
      17         26          1
      18         26          1
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      21         26          1
      22         26          1
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Input data FOR013.DAT

```
1
1
18    18    19    18
18    19    19    19
18    20    19    20
18    21    19    21
18    22    19    22
18    23    19    23
18    24    19    24
18    25    19    24
19    25    19    24
20    25    20    24
21    25    21    24
22    25    22    24
23    25    23    24
24    25    24    24
25    25    24    24
25    24    24    24
25    23    24    23
25    22    24    22
25    21    24    21
25    20    24    20
25    19    24    19
25    18    24    18
   1.00        0.01    G
   1.00        0.01    G
   1.00        0.01    G
   1.00        0.01    G
   1.00        0.01    G
   1.00        0.01    G
   1.00        0.01    G
   1.00        0.01    G
   1.00        0.01    G
   1.00        0.01    G
   1.00        0.01    G
   1.00        0.01    G
   1.00        0.01    G
   1.00        0.01    G
   1.00        0.01    G
   1.00        0.01    G
   1.00        0.01    G
   1.00        0.01    G
   1.00        0.01    G
   1.00        0.01    G
   1.00        0.01    G
   1.00        0.01    G
   1.00        0.01    G
   1.00        0.01    G
   1.00        0.01    G
   1.00        0.01    G
   1.00        0.01    G
   1.00        0.01    G
   1.00        0.01    G
   1.00        0.01    G
   1.00        0.01    G
   1.00        0.01    G
   1.00        0.01    G
   1.00        0.01    G
   1.00        0.01    G
   1.00        0.01    G
   1.00        0.01    G
   1.00        0.01    G
   1.00        0.01    G
   1.00        0.01    G
   1.00        0.01    G
   1.00        0.01    G
   1.00        0.01    G
   1.00        0.01    G
```

Input data FOR004

```
Begin DEMO1 Problem
   MINIMIZE
   Objective              OBJ
   RHS                    RHS
   NONLINEAR  VARIABLES          0
   SUPERBASICS LIMIT             1
   DERIVATIVE LEVEL              3
   VERIFY LEVEL                  1
   MULTIPLE PRICE                1
   Rows                        150
   Columns                     150
   Elements                   6000
   SCALE PRINT                 YES
   SCALE OPTION                 NO
   FUNCTION PRECISION     3.0E-13
   MPS file                     10
   OLD BASIS FILE                0
   INSERT FILE                   0
   New basis file               55
   PUNCH FILE                   56
   BACKUP FILE                  57
   SAVE FREQUENCY               10
   SOLUTION                    YES
   MAJOR ITERATIONS             10
   Iterations                  300
End DEMO1 Problem
```

# APPENDIX F

## Selected parts of MACMAN output file.

Output file FOR018.DAT (MPS format)

```
NAME          Scenario 8.1: Manag.farm irrig. system with streamflow constrain
ROWS
 L  DF011001
 L  DF011002
 L  DF011003
 L  DF011004
 L  DF011005
 L  DF011006
 L  DF011007
 L  DF011008
 L  DF011009
 L  DF011010
 L  DF011011
 L  DF011012
 L  DF011013
 L  DF011014
 L  DF011015
 L  DF011016
 L  DF011017
 L  DF011018
 L  DF011019
 L  DF011020
 L  DF011021
 L  DF011022
 L  DR110001
 L  DR110002
 L  DR110003
 L  DR110004
 L  DR110005
 L  DR110006
 G  DR110007
 G  DR110008
 G  DR110009
 G  DR110010
 G  DR110011
 G  DR110012
 G  DR110013
 G  DR110014
 G  DR110015
 G  DR110016
 G  DR110017
 G  DR110018
 G  DR110019
 G  DR110020
 G  DR110021
 G  DR110022
 G  DR110023
 G  DR110024
 G  DR110025
 G  DR110026
 G  DR110027
 G  DR110028
 G  DR110029
 G  DR110030
 G  DR110031
 L  DR210001
 L  DR210002
 L  DR210003
 L  DR210004
 L  DR210005
 L  DR210006
 G  DR210007
```

```
 G  DR210008
 G  DR210009
 G  DR210010
 G  DR210011
 G  DR210012
 G  DR210013
 G  DR210014
 G  DR210015
 G  DR210016
 G  DR210017
 G  DR210018
 G  DR210019
 G  DR210020
 G  DR210021
 G  DR210022
 G  DR210023
 G  DR210024
 G  DR210025
 G  DR210026
 G  DR210027
 G  DR210028
 G  DR210029
 G  DR210030
 G  DR210031
 N  OBJ
COLUMNS
    Q011001   OBJ         0.10000E-01
    Q011001   DF011001   -0.66267E-02   DF011002   -0.13290E-01
    Q011001   DF011003   -0.27805E-01   DF011004   -0.58374E-01
    Q011001   DF011005   -0.10731E+00   DF011006   -0.58819E-01
    Q011001   DF011007   -0.28235E-01   DF011008   -0.51549E-01
    Q011001   DF011009   -0.37933E-01   DF011010   -0.51076E-01
    Q011001   DF011011   -0.37844E-01   DF011012   -0.23176E-01
    Q011001   DF011013   -0.13300E-01   DF011014   -0.75417E-02
    Q011001   DF011015   -0.16245E-01   DF011016   -0.11917E-01
    Q011001   DF011017   -0.15034E-01   DF011018   -0.16532E-01
    Q011001   DF011019   -0.14924E-01   DF011020   -0.11729E-01
    Q011001   DF011021   -0.84648E-02   DF011022   -0.58117E-02
    Q011001   DR110001    0.96756E+00   DR110002    0.24168E+00
    Q011001   DR110003    0.17357E+00   DR110004    0.13439E+00
    Q011001   DR110005    0.11474E+00   DR110006    0.83353E-01
    Q011001   DR110007    0.36470E-01   DR110008    0.48163E-01
    Q011001   DR110009    0.62107E-01   DR110010    0.75938E-01
    Q011001   DR110011    0.83497E-01   DR110012    0.76705E-01
    Q011001   DR110013    0.63504E-01   DR110014    0.50073E-01
    Q011001   DR110015    0.38841E-01   DR110016    0.46698E-01
    Q011001   DR110017    0.53569E-01   DR110018    0.56702E-01
    Q011001   DR110019    0.53791E-01   DR110020    0.47040E-01
    Q011001   DR110021    0.39168E-01   DR110022    0.31830E-01
    Q011001   DR110023    0.25734E-01   DR110024    0.23750E-01
    Q011001   DR110025    0.26288E-01   DR110026    0.28088E-01
    Q011001   DR110027    0.28620E-01   DR110028    0.27622E-01
    Q011001   DR110029    0.25359E-01   DR110030    0.22358E-01
    Q011001   DR110031    0.19104E-01
    Q011001   DR210001    0.19959E-01   DR210002    0.19087E-01
    Q011001   DR210003    0.18752E-01   DR210004    0.17791E-01
    Q011001   DR210005    0.17663E-01   DR210006    0.16413E-01
    Q011001   DR210007    0.12332E-01   DR210008    0.13686E-01
    Q011001   DR210009    0.14889E-01   DR210010    0.15817E-01
    Q011001   DR210011    0.16323E-01   DR210012    0.16306E-01
    Q011001   DR210013    0.15867E-01   DR210014    0.15156E-01
    Q011001   DR210015    0.14300E-01   DR210016    0.14990E-01
    Q011001   DR210017    0.15474E-01   DR210018    0.15662E-01
    Q011001   DR210019    0.15508E-01   DR210020    0.15056E-01
    Q011001   DR210021    0.14395E-01   DR210022    0.13616E-01
    Q011001   DR210023    0.12788E-01   DR210024    0.12389E-01
    Q011001   DR210025    0.12679E-01   DR210026    0.12790E-01
    Q011001   DR210027    0.12686E-01   DR210028    0.12354E-01
    Q011001   DR210029    0.11805E-01   DR210030    0.11071E-01
    Q011001   DR210031    0.10194E-01
    Q011002   OBJ         0.10000E-01
    Q011002   DF011001   -0.76518E-02   DF011002   -0.13422E-01
```

| | | | | |
|---|---|---|---|---|
| Q011002 | DF011003 | -0.23263E-01 | DF011004 | -0.37861E-01 |
| Q011002 | DF011005 | -0.51092E-01 | DF011006 | -0.38127E-01 |
| Q011002 | DF011007 | -0.23592E-01 | DF011008 | -0.37012E-01 |
| Q011002 | DF011009 | -0.23295E-01 | DF011010 | -0.37901E-01 |
| Q011002 | DF011011 | -0.51029E-01 | DF011012 | -0.37796E-01 |
| Q011002 | DF011013 | -0.23155E-01 | DF011014 | -0.13311E-01 |
| Q011002 | DF011015 | -0.24701E-01 | DF011016 | -0.17135E-01 |
| Q011002 | DF011017 | -0.23761E-01 | DF011018 | -0.27812E-01 |
| Q011002 | DF011019 | -0.23581E-01 | DF011020 | -0.16859E-01 |
| Q011002 | DF011021 | -0.11074E-01 | DF011022 | -0.69919E-02 |
| Q011002 | DR110001 | 0.24185E+00 | DR110002 | 0.96701E+00 |
| Q011002 | DR110003 | 0.24285E+00 | DR110004 | 0.24161E+00 |
| Q011002 | DR110005 | 0.17357E+00 | DR110006 | 0.13439E+00 |
| Q011002 | DR110007 | 0.29395E-01 | DR110008 | 0.36997E-01 |
| Q011002 | DR110009 | 0.45139E-01 | DR110010 | 0.52229E-01 |
| Q011002 | DR110011 | 0.55556E-01 | DR110012 | 0.52864E-01 |
| Q011002 | DR110013 | 0.46351E-01 | DR110014 | 0.38727E-01 |
| Q011002 | DR110015 | 0.31613E-01 | DR110016 | 0.38869E-01 |
| Q011002 | DR110017 | 0.46766E-01 | DR110018 | 0.53689E-01 |
| Q011002 | DR110019 | 0.56864E-01 | DR110020 | 0.53944E-01 |
| Q011002 | DR110021 | 0.47122E-01 | DR110022 | 0.39167E-01 |
| Q011002 | DR110023 | 0.31829E-01 | DR110024 | 0.30214E-01 |
| Q011002 | DR110025 | 0.34566E-01 | DR110026 | 0.37920E-01 |
| Q011002 | DR110027 | 0.39102E-01 | DR110028 | 0.37410E-01 |
| Q011002 | DR110029 | 0.33562E-01 | DR110030 | 0.28728E-01 |
| Q011002 | DR110031 | 0.23811E-01 | | |
| Q011002 | DR210001 | 0.19092E-01 | DR210002 | 0.20006E-01 |
| Q011002 | DR210003 | 0.19354E-01 | DR210004 | 0.19147E-01 |
| Q011002 | DR210005 | 0.18812E-01 | DR210006 | 0.17866E-01 |
| Q011002 | DR210007 | 0.11558E-01 | DR210008 | 0.12733E-01 |
| Q011002 | DR210009 | 0.13749E-01 | DR210010 | 0.14517E-01 |
| Q011002 | DR210011 | 0.14949E-01 | DR210012 | 0.15000E-01 |
| Q011002 | DR210013 | 0.14716E-01 | DR210014 | 0.14187E-01 |
| Q011002 | DR210015 | 0.13504E-01 | DR210016 | 0.14321E-01 |
| Q011002 | DR210017 | 0.15021E-01 | DR210018 | 0.15515E-01 |
| Q011002 | DR210019 | 0.15713E-01 | DR210020 | 0.15567E-01 |
| Q011002 | DR210021 | 0.15124E-01 | DR210022 | 0.14471E-01 |
| Q011002 | DR210023 | 0.13701E-01 | DR210024 | 0.13433E-01 |
| Q011002 | DR210025 | 0.13834E-01 | DR210026 | 0.14023E-01 |
| Q011002 | DR210027 | 0.13945E-01 | DR210028 | 0.13577E-01 |
| Q011002 | DR210029 | 0.12940E-01 | DR210030 | 0.12087E-01 |
| Q011002 | DR210031 | 0.11078E-01 | | |
| Q011003 | OBJ | 0.10000E-01 | | |
| Q011003 | DF011001 | -0.44244E-02 | DF011002 | -0.76690E-02 |
| Q011003 | DF011003 | -0.13446E-01 | DF011004 | -0.23310E-01 |
| Q011003 | DF011005 | -0.37955E-01 | DF011006 | -0.51249E-01 |
| Q011003 | DF011007 | -0.38258E-01 | DF011008 | -0.51534E-01 |
| Q011003 | DF011009 | -0.27849E-01 | DF011010 | -0.58512E-01 |
| Q011003 | DF011011 | -0.10746E+00 | DF011012 | -0.58343E-01 |
| Q011003 | DF011013 | -0.27648E-01 | DF011014 | -0.13137E-01 |
| Q011003 | DF011015 | -0.30382E-01 | DF011016 | -0.23861E-01 |
| Q011003 | DF011017 | -0.27899E-01 | DF011018 | -0.23637E-01 |
| Q011003 | DF011019 | -0.16893E-01 | DF011020 | -0.11097E-01 |
| Q011003 | DF011021 | -0.70121E-02 | DF011022 | -0.43678E-02 |
| Q011003 | DR110001 | 0.17293E+00 | DR110002 | 0.24176E+00 |
| Q011003 | DR110003 | 0.97161E+00 | DR110004 | 0.17279E+00 |
| Q011003 | DR110005 | 0.24273E+00 | DR110006 | 0.11426E+00 |
| Q011003 | DR110007 | 0.23725E-01 | DR110008 | 0.30092E-01 |
| Q011003 | DR110009 | 0.37606E-01 | DR110010 | 0.45674E-01 |
| Q011003 | DR110011 | 0.52700E-01 | DR110012 | 0.55967E-01 |
| Q011003 | DR110013 | 0.53207E-01 | DR110014 | 0.46622E-01 |
| Q011003 | DR110015 | 0.38921E-01 | DR110016 | 0.50314E-01 |
| Q011003 | DR110017 | 0.64097E-01 | DR110018 | 0.77877E-01 |
| Q011003 | DR110019 | 0.85358E-01 | DR110020 | 0.78228E-01 |
| Q011003 | DR110021 | 0.64546E-01 | DR110022 | 0.50642E-01 |
| Q011003 | DR110023 | 0.39122E-01 | DR110024 | 0.34802E-01 |
| Q011003 | DR110025 | 0.38215E-01 | DR110026 | 0.39458E-01 |
| Q011003 | DR110027 | 0.37830E-01 | DR110028 | 0.34052E-01 |
| Q011003 | DR110029 | 0.29299E-01 | DR110030 | 0.24475E-01 |
| Q011003 | DR110031 | 0.20060E-01 | | |
| Q011003 | DR210001 | 0.18751E-01 | DR210002 | 0.19347E-01 |
| Q011003 | DR210003 | 0.20469E-01 | DR210004 | 0.18807E-01 |

| | | | | |
|---|---|---|---|---|
| Q011003 | DR210005 | 0.19605E-01 | DR210006 | 0.17734E-01 |
| Q011003 | DR210007 | 0.10977E-01 | DR210008 | 0.12189E-01 |
| Q011003 | DR210009 | 0.13311E-01 | DR210010 | 0.14276E-01 |
| Q011003 | DR210011 | 0.14996E-01 | DR210012 | 0.15381E-01 |
| Q011003 | DR210013 | 0.15386E-01 | DR210014 | 0.15058E-01 |
| Q011003 | DR210015 | 0.14486E-01 | DR210016 | 0.15479E-01 |
| Q011003 | DR210017 | 0.16366E-01 | DR210018 | 0.17021E-01 |
| Q011003 | DR210019 | 0.17291E-01 | DR210020 | 0.17076E-01 |
| Q011003 | DR210021 | 0.16472E-01 | DR210022 | 0.15633E-01 |
| Q011003 | DR210023 | 0.14685E-01 | DR210024 | 0.14157E-01 |
| Q011003 | DR210025 | 0.14389E-01 | DR210026 | 0.14356E-01 |
| Q011003 | DR210027 | 0.14033E-01 | DR210028 | 0.13444E-01 |
| Q011003 | DR210029 | 0.12641E-01 | DR210030 | 0.11684E-01 |
| Q011003 | DR210031 | 0.10626E-01 | | |
| Q011031 | OBJ | 0.10000E-01 | | |
| Q011031 | DF011001 | 0.45379E-02 | DF011002 | 0.44128E-02 |
| Q011031 | DF011003 | 0.39963E-02 | DF011004 | 0.34171E-02 |
| Q011031 | DF011005 | 0.27993E-02 | DF011006 | 0.22267E-02 |
| Q011031 | DF011007 | 0.17398E-02 | DF011008 | 0.27026E-02 |
| Q011031 | DF011009 | 0.13542E-02 | DF011010 | 0.18869E-02 |
| Q011031 | DF011011 | 0.25895E-02 | DF011012 | 0.34725E-02 |
| Q011031 | DF011013 | 0.45002E-02 | DF011014 | 0.55516E-02 |
| Q011031 | DF011015 | 0.43385E-02 | DF011016 | -0.20539E-02 |
| Q011031 | DF011017 | -0.36425E-02 | DF011018 | -0.68122E-02 |
| Q011031 | DF011019 | -0.13447E-01 | DF011020 | -0.27721E-01 |
| Q011031 | DF011021 | -0.57335E-01 | DF011022 | -0.10393E+00 |
| Q011031 | DR110001 | -0.19406E-01 | DR110002 | -0.24195E-01 |
| Q011031 | DR110003 | -0.20424E-01 | DR110004 | -0.30258E-01 |
| Q011031 | DR110005 | -0.24559E-01 | DR110006 | -0.37528E-01 |
| Q011031 | DR110007 | -0.11369E-01 | DR110008 | -0.11682E-01 |
| Q011031 | DR110009 | -0.11639E-01 | DR110010 | -0.11315E-01 |
| Q011031 | DR110011 | -0.10798E-01 | DR110012 | -0.10168E-01 |
| Q011031 | DR110013 | -0.94913E-02 | DR110014 | -0.88104E-02 |
| Q011031 | DR110015 | -0.81493E-02 | DR110016 | -0.90609E-02 |
| Q011031 | DR110017 | -0.10106E-01 | DR110018 | -0.11286E-01 |
| Q011031 | DR110019 | -0.12580E-01 | DR110020 | -0.13932E-01 |
| Q011031 | DR110021 | -0.15230E-01 | DR110022 | -0.16318E-01 |
| Q011031 | DR110023 | -0.17056E-01 | DR110024 | -0.21899E-01 |
| Q011031 | DR110025 | -0.28634E-01 | DR110026 | -0.38923E-01 |
| Q011031 | DR110027 | -0.55267E-01 | DR110028 | -0.82639E-01 |
| Q011031 | DR110029 | -0.13239E+00 | DR110030 | -0.23564E+00 |
| Q011031 | DR110031 | -0.90014E+00 | | |
| Q011031 | DR210001 | -0.10111E-01 | DR210002 | -0.10984E-01 |
| Q011031 | DR210003 | -0.10542E-01 | DR210004 | -0.11866E-01 |
| Q011031 | DR210005 | -0.11292E-01 | DR210006 | -0.12711E-01 |
| Q011031 | DR210007 | -0.71821E-02 | DR210008 | -0.75093E-02 |
| Q011031 | DR210009 | -0.77094E-02 | DR210010 | -0.77929E-02 |
| Q011031 | DR210011 | -0.77745E-02 | DR210012 | -0.76713E-02 |
| Q011031 | DR210013 | -0.75004E-02 | DR210014 | -0.72775E-02 |
| Q011031 | DR210015 | -0.70162E-02 | DR210016 | -0.74976E-02 |
| Q011031 | DR210017 | -0.79907E-02 | DR210018 | -0.84852E-02 |
| Q011031 | DR210019 | -0.89670E-02 | DR210020 | -0.94182E-02 |
| Q011031 | DR210021 | -0.98182E-02 | DR210022 | -0.10145E-01 |
| Q011031 | DR210023 | -0.10379E-01 | DR210024 | -0.11349E-01 |
| Q011031 | DR210025 | -0.12258E-01 | DR210026 | -0.13232E-01 |
| Q011031 | DR210027 | -0.14263E-01 | DR210028 | -0.15323E-01 |
| Q011031 | DR210029 | -0.16358E-01 | DR210030 | -0.17239E-01 |
| Q011031 | DR210031 | -0.17628E-01 | | |
| RHS | | | | |
| RHS | DF011001 | -0.22237E-01 | DF011002 | -0.22463E-01 |
| RHS | DF011003 | -0.22138E-01 | DF011004 | -0.21020E-01 |
| RHS | DF011005 | -0.18700E-01 | DF011006 | -0.14532E-01 |
| RHS | DF011007 | -0.75435E-02 | DF011008 | -0.83127E-01 |
| RHS | DF011009 | -0.96744E-01 | DF011010 | -0.11088E+00 |
| RHS | DF011011 | -0.12647E+00 | DF011012 | -0.13945E+00 |
| RHS | DF011013 | -0.14347E+00 | DF011014 | -0.13415E+00 |
| RHS | DF011015 | -0.72777E-01 | DF011016 | 0.33302E-01 |
| RHS | DF011017 | 0.22932E-01 | DF011018 | 0.16385E-01 |
| RHS | DF011019 | 0.11840E-01 | DF011020 | 0.83912E-02 |
| RHS | DF011021 | 0.55678E-02 | DF011022 | 0.31229E-02 |
| RHS | DR110001 | 0.17080E+01 | DR110002 | 0.17190E+02 |
| RHS | DR110003 | 0.16430E+01 | DR110004 | 0.17330E+01 |

```
    RHS       DR110005    0.16540E+01   DR110006    0.17510E+01
    RHS       DR110007   -0.81043E+01   DR110008   -0.81551E+01
    RHS       DR110009   -0.82075E+01   DR110010   -0.82620E+01
    RHS       DR110011   -0.83190E+01   DR110012   -0.83790E+01
    RHS       DR110013   -0.84425E+01   DR110014   -0.85099E+01
    RHS       DR110015   -0.85809E+01   DR110016   -0.86006E+01
    RHS       DR110017   -0.86311E+01   DR110018   -0.86723E+01
    RHS       DR110019   -0.87185E+01   DR110020   -0.87544E+01
    RHS       DR110021   -0.87533E+01   DR110022   -0.86933E+01
    RHS       DR110023   -0.85975E+01   DR110024   -0.83870E+01
    RHS       DR110025   -0.83013E+01   DR110026   -0.82308E+01
    RHS       DR110027   -0.81712E+01   DR110028   -0.81193E+01
    RHS       DR110029   -0.80729E+01   DR110030   -0.80304E+01
    RHS       DR110031   -0.79911E+01
    RHS       DR210001    0.17560E+01   DR210002    0.17740E+01
    RHS       DR210003    0.17260E+01   DR210004    0.17930E+01
    RHS       DR210005    0.17460E+01   DR210006    0.18130E+01
    RHS       DR210007   -0.80906E+01   DR210008   -0.81418E+01
    RHS       DR210009   -0.81927E+01   DR210010   -0.82433E+01
    RHS       DR210011   -0.82938E+01   DR210012   -0.83446E+01
    RHS       DR210013   -0.83957E+01   DR210014   -0.84473E+01
    RHS       DR210015   -0.84996E+01   DR210016   -0.84838E+01
    RHS       DR210017   -0.84662E+01   DR210018   -0.84463E+01
    RHS       DR210019   -0.84241E+01   DR210020   -0.83990E+01
    RHS       DR210021   -0.83708E+01   DR210022   -0.83392E+01
    RHS       DR210023   -0.83053E+01   DR210024   -0.82343E+01
    RHS       DR210025   -0.81978E+01   DR210026   -0.81609E+01
    RHS       DR210027   -0.81237E+01   DR210028   -0.80863E+01
    RHS       DR210029   -0.80486E+01   DR210030   -0.80107E+01
    RHS       DR210031   -0.79725E+01
ENDATA
```

```
                    ==============================
                    M I N O S    5.3     (Jun 1989)
                    ==============================

        OPTIONS file
        ------------
             Begin EX3 Problem
                MINIMIZE
                Objective          OBJ
                RHS                RHS
                NONLINEAR  VARIABLES        0
                SUPERBASICS LIMIT           1
                DERIVATIVE LEVEL            3
                VERIFY LEVEL                1
                MULTIPLE PRICE              1
                Rows                      250
                Columns                   150
                Elements                10000
                SCALE PRINT               YES
                SCALE OPTION               NO
                FUNCTION PRECISION   3.0E-13
                MPS file                   10
                OLD BASIS FILE              0
                INSERT FILE                 0
                New basis file             55
                PUNCH FILE                 56
                BACKUP FILE                57
                SAVE FREQUENCY             10
                SOLUTION                  YES
                MAJOR ITERATIONS           10
                Iterations                300
             End EX3 Problem

        Reasonable WORKSPACE limits are          0 ...    61510
        Actual     WORKSPACE limits are          0 ...    40000 ...    40000   words of  Z.
1
        MPS file
        --------
              1    NAME           Scenario
              2    ROWS
             88    COLUMNS
           1453    RHS
           1497    ENDATA


        Names selected
        --------------
        OBJECTIVE       OBJ       (MIN)       1
        RHS             RHS                  84
        RANGES                                0
        BOUNDS                                0

        PARTIAL PRICE section size (A)             3
        PARTIAL PRICE section size (I)             8

        Nonzeros allowed for in LU factors    23497


        Matrix statistics
        -----------------
                        Total      Normal        Free        Fixed     Bounded
        Rows              85         84            1           0           0
        Columns           31         31            0           0           0

        No. of matrix elements                  2635    Density     100.000
        Biggest                           9.7161E-01   (excluding fixed columns,
        Smallest                          1.5624E-04    free rows, and RHS)

        No. of objective coefficients             31
        Biggest                           1.0000E-02   (excluding fixed columns)
```

```
Smallest                              1.0000E-02
1

Initial basis
-------------

No basis file supplied

CRASH option   1
Free rows          1    Free cols      0   Unit cols        0
Double cols        0    LG slacks     84   Triang cols      0    Pad          0


Iterations
----------

   Itn      DJ  Ninf       Sinf        Objective     LU
     1 -5.5E-01   15 1.036E+00  1.69100771E-02     85

Itn      5 -- Feasible solution.  Objective =   5.191159207E-02

NEW BASIS FILE saved on file  55    Itn =      10

NEW BASIS FILE saved on file  57    Itn =      10

NEW BASIS FILE saved on file  55    Itn =      20

NEW BASIS FILE saved on file  57    Itn =      20
Itn     23 --       2  nonbasics set on bound, basics recomputed

Itn     23 -- Feasible solution.  Objective =   3.358022762E-02

1

EXIT -- OPTIMAL SOLUTION FOUND

NEW BASIS FILE saved on file  55    Itn =      23

No. of iterations                  23     Objective value       3.3580227623E-02

No. of degenerate steps             3     Percentage                       13.04

Norm of X                   9.337E-01     Norm of PI                   1.000E+00

PUNCH FILE saved on file  56
1
NAME              Scenario               Objective value      3.3580227623E-02

Status            OPTIMAL SOLN           Iteration      23    Superbasics      0

OBJECTIVE         OBJ        (MIN)
RHS               RHS
RANGES
BOUNDS
```

SECTION 1 - ROWS

| NUMBER | ...ROW.. | STATE | ...ACTIVITY... | SLACK ACTIVITY | ..LOWER LIMIT. | ..UPPER LIMIT. | .DUAL ACTIVITY | ..I |
|---|---|---|---|---|---|---|---|---|
| 32 | DF011001 | UL | -0.02224 | 0.00000 | NONE | -0.02224 | -0.06764 | 1 |
| 33 | DF011002 | UL | -0.02246 | 0.00000 | NONE | -0.02246 | -0.04173 | 2 |
| 34 | DF011003 | UL | -0.02214 | 0.00000 | NONE | -0.02214 | -0.05106 | 3 |
| 35 | DF011004 | BS | -0.02987 | 0.00885 | NONE | -0.02102 | 0.00000 | 4 |
| 36 | DF011005 | BS | -0.04473 | 0.02603 | NONE | -0.01870 | 0.00000 | 5 |
| 37 | DF011006 | BS | -0.05095 | 0.03642 | NONE | -0.01453 | 0.00000 | 6 |
| 38 | DF011007 | BS | -0.02650 | 0.01896 | NONE | -0.00754 | 0.00000 | 7 |
| 39 | DF011008 | UL | -0.08313 | 0.00000 | NONE | -0.08313 | -0.04304 | 8 |
| 40 | DF011009 | UL | -0.09674 | 0.00000 | NONE | -0.09674 | -0.05310 | 9 |
| 41 | DF011010 | UL | -0.11088 | 0.00000 | NONE | -0.11088 | -0.03706 | 10 |
| 42 | DF011011 | BS | -0.16265 | 0.03618 | NONE | -0.12647 | 0.00000 | 11 |
| 43 | DF011012 | BS | -0.14688 | 0.00743 | NONE | -0.13945 | 0.00000 | 12 |
| 44 | DF011013 | UL | -0.14347 | 0.00000 | NONE | -0.14347 | -0.06043 | 13 |
| 45 | DF011014 | UL | -0.13415 | 0.00000 | NONE | -0.13415 | -0.05590 | 14 |
| 46 | DF011015 | UL | -0.07278 | 0.00000 | NONE | -0.07278 | -0.01395 | 15 |
| 47 | DF011016 | BS | -0.00238 | 0.03569 | NONE | 0.03330 | 0.00000 | 16 |
| 48 | DF011017 | BS | -0.02822 | 0.05115 | NONE | 0.02293 | 0.00000 | 17 |
| 49 | DF011018 | BS | -0.02716 | 0.04354 | NONE | 0.01639 | 0.00000 | 18 |
| 50 | DF011019 | BS | -0.01927 | 0.03111 | NONE | 0.01184 | 0.00000 | 19 |
| 51 | DF011020 | BS | -0.01210 | 0.02049 | NONE | 0.00839 | 0.00000 | 20 |
| 52 | DF011021 | BS | -0.00711 | 0.01268 | NONE | 0.00557 | 0.00000 | 21 |
| 53 | DF011022 | BS | -0.00400 | 0.00712 | NONE | 0.00312 | 0.00000 | 22 |
| 54 | DR110001 | BS | 0.18046 | 1.52754 | NONE | 1.70800 | 0.00000 | 23 |
| 55 | DR110002 | BS | 0.21839 | 1.50061 | NONE | 1.71900 | 0.00000 | 24 |
| 56 | DR110003 | BS | 0.91800 | 0.72500 | NONE | 1.64300 | 0.00000 | 25 |
| 57 | DR110004 | BS | 0.16315 | 1.56985 | NONE | 1.73300 | 0.00000 | 26 |
| 58 | DR110005 | BS | 0.42554 | 1.22846 | NONE | 1.65400 | 0.00000 | 27 |
| 59 | DR110006 | BS | 0.08054 | 1.67046 | NONE | 1.75100 | 0.00000 | 28 |
| 60 | DR110007 | BS | -0.12803 | -7.97627 | -8.10430 | NONE | 0.00000 | 29 |
| 61 | DR110008 | BS | -0.07560 | -8.07950 | -8.15510 | NONE | 0.00000 | 30 |
| 62 | DR110009 | BS | -0.01603 | -8.19147 | -8.20750 | NONE | 0.00000 | 31 |
| 63 | DR110010 | BS | -0.00038 | -8.26162 | -8.26200 | NONE | 0.00000 | 32 |
| 64 | DR110011 | BS | 0.00469 | -8.32369 | -8.31900 | NONE | 0.00000 | 33 |
| 65 | DR110012 | BS | -0.00167 | -8.37733 | -8.37900 | NONE | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| 0.00000 | 34 | | | | | |
| 66 | DR110013 | BS | -0.02078 | -8.42172 | -8.44250 | NONE |
| 0.00000 | 35 | | | | | |
| 67 | DR110014 | BS | -0.04850 | -8.46140 | -8.50990 | NONE |
| 0.00000 | 36 | | | | | |
| 68 | DR110015 | BS | -0.07382 | -8.50708 | -8.58090 | NONE |
| 0.00000 | 37 | | | | | |
| 69 | DR110016 | BS | -0.18183 | -8.41877 | -8.60060 | NONE |
| 0.00000 | 38 | | | | | |
| 70 | DR110017 | BS | -0.46801 | -8.16309 | -8.63110 | NONE |
| 0.00000 | 39 | | | | | |
| 71 | DR110018 | BS | -0.12074 | -8.55156 | -8.67230 | NONE |
| 0.00000 | 40 | | | | | |
| 72 | DR110019 | BS | -0.09643 | -8.62207 | -8.71850 | NONE |
| 0.00000 | 41 | | | | | |
| 73 | DR110020 | BS | -0.16197 | -8.59243 | -8.75440 | NONE |
| 0.00000 | 42 | | | | | |
| 74 | DR110021 | BS | -0.55669 | -8.19661 | -8.75330 | NONE |
| 0.00000 | 43 | | | | | |
| 75 | DR110022 | BS | -0.80038 | -7.89292 | -8.69330 | NONE |
| 0.00000 | 44 | | | | | |
| 76 | DR110023 | BS | -0.21567 | -8.38183 | -8.59750 | NONE |
| 0.00000 | 45 | | | | | |
| 77 | DR110024 | BS | -0.09000 | -8.29700 | -8.38700 | NONE |
| 0.00000 | 46 | | | | | |
| 78 | DR110025 | BS | -0.05583 | -8.24547 | -8.30130 | NONE |
| 0.00000 | 47 | | | | | |
| 79 | DR110026 | BS | -0.02832 | -8.20248 | -8.23080 | NONE |
| 0.00000 | 48 | | | | | |
| 80 | DR110027 | BS | -0.01136 | -8.15984 | -8.17120 | NONE |
| 0.00000 | 49 | | | | | |
| 81 | DR110028 | BS | -0.00285 | -8.11645 | -8.11930 | NONE |
| 0.00000 | 50 | | | | | |
| 82 | DR110029 | BS | 0.00050 | -8.07340 | -8.07290 | NONE |
| 0.00000 | 51 | | | | | |
| 83 | DR110030 | BS | 0.00122 | -8.03162 | -8.03040 | NONE |
| 0.00000 | 52 | | | | | |
| 84 | DR110031 | BS | 0.00087 | -7.99197 | -7.99110 | NONE |
| 0.00000 | 53 | | | | | |
| 85 | DR210001 | BS | -0.00370 | 1.75970 | NONE | 1.75600 |
| 0.00000 | 54 | | | | | |
| 86 | DR210002 | BS | -0.00336 | 1.77736 | NONE | 1.77400 |
| 0.00000 | 55 | | | | | |
| 87 | DR210003 | BS | -0.00422 | 1.73022 | NONE | 1.72600 |
| 0.00000 | 56 | | | | | |
| 88 | DR210004 | BS | -0.00400 | 1.79700 | NONE | 1.79300 |
| 0.00000 | 57 | | | | | |
| 89 | DR210005 | BS | -0.00520 | 1.75120 | NONE | 1.74600 |
| 0.00000 | 58 | | | | | |
| 90 | DR210006 | BS | -0.00517 | 1.81817 | NONE | 1.81300 |
| 0.00000 | 59 | | | | | |
| 91 | DR210007 | BS | -0.00425 | -8.08635 | -8.09060 | NONE |
| 0.00000 | 60 | | | | | |
| 92 | DR210008 | BS | -0.00451 | -8.13729 | -8.14180 | NONE |
| 0.00000 | 61 | | | | | |
| 93 | DR210009 | BS | -0.00471 | -8.18799 | -8.19270 | NONE |
| 0.00000 | 62 | | | | | |
| 94 | DR210010 | BS | -0.00505 | -8.23825 | -8.24330 | NONE |
| 0.00000 | 63 | | | | | |
| 95 | DR210011 | BS | -0.00564 | -8.28816 | -8.29380 | NONE |
| 0.00000 | 64 | | | | | |
| 96 | DR210012 | BS | -0.00654 | -8.33806 | -8.34460 | NONE |
| 0.00000 | 65 | | | | | |
| 97 | DR210013 | BS | -0.00772 | -8.38798 | -8.39570 | NONE |
| 0.00000 | 66 | | | | | |
| 98 | DR210014 | BS | -0.00899 | -8.43831 | -8.44730 | NONE |
| 0.00000 | 67 | | | | | |
| 99 | DR210015 | BS | -0.01003 | -8.48957 | -8.49960 | NONE |
| 0.00000 | 68 | | | | | |
| 100 | DR210016 | BS | -0.01088 | -8.47292 | -8.48380 | NONE |
| 0.00000 | 69 | | | | | |
| 101 | DR210017 | BS | -0.01160 | -8.45460 | -8.46620 | NONE |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | 0.00000 | 70 |
| 102 | DR210018 | BS | -0.01177 | -8.43453 | -8.44630 | NONE | 0.00000 | 71 |
| 103 | DR210019 | BS | -0.01226 | -8.41184 | -8.42410 | NONE | 0.00000 | 72 |
| 104 | DR210020 | BS | -0.01327 | -8.38573 | -8.39900 | NONE | 0.00000 | 73 |
| 105 | DR210021 | BS | -0.01457 | -8.35623 | -8.37080 | NONE | 0.00000 | 74 |
| 106 | DR210022 | BS | -0.01512 | -8.32408 | -8.33920 | NONE | 0.00000 | 75 |
| 107 | DR210023 | BS | -0.01432 | -8.29098 | -8.30530 | NONE | 0.00000 | 76 |
| 108 | DR210024 | BS | -0.01212 | -8.22218 | -8.23430 | NONE | 0.00000 | 77 |
| 109 | DR210025 | BS | -0.01056 | -8.18724 | -8.19780 | NONE | 0.00000 | 78 |
| 110 | DR210026 | BS | -0.00894 | -8.15196 | -8.16090 | NONE | 0.00000 | 79 |
| 111 | DR210027 | BS | -0.00750 | -8.11620 | -8.12370 | NONE | 0.00000 | 80 |
| 112 | DR210028 | BS | -0.00632 | -8.07998 | -8.08630 | NONE | 0.00000 | 81 |
| 113 | DR210029 | BS | -0.00538 | -8.04322 | -8.04860 | NONE | 0.00000 | 82 |
| 114 | DR210030 | BS | -0.00465 | -8.00605 | -8.01070 | NONE | 0.00000 | 83 |
| 115 | DR210031 | BS | -0.00404 | -7.96846 | -7.97250 | NONE | 0.00000 | 84 |
| 116 | OBJ | BS | 0.03358 | -0.03358 | NONE | NONE | -1.00000 | 85 |

1

SECTION 2 - COLUMNS

| NUMBER | .COLUMN. | | STATE | ...ACTIVITY... | .OBJ GRADIENT. | ..LOWER LIMIT. | ..UPPER LIMIT. | REDUCED GRADNT | M+J |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Q011001 | | BS | 0.05990 | 0.01000 | 0.00000 | NONE | 0.00000 | 86 |
| 2 | Q011002 | | LL | 0.00000 | 0.01000 | 0.00000 | NONE | 0.00101 | 87 |
| 3 | Q011003 | | BS | 0.96886 | 0.01000 | 0.00000 | NONE | 0.00000 | 88 |
| 4 | Q011004 | | LL | 0.00000 | 0.01000 | 0.00000 | NONE | 0.00146 | 89 |
| 5 | Q011005 | | BS | 0.30928 | 0.01000 | 0.00000 | NONE | 0.00000 | 90 |
| 6 | Q011006 | | LL | 0.00000 | 0.01000 | 0.00000 | NONE | 0.00113 | 91 |
| 7 | Q011007 | | BS | 0.13605 | 0.01000 | 0.00000 | NONE | 0.00000 | 92 |
| 8 | Q011008 | | BS | 0.06242 | 0.01000 | 0.00000 | NONE | 0.00000 | 93 |
| 9 | Q011009 | N | UL | 0.00000 | 0.01000 | 0.00000 | NONE | 0.00197 | 94 |
| 10 | Q011010 | | LL | 0.00000 | 0.01000 | 0.00000 | NONE | 0.00707 | 95 |
| 11 | Q011011 | | LL | 0.00000 | 0.01000 | 0.00000 | NONE | 0.01002 | 96 |
| 12 | Q011012 | | LL | 0.00000 | 0.01000 | 0.00000 | NONE | 0.01097 | 97 |
| 13 | Q011013 | | LL | 0.00000 | 0.01000 | 0.00000 | NONE | 0.00912 | 98 |
| 14 | Q011014 | N | UL | 0.00000 | 0.01000 | 0.00000 | NONE | 0.00278 | 99 |
| 15 | Q011015 | | LL | 0.00000 | 0.01000 | 0.00000 | NONE | 0.00390 | 100 |
| 16 | Q011016 | | BS | 0.08496 | 0.01000 | 0.00000 | NONE | 0.00000 | 101 |
| 17 | Q011017 | | BS | 0.50215 | 0.01000 | 0.00000 | NONE | 0.00000 | 102 |
| 18 | Q011018 | | LL | 0.00000 | 0.01000 | 0.00000 | NONE | 0.00198 | 103 |
| 19 | Q011019 | | LL | 0.00000 | 0.01000 | 0.00000 | NONE | 0.00466 | 104 |
| 20 | Q011020 | | LL | 0.00000 | 0.01000 | 0.00000 | NONE | 0.00395 | 105 |
| 21 | Q011021 | | BS | 0.44594 | 0.01000 | 0.00000 | NONE | 0.00000 | 106 |
| 22 | Q011022 | | BS | 0.78846 | 0.01000 | 0.00000 | NONE | 0.00000 | 107 |
| 23 | Q011023 | | LL | 0.00000 | 0.01000 | 0.00000 | NONE | 0.00341 | 108 |
| 24 | Q011024 | | LL | 0.00000 | 0.01000 | 0.00000 | NONE | 0.00700 | 109 |
| 25 | Q011025 | | LL | 0.00000 | 0.01000 | 0.00000 | NONE | 0.01155 | 110 |
| 26 | Q011026 | | LL | 0.00000 | 0.01000 | 0.00000 | NONE | 0.01311 | 111 |
| 27 | Q011027 | | LL | 0.00000 | 0.01000 | 0.00000 | NONE | 0.01316 | 112 |
| 28 | Q011028 | | LL | 0.00000 | 0.01000 | 0.00000 | NONE | 0.01277 | 113 |
| 29 | Q011029 | | LL | 0.00000 | 0.01000 | 0.00000 | NONE | 0.01233 | 114 |
| 30 | Q011030 | | LL | 0.00000 | 0.01000 | 0.00000 | NONE | 0.01194 | 115 |
| 31 | Q011031 | | LL | 0.00000 | 0.01000 | 0.00000 | NONE | 0.01160 | 116 |

ENDRUN

Output file FOR017.DAT

CONTROL LOCATIONS AND UNSTRESSED HEADS

| | Period | Layer | Loc # | I-Loc. | J-Loc. | Unmanaged Head | KEYWL |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 20 | 22 | 16.7079261 | 1 |
| 2 | 1 | 1 | 2 | 21 | 22 | 16.7188919 | 1 |
| 3 | 1 | 1 | 3 | 21 | 23 | 16.6428035 | 1 |
| 4 | 1 | 1 | 4 | 22 | 22 | 16.7328648 | 1 |
| 5 | 1 | 1 | 5 | 22 | 23 | 16.6544444 | 1 |
| 6 | 1 | 1 | 6 | 23 | 22 | 16.7509285 | 1 |
| 7 | 1 | 1 | 7 | 17 | 18 | 16.8956684 | 1 |
| 8 | 1 | 1 | 8 | 17 | 19 | 16.8449315 | 1 |
| 9 | 1 | 1 | 9 | 17 | 20 | 16.7924571 | 1 |
| 10 | 1 | 1 | 10 | 17 | 21 | 16.7379667 | 1 |
| 11 | 1 | 1 | 11 | 17 | 22 | 16.6810113 | 1 |
| 12 | 1 | 1 | 12 | 17 | 23 | 16.6210364 | 1 |
| 13 | 1 | 1 | 13 | 17 | 24 | 16.5575005 | 1 |
| 14 | 1 | 1 | 14 | 17 | 25 | 16.4900929 | 1 |
| 15 | 1 | 1 | 15 | 17 | 26 | 16.4190996 | 1 |
| 16 | 1 | 1 | 16 | 18 | 26 | 16.3994415 | 1 |
| 17 | 1 | 1 | 17 | 19 | 26 | 16.3688969 | 1 |
| 18 | 1 | 1 | 18 | 20 | 26 | 16.3277179 | 1 |
| 19 | 1 | 1 | 19 | 21 | 26 | 16.2814640 | 1 |
| 20 | 1 | 1 | 20 | 22 | 26 | 16.2456039 | 1 |
| 21 | 1 | 1 | 21 | 23 | 26 | 16.2467345 | 1 |
| 22 | 1 | 1 | 22 | 24 | 26 | 16.3066558 | 1 |
| 23 | 1 | 1 | 23 | 25 | 26 | 16.4025292 | 1 |
| 24 | 1 | 1 | 24 | 26 | 25 | 16.6129684 | 1 |
| 25 | 1 | 1 | 25 | 26 | 24 | 16.6987075 | 1 |
| 26 | 1 | 1 | 26 | 26 | 23 | 16.7692123 | 1 |
| 27 | 1 | 1 | 27 | 26 | 22 | 16.8287802 | 1 |
| 28 | 1 | 1 | 28 | 26 | 21 | 16.8806501 | 1 |
| 29 | 1 | 1 | 29 | 26 | 20 | 16.9270835 | 1 |
| 30 | 1 | 1 | 30 | 26 | 19 | 16.9695552 | 1 |
| 31 | 1 | 1 | 31 | 26 | 18 | 17.0089231 | 1 |
| 32 | 1 | 1 | 32 | 18 | 18 | 16.9082426 | 0 |
| 33 | 1 | 1 | 33 | 18 | 19 | 16.8575842 | 0 |
| 34 | 1 | 1 | 34 | 18 | 20 | 16.8046739 | 0 |
| 35 | 1 | 1 | 35 | 18 | 21 | 16.7490479 | 0 |
| 36 | 1 | 1 | 36 | 18 | 22 | 16.6899642 | 0 |
| 37 | 1 | 1 | 37 | 18 | 23 | 16.6264423 | 0 |
| 38 | 1 | 1 | 38 | 18 | 24 | 16.5573729 | 0 |
| 39 | 1 | 1 | 39 | 18 | 25 | 16.4817890 | 0 |
| 40 | 1 | 1 | 40 | 19 | 25 | 16.4681726 | 0 |
| 41 | 1 | 1 | 41 | 20 | 25 | 16.4507685 | 0 |
| 42 | 1 | 1 | 42 | 21 | 25 | 16.4341494 | 0 |
| 43 | 1 | 1 | 43 | 22 | 25 | 16.4270211 | 0 |
| 44 | 1 | 1 | 44 | 23 | 25 | 16.4407097 | 0 |
| 45 | 1 | 1 | 45 | 24 | 25 | 16.4819459 | 0 |
| 46 | 1 | 1 | 46 | 25 | 25 | 16.5433209 | 0 |
| 47 | 1 | 1 | 47 | 25 | 24 | 16.6493995 | 0 |
| 48 | 1 | 1 | 48 | 25 | 23 | 16.7322823 | 0 |
| 49 | 1 | 1 | 49 | 25 | 22 | 16.7998410 | 0 |
| 50 | 1 | 1 | 50 | 25 | 21 | 16.8572357 | 0 |
| 51 | 1 | 1 | 51 | 25 | 20 | 16.9077730 | 0 |
| 52 | 1 | 1 | 52 | 25 | 19 | 16.9535067 | 0 |
| 53 | 1 | 1 | 53 | 25 | 18 | 16.9956182 | 0 |
| 54 | 1 | 1 | 54 | 19 | 18 | 16.9204799 | 0 |
| 55 | 1 | 1 | 55 | 19 | 19 | 16.8700470 | 0 |
| 56 | 1 | 1 | 56 | 19 | 20 | 16.8168119 | 0 |
| 57 | 1 | 1 | 57 | 19 | 21 | 16.7600676 | 0 |
| 58 | 1 | 1 | 58 | 19 | 22 | 16.6986640 | 0 |
| 59 | 1 | 1 | 59 | 19 | 23 | 16.6309742 | 0 |
| 60 | 1 | 1 | 60 | 19 | 24 | 16.5549164 | 0 |
| 61 | 1 | 1 | 61 | 19 | 24 | 16.5549164 | 0 |
| 62 | 1 | 1 | 62 | 19 | 24 | 16.5549164 | 0 |
| 63 | 1 | 1 | 63 | 20 | 24 | 16.5516438 | 0 |
| 64 | 1 | 1 | 64 | 21 | 24 | 16.5506151 | 0 |
| 65 | 1 | 1 | 65 | 22 | 24 | 16.5564706 | 0 |
| 66 | 1 | 1 | 66 | 23 | 24 | 16.5741807 | 0 |
| 67 | 1 | 1 | 67 | 24 | 24 | 16.6060980 | 0 |
| 68 | 1 | 1 | 68 | 24 | 24 | 16.6060980 | 0 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 69 | 1 | 1 | 69 | 24 | 24 | 16.6060980 | 0 |
| 70 | 1 | 1 | 70 | 24 | 23 | 16.6993507 | 0 |
| 71 | 1 | 1 | 71 | 24 | 22 | 16.7734559 | 0 |
| 72 | 1 | 1 | 72 | 24 | 21 | 16.8353959 | 0 |
| 73 | 1 | 1 | 73 | 24 | 20 | 16.8893818 | 0 |
| 74 | 1 | 1 | 74 | 24 | 19 | 16.9379389 | 0 |
| 75 | 1 | 1 | 75 | 24 | 18 | 16.9824952 | 0 |
| 76 | 1 | 2 | 1 | 20 | 22 | 16.7558550 | 1 |
| 77 | 1 | 2 | 2 | 21 | 22 | 16.7738631 | 1 |
| 78 | 1 | 2 | 3 | 21 | 23 | 16.7255350 | 1 |
| 79 | 1 | 2 | 4 | 22 | 22 | 16.7927721 | 1 |
| 80 | 1 | 2 | 5 | 22 | 23 | 16.7459353 | 1 |
| 81 | 1 | 2 | 6 | 23 | 22 | 16.8125971 | 1 |
| 82 | 1 | 2 | 7 | 17 | 18 | 16.9094186 | 1 |
| 83 | 1 | 2 | 8 | 17 | 19 | 16.8581673 | 1 |
| 84 | 1 | 2 | 9 | 17 | 20 | 16.8073478 | 1 |
| 85 | 1 | 2 | 10 | 17 | 21 | 16.7567465 | 1 |
| 86 | 1 | 2 | 11 | 17 | 22 | 16.7061653 | 1 |
| 87 | 1 | 2 | 12 | 17 | 23 | 16.6554197 | 1 |
| 88 | 1 | 2 | 13 | 17 | 24 | 16.6043356 | 1 |
| 89 | 1 | 2 | 14 | 17 | 25 | 16.5527417 | 1 |
| 90 | 1 | 2 | 15 | 17 | 26 | 16.5004483 | 1 |
| 91 | 1 | 2 | 16 | 18 | 26 | 16.5161627 | 1 |
| 92 | 1 | 2 | 17 | 19 | 26 | 16.5338191 | 1 |
| 93 | 1 | 2 | 18 | 20 | 26 | 16.5536639 | 1 |
| 94 | 1 | 2 | 19 | 21 | 26 | 16.5759324 | 1 |
| 95 | 1 | 2 | 20 | 22 | 26 | 16.6009866 | 1 |
| 96 | 1 | 2 | 21 | 23 | 26 | 16.6292429 | 1 |
| 97 | 1 | 2 | 22 | 24 | 26 | 16.6607542 | 1 |
| 98 | 1 | 2 | 23 | 25 | 26 | 16.6947132 | 1 |
| 99 | 1 | 2 | 24 | 26 | 25 | 16.7656991 | 1 |
| 100 | 1 | 2 | 25 | 26 | 24 | 16.8022088 | 1 |
| 101 | 1 | 2 | 26 | 26 | 23 | 16.8391452 | 1 |
| 102 | 1 | 2 | 27 | 26 | 22 | 16.8763430 | 1 |
| 103 | 1 | 2 | 28 | 26 | 21 | 16.9137463 | 1 |
| 104 | 1 | 2 | 29 | 26 | 20 | 16.9513676 | 1 |
| 105 | 1 | 2 | 30 | 26 | 19 | 16.9892635 | 1 |
| 106 | 1 | 2 | 31 | 26 | 18 | 17.0275219 | 1 |
| 107 | 1 | 2 | 32 | 18 | 18 | 16.9236891 | 0 |
| 108 | 1 | 2 | 33 | 18 | 19 | 16.8730209 | 0 |
| 109 | 1 | 2 | 34 | 18 | 20 | 16.8226843 | 0 |
| 110 | 1 | 2 | 35 | 18 | 21 | 16.7724636 | 0 |
| 111 | 1 | 2 | 36 | 18 | 22 | 16.7221522 | 0 |
| 112 | 1 | 2 | 37 | 18 | 23 | 16.6715522 | 0 |
| 113 | 1 | 2 | 38 | 18 | 24 | 16.6204761 | 0 |
| 114 | 1 | 2 | 39 | 18 | 25 | 16.5687428 | 0 |
| 115 | 1 | 2 | 40 | 19 | 25 | 16.5862201 | 0 |
| 116 | 1 | 2 | 41 | 20 | 25 | 16.6054406 | 0 |
| 117 | 1 | 2 | 42 | 21 | 25 | 16.6266564 | 0 |
| 118 | 1 | 2 | 43 | 22 | 25 | 16.6501281 | 0 |
| 119 | 1 | 2 | 44 | 23 | 25 | 16.6760457 | 0 |
| 120 | 1 | 2 | 45 | 24 | 25 | 16.7043280 | 0 |
| 121 | 1 | 2 | 46 | 25 | 25 | 16.7344646 | 0 |
| 122 | 1 | 2 | 47 | 25 | 24 | 16.7744965 | 0 |
| 123 | 1 | 2 | 48 | 25 | 23 | 16.8145648 | 0 |
| 124 | 1 | 2 | 49 | 25 | 22 | 16.8545924 | 0 |
| 125 | 1 | 2 | 50 | 25 | 21 | 16.8945966 | 0 |
| 126 | 1 | 2 | 51 | 25 | 20 | 16.9346494 | 0 |
| 127 | 1 | 2 | 52 | 25 | 19 | 16.9748550 | 0 |
| 128 | 1 | 2 | 53 | 25 | 18 | 17.0153399 | 0 |
| 129 | 1 | 2 | 54 | 19 | 18 | 16.9375180 | 0 |
| 130 | 1 | 2 | 55 | 19 | 19 | 16.8876567 | 0 |
| 131 | 1 | 2 | 56 | 19 | 20 | 16.8380370 | 0 |
| 132 | 1 | 2 | 57 | 19 | 21 | 16.7884429 | 0 |
| 133 | 1 | 2 | 58 | 19 | 22 | 16.7386620 | 0 |
| 134 | 1 | 2 | 59 | 19 | 23 | 16.6884887 | 0 |
| 135 | 1 | 2 | 60 | 19 | 24 | 16.6377311 | 0 |
| 136 | 1 | 2 | 61 | 19 | 24 | 16.6377311 | 0 |
| 137 | 1 | 2 | 62 | 19 | 24 | 16.6377311 | 0 |
| 138 | 1 | 2 | 63 | 20 | 24 | 16.6563388 | 0 |
| 139 | 1 | 2 | 64 | 21 | 24 | 16.6765135 | 0 |
| 140 | 1 | 2 | 65 | 22 | 24 | 16.6984332 | 0 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 141 | 1 | 2 | 66 | 23 | 24 | 16.7221809 | 0 |
| 142 | 1 | 2 | 67 | 24 | 24 | 16.7476509 | 0 |
| 143 | 1 | 2 | 68 | 24 | 24 | 16.7476509 | 0 |
| 144 | 1 | 2 | 69 | 24 | 24 | 16.7476509 | 0 |
| 145 | 1 | 2 | 70 | 24 | 23 | 16.7906200 | 0 |
| 146 | 1 | 2 | 71 | 24 | 22 | 16.8332615 | 0 |
| 147 | 1 | 2 | 72 | 24 | 21 | 16.8756697 | 0 |
| 148 | 1 | 2 | 73 | 24 | 20 | 16.9179741 | 0 |
| 149 | 1 | 2 | 74 | 24 | 19 | 16.9603231 | 0 |
| 150 | 1 | 2 | 75 | 24 | 18 | 17.0028765 | 0 |

USER IMPOSED LIMITS ON HEAD AT CONTROL LOCATIONS

| PERIOD | LOC. # | I-LOCATION | J-LOCATION | LIMIT | TYPE | KEYGRD | KDEFHD |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 20 | 22 | 0.000E+00 | G | 0 | 0 |
| 1 | 2 | 21 | 22 | 0.000E+00 | G | 0 | 0 |
| 1 | 3 | 21 | 23 | 0.000E+00 | G | 0 | 0 |
| 1 | 4 | 22 | 22 | 0.000E+00 | G | 0 | 0 |
| 1 | 5 | 22 | 23 | 0.000E+00 | G | 0 | 0 |
| 1 | 6 | 23 | 22 | 0.000E+00 | G | 0 | 0 |
| 1 | 7 | 17 | 18 | 25.0 | L | 0 | 0 |
| 1 | 8 | 17 | 19 | 25.0 | L | 0 | 0 |
| 1 | 9 | 17 | 20 | 25.0 | L | 0 | 0 |
| 1 | 10 | 17 | 21 | 25.0 | L | 0 | 0 |
| 1 | 11 | 17 | 22 | 25.0 | L | 0 | 0 |
| 1 | 12 | 17 | 23 | 25.0 | L | 0 | 0 |
| 1 | 13 | 17 | 24 | 25.0 | L | 0 | 0 |
| 1 | 14 | 17 | 25 | 25.0 | L | 0 | 0 |
| 1 | 15 | 17 | 26 | 25.0 | L | 0 | 0 |
| 1 | 16 | 18 | 26 | 25.0 | L | 0 | 0 |
| 1 | 17 | 19 | 26 | 25.0 | L | 0 | 0 |
| 1 | 18 | 20 | 26 | 25.0 | L | 0 | 0 |
| 1 | 19 | 21 | 26 | 25.0 | L | 0 | 0 |
| 1 | 20 | 22 | 26 | 25.0 | L | 0 | 0 |
| 1 | 21 | 23 | 26 | 25.0 | L | 0 | 0 |
| 1 | 22 | 24 | 26 | 25.0 | L | 0 | 0 |
| 1 | 23 | 25 | 26 | 25.0 | L | 0 | 0 |
| 1 | 24 | 26 | 25 | 25.0 | L | 0 | 0 |
| 1 | 25 | 26 | 24 | 25.0 | L | 0 | 0 |
| 1 | 26 | 26 | 23 | 25.0 | L | 0 | 0 |
| 1 | 27 | 26 | 22 | 25.0 | L | 0 | 0 |
| 1 | 28 | 26 | 21 | 25.0 | L | 0 | 0 |
| 1 | 29 | 26 | 20 | 25.0 | L | 0 | 0 |
| 1 | 30 | 26 | 19 | 25.0 | L | 0 | 0 |
| 1 | 31 | 26 | 18 | 25.0 | L | 0 | 0 |
| 1 | 32 | 18 | 18 | 0.000E+00 | | 1 | 0 |
| 1 | 33 | 18 | 19 | 0.000E+00 | | 1 | 0 |
| 1 | 34 | 18 | 20 | 0.000E+00 | | 1 | 0 |
| 1 | 35 | 18 | 21 | 0.000E+00 | | 1 | 0 |
| 1 | 36 | 18 | 22 | 0.000E+00 | | 1 | 0 |
| 1 | 37 | 18 | 23 | 0.000E+00 | | 1 | 0 |
| 1 | 38 | 18 | 24 | 0.000E+00 | | 1 | 0 |
| 1 | 39 | 18 | 25 | 0.000E+00 | | 1 | 0 |
| 1 | 40 | 19 | 25 | 0.000E+00 | | 1 | 0 |
| 1 | 41 | 20 | 25 | 0.000E+00 | | 1 | 0 |
| 1 | 42 | 21 | 25 | 0.000E+00 | | 1 | 0 |
| 1 | 43 | 22 | 25 | 0.000E+00 | | 1 | 0 |
| 1 | 44 | 23 | 25 | 0.000E+00 | | 1 | 0 |
| 1 | 45 | 24 | 25 | 0.000E+00 | | 1 | 0 |
| 1 | 46 | 25 | 25 | 0.000E+00 | | 1 | 0 |
| 1 | 47 | 25 | 24 | 0.000E+00 | | 1 | 0 |
| 1 | 48 | 25 | 23 | 0.000E+00 | | 1 | 0 |
| 1 | 49 | 25 | 22 | 0.000E+00 | | 1 | 0 |
| 1 | 50 | 25 | 21 | 0.000E+00 | | 1 | 0 |
| 1 | 51 | 25 | 20 | 0.000E+00 | | 1 | 0 |
| 1 | 52 | 25 | 19 | 0.000E+00 | | 1 | 0 |
| 1 | 53 | 25 | 18 | 0.000E+00 | | 1 | 0 |
| 1 | 54 | 19 | 18 | 0.000E+00 | | 1 | 0 |
| 1 | 55 | 19 | 19 | 0.000E+00 | | 1 | 0 |
| 1 | 56 | 19 | 20 | 0.000E+00 | | 1 | 0 |
| 1 | 57 | 19 | 21 | 0.000E+00 | | 1 | 0 |
| 1 | 58 | 19 | 22 | 0.000E+00 | | 1 | 0 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 | 59 | 19 | 23 | 0.000E+00 | | 1 | 0 |
| 1 | 60 | 19 | 24 | 0.000E+00 | | 1 | 0 |
| 1 | 61 | 19 | 24 | 0.000E+00 | | 1 | 0 |
| 1 | 62 | 19 | 24 | 0.000E+00 | | 1 | 0 |
| 1 | 63 | 20 | 24 | 0.000E+00 | | 1 | 0 |
| 1 | 64 | 21 | 24 | 0.000E+00 | | 1 | 0 |
| 1 | 65 | 22 | 24 | 0.000E+00 | | 1 | 0 |
| 1 | 66 | 23 | 24 | 0.000E+00 | | 1 | 0 |
| 1 | 67 | 24 | 24 | 0.000E+00 | | 1 | 0 |
| 1 | 68 | 24 | 24 | 0.000E+00 | | 1 | 0 |
| 1 | 69 | 24 | 24 | 0.000E+00 | | 1 | 0 |
| 1 | 70 | 24 | 23 | 0.000E+00 | | 1 | 0 |
| 1 | 71 | 24 | 22 | 0.000E+00 | | 1 | 0 |
| 1 | 72 | 24 | 21 | 0.000E+00 | | 1 | 0 |
| 1 | 73 | 24 | 20 | 0.000E+00 | | 1 | 0 |
| 1 | 74 | 24 | 19 | 0.000E+00 | | 1 | 0 |
| 1 | 75 | 24 | 18 | 0.000E+00 | | 1 | 0 |
| 1 | 1 | 20 | 22 | 0.000E+00 | G | 0 | 0 |
| 1 | 2 | 21 | 22 | 0.000E+00 | G | 0 | 0 |
| 1 | 3 | 21 | 23 | 0.000E+00 | G | 0 | 0 |
| 1 | 4 | 22 | 22 | 0.000E+00 | G | 0 | 0 |
| 1 | 5 | 22 | 23 | 0.000E+00 | G | 0 | 0 |
| 1 | 6 | 23 | 22 | 0.000E+00 | G | 0 | 0 |
| 1 | 7 | 17 | 18 | 25.0 | L | 0 | 0 |
| 1 | 8 | 17 | 19 | 25.0 | L | 0 | 0 |
| 1 | 9 | 17 | 20 | 25.0 | L | 0 | 0 |
| 1 | 10 | 17 | 21 | 25.0 | L | 0 | 0 |
| 1 | 11 | 17 | 22 | 25.0 | L | 0 | 0 |
| 1 | 12 | 17 | 23 | 25.0 | L | 0 | 0 |
| 1 | 13 | 17 | 24 | 25.0 | L | 0 | 0 |
| 1 | 14 | 17 | 25 | 25.0 | L | 0 | 0 |
| 1 | 15 | 17 | 26 | 25.0 | L | 0 | 0 |
| 1 | 16 | 18 | 26 | 25.0 | L | 0 | 0 |
| 1 | 17 | 19 | 26 | 25.0 | L | 0 | 0 |
| 1 | 18 | 20 | 26 | 25.0 | L | 0 | 0 |
| 1 | 19 | 21 | 26 | 25.0 | L | 0 | 0 |
| 1 | 20 | 22 | 26 | 25.0 | L | 0 | 0 |
| 1 | 21 | 23 | 26 | 25.0 | L | 0 | 0 |
| 1 | 22 | 24 | 26 | 25.0 | L | 0 | 0 |
| 1 | 23 | 25 | 26 | 25.0 | L | 0 | 0 |
| 1 | 24 | 26 | 25 | 25.0 | L | 0 | 0 |
| 1 | 25 | 26 | 24 | 25.0 | L | 0 | 0 |
| 1 | 26 | 26 | 23 | 25.0 | L | 0 | 0 |
| 1 | 27 | 26 | 22 | 25.0 | L | 0 | 0 |
| 1 | 28 | 26 | 21 | 25.0 | L | 0 | 0 |
| 1 | 29 | 26 | 20 | 25.0 | L | 0 | 0 |
| 1 | 30 | 26 | 19 | 25.0 | L | 0 | 0 |
| 1 | 31 | 26 | 18 | 25.0 | L | 0 | 0 |
| 1 | 32 | 18 | 18 | 0.000E+00 | | 1 | 0 |
| 1 | 33 | 18 | 19 | 0.000E+00 | | 1 | 0 |
| 1 | 34 | 18 | 20 | 0.000E+00 | | 1 | 0 |
| 1 | 35 | 18 | 21 | 0.000E+00 | | 1 | 0 |
| 1 | 36 | 18 | 22 | 0.000E+00 | | 1 | 0 |
| 1 | 37 | 18 | 23 | 0.000E+00 | | 1 | 0 |
| 1 | 38 | 18 | 24 | 0.000E+00 | | 1 | 0 |
| 1 | 39 | 18 | 25 | 0.000E+00 | | 1 | 0 |
| 1 | 40 | 19 | 25 | 0.000E+00 | | 1 | 0 |
| 1 | 41 | 20 | 25 | 0.000E+00 | | 1 | 0 |
| 1 | 42 | 21 | 25 | 0.000E+00 | | 1 | 0 |
| 1 | 43 | 22 | 25 | 0.000E+00 | | 1 | 0 |
| 1 | 44 | 23 | 25 | 0.000E+00 | | 1 | 0 |
| 1 | 45 | 24 | 25 | 0.000E+00 | | 1 | 0 |
| 1 | 46 | 25 | 25 | 0.000E+00 | | 1 | 0 |
| 1 | 47 | 25 | 24 | 0.000E+00 | | 1 | 0 |
| 1 | 48 | 25 | 23 | 0.000E+00 | | 1 | 0 |
| 1 | 49 | 25 | 22 | 0.000E+00 | | 1 | 0 |
| 1 | 50 | 25 | 21 | 0.000E+00 | | 1 | 0 |
| 1 | 51 | 25 | 20 | 0.000E+00 | | 1 | 0 |
| 1 | 52 | 25 | 19 | 0.000E+00 | | 1 | 0 |
| 1 | 53 | 25 | 18 | 0.000E+00 | | 1 | 0 |
| 1 | 54 | 19 | 18 | 0.000E+00 | | 1 | 0 |
| 1 | 55 | 19 | 19 | 0.000E+00 | | 1 | 0 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 1 | 56 | 19 | 20 | 0.000E+00 | 1 | 0 |
| 1 | 57 | 19 | 21 | 0.000E+00 | 1 | 0 |
| 1 | 58 | 19 | 22 | 0.000E+00 | 1 | 0 |
| 1 | 59 | 19 | 23 | 0.000E+00 | 1 | 0 |
| 1 | 60 | 19 | 24 | 0.000E+00 | 1 | 0 |
| 1 | 61 | 19 | 24 | 0.000E+00 | 1 | 0 |
| 1 | 62 | 19 | 24 | 0.000E+00 | 1 | 0 |
| 1 | 63 | 20 | 24 | 0.000E+00 | 1 | 0 |
| 1 | 64 | 21 | 24 | 0.000E+00 | 1 | 0 |
| 1 | 65 | 22 | 24 | 0.000E+00 | 1 | 0 |
| 1 | 66 | 23 | 24 | 0.000E+00 | 1 | 0 |
| 1 | 67 | 24 | 24 | 0.000E+00 | 1 | 0 |
| 1 | 68 | 24 | 24 | 0.000E+00 | 1 | 0 |
| 1 | 69 | 24 | 24 | 0.000E+00 | 1 | 0 |
| 1 | 70 | 24 | 23 | 0.000E+00 | 1 | 0 |
| 1 | 71 | 24 | 22 | 0.000E+00 | 1 | 0 |
| 1 | 72 | 24 | 21 | 0.000E+00 | 1 | 0 |
| 1 | 73 | 24 | 20 | 0.000E+00 | 1 | 0 |
| 1 | 74 | 24 | 19 | 0.000E+00 | 1 | 0 |
| 1 | 75 | 24 | 18 | 0.000E+00 | 1 | 0 |

user imposed limits on pumping at wells

| Layer | Loc. # | I-Location | J-Location | Limit |
|---|---|---|---|---|

WELL LOCATIONS AND TYPE

| Period | Loc. # | I-Loc. | J-Loc. | KEYQ | Fixed or Unit Rate |
|---|---|---|---|---|---|
| 1 | 1 | 15 | 51 | 1 | -.1100 |
| 1 | 2 | 18 | 33 | 1 | -.1200 |
| 1 | 3 | 23 | 30 | 1 | -.1000E+00 |
| 1 | 4 | 22 | 18 | 1 | 0.1530E-04 |
| 1 | 5 | 20 | 22 | 0 | -.1000E-01 |
| 1 | 6 | 21 | 22 | 0 | -.1000E-01 |
| 1 | 7 | 21 | 23 | 0 | -.1000E-01 |
| 1 | 8 | 22 | 22 | 0 | -.1000E-01 |
| 1 | 9 | 22 | 23 | 0 | -.1000E-01 |
| 1 | 10 | 23 | 22 | 0 | -.1000E-01 |
| 1 | 11 | 17 | 18 | 0 | 0.1000E-01 |
| 1 | 12 | 17 | 19 | 0 | 0.1000E-01 |
| 1 | 13 | 17 | 20 | 0 | 0.1000E-01 |
| 1 | 14 | 17 | 21 | 0 | 0.1000E-01 |
| 1 | 15 | 17 | 22 | 0 | 0.1000E-01 |
| 1 | 16 | 17 | 23 | 0 | 0.1000E-01 |
| 1 | 17 | 17 | 24 | 0 | 0.1000E-01 |
| 1 | 18 | 17 | 25 | 0 | 0.1000E-01 |
| 1 | 19 | 17 | 26 | 0 | 0.1000E-01 |
| 1 | 20 | 18 | 26 | 0 | 0.1000E-01 |
| 1 | 21 | 19 | 26 | 0 | 0.1000E-01 |
| 1 | 22 | 20 | 26 | 0 | 0.1000E-01 |
| 1 | 23 | 21 | 26 | 0 | 0.1000E-01 |
| 1 | 24 | 22 | 26 | 0 | 0.1000E-01 |
| 1 | 25 | 23 | 26 | 0 | 0.1000E-01 |
| 1 | 26 | 24 | 26 | 0 | 0.1000E-01 |
| 1 | 27 | 25 | 26 | 0 | 0.1000E-01 |
| 1 | 28 | 26 | 25 | 0 | 0.1000E-01 |
| 1 | 29 | 26 | 24 | 0 | 0.1000E-01 |
| 1 | 30 | 26 | 23 | 0 | 0.1000E-01 |
| 1 | 31 | 26 | 22 | 0 | 0.1000E-01 |
| 1 | 32 | 26 | 21 | 0 | 0.1000E-01 |
| 1 | 33 | 26 | 20 | 0 | 0.1000E-01 |
| 1 | 34 | 26 | 19 | 0 | 0.1000E-01 |
| 1 | 35 | 26 | 18 | 0 | 0.1000E-01 |

CONTROL PAIR LOCATIONS AND DEFINITIONS

| Pair # | 1st I-Loc. | 1st J-Loc. | 2nd I-Loc. | 2nd J-Loc. | KDEFGR |
|---|---|---|---|---|---|
| 1 | 18 | 18 | 19 | 18 | 0 |
| 2 | 18 | 19 | 19 | 19 | 0 |
| 3 | 18 | 20 | 19 | 20 | 0 |
| 4 | 18 | 21 | 19 | 21 | 0 |
| 5 | 18 | 22 | 19 | 22 | 0 |
| 6 | 18 | 23 | 19 | 23 | 0 |
| 7 | 18 | 24 | 19 | 24 | 0 |
| 8 | 18 | 25 | 19 | 24 | 0 |
| 9 | 19 | 25 | 19 | 24 | 0 |
| 10 | 20 | 25 | 20 | 24 | 0 |
| 11 | 21 | 25 | 21 | 24 | 0 |
| 12 | 22 | 25 | 22 | 24 | 0 |
| 13 | 23 | 25 | 23 | 24 | 0 |
| 14 | 24 | 25 | 24 | 24 | 0 |
| 15 | 25 | 25 | 24 | 24 | 0 |
| 16 | 25 | 24 | 24 | 24 | 0 |
| 17 | 25 | 23 | 24 | 23 | 0 |
| 18 | 25 | 22 | 24 | 22 | 0 |
| 19 | 25 | 21 | 24 | 21 | 0 |
| 20 | 25 | 20 | 24 | 20 | 0 |
| 21 | 25 | 19 | 24 | 19 | 0 |
| 22 | 25 | 18 | 24 | 18 | 0 |

USER IMPOSED LIMITS ON HEAD DIFFERENCE AT CONTROL PAIRS

| PERIOD | PAIR # | CONVERSION FACTOR | DIFFERENCE LIMIT | TYPE |
|---|---|---|---|---|
| 1 | 1 | 1.00000 | 0.100000E-01 | G |
| 1 | 2 | 1.00000 | 0.100000E-01 | G |
| 1 | 3 | 1.00000 | 0.100000E-01 | G |
| 1 | 4 | 1.00000 | 0.100000E-01 | G |
| 1 | 5 | 1.00000 | 0.100000E-01 | G |
| 1 | 6 | 1.00000 | 0.100000E-01 | G |
| 1 | 7 | 1.00000 | 0.100000E-01 | G |
| 1 | 8 | 1.00000 | 0.100000E-01 | G |
| 1 | 9 | 1.00000 | 0.100000E-01 | G |
| 1 | 10 | 1.00000 | 0.100000E-01 | G |
| 1 | 11 | 1.00000 | 0.100000E-01 | G |
| 1 | 12 | 1.00000 | 0.100000E-01 | G |
| 1 | 13 | 1.00000 | 0.100000E-01 | G |
| 1 | 14 | 1.00000 | 0.100000E-01 | G |
| 1 | 15 | 1.00000 | 0.100000E-01 | G |
| 1 | 16 | 1.00000 | 0.100000E-01 | G |
| 1 | 17 | 1.00000 | 0.100000E-01 | G |
| 1 | 18 | 1.00000 | 0.100000E-01 | G |
| 1 | 19 | 1.00000 | 0.100000E-01 | G |
| 1 | 20 | 1.00000 | 0.100000E-01 | G |
| 1 | 21 | 1.00000 | 0.100000E-01 | G |
| 1 | 22 | 1.00000 | 0.100000E-01 | G |
| 1 | 1 | 1.00000 | 0.100000E-01 | G |
| 1 | 2 | 1.00000 | 0.100000E-01 | G |
| 1 | 3 | 1.00000 | 0.100000E-01 | G |
| 1 | 4 | 1.00000 | 0.100000E-01 | G |
| 1 | 5 | 1.00000 | 0.100000E-01 | G |
| 1 | 6 | 1.00000 | 0.100000E-01 | G |
| 1 | 7 | 1.00000 | 0.100000E-01 | G |
| 1 | 8 | 1.00000 | 0.100000E-01 | G |
| 1 | 9 | 1.00000 | 0.100000E-01 | G |
| 1 | 10 | 1.00000 | 0.100000E-01 | G |
| 1 | 11 | 1.00000 | 0.100000E-01 | G |
| 1 | 12 | 1.00000 | 0.100000E-01 | G |
| 1 | 13 | 1.00000 | 0.100000E-01 | G |
| 1 | 14 | 1.00000 | 0.100000E-01 | G |
| 1 | 15 | 1.00000 | 0.100000E-01 | G |
| 1 | 16 | 1.00000 | 0.100000E-01 | G |
| 1 | 17 | 1.00000 | 0.100000E-01 | G |
| 1 | 18 | 1.00000 | 0.100000E-01 | G |
| 1 | 19 | 1.00000 | 0.100000E-01 | G |
| 1 | 20 | 1.00000 | 0.100000E-01 | G |
| 1 | 21 | 1.00000 | 0.100000E-01 | G |
| 1 | 22 | 1.00000 | 0.100000E-01 | G |

# APPENDIX G

## MODFLOW+STR (transient) input data files for the subsystem.

Selected parts of input data STRBAS.DAT

```
cenario 8.1, meandering river with diversion, smaller grid sys. Dec. 07, 1991.
-- Unsteady State, const. head, rech. two layers, stream stage,lower lake level
          2         39        58         1         1
  7  4                    8 13       14 15
          0          1
          1          1 (5813)                 -1
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
 -1  0  0  0  0  0  0  0  0  0  0  0  0 -1 -1 -1 -1  0  0  0  0  0  0  0
 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  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  0  0  0  0  0  0 -1 -1  1  1  1  1  1  0  0  0  0  0  0
  0 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  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  0  0  0
  0  0 -1 -1 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
  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
  0  0  0  0  0 -1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
  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

  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  1  1  1  1  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  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  1
  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  1  1  1  1  1  1  1  1  1  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
          1          1 (5813)                 -1
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  1  1  1  1  1  1  1  1  1  1  1  1  1  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  0  0  0  0  0  0  1  1  1  1  1  1  1  0  0  0  0  0  0
  0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  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  0  0  0
  0  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
  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

  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  1  1  1  1  1  1  1  1  1  1  1  1  1  1
  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
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  1  1  1  1  1  1  1  1  1
  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
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  1  1  1  1  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  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  1
  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  1  1  1  1  1  1  1  1  1  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
       999.
          1         1.0    (58F9.3)               -1
   999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000
 999.000  999.000  999.000  999.000  999.000  999.000   14.300   14.300   14.300   14.300   14.300
  14.300   14.300   14.300   14.300   14.300   14.300   14.300   14.300   14.300   14.300   14.300
  14.300   14.300  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000
 999.000  999.000  999.000   14.300   14.300   14.300   14.300  999.000  999.000  999.000  999.000
 999.000  999.000  999.000
    17.160   17.013   16.867   16.652   16.434   16.247   16.101   15.989   15.911   15.855   15.815
  15.786   15.761   15.735   15.710   15.683   15.656   15.628   15.601   15.574   15.547   15.520
  15.492   15.464   15.434   15.403   15.368   15.330   15.286   15.232   15.166   15.079   14.963
  14.802   14.575   14.300   14.300   14.300  999.000  999.000  999.000  999.000  999.000  999.000
 999.000   14.300   14.300   14.326   14.355   14.382   14.513   14.582  999.000  999.000  999.000
```

```
999.000  999.000  999.000
  999.000   17.160   16.999   16.820   16.617   16.418   16.257   16.131   16.043   15.978   15.931
15.897   15.867   15.838   15.807   15.777   15.746   15.714   15.682   15.649   15.615   15.581
15.546   15.510   15.472   15.432   15.390   15.344   15.293   15.235   15.167   15.084   14.979
14.842   14.657   14.443   14.327   14.311   14.300   14.300   14.300   14.300   14.300   14.300
14.300   14.341   14.395   14.458   14.528   14.591   14.891   15.064   15.177   15.267   999.000
999.000  999.000  999.000

  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000
999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000
999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000
999.000  999.000  999.000   18.197   18.197   18.197   18.197   18.197   18.197   18.197   18.196
18.196   999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000
999.000  999.000  999.000
  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000
999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000
999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000
999.000  999.000  999.000  999.000  999.000  999.000   18.302  999.000  999.000  999.000  999.000
999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000
999.000  999.000  999.000
          1        1.0   (58F9.3)                  -1
  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000
999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000
999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000
999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000
999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000
999.000  999.000  999.000
  999.000   17.009   16.865   16.649   16.431   16.244   16.098   15.987   15.909   15.853   15.813
15.784   15.759   15.735   15.710   15.684   15.659   15.634   15.608   15.583   15.557   15.532
15.506   15.481   15.455   15.430   15.405   15.380   15.355   15.331   15.308   15.286   15.265
15.247   15.232   15.223   15.220   15.219   999.000  999.000  999.000  999.000  999.000  999.000
999.000   14.531   14.531   14.533   14.538   14.547   14.565   14.586   999.000  999.000  999.000
999.000  999.000  999.000
  999.000   17.133   16.997   16.816   16.612   16.415   16.254   16.129   16.040   15.975   15.928
15.894   15.865   15.835   15.805   15.774   15.743   15.712   15.680   15.648   15.615   15.582
15.548   15.514   15.479   15.444   15.408   15.372   15.335   15.298   15.261   15.224   15.187
15.151   15.117   15.090   15.073   15.062   15.055   15.050   15.045   15.040   15.036   15.030
15.022   15.012   15.000   14.988   14.979   14.983   15.013   15.077   15.176   15.265   999.000
999.000  999.000  999.000

  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000
999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000
999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000
999.000  999.000  999.000   18.146   18.146   18.146   18.146   18.146   18.146   18.146   18.146
18.146   999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000
999.000  999.000  999.000
  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000
999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000
999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000
999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000
999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000
999.000  999.000  999.000
  15552000         1          1.0
        12        16         28         35        100
                                                        ibeg,jbeg,iend,jend,imult
                                                        variables for sub-system.
```

Selected parts of input data STRBCF.DAT

```
         0         0               iss=0 (transient condition)
 1 0
         0         1.
         7         1.(58F5.0)
 400. 400. 350. 250. 180. 120.  90.  60.  40.  30.  20.  15.  15.  15.  15.  15.  15.  15.  15.  15.
```

```
 15.  15.  15.  15.  15.  15.  15.  15.  15.  15.  15.  15.  15.  15.  15.  10.   7.   5.   3.   3.
 3.   3.   3.   5.   7.  10.  15.  20.  30.  40.  60.  90. 120. 180. 250. 350. 400. 400.
         7         1.(39F5.0)
 400. 400. 350. 250. 180. 120.  90.  60.  40.  30.  20.  15.  15.  15.  15.  15.  15.  15.  15.  15.
 15.  15.  15.  15.  15.  15.  15.  15.  20.  30.  40.  60.  90. 120. 180. 250. 350. 400. 400.
         7         1. (58f5.2)                    specific yield - layer 1
 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27
0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.25 0.25 0.25 0.25
0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.28 0.28 0.28 0.28 0.28 0.28 0.27 0.27
 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27
0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.25 0.25 0.25 0.25
0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.28 0.28 0.28 0.28 0.28 0.28 0.27 0.27

 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27
0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.25 0.25 0.25 0.25
0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.28 0.28 0.28 0.28 0.28 0.28 0.27 0.27
 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27
0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.27 0.25 0.25 0.25 0.25
0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.25 0.28 0.28 0.28 0.28 0.28 0.28 0.27 0.27
         7 5.208E-04  (58F5.0)                -1  hy.cond. - layer 1
   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
 1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.  10.  10.  10.  10.  10.
10.  10.  10.  10.  10.  10.  10.  10.  10. .666 .666 .666 .666 .666 .666   1.   1.
   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
 1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.  10.  10.  10.  10.  10.
10.  10.  10.  10.  10.  10.  10.  10.  10. .666 .666 .666 .666 .666 .666   1.   1.

   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
 1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.  10.  10.  10.  10.  10.
10.  10.  10.  10.  10.  10.  10.  10.  10. .666 .666 .666 .666 .666 .666   1.   1.
   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
 1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.  10.  10.  10.  10.  10.
10.  10.  10.  10.  10.  10.  10.  10.  10. .666 .666 .666 .666 .666 .666   1.   1.
   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
 1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.  10.  10.  10.  10.  10.
10.  10.  10.  10.  10.  10.  10.  10.  10. .666 .666 .666 .666 .666 .666   1.   1.
         0       0.0                           bottom layer 1
         0  5.00E-06                           vert.hy.cond/thick layer 1
         0    .00015                           storage coeff - layer 2
         0   0.15624                           trans. - layer
```

Selected parts of input data STRRCH.DAT

```
         1         0
         1
         8 1.176E-08 (58F5.0)            -1
    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1
  1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1
1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1
    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1
  1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1
1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1
    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1
  1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1
1    1    1    1    1    1    1    1    1    11.6521.6521.6521.6521.6521.652    1    1

    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1
  1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1
1    1    1    1    1    1    1    1    1    11.6521.6521.6521.6521.6521.652    1    1
    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1
  1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1
1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1
    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1
  1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1
1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1
```

Input data STRSTR.DAT

1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1

Input data STRSTR.DAT

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 41 | | 3 | | 1 | 1 | 1 | 1.000 | -1 | 0 |
| | 41 | | 0 | | 0 | | | | | |
| 1 | 39 | 40 | 1 | 1 | | 1.14 | 19.5 | 1.00 | 17.5 | 18.0 |
| 1 | 38 | 40 | 1 | 2 | | | 19.4 | 1.00 | 17.4 | 17.9 |
| 1 | 37 | 41 | 1 | 3 | | | 19.3 | 1.00 | 17.3 | 17.8 |
| 1 | 36 | 42 | 1 | 4 | | | 19.2 | 1.00 | 17.2 | 17.7 |
| 1 | 35 | 43 | 1 | 5 | | | 19.1 | 1.00 | 17.1 | 17.6 |
| 1 | 34 | 43 | 1 | 6 | | | 19.0 | 1.00 | 17.0 | 17.5 |
| 1 | 33 | 43 | 1 | 7 | | | 18.9 | 1.00 | 16.9 | 17.4 |
| 1 | 32 | 43 | 1 | 8 | | | 18.8 | 1.00 | 16.8 | 17.3 |
| 1 | 31 | 42 | 1 | 9 | | | 18.7 | 1.00 | 16.7 | 17.2 |
| 1 | 30 | 41 | 1 | 10 | | | 18.6 | 1.00 | 16.6 | 17.1 |
| 1 | 29 | 40 | 1 | 11 | | | 18.5 | 1.00 | 16.5 | 17.0 |
| 1 | 28 | 39 | 1 | 12 | | | 18.4 | 1.00 | 16.4 | 16.9 |
| 1 | 27 | 39 | 1 | 13 | | | 18.3 | 1.00 | 16.3 | 16.8 |
| 1 | 26 | 39 | 1 | 14 | | | 18.2 | 1.00 | 16.2 | 16.7 |
| 1 | 25 | 39 | 1 | 15 | | | 18.1 | 1.00 | 16.1 | 16.6 |
| 1 | 24 | 39 | 1 | 16 | | | 18.0 | 1.00 | 16.0 | 16.5 |
| 1 | 23 | 39 | 1 | 17 | | | 17.9 | 1.00 | 15.9 | 16.4 |
| 1 | 22 | 39 | 1 | 18 | | | 17.8 | 1.00 | 15.8 | 16.3 |
| 1 | 21 | 39 | 1 | 19 | | | 17.7 | 1.00 | 15.7 | 16.2 |
| 1 | 20 | 39 | 1 | 20 | | | 17.6 | 1.00 | 15.6 | 16.1 |
| 1 | 19 | 39 | 1 | 21 | | | 17.5 | 1.00 | 15.5 | 16.0 |
| 1 | 18 | 40 | 1 | 22 | | | 17.4 | 1.00 | 15.4 | 15.9 |
| 1 | 17 | 41 | 1 | 23 | | | 17.3 | 1.00 | 15.3 | 15.8 |
| 1 | 16 | 42 | 1 | 24 | | | 17.2 | 1.00 | 15.2 | 15.7 |
| 1 | 15 | 43 | 1 | 25 | | | 17.1 | 1.00 | 15.1 | 15.6 |
| 1 | 14 | 43 | 1 | 26 | | | 17.0 | 1.00 | 15.0 | 15.5 |
| 1 | 13 | 43 | 1 | 27 | | | 16.9 | 1.00 | 14.9 | 15.4 |
| 1 | 12 | 43 | 1 | 28 | | | 16.8 | 1.00 | 14.8 | 15.3 |
| 1 | 11 | 40 | 1 | 29 | | | 16.7 | 1.00 | 14.7 | 15.2 |
| 1 | 10 | 40 | 1 | 30 | | | 16.6 | 1.00 | 14.6 | 15.1 |
| 1 | 10 | 40 | 2 | 1 | | 0.20 | 16.6 | 1.00 | 14.6 | 15.1 |
| 1 | 10 | 41 | 2 | 2 | | | 16.5 | 1.00 | 14.5 | 15.0 |
| 1 | 10 | 42 | 2 | 3 | | | 16.4 | 1.00 | 14.4 | 14.9 |
| 1 | 10 | 43 | 2 | 4 | | | 16.3 | 1.00 | 14.3 | 14.8 |
| 1 | 10 | 40 | 3 | 1 | | -1.0 | 16.6 | 1.00 | 14.6 | 15.1 |
| 1 | 9 | 40 | 3 | 2 | | | 16.5 | 1.00 | 14.5 | 15.0 |
| 1 | 8 | 40 | 3 | 3 | | | 16.4 | 1.00 | 14.4 | 14.9 |
| 1 | 7 | 41 | 3 | 4 | | | 16.3 | 1.00 | 14.3 | 14.8 |
| 1 | 6 | 42 | 3 | 5 | | | 16.2 | 1.00 | 14.2 | 14.7 |
| 1 | 5 | 42 | 3 | 6 | | | 16.1 | 1.00 | 14.1 | 14.6 |
| 1 | 4 | 42 | 3 | 7 | | | 16.0 | 1.00 | 14.0 | 14.5 |
| | 3. | | 0.007 | | 0.030 | | | | | |
| | 3. | | 0.007 | | 0.030 | | | | | |
| | 3. | | 0.002 | | 0.022 | | | | | |
| | 3. | | 0.002 | | 0.022 | | | | | |
| | 3. | | 0.002 | | 0.022 | | | | | |
| | 3. | | 0.004 | | 0.030 | | | | | |
| | 3. | | 0.005 | | 0.030 | | | | | |
| | 3. | | 0.005 | | 0.030 | | | | | |
| | 3. | | 0.005 | | 0.030 | | | | | |
| | 3. | | 0.005 | | 0.025 | | | | | |
| | 3. | | 0.005 | | 0.022 | | | | | |
| | 3. | | 0.005 | | 0.020 | | | | | |
| | 3. | | 0.006 | | 0.025 | | | | | |
| | 3. | | 0.007 | | 0.030 | | | | | |

```
          3.     0.007     0.030
          3.     0.002     0.022
          3.     0.002     0.022
          3.     0.002     0.022
          3.     0.004     0.030
          3.     0.005     0.030
          3.     0.005     0.030
          3.     0.005     0.030
          3.     0.005     0.025
          3.     0.005     0.022
          3.     0.005     0.020
          3.     0.006     0.025
          3.     0.007     0.030
          3.     0.007     0.030
          3.     0.002     0.022
          3.     0.002     0.022
          3.     0.002     0.022
          3.     0.004     0.030
          3.     0.005     0.030
          3.     0.005     0.030
          3.     0.005     0.030
          3.     0.005     0.025
          3.     0.005     0.022
          3.     0.005     0.020
          3.     0.006     0.025
          3.     0.007     0.030
          3.     0.007     0.030
    0     0     0
    0     0     0
    1     0     0
          0
          1
          0
```

Input data STRWEL.DAT

```
      13          0
      13
       1         15          51    -0.11
       2         18          33    -0.12
       1         23          30    -0.10
       1         22          181.53e-05
       1         20          22-.000599
       1         21          23-.009689
       1         22          23-.003093
       1         17          18.0013605
       1         17          19.0006242
       1         18          26.0008496
       1         19          26.0050215
       1         23          26.0044594
       1         24          26.0078846
```

Input data STRSIP.DAT

```
     790          5
     0.1    1.0E-03        1         0         0
```

```
FORMAT:     (58F9.3)

------------------------------------------------------------------------------------------------
0                                           INITIAL HEAD FOR LAYER  2 WILL BE READ ON UNIT  1 USING
FORMAT:    (58F9.3)

------------------------------------------------------------------------------------------------
0HEAD PRINT FORMAT IS FORMAT NUMBER  12    DRAWDOWN PRINT FORMAT IS FORMAT NUMBER  12
0HEADS WILL BE SAVED ON UNIT  0    DRAWDOWNS WILL BE SAVED ON UNIT  0
0OUTPUT CONTROL IS SPECIFIED EVERY TIME STEP
0                                                   COLUMN TO ROW ANISOTROPY =    1.000000
0                                                 DELR WILL BE READ ON UNIT  7 USING FORMAT: (58F5.0)

------------------------------------------------------------------------------

  400.00     400.00     350.00     250.00     180.00     120.00     90.000     60.000
   40.000     30.000
  20.000     15.000     15.000     15.000     15.000     15.000     15.000     15.000
   15.000     15.000
  15.000     15.000     15.000     15.000     15.000     15.000     15.000     15.000
   15.000     15.000
  15.000     15.000     15.000     15.000     15.000     10.000     7.0000     5.0000
   3.0000     3.0000
  3.0000     3.0000     3.0000     5.0000     7.0000     10.000     15.000     20.000
   30.000     40.000
  60.000     90.000     120.00     180.00     250.00     350.00     400.00     400.00
0
                                                   DELC WILL BE READ ON UNIT  7 USING FORMAT: (39F5.0)

------------------------------------------------------------------------------

  400.00     400.00     350.00     250.00     180.00     120.00     90.000     60.000
   40.000     30.000
  20.000     15.000     15.000     15.000     15.000     15.000     15.000     15.000
   15.000     15.000
  15.000     15.000     15.000     15.000     15.000     15.000     15.000     15.000
   20.000     30.000
  40.000     60.000     90.000     120.00     180.00     250.00     350.00     400.00
   400.00
0
                                   PRIMARY STORAGE COEF FOR LAYER  1 WILL BE READ ON UNIT  7 USING
FORMAT:  (58f5.2)

------------------------------------------------------------------------------------------------
            1           2           3           4           5           6           7           8
       9          10
           11          12          13          14          15          16          17          18
      19          20
           21          22          23          24          25          26          27          28
      29          30
           31          32          33          34          35          36          37          38
      39          40
           41          42          43          44          45          46          47          48
      49          50
           51          52          53          54          55          56          57          58
................................................................................................
..........................
* 1     0.270    0.270    0.270    0.270    0.270    0.270    0.270    0.270    0.270    0.270
0.270   0.270    0.270    0.270    0.270    0.270    0.270    0.270    0.270    0.270    0.270
0.270   0.270    0.270    0.270    0.270    0.270    0.270    0.270    0.270    0.270    0.270
0.270   0.270    0.270    0.270    0.250    0.250    0.250    0.250    0.250    0.250    0.250
0.250   0.250    0.250    0.250    0.250    0.250    0.250    0.280    0.280    0.280    0.280
0.280   0.280    0.270    0.270
* 2     0.270    0.270    0.270    0.270    0.270    0.270    0.270    0.270    0.270    0.270
0.270   0.270    0.270    0.270    0.270    0.270    0.270    0.270    0.270    0.270    0.270
0.270   0.270    0.270    0.270    0.270    0.270    0.270    0.270    0.270    0.270    0.270
0.270   0.270    0.270    0.270    0.250    0.250    0.250    0.250    0.250    0.250    0.250
0.250   0.250    0.250    0.250    0.250    0.250    0.250    0.280    0.280    0.280    0.280
0.280   0.280    0.270    0.270

* 39    0.270    0.270    0.270    0.270    0.270    0.270    0.270    0.270    0.270    0.270
0.270   0.270    0.270    0.270    0.270    0.270    0.270    0.270    0.270    0.270    0.270
```

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 17.80 | 1 | 36 | 42 | 1 | 4 | 0.0000E+00 | 19.20 | 1.000 | 17.20 |
| 17.70 | 1 | 35 | 43 | 1 | 5 | 0.0000E+00 | 19.10 | 1.000 | 17.10 |
| 17.60 | 1 | 34 | 43 | 1 | 6 | 0.0000E+00 | 19.00 | 1.000 | 17.00 |
| 17.50 | 1 | 33 | 43 | 1 | 7 | 0.0000E+00 | 18.90 | 1.000 | 16.90 |
| 17.40 | 1 | 32 | 43 | 1 | 8 | 0.0000E+00 | 18.80 | 1.000 | 16.80 |
| 17.30 | 1 | 31 | 42 | 1 | 9 | 0.0000E+00 | 18.70 | 1.000 | 16.70 |
| 17.20 | 1 | 30 | 41 | 1 | 10 | 0.0000E+00 | 18.60 | 1.000 | 16.60 |
| 17.10 | 1 | 29 | 40 | 1 | 11 | 0.0000E+00 | 18.50 | 1.000 | 16.50 |
| 17.00 | 1 | 28 | 39 | 1 | 12 | 0.0000E+00 | 18.40 | 1.000 | 16.40 |
| 16.90 | 1 | 27 | 39 | 1 | 13 | 0.0000E+00 | 18.30 | 1.000 | 16.30 |
| 16.80 | 1 | 26 | 39 | 1 | 14 | 0.0000E+00 | 18.20 | 1.000 | 16.20 |
| 16.70 | 1 | 25 | 39 | 1 | 15 | 0.0000E+00 | 18.10 | 1.000 | 16.10 |
| 16.60 | 1 | 24 | 39 | 1 | 16 | 0.0000E+00 | 18.00 | 1.000 | 16.00 |
| 16.50 | 1 | 23 | 39 | 1 | 17 | 0.0000E+00 | 17.90 | 1.000 | 15.90 |
| 16.40 | 1 | 22 | 39 | 1 | 18 | 0.0000E+00 | 17.80 | 1.000 | 15.80 |
| 16.30 | 1 | 21 | 39 | 1 | 19 | 0.0000E+00 | 17.70 | 1.000 | 15.70 |
| 16.20 | 1 | 20 | 39 | 1 | 20 | 0.0000E+00 | 17.60 | 1.000 | 15.60 |
| 16.10 | 1 | 19 | 39 | 1 | 21 | 0.0000E+00 | 17.50 | 1.000 | 15.50 |
| 16.00 | 1 | 18 | 40 | 1 | 22 | 0.0000E+00 | 17.40 | 1.000 | 15.40 |
| 15.90 | 1 | 17 | 41 | 1 | 23 | 0.0000E+00 | 17.30 | 1.000 | 15.30 |
| 15.80 | 1 | 16 | 42 | 1 | 24 | 0.0000E+00 | 17.20 | 1.000 | 15.20 |
| 15.70 | 1 | 15 | 43 | 1 | 25 | 0.0000E+00 | 17.10 | 1.000 | 15.10 |
| 15.60 | 1 | 14 | 43 | 1 | 26 | 0.0000E+00 | 17.00 | 1.000 | 15.00 |
| 15.50 | 1 | 13 | 43 | 1 | 27 | 0.0000E+00 | 16.90 | 1.000 | 14.90 |
| 15.40 | 1 | 12 | 43 | 1 | 28 | 0.0000E+00 | 16.80 | 1.000 | 14.80 |
| 15.30 | 1 | 11 | 40 | 1 | 29 | 0.0000E+00 | 16.70 | 1.000 | 14.70 |
| 15.20 | 1 | 10 | 40 | 1 | 30 | 0.0000E+00 | 16.60 | 1.000 | 14.60 |
| 15.10 | 1 | 10 | 40 | 2 | 1 | 0.2000 | 16.60 | 1.000 | 14.60 |
| 15.10 | 1 | 10 | 41 | 2 | 2 | 0.0000E+00 | 16.50 | 1.000 | 14.50 |
| 15.00 | 1 | 10 | 42 | 2 | 3 | 0.0000E+00 | 16.40 | 1.000 | 14.40 |
| 14.90 | 1 | 10 | 43 | 2 | 4 | 0.0000E+00 | 16.30 | 1.000 | 14.30 |
| 14.80 | 1 | 10 | 40 | 3 | 1 | -1.000 | 16.60 | 1.000 | 14.60 |
| 15.10 | 1 | 9 | 40 | 3 | 2 | 0.0000E+00 | 16.50 | 1.000 | 14.50 |
| 15.00 | 1 | 8 | 40 | 3 | 3 | 0.0000E+00 | 16.40 | 1.000 | 14.40 |
| 14.90 | 1 | 7 | 41 | 3 | 4 | 0.0000E+00 | 16.30 | 1.000 | 14.30 |
| 14.80 | 1 | 6 | 42 | 3 | 5 | 0.0000E+00 | 16.20 | 1.000 | 14.20 |

```
 14.70
        1      5      42        3        6        0.0000E+00   16.10      1.000            14.10
 14.60
        1      4      42        3        7        0.0000E+00   16.00      1.000            14.00
 14.50
```

0

| LAYER | ROW | COL | SEGMENT NUMBER | REACH NUMBER | STREAM WIDTH | STREAM SLOPE | ROUGH COEF. |
|---|---|---|---|---|---|---|---|
| 1 | 39 | 40 | 1 | 1 | 3.000 | 0.7000E-02 | 0.3000E-01 |
| 1 | 38 | 40 | 1 | 2 | 3.000 | 0.7000E-02 | 0.3000E-01 |
| 1 | 37 | 41 | 1 | 3 | 3.000 | 0.2000E-02 | 0.2200E-01 |
| 1 | 36 | 42 | 1 | 4 | 3.000 | 0.2000E-02 | 0.2200E-01 |
| 1 | 35 | 43 | 1 | 5 | 3.000 | 0.2000E-02 | 0.2200E-01 |
| 1 | 34 | 43 | 1 | 6 | 3.000 | 0.4000E-02 | 0.3000E-01 |
| 1 | 33 | 43 | 1 | 7 | 3.000 | 0.5000E-02 | 0.3000E-01 |
| 1 | 32 | 43 | 1 | 8 | 3.000 | 0.5000E-02 | 0.3000E-01 |
| 1 | 31 | 42 | 1 | 9 | 3.000 | 0.5000E-02 | 0.3000E-01 |
| 1 | 30 | 41 | 1 | 10 | 3.000 | 0.5000E-02 | 0.2500E-01 |
| 1 | 29 | 40 | 1 | 11 | 3.000 | 0.5000E-02 | 0.2200E-01 |
| 1 | 28 | 39 | 1 | 12 | 3.000 | 0.5000E-02 | 0.2000E-01 |
| 1 | 27 | 39 | 1 | 13 | 3.000 | 0.6000E-02 | 0.2500E-01 |
| 1 | 26 | 39 | 1 | 14 | 3.000 | 0.7000E-02 | 0.3000E-01 |
| 1 | 25 | 39 | 1 | 15 | 3.000 | 0.7000E-02 | 0.3000E-01 |
| 1 | 24 | 39 | 1 | 16 | 3.000 | 0.2000E-02 | 0.2200E-01 |
| 1 | 23 | 39 | 1 | 17 | 3.000 | 0.2000E-02 | 0.2200E-01 |
| 1 | 22 | 39 | 1 | 18 | 3.000 | 0.2000E-02 | 0.2200E-01 |
| 1 | 21 | 39 | 1 | 19 | 3.000 | 0.4000E-02 | 0.3000E-01 |
| 1 | 20 | 39 | 1 | 20 | 3.000 | 0.5000E-02 | 0.3000E-01 |
| 1 | 19 | 39 | 1 | 21 | 3.000 | 0.5000E-02 | 0.3000E-01 |
| 1 | 18 | 40 | 1 | 22 | 3.000 | 0.5000E-02 | 0.3000E-01 |
| 1 | 17 | 41 | 1 | 23 | 3.000 | 0.5000E-02 | 0.2500E-01 |
| 1 | 16 | 42 | 1 | 24 | 3.000 | 0.5000E-02 | 0.2200E-01 |
| 1 | 15 | 43 | 1 | 25 | 3.000 | 0.5000E-02 | 0.2000E-01 |
| 1 | 14 | 43 | 1 | 26 | 3.000 | 0.6000E-02 | 0.2500E-01 |
| 1 | 13 | 43 | 1 | 27 | 3.000 | 0.7000E-02 | 0.3000E-01 |
| 1 | 12 | 43 | 1 | 28 | 3.000 | 0.7000E-02 | 0.3000E-01 |
| 1 | 11 | 40 | 1 | 29 | 3.000 | 0.2000E-02 | 0.2200E-01 |
| 1 | 10 | 40 | 1 | 30 | 3.000 | 0.2000E-02 | 0.2200E-01 |
| 1 | 10 | 40 | 2 | 1 | 3.000 | 0.2000E-02 | 0.2200E-01 |
| 1 | 10 | 41 | 2 | 2 | 3.000 | 0.4000E-02 | 0.3000E-01 |
| 1 | 10 | 42 | 2 | 3 | 3.000 | 0.5000E-02 | 0.3000E-01 |
| 1 | 10 | 43 | 2 | 4 | 3.000 | 0.5000E-02 | 0.3000E-01 |
| 1 | 10 | 40 | 3 | 1 | 3.000 | 0.5000E-02 | 0.3000E-01 |
| 1 | 9 | 40 | 3 | 2 | 3.000 | 0.5000E-02 | 0.2500E-01 |
| 1 | 8 | 40 | 3 | 3 | 3.000 | 0.5000E-02 | 0.2200E-01 |
| 1 | 7 | 41 | 3 | 4 | 3.000 | 0.5000E-02 | 0.2000E-01 |
| 1 | 6 | 42 | 3 | 5 | 3.000 | 0.6000E-02 | 0.2500E-01 |
| 1 | 5 | 42 | 3 | 6 | 3.000 | 0.7000E-02 | 0.3000E-01 |
| 1 | 4 | 42 | 3 | 7 | 3.000 | 0.7000E-02 | 0.3000E-01 |

0 MAXIMUM NUMBER OF TRIBUTARY STREAMS IS 1

| STREAM SEGMENT | TRIBUTARY STREAM SEGMENT NUMBERS |
|---|---|
| 1 | 0 |
| 2 | 0 |
| 3 | 1 |

0

| DIVERSION SEGMENT NUMBER | UPSTREAM SEGMENT NUMBER |
|---|---|
| 1 | 0 |
| 2 | 1 |
| 3 | 0 |

0AVERAGE SEED = 0.00032530
MINIMUM SEED = 0.00000018
0
5 ITERATION PARAMETERS CALCULATED FROM AVERAGE SEED:

0.0000000E+00 0.8657019E+00 0.9819640E+00 0.9975778E+00 0.9996747E+00
0
45 ITERATIONS FOR TIME STEP 1 IN STRESS PERIOD 1
0MAXIMUM HEAD CHANGE FOR EACH ITERATION:
0 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

-----------------------------------------------------------------------------------------------------------------------

# APPENDIX H

## MODFLOW+STR output files (transient state).

Selected parts of output file MODSTR.OUT

```
1                    U.S. GEOLOGICAL SURVEY MODULAR FINITE-DIFFERENCE GROUND-WATER MODEL
0Scenario 8, meandering river with diversion, smaller grid sys. Dec. 07, 1991.   -- Unsteady State,
const. head, rech. two layers
    2 LAYERS         39 ROWS        58 COLUMNS
   1 STRESS PERIOD(S) IN SIMULATION
 MODEL TIME UNIT IS SECONDS
0I/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:  7  4  0  0  0  0  0  8 13  0  0 14 15  0  0  0  0  0  0  0  0  0  0  0
0BAS1 -- BASIC MODEL PACKAGE, VERSION 1, 9/1/87 INPUT READ FROM UNIT  1
 ARRAYS RHS AND BUFF WILL SHARE MEMORY.
 START HEAD WILL BE SAVED
     43083 ELEMENTS IN X ARRAY ARE USED BY BAS
     43083 ELEMENTS OF X ARRAY USED OUT OF  100000
0BCF1 -- BLOCK-CENTERED FLOW PACKAGE, VERSION 1, 9/1/87 INPUT READ FROM UNIT  7
 TRANSIENT SIMULATION
       LAYER  AQUIFER TYPE
       ------------------
           1         1
           2         0
      9050 ELEMENTS IN X ARRAY ARE USED BY BCF
     52133 ELEMENTS OF X ARRAY USED OUT OF  100000
0WEL1 -- WELL PACKAGE, VERSION 1, 9/1/87 INPUT READ FROM  4
 MAXIMUM OF    13 WELLS
        52 ELEMENTS IN X ARRAY ARE USED FOR WELLS
     52185 ELEMENTS OF X ARRAY USED OUT OF  100000
0RCH1 -- RECHARGE PACKAGE, VERSION 1, 9/1/87 INPUT READ FROM UNIT  8
 OPTION 1 -- RECHARGE TO TOP LAYER
      2262 ELEMENTS OF X ARRAY USED FOR RECHARGE
     54447 ELEMENTS OF X ARRAY USED OUT OF  100000
0STRM -- STREAM PACKAGE, VERSION 1, 10/23/87INPUT READ FROM UNIT 15
 MAXIMUM OF    41 STREAM NODES

 NUMBER OF STREAM SEGMENTS IS     3

 NUMBER OF STREAM TRIBUTARIES IS     1


 DIVERSIONS FROM STREAMS HAVE BEEN SPECIFIED
 STREAM STAGES WILL BE CALCULATED USING A CONSTANT OF      1.0000
       665 ELEMENTS IN X ARRAY ARE USED FOR STREAMS
     55112 ELEMENTS OF X ARRAY USED OUT OF 100000
0SIP1 -- STRONGLY IMPLICIT PROCEDURE SOLUTION PACKAGE, VERSION 1, 9/1/87 INPUT READ FROM UNIT 13
 MAXIMUM OF 790 ITERATIONS ALLOWED FOR CLOSURE
  5 ITERATION PARAMETERS
     21261 ELEMENTS IN X ARRAY ARE USED BY SIP
     76373 ELEMENTS OF X ARRAY USED OUT OF  100000
1Scenario 8, meandering river with diversion, smaller grid sys. Dec. 07, 1991.   -- Unsteady State,
const. head, rech. two layers
0
                                       BOUNDARY ARRAY FOR LAYER  1 WILL BE READ ON UNIT  1 USING
FORMAT:  (58I3)
------------------------------------------------------------------------------------------------
0                                      BOUNDARY ARRAY FOR LAYER  2 WILL BE READ ON UNIT  1 USING
FORMAT:  (58I3)
------------------------------------------------------------------------------------------------
0AQUIFER HEAD WILL BE SET TO  999.00     AT ALL NO-FLOW NODES (IBOUND=0).
0                                          INITIAL HEAD FOR LAYER  1 WILL BE READ ON UNIT  1 USING
```

```
0.270    0.270    0.270    0.270    0.270    0.270    0.270    0.270    0.270    0.270    0.270
0.270    0.270    0.270    0.270    0.250    0.250    0.250    0.250    0.250    0.250    0.250
0.250    0.250    0.250    0.250    0.250    0.250    0.250    0.280    0.280    0.280    0.280
0.280    0.280    0.270    0.270
0
                          HYD. COND. ALONG ROWS FOR LAYER  1 WILL BE READ ON UNIT  7 USING
FORMAT:   (58F5.0)

-----------------------------------------------------------------------------------------
0                                                     BOTTOM =  0.0000000E+00 FOR
LAYER  1
0                                      VERT HYD COND /THICKNESS =  0.5000000E-05 FOR
LAYER  1
0                                         PRIMARY STORAGE COEF =  0.1500000E-03 FOR
LAYER  2
0                                         TRANSMIS. ALONG ROWS =  0.1562400     FOR
LAYER  2
0


                                          SOLUTION BY THE STRONGLY IMPLICIT PROCEDURE
                                          -------------------------------------------
0                               MAXIMUM ITERATIONS ALLOWED FOR CLOSURE =      790
                                                 ACCELERATION PARAMETER =    0.10000
                                     HEAD CHANGE CRITERION FOR CLOSURE =  0.10000E-02
                                     SIP HEAD CHANGE PRINTOUT INTERVAL =      999
0                                          CALCULATE ITERATION PARAMETERS FROM MODEL
CALCULATED WSEED
1                                       STRESS PERIOD NO.   1, LENGTH =  0.1555200E+08
                                        ----------------------------------------------

                                        NUMBER OF TIME STEPS =      1

                                          MULTIPLIER FOR DELT =      1.000

                                      INITIAL TIME STEP SIZE =  0.1555200E+08
0             13 WELLS
                                LAYER    ROW    COL    STRESS RATE    WELL NO.
                                ----------------------------------------------
                                  1       15     51    -0.11000           1
                                  2       18     33    -0.12000           2
                                  1       23     30    -0.10000           3
                                  1       22     18     0.15300E-04       4
                                  1       20     22    -0.59900E-03       5
                                  1       21     23    -0.96890E-02       6
                                  1       22     23    -0.30930E-02       7
                                  1       17     18     0.13605E-02       8
                                  1       17     19     0.62420E-03       9
                                  1       18     26     0.84960E-03      10
                                  1       19     26     0.50215E-02      11
                                  1       23     26     0.44594E-02      12
                                  1       24     26     0.78846E-02      13
0
                                RECHARGE WILL BE READ ON UNIT   8 USING FORMAT:
(58F5.0)
-----------------------------------------------------------------------------
0


   41 STREAM NODES
   LAYER   ROW    COL    SEGMENT   REACH   STREAMFLOW      STREAM   STREAMBED     STREAMBED BOT  STRE
                         NUMBER    NUMBER                   STAGE   CONDUCTANCE      ELEVATION
ELEVATION

----------------------------------------------------------------------------------------------------
---------
       1     39     40       1        1       1.140        19.50      1.000             17.50
 18.00
       1     38     40       1        2     0.0000E+00     19.40      1.000             17.40
 17.90
       1     37     41       1        3     0.0000E+00     19.30      1.000             17.30
 17.80
```

------------------------------------------------------------------------------------------------------------------------------
--------------------------------
-0.4116E-01 ( 1, 21, 23) -0.3817E-01 ( 1, 21, 23) -0.3301E-01 ( 1, 21, 23) 0.2696E-01 ( 1, 24,
26) -0.2189E-01 ( 1, 21, 23)
-0.2812E-01 ( 1, 21, 23) -0.2597E-01 ( 1, 21, 23) 0.2432E-01 ( 1, 24, 26) -0.1779E-01 ( 1, 21,
23) 0.1466E-01 ( 1, 24, 26)
-0.1909E-01 ( 1, 21, 23) 0.1800E-01 ( 1, 24, 26) -0.1558E-01 ( 1, 21, 23) 0.1291E-01 ( 1, 24,
26) -0.1038E-01 ( 1, 21, 23)
-0.1305E-01 ( 1, 21, 23) -0.1203E-01 ( 1, 21, 23) 0.1201E-01 ( 1, 24, 26) -0.8441E-02 ( 1, 21,
23) 0.7411E-02 ( 1, 24, 26)
-0.8829E-02 ( 1, 21, 23) 0.8722E-02 ( 1, 24, 26) -0.7304E-02 ( 1, 21, 23) 0.6562E-02 ( 1, 24,
26) -0.4862E-02 ( 1, 21, 23)
-0.6037E-02 ( 1, 21, 23) -0.5532E-02 ( 1, 21, 23) 0.6031E-02 ( 1, 24, 26) -0.3964E-02 ( 1, 21,
23) 0.3818E-02 ( 1, 24, 26)
-0.4067E-02 ( 1, 21, 23) 0.4259E-02 ( 1, 24, 26) -0.3395E-02 ( 1, 21, 23) 0.3395E-02 ( 1, 24,
26) -0.2226E-02 ( 1, 21, 23)
-0.2780E-02 ( 1, 21, 23) 0.2684E-02 ( 1, 24, 26) 0.3068E-02 ( 1, 24, 26) -0.1832E-02 ( 1, 21,
23) 0.2008E-02 ( 1, 24, 26)
-0.1864E-02 ( 1, 21, 23) 0.2095E-02 ( 1, 24, 26) -0.1559E-02 ( 1, 21, 23) 0.1792E-02 ( 1, 24,
26) 0.9853E-03 ( 1, 24, 26)
0
0HEAD/DRAWDOWN PRINTOUT FLAG = 1 TOTAL BUDGET PRINTOUT FLAG = 1 CELL-BY-CELL FLOW TERM FLAG
= 1
0OUTPUT FLAGS FOR ALL LAYERS ARE THE SAME:

| HEAD PRINTOUT | DRAWDOWN PRINTOUT | HEAD SAVE | DRAWDOWN SAVE |
|---|---|---|---|
| 1 | 0 | 0 | 0 |

| LAYER | ROW | COLUMN | STREAM NUMBER | REACH NUMBER | FLOW INTO STREAM REACH | FLOW INTO AQUIFER | FLOW OUT OF STREAM REACH | HEAD IN STREAM | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 39 | 40 | 1 | 1 | 1.14 | 0.193E-03 | 1.14 | 18.302406 | | | | |
| 1 | 38 | 40 | 1 | 2 | 1.14 | 0.502E-02 | 1.13 | 18.201988 | | | | |
| 1 | 37 | 41 | 1 | 3 | 1.13 | 0.658E-01 | 1.07 | 18.158222 | | | | |
| 1 | 36 | 42 | 1 | 4 | 1.07 | 0.676E-01 | 1.00 | 18.045053 | | | | |
| 1 | 35 | 43 | 1 | 5 | 1.00 | 0.645E-01 | 0.937 | 17.931671 | | | | |
| 1 | 34 | 43 | 1 | 6 | 0.937 | 0.530E-01 | 0.884 | 17.812548 | | | | |
| 1 | 33 | 43 | 1 | 7 | 0.884 | 0.432E-01 | 0.841 | 17.682936 | | | | |
| 1 | 32 | 43 | 1 | 8 | 0.841 | 0.359E-01 | 0.805 | 17.575073 | | | | |
| 1 | 31 | 42 | 1 | 9 | 0.805 | 0.309E-01 | 0.774 | 17.468315 | | | | |
| 1 | 30 | 41 | 1 | 10 | 0.774 | 0.216E-01 | 0.752 | 17.335672 | | | | |
| 1 | 29 | 40 | 1 | 11 | 0.752 | 0.145E-01 | 0.738 | 17.215153 | | | | |
| 1 | 28 | 39 | 1 | 12 | 0.738 | 0.690E-02 | 0.731 | 17.101435 | | | | |
| 1 | 27 | 39 | 1 | 13 | 0.731 | 0.700E-02 | 0.724 | 17.016794 | | | | |
| 1 | 26 | 39 | 1 | 14 | 0.724 | 0.694E-02 | 0.717 | 16.929596 | | | | |
| 1 | 25 | 39 | 1 | 15 | 0.717 | 0.284E-02 | 0.714 | 16.828659 | | | | |
| 1 | 24 | 39 | 1 | 16 | 0.714 | 0.103E-01 | 0.704 | 16.774906 | | | | |
| 1 | 23 | 39 | 1 | 17 | 0.704 | 0.706E-02 | 0.697 | 16.672880 | | | | |
| 1 | 22 | 39 | 1 | 18 | 0.697 | 0.612E-02 | 0.691 | 16.571339 | | | | |
| 1 | 21 | 39 | 1 | 19 | 0.691 | 0.488E-02 | 0.686 | 16.464211 | 1 | 20 | 39 | 1 |
| 20 | 0.686 | | 0.138E-02 | 0.684 | 16.346428 | | | | | | | |
| 1 | 19 | 39 | 1 | 21 | 0.684 | 0.170E-02 | 0.683 | 16.246096 | | | | |
| 1 | 18 | 40 | 1 | 22 | 0.683 | 0.240E-02 | 0.680 | 16.145655 | | | | |
| 1 | 17 | 41 | 1 | 23 | 0.680 | -.205E-02 | 0.682 | 16.020166 | | | | |
| 1 | 16 | 42 | 1 | 24 | 0.682 | -.427E-02 | 0.687 | 15.904480 | | | | |
| 1 | 15 | 43 | 1 | 25 | 0.687 | -.708E-02 | 0.694 | 15.794075 | | | | |
| 1 | 14 | 43 | 1 | 26 | 0.694 | -.537E-02 | 0.699 | 15.711204 | | | | |
| 1 | 13 | 43 | 1 | 27 | 0.699 | -.496E-02 | 0.704 | 15.625972 | | | | |
| 1 | 12 | 43 | 1 | 28 | 0.704 | -.774E-02 | 0.712 | 15.527199 | | | | |
| 1 | 11 | 40 | 1 | 29 | 0.712 | 0.408E-02 | 0.708 | 15.475094 | | | | |
| 1 | 10 | 40 | 1 | 30 | 0.708 | 0.757E-01 | 0.432 | 15.341145 | | | | |
| 1 | 10 | 40 | 2 | 1 | 0.200 | -.309E-01 | 0.231 | 15.234551 | | | | |
| 1 | 10 | 41 | 2 | 2 | 0.231 | -.204E-01 | 0.251 | 15.140844 | | | | |
| 1 | 10 | 42 | 2 | 3 | 0.251 | -.373E-01 | 0.289 | 15.040972 | | | | |
| 1 | 10 | 43 | 2 | 4 | 0.289 | -.783E-01 | 0.367 | 14.958365 | | | | |
| 1 | 10 | 40 | 3 | 1 | 0.432 | 0.189E-01 | 0.413 | 15.284404 | | | | |
| 1 | 9 | 40 | 3 | 2 | 0.413 | -.179E-01 | 0.431 | 15.165176 | | | | |
| 1 | 8 | 40 | 3 | 3 | 0.431 | -.381E-01 | 0.469 | 15.058992 | | | | |
| 1 | 7 | 41 | 3 | 4 | 0.469 | -.588E-01 | 0.528 | 14.959653 | | | | |
| 1 | 6 | 42 | 3 | 5 | 0.528 | -.733E-01 | 0.601 | 14.886204 | | | | |
| 1 | 5 | 42 | 3 | 6 | 0.601 | -.938E-01 | 0.695 | 14.815471 | | | | |

```
  1     4   42     3      7   0.695        -.101      0.795         14.734313
1                               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            16            17            18
        19             20
              21            22            23            24            25            26            27            28
        29             30
              31            32            33            34            35            36            37            38
        39             40
              41            42            43            44            45            46            47            48
        49             50
              51            52            53            54            55            56            57            58
..................................................................................................................
.........................
*  1    999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000
999.000 999.000  999.000  999.000  999.000  999.000  999.000   14.300   14.300   14.300   14.300
 14.300  14.300   14.300   14.300   14.300   14.300   14.300   14.300   14.300   14.300   14.300
 14.300  14.300   14.300  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000
999.000 999.000  999.000  999.000   14.300   14.300   14.300   14.300  999.000  999.000  999.000
999.000 999.000  999.000  999.000
*  2     17.160   17.013   16.867   16.652   16.434   16.247   16.101   15.989   15.912   15.856
 15.815  15.786   15.761   15.736   15.710   15.684   15.657   15.629   15.601   15.574   15.547
 15.520  15.492   15.464   15.434   15.403   15.369   15.330   15.286   15.232   15.166   15.079
 14.963  14.802   14.575   14.300   14.300   14.300  999.000  999.000  999.000  999.000  999.000
999.000 999.000   14.300   14.300   14.326   14.355   14.382   14.514   14.582  999.000  999.000
999.000 999.000  999.000  999.000


* 10    999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000   17.160
 17.098  17.051   17.007   16.962   16.916   16.869   16.822   16.775   16.727   16.679   16.631
 16.584  16.536   16.487   16.439   16.389   16.338   16.285   16.229   16.167   16.096   16.012
 15.904  15.760   15.553   15.386   15.350   15.314   15.288   15.265   15.161   15.078   15.037
 15.105  15.189   15.279   15.373   15.456   15.521   15.696   15.751   15.966   16.097   16.185
 16.254  16.296  999.000  999.000
* 11    999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000   17.160
 17.129  17.085   17.042   16.997   16.951   16.903   16.855   16.807   16.758   16.709   16.660
 16.611  16.562   16.512   16.462   16.411   16.360   16.306   16.250   16.189   16.121   16.042
 15.944  15.816   15.643   15.514   15.497   15.484   15.476   15.471   15.459   15.450   15.445
 15.444  15.453   15.475   15.515   15.564   15.609   15.722   15.552   15.958   16.127   16.213
 16.277  16.314  999.000  999.000
* 12    999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000
 17.160  17.108   17.064   17.019   16.973   16.925   16.877   16.829   16.779   16.729   16.679
 16.629  16.579   16.528   16.477   16.426   16.373   16.319   16.262   16.203   16.138   16.065
 15.976  15.864   15.715   15.606   15.591   15.578   15.569   15.562   15.553   15.545   15.535
 15.546  15.562   15.582   15.611   15.646   15.679   15.736   15.221   15.939   16.148   16.234
 16.293  16.326   16.269  999.000
* 13    999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000
 17.160  17.120   17.079   17.036   16.990   16.944   16.896   16.847   16.797   16.746   16.695
 16.644  16.593   16.541   16.489   16.437   16.383   16.328   16.271   16.213   16.151   16.083
 16.004  15.907   15.779   15.686   15.673   15.663   15.655   15.649   15.643   15.637   15.631
 15.639  15.652   15.669   15.692   15.719   15.743   15.767   14.688   15.916   16.167   16.252
 16.307  16.337   16.268  999.000
* 14    999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000
 17.160  17.128   17.092   17.051   17.007   16.961   16.915   16.867   16.816   16.763   16.710
 16.657  16.605   16.553   16.501   16.447   16.391   16.334   16.276   16.218   16.159   16.098
 16.030  15.949   15.845   15.768   15.757   15.748   15.740   15.735   15.729   15.723   15.717
 15.725  15.738   15.754   15.773   15.793   15.810   15.821   13.674   15.892   16.187   16.270
 16.321  16.349  999.000  999.000
* 15    999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000
 17.160  17.134   17.102   17.063   17.022   16.979   16.935   16.889   16.836   16.780   16.724
 16.669  16.616   16.564   16.511   16.456   16.397   16.336   16.275   16.217   16.161   16.107
 16.052  15.990   15.912   15.853   15.844   15.835   15.828   15.822   15.816   15.809   15.801
 15.812  15.826   15.840   15.856   15.869   15.875   15.849   11.506   15.886   16.209   16.288
 16.335  16.360  999.000  999.000

* 38    999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000
999.000 999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000
999.000 999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000
999.000 999.000  999.000  999.000   18.197   18.197   18.197   18.197   18.197   18.197   18.196
```

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18.196    18.196   999.000   999.000   999.000   999.000   999.000   999.000   999.000   999.000   999.
999.000  999.000  999.000  999.000
 * 39     999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000
999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000
999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000
999.000  999.000  999.000  999.000  999.000  999.000  999.000   18.302  999.000  999.000  999.000
999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000
999.000  999.000  999.000  999.000
1                       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           16           17           18
        19           20
             21           22           23           24           25           26           27           28
        29           30
             31           32           33           34           35           36           37           38
        39           40
             41           42           43           44           45           46           47           48
        49           50
             51           52           53           54           55           56           57           58
...............................................................................................
..........................
 *  1     999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000
999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000
999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000
999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000
999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000
999.000  999.000  999.000  999.000
 *  2     999.000   17.009   16.865   16.650   16.432   16.245   16.099   15.987   15.909   15.854
 15.813   15.784   15.760   15.735   15.710   15.685   15.659   15.634   15.609   15.583   15.557
 15.532   15.506   15.481   15.455   15.430   15.405   15.380   15.355   15.331   15.308   15.286
 15.265   15.247   15.232   15.224   15.220   15.220  999.000  999.000  999.000  999.000  999.000
999.000  999.000   14.531   14.532   14.534   14.538   14.547   14.565   14.587  999.000  999.000
999.000  999.000  999.000  999.000

 * 12     999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000   17.420   17.352
 17.237   17.162   17.102   17.044   16.988   16.935   16.882   16.831   16.781   16.731   16.681
 16.633   16.584   16.536   16.488   16.441   16.394   16.347   16.302   16.258   16.217   16.179
 16.144   16.114   16.089   16.072   16.062   16.055   16.051   16.048   16.045   16.043   16.040
 16.037   16.033   16.028   16.021   16.013   16.004   15.993   15.975   16.061   16.154   16.230
 16.289   16.323   16.269  999.000
 * 13     999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000   17.420
 17.270   17.188   17.124   17.065   17.008   16.954   16.901   16.849   16.798   16.748   16.698
 16.649   16.600   16.551   16.502   16.454   16.406   16.358   16.311   16.266   16.223   16.184
 16.151   16.123   16.101   16.087   16.079   16.074   16.070   16.068   16.066   16.064   16.062
 16.060   16.056   16.052   16.046   16.039   16.030   16.016   15.984   16.081   16.174   16.248
 16.303   16.334   16.269  999.000
 * 14     999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000   17.420
 17.288   17.207   17.143   17.084   17.027   16.972   16.918   16.866   16.815   16.764   16.714
 16.664   16.615   16.566   16.516   16.467   16.418   16.368   16.320   16.272   16.227   16.186
 16.152   16.128   16.111   16.101   16.096   16.092   16.090   16.089   16.087   16.086   16.085
 16.083   16.081   16.078   16.073   16.068   16.059   16.042   15.996   16.104   16.196   16.266
 16.317   16.345  999.000  999.000

 * 39     999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000
999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000
999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000
999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000
999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000  999.000
999.000  999.000  999.000  999.000
                              VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  1 IN STRESS PERIOD
1
------------------------------------------------------------------------------
0                  CUMULATIVE VOLUMES        L**3                                    RATES FOR THIS
TIME STEP       L**3/T
                   ------------------
-----------------------
                         IN:                                                                    IN:
                         ---                                                                    ---
                            STORAGE =      215.99
STORAGE =     0.13888E-04
```

# APPENDIX I

MOC (transient state) input files for subsystem.

```
MOC concentration (Unsteady, cons. cont.,unmanaged heads)    Jan. 21st, 1992.
 100   1  20  173200   1   4    2 100  11   9   0   0   1   0   0   0
  0.5 .001  0.3    1. .250 30. 86400  50.  50.  0.3  0.5   1.
17 9
19 9
1512  3.5310                (+):extraction;  (-):injection
 311-.000541 583000.
 7 9 .021151
 810 .342119
 811 .109214
 3 6-.048039
 4 6-.022041
11 7-.029999
11 8-.177310
1112-.157461
1113-.278405
1.005606412              Trans. Factor=5.208e-04*10.765 (m/s*ft^2/m^2) FORMAT(20G7.3)
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
 0.     0.     0.     0.     0.     0.
     0. 16.896 16.847 16.797 16.746 16.695 16.644 16.593 16.541 16.489 16.437 16.383 16.328 16.271
16.213 16.151 16.083 16.004 15.907     0.
     0. 16.915 16.867 16.816 16.763 16.710 16.657 16.605 16.553 16.501 16.447 16.391 16.334 16.276
16.218 16.159 16.098 16.030 15.949     0.
     0. 16.935 16.889 16.836 16.780 16.724 16.669 16.616 16.564 16.511 16.456 16.397 16.336 16.275
16.217 16.161 16.107 16.052 15.990     0.
     0. 16.956 16.918 16.861 16.796 16.735 16.677 16.623 16.572 16.522 16.467 16.401 16.332 16.265
16.205 16.152 16.107 16.067 16.028     0.
     0. 16.978 16.968 16.895 16.809 16.740 16.678 16.623 16.577 16.534 16.487 16.404 16.318 16.239
16.175 16.127 16.094 16.072 16.063     0.
     0. 16.977 16.937 16.876 16.805 16.733 16.665 16.609 16.572 16.549 16.538 16.405 16.285 16.186
16.115 16.076 16.063 16.067 16.095     0.
     0. 16.977 16.928 16.867 16.795 16.716 16.632 16.565 16.545 16.551 16.617 16.384 16.216 16.082
15.997 15.980 16.009 16.061 16.128     0.
     0. 16.980 16.927 16.864 16.787 16.690 16.562 16.453 16.477 16.481 16.442 16.277 16.080 15.888
15.766 15.799 15.908 16.033 16.154     0.
     0. 16.985 16.932 16.868 16.788 16.678 16.505 16.175 16.397 16.436 16.368 16.172 15.886 15.546
15.289 15.470 15.741 15.979 16.173     0.
     0. 16.994 16.942 16.881 16.806 16.708 16.572 16.372 16.464 16.474 16.394 16.107 15.655 14.980
14.167 14.908 15.521 15.921 16.197     0.
     0. 17.005 16.956 16.900 16.835 16.759 16.671 16.584 16.580 16.583 16.596 16.140 15.510 14.273
10.522 14.202 15.374 15.921 16.248     0.
     0. 17.017 16.972 16.923 16.868 16.808 16.746 16.692 16.668 16.672 16.755 16.272 15.766 15.082
14.280 15.024 15.645 16.057 16.348     0.
     0. 17.031 16.990 16.946 16.899 16.850 16.801 16.754 16.715 16.674 16.607 16.363 16.061 15.729
15.490 15.690 15.984 16.249 16.474     0.
     0. 17.044 17.007 16.968 16.927 16.885 16.842 16.798 16.752 16.696 16.614 16.471 16.301 16.138
16.049 16.118 16.265 16.433 16.603     0.
     0. 17.057 17.024 16.989 16.952 16.915 16.876 16.834 16.789 16.735 16.666 16.577 16.479 16.396
16.358 16.391 16.476 16.589 16.722     0.
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
 0.     0.     0.     0.     0.     0.
1      3.281           Thickness values  factor=3.281 ft/m. Format (20g7.3)
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
 0.     0.     0.     0.     0.     0.
     0. 16.896 16.847 16.797 16.746 16.695 16.644 16.593 16.541 16.489 16.437 16.383 16.328 16.271
16.213 16.151 16.083 16.004 15.907     0.
     0. 16.915 16.867 16.816 16.763 16.710 16.657 16.605 16.553 16.501 16.447 16.391 16.334 16.276
16.218 16.159 16.098 16.030 15.949     0.
     0. 16.935 16.889 16.836 16.780 16.724 16.669 16.616 16.564 16.511 16.456 16.397 16.336 16.275
16.217 16.161 16.107 16.052 15.990     0.
     0. 16.956 16.918 16.861 16.796 16.735 16.677 16.623 16.572 16.522 16.467 16.401 16.332 16.265
16.205 16.152 16.107 16.067 16.028     0.
```

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00000000000000000000
00000000000000000000
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00000000000000000000
1     3.281         20(G7.3)                        initial unmanaged heads
      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
  0.      0.      0.      0.      0.      0.
      0. 16.888 16.839 16.789 16.738 16.687 16.636 16.584 16.532 16.479 16.426 16.372 16.317 16.261
16.204 16.143 16.077 15.999 15.903      0.
      0. 16.904 16.854 16.804 16.753 16.701 16.649 16.596 16.542 16.487 16.431 16.375 16.319 16.263
16.207 16.150 16.090 16.024 15.945      0.
      0. 16.918 16.869 16.818 16.767 16.714 16.661 16.606 16.549 16.492 16.433 16.374 16.315 16.257
16.202 16.149 16.098 16.045 15.985      0.
      0. 16.932 16.883 16.832 16.780 16.726 16.671 16.614 16.555 16.493 16.430 16.365 16.301 16.241
16.186 16.138 16.096 16.059 16.023      0.
      0. 16.945 16.896 16.845 16.792 16.738 16.681 16.621 16.558 16.490 16.419 16.346 16.274 16.207
16.151 16.110 16.081 16.063 16.057      0.
      0. 16.957 16.908 16.858 16.805 16.749 16.690 16.626 16.557 16.482 16.399 16.312 16.224 16.144
16.085 16.055 16.048 16.057 16.088      0.
      0. 16.968 16.920 16.870 16.817 16.760 16.699 16.631 16.555 16.468 16.369 16.257 16.140 16.032
15.963 15.956 15.992 16.049 16.121      0.
      0. 16.980 16.933 16.883 16.829 16.772 16.708 16.636 16.552 16.451 16.328 16.178 16.006 15.834
15.727 15.772 15.889 16.019 16.146      0.
      0. 16.991 16.945 16.896 16.842 16.784 16.719 16.643 16.551 16.434 16.281 16.077 15.807 15.487
15.246 15.439 15.720 15.965 16.164      0.
      0. 17.002 16.958 16.909 16.857 16.799 16.733 16.654 16.556 16.427 16.246 15.976 15.558 14.910
14.117 14.875 15.498 15.906 16.187      0.
      0. 17.013 16.970 16.923 16.872 16.816 16.751 16.673 16.574 16.441 16.247 15.939 15.386 14.189
10.453 14.165 15.350 15.905 16.238      0.
      0. 17.024 16.982 16.938 16.889 16.835 16.773 16.699 16.606 16.482 16.307 16.045 15.636 15.000
14.224 14.989 15.621 16.041 16.338      0.
      0. 17.035 16.996 16.954 16.908 16.857 16.800 16.732 16.649 16.543 16.403 16.212 15.959 15.659
15.442 15.657 15.961 16.232 16.464      0.
      0. 17.046 17.009 16.970 16.927 16.881 16.829 16.769 16.699 16.613 16.507 16.378 16.228 16.084
16.009 16.089 16.244 16.418 16.594      0.
      0. 17.056 17.022 16.986 16.947 16.905 16.859 16.807 16.749 16.682 16.604 16.518 16.429 16.356
16.327 16.366 16.456 16.575 16.713      0.
      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
  0.      0.      0.      0.      0.      0.
1       1.0     20(g7.0)
      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
  0.      0.      0.      0.      0.      0.
      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
  0.      0.      0.      0.      0.      0.
      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
  0.      0.      0.      0.      0.      0.
      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
  0.      0.      0.      0.      0.      0.
      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
  0.      0.      0.      0.      0.      0.
      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
  0.      0.      0.      0.      0.      0.
      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
  0.      0.      0.      0.      0.      0.
      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
  0.      0.      0.      0.      0.      0.
      0.      0.      7.     18.     15.      6.      1.      0.      0.      0.      0.      0.      0.      0.
  0.      0.      0.      0.      0.      0.
      0.      0.    541.    823.    456.    123.     20.      3.      0.      0.      0.      0.      0.      0.
  0.      0.      0.      0.      0.      0.
      0.   2179.  26906.  20818.   6269.    699.     96.      9.      1.      0.      0.      0.      0.      0.
  0.      0.      0.      0.      0.      0.
      0.    176.    740.    651.     47.      0.      0.      0.      0.      0.      0.      0.      0.      0.
  0.      0.      0.      0.      0.      0.
      0.      5.     20.     10.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
  0.      0.      0.      0.      0.      0.
      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
  0.      0.      0.      0.      0.      0.
      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
  0.      0.      0.      0.      0.      0.
      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
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0. 0. 0. 0. 0. 0.
0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
0. 0. 0. 0. 0. 0.

# APPENDIX J

## Selected parts of MOC (transient) output file.

```
1                    INTERNATIONAL GROUND WATER MODELING CENTER
                            INDIANAPOLIS, INDIANA, USA
                               MOC VERSION  2.2
0U.S.G.S. METHOD-OF-CHARACTERISTICS MODEL FOR SOLUTE TRANSPORT IN GROUND WATER
0MOC concentration (Unsteady, cons. cont.,unmanaged heads)    Jan. 21st, 1992.

0                     I N P U T     D A T A
0                      GRID DESCRIPTORS

            NX    (NUMBER OF COLUMNS)  =    20
            NY    (NUMBER OF ROWS)     =    17
            XDEL  (X-DISTANCE IN FEET) =    50.0
            YDEL  (Y-DISTANCE IN FEET) =    50.0
0                      TIME  PARAMETERS

            NTIM   (MAX. NO. OF TIME STEPS)        =    100
            NPMP   (NO. OF PUMPING PERIODS)        =      1
            PINT   (PUMPING PERIOD IN YEARS)       =      0.500
            TIMX   (TIME INCREMENT MULTIPLIER)     =     30.00
            TINIT  (INITIAL TIME STEP IN SEC.)     =   86400.
0             HYDROLOGIC AND CHEMICAL PARAMETERS

            S        (STORAGE COEFFICIENT)        =       0.250000
            POROS    (EFFECTIVE POROSITY)         =       0.300
            BETA     (LONGITUDINAL DISPERSIVITY) =       1.0
            DLTRAT   (RATIO OF TRANSVERSE TO
                     LONGITUDINAL DISPERSIVITY)   =       0.30
            ANFCTR   (RATIO OF T-YY TO T-XX)      =       1.000000
0                    EXECUTION PARAMETERS

            NITP   (NO. OF ITERATION PARAMETERS) =    4
            TOL    (CONVERGENCE CRITERIA - ADIP) =    0.0010
            ITMAX  (MAX.NO.OF ITERATIONS - ADIP) =  100
            CELDIS (MAX.CELL DISTANCE PER MOVE
                      OF PARTICLES - M.O.C.)     =    0.500
            NPMAX  (MAX. NO. OF PARTICLES)       = 3200
            NPTPND (NO. PARTICLES PER NODE)      =     9
1
0                      PROGRAM OPTIONS

            NPNT   (TIME STEP INTERVAL FOR
                    COMPLETE PRINTOUT)        =     1
            NPNTMV (MOVE INTERVAL FOR CHEM.
                    CONCENTRATION PRINTOUT)   =     0
            NPNTVL (PRINT OPTION-VELOCITY
                    0=NO; 1=FIRST TIME STEP;
                    2=ALL TIME STEPS)         =     1
            NPNTD  (PRINT OPTION-DISP.COEF.
                    0=NO; 1=FIRST TIME STEP;
                    2=ALL TIME STEPS)         =     0
            NUMOBS (NO. OF OBSERVATION WELLS
                    FOR HYDROGRAPH PRINTOUT)  =     2
            NREC   (NO. OF PUMPING WELLS)     =    11
            NCODES (FOR NODE IDENT.)          =     0
            NPNCHV (PUNCH VELOCITIES)         =     0
            NPDELC (PRINT OPT.-CONC. CHANGE)  =     0
0                    REACTION TERMS

            DK       (DISTRIBUTION COEFFICIENT) =  0.00000E+00
            RHOB     (BULK DENSITY OF SOLIDS)   =  0.00000E+00
            RF       (RETARDATION FACTOR)       =  0.10000E+01
            THALF    (HALF LIFE OF DECAY,IN SEC)=  0.00000E+00
            DECAY    (DECAY CONSTANT=LN 2/THALF)=  0.00000E+00
```

```
1TIME INTERVALS (IN SECONDS)
     86400.      0.25920E+07 0.77760E+08 0.23328E+10 0.69984E+11 0.20995E+13 0.62986E+14 0.18896E+16
0.56687E+17 0.17006E+19
    0.51018E+20 0.15306E+22 0.45917E+23 0.13775E+25 0.41325E+26 0.12397E+28 0.37192E+29 0.11158E+31
0.33473E+32 0.10042E+34
    0.30126E+35 0.90377E+36 0.27113E+38 0.81340E+39 0.24402E+41 0.73206E+42 0.21962E+44 0.65885E+45
0.19766E+47 0.59297E+48
    0.17789E+50 0.53367E+51 0.16010E+53 0.48030E+54 0.14409E+56 0.43227E+57 0.12968E+59 0.38905E+60
0.11671E+62 0.35014E+63

    0.12771+124 0.38312+125 0.11494+127 0.34481+128 0.10344+130 0.31033+131 0.93098+132 0.27929+134
0.83788+135 0.25137+137
    0.75410+138 0.22623+140 0.67869+141 0.20361+143 0.61082+144 0.18325+146 0.54974+147 0.16492+149
0.49476+150 0.14843+152

0          LOCATION OF OBSERVATION WELLS

                NO.      X      Y

                 1      17      9
                 2      19      9

0          LOCATION  OF  PUMPING  WELLS

           X    Y    RATE(IN CFS)   CONC.

          15   12     3.531000     0.000000E+00
           3   11    -0.000541     0.583000E+06
           7    9     0.021151     0.000000E+00
           8   10     0.342119     0.000000E+00
           8   11     0.109214     0.000000E+00
           3    6    -0.048039     0.000000E+00
           4    6    -0.022041     0.000000E+00
          11    7    -0.029999     0.000000E+00
          11    8    -0.177310     0.000000E+00
          11   12    -0.157461     0.000000E+00
          11   13    -0.278405     0.000000E+00

0          AREA OF ONE CELL =     2500.
0          X-Y SPACING:
              50.000
              50.000
1TRANSMISSIVITY MAP (FT*FT/SEC)
  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00

  0.00E+00  9.56E-02  9.54E-02  9.52E-02  9.50E-02  9.48E-02  9.46E-02  9.44E-02  9.41E-02  9.38E-02
  9.34E-02  9.29E-02  9.24E-02  9.19E-02  9.17E-02  9.19E-02  9.24E-02  9.30E-02  9.38E-02  0.00E+00
  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00

1AQUIFER THICKNESS (FT)
    0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0
    0.0 55.4 55.3 55.1 54.9 54.8 54.6 54.4 54.3 54.1 53.9 53.8 53.6 53.4 53.2 53.0 52.8 52.5 52.2  0.0

    0.0 56.0 55.9 55.7 55.6 55.5 55.4 55.2 55.1 54.9 54.7 54.4 54.1 53.8 53.7 53.8 54.1 54.4 54.9  0.0
    0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0

1DIFFUSE RECHARGE AND DISCHARGE (FT/SEC)
  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
  0.00E+00 -3.73E-06  2.26E-06  2.19E-06  2.03E-06  1.85E-06  1.69E-06  1.52E-06  1.38E-06  1.23E-06

 -9.26E-06 -1.39E-05 -1.98E-05 -2.54E-05 -2.83E-05 -2.63E-05 -2.16E-05 -1.63E-05 -3.07E-05  0.00E+00
  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00

1PERMEABILTY MAP (FT/SEC)
  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00  0.00E+00
  0.00E+00  1.71E-03  1.71E-03  1.71E-03  1.71E-03  1.71E-03  1.71E-03  1.71E-03  1.71E-03  1.71E-03
```

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1.71E-03 | 1.71E-03 | 1.71E-03 | 1.71E-03 | 1.71E-03 | 1.71E-03 | 1.71E-03 | 1.71E-03 | 1.71E-03 | 0.00E+00 |
| 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |

1HEAD DISTRIBUTION - ROW

NUMBER OF TIME STEPS = 0

TIME(SECONDS) = 0.00000E+00

TIME(DAYS) = 0.00000E+00

TIME(YEARS) = 0.00000E+00

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| * | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| * | 0.00 | 55.41 | 55.25 | 55.08 | 54.92 | 54.75 | 54.58 | 54.41 | 54.24 | 54.07 |
| | 53.89 | 53.72 | 53.54 | 53.35 | 53.17 | 52.97 | 52.75 | 52.49 | 52.18 | 0.00 |
| * | 0.00 | 55.46 | 55.30 | 55.13 | 54.97 | 54.80 | 54.63 | 54.45 | 54.27 | 54.09 |
| | 53.91 | 53.73 | 53.54 | 53.36 | 53.18 | 52.99 | 52.79 | 52.57 | 52.32 | 0.00 |
| * | 0.00 | 55.51 | 55.35 | 55.18 | 55.01 | 54.84 | 54.66 | 54.48 | 54.30 | 54.11 |
| | 53.92 | 53.72 | 53.53 | 53.34 | 53.16 | 52.98 | 52.82 | 52.64 | 52.45 | 0.00 |
| * | 0.00 | 55.55 | 55.39 | 55.23 | 55.06 | 54.88 | 54.70 | 54.51 | 54.32 | 54.11 |
| | 53.91 | 53.69 | 53.48 | 53.29 | 53.11 | 52.95 | 52.81 | 52.69 | 52.57 | 0.00 |
| * | 0.00 | 55.60 | 55.44 | 55.27 | 55.09 | 54.92 | 54.73 | 54.53 | 54.33 | 54.10 |
| | 53.87 | 53.63 | 53.39 | 53.18 | 52.99 | 52.86 | 52.76 | 52.70 | 52.68 | 0.00 |
| * | 0.00 | 55.64 | 55.48 | 55.31 | 55.14 | 54.95 | 54.76 | 54.55 | 54.32 | 54.08 |
| | 53.81 | 53.52 | 53.23 | 52.97 | 52.77 | 52.68 | 52.65 | 52.68 | 52.78 | 0.00 |
| * | 0.00 | 55.67 | 55.51 | 55.35 | 55.18 | 54.99 | 54.79 | 54.57 | 54.32 | 54.03 |
| | 53.71 | 53.34 | 52.96 | 52.60 | 52.37 | 52.35 | 52.47 | 52.66 | 52.89 | 0.00 |
| * | 0.00 | 55.71 | 55.56 | 55.39 | 55.22 | 55.03 | 54.82 | 54.58 | 54.31 | 53.98 |
| | 53.57 | 53.08 | 52.52 | 51.95 | 51.60 | 51.75 | 52.13 | 52.56 | 52.98 | 0.00 |
| * | 0.00 | 55.75 | 55.60 | 55.44 | 55.26 | 55.07 | 54.86 | 54.61 | 54.30 | 53.92 |
| | 53.42 | 52.75 | 51.86 | 50.81 | 50.02 | 50.66 | 51.58 | 52.38 | 53.03 | 0.00 |
| * | 0.00 | 55.78 | 55.64 | 55.48 | 55.31 | 55.12 | 54.90 | 54.64 | 54.32 | 53.90 |
| | 53.30 | 52.42 | 51.05 | 48.92 | 46.32 | 48.80 | 50.85 | 52.19 | 53.11 | 0.00 |
| * | 0.00 | 55.82 | 55.68 | 55.52 | 55.36 | 55.17 | 54.96 | 54.70 | 54.38 | 53.94 |
| | 53.31 | 52.30 | 50.48 | 46.55 | 34.30 | 46.48 | 50.36 | 52.18 | 53.28 | 0.00 |
| * | 0.00 | 55.86 | 55.72 | 55.57 | 55.41 | 55.24 | 55.03 | 54.79 | 54.48 | 54.08 |
| | 53.50 | 52.64 | 51.30 | 49.22 | 46.67 | 49.18 | 51.25 | 52.63 | 53.60 | 0.00 |
| * | 0.00 | 55.89 | 55.76 | 55.63 | 55.48 | 55.31 | 55.12 | 54.90 | 54.63 | 54.28 |
| | 53.82 | 53.19 | 52.36 | 51.38 | 50.67 | 51.37 | 52.37 | 53.26 | 54.02 | 0.00 |
| * | 0.00 | 55.93 | 55.81 | 55.68 | 55.54 | 55.39 | 55.22 | 55.02 | 54.79 | 54.51 |
| | 54.16 | 53.74 | 53.24 | 52.77 | 52.53 | 52.79 | 53.30 | 53.87 | 54.44 | 0.00 |
| * | 0.00 | 55.96 | 55.85 | 55.73 | 55.60 | 55.47 | 55.31 | 55.14 | 54.95 | 54.73 |
| | 54.48 | 54.20 | 53.90 | 53.66 | 53.57 | 53.70 | 53.99 | 54.38 | 54.84 | 0.00 |
| * | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

1CONCENTRATION

NUMBER OF TIME STEPS = 0

TIME(SECONDS) = 0.00000E+00

CHEM.TIME(SECONDS) = 0.00000E+00

CHEM.TIME(DAYS) = 0.00000E+00

TIME(YEARS) = 0.00000E+00

CHEM.TIME(YEARS) = 0.00000E+00

NO. MOVES COMPLETED = 0

| | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| * | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| * | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| * | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

```
*    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
*    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
*    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
*    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
*    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
*    0    0    0    0    7    0   18    0   15    0    6    1    0    0    0    0    0    0    0    0
*    0    0    0    0  541    0  823    4   56   12    3   20    0    3    0    0    0    0    0    0
*    0    0  217    9 6906    0  818   62   69   69    9   96    0    9    0    1    0    0    0    0
*    0    0   17    6  740    0  651    0   47    0    0    0    0    0    0    0    0    0    0    0
*    0    0    0    5   20    0   10    0    0    0    0    0    0    0    0    0    0    0    0    0
*    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
*    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
*    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
*    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
   N =   3
   NUMBER OF ITERATIONS =     4
1HEAD DISTRIBUTION - ROW
 NUMBER OF TIME STEPS =      3
        TIME(SECONDS) =  0.15779E+08
        TIME(DAYS)    =  0.18263E+03
        TIME(YEARS)   =  0.50000E+00
*   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
    0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00

*   0.00  55.56  55.40  55.24  55.08  54.91  54.75  54.59  54.44  54.28
   54.11  53.94  53.77  53.59  53.40  53.20  52.98  52.72  52.40   0.00

*   0.00  55.63  55.47  55.30  55.13  54.96  54.80  54.63  54.47  54.31
   54.15  53.97  53.79  53.60  53.42  53.23  53.02  52.80  52.54   0.00

*   0.00  55.69  55.54  55.37  55.19  55.01  54.83  54.67  54.51  54.35
   54.18  53.99  53.80  53.60  53.42  53.23  53.06  52.87  52.67   0.00

*   0.00  55.76  55.63  55.45  55.24  55.04  54.85  54.69  54.53  54.39
   54.22  54.01  53.79  53.58  53.38  53.21  53.06  52.93  52.80   0.00

*   0.00  55.82  55.80  55.56  55.27  55.05  54.85  54.68  54.55  54.43
   54.29  54.03  53.75  53.50  53.29  53.13  53.02  52.95  52.91   0.00

*   0.00  55.82  55.69  55.49  55.25  55.02  54.80  54.63  54.53  54.48
   54.47  54.04  53.65  53.33  53.09  52.96  52.92  52.93  53.02   0.00

*   0.00  55.82  55.66  55.46  55.22  54.96  54.69  54.48  54.44  54.48
   54.74  53.97  53.43  52.99  52.71  52.65  52.74  52.91  53.13   0.00

*   0.00  55.83  55.65  55.45  55.19  54.87  54.45  54.11  54.21  54.26
   54.15  53.63  52.99  52.36  51.95  52.06  52.41  52.82  53.22   0.00

*   0.00  55.85  55.67  55.46  55.20  54.84  54.28  53.18  53.96  54.12
   53.92  53.30  52.36  51.24  50.40  50.98  51.87  52.64  53.28   0.00

*   0.00  55.88  55.71  55.51  55.27  54.95  54.51  53.86  54.19  54.26
   54.03  53.10  51.62  49.39  46.72  49.14  51.15  52.45  53.36   0.00

*   0.00  55.92  55.77  55.58  55.37  55.12  54.84  54.58  54.59  54.63
   54.71  53.22  51.15  47.08  34.78  46.83  50.66  52.45  53.52   0.00

*   0.00  55.97  55.82  55.66  55.48  55.29  55.09  54.93  54.88  54.92
   55.24  53.65  51.98  49.73  47.09  49.52  51.55  52.89  53.85   0.00

*   0.00  56.01  55.88  55.74  55.58  55.43  55.27  55.13  55.03  54.92
   54.72  53.93  52.94  51.84  51.05  51.70  52.65  53.52  54.26   0.00

*   0.00  56.06  55.94  55.81  55.67  55.54  55.40  55.27  55.15  54.99
   54.74  54.28  53.72  53.18  52.88  53.10  53.57  54.12  54.68   0.00

*   0.00  56.10  55.99  55.87  55.75  55.63  55.51  55.39  55.27  55.11
   54.91  54.62  54.30  54.02  53.89  53.99  54.26  54.63  55.06   0.00

*   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
    0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
```

1CONCENTRATION

NUMBER OF TIME STEPS = 3
DELTA T = 0.13100E+08
TIME(SECONDS) = 0.15779E+08
CHEM.TIME(SECONDS) = 0.15779E+08
CHEM.TIME(DAYS) = 0.18263E+03
TIME(YEARS) = 0.50000E+00
CHEM.TIME(YEARS) = 0.50000E+00
NO. MOVES COMPLETED = 735

| | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| * | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| * | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| * | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| * | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| * | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| * | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| * | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| * | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| * | 0 | 0 | 2 | 5 | 30 | 85 | 176 | 60 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| * | 0 | -37 | 380 | 926 | 7298 | 15741 | 14569 | 3337 | 41 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| * | 0 | 17119002484196531242578612449 | | | | | | 2471 | 33 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| * | 0 | 111 | 890 | 958 | 576 | 264 | 78 | 20 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| * | 0 | 2 | 9 | 10 | 7 | 3 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| * | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| * | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| * | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| * | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

CHEMICAL MASS BALANCE

MASS IN BOUNDARIES = 0.00000E+00
MASS OUT BOUNDARIES = 0.00000E+00
MASS PUMPED IN = 0.19265E+11
MASS PUMPED OUT = -0.12222E+11
MASS LOST BY DECAY = 0.00000E+00
MASS ADSORBED ON SOLIDS= 0.00000E+00
INITIAL MASS ADSORBED = 0.00000E+00
INFLOW MINUS OUTFLOW = 0.70428E+10
INITIAL MASS DISSOLVED = 0.46434E+09
PRESENT MASS DISSOLVED = 0.13051E+11
CHANGE MASS DISSOLVED = 0.12587E+11
CHANGE TOTL.MASS STORED= 0.12587E+11
COMPARE RESIDUAL WITH NET FLUX AND MASS ACCUMULATION:
MASS BALANCE RESIDUAL = -0.55442E+10
ERROR (AS PERCENT) = -0.28779E+02

# APPENDIX K

## MODFLOW+STR input data format

**(from page 4-9 of McDonald & Harbaugh )**

Basic Package Input

Input for the Basic (BAS) Package except for output control is read from unit 1 as specified in the main program. If necessary, the unit number for BAS input can be changed to meet the requirements of a particular computer. Input for the output control option is read from the unit number specified in IUNIT(12).

Information for the Basic Package must be submitted in the following order:

FOR EACH SIMULATION

BAS1DF

| | | | | | | |
|---|---|---|---|---|---|---|
| 1. | Data: | HEADING(32) | | | | |
| | Format: | 20A4 | | | | |
| 2. | Data: | HEADING (continued) | | | | |
| | Format: | 12A4 | | | | |
| 3. | Data: | NLAY | NROW | NCOL | NPER | ITMUNI |
| | Format: | I10 | I10 | I10 | I10 | I10 |
| 4. | Data: | IUNIT(24) | | | | |
| | Format: | 24I3 | | | | |

———————— Top of changed portion ————————

(BCF WEL DRN RIV EVT XXX GHB RCH SIP XXX SOR OC STR)

———————— Bottom of changed portion ————————

BAS1AL

| | | | |
|---|---|---|---|
| 5. | Data: | IAPART | ISTRT |
| | Format: | I10 | I10 |

BAS1RP

| | | |
|---|---|---|
| 6. | Data: | IBOUND(NCOL,NROW) |
| | Module: | U2DINT |
| | | (One array for each layer in the grid) |
| 7. | Data: | HNOFLO |
| | Format: | F10.0 |
| 8. | Data: | Shead(NCOL,NROW) |
| | Module: | U2DREL |
| | | (One array for each layer in the grid) |

NOTE:IBOUND and Shead are treated as three-dimensional arrays in the program. However, the input to each of these arrays is handled as a series of two-dimensional arrays, one for each layer in the grid.

(from page 4-10 of McDonald & Harbaugh)

FOR EACH STRESS PERIOD

BAS1ST

| | | | | |
|---|---|---|---|---|
| 9. | Data: | PERLEN | NSTP | TSMULT |
| | Format: | F10.0 | I10 | F10.0 |

——— Top of changed portion ———

| | | |
|---|---|---|
| 10. | Data: | IBEG, JBEG, IEND, JEND |
| | Format: | 5I10 |

——— Bottom of changed portion ———

Explanation of Fields Used in
Input Instructions

HEADNG– Is the simulation title that is printed on the printout. It may be up to 132 characters long; 80 in the first record and 52 in the second. Both records must be included even if they are blank.

NLAY– is the number of model layers.

NROW– is the number of model rows.

NCOL– is the number of model columns.

NPER– is the number of stress periods in the simulation.

ITMUNI– indicates the time unit of model data. (It is used only for printout of elapsed simulation time. It does not affect model calculations.)

| | |
|---|---|
| 0 - undefined | 3 - hours |
| 1 - seconds | 4 - days |
| 2 - minutes | 5 - years |

The unit of time must be consHxtent for all data values that involve time. For example, if years is the chosen time unit, stress-period length, time-step length, transmissivity, etc., must all be expressed using years for their time units. Likewise, the length unit must also be consistent.

(from page 4-11 of McDonald & Harbaugh )

———————————— Top of changed portion ————————————

IUNIT-- is a 24-element table of input units for use by all major options. Only 11 elements (1-5, 7-9, 11, and 12-13) are being used. Element 6 has been reserved for a transient leakage package, while element 10 has been reserved for an additional solver, both on the assumption that such packages will be added to the model in the future. Elements 14-24 are reserved for future major options.

| IUNIT LOCATION | MAJOR OPTION |
|---|---|
| 1 | Block-Centered Flow Package |
| 2 | Well Package |
| 3 | Drain Package |
| 4 | River Package |
| 5 | Evapotranspiration Package |
| 6 | Reserved for Transient Leakage Package |
| 7 | General-Head Boundary Package |
| 8 | Recharge Package |
| 9 | SIP Package |
| 10 | Reserved for additional solver |
| 11 | SSOR Package |
| 12 | Output Control Option |
| 13 | Streamflow-routing |

———————————— Bottom of changed portion ————————————

**If IUNIT(n) < O, the corresponding major option is not being used.**

**If IUNIT(n) > O, the corresponding major option is being used and data for that option will be read from the unit number contained in IUNIT(n). The unit numbers in IUNIT should be integers from 1 to 99. Although the same number may be used for all or some of the major options, it is recommended that a different number be used for each major option. Printer output is assigned to unit 6 (unless it is changed to meet computer requirements). That unit number should not be used for any other input or output. The user is also permitted to assign unit numbers for output. Those numbers should be different from those assigned to input. The Basic Package reads from unit 1 (unless it is changed to meet computer requirements). It is permissible but unwise to use that unit for other major options.**

IAPART-- Indicates whether array BUFF is separate from array RHS.

If IAPART = O, the arrays BUFF and RHS occupy the same space. This option conserves space. This option should be used unless some other package explicitly says otherwise.

If IAPART ≠ 0, the arrays BUFF and RHS occupy different space. This option is not needed in the program as documented in this publication. It may be needed for packages yet to be written.

ISTRT-- indicates whether starting heads are to be saved. If they are saved, they will be stored in array STRT. They must be saved if drawdown is calculated.

If ISTRT = O, starting heads are not saved.

If ISTRT O, starting heads are saved.

IBOUND-- is the boundary array.

If IBOUND(I,J,K) < O, cell I,J,K has a constant head.

If IBOUND(I,J,K) = O, cell I,J,K is inactive (no-flow).

If IBOUND(I,J,K) > O, cell I,J,K is variable-head.

HNOFLO-- is the value of head to be assigned to all inactive cells (IBOUND = O) throughout the simulation. Since heads at inactive cells are unused, this does not affect model results but serves to identify inactive cells when head is printed. This value is also used as drawdown at inactive cells if the drawdown option is used. Even if the user does not anticipate having inactive cells, a value for HNOFLO must be submitted.

Shead-- is head at the start of the simulation. Regardless of whether starting head is saved, these values must be input to initialize the solution.

PERLEN-- is the length of a stress period. It is specified for each stress period.

NSTP-- is the number of time steps in a stress period.

TSMULT-- is the multiplier for the length of successive time steps. The length of the first time step DELT(1) is related to PERLEN, NSTP and TSMULT by the relation DELT(1) = PERLEN(1-TSMULT)/(1-TSMULT**NSTP).

——————————— Top of changed portion ———————————

IBEG, JBEG-- upper left i and j coordinates of the subsystem.

IEND, JEND-- upper left i and j coordinates of the subsystem.

——————————— Bottom of changed portion ———————————

(from page 4-14 of McDonald & Harbaugh )

## Output Control Input

Output Control is a major option separate from the rest of the Basic Package. Input to Output Control is read from the unit specified in IUNIT(12). If IUNIT(12) is zero, no output control data are read, and default output control is used. Under the default, head and total budget are printed at the end of every stress period. Additionally, if starting heads are saved (ISTRT is not O), drawdown is printed at the end of every stress period. The default printout format for head and drawdown is 10G11.4. All printer output goes to unit 6 as specified in the main program. If necessary, the unit number for printer output can be changed to meet the requirements of a particular computer.

FOR EACH SIMULATION

BAS1RP

| | | | | | |
|---|---|---|---|---|---|
| 1. | Data: | IHEDFM | IDDNFM | IHEDUN | IDDNUN |
| | Format: | I10 | I10 | I10 | I10 |

FOR EACH TIME STEP

BAS1OC

| | | | | | |
|---|---|---|---|---|---|
| 2. | Data: | INCODE | IHDDFL | IBUDFL | ICBCFL |
| | Format: | I10 | I10 | I10 | I10 |
| 3. | Data: | Hdpr | Ddpr | Hdsv | Ddsv |
| | Format: | I10 | I10 | I10 | I10 |

(Record 3 is read O, 1, or NLAY times, depending on the value of INCODE.)

Explanation of Fields Used in Input Instructions

IHEDFM-- is a code for the format in which heads will be printed.

IDDNFM-- is a code for the format in which drawdowns will be printed. Format codes have the same meaning for both head and drawdown. A positive format code indicates that each row of data is printed completely before starting the next row. This means that when there are more columns in a row than will fit on one line, additional lines are used as required to complete-the row. This format is called the wrap format. A negative format code indicates that the printout is broken into strips where only that number of columns that will fit across one line are printed in a strip. As many strips are used as are required to print the entire model width. This format is called the strip format. The absolute value of the format code specifies the printout format as follows.

(from page 4-15 of McDonald & Harbaugh )

| | |
|---|---|
| 0 - (10G11.4) | 7 - (20F5.0) |
| 1 - (11G10.3) | 8 - (20F5.1) |
| 2 - (9G13.6) | 9 - (20F5.2) |
| 3 - (15F7.1) | 10 - (20F5.3) |
| 4 - (15F7.2) | 11 - (20F5.4) |
| 5 - (15F7.3) | 12 - (10G11.4) |
| 6 - (15F7.4) | |

IHEDUN-- is the unit number to which heads will be written if they are saved on disk.

IDDNUN-- is the unit number to which drawdowns will be written if they are saved on disk.

INCODE-- is the head/drawdown output code. It determines the number of records in input item 3.

If INCODE < 0, layer-by-layer specifications from the last time steps are used. Input item 3 is not read.

If INCODE = 0, all layers are treated the same way. Input item 3 will consist of one record.

If INCODE > 0, input item 3 will consist of one record for each layer.

IHDDFL-- is a head and drawdown output flag.

If IHDDFL = 0, neither heads nor drawdowns will be printed or saved on disk.

If IHDDFL ≠ 0, heads and drawdowns will be printed or saved according to the flags for each layer specified in input item 3.

IBUDFL-- is a budget print flag.

If IBUDFL = 0, overall volumetric budget will not be printed.

If IBUDFL ≠ 0, overall volumetric budget will be printed.

(Note that he overall volumetric budget will always be printed at the end of a stress period even if the value of IBUDFL is zero.)

ICBCFL-- is a cell-by-cell flow-term flag.

If ICRCFL = 0, cell-by-cell flow terms are not saved or printed.

If ICBCFL ≠ 0, cell-by-cell flow terms are printed or recorded on disk depending on flags set in the component of flow packages i.e. IWELCB, IRCHCB, etc.

(from page 4-16 of McDonald & Harbaugh )

| | | |
|---|---|---|
| Hdpr– | is the output flag for head printout. | |
| | If Hdpr = 0, | head is not printed for the corresponding layer. |
| | If Hdpr ≠ 0, | head is printed for the corresponding layer. |
| Ddpr– | is the output flag for drawdown printout. | |
| | If Ddpr = 0, | drawdown is not printed for the corresponding layer. |
| | If Ddpr ≠ 0, | drawdown is printed for the corresponding layer. |
| Hdsv– | is the output flag for head save. | |
| | If Hdsv = 0, | head is not saved for the corresponding layer. |
| | If Hdsv ≠ 0, | head is saved for the corresponding layer. |
| Ddsv– | is the output flag for drawdown save. | |
| | If Ddsv = 0, | drawdown is not saved for the corresponding layer. |
| | If Ddsv ≠ 0, | drawdown is saved for the corresponding layer. |

(from page 5-37 of McDonald & Harbaugh)

Block-Centered Flow Package Input

Input for the Block-Centered Flow (BCF) Package is read from the unit specified in IUNIT(1).

FOR EACH SIMULATION

BCF1AL

| | | | |
|---|---|---|---|
| 1. | Data: | ISS | IBCFCB |
| | Format: | I10 | I10 |
| 2. | Data: | LAYCON(NLAY) (Maximum of 80 layers) | |
| | Format: | 40I2 | |

(If there are 40 or fewer layers, use one record; otherwise, use two records.)

BCF1RP

| | | |
|---|---|---|
| 3. | Data: | TRPY(NLAY) |
| | Module: | U1DREL |
| 4. | Data: | DELR(NCOL) |
| | Module: | U1DREL |
| 5. | Data: | DELC(NROW) |
| | Module: | U1DREL |

A subset of the following two-dimensional arrays are used to describe each layer. The arrays needed for each layer depend on the layer type code (LAYCON) and whether the simulation is transient (ISS = 0) or steady state (ISS <> 0). If an array is not needed, it must be omitted. All of the arrays (items 6-12) for layer 1 are read first; then all of the arrays for layer 2, etc.

IF THE SIMULATION IS TRANSIENT

| | | |
|---|---|---|
| 6. | Data: | sf1(NCOL,NROW) |
| | Module: | U2DREL |

IF THE LAYER TYPE CODE (LAYCON) IS ZERO OR TWO

| | | |
|---|---|---|
| 7. | Data: | Tran(NCOL,NROW) |
| | Module: | U2DREL |

IF THE LAYER TYPE CODE (LAYCON) IS ONE OR THREE

| | | |
|---|---|---|
| 8. | Data: | HY(NCOL,NROW) |
| | Module: | U2DREL |
| 9. | Data: | BOT(NCOL,NROW) |
| | Module: | U2DREL |

(from page 5-38 of McDonald & Harbaugh)

IF THIS IS NOT THE BOTTOM LAYER

10. Data: Vcont(NCOL,NROW)
    Module: U2DREL

IF THE SIMULATION IS TRANSIENT AND THE LAYER TYPE CODE (LAYCON) IS TWO OR THREE

11. Data: sf2(NCOL,NROW)
    Module: U2DREL

IF THE LAYER TYPE CODE IS TWO OR THREE

12. Data: TOP(NCOL,NROW)
    Module: U2DREL

Explanation of Fields Used in Input Instructions

ISS-- is the steady-state flag.

If ISS <> 0, the simulation is steady state.

If ISS = 0, the simulation is transient.

IBCFCB-- is a flag and a unit number.

If IBCFCB > O, it is the unit number on which cell-by-cell flow terms will be recorded whenever ICBCFL (see Output Control) is set; the terms which are saved will include cell-by-cell storage terms, cell-by-cell constant head flows, and internal cell-by-cell flows.

If IBCFCB = 0, cell-by-cell flow terms will not be printed or recorded.

If IBCFCB < 0, flow for each constant-head cell will be printed, rather than saved on disk, whenever ICBCFL is set; cell-by-cell storage terms and internal cell-by-cell flows will neither be saved nor printed.

LAYCON-- is the layer type table. Each element holds the code for the respective layer. Read one value for each layer. There is a limit of 80 layers. Leave unused elements blank.

0 - confined-- Transmissivity and storage coefficient of the layer are constant for the entire simulation.

1 - unconfined-- Transmissivity of the layer varies. It is calculated from the saturated thickness and hydraulic conductivity. The storage coefficient is constant; valid only for layer 1.

(from pages 5-39 and 5-40 of McDonald & Harbaugh)

2 - confined/unconfined--

Transmissivity of the layer is constant. The storage coefficient may alternate between confined and unconfined values. Vertical leakage from above is limited if the layer desaturates.

3 - confined/unconfined--

Transmissivity of the layer varies. It is calculated from the saturated thickness and hydraulic conductivity. The storage coefficient may alternate between confined and unconfined values. Vertical leakage from above is limited if the aquifer desaturates.

TRPY-- is a one-dimensional array containing an anisotropy factor for each layer. It is the ratio of transmissivity or hydraulic conductivity (whichever is being used) along a column to transmissivity or hydraulic conductivity along a row. Read one value per layer. Set to 1.0 for isotropic conditions. NOTE: This is one array with one value for each layer.

DELR-- is the cell width along rows. Read one value for each of the NCOL columns.

DELC-- is the cell width along columns. Read one value for each of the NROW rows.

sf1-- is the primary storage coefficient. Read only for a transient simulation (steady-state flag, ISS, is 0). Note that for Laycon=1, sf1 will always be specific yield, while for Laycon=2 or 3, sf1 will always be confined storage coefficient. For Laycon=0, sf1 would normally be confined storage coefficient; however, layer-type O can also be used for simulation of water table conditions where drawdowns are expected to remain every- where a small fraction of the saturated thickness, and where there is no layer above, or flow from the layer above is negligible; and in this case specific yield values would be entered in sf1.

Tran-- is the transmissivity along rows. Tran is multiplied by TRPY to obtain transmissivity along columns. Read only for layers where LAYCON is zero or two.

HY-- is the hydraulic conductivity along rows. HY is multiplied by TRPY to obtain the hydraulic conductivity along columns. Read only for layers where LAYCON is one or three.

BOT-- is the elevation of the aquifer bottom. Read only for layers where LAYCON is one or three.

Vcont-- is the vertical hydraulic conductivity divided by the thickness from a layer to the layer beneath it. Since there is not a layer beneath the bottom layer, Vcont cannot be specified for the bottom layer.

sf2-- is the secondary storage coefficient. Read it only for layers where LAYCON is two or three and only if a transient simulation (steady- state flag, ISS, is zero). The secondary storage coefficient is always specific yield.

TOP-- is the elevation of the aquifer top. Read only for layers where LAYCON is two or three.

(from pages 7-6 and 7-7 of McDonald & Harbaugh)

Recharge Package Input

Input to the Recharge (RCH) Package is read from the unit specified in IUNIT(8).

FOR EACH SIMULATION

RCH1AL

| | | | | |
|---|---|---|---|---|
| 1. | Data: | NRCHOP | IRCHCB | |
| | Format: | I10 | | I10 |

FOR EACH STRESS PERIOD

RCH1RP

| | | | |
|---|---|---|---|
| 2. | Data: | INRECH | INIRCH |
| | Format: | I10 | I10 |
| 3. | Data: | RECH(NCOL,NROW) | |
| | Module: | U2DREL | |

IF THE RECHARGE OPTION IS EQUAL TO 2

| | | |
|---|---|---|
| 4. | Data: | IRCH(NCOL,NROW) |
| | Module: | U2DINT |

Explanation of Fields Used in Input Instructions

NRCHOP– is the recharge option code. Recharge fluxes are defined in a two-dimensional array, RECH, with one value for each vertical column. Accordingly, recharge is applied to one cell in each vertical column, and the option code determines which cell in the column is selected for recharge.

1 - Recharge is only to the top grid layer.

2 - Vertical distribution of recharge is specified in array IRCH.

3 - Recharge is applied to the highest active cell in each vertical column. A constant-head node intercepts recharge and prevents deeper infiltration.

IRCHCB–is a flag and a unit number.
- If IRCHCB > 0, it is the unit number on which cell-by-cell flow terms will be recorded whenever ICBCFL (see Output Control) is set.
- If IRCHCB ≤ 0, cell-by-cell flow terms will not be printed or recorded.

INRECH–is the RECH read flag.
- If INRECH ≥ 0, an array of recharge fluxes, RECH, is read.
- If INRECH < 0, recharge rates from the preceding stress period are used.

INIRCH–is the IRCH read flag. When NRCHOP is two,
- If INIRCH ≥ 0, an array of layer numbers (IRCH) is read.
- If INIRCH < 0, the array (IRCH) used in the preceding stress period is reused.

Note: When NRCHOP is one or three, INIRCH is ignored.

RECH– is the recharge flux ($Lt^{-1}$). Read only if INRECH is greater than or equal to zero.

IRCH– is the layer number array that defines the layer in each vertical column where recharge is applied. Read only if NRCHOP is two and if INIRCH is greater than or equal to zero.

(from pages 6-14 and 6-15 of McDonald & Harbaugh)

River Package Input

Input to the River (RIV) Package is read from the unit specified in IUNIT(4).

FOR EACH SIMULATION

RIV1AL

| | | | |
|---|---|---|---|
| 1. | Data: | MXRIVR | IRIVCB |
| | Format: | I10 | I10 |

FOR EACH STRESS PERIOD

RIV1RP

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 2. | Data: | ITMP | | | | | | |
| | Format: | I10 | | | | | | |
| 3. | Data: | Layer | Row | Column | Stage | Cond | Rbot |
| | Format: | I10 | I10 | I10 | F10.0 | F10.0 | F10.0 |

(Input item 3 normally consists of one record for each river reach. If ITMP is negative or zero, item 3 is not read.)

Explanation of Fields Used in Input Instructions

MXRIVR-- is the maximum number of river reaches active at one time.

IRIVCB-- is a flag and a unit number.

If IRIVCB > 0, it is the unit number on which cell-by-cell flow terms will be recorded whenever ICBCFL (see Output Control) is set.

If IRIVCB = 0, cell-by-cell flow terms will not be printed or recorded.

If IRIVCB < 0, river leakage for each reach will be printed whenever ICBCFL is set.

ITMP-- is a flag and a counter.

If ITMP < 0, river data from the last stress period will be reused.

If ITMP > 0, ITMP will be the number of reaches active during the current stress period.

Layer-- is the layer number of the cell containing the river reach.

Row-- is the row number of the cell containing the river reach.

Column-- is the column number of the cell containing the river reach.
Stage-- is the head in the river.
Cond-- is the riverbed hydraulic conductance.
Rbot-- is the elevation of the bottom of the riverbed.

(from page 8-3 of McDonald & Harbaugh)

## Well Package Input

Input for the Well (WEL) Package is read from the unit specified in IUNIT(2).

FOR EACH SIMULATION

WEL1AL

| | | | |
|---|---|---|---|
| 1. | Data: | MXWELL | IWELCB |
| | Format: | I10 | I10 |

FOR EACH STRESS PERIOD

WEL1RP

| | | | | | | |
|---|---|---|---|---|---|---|
| 2. | Data: | ITMP | | | | |
| | Format: | I10 | | | | |
| 3. | Data: | Layer | Row | Column | Q |
| | Format: | I10 | I10 | I10 | F10.0 |

(Input item 3 normally consists of one record for each well. If ITMP is negative or zero, item 3 is not read.)

### Explanation of Fields Used in Input Instructions

MXWELL– is the maximum number of wells used at any time.

IWELCB– is a flag and a unit number.

If IWELCB > 0, it is the unit number on which cell-by-cell flow terms will be recorded whenever ICBCFL (see Output Control) is set.

If IWELCB = 0, cell-by-cell flow terms will not be printed or recorded.

If IWELCB < 0, well recharge will be printed whenever ICBCFL is set.

ITMP– is a flag and a counter.

If ITMP < 0, well data from the last stress period will be reused.

If ITMP > 0, ITMP will be the number of wells active during the current stress period.

Layer– is the layer number of the model cell that contains the well.

Row– is the row number of the model cell that contains the well.

Column– is the column number of the model cell that contains the well.

Q– is the volumetric recharge rate. A positive value indicates recharge and a negative value indicates discharge.

(from pages 9-7 and 9-8 of McDonald & Harbaugh)

Drain Package Input

Input to the Drain (DRN) Package is read from the unit specified in IUNIT(3).

FOR EACH SIMULATION

DRN1AL

| | | | |
|---|---|---|---|
| 1. | Data: | MXDRN | IDRNCB |
| | Format: | I10 | I10 |

FOR EACH STRESS PERIOD

DRN1RP

| | | | | | | |
|---|---|---|---|---|---|---|
| 2. | Data: | ITMP | | | | |
| | Format: | I10 | | | | |
| 3. | Data: | Layer | Row | Col | Elevation | Cond |
| | Format: | I10 | I10 | I10 | F10.0 | F10.0 |

(Input item 3 normally consists of one record for each drain. If ITMP is negative or zero, item 3 will not be read.)

Explanation of Fields Used in
Input Instructions

MXDRN– is the maximum number of drain cells active at one time.

IDRNCB– is a flag and a unit number.

If IDRNCB > 0, it is the unit number on which cell-by-cell flow terms will be recorded whenever ICBCFL (see Output Control) is set.

If IDRNCB = 0, cell-by-cell flow terms will not be printed or recorded.

If IDRNCB < 0, drain leakage for each cell will be printed whenever ICBCFL is set.

ITMP– is a flag and a counter.

If ITMP < 0, drain data from the last stress period will be reused.

If ITMP ≥ 0, ITMP will be the number of drains active during the current stress period.

Layer– is the layer number of the cell containing the drain.

Row– is the row number of the cell containing the drain.

Column– is the column number of the cell containing the drain.

Elevation– is elevation of the drain.

Cond– is the hydraulic conductance of the interface between the aquifer and the drain.

Evapotranspiration Package Input

Input to the Evapotranspiration (EVT) Package is read from the unit specified in IUNIT (5).

FOR EACH SIMULATION

EVT1AL

| | | | |
|---|---|---|---|
| 1. | Data: | NEVTOP | IEVTCB |
| | Format: | I10 | I10 |

FOR EACH STRESS PERIOD

EVT1RP

| | | | | | |
|---|---|---|---|---|---|
| 2. | Data: | INSURF | INEVTR | INEXDP | INIEVT |
| | Format: | I10 | I10 | I10 | I10 |
| 3. | Data: | SURF | | | |
| | Module: | U2DREL | | | |
| 4. | Data: | EVTR | | | |
| | Module: | U2DREL | | | |
| 5. | Data: | EXDP | | | |
| | Module: | U2DREL | | | |

IF THE ET OPTION IS EQUAL TO TWO

| | | |
|---|---|---|
| 6. | Data: | IEVT |
| | Module: | U2DINT |

Explanation of Fields Used in
Input Instructions

NEVTOP-- is the evapotranspiration (ET) option code. ET parameters (ET surface, maximum ET rate, and extinction depth) are specified in two-dimensional arrays, SURF, EVTR, and EXDP, with one value for each vertical column. Accordingly, ET is calculated for one cell in each vertical column. The option codes determine for which cell in the column ET will be calculated.

1 - ET is calculated only for cells in the top grid layer.

2 - The cell for each vertical column is specified by the user in array IEVT.

(from page 10-9 of McDonald & Harbaugh)

<u>IEVTCB</u>– is a flag and a unit number

If IEVTCB >0, it is the unit number on which cell-by-cell flow terms will be recorded whenever ICBCFL (see Output Control) is set.

If IEVTCB < 0, cell-by-cell flow terms will not be printed or recorded.

<u>INSURF</u>– is the ET surface (SURF) read flag.

If INSURF > 0, an array containing the ET surface elevation will be read.

If INSURF < 0, the ET surface from the preceding stress period will be reused.

<u>INEVTR</u>– is the maximum ET rate (EVTR) read flag.

If INEVTR > 0, an array containing the maximum ET rate will be read.

If INEVTR < 0, the maximum ET rate from the preceding stress period will be reused.

<u>INEXDP</u>– is the extinction depth (EXDP) read flag.

If INEXDP > 0, an array containing the extinction depth (EXDP) will be read.

If INEXDP < 0, the extinction depth from the preceding stress period will be reused.

<u>INIEVT</u>– is the layer indicator (IEVT) read flag. It is used only if the ET option (NEVTOP) is equal to two.

If INIEVT > 0, an array containing the layer indicators (IEVT) will be read.

If INIEVT < 0, layer indicators used during the preceding stress period will be reused.

<u>SURF</u>– is the elevation of the ET surface.

<u>EVTR</u>– is the maximum ET rate (volume of water per unit area (Lt EXDP–is the ET extinction depth.

<u>IEVT</u>– is the layer indicator array. For each horizontal location, it indicates the layer from which ET is removed. It is needed only if the ET option is equal to two.

(from pages 11-5 and 11-6 of McDonald & Harbaugh)

General-Head Boundary Package Input

Input for the General-Head Boundary (GHB) Package is read from the unit specified in IUNIT(7).

FOR EACH SIMULATION

GHB1AL

| | | | |
|---|---|---|---|
| 1. | Data: | MXBND | IGHBCB |
| | Format: | I10 | I10 |

FOR EACH STRESS PERIOD

GHB1RP

| | | |
|---|---|---|
| 2. | Data: | ITMP |
| | Format: | I10 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 3. | Data: | Layer | Row | Column | Boundary Head | Cond |
| | Format: | I10 | I10 | I10 | F10.0 | F10.0 |

(Input item 3 normally consists of one record for each GHB. If ITMP is negative or zero, item 3 is not read.)

Explanation of Fields Used in
Input Instructions

MXBND-- is the maximum number of general-head boundary cells at one time

IGHBCB-- is a flag and a unit number.

If IGHBCB > 0, it is the unit number on which cell-by-cell flow terms will be recorded whenever ICBCFL (see Output Control) is set.

If IGHBCB = 0, cell-by-cell flow terms will not be printed or recorded.

If IGHBCB < 0, boundary leakage for each cell will be printed whenever ICBCFL is set.

ITMP-- is a flag and a counter.

If ITMP < 0, GHB data from the preceding stress period will be reused.

If ITMP > 0, ITMP is the number of general-head boundaries during the current stress period.

Layer-- is the layer number d the cell affected by the head-dependent boundary.

Row-- is the row number of the cell affected by the head-dependent boundary.

Column-- is the column number of the cell affected by the head-dependent boundary.

Boundary head-- is the head on the boundary.

Cond-- is the hydraulic conductance of the interface between the aquifer cell and the boundary.

(from page 12-30 of McDonald & Harbaugh)

## Strongly Implicit Procedure Package Input

Input to the Strongly Implicit Procedure (SIP) Package is read from the unit specified in IUNIT(9).

FOR EACH SIMULATION

SIPIAL

| | | | |
|---|---|---|---|
| 1. | Data: | MXITER | NPARM |
| | Format: | I10 | I10 |

SIPIRP

| | | | | | | |
|---|---|---|---|---|---|---|
| 2. | Data: | ACCL | HCLOSE | IPCALC | WSEED | IPRSIP |
| | Format: | F10.0 | F10.0 | I10 | F10.0 | I10 |

Explanation of Fields Used in
Input Instructions

MXITER– is the maximum number of times through the iteration loop in one time step in an attempt to solve the system of finite-difference equations. Fifty iterations are generally sufficient.

NPARM– is the number of iteration parameters to be used. Five parameters are generally sufficient.

ACCL– is the acceleration parameter. It must be greater than zero and is generally equal to one. If a zero is entered, it is changed to one.

HCLOSE– is the head change criterion for convergence. When the maximum absolute value of head change from all nodes during an iteration is less than or equal to HCLOSE, iteration stops.

IPCALC– is a flag indicating where the iteration parameter seed will come from.

- 0 - the seed will be entered by the user.
- 1 - the seed will be calculated at the start of the simulation from problem parameters.

WSEED– is the seed for calculating iteration parameters. It is only specified if IPCALC is equal to zero.

IPRSIP– is the printout interval for SIP. If IPRSIP is equal to zero, it is changed to 999. The maximum head change (positive or negative) is printed for each iteration of a time step whenever the time step is an even multiple of IPRSIP. This printout also occurs at the end of each stress period regardless of the value of IPRSIP.

(from pages 13-10 and 13-11 of McDonald & Harbaugh)

## Slice-Successive Overrelaxation Package Input

Input to the Slice-Successive Overrelaxation (SOR) Package is read from the unit specified in IUNIT(11).

FOR EACH SIMULATION

SORIAL

| | | | | |
|---|---|---|---|---|
| 1. | Data: | MXITER | | |
| | Format: | I10 | | |

SORIRP

| | | | | |
|---|---|---|---|---|
| 2. | Data: | ACCL | HCLOSE | IPRSOR |
| | Format: | F10.0 | F10.0 | I10 |

Explanation of Fields Used in
Input Instructions

MXITER-- is the maximum number of iterations allowed in a time step.

ACCL-- is the acceleration parameter, usually between 1.0 and 2.0.

HCLOSE-- is the head change criterion for convergence. When the maximum absolute value of head change from all nodes during an iteration is less than or equal to HCLOSE, iteration stops.

IPRSOR-- is the printout interval for SOR. IF IPRSOR is equal to zero, it is changed to 999. The maximum head change (positive or negative) is printed for each iteration of a time step whenever the time step is an even multiple of IPRSOR. This printout also occurs at the end of each stress period regardless of the value of IPRSOR.

## Module Documentation for the Slice-Successive Overrelaxation Package

The Slice-Successive Overrelaxation Package (SOR1) consists of three primary modules and one submodule. They are:

Primary Modules

| | |
|---|---|
| SOR1AL | Allocates space for arrays. |
| SOR1RP | Reads control information needed by the SOR1 Package. |
| SOR1AP | Performs one iteration of slice-successive overrelaxation. |

Submodule

| | |
|---|---|
| SSOR1B | Solves a system of linear equations. |

(from page 28 of Prudic)

Streamflow-routing Package Input

FOR EACH SIMULATION:

STR1AL

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1. | Data: | MXSTRM | NSS | NTRIB | NDIV | ICALC | CONST | ISTCBI | ISTCB2 |
| | Format: | I10 | I10 | I10 | I10 | I10 | F10.0 | I10 | I10 |

FOR EACH STRESS PERIOD:

STR1RP

| | | | | |
|---|---|---|---|---|
| 2. | Data: | ITMP | IRDFLG | IPTFLG |
| | Format: | I10 | I10 | I10 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 3. | Data: | Layer | Row | Col | Seg | Reach | Flow | Stage | Cond | Sbot | Stop |
| | Format: | I5 | I5 | I5 | I5 | I5 | F15.0 | F10.0 | F10.0 | F10.0 | F10.0 |

(Item 3 normally consists of one record for each reach. Records are read in sequential order from upstream to downstream, first by segments, and then by reaches. The downstream ordering and reading of segments and reaches are important as the order determines the connection of inflows and outflows. If ITMP is negative or zero, items 3-6 are not read.)

If stream stages for each reach are to be calculated (ICALC>0), then the following data set is read in sequential order of segment and reach.

| | | | | |
|---|---|---|---|---|
| 4. | Data: | Width | Slope | Rough |
| | Format: | F10.0 | F10.0 | F10.0 |

If the maximum number of tributaries (NTRIB) that can join a segment is greater than zero, then the following data set is read. One record for each segment is read in sequential order. A record is necessary even for segments that do not have tributaries. In this case a blank record or a record with all zeros is read.

| | | | | | |
|---|---|---|---|---|---|
| 5. | Data: | Itrib(l) | Itrib(2) | ... | Itrib(NTRI) |
| | Format: | I5 | I5 | ... | I5 |

If diversions are specified (NDIV>0), then the following data set is read. One record is read for each segment in sequential order. For segments that are not diversions, zeros or blanks are specified for each input item.

| | | |
|---|---|---|
| 6. | Data: | Iupseg |
| | Format: | I10 |

(from page 29 of Prudic)

Explanation of Fields Used in Input Instructions

MXSTRM – is the maximum number of stream reaches that can be active during the simulation.

NSS – is the maximum number of segments that can be used during the simulation.

NTRIB – is the maximum number of tributary segments that can join during a simulation. Ten is the maximum number allowed as currently specified in the program.

NDIV - is a flag, which when positive, specifies that diversions from segments are to be simulated.

ICALC – is a flag, which when positive, specifies that stream stages in reaches are to be calculated.

CONST – is a constant value used in calculating stream stage in reaches. It is specified whenever ICALC is greater than zero. This constant is 1.486 for flow units of cubic feet per second and 1.0 for units of cubic meters per second. The constant must be multiplied by 86,400 when using time units of days in the simulation. (For an explanation of time units, see McDonald and Harbaugh, 1988, p. 4-10.)

ISTCBI – is a flag and a unit number.

If ISTCB1 > 0, it is the unit number to which leakage between each stream reach and the corresponding model cell will be saved on disk whenever the variable ICBCFL is specified. (See Mcdonald and Harbaugh, 1988, p. 4-15, for details about the Output Control Package used to specify ICBCFL.)

If ISTCB1 = 0, leakage between each reach and corresponding model cell will not be printed nor filed on disk.

If ISTCB1 < 0, streamflows into and out of each reach and leakage between each reach and corresponding model cell will be printed whenever the variable ICBCFL is specified.

ISTCB2 – is a flag and unit number for an option of storing streamflow out of each reach instead o having the results printed.

If ISTCB2 >0, it is the unit number where streamflow out of each reach will be saved on disk whenever the variable ICBCFL is specified.

If ISTCB2 ≤ 0, streamflows out of each reach will not be saved on disk.

| | |
|---|---|
| ITMP -- | is a flag and a counter. |
| If ITMP < 0, | stream data from the last stress period will be reused. |
| If ITMP ≥ 0, | ITMP will be the number of reaches active during the current stress period. |
| IRDFLG -- | is a flag, which when positive, suppresses printing of the input data set specified for a stress period. The input data set is printed for a stress period if the value is zero or blank. |
| IPTFLG -- | is a flag, which when positive, suppresses printing of results for a stress period. The results are printed for a stress period if the value is zero or blank and whenever the variable ICBCFL is specified. |
| Layer -- | is the layer number of the cell containing the stream reach. |
| Row -- | is the row number of the cell containing the stream reach. |
| Col -- | is the column number of the cell containing the stream reach. |
| Seg -- | is a number assigned to a group of reaches. Segments must be numbered in downstream order and are read into the program in sequential order. |
| Reach -- | is a sequential number in a segment that begins with one for the farthest upstream reach and continues in downstream order to the last reach in the segment. Reaches must be read in sequentially as the order reaches are read into the program determines the order of connection of inflows and outflows. |
| Flow -- | is the streamflow, in length cubed per time, entering a segment. This value is specified only for the first reach in each segment. The value is either a zero or a blank when the reach number (Reach) is not 1. When inflow into a segment is the sum of outflow from a specified number of tributary segments, the segment inflow values are specified as a -1. (Note: if the specified inflow to a diversion is greater than the flow in the reach from which flow is to be diverted, then no flow is diverted from the stream.) |
| Stage -- | is the stream stage, in units of length. |
| Cond -- | is the streambed hydraulic conductance, in units of length squared per time. |
| Sbot -- | is the elevation of the bottom of the streambed, in units of length. |
| Stop -- | is the elevation of the top of the streambed, in units of length. |
| Width -- | is the width of the stream channel, in units of length. It is used only when stream stage in each reach is calculated. |
| Slope -- | is the slope of the stream channel in each reach, in units of length per length. It is used only when stream stage in each reach is calculated. |
| Rough -- | is Manning's roughness coefficient for each stream reach. It is used only when stream stage in each reach is calculated. |
| Itrib(1)-- | for a segment that has tributary segments, Itrib(1) is the number of the first tributary segment. For a segment with no tributaries, Itrib(1) must be specified as zero. |
| Itrib(2)-- | for a segment that has tributary segments, Itrib(2) is the number of the second tributary segment. For a segment with no or only one tributary segment, Itrib(2) must be specified as zero. |
| Iupseg -- | for a diversion segment, Iupseg is the number of the upstream segment from which water is diverted. For a segment that is not a diversion, Iupseg must be specified as zero. |

(from page E-1 of McDonald & Harbaugh)

Array Input

The real two-dimensional array reader (U2DREL), the integer two-dimensional array reader (U2DINT), and the real one-dimensional array reader (U1DREL) read one array-control record and, optionally, a data array in a format specified on the array-control record.

FOR REAL ARRAY READER (U2DREL or U1DREL)

| | | | | |
|---|---|---|---|---|
| Data: | LOCAT | CNSTNT | FMTIN | IPRN |
| Format: | I10 | F10.0 | 5A4 | I10 |

FOR INTEGER ARRAY READER (U2DINT)

| | | | | |
|---|---|---|---|---|
| Data: | LOCAT | ICONST | FMTIN | IPRN |
| Format: | I10 | I10 | 5A4 | I10 |

IPRN– is a flag indicating that the array being read should be printed and a code for indicating the format that should be used. It is used only of LOCAT is not equal to zero. The format codes are different for each of the three modules. IPRN is set to zero when the specified value exceeds those defined in the chart below. If IPRN is less than zero, the array will not be printed.

| IPRN | U2DREL | U2DINT | U1DREL |
|---|---|---|---|
| 0 | 10G11.4 | 10I11 | 10g12.5 |
| 1 | 11G10.3 | 60I1 | |
| 2 | 9G13.6 | 40I2 | |
| 3 | 15F7.1 | 30I3 | |
| 4 | 15F7.2 | 25I4 | |
| 5 | 15F7.3 | 20I5 | |
| 6 | 15F7.4 | | |
| 7 | 20F5.0 | | |
| 8 | 20F5.1 | | |
| 9 | 20F5.2 | | |
| 10 | 20F5.3 | | |
| 11 | 20F5.4 | | |
| 12 | 10G11.4 | | |

LOCAT–indicates the location of the data which will be put in the array.

If LOCAT < 0, unit number for unformatted records.

If LOCAT = 0, all elements are set equal to CNSTNT or ICONST.

If LOCAT > 0, unit number for formatted records.

# APPENDIX L

## MACMAN input data format

**(from page 4-9 of McDonald & Harbaugh )**

Basic Package Input

Input for the Basic (BAS) Package except for output control is read from unit 1 as specified in the main program. If necessary, the unit number for BAS input can be changed to meet the requirements of a particular computer. Input for the output control option is read from the unit number specified in IUNIT(12).

Information for the Basic Package must be submitted in the following order:

FOR EACH SIMULATION

BAS1DF

1. Data: HEADING(32)
   Format: 20A4

2. Data: HEADING (continued)
   Format: 12A4

------------------ Top of changed portion ------------------

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 3. | Data: | NLAY | NROW | NCOL | NPER | ITMUNI | ITHEISS | ITHIEM |
| | Format: | I10 | I10 | I10 | I10 | I10 | I10 | I10 |

4. Data: IUNIT(24)
   Format: 24I3
   (BCF WEL DRN RIV EVT XXX GHB RCII SIP XXX SOR OC STR)

------------------ Bottom of changed portion ------------------

BAS1AL

| | | | |
|---|---|---|---|
| 5. | Data: | IAPART | ISTRT |
| | Format: | I10 | I10 |

BAS1RP

6. Data: IBOUND(NCOL,NROW)
   Module: U2DINT
   (One array for each layer in the grid)

7. Data: HNOFLO
   Format: F10.0

8. Data: Shead(NCOL,NROW)
   Module: U2DREL
   (One array for each layer in the grid)

NOTE: IBOUND and Shead are treated as three-dimensional arrays in the program. However, the input to each of these arrays is handled as a series of two-dimensional arrays, one for each layer in the grid.

(from page 4-10 of McDonald & Harbaugh )

FOR EACH STRESS PERIOD

BAS1ST

| | | | | |
|---|---|---|---|---|
| 9. | Data: | PERLEN | NSTP | TSMULT |
| | Format: | F10.0 | I10 | F10.0 |

Explanation of Fields Used in
Input Instructions

HEADNG-- is the simulation title that is printed on the printout. It may be up to 132 characters long; 80 in the first record and 52 in the second. Both records must be included even if they are blank.

NLAY-- is the number of model layers.

NROW-- is the number of model rows.

NCOL-- is the number of model columns.

NPER-- is the number of stress periods in the simulation.

ITMUNI-- indicates the time unit of model data. (It is used only for printout of elapsed simulation time. It does not affect model calculations.)

O - undefined
1 - seconds
2 - minutes
3 - hours
4 - days
5 - years

The unit of time must be consHxtent for all data values that involve time. For example, if years is the chosen time unit, stress-period length, time-step length, transmissivity, etc., must all be expressed using years for their time units. Likewise, the length unit must also be consistent.

—— Top of changed portion ——

IUNIT-- is a 24-element table of input units for use by all major options. Only 11 elements (1-5, 7-9, 11, and 12-13) are being used. Element 6 has been reserved for a transient leakage package, while element 10 has been reserved for an additional solver, both on the assumption that such packages will be added to the model in the future. Elements 14-24 are reserved for future major options.

| IUNIT LOCATION | MAJOR OPTION |
|---|---|
| 1 | Block-Centered Flow Package |
| 2 | Well Package |
| 3 | Drain Package |
| 4 | River Package |
| 5 | Evapotranspiration Package |
| 6 | Reserved for Transient Leakage Package |
| 7 | General-Head Boundary Package |
| 8 | Recharge Package |
| 9 | SIP Package |
| 10 | Reserved for additional solver |
| 11 | SSOR Package |
| 12 | Output Control Option |
| 13 | Streamflow-routing |

—— Bottom of changed portion ——

If IUNIT(n) < O, the corresponding major option is not being used.

If IUNIT(n) > O, the corresponding major option is being used and data for that option will be read from the unit number contained in IUNIT(n). The unit numbers in IUNIT should be integers from 1 to 99. Although the same number may be used for all or some of the major options, it is recommended that a different number be used for each major option. Printer output is assigned to unit 6 (unless it is changed to meet computer requirements). That unit number should not be used for any other input or output. The user is also permitted to assign unit numbers for output. Those numbers should be different from those assigned to input. The Basic Package reads from unit 1 (unless it is changed to meet computer requirements). It is permissible but unwise to use that unit for other major options.

IAPART-- indicates whether array BUFF is separate from array RHS.

If IAPART = O, the arrays BUFF and RHS occupy the same space. This option conserves space. This option should be used unless some other package explicitly says otherwise.

If IAPART ≠ 0, the arrays BUFF and RHS occupy different space. This option is not needed in the program as documented in this publication. It may be needed for packages yet to be written.

(from page 4-12 of McDonald & Harbaugh )

ISTRT– indicates whether starting heads are to be saved. If they are saved, they will be stored in array STRT. They must be saved if drawdown is calculated.

If ISTRT = O, starting heads are not saved.

If ISTRT  O, starting heads are saved.

IBOUND– is the boundary array.

If IBOUND(I,J,K) < O, cell I,J,K has a constant head.

If IBOUND(I,J,K) = O, cell I,J,K is inactive (no-flow).

If IBOUND(I,J,K) > O, cell I,J,K is variable-head.

HNOFLO– is the value of head to be assigned to all inactive cells (IBOUND = O) throughout the simulation. Since heads at inactive cells are unused, this does not affect model results but serves to identify inactive cells when head is printed. This value is also used as drawdown at inactive cells if the drawdown option is used. Even if the user does not anticipate having inactive cells, a value for HNOFLO must be submitted.

Shead– is head at the start of the simulation. Regardless of whether starting head is saved, these values must be input to initialize the solution.

PERLEN– is the length of a stress period. It is specified for each stress period.

NSTP– is the number of time steps in a stress period.

TSMULT– is the multiplier for the length of successive time steps. The length of the first time step DELT(1) is related to PERLEN, NSTP and TSMULT by the relation DELT(1) = PERLEN(1-TSMULT)/(1-TSMULT**NSTP).

———————— Top of changed portion ————————

ITHEISS– flag to activate well head correction using Theis equation. 0=not active, 1=active

ITHIEM– flag to activate well head correction using Thiem equation. 0=not active, 1=active

———————— Bottom of changed portion ————————

UNIT 12 Input

Unit 12 is used only if IRLN is greater than or equal to 2 realizations.

| Data Set | Number of lines | Columns | Format | Variable | Definition |
|---|---|---|---|---|---|
| 1 | 1 | 1-5 | I5 | NRZT | Number of realizations. |
| 2 | NRZT | 1-10 | I10 | ISEEDU(I) | Seed number for random number generation for realization I. |
| | | 1-20 | I10 | ISEEDV(I) | Seed number for random lumber generation for realization I. |
| | | 21-30 | F10.5 | STDEV(I)) | Standard deviation for realization I. |
| | | 31-35 | I5 | JUANITA(I) | Unit number of RFILEA(I) for realization I. |
| | | 36-40 | I5 | JUANITAB(I) | Unit number of RFILEB(I) fo realization I. |
| | | 41-55 | A15 | RFILEA(I) | File name for realization I. |
| | | 56-70 | A15 | RFILEB(I) | File name for realization I. |

(from pages 65 and 66 of Lefkoff and Gorelick)

UNIT 13 Input

Unit 13 is used only if NGRAD or LGRAD is positive

| Data Set | Number of lines | Columns | Format | Variable | Definition |
|---|---|---|---|---|---|
| | | | | | ——— Top of changed portion ——— |
| 1 | 1 | 1-10 | I10 | ITOTGRAD | Total number of layers to be considered for gradient constraint. |
| 2 | ITOTGRAD | 1-10 | I10 | IGRD(L) | Layer number specification. This is the list of the layers in which gradient constraint will be considered. |
| | | | | | ——— Bottom of changed portion ——— |
| 3 | NGRAD | 1-10 | I10 | ILOCG1(K) | Row (y-axis) location of the first node of control pair K. Must correspond to some ILOCC, i.e., must already be specified as a head control location. |
| | | 11-20 | I10 | JLOCG1(K) | Column (x-axis) location of the first node of control pair K. Must correspond to some JLOCC, i.e., must already be specified as a head control location. |
| | | 21-30 | I10 | ILOCG2(K) | Row (y-axis) location of the second node of control pair K. Must correspond to some ILOCC, i.e., must already be specified as a head control location. |
| | | 31-40 | I10 | JLOCG2(K) | Column (x-axis) location of the second node of control pair K. Must correspond to some JLOCC, i.e., must already be specified as a head control location. |
| | | 41-50 | I10 | KDEFGR(K) | Switch to indicate whether head definition is desired at control pair K. If KDEFGR(K)=0, total difference-in-drawdown is constrained. If KDEFGR(K)=1, difference in head is defined and any constant must be manually added to the MPS file. |
| | | | | | ——— Top of changed portion ——— |
| 4 | LGRAD | 1-10 | I10 | ILOCLY(I) | Row (y-axis) location of a node with head control between layers. Must correspond to some ILOCC. |
| | | 11-20 | I10 | JLOCLY(I) | Column (x-axis) location of a node with head control between layers. Must correspond to some JLOCC. |
| | | 21-30 | I10 | LTOP(I) | Layer number location of bottom layer. |
| | | 31-40 | I10 | LBOT(I) | Layer number location of top layer. |
| | | | | | ——— Bottom of changed portion ——— |
| FOR EACH TIME PERIOD AND EACH LAYER: | | | | | |
| 5 | NNPER x NGRAD | 1-15 | G15.6 | GFACT(KN) | Factor by which GCON is multiplied. GFACT converts GCON to a difference in head. To control:<br>- difference in head between two points, GFACT = 1.0;<br>- gradient, GFACT = distance between two locations;<br>- velocity, GFACT = (distance between two locations) x (effective porosity)/(hydraulic conductivity). |
| | | 16-30 | G15.6 | GCON(KN) | User-defined bounds on head difference [L], gradient [L/L], velocity [L/T] between two points. To control:<br>- head difference, GCON = head(1) - head(2);<br>- gradient, GCON=(head(1)-head(2))/dist.between two locations;<br>- velocity, GCON=(hydraulic conductivity * (head(1)-head(2))/(dist.between two locations * effective porosity).<br>For example, to cause h(1)-h(2) to exceed 0.02, GCON equals 0.02. To cause h(1)-h(2) to exceed 0.002, GCON equals 0.002. These are the equivalent statements when multiplied by proper GFACT (gradients and velocities are positive when h(1) > h(2)). |

| | | | |
|---|---|---|---|
| 35 | A1 | GRATYP(KN) | The type of gradient or velocity constraint at a control pair. Must be either 'L' for ≤, 'G' for ≥, 'E' for =. |

Three output files must always be open for program execution. Unit 16 will contain error and warning messages. Unit 17 will contain the user-defined limits on head and the unmanaged heads for all control locations, and pumping or recharge rates at all wells. Unit 18 is the MPS file, to be used as input for a mathematical programming package.

**(from page 61 and 62 of Lefkoff and Gorelick)**

MAQMAN requires all input data files from MODFLOW+STR, except the Well Package Input and the following two data files.

UNIT 14 Input

| Data Set | Number of Lines | Columns | Format | Variable | Definition |
|---|---|---|---|---|---|
| 1 | 1 | 1-4 | A4 | CASE | The type of objective function in a linear problem. LINE for linear function, QUAD for quadratic. |
| | | 7-70 | 16A4 | NNAME | Any title the user wishes to print on the first line of the MPS file. |
| 2 | 1 | 1-10 | I10 | NWLS | Total number of wells (managed plus unmanaged) in the system. NWLS must be constant for all pumping periods. |
| | | 11-20 | I10 | NCNTR | Number of control locations, constant for all pumping periods. HD and XHEAD will contain the computed head at these nodal locations. |
| | | 21-30 | I10 | NNPER | Number of pumping periods to be simulated. NNPER and NPER (page L-1) values must be equal. |
| | | 31-40 | I10 | NGRAD | Number of gradient controls. Each control consists of two locations, specified by ILOCG1 JLOCG1, ILOCG2, and JLOCG2. If there are no gradients, velocities, or head-differences to control, enter 0 for NGRAD. |
| | | | | | ------ Top of changed portion ------ |
| | | 41-45 | I5 | LGRAD | Number of gradient control points between layers. |
| | | 46-50 | I5 | KSTR | Number of stream stage control points. |
| | | 51-55 | I5 | NWBOUND | Number of cells with upper or lower bounds on pumping. |
| | | 56-60 | I5 | IRLN | Number of hydraulic conductivity realizations. |
| | | | | | ------ Bottom of changed portion ------ |
| 3 | 1 | 1-10 | I10 | NKEYQ | Number of fixed (unmanaged) wells. Cannot be greater than NWLS. |
| 4 | NWLS | 1-10 | I10 | ILOCW(I) | Row (y-axis) location of well I. ILOCW is a vector containing NWLS elements. |
| | | 11-20 | I10 | JLOCW(I) | Column (x-axis) location of well I. JLOCW is a vector containing NWLS elements. |
| | | 21-30 | G10.0 | XRAD(I) | Radius [L] of well I. XRAD is a vector containing NWLS elements. |
| | | 31-40 | I10 | KEYQ(I) | Switch (0=no, 1=yes) to indicate whether I is an unmanaged well. For all cases, if KEYQ(I)=1 pumpage at well I is not a decision variable, and no draw-down response is computed for it. For a quadratic objective, KEYQ(I)=2 if I is a nonquadratic, managed well, and KEYQ(I)=0 if I is quadratic, managed well. |
| | | 41-50 | F10.0 | UNITQ(I) | The unit pumping [$L^3/T$] rate used at well I obtain drawdown responses. A negative value indicates a pumping well; a positive value indicates a recharge well. **Use care if UNITQ is not constant for all decision wells. |

(from page 63 and 64 of Lefkoff and Gorelick)

———————————— Top of changed portion ————————————

| | | | | | |
|---|---|---|---|---|---|
| | | 51-60 | I10 | LLOCW(I) | Layer location of managed well. Ground surface layer is number 1. |
| | | 61-70 | I10 | KWBOUND(I) | Flag indicating bounds on pumping. |

———————————— Bottom of changed portion ————————————

Note--If a KEYQ=1 is read for well I, the reading of the above five variables is interrupted, and FIXQ is read for each period at well I. NNPER lines are required at each interruption.

| | | | | | |
|---|---|---|---|---|---|
| 4 | NNPER | 1-10 | G10.0 | FIXQ(I,N) | Pumpage or recharge [$L^3/T$] at the unmanaged well I during period N. There must be NNPER values for FIXQ following a KEYQ=1. |
| 5 | NCNTR | 1-10 | I10 | ILOCC(J) | Row (y-axis) location of control node J. ILOCC is a vector containing NCNTR elements. |
| | | 11-20 | I10 | JLOCC(J) | Column(x-axis) location to control node J. JLOCC is a vector containing NCNTR elements. |
| | | 21-30 | I10 | KEYWL(J) | Switch to indicate whether control location J also contains a well. If KEYWL(J) does not equal zero, a well exists at J, and XRAD is used to compute head at the well, rather than a cell-averaged head. |

Note-- For each non-zero value of KEYWL, XRAD at that node must be positive.

| | | | | | |
|---|---|---|---|---|---|
| | | 31-40 | I10 | KEYGRD(J) | Switch to indicate whether control location J is to be used only for gradient or velocity control. If KEYGRD(J)=0, J will be used for head control and may be used for gradient or velocity control. If KEYGRD(J)=1, J will not be used for head control: no constraint row and no response coefficient for J will be written in the MPS file. |
| | | 41-50 | I10 | KDEFHD(J) | Switch to indicate whether head defination is desired at location J. If KDEFHD(J)=0, total drawdown is constrained. If KDEFHD(J)=1, head is defined and any constraint must be manually added to the MPS file. |

———————————— Top of changed portion ————————————

| | | | | | |
|---|---|---|---|---|---|
| | | 51-60 | I10 | KLAY(I) | Coefficient indicating head constraint between layers. |
| | | 61-70 | I10 | KRIV(I) | Coefficient indicating stream stage constraint. |

———————————— Bottom of changed portion ————————————

FOR EACH TIME PERIOD AND EACH LAYER:

| | | | | | |
|---|---|---|---|---|---|
| 6 | NNPER x NCNTR | 1-10 | G10.0 | CONDH(JN) | Desired upper or lower limit [L] on average cell head or head at well radius at each control location during each pumping period. The first NCNTR lines are for period 1, the second lines are for period 2, etc. Read dummy values for locations where head is not constrained. |
| | | 15 | A1 | CONTYP(JN) | Type of constraint on head at each control location. Must be either "L" for ≤, "G" for ≥, or "E" for =. |

(from pages 17 to 20 of Murtagh and Saunders)

## The SPECIFICATIONS file for MINOS

The SPECS file sets various run-time parameters that describe the nature of the problem being solved and the manner in which a solution is to be obtained. The file consists of a sequence of card images, each of which contains a keyword and certain associated values.

The first keyword is BEGIN and the last keyword is END. If the problem could be solved using default values all parameters, the SPECS file could consist of just those two keywords (on separate cards).

### SPECS File Format

Each card in the SPECS file contains a sequence of items in free format (they may appear anywhere in columns 1 to 72). The items are separated by spaces or equal signs (' ' or '='). Those selected from each card are:

1. The first word (the keyword). Only the first 3 characters are significant).

2. The second word (if any). Sometimes this is the keyword's associated name value, an 8-character name. More often it qualifies the keyword, and its first 4 characters are significant.

3. The first number (if any). This may be an integer value or a real value; up to 8 characters in Fortran's I, F, E or D format.

In the following examples the significant characters are underlined:

```
OBJECTIVE        PROFIT
SOLUTION FILE    12
ROWS             500
ROW TOLERANCE    0.0001
LOWER BOUND      -1.0
AIJ              1.0E-6
```

If the first character of an item is one of the following numeric characters

1 2 3 4 5 6 7 8 9 0 + - .

then the item is taken to be a number. The number may be from 1 to 8 contiguous numeric characters, including an E or a D if need be. It is determined by a non-numeric character such as a space.

(An exception is made for the keyword OBJECTIVE, RHS, RANGE and BOUNDS, which specify names to be extracted from the MPS file. For these keyword the second item is taken to be the required name value even if it begins with a numeric character. Thus,

```
AIJ TOLERANCE    .00001
OBJECTIVE        .00001
RHS              ...ZE001
BOUND            +1000
```

are all allowed. However, names like OBJECTIVE = COST or RHS = DEMANDO2 will be more common.)

Blank cards and comments may be used to improve readability. A comment begins with an asterisk ('*') and includes all subsequent characters on the same card; these are ignored. The '*' may be the first non-blank character on the card, or the first non-blank after a space or an equal sign.

```
*
*  MPS file parameters
*
     ROWS           1000          * (or less)
     COLUMNS        2000          * (or less)
     ELEMENTS       8000          * (or less)
     OBJECTIVE      PROFIT02      * (the 2nd N rows)
```

Scanning terminates once a number has been recognized. An asterisk is therefore not essential following a number:

```
     WEIGHT ON OBJECTIVE  =  10.0      DURING PHASE 1
```

### SPECS File Checklist and Defaults

The following example SPECS file shows all valid keywords and their default values. The keywords are grouped according to the function they perform.

Some of the default values depend on $\epsilon$, the relative precision of the machine being used. The values given here correspond to double-precision arithmetic on IBM 360 and 370 systems and their successors ($\epsilon \approx$ 2.22e-16 _. Similar values would apply to any machine having about 15 decimal digits of precision.

```
BEGIN checklist of SPEC file parameters and their default values
*
*  Keywords for the MPS file
*
MINIMIZE                                              * (opposite of MAXIMIZE)
OBJECTIVE =                      ?                    * the first name encountered
RHS       =                      ?                    * the first name encountered
BOUNDS    =                      ?                    * the first name encountered
ROWS                             100                  *
COLUMNS                          300                  * or 3*ROWS
ELEMENTS(or coefficients)        1500                 * or 5*COLUMNS
AIJ TOLERANCE                    1.0E-10              *
LOWER BOUND                      0.0                  *
UPPER BOUND                      1.0E+20              * plus infinity
MPS FILE                         ?                    * depends on installation
LIST LIMIT                       0                    * for printing MPS data
ERROR MESSAGE LIMIT              10                   * during MPS input
*
*  Keywords for the simplex method
*
CRASH OPTION                     1                    * all variables eligible for initial basis
ITERATIONS LIMIT                 300                  * or 3*ROWS + 10*NONLINEAR VARIABLES
PARTIAL PRICE                    1                    * or COLS/(2*ROWS) if COLS is large
MULTIPLE PRICE                   1                    * BEWARE - not like commercial LP
WEIGHT ON LINEAR OBJECTIVE       0.0                  * during phase 1
SUMMARY FILE                     0                    * ) 0 for occasional output to terminal
SUMMARY FREQUENCY                100                  * iteration log on SUMMARY file
LOG FREQUENCY                    1                    * iteration log on PRINT file
CHECK FREQUENCY                  30                   * numerical test on row residuals
FACTORIZATION FREQUENCY          50                   * refactorize the basis matrix
SAVE FREQUENCY                   100                  * basis map
SCALE                            NO                   * linear constraints and variables
SOLUTION                         YES                  * on PRINT file
*
*  BASIS files
*
OLD BASIS FILE                   0                    * input basis map
NEW BASIS FILE                   0                    * output basis map
BACKUP BASIS FILE                0                    * output basis map
INSERT FILE                      0                    * input in industry format
PUNCH FILE                       0                    * output INSERT data
LOAD FILE                        0                    * input names and values
DUMP FILE                        0                    * output LOAD data
SOLUTION FILE                    0                    * separate from printed solution
*
*  Convergence and stability tolerances
*
FEASIBILITY TOLERANCE            1.0E-6               * for satisfying bounds
OPTIMAL TOLERANCE                1.0E-6               * for reduced gradients
PIVOT TOLERANCE                  3.7E-11              * ∈ 2/3
LU FACTOR TOLERANCE              10.0                 * limits size of multipliers in L
LU UPDATE TOLERANCE              10.0                 * the same during updates
*
*  Parameters for nonlinear problems
*
NONLINEAR CONSTRAINTS            0                    * must be exact number, m1
NONLINEAR VARIABLES              0                    * must be the exact number, n1
```

```
NONLINEAR OBJECTIVE VARIABLES     0          * use if different from Jacobian variables
NONLINEAR JACOBIAN VARIABLES      0          * use if different from objective variables
SUPERBASICS LIMIT                 1          * or HESSIAN DIMENSION
HESSIAN DIMENSION                 1          * or SUPERBASIC LIMIT
*
PROBLEM NUMBER                    0          * sets subroutine parameter NPROB
DERIVATIVE LEVEL                  3          * assumes all gradients are known
VERIFY LEVEL                      0          * gives cheap check on gradients
EMERGENCY VERIFY LEVEL            0          * cheap check before stopping
*
START OBJECTIVE  CHECK AT COL     1          *
STOP  OBJECTIVE  CHECK AT COL     n_1        *
START CONSTRAINT CHECK AT COL     1          *
STOP  CONSTRAINT CHECK AT COL     n_1        *
LINESEARCH TOLERANCE              0.1        * smaller for more accurate search
SUBSPACE TOLERANCE                0.5        * affects when to PRICE
FUNCTION PRECISION                3.0E-13    * ∈^0.8 (almost full accuracy)
DIFFERENCE INTERVAL               5.5E-7     * (FUNCTION PRECISION)^1/2
CENTRAL DIFFERENCE INTERVAL       6.7E-5     * (FUNCTION PRECISION)^1/3
*
* Further parameters for nonlinear constraints
*
JACOBIAN                          DENSE      *
LAGRANGIAN                        YES        *
MAJOR ITERATIONS                  20         *
MINOR ITERATIONS                  40         *
PENALTY PARAMETER                 100/m_1    * may need to be larger if very nonlinear
DAMPING PARAMETER                 2.0        * affects step-size between subproblems
*
COMPLETION                        PARTIAL    * FULL if no nonlinear constraints
ROW TOLERANCE                     1.0E-6     * allowable nonlinear constraint violation
RADIUS OF CONVERGENCE             0.01       * for reducing the penalty parameter
PRINT LEVEL (JFLXB)               00001      * J(x_k), f(x_k), λ_k, x_k, Basis statistics
*
* Sequences of related problems
*
CYCLE LIMIT                       1          *
CYCLE PRINT                       1          *
CYCLE TOLERANCE                   0.0        *
PHANTOM COLUMNS                   0          *
PHANTOM ELEMENTS                  0          *
*
* Miscellaneous
*
DEBUG LEVEL                       0          *
LINESEARCH DEBUG AFTER ITN        999999     *
WORKSPACE (USER)                  0          *
WORKSPACE (TOTAL)                 ?          * depends on installation
* SUPPRESS PARAMETER LISTING
END of SPECS file checklist
```

# APPENDIX M
## MOC input data format

(from page 76 of Konikow and Bredehoeft)

MOC Input Formats

| Card | Column | Format | Variable | Definition |
|---|---|---|---|---|
| 1 | 1-80 | 10A8 | TITLE | Description of problem |
| 2 | 1-4 | I4 | NTIM | Maximum number of time steps in a pumping period (limit = 100)*. |
| must | 5-8 | I4 | NPMP | Number of pumping periods. Note that if NPMP>1, then data set 10 be completed. |
| | 9-12 | I4 | NX | Number of nodes in *x* direction (limit=20)*. |
| | 13-16 | I4 | NY | Number of nodes in *y* direction (limit=20)*. |
| | 17-20 | I4 | NPMAX | Maximum number of particles (limit=3200)*. (see eq 71.) |
| | 21-24 | I4 | NPNT | Time-step interval for printing hydraulic and chemical output data. |
| | 25-28 | I4 | NITP | Number of iteration parameters (usually $4 \leq NITP \leq 7$). |
| | 29-32 | I4 | NUMOBS | Number of observation points to be specified in a following data set (limit=5)*. |
| | 33-36 | I4 | ITMAX | Maximum allowable number of iterations in ADIP (usually $100 \leq ITMAX \leq 200$). |
| | 37-40 | I4 | NREC | Number of pumping or injection wells to be specified in a following data set. |
| | 41-44 | I4 | NPTPND | Initial number of particles per node (options=4, 5, 8, 9). |
| | 45-48 | I4 | NCODES | Number of node identification codes to be specified in a following data set (limit=10)*. |
| | 49-52 | I4 | NPNTMV | Particle movement interval (IMOV) for printing chemical output data. (Specify 0 to print only at end of time steps.) |
| | 53-56 | I4 | NPNTVL | Option for printing computed velocities (0=do not print; 1=print for first time step; 2=print for all time steps). |
| | 57-60 | I4 | NPNTD | Option for printing computed dispersion equation coefficients (option definition same as for NPNTVL). |
| | 61-64 | I4 | NPDELC | Option for printing computed changes in concentration (0=do not print; 1=print). |
| | 65-68 | I4 | NPNCHV | Option to punch velocity data (option definition same as for NPNTVL). When specified, program will punch on unit 7 the velocities at nodes. |

---Topofchangedportion---

| | Column | Format | Variable | Definition |
|---|---|---|---|---|
| | 69-72 | I4 | NREACT | Option for contaminant decay (1=cont. decay). |

---Bottomofchangedportion---

(from page 77 of Konikow and Bredehoeft)

| Card | Column | Format | Variable | Definition |
|---|---|---|---|---|
| | 1-5 | G5.0 | PINT | Pumping period in years. |
| | 6-10 | G5.0 | TOL | Convergence criteria in ADIP (usually TOL≤0.01). |
| | 11-15 | G5.0 | POROS | Effective porosity. |
| | 16-20 | G5.0 | BETA | Characteristic length, in feet (=longitudinal dispersivity). |
| | 21-25 | G5.0 | S | Storage coefficient (set S=0 for steady flow problems). |
| | 26-30 | G5.0 | TIMX | Time increment multiplier for transient flow problems. TIMX is disregarded if S=0. |
| | 31-35 | G5.0 | TINIT | Size of initial time step in seconds. TINIT is disregarded if S=0. |
| | 36-40 | G5.0 | XDEL | Width of finite-difference cell in *x* direction, in feet. |
| | 41-45 | G5.0 | YDEL | Width of finite-difference cell in *y* direction, in feet. |
| | 46-50 | G5.0 | DLTRAT | Ratio of transverse to longitudinal dispersivity. |
| | 51-55 | G5.0 | CELDIS | Maximum cell distance per particle move (value between 0 and 1.0). |
| | 56-60 | G5.0 | ANFCTR | Ratio of $T_{yy}$ to $T_{xx}$. |
| 4 | Free format. Values separated by space. | | DK, RHOB, THALF | Optional. Enter only if NREACT=1. DK is the distribution coefficient, RHOB the bulk density of the solid, and THALF the half-life of the solute. |

| Data Set | Number of Cards | Format | Variable | Definition |
|---|---|---|---|---|
| 1 | Value of NUMOBS | 2I2 | IXOBS, IYOBS | x and *y* coordinates of observation points. This (limit=5)* data set is eliminated in NUMOBS is specified as =0. |
| 2 | Value of NREC | 2I2,2G8.2 | IX,IY,REC,CNRECH | *x* and *y* coordinates of pumping (+) or injection (-) wells, rate n $ft^3$/s, and if an injection well, the concentration of injected water. This data set is eliminated if NREC=0. |
| 3 | a.1 | I1,G10.0 | INPUT, FCTR | Parameter card• for transmissivity. |
| | b.Value of NY (limit=20)* | 20G4.1 | VPRM | Array for temporary storage of transmissivity data, in $ft^2$/s. For an anisotropic aquifer, read in values of $T_{xx}$ and the program will adjust for anisotropy by multiplying $T_{yy}$ by ANFCTR. |
| 4 | a.1 | I1,G10.0 | INPUT, FCTR | Parameter card• for THICK. |
| | b.Value of NY (limit=20)* | 20G3.0 | THCK | Saturated thickness of aquifer, in feet. |
| 5 | a.1 | I1,G10.0 | INPUT, FCTR | Parameter card• for RECH. |
| | b.Value of NY (limit=20)* | 20G4.1 | RECH | Diffuse recharge (-) or discharge (+), in ft/s. |
| 6 | a.1 | I1,G10.0 | INPUT,FCTR | Parameter card• for NODEID. |
| | b.Value of NY (limit=20)* | 20I1 | NODEID | Node identification matrix (used to define constant-head nodes or other boundary conditions and stresses). |

| Data Set | Number of Cards | Format | Variable | Definition |
|---|---|---|---|---|
| 7 | Value of NCODES (limit=10)* | I2,3G10.2 I2 | ICODE,FCTR1, FCTR2,FCTR3, OVERRD | Instructions for using NODEID array. When NODEID=ICODE, program seeks leakance=FCTR1, CNRECH=FCTR2, and if OVERRD is nonzero, RECH=FCTR3. Set OVERRD=0 to preserve values of RECH specified in data set 5. |
| 8 | a.1 | I1,G10.0 | INPUT,FCTR, | Parameter card● for WT. |
| | b.Value of NY (limit=20)* | 20G4.0 | WT | Initial water-table or potentiometric elevation, or constant head in stream or source bed, in feet. |
| 9 | a.1 | I1, G10.0 | INPUT,FCTR, | Parameter card● for CONC. |
| | b.Value of NY (limit=20)* | | 20G4.0 | Initial concentration in aquifer. |
| 10 | | | | This data set allows time step parameters, print options, and pumpage data to be revised for each pumping period of the simulation. Data set 10 is only used if NPMP>1. The sequence of cards in data set 10 must be repeated (NPMP-1) times (that is, data set 10 is required for each pumping period after the first). |
| | a.1 | I1 | ICHK | Parameter to check whether any revisions are desired. Set ICHK-1 if data are to be revised, and then complete data set 10b and c. Set ICHK=0 if data are not to be revised for the next pumping period, and skip the rest of data set 10. |
| | b.1 | 10I4,3G5.0 | NTIM,NPNT,NITP, ITMAX,NREC, NPNTMV,NPNTVL, NPNTD,NPDELC, NPNCHV,PINT,TIMX, TINIT | Thirteen parameters to be revised for next pumping period; the parameters were previously defined in the description of data cards 2 and 3. Only include this card if ICHK=1 in previous part a. |
| | c.Value of NREC | 2I2,2G8.2 | IX,IY,REC,CNRECH | Revision of previously defined data set 2. Include part c only if ICHK=1 in previous part a and if NREC>0 in previous part b. |

* These limits can be modified if necessary by changing the corresponding array dimensions in the COMMON statements of the program.

● The parameter card must be the first of the indicated data sets. It is used to specify whether the parameter is constant and uniform, and can be defined by one value, or whether, it varies in space and must be defined at each node. If INPUT=0, the data set has a constant value, which is defined by FCTR. If INPUT=1, the data set is read from cards as described by part b. Then FCTR is a multiplication factor for the values read in the data set.

# APPENDIX N

## ERROR MESSAGES

**(from pages B-1 to B-2 of FTN77/386 manual)**

Execution error messages of FTN77/386 FORTRAN compiler.

Execution errors corresponding to input/output statements can be trapped by means of the ERR= and/or IOSTAT= keyword specifiers used with the input/output statements. The value returned by IOSTAT in this case is n, where n is the execution error number that appears in the table below.

| Error number | Message |
|---|---|
| 0 | Undefined error |
| 1 | Floating point arithmetic overflow |
| 2 | Integer arithmetic overflow |
| 3 | Argument to CHAR outside range 0-255 |
| 4 | Character argument/function name of wrong length |
| 5 | Attempt to execute invalid assigned GOTO |
| 6 | Inconsistent call to routine |
| 7 | DO-loop has zero increment |
| 8 | User-specified range check error |
| 9 | Might be array bound error or corrupt program rerun with checks |
| 10 | Lower substring expression > upper |
| 11 | Array subscript(s) out-of-bounds |
| 12 | Lower substring expression out-of-range |
| 13 | Illegal character assignment |
| 14 | Attempt to alter an actual argument that is either a constant or a DO variable |
| 15 | Attempt to access undefined argument to routine |
| 16 | Lower array bound > upper bound |
| 17 | Upper substring expression out-of-range |
| 18 | This routine has been entered recursevily (-ANSI mode) |
| 19 | Actual array argument size smaller than dummy array argument size |
| 20 | Argument to SINH/COSH out of range |
| 21 | Zero raised to negative or zero power |
| 22 | Floating point division by zero |
| 23 | Floating point arithmetic underflow |
| 24 | This source has not been compiled with \PROFILE |
| 25 | Argument to EXP out-of-range |
| 26 | Argument to ASIN/ACOS out-of-range |
| 27 | Invalid floating point number |
| 28 | Negative argument to square root |
| 29 | Call to missing routine |
| 30 | Storage heap is corrupt |
| 31 | Floating point number too big for integer conversion |
| 32 | Second argument to MOD is zero |
| 33 | Both arguments to ATAN2/DATAN2 zero |
| 34 | Negative zero argument to logarithm routine |
| 35 | Illegal argument to TAN routine |
| 36 | Negative number raised to non-integer power |
| 37 | Integer divide overflow |
| 38 | Illegal character assignment (R.H.S. overlaps L.H.S.) |
| 39 | Illegal window |
| 40 | No more windows available |
| 41 | Maximum number of breakpoints already set |
| 42 | This line number is not available as a breakpoint |
| 43 | Invalid command |

(from pages B-2 and B-3 of FTN77/386 manual)

| Error number | Message |
|---|---|
| 44 | Unable to open file |
| 45 | String not found |
| 46 | Routine not found or not compiled in check mode |
| 47 | Invalid expression |
| 48 | No more room for debugger information |
| 49 | Attempt to call a block data subprogram |
| 50 | Undefined input/output error |
| 51 | Format/data mismatch |
| 52 | Invalid character in field |
| 53 | Overflow detected by input/output routine (data out-of-range) |
| 54 | m > w in Iw.m run-time format |
| 55 | m > w in Ow.m or Bw.m run-time format |
| 56 | Unit has been closed by means other than a CLOSE statement |
| 57 | Attempt to read past end-of-file |
| 58 | Corrupt listing file |
| 59 | There is no repeatable edit descriptor in this format |
| 60 | Invalid external unit identifier |
| 61 | Invalid scale factor |
| 62 | Invalid or missing repeat count |
| 63 | Preconnected file comprises formatted records |
| 64 | Preconnected file comprises unformatted records |
| 65 | This command is not permitted from this window |
| 66 | File nor in correct format |
| 67 | Character buffer too small |
| 68 | Field width exceeds direct access record size 69Invalid |
| record length | |
| 70 | Logical input field is blank |
| 71 | H or apostrophe editing not allowed for input |
| 72 | Repeated formats nested too deep (>10) |
| 73 | Missing opening parenthesis in 'run-time' format |
| 74 | Invalid editing descriptor |
| 75 | A zero or signed repeat count is not allowed |
| 76 | Repeat count not allowed |
| 77 | Digit(s) expected |
| 78 | Decimal point missing |
| 79 | Missing separator |
| 80 | Invalid ACCESS specifier |
| 81 | Invalid combination of specifiers |
| 82 | ANSI - RECL is an invalid specifier |
| 83 | Label does not reference a format statement |
| 84 | Only BLANK may be changed for a file that exists for a given program |
| 85 | Repeated character constant must not extend past the end of line |
| 86 | Character input/output list item is part of internal file |
| 87 | ENCODE/DECODE character count zero or negative |
| 88 | Internal file must not be constant or expression |
| 89 | Attempt to write past end of internal file |
| 90 | File access and properties are incompatible |
| 91 | Missing ) from complex number |
| 92 | Invalid CLOSE statement |
| 93 | Missing ( from complex number |
| 94 | Unit has neither been OPENED nor preconnected |
| 95 | Invalid direct access record number |
| 96 | Illegal operation (BACKSPACE/ENDFILE/REWIND) on a direct access file |
| 97 | Direct access record length too big |
| 98 | Invalid FILETYPE specifier |

(from pages B-3 and B-4 of FTN77/386 manual)

| Error number | Message |
| --- | --- |
| 99 | A function which performs i/o must not be referenced in a WRITE or PRINT statement |
| 100 | List-directed input/output is not allowed with direct access |
| 101 | Direct access is not allowed with an internal file |
| 102 | A formatted, direct access statement must only transfer one record |
| 103 | Missing file specifier |
| 104 | File positioned at end-of-file |
| 105 | Invalid record length for existing direct access file |
| 106 | A valid record length must be specified if access is direct |
| 107 | STATUS=NEW must not be used with an existing file |
| 108 | Direct access record length mismatch |
| 109 | Brackets needed to deeply (>20) |
| 110 | Unformatted record is corrupt |
| 111 | Coprocessor invalid operation |
| 112 | Reference to undefined variable or array element (-UNDEF) |
| 113 | Insufficient allocatable storage |
| 114 | Emulator failure |
| 115 | Invalid hash table |
| 116 | Too many file open |
| 117 | Disk full |
| 118 | ANSI - exponent out-of-range (use Ew.dEe or Gw.dEe edit descriptors) |
| 119 | Down to page reserve |
| 120 | Reference to non-existent Weitek coprocessor |
| 121 | Too many registered traps |
| 122 | No high resolution graphics mode is available |
| 123 | Reserved |
| 124 | Reserved |
| 125 | A file of this name already exists |
| 126 | ANSI - invalid STATUS specifier |
| 127 | ANSI - invalid edit descriptor |
| 128 | File does not exist |
| 129 | Invalid attempt to use peripheral |
| 130 | Unformatted record too big |
| 131 | ANSI - octal/hexadecimal/binary input not permitted |
| 132 | Device type not known on this installation |
| 133 | Reserved |
| 134 | File already in use |
| 135 | Sign not at start of field in business editing descriptor |
| 136 | Business editing not allowed for input |
| 137 | Illegal operation after a BACKSPACE |
| 138 | Attempt to write to readonly file or inconsistent file access |
| 139 | You may not write to a file that is 'READONLY' |
| 140 | You cannot OPEN a directory |
| 141 | ANSI - invalid $ in format descriptor |
| 142 | $ editing not allowed for input |
| 143 | Incorrectly positioned $ character in format descriptor |
| 144 | Illegal name in OPEN/INQUIRE statement |
| 145 | ANSI - the Aw edit descriptor must be used with an item of type CHARACTER |
| 146 | File path not found |
| 147 | Reserved |
| 148 | Reference to undefined variable or array element (-UNDEF) |
| 149 | Value returned by RECL= r NEXTREC= will cause overflow (use INTEGER*4 instead of INTEGER*2) |
| 150 | Count for ENCODE/DECODE must be in the range 1 to 32767 |