APPLICATION OF THE USGS MODFLOW GROUND-WATER MODEL TO THE WENATCHEE RIVER AQUIFER AT LEAVENWORTH

Arthur G. Larson

February, 1991

OFTR 91-05

This Open-File Technical Report presents the results of a hydrologic investigation by the Water Resources Program, Department of Ecology. It is intended as a working document and has received internal review. This report may be circulated to other Agencies and the Public, but it is not a formal Ecology Publication.

Author: Arthur G. Larson

Reviewed by: John J. Covert

Supervisor: Gary E. Hanson

TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

In October, 1989, I was asked by the Central Region Office (CRO) to review a water-right application by the city of Leavenworth for a well located about 120 feet from the Wenatchee River. The CRO believed the well would be in hydraulic continuity with the river. They were concerned that pumping from this well would deplete streamflow of the Wenatchee River, especially during low-flow periods. Specifically, would the river likely provide over 50 percent of the water pumped from the well? At the time of this investigation, the CRO regulated wells in hydraulic continuity with surface water only when the water captured from the surface water was greater than 50 percent of the volume pumped.

To investigate this problem, I used the USGS finite-difference computer model, MODFLOW, to model the local ground-water flow and the interaction between the river, the ground water, and the proposed well.

PURPOSE

This report has two purposes. The first is to document the assumptions I made about hydrogeologic conditions in the Leavenworth area and to present the results of the modeling exercise. The second, and more important purpose, is to provide a Washington State example for first time MODFLOW users (like myself). In this report I provide all the information and data files necessary to run and study MODFLOW with a real world example. I do not, however, explain the inner workings of MODFLOW nor why the various input data are necessary. I assume the interested reader has studied the MODFLOW documentation (McDonald and Harbaugh, 1988). All references to page numbers refer to this MODFLOW document.

BACKGROUND

The City of Leavenworth applied for a water right to pump 1000 gallons/minute (2.23 cfs) from a well located approximately 120 feet north of the low-flow edge of the Wenatchee River (in Section 14, Township 24 N., Range 17 E.). The well was situated within a bend of the river with the river about 1000 feet west, 120 feet south, and 2000 feet east (Figure 1). Approximately 2500 feet of river channel lies within a 1000 ft. radius of the well.

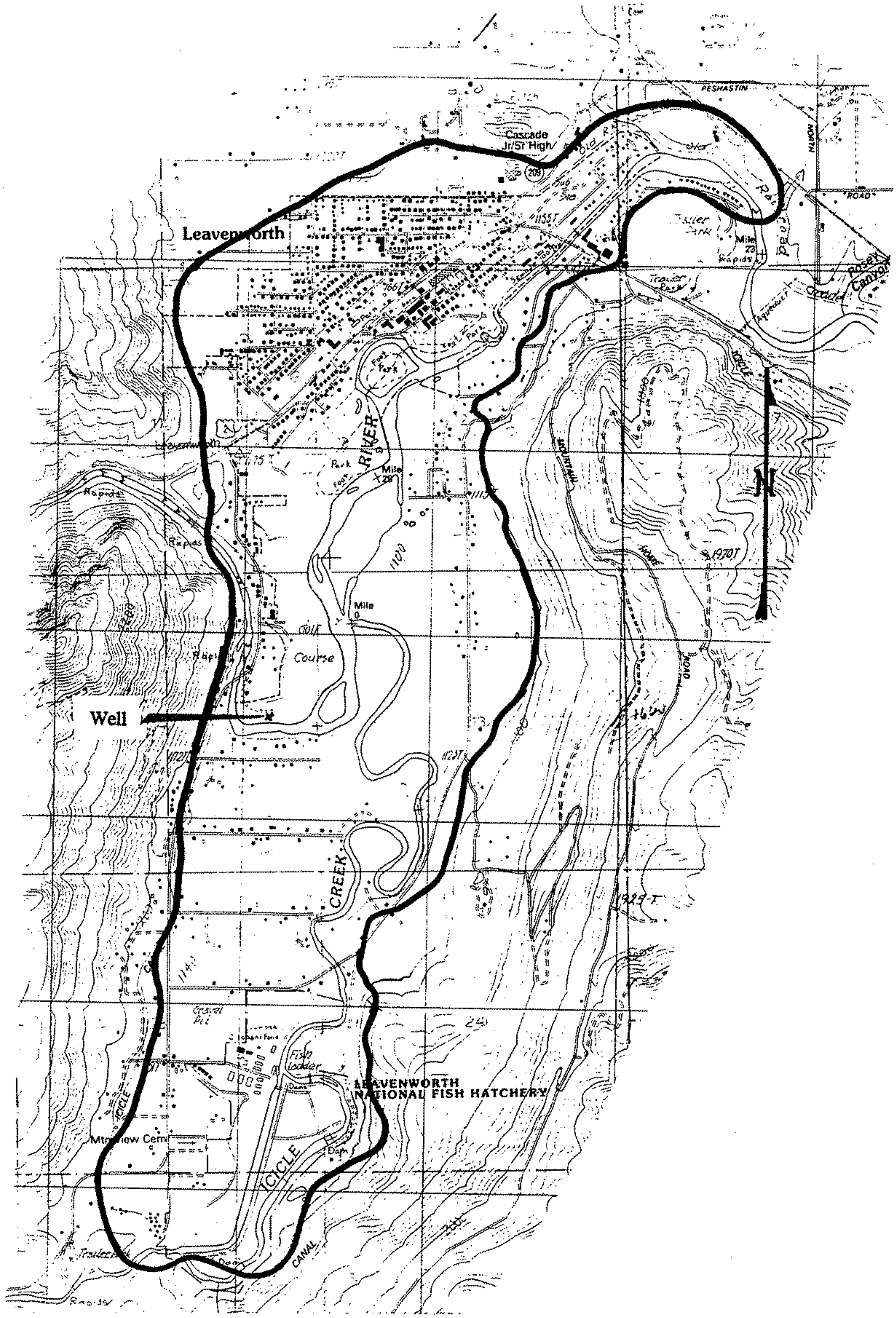

Figure 1. Location of proposed well in relation to the City of Leavenworth, the Wenatchee River, and the aquifer boundaries.

The well taps an unconfined aquifer about 3.15 square miles in area underlying the confluence of Icicle Creek and the Wenatchee River. The aquifer is surrounded by bedrock ridges and the depth to bedrock in the valley fill is believed no more than 200 feet. This estimate is based on the extrapolation of the bedrock profile from surrounding hillslopes (Figure 2), one Leavenworth well log, and consultant reports to the city of Leavenworth (Golder Associates, 1989). Based on a resistivity survey, the consultants estimated that much of the aquifer was less than 200 feet thick. I found no well logs for domestic wells that had drilled deep enough to encounter bedrock, most domestic wells are less than 100 feet deep.

The aquifer appears to pinch-out up the Wenatchee River just upstream of Leavenworth and up the Icicle Creek about three miles south of Leavenworth. Both streams emerge from bedrock canyons at these locations. The aquifer also appears to pinch-out about one-half mile downstream from Leavenworth where the valley narrows and the Wenatchee River cuts near bedrock. The aquifer boundaries, the location of the Wenatchee River, and the location of the Leavenworth well are shown in Figure 1.

The aquifer is not part of any larger, regional groundwater system. Rather, it is recharged by precipitation, runoff from surrounding ridges, and streambed leakage from Icicle Creek and the Wenatchee River. The aquifer discharges to the Wenatchee River below Leavenworth, and because of this, any water pumped from the aquifer and not returned will cause an eventual decrease in streamflow.

The city proposes to pump the well from about mid-June through September, or about 105 days each year. Ecology's concern is that the later half of this period (Aug-Sept) coincides with low streamflow of the Wenatchee River and Icicle Creek. The normal September low flow of the Wenatchee River at Peshastin, just downstream from Leavenworth, is about 700-800 cubic-feet/sec. (cfs). Both the Wenatchee and the Icicle have established instream-flow levels, and surface water withdrawals when the streams are below these flows are not allowed. The instream flow of the Wenatchee River at Peshastin during September is 780 cfs. New ground-water withdrawals that affect streamflow during this period must be conditioned with low-flow restrictions. That is, they may be interupted or shut down whenever the Wenatchee River falls below its minimum instream flow. This is usually considered an unacceptable restriction for municipal water suppliers.

MODEL ASSUMPTIONS

In addition to the preceeding geologic and hydrologic conditions, I made several other major assumptions with respect to MODFLOW. I decided that the model would be two rather than three dimensional. Available data was limited and did not justify the division of the aquifer into layers. The model was constructed for transient conditions, but the beginning head values were arbitrary. I assumed the aquifer was unconfined, 100

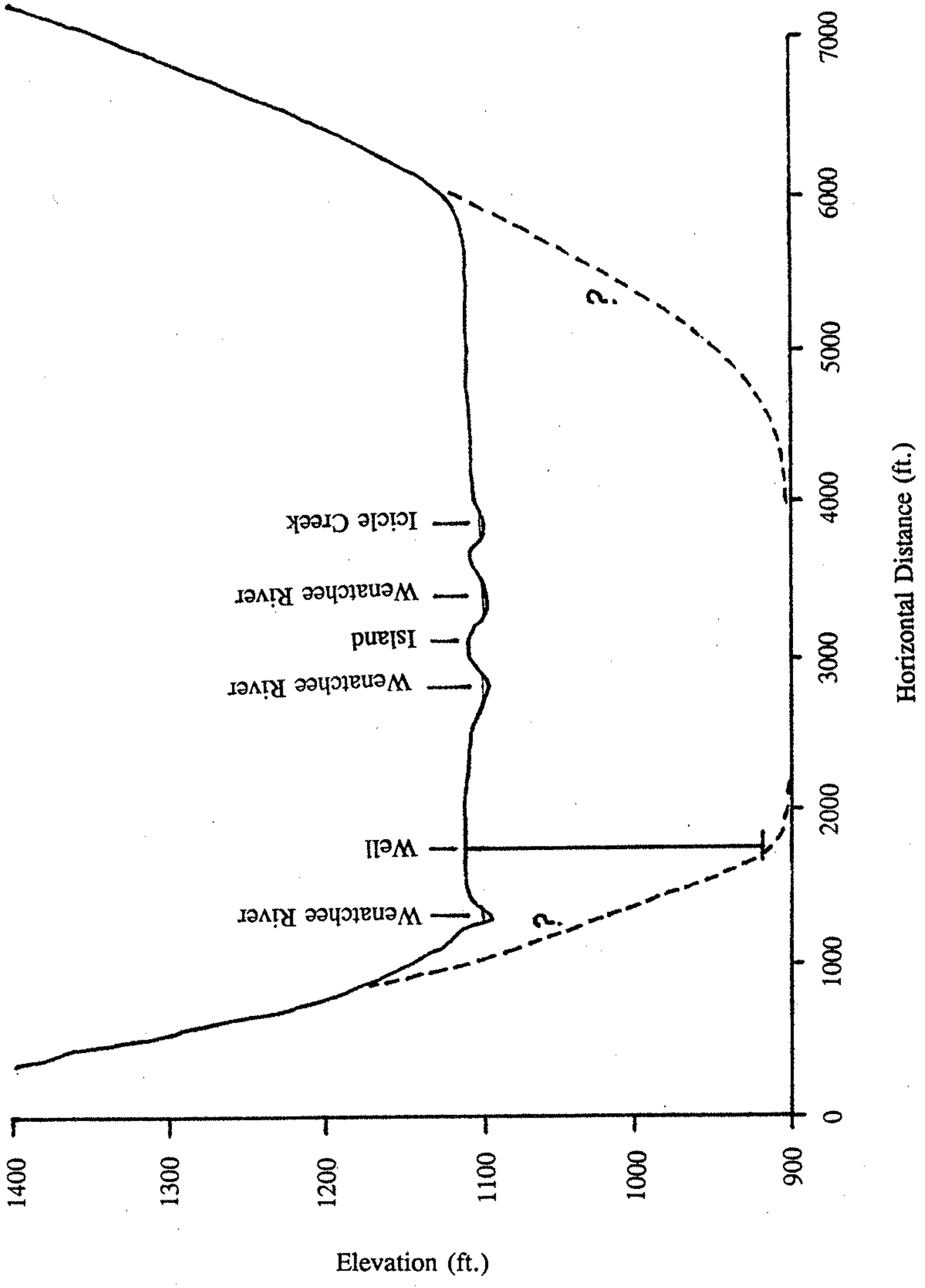

Figure 2. Cross section of Wenatchee River valley near proposed well.

feet thick throughout, and had an initial head of 115 feet. The initial head was determined by subtracting 1000 ft. from the approximate elevation of the well. Thus, the model's base elevation of zero is equal to 1000 ft. above sea level (see Figure 1). I also assigned a single transmissivity value (T) of 30,000 square-ft.day (224,000 gallons/day/ft) to the entire aquifer and assumed a storage coefficient (S) of 0.10. Because the aquifer is unconfined, I converted T to conductivity by dividing it by the assumed aquifer depth of 100 feet (conductivity = 300 ft/day or 0.00347 ft/sec).

The first step in model development was overlaying a two-dimensional, row-column grid onto the aquifer. The grid (Figure 3) was alligned in a general north-south (column) and east-west direction (row). Because the aquifer is several times longer than wide, I used 80 rows and 25 columns for a total of 2000 cells. The resulting square cells were 260 ft. on a side, adequate I believe for this problem. I used a fixed grid spacing because the streams wander across the aquifer and a variable spacing, with some columns or rows wider than others, would have resulted in varying sized river cells. If I were to do it over again, I might use fewer cells. Each cell requires the input of several data values, a time consuming task - the more cells the longer the setup time.

The next step was to draw the Wenatchee River and Icicle Creek on this grid, thus identifying certain cells as river cells. One of the reasons the cell size was kept small was so that river cells would not greatly exceed the width of the river. This is not, however, a requirement of the model.

After the streams were located and river cells assigned, I located the proposed well on the grid. The well was assigned to row-42 and column-10. The proposed well was the only well used in the analysis.

In the model, I used three of MODFLOW's optional modules or packages, the Well package to represent the proposed well, the River package to represent the Wenatchee River and Icicle Creek, and the Recharge package to account for any rainfall that might occur during the study period.

The study period was set at 120 days. Only one stress period was modeled and no changes to pumping, river flow, or recharge were introduced during the run. I divided the stress period into five steps. I selected seconds as the time unit for data input and output. I did this because I am used to thinking in cfs, days might have been a more appropriate time unit. All input data must be converted to this consistent time base.

The 120 day study period was an attempt to model the four month, July through October, low flow period of the Wenatchee River. To represent low flow conditions, I assumed a river width of 100 feet and a depth of three feet. The river head (depth) was kept at a constant three feet throughout the study.

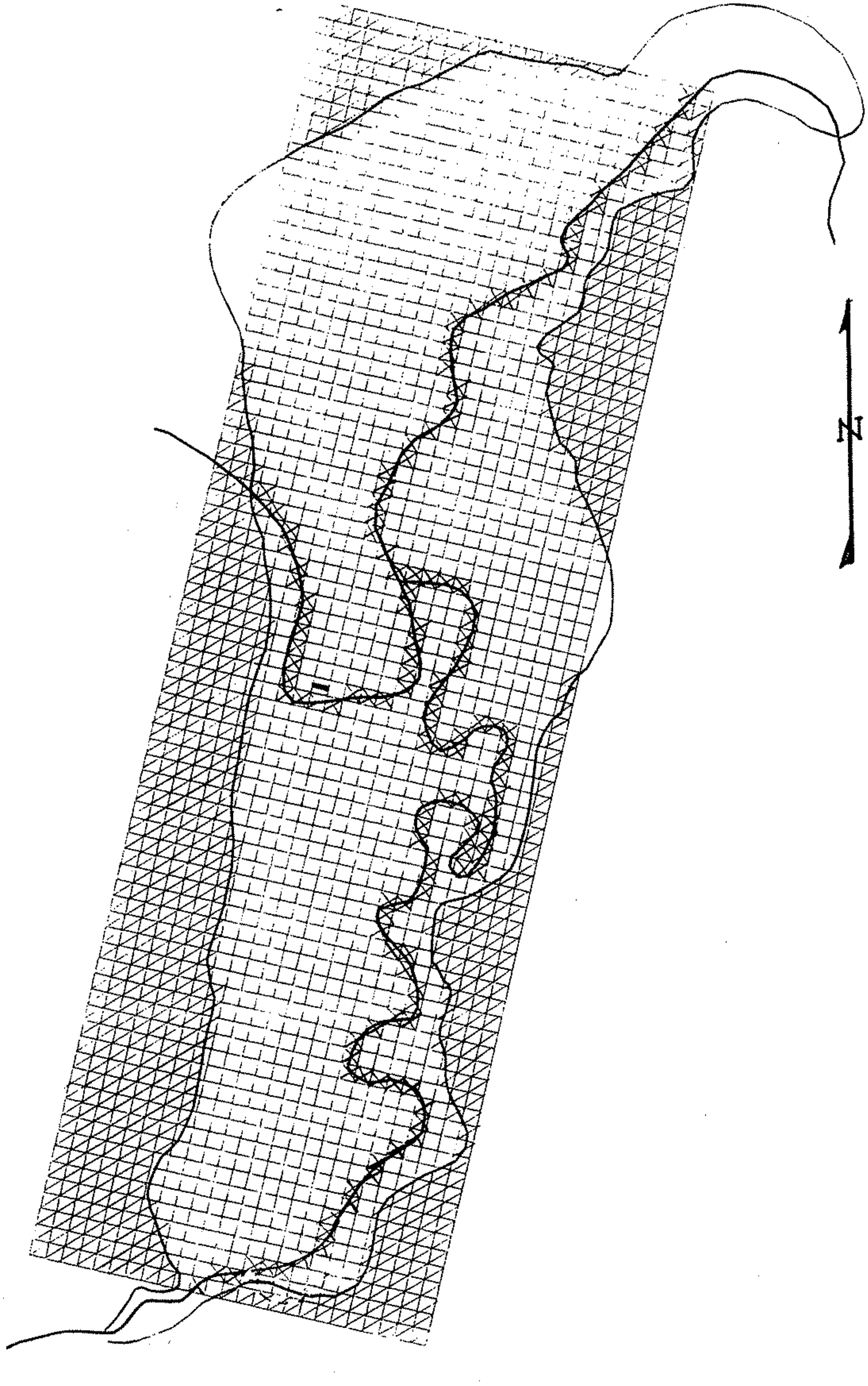

Figure 3. Row-Column grid overlay for Leavenworth aquifer and stream system. 80 rows x 25 columns.

From one of the consultants reports, I estimated that the river leakage was about 87 gallons/minute/acre of streambed/foot of head difference between the stream and the aquifer. Assuming the stream width is 100 ft. and the length of stream within each cell is equal to the cell width (260 ft.), then the leakage or streambed conductance for a cell converts to 52 gallons/min/ft. head difference. Converting from gallons to feet and minutes to seconds results in a conductance of 0.12 cubic-ft./sec., I rounded this to 0.1 for use in the model. This value is equivalent to a vertical hydraulic conductivity of 0.33 ft./day, a low value when compared to the aquifer's 300 ft./day horizontal conductivity.

RESULTS OF THE MODELING EXERCISE

I made two model runs with the MODFLOW model, one with and one without the proposed well. The first run established the background hydrologic conditions with which the second model run was compared. I ignored all other wells in the aquifer, I was only interested in approximate changes to the hydrologic regime from the addition of one new well. Because the initial heads were selected arbitrarily, I ignored the results from the first four of the five stress-period steps. The heads during the stress period had reached a steady state by step 4. Only one iteration of the model was required to solve step 5, thus the final heads are not greatly influenced by initial heads. The results of the model calculations, with and without the well, at the end of step five are presented in Table 1.

Without a discharging well, the model estimated a head of 103.5 ft. in the cell containing the well. The model further estimated that the constant head boundaries, where the two streams enter the system, provide about 1.47 cfs to the aquifer. Recharge provides another 0.46 cfs and leakage from the river channel, another 1.74 cfs. The total water entering the aquifer was about 4.0 cfs (includes 0.34 cfs released from storage).

The model also estimated that 1.96 cfs leaves the aquifer through the constant head boundary at the downstream end of the aquifer. An additional 2.05 cfs leaves the aquifer as discharge to river and stream channels.

After adding the well (discharging 2.23 cfs) to the system, the head in the cell containing the well declined to 102.6 ft. The pumping increased the leakage from the river to the aquifer from 1.74 cfs to 3.20 cfs, an increase of 1.5 cfs. That is, 1.5 cfs was obtained directly from the river. The pumping also decreased the water moving from the aquifer to the stream by 0.6 cfs, from 2.05 cfs to 1.39 cfs. That is, the well intercepted 0.6 cfs of water that would have reached the stream had there been no pumping.

The pumping slightly increased flow into the aquifer from the constant head cells (by 0.1 cfs) and slightly decreased outflow via the downstream constant head cells.

However, the major changes to the hydrologic system were an increase of 1.5 cfs in water leaking from the river into the aquifer and a reduction of 0.6 cfs in the water discharging from the aquifer into the river. This 2.1 cfs in stream capture accounts for 94 percent of the pumping rate.

In summary, the model indicates that by the end of 120 days, practically all of the water pumped from the well is extracted from the Wenatchee River or Icicle Creek. The well either increased leakage from the streams or decreased discharge to the streams.

I did not attempt to verify the model by measuring actual heads in the aquifer. Heads are, however, constrained by the constant-head cells and should be reasonable. Changing the constant-head-boundary cells, at the entrance and exits of the streams, to variable-head cells would probably reduce the water entering and leaving the aquifer at these points. This would decrease the total flow through the aquifer, but would not greatly change the relationship between the well and the surrounding streams. If anything, I would expect it to cause more water to be captured from the stream as the constant head boundaries are no longer an infinite source of groundwater. To anyone wishing to experiment with this model, I suggest a valuable exercise would be changing the constant-head cells to variable-head cells and studying the resultant changes to the aquifer heads and flow rates.

TABLE 1. Model results with and without a 2.23 cfs pumping well.

Source	Without Well (cfs)	With Well (cfs)
Flow into aquifer from Source		
Constant head	1.47	1.57
Recharge	0.46	0.46
River leakage	1.74	3.20
Storage	0.34	0.34
TOTAL	4.01	5.57
Flow out of aquifer via Source		
Constant head	1.96	1.95
Well discharge	0	2.23
River gain	2.05	1.39
TOTAL	4.01	5.57

DATA FILES

To satisfy the second purpose of this report, I have included a discussion of the necessary input files and their data. The only difference between the model runs with and without the well is the inclusion of the WELL.DAT file and the inclusion of the Unit number for the Well Package in line 4 of BASIC.DAT. Listings of the files are included as Appendices A - F, and on the enclosed computer disk. A copy of MODFLOW.EXE is also included on the disk.

BASIC.DAT = Unit 1

This file contains input data for the Basic Package (BAS). See page 4-9 of the MODFLOW manual for a list of required data and formatting specifications. The file contains, line by line:

1-2: Text the model uses as a heading or title on the printouts. I entered "Leavenworth" on line 1 and "River, Wells, Recharge modules" on line 2.

3: The number of layers (NLAY), rows (NROW), columns (NCOL), stress periods (NPER), and the time units of the simulation (ITMUNI). I used 1 layer, 80 rows, and 25 columns. I used a 1 for the fourth entry to indicate one stress period and I used a 1 for the time unit entry. This indicates that "seconds" will be used as the consistent time unit.

4: The Unit numbers for each package used in the analysis (IUNIT table). In this instance I have assigned Unit 15 to the Block Centered Flow package (BCF), Unit 20 to the Well package (WEL), Unit 25 to the River package (RIV), Unit 30 to the Recharge package (RCH), and Unit 35 to the Strongly Implicit Procedure package (SIP). I did not use the remaining packages, a zero was entered for their Unit number. The Unit numbers, other than Unit 1, are arbitrary.

5: IAPART and ISTRT - see page 4-11 and 4-12 of manual. IAPART determines whether the arrays BUFF and RHS will occupy the same space. I used a 0 indicating they will. ISTRT determines whether starting heads are saved. I used a 0 indicating heads will not be saved.

6: The control record for the IBOUND or boundary array. This record is poorly documented in the manual. It is read by subroutine U2DINT - see page 14-32. The first entry (LOCAT) is the Unit number location of the IBOUND array. See comments C1, C2, C3, C4, and C5 page 14-32. I entered a 1 because IBOUND is located in the Basic.Dat file on Unit 1. The second entry (ICONST), also a 1, is discussed in comment C6 on page 14-33. It is a multiplier for the array, a 0 would have been equally valid. The third entry is the format of the IBOUND array (FMTIN). FMTIN controls reading of the IBOUND data, I used a 25I2 format. The model will thus read 25 two-digit integer values per line. This controls reading of the IBOUND array presented in the following line 7. The final entry on line 6 is the output control option (IPRN) for printing the IBOUND array. These are the default options if the OUTPUT Control package (OC) is not used. I choose default option 3, primarily because it was the option presented in the example problem. See Appendix E of the Modflow manual for a discussion of IPRN.

7-86: Contains the boundary array (IBOUND) in the format presented in line 6 (25I2). The 80 lines (rows) of 25 entries (columns) contain one value for each cell of the model. A 0 indicates a no-flow cell, a 1 represents a variable head cell, and a -1 represents a constant head cell. This array represents the boundary conditions for the problem. Because I only used one layer in this model, only one IBOUND array is presented.

87: The head assigned to all no-flow cells so they can be easliy identified in the printout. I choose 999.99.

88: A control record for reading the starting heads array (SHEAD). See line 6 above.

89-168: The starting head array (SHEAD) entered in the format presented in line 88 (25F4.0). One head value for each cell. I used 95 for down river and 105 for up river constant head cells and 115 for the variable head cells. Note that any value assigned to a constant head cell will remain constant throughout the model run. Constant head cells, because they are an infinite source of water, have tremendous impact on the model results so the input values must be reasonable.

169: The length of the stress period (PERLEN), the number of steps in the stress period (NTSP), and the multiplier for successive time steps (TSMULT). See page 4-5 for an explanation of stress periods. PERLEN must be in time units selected in line 3 above (ITMUNI). I used a PERLEN of 10368000.0 seconds (120 days = 4 months) divided into 5 equal time steps (NTSP = 5 and TSMULT = 1).

BLOCK.DAT = Unit 15

This file contains the input data for the Block Centered Flow package (BCF). See page 5-37 of MODFLOW manual for a list of required data and formatting specifications. Lines contain:

1: The steady state/transient flow flag (ISS). I entered a 0 indicating a transient model. The second entry is a flag indicating whether cell by cell flow terms will be saved or printed. I entered a 0 indicating no cell by cell save or printout. See page 5-38.

2: The layer code (LAYCON). I entered a 1 to represent an unconfined layer and also because only one layer is modeled. See page 5-33 and 5-38 of the manual.

3: Control record for reading the one-dimensional array TRPY (page 5-39) via module U1DREL (page 4-35). This control record is not well documented in the manual. I entered a 0 as the first entry (LOCAT) indicating that all array values are to be set to a constant and that the constant is the next value on this line. I used a 1 for this constant value (CNSTNT) representing the anisotropy factor for the layer.

4: Control record for reading the one dimensional array DELR. DELR contains the cell width along each row. I used a constant value of 260 ft. (CNSTNT) with a LOCAT of 0. See line 3 above.

5: Control record for reading array DELC. DELC contains the cell width along columns. I used a constant value of 260 ft. (CNSTNT) with a LOCAT of 0. See line 3 above.

Equal and constant values in both DELR and DELC results in a grid of square cells of identical size.

6: Control record for reading the two-dimensional array sf1 (read by module U2DREL, see page 14-26). sf1 is the primary storage coefficient array for the layer. Again, I used a constant value for the entire grid (CNSTNT = 0.10). This is equivalent to the specific yield since the single layer is unconfined. The value 0.10 was chosen as a reasonable value for an unconfined aquifer.

7: Control record for reading the two-dimensional array HY (read by module U2DREL, see page 14-26). HY is the row hydraulic conductivity array for the layer. Again, I used a constant value for the entire grid (CNSTNT = 0.00347 ft./sec). Hydraulic conductivity, rather than transmissivity, is required because the single layer is unconfined.

8: Control record for reading the two-dimensional array BOT. The BOT array contains the bottom elevations of each cell. I used a constant value of -100 ft. The line is read by module U2DREL, see page 14-26 of the manual.

WELL.DAT = Unit 20

This file contains the input data for the Well package (WEL). Data and formatting specifications for this package are discussed on page 8-3 of the manual. Lines include:

1: The first entry is the number of wells used in the analysis (MXWELL). I used 1 well. The second entry is a flag indicating how and where the cell-by-cell flow terms will be recorded (IWELCB). I used a 0 indicating that flows will not be recorded or printed.

2: The single entry is a flag and counter indicating whether well data from the prior stress period is used or, if not, how many wells are active during the current stress period (ITMP). I used a 1 indicating that one well would be active during the stress period.

3: The first entry is the layer in which the well is located, the second is the row, and the third is the column. I used a 1 for the layer, 42 for the row, and 10 for the column. The fourth entry is the discharge or recharge rate for the well. I used -2.23 cfs. The negative sign indicates that it is a discharge well rather than a recharge well. If more than one well were modeled, this line would be repeated for each well.

RIVER.DAT = Unit 25

This file contains the input data to the River package (RIV). Input consists of six entries for each river cell, specifying the layer,row,and column of the cell, and the three parameters needed to calculate seepage: 1) stream stage (HRIV), 2) the conductance of the stream-aquifer connection (CRIV), and 3) the bottom elevation (RBOT). Data formatting specifications are found on page 6-14 of the manual. Lines contain:

1: This line contains two entries. The first entry is the maximum number of active river cells (MXRIVR). I used 126 river cells to represent both the Wenatchee River and Icicle Creek. The second entry is a flag indicating where and how to record the stream leakage results. I used a -1 to include leakage in the printout (see page 6-14 of the manual).

2: The single entry is ITMP, a temporay flag containing the number of active cells during the current stress period. Again I entered 126.

3-128: The following 126 lines contain the entries for each river cell. The first three entries are the layer, row, and column of the river cell. The fourth entry is the river stage for that cell. Stage must be related to the same base elevation as the aquifer heads. I used a gradually declining stage from 105 ft. upstream to 95 ft. downstream. The fifth entry is the riverbed conductivity for the cell. I used a value of 0.10 for all cells (see note). The sixth and final entry is the riverbed bottom elevation for each cell. I used a gradually declining value ranging from 102 ft. to 92 ft. - upstream to downstream. The difference between river stage and riverbed elevation is the head in the river. I used a constant head of three feet of water in the river to mimic the low streamflow condition.

RECHARGE.DAT = Unit 30

This file contains input data for the Recharge package (RCH). The recharge package input is discussed on page 7-6 of the manual. Lines included in the data file are:

1: The first entry is the recharge option code (NRCHOP). I used a 1 indicating that recharge is only to the top layer. The second entry is a flag indicating where to save the cell-by-cell flow terms (IRCHCB). I used a 0 indicating that flow will not be saved or printed.

2: The first and only entry is a flag declaring how the recharge values will be read (INRECH). I used a 0 indicating that the array of recharge input values would be read as input rather than reused from any prior stress periods.

3: Control record for reading the two-dimensional array RECH via module U2DREL (page 14-26). This control record is not well documented in the manual. I entered a 0 as the first entry (LOCAT) indicating that all array values are to be set to a constant and that the constant is the next value on this line. I used a value of 5.28E-9 ft./sec for this constant value (CNSTNT) representing the rainfall during the stress period. Remember, all units in the model must be consistent.

SIP.DAT = Unit 35

Input file for the Strongly Implicit Procedure package (SIP). See page 12-30 of the manual for discussion. Lines in the file contain:

1: The first entry is the maximum number of iteration loops allowed before the program assumes the model will not "close" on an answer, and the program quits (MXITER). I used the suggested value of 50. The second entry is the number of iteration parameters (NPARM). See page 12-23. I used the suggested value of 5.

2: This line contains four entries. The first is the acceleration parameter (ACCL). I used the suggested value of 1. The second is the convergence criteria (HCLOSE). I used 0.001. Thus, the model will stop when heads no longer change by amounts greater than 0.001 ft. The third entry is a a flag indicating where the iteration parameter seed is to be gotten. I used a 1 instructing the program to calculate the seed. Because it is calculated, the seed is not provided as input. However, whether needed or not, WSEED is read by the program and the required F10.0 format spacing must be included on this line. Thus the ten-character gap between the third and fourth entries on this line. The fourth and final entry is the printout interval (IPRSIP). I used a 10 as per the example in the manual.

RUNNING THIS APPLICATION OF MODFLOW

While I have listed the input data for the Leavenworth application of MODFLOW, I have not discussed the output file, that is what the results look like. Because MODFLOW has many options for formatting the output and the output is quite lengthy, I do not describe them here. Rather, I believe at this point, if the reader is ready to examine the output file, he/she should run the model and obtain a printout of the results.

Before running MODFLOW, make sure you have adequate free memory in your computer. MODFLOW requires over 580 kilobytes. For convenience, place MODFLOW.EXE and the data files in the same subdirectory. Run Modflow by entering MODFLOW. Modflow will respond with a series of input requests:

Request-- Enter the file name for the ASCII output file, UNIT 6:
Response- You can enter any filename you wish for the output file. I used MODFLOW.OUT.

Request-- Enter the filename for the BASIC package file, UNIT 1:
Response- BASIC.DAT

Request-- Enter the filename for the BCF package file, UNIT 15:
Response- BLOCK.DAT

Request-- Enter the filename for the WELL package file, UNIT 20:
Response- WELL.DAT

Request-- Enter the filename for the RIVER package file, UNIT 25:
Response- RIVER.DAT

Request-- Enter the filename for the RECH package file, UNIT 30:

Response- RECHARGE.DAT

Request-- Enter the filename for the SIP package file, UNIT 35:
Response- SIP.DAT

After these requests have been entered the computer will start running the model. The model does **not** indicate the progress of the run, you can only WAIT and hope it is running correctly. The run time for this application is about one-minute on my 25 kilohertz 80386 computer. When the program has completed a run, it will respond by writing:

```
Stop - Program Terminated
```

The results from the run will be in the output data file, MODFLOW.OUT (or whatever you named the output file).

I have included the final pages of the output file as Appendix G. These pages include the map of final head values and a volumetric budget of aquifer inflow and outflow. Refer to pages 4-5 to 4-7 and Appendix D of the MODFLOW manual for reference. Ouput listings are not discussed in any detail in the manual, but are relatively self explanatory. The 1000. values are the no-flow cells (999.99 rounded off by the print formatting).

APPENDICES - Input Data Files

Appendix A. BASIC.DAT

```
Leavenworth
River, Wells, Recharge modules.
         1        80        25         1         1
 15 20  0 25  0  0  0 30 35  0  0  0
         0         0                                      (one buffer, no save)
         1         1 (25I2)                          3        (control record IBound
1)
 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
 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 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 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 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 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 0 0 0
 0 0 0 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 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 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 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 0 0 0 0 0
 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 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 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 0 0 0 0 0 0
 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 1 1 1 1 1 1 1 1 1 1 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
 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 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 1 1 1 1 1 1 1 1 1 1 1 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 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 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 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 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 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 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 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
 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
 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 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
 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
 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
 0 0 0 0 0 0 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 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 1 1 1 1 1 1 1 1 1 1 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 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 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 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 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 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 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 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 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 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 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 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 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 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 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 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 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 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 1 1 1 1 1 1 1 1 1 1 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 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 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 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 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 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 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 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 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 0
0 0 0 0 0 0 0 0 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 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 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 1 1 1 1 1 1 1 1 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 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 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 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 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 0 0 0 0 0
0 0 0 0 0 0 0 0 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 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 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0
   999.99                                            (no flow head)
        1         1 (25F4.0)                    6    (control record SHeads 1)
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115  95  95  95  95  95  95
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
```

```
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 105 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
```

```
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 105 115 115 115 115 115 115 115 115 115 115 115 115
115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115 115
10368000.0       5       1
```

Appendix B. BLOCK.DAT

```
        0       0
 1
        0       1.
        0     260.
        0     260.
        0     0.10
        0  0.00347
        0    -100.
```

Appendix C. WELL.DAT

```
        1       0
        1
        1      42       10      -2.23
```

Appendix D. RIVER.DAT

```
      126      -1
      126
        1      32        4      105      0.10      102
        1      32        5      105      0.10      102
        1      33        6      105      0.10      102
        1      34        7      105      0.10      102
        1      35        8      104      0.10      101
        1      36        8      104      0.10      101
        1      37        8      104      0.10      101
        1      38        8      104      0.10      101
        1      39        8      104      0.10      101
        1      40        8      104      0.10      101
        1      41        8      104      0.10      101
        1      42        8      104      0.10      101
        1      43        9      104      0.10      101
        1      43       10      104      0.10      101
        1      43       11      104      0.10      101
        1      42       12      104      0.10      101
```

1	41	13	103	0.10	100
1	40	14	103	0.10	100
1	39	15	103	0.10	100
1	38	15	103	0.10	100
1	37	15	103	0.10	100
1	36	15	103	0.10	100
1	35	14	103	0.10	100
1	34	13	102	0.10	99
1	33	12	102	0.10	99
1	32	12	102	0.10	99
1	31	11	102	0.10	99
1	30	11	102	0.10	99
1	29	11	102	0.10	99
1	28	11	102	0.10	99
1	27	11	102	0.10	99
1	26	12	102	0.10	99
1	25	13	101	0.10	98
1	24	13	101	0.10	98
1	23	14	101	0.10	98
1	22	14	101	0.10	98
1	21	13	101	0.10	98
1	20	13	100	0.10	97
1	19	12	100	0.10	97
1	18	12	100	0.10	97
1	17	13	100	0.10	97
1	16	14	100	0.10	97
1	16	15	100	0.10	97
1	15	16	99	0.10	96
1	14	16	99	0.10	96
1	13	17	99	0.10	96
1	12	18	99	0.10	96
1	11	18	99	0.10	96
1	10	18	98	0.10	95
1	9	18	98	0.10	95
1	8	18	98	0.10	95
1	7	19	98	0.10	95
1	6	20	97	0.10	94
1	5	21	97	0.10	94
1	4	22	97	0.10	94
1	3	22	96	0.10	93
1	2	23	96	0.10	93
1	1	23	95	0.10	92
1	34	14	102	0.10	99
1	34	15	102	0.10	99

1	34	16	102	0.10	99
1	34	17	103	0.10	100
1	34	18	103	0.10	100
1	35	19	103	0.10	100
1	36	19	103	0.10	100
1	37	19	103	0.10	100
1	38	19	103	0.10	100
1	39	18	103	0.10	100
1	40	17	103	0.10	100
1	41	17	103	0.10	100
1	42	17	103	0.10	100
1	43	18	103	0.10	100
1	43	19	103	0.10	100
1	43	20	103	0.10	100
1	42	21	103	0.10	100
1	41	21	103	0.10	100
1	41	22	103	0.10	100
1	42	22	103	0.10	100
1	43	22	103	0.10	100
1	44	22	103	0.10	100
1	45	22	103	0.10	100
1	46	22	103	0.10	100
1	47	22	103	0.10	100
1	48	22	103	0.10	100
1	49	22	103	0.10	100
1	50	22	103	0.10	100
1	50	21	103	0.10	100
1	50	20	103	0.10	100
1	49	20	103	0.10	100
1	48	20	103	0.10	100
1	47	20	103	0.10	100
1	47	19	103	0.10	100
1	47	18	103	0.10	100
1	48	18	103	0.10	100
1	49	18	103	0.10	100
1	50	18	103	0.10	100
1	51	18	103	0.10	100
1	52	18	103	0.10	100
1	53	18	103	0.10	100
1	54	18	103	0.10	100
1	55	18	104	0.10	101
1	56	18	104	0.10	101
1	57	19	104	0.10	101
1	58	19	104	0.10	101

```
1    59    20    104    0.10    101
1    60    20    104    0.10    101
1    61    19    104    0.10    101
1    62    19    104    0.10    101
1    63    19    104    0.10    101
1    64    19    104    0.10    101
1    65    19    104    0.10    101
1    66    19    104    0.10    101
1    67    19    104    0.10    101
1    68    19    104    0.10    101
1    69    19    104    0.10    101
1    70    19    105    0.10    102
1    71    19    105    0.10    102
1    72    19    105    0.10    102
1    73    18    105    0.10    102
1    74    18    105    0.10    102
1    75    17    105    0.10    102
1    76    16    105    0.10    102
1    76    15    105    0.10    102
1    77    14    105    0.10    102
1    78    13    105    0.10    102
1    79    13    105    0.10    102
```

Appendix E. RECHARGE.DAT

```
1     0
0
0  5.28E-9
```

Appendix F. SIP.DAT

```
50     5
1.    .01     1           10
```

Appendix G. MODFLOW.OUT

(Data output from Model run number 1, with well.)

```
1                    U.S. GEOLOGICAL SURVEY MODULAR FINITE-DIFFERENCE GROUND-WATER MODEL
0Leavenworth                                                                  River, Wells, Recharge modules.

    1 LAYERS         80 ROWS         25 COLUMNS
   1 STRESS PERIOD(S) IN SIMULATION
 MODEL TIME UNIT IS SECONDS
***************************************************************************
0                                                   COLUMN TO ROW ANISOTROPY =   1.000000
0                                                                       DELR =   260.0000
0                                                                       DELC =   260.0000
0                                                       PRIMARY STORAGE COEF =   .1000000     FOR LAYER  1
0                                                      HYD. COND. ALONG ROWS =   .3470000E-02 FOR LAYER  1
0                                                                     BOTTOM =  -100.0000     FOR LAYER  1
***************************************************************************
    22 ITERATIONS FOR TIME STEP   1 IN STRESS PERIOD  1
    19 ITERATIONS FOR TIME STEP   2 IN STRESS PERIOD  1
    15 ITERATIONS FOR TIME STEP   3 IN STRESS PERIOD  1
    11 ITERATIONS FOR TIME STEP   4 IN STRESS PERIOD  1
     1 ITERATIONS FOR TIME STEP   5 IN STRESS PERIOD  1
***************************************************************************
1                      HEAD IN LAYER  1 AT END OF TIME STEP  5 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

.........................................................................................................................
0  1    1000.       1000.       1000.       1000.       1000.       1000.       1000.       1000.       1000.       1000.
        1000.       1000.       1000.       1000.       1000.       1000.       1000.       1000.       1000.       95.00
        95.00       95.00       95.00       95.00       95.00
0  2    1000.       1000.       1000.       1000.       1000.       1000.       1000.       1000.       1000.       1000.
        99.21       99.10       98.94       98.74       98.48       98.18       97.83       97.39       96.83       96.03
        95.71       95.56       95.48       95.42       1000.
0  3    1000.       1000.       1000.       1000.       1000.       1000.       1000.       1000.       1000.       99.43
        99.30       99.16       98.99       98.78       98.53       98.24       97.90       97.51       97.06       96.57
        96.25       96.04       95.88       95.77       1000.
0  4    1000.       1000.       1000.       1000.       1000.       1000.       1000.       1000.       99.71       99.56
        99.41       99.25       99.07       98.85       98.61       98.34       98.03       97.69       97.32       96.96
        96.67       96.45       96.24       96.01       1000.
0  5    1000.       1000.       1000.       1000.       1000.       1000.       100.2       100.1       99.86       99.69
        99.53       99.36       99.17       98.96       98.73       98.47       98.19       97.89       97.58       97.27
        97.01       96.79       96.63       1000.       1000.
0  6    1000.       1000.       1000.       1000.       1000.       100.4       100.3       100.1       99.98       99.81
        99.65       99.47       99.29       99.08       98.86       98.62       98.37       98.10       97.82       97.54
        97.30       97.06       96.85       1000.       1000.
0  7    1000.       1000.       1000.       1000.       100.6       100.5       100.4       100.2       100.1       99.94
        99.78       99.60       99.42       99.22       99.02       98.79       98.56       98.31       98.08       97.84
        97.58       97.32       1000.       1000.       1000.
0  8    1000.       1000.       1000.       100.8       100.7       100.6       100.5       100.4       100.2       100.1
        99.91       99.74       99.56       99.38       99.18       98.97       98.75       98.52       98.34       98.14
        97.86       1000.       1000.       1000.       1000.
0  9    1000.       1000.       101.1       101.0       100.8       100.7       100.6       100.5       100.3       100.2
        100.0       99.89       99.72       99.54       99.35       99.15       98.95       98.74       98.63       98.53
        1000.       1000.       1000.       1000.       1000.
0 10    1000.       101.2       101.2       101.1       101.0       100.9       100.7       100.6       100.5       100.3
        100.2       100.0       99.87       99.70       99.52       99.34       99.16       98.97       98.89       98.83
        1000.       1000.       1000.       1000.       1000.
0 11    1000.       101.3       101.3       101.2       101.1       101.0       100.9       100.8       100.6       100.5
        100.3       100.2       100.0       99.87       99.70       99.54       99.37       99.22       99.13       99.06
        1000.       1000.       1000.       1000.       1000.
```

```
0 12   101.5   101.4   101.4   101.3   101.2   101.1   101.0   100.9   100.8   100.6
       100.5   100.3   100.2   100.0   99.88   99.72   99.58   99.45   99.36   99.21
       1000.   1000.   1000.   1000.   1000.
0 13   101.6   101.6   101.5   101.4   101.4   101.3   101.2   101.0   100.9   100.8
       100.7   100.5   100.4   100.2   100.0   99.89   99.76   99.69   99.64   1000.
       1000.   1000.   1000.   1000.   1000.
0 14   101.7   101.7   101.6   101.6   101.5   101.4   101.3   101.2   101.1   101.0
       100.8   100.7   100.5   100.4   100.2   100.0   99.98   99.92   99.87   1000.
       1000.   1000.   1000.   1000.   1000.
0 15   101.8   101.8   101.8   101.7   101.7   101.6   101.5   101.4   101.2   101.1
       101.0   100.8   100.7   100.5   100.4   100.2   100.2   100.1   100.1   1000.
       1000.   1000.   1000.   1000.   1000.
0 16   102.0   102.0   101.9   101.9   101.8   101.7   101.7   101.5   101.4   101.3
       101.1   101.0   100.8   100.7   100.6   100.5   100.4   100.3   100.2   1000.
       1000.   1000.   1000.   1000.   1000.
0 17   102.2   102.1   102.1   102.1   102.0   101.9   101.8   101.7   101.6   101.5
       101.3   101.1   101.0   100.9   100.9   100.8   100.7   100.5   1000.   1000.
       1000.   1000.   1000.   1000.   1000.
0 18   102.3   102.3   102.3   102.3   102.2   102.1   102.0   101.9   101.8   101.6
       101.5   101.3   101.2   101.2   101.1   101.1   101.0   1000.   1000.   1000.
       1000.   1000.   1000.   1000.   1000.
0 19   102.5   102.5   102.5   102.5   102.4   102.3   102.2   102.1   102.0   101.9
       101.7   101.5   101.4   101.4   101.4   101.3   101.3   1000.   1000.   1000.
       1000.   1000.   1000.   1000.   1000.
0 20   102.7   102.7   102.7   102.7   102.6   102.6   102.5   102.4   102.2   102.1
       101.9   101.7   101.6   101.6   101.6   101.6   101.6   101.8   1000.   1000.
       1000.   1000.   1000.   1000.   1000.
0 21   102.9   102.9   103.0   102.9   102.9   102.8   102.7   102.6   102.5   102.3
       102.1   102.0   101.8   101.8   101.8   101.8   101.9   101.9   1000.   1000.
       1000.   1000.   1000.   1000.   1000.
0 22   103.0   103.2   103.2   103.2   103.2   103.1   103.0   102.8   102.7   102.5
       102.4   102.2   102.1   102.0   102.0   102.0   102.1   102.1   1000.   1000.
       1000.   1000.   1000.   1000.   1000.
0 23   1000.   103.5   103.5   103.5   103.5   103.4   103.3   103.1   103.0   102.8
       102.6   102.4   102.3   102.2   102.2   102.2   102.3   102.3   102.4   1000.
       1000.   1000.   1000.   1000.   1000.
0 24   1000.   103.8   103.8   103.8   103.8   103.7   103.6   103.4   103.2   103.0
       102.8   102.6   102.4   102.4   102.4   102.4   102.4   102.5   102.5   102.6
       1000.   1000.   1000.   1000.   1000.
0 25   1000.   104.1   104.2   104.2   104.2   104.1   103.9   103.7   103.5   103.2
       103.0   102.8   102.6   102.6   102.6   102.6   102.6   102.6   102.6   102.7
       102.7   1000.   1000.   1000.   1000.
0 26   1000.   104.4   104.6   104.7   104.6   104.5   104.3   104.0   103.8   103.5
       103.2   103.0   102.9   102.8   102.7   102.7   102.7   102.7   102.7   102.8
       102.8   1000.   1000.   1000.   1000.
0 27   1000.   1000.   105.1   105.2   105.2   105.0   104.7   104.4   104.0   103.7
       103.3   103.2   103.0   103.0   102.9   102.8   102.8   102.8   102.8   102.8
       102.9   102.9   1000.   1000.   1000.
0 28   1000.   1000.   105.5   105.9   105.8   105.5   105.2   104.7   104.3   103.9
       103.5   103.3   103.2   103.1   103.0   103.0   102.9   102.9   102.9   102.9
       102.9   102.9   103.0   1000.   1000.
0 29   1000.   1000.   1000.   107.1   106.7   106.2   105.6   105.1   104.6   104.1
       103.7   103.5   103.3   103.2   103.1   103.0   103.0   103.0   102.9   102.9
       103.0   103.0   103.0   1000.   1000.
0 30   1000.   1000.   1000.   108.6   107.8   106.9   106.1   105.4   104.8   104.3
       103.8   103.6   103.4   103.3   103.2   103.1   103.0   103.0   103.0   103.0
       103.0   103.0   103.0   103.0   1000.
0 31   1000.   1000.   1000.   110.9   109.0   107.5   106.4   105.6   104.9   104.4
       103.9   103.6   103.5   103.3   103.2   103.1   103.1   103.1   103.0   103.0
       103.0   103.0   103.0   103.0   103.0
0 32   1000.   1000.   1000.   115.0   109.8   107.7   106.5   105.6   105.0   104.4
       104.0   103.6   103.5   103.3   103.2   103.2   103.1   103.1   103.1   103.0
       103.0   103.0   103.0   103.0   103.0
0 33   1000.   1000.   1000.   1000.   108.0   107.0   106.2   105.5   104.9   104.4
       104.0   103.6   103.4   103.3   103.2   103.1   103.1   103.1   103.1   103.1
       103.1   103.1   103.1   103.1   103.1
0 34   1000.   1000.   1000.   1000.   107.2   106.4   105.7   105.2   104.7   104.3
       104.0   103.7   103.4   103.2   103.1   103.1   103.1   103.1   103.1   103.1
       103.1   103.1   103.1   103.1   103.1
```

```
0 35   1000.   1000.   1000.   1000.   1000.   105.6   105.2   104.8   104.5   104.2
       103.9   103.6   103.4   103.3   103.2   103.1   103.1   103.1   103.1   103.1
       103.1   103.1   103.1   103.1   103.1
0 36   1000.   1000.   1000.   1000.   1000.   105.2   104.8   104.5   104.2   104.0
       103.8   103.6   103.4   103.3   103.2   103.2   103.1   103.1   103.1   103.1
       103.1   103.1   103.1   103.1   103.1
0 37   1000.   1000.   1000.   1000.   1000.   1000.   104.3   104.2   104.0   103.8
       103.6   103.5   103.4   103.3   103.2   103.2   103.1   103.1   103.1   103.1
       103.1   103.1   103.1   103.1   103.1
0 38   1000.   1000.   1000.   1000.   1000.   1000.   103.9   103.9   103.7   103.6
       103.5   103.4   103.3   103.2   103.2   103.1   103.1   103.1   103.1   103.1
       103.1   103.1   103.1   103.1   1000.
0 39   1000.   1000.   1000.   1000.   1000.   1000.   103.7   103.6   103.5   103.4
       103.3   103.2   103.2   103.2   103.1   103.1   103.1   103.1   103.1   103.1
       103.1   103.1   103.1   103.1   1000.
0 40   1000.   1000.   1000.   1000.   1000.   1000.   103.4   103.4   103.2   103.1
       103.1   103.1   103.1   103.1   103.1   103.1   103.1   103.1   103.1   103.1
       103.1   103.1   103.1   1000.   1000.
0 41   1000.   1000.   1000.   1000.   1000.   1000.   103.2   103.2   102.9   102.7
       102.8   103.0   103.0   103.1   103.1   103.1   103.1   103.1   103.1   103.1
       103.1   103.1   103.1   1000.   1000.
0 42   1000.   1000.   1000.   1000.   1000.   1000.   103.1   103.0   102.7   101.8
       102.6   102.9   103.0   103.0   103.1   103.1   103.1   103.1   103.1   103.1
       103.1   103.1   103.1   1000.   1000.
0 43   1000.   1000.   1000.   1000.   1000.   1000.   103.0   103.0   102.8   102.6
       102.8   102.9   103.0   103.0   103.1   103.1   103.1   103.1   103.1   103.1
       103.1   103.1   103.1   1000.   1000.
0 44   1000.   1000.   1000.   1000.   1000.   1000.   103.0   103.0   102.9   102.9
       102.9   103.0   103.0   103.1   103.1   103.1   103.1   103.1   103.1   103.1
       103.1   103.1   103.1   1000.   1000.
0 45   1000.   1000.   1000.   1000.   1000.   1000.   103.0   103.0   103.0   103.0
       103.0   103.0   103.1   103.1   103.1   103.1   103.1   103.1   103.1   103.1
       103.1   103.1   103.1   1000.   1000.
0 46   1000.   1000.   1000.   1000.   1000.   1000.   103.1   103.1   103.1   103.1
       103.1   103.1   103.1   103.1   103.1   103.1   103.1   103.1   103.1   103.1
       103.1   103.1   103.1   1000.   1000.
0 47   1000.   1000.   1000.   1000.   1000.   1000.   103.2   103.1   103.1   103.1
       103.2   103.2   103.2   103.2   103.2   103.2   103.2   103.1   103.1   103.1
       103.1   103.1   103.1   1000.   1000.
0 48   1000.   1000.   1000.   1000.   1000.   1000.   103.2   103.2   103.2   103.2
       103.2   103.2   103.2   103.2   103.2   103.2   103.2   103.2   103.1   103.1
       103.1   103.1   103.1   1000.   1000.
0 49   1000.   1000.   1000.   1000.   1000.   1000.   103.3   103.3   103.3   103.3
       103.3   103.3   103.3   103.3   103.3   103.2   103.2   103.2   103.2   103.1
       103.1   103.1   103.1   1000.   1000.
0 50   1000.   1000.   1000.   1000.   1000.   1000.   103.3   103.3   103.3   103.3
       103.3   103.3   103.3   103.3   103.3   103.3   103.3   103.2   103.2   103.2
       103.2   103.1   103.1   1000.   1000.
0 51   1000.   1000.   1000.   1000.   1000.   1000.   103.3   103.4   103.4   103.4
       103.4   103.4   103.4   103.4   103.4   103.3   103.3   103.3   103.2   103.2
       103.2   103.2   1000.   1000.   1000.
0 52   1000.   1000.   1000.   1000.   1000.   1000.   1000.   103.4   103.5   103.5
       103.5   103.5   103.4   103.4   103.4   103.4   103.4   103.3   103.3   103.2
       103.2   1000.   1000.   1000.   1000.
0 53   1000.   1000.   1000.   1000.   1000.   1000.   1000.   103.5   103.5   103.5
       103.5   103.5   103.5   103.5   103.5   103.5   103.4   103.4   103.4   1000.
       1000.   1000.   1000.   1000.   1000.
0 54   1000.   1000.   1000.   1000.   1000.   1000.   1000.   103.6   103.6   103.6
       103.6   103.6   103.6   103.6   103.6   103.6   103.5   103.5   103.5   1000.
       1000.   1000.   1000.   1000.   1000.
0 55   1000.   1000.   1000.   1000.   1000.   1000.   1000.   103.6   103.6   103.6
       103.6   103.6   103.6   103.6   103.6   103.6   103.6   103.6   103.6   1000.
       1000.   1000.   1000.   1000.   1000.
0 56   1000.   1000.   1000.   1000.   1000.   1000.   1000.   103.7   103.7   103.7
       103.7   103.7   103.7   103.7   103.7   103.7   103.7   103.7   103.7   1000.
       1000.   1000.   1000.   1000.   1000.
0 57   1000.   1000.   1000.   1000.   1000.   1000.   1000.   103.8   103.8   103.8
       103.8   103.8   103.8   103.8   103.8   103.8   103.8   103.8   103.8   1000.
       1000.   1000.   1000.   1000.   1000.
```

```
0 58   1000.    1000.    1000.    1000.    1000.    1000.    1000.    103.8    103.8    103.8
       103.8    103.8    103.8    103.8    103.8    103.9    103.9    103.9    103.9    103.9
       1000.    1000.    1000.    1000.    1000.
0 59   1000.    1000.    1000.    1000.    1000.    1000.    1000.    103.9    103.9    103.9
       103.9    103.9    103.9    103.9    103.9    103.9    103.9    103.9    104.0    104.0
       104.0    1000.    1000.    1000.    1000.
0 60   1000.    1000.    1000.    1000.    1000.    1000.    1000.    103.9    103.9    103.9
       103.9    104.0    104.0    104.0    104.0    104.0    104.0    104.0    104.0    104.0
       104.0    1000.    1000.    1000.    1000.
0 61   1000.    1000.    1000.    1000.    1000.    1000.    1000.    104.0    104.0    104.0
       104.0    104.0    104.0    104.0    104.0    104.0    104.0    104.0    104.0    104.1
       104.1    1000.    1000.    1000.    1000.
0 62   1000.    1000.    1000.    1000.    1000.    1000.    1000.    1000.    104.1    104.1
       104.1    104.1    104.1    104.1    104.1    104.1    104.1    104.1    104.1    104.1
       104.1    1000.    1000.    1000.    1000.
0 63   1000.    1000.    1000.    1000.    1000.    1000.    1000.    1000.    104.1    104.1
       104.1    104.1    104.1    104.1    104.1    104.1    104.1    104.1    104.1    104.1
       104.2    104.2    1000.    1000.    1000.
0 64   1000.    1000.    1000.    1000.    1000.    1000.    1000.    1000.    104.2    104.2
       104.2    104.2    104.2    104.2    104.2    104.2    104.2    104.2    104.2    104.2
       104.2    104.2    1000.    1000.    1000.
0 65   1000.    1000.    1000.    1000.    1000.    1000.    1000.    1000.    104.2    104.2
       104.2    104.2    104.2    104.2    104.2    104.2    104.2    104.2    104.2    104.2
       104.2    104.3    104.3    1000.    1000.
0 66   1000.    1000.    1000.    1000.    1000.    1000.    1000.    1000.    104.3    104.3
       104.3    104.3    104.3    104.3    104.3    104.3    104.3    104.3    104.3    104.3
       104.3    104.3    104.3    1000.    1000.
0 67   1000.    1000.    1000.    1000.    1000.    1000.    1000.    1000.    104.3    104.3
       104.3    104.3    104.3    104.3    104.3    104.3    104.3    104.3    104.3    104.3
       104.3    104.3    104.3    104.3    1000.
0 68   1000.    1000.    1000.    1000.    1000.    1000.    1000.    1000.    104.4    104.4
       104.4    104.4    104.4    104.4    104.4    104.4    104.4    104.4    104.3    104.4
       104.4    104.4    104.4    104.3    1000.
0 69   1000.    1000.    1000.    1000.    1000.    1000.    1000.    1000.    104.4    104.4
       104.4    104.4    104.4    104.4    104.4    104.4    104.4    104.4    104.4    104.4
       104.4    104.4    104.4    1000.    1000.
0 70   1000.    1000.    1000.    1000.    1000.    1000.    1000.    1000.    104.5    104.5
       104.5    104.5    104.5    104.5    104.5    104.5    104.5    104.5    104.5    104.5
       104.4    104.4    1000.    1000.    1000.
0 71   1000.    1000.    1000.    1000.    1000.    1000.    1000.    1000.    104.5    104.5
       104.5    104.5    104.5    104.5    104.5    104.6    104.6    104.6    104.6    104.5
       104.5    1000.    1000.    1000.    1000.
0 72   1000.    1000.    1000.    1000.    1000.    1000.    1000.    1000.    104.6    104.6
       104.6    104.6    104.6    104.6    104.6    104.6    104.6    104.6    104.6    104.6
       1000.    1000.    1000.    1000.    1000.
0 73   1000.    1000.    1000.    1000.    1000.    1000.    1000.    104.7    104.6    104.6
       104.6    104.6    104.6    104.6    104.6    104.6    104.7    104.7    104.7    104.6
       1000.    1000.    1000.    1000.    1000.
0 74   1000.    1000.    1000.    1000.    1000.    1000.    1000.    104.7    104.7    104.7
       104.7    104.7    104.7    104.7    104.7    104.7    104.7    104.7    104.7    104.7
       1000.    1000.    1000.    1000.    1000.
0 75   1000.    1000.    1000.    1000.    1000.    1000.    1000.    104.7    104.7    104.7
       104.7    104.7    104.7    104.7    104.7    104.7    104.7    104.7    104.7    104.7
       1000.    1000.    1000.    1000.    1000.
0 76   1000.    1000.    1000.    1000.    1000.    1000.    1000.    104.7    104.7    104.7
       104.8    104.8    104.8    104.8    104.8    104.8    104.7    104.7    104.7    104.7
       1000.    1000.    1000.    1000.    1000.
0 77   1000.    1000.    1000.    1000.    1000.    1000.    1000.    1000.    104.8    104.8
       104.8    104.8    104.8    104.8    104.8    104.8    104.8    104.7    104.7    104.7
       1000.    1000.    1000.    1000.    1000.
0 78   1000.    1000.    1000.    1000.    1000.    1000.    1000.    1000.    104.8    104.8
       104.8    104.9    104.9    104.8    104.8    104.8    104.8    104.7    104.7    1000.
       1000.    1000.    1000.    1000.    1000.
0 79   1000.    1000.    1000.    1000.    1000.    1000.    1000.    1000.    1000.    104.8
       104.9    104.9    105.0    1000.    1000.    1000.    1000.    1000.    1000.    1000.
       1000.    1000.    1000.    1000.    1000.
0 80   1000.    1000.    1000.    1000.    1000.    1000.    1000.    1000.    1000.    1000.
       104.9    1000.    1000.    1000.    1000.    1000.    1000.    1000.    1000.    1000.
       1000.    1000.    1000.    1000.    1000.
```

```
0


                       VOLUMETRIC BUDGET FOR ENTIRE MODEL AT END OF TIME STEP  5 IN STRESS PERIOD  1
                       -----------------------------------------------------------------------------
0            CUMULATIVE VOLUMES      L**3                             RATES FOR THIS TIME STEP      L**3/T
             ------------------                                       ------------------------

                   IN:                                                               IN:
                   ---                                                               ---
                     STORAGE =     .10595E+09                                     STORAGE =    .85297E-02
               CONSTANT HEAD =     .67204E+08                               CONSTANT HEAD =    7.0410
                       WELLS =     .00000                                           WELLS =    .00000
                    RECHARGE =     .47406E+07                                    RECHARGE =    .45723
               RIVER LEAKAGE =     .81700E+07                               RIVER LEAKAGE =    1.2754
0                   TOTAL IN =     .18606E+09                                    TOTAL IN =    8.7822
0                 OUT:                                                             OUT:
                  ----                                                             ----
                     STORAGE =     40247.                                         STORAGE =    .00000
               CONSTANT HEAD =     .33933E+08                               CONSTANT HEAD =    2.1697
                       WELLS =     .23121E+08                                       WELLS =    2.2300
                    RECHARGE =     .00000                                        RECHARGE =    .00000
               RIVER LEAKAGE =     .13129E+09                               RIVER LEAKAGE =    5.3854
0                  TOTAL OUT =     .18839E+09                                   TOTAL OUT =    9.7851
0                   IN - OUT =    -.23276E+07                                    IN - OUT =   -1.0030
0        PERCENT DISCREPANCY =    -1.24                               PERCENT DISCREPANCY =   -10.80



0


         TIME SUMMARY AT END OF TIME STEP  5 IN STRESS PERIOD  1
                                  SECONDS      MINUTES      HOURS        DAYS        YEARS
                               -----------------------------------------------------------
            TIME STEP LENGTH    .207360E+07  34560.0      576.000      24.0000     .657084E-01
          STRESS PERIOD TIME    .103680E+08  172800.      2880.00      120.000     .328542
       TOTAL SIMULATION TIME    .103680E+08  172800.      2880.00      120.000     .328542
1
```

BIBLIOGRAPHY

Golder Associates, 1989, Various letters and reports to the City of Leavenworth on ground-water interactions. On file in the Washingaton State Department of Ecology, Water Resources Program Library, County Files, Wenatchee River, Leavenworth.

McDonald, M.G. and A.W Harbaugh, 1988, A modular three-dimensional finite-difference ground water flow model, Chapter A1, Book 6, Techniques of Water-Resources Investigations of the United States Geological Survey, USGS Open-File Report 83-875.