SCIENTIFIC NOTEBOOK
No. 311 E
Valid Dates: ~~3/12/99–3/31/99~~ 3/4/99

by

NEIL COLEMAN
U.S. Nuclear Regulatory Commission

on staff exchange to

Center for Nuclear Waste Regulatory Analyses
Southwest Research Institute
San Antonio, TX

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List of Figures

Numerous additional figures (unnumbered) are included in the file for this scientific notebook to illustrate output from the different types of simulations. The electronic file name for the model or graphic image is provided on each figure.

Initial Entries

Scientific Notebook: 311

Issued to: Neil Coleman, NRC Hydrogeologist [signature]

Issue Date: March 4, 1999

By agreement with the CNWRA QA this Notebook is to be printed at approximate quarterly intervals. This computerized Scientific Notebook is intended to address the criteria of CNWRA QAP-001. NC

Notebook used for 3 weeks and turned in to QA on 3/24/99.

1. Unsaturated and Saturated Flow Under Isothermal Conditions (USFIC) KTI

Account Number: 20-1402-861
Collaborators: James Winterle, Amit Armstrong

Objective:

The objective of this work is to analyze likely effects of horizontal aquifer anisotropy on groundwater flow paths from the proposed Yucca Mountain, Nevada high-level waste repository. It is not the intent of this brief study to develop detailed and well-calibrated flow models of the Yucca Mt. site because extensive new information for the saturated zone is being collected at this time by Nye County, NV. The nature of this new data, in the form of hydraulic heads and properties, stratigraphy, and water chemistry data will probably lead to significant revisions of current flow models. New data sets will be incorporated as they becomes available for future work.

Methodology:

To apply the groundwater code Micro-FEM (Hemker and Nijsten, 1999) to the Yucca Mountain site to gain insights about the effects of aquifer anisotropy. Available site information will be used to develop approximate boundary conditions and properties for a saturated-zone flow model.

Computing Equipment: Pentium Processor - CNWRA Tag #2121
Operating System: Windows NT Version 4.0
Computer code: Micro-FEM, Version 3.12EM; (disk #447 in software package)
Location of workstation: Bldg. 189 Room A202

Code Verification:

The Micro-FEM code is an "off the shelf " groundwater model that has a 10-year developmental history (Diodato, 1997). This code has been evaluated under the requirements for acquired software that is not to be modified (see CNWRA, 1998, Table 1).One test problem was run under this scientific notebook to compare model results with an analytical solution, providing a basic check that the model outputs are reasonable. A serious bug was found in the DOS version of the module called "FEMODEL!.EXE". The bug did not affect calculations. It inhibited the program from running anisotropic models in a new session because the accessory parameter files *.AD1 and *.AF1 could not be read. An e-mail was sent to the code developer, C. J. Hemker, who sent corrected versions of modules FEMODEL!.EXE and FEMODEL.EXE. These executables were substituted for the defective ones in the software package. The scientific notebook package includes copies of communications sent to and from C. J. Hemker. The model verification test was run on both versions of FEMODEL!.EXE, producing identical results.

A grid was developed to test the ability of FEMODEL!.EXE to properly compute drawdowns at varying distances from a pumping well under steady-state conditions. The test grid was square, 20,000 m (20 km) on a side with a node spacing of 500 m. The center of the grid was more highly discretized with a node spacing of 200 m to better represent the region close to the pumping well. See attached Figure 1 which shows the locations and numbers of fixed nodes used to generate the grid. Figure 2 shows the coordinates of the grid corners in meters, along with the numbers of nodes and elements in the mesh. The following input data illustrate how information is input to the Micro-FEM module called Femgrid! to create a finite element mesh. Data are contained in ASCII files "thiemtst.fen" [network] and "thiemtst.fem" [model]. The grid is also displayed in a graphics file called "testgrid.jpg."

# of regions	3
# of line segments	6
# of fixed nodes	10

DEFINITION OF NODE # AND COORDINATES

#	x-coord. (m)	y-coord. (M)
1	1	15000
2	1	1
3	20000	1
4	20000	15000
5	20000	20000
6	1	20000
7	5000	15000
8	5000	5000
9	15000	5000
10	15000	15000

DEFINITION OF LINE SEGMENTS

Segment #	Node	# of nodes	Node #s

	spacing (m)					
1	500	4	1	2	3	4
2	500	4	4	5	6	1
3	200	4	7	8	9	10
4	500	2	1	7		
5	500	2	10	4		
6	200	2	7	10		

DEFINITION OF MODEL REGIONS

Region #	Node spacing (m)	# of segments	Segment #s			
1	500	4	1	3	4	5
2	200	2	3	6		
3	500	4	2	4	6	5

Using a transmissivity (T) of 2000 m^2/d, a well pumping rate of 5000 m^3/d, and an initial domain head of 10 m, a steady-state solution was obtained and a map of drawdowns was generated (see Figure 3 and graphics file "femtest.jpg"). Drawdowns were then determined at various radial distances as shown below (also see Figure 4):

#	Distance from pumping well (m)	Head (m)
1	1400	9.18
2	2400	9.40
3	4000	9.60
4	6426	9.80

The above head values were substituted into the well-known Thiem equation (Kruseman and de Ridder, 1994, p. 56). This equation enables the estimate of T for the aquifer given the steady-state drawdowns in two or more piezometers.

$$Q = \frac{2 * PI * T \ (h_2 - h_1)}{\ln \ (r_2 / r_1)}$$

where

Q = discharge rate (m^3/d)
PI = 3.14
T = transmissivity (m^2/d)
h_2 and h_1 = respective steady-state elevations of water levels in piezometers (m)
ln = natural logarithm
r_2 and r_1 = respective distances of piezometers from pumping well (m)

The Thiem equation was rearranged to solve for T. Using drawdowns at distances of 1400 and 4000 m, a T of 1989 m^2/d was obtained. For distances of 2400 and 6426 m, a T of 1960 m^2/d was derived. These T values confirm that the numerical approximation is reasonably accurate with errors of ~2 percent or less for the given problem..

Well data used to define outer boundary of finite-element model:

Locations of most of the following wells are shown in Figure 5. Fixed node numbers refer to those nodes used to construct the outline and subarea boundaries of the finite element grid. Internal node numbers define each node within the grid, and this can be seen when displaying the model through the module FEMODEL!.EXE. In "walking mode," the node number of the current cursor position is located at the lower left portion of the screen. The locations of fixed nodes #1 through #12 define the outer boundary of the model and are reflected in the grid with the precision of the UTM coordinates. None of the wells within the interior of the model occur exactly at model nodes. Node numbers closest to these interior wells are identified.

Name	Fixed and (internal) Node #	UTM-x (m)	UTM-y (m)	Head (m)	Source
Cind-R-Lite Well	1 (944)	544027	4059809	730	6
NC-EWDP-2D	2 (1383)	547821	4057168	TBD	
Washburn	3 (1636)	550858	4057124	716	12
NDOT	4 (1840)	553685	4055242	706	7
TW-5	5 (1794)	562605	4054686	725	6, 7
J-11	6 (754)	563816	4071049	732.2	3
"The Narrows" (stream gage)	7 (2)	~554595	~4081550	~731 (estimate - no well)	
WT-4	8 (21)	550446	4079420	730.8	3
H-1	9 (20)	548727	4079925	730.9	3
SD-6	10 (221)	547592	4077514	731	++
H-3	11 (417)	547537	4075762	731.2	3
WT-11	12 (825)	547533	4070438	730.6	3
H-4	13 (240)	549195	4077322	730.4	3, 6
WT-17	14 (644)	549905	4073307	729.4	7

WT-3	15 (718)	552090	4072550	729.7	6
WT-14	16 (236)	552638	4077337	729.6	3, 6

++ Personal communication with Chad Glenn, NRC Onsite Representative

Well data that may be used to define internal nodes for calibration purposes:

Name	Node#	UTM-x (m)	UTM-y (m)	Head (m)	Source
WT-15	135	554034	4078702	729.2	3, 6
WT-13	393	553729	4075826	729.2	7
J-13	621	554004	4073550	728.4	3, 6
J-12	1067	554436	4068767	727.9	3, 6
JF-3	1118	554498	4067974	728.0	6, 10
C#3	170	550920	4075886	730	2, 6
WT-1		549151	4074966	730.3	3, 7
b#1		549954	4078422	730.6	3, 6
WT-12	862	550163	4070647	730	6
ONC-1	111	550480	4076608		

Other well information:

UE-25a#3	561084	4079697	748.3	7

(well is north of J-11 in carbonates - outside of this model domain)

NC-EWDP-4D	553274	4056763
NC-EWDP-5S	555794	4058101

Model descriptions:

Two basic models were developed, one assuming isotropic (nondirectional) conditions in lateral transmissivities and the other invoking varying degrees and directions of anisotropy. These are described further below, but they are based on the same grid and have numerous features in common that are described here. In both models the external boundary is defined by constant head nodes that correspond to actual water levels observed in wells. Figure 6 shows the model and its' boundaries as defined by peripheral wells and a stream gage that were designated as fixed nodes to construct the finite-element mesh. Constant heads for nodes between wells were extrapolated in gradational fashion. The lowest groundwater elevation (706 m) in the model is found at well NDOT, a well completed in alluvium at the southern boundary of the model. The highest head (732 m) is found at J-11 in eastern Jackass Flats. A constant head of 731 m was assumed at the northern and western boundaries extending from J-11 around to the Cind-R-Lite well. As discussed below, the three northernmost model nodes had specified fluxes rather than specified heads. All simulations for both models were performed assuming steady-state conditions. For anisotropic models the principal axis of anisotropy was assumed to vary within an arc of azimuth of from 0 to 30 degrees. This is the direction along which it is expected water could flow most easily in the aquifer. Most anisotropic simulations were performed using a direction of 5 degrees, which is the approximate alignment of the largest-scale structural features in the Yucca Mountain area. In the anisotropic simulations only the tuff aquifer system was treated as having directional properties.

The general geology assumed in the model is shown in Figure 7. For all deep wells in Jackass Flats, the water table occurs in volcanic tuffs. Wells Nye 2D, Washburn, and NDOT are completed in alluvium but the full extent of saturated alluvium to the south of Yucca Mountain is still being explored by the Nye County drilling program. Well TW-5 occurs near areas of exposed Paleozoic carbonate rocks. There is a discrepancy in several references regarding whether this well is completed in carbonates or alluvium (Czarnecki et al., 1997; Oliver and Root, 1997). However, the water chemistry from TW-5 is typical of other wells in alluvium and does not display the high calcium and magnesium ion concentrations seen in well UE-25p#1, which is in carbonates. Nonetheless, a small area of carbonate geology is included in the southeastern corner of the model. It is expected that Nye County's drilling program will much better define the geology in the southern part of the flow system, especially where the water table transitions from tuffs to overlying alluvium.

Transmissivities

T values used for the tuffs are based on the long-term large-scale hydrologic test conducted at the C-well complex (see Geldon, 1997). An average T of 1300 m^2/d was derived from analysis of that test and this value was used to represent the tuffs in the isotropic models. Much higher values of T were used to simulate drain conditions along Fortymile Wash. For the anisotropic models a maximum T of 5600 m^2/d was used oriented in the direction of principal conductance. This was aligned along azimuth 5 degrees for most models. The value of T at right angles to the direction of principal conductance depended on the ratio of T_{min}/T_{max} that was input. Values ranging from 6% to 100% were used. A 100% ratio is the same as isotropic. A 6% ratio means that the T in one direction is about 17 times greater than in the direction at right angles.

T values for the alluvium south of Yucca Mountain have not been measured, and the actual locations where the water table transitions from tuffs to the overlying alluvium known.only approximately. Various T values were used in an anisotropic model to evaluate the effect on head distributions. T values of 500, 1000, 1500, and 2600 m2/d were simulated. For the anisotropic case (azimuth = 5 degrees; ratio = 6%; max T = 5600 m^2/d for tuffs) it was found that an approximate fit to potentiometric data in the model domain was obtained using a T of 1000 for the alluvium and no drain in Fortymile Wash. T values assumed for the alluvium were found to have a significant affect on heads in the tuffs farther north.

A T value of 10,000 m2/d was input for the Paleozoic carbonate rocks in the southeastern corner of the model. Czarnecki et al. (1997) estimated a broad range for the hydraulic conductivity of the lower carbonate aquifer, ranging from 225 m/d to 5E-4 m/d. A value of 20 m/d was selected and multiplied by an aquifer thickness of 500 m to obtain a T of 10,000 m^2/d.

Groundwater Recharge:

Significant groundwater recharge occurs along most of Fortymile Wash. Savard (1998) estimated recharge along four reaches of Fortymile Wash based on streamflow infiltration losses between gaging points during discharge events. The various reaches, from north to south, were estimated to have the following long-term average recharge rates:

Reach	Location	Est. Long-Term Recharge Rate (m^3/yr)
Fortymile Canyon Reach	Upper canyon down to "Narrows" gage	27,000
Upper Jackass Flats	"Narrows" gage to J-13 gage	1,100
Lower Jackass Flats	J-13 gage to Amargosa Valley gage	16,400
Amargosa Desert	Reach below Amargosa Valley gage	64,300

Flux into the model from the Fortymile Canyon Reach was added to the model at the three northernmost model nodes, corresponding to location of the "Narrows" gage. The model input value was 74 m^3/day (total at three nodes). The Upper Jackass Flats recharge was neglected because it is very small and unlikely to affect model results. Recharge along the Lower Jackass Flats reach is much larger and was input as flux along a line of nodes corresponding to Fortymile Wash, from node 621 (J-13 gage) to a node (1539) at the south boundary of the model near the Washburn well and the Amargosa Valley gage. The recharge rate applied at each node was 1.4 m^3/day, with a total recharge ~ 16,400 m^3/yr. The Amargosa Desert reach is located outside and downgradient of the region of interest and therefore data for that reach were not used. All of the simulations reported here incorporated the flux from the north and recharge along the reach of Lower Jackass Flats.

One simulation was run (GRID8) that incorporates a zone of areally distributed recharge. This zone was placed in the northwestern part of the model to correspond to the Yucca Mountain site and areas of higher elevation to the south of the site. The recharge rate over this area is 10 mm/yr. This is the aggregate estimate of recharge at YM under present climate conditions that was estimated by members of an expert elicitation panel (Geomatrix, 1997). A recharge rate of 2.74E-5 m/d was applied to 62 nodes at the northwest corner of the model.

Scaling Transmissivity to Aquifer Thickness

We hypothesize that the vertical extent of the volcanic tuff aquifer to be from the water table to approximately the bottom half of the Tram Member of the Crater Flat Group.

This hypothesis is supported by:

- Borehole flow surveys for wells UE-25 p#1, UE-25 b#1, USW H-6, USW H-3, USW H-4, and USW H-1. These are the wells in the vicinity of YM that penetrate below the Tram tuff of the Crater Flat Group, and without exception, they all show intervals of at least 100 m in the Tram Tuff that produce no significant quantity of water in the flow surveys.

- Monitoring of hydraulic heads during construction of well UE-25 p#1 shows that hydraulic head increases slightly from about the middle the Tram Tuff to the bottom of the Lithic Ridge

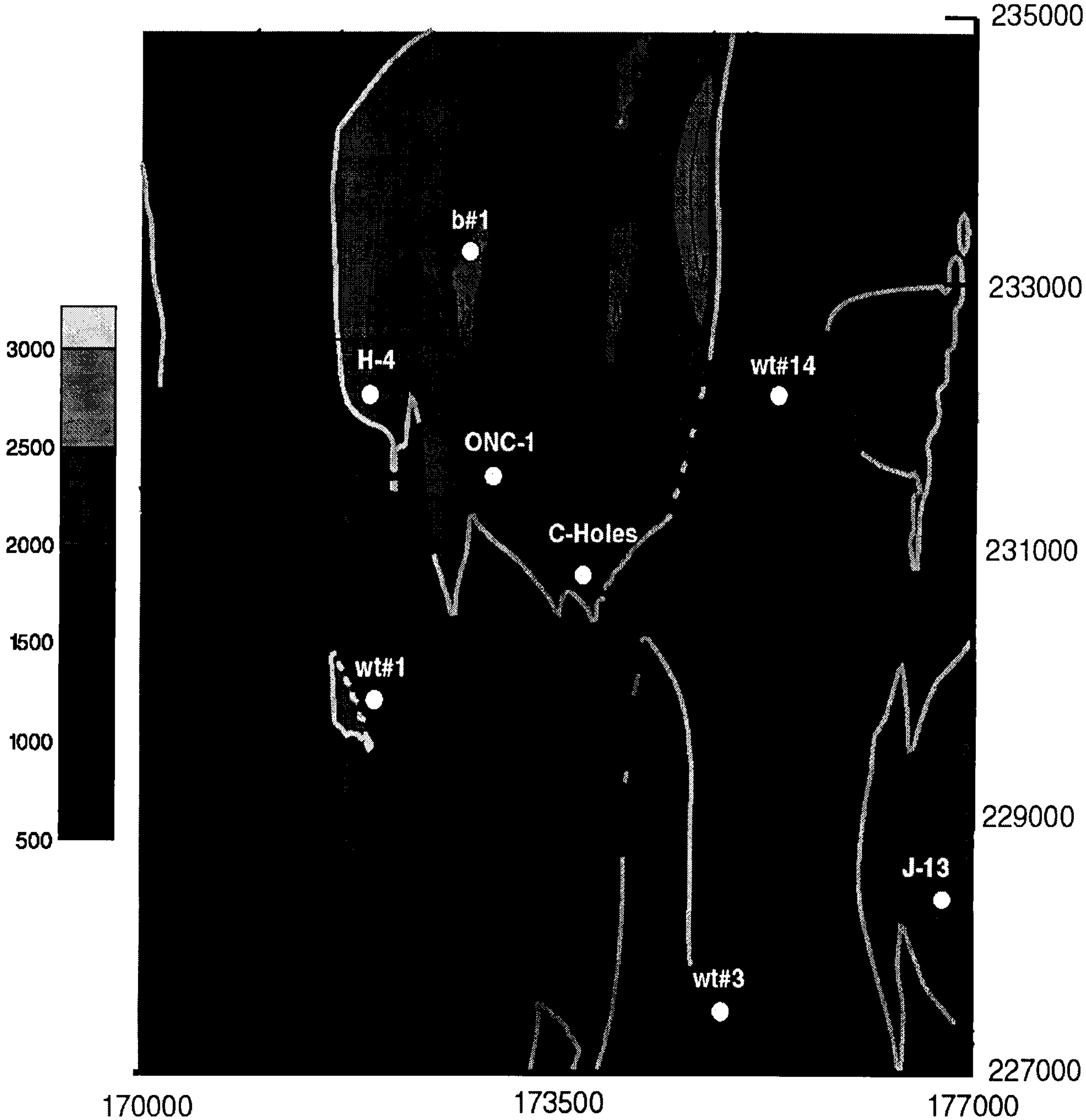
Tuff, and then increases by about 20 m very suddenly just below the bottom of the Lithic Ridge Tuff. This indicates the presence of an effective confining layer above the Lithic Ridge Tuff.

- Borehole Core analyses by Bish and Chipera (1989) shows that below the Tram Tuff, fractures are frequently filled with calcite mineralization, which may explain the confining nature of these tuff units.

- Besides UE-25 p#1, the only other well downgradient from YM that penetrates to the depth of the Older Tuffs under the Lithic Ridge tuff is USW H-1. This well is packed off into four monitored intervals. In the bottom interval the heads are about 786 m asl; this interval monitors depths from 1783 to 1814 m in the Older Tuffs (Graves, 1998). The head in this bottom interval is nearly 50 m higher than the heads in the Tram Tuff, monitored from depths of 1097 to 1123 m.

- C-holes testing shows good vertical communication between the stratigraphic members of the Crater Flat Group, but the heads in the underlying Paleozoic aquifer do not appear to be affected by pumping in the Crater Flat Group.

If the above hypothesis is true, then the vertical thickness of the aquifer transmissive interval would be affected by the offset of layers caused by faulting. To investigate the importance of this effect, we use the DOE Geologic Framework Model, GFM 3.0, to map the difference between the water table and the Tram Bedded Tuff layer (designated trambt in GFM 3.0). We use the trambt layer to approximate the bottom of the aquifer mostly out of convenience as this is a thin layer near the bottom of the Tram Tuff. The difference in elevation between the water table and the trambt layer should reflect the transmissive thickness of the aquifer and thus the aquifer transmissivity. The resulting aquifer thickness map is shown below.



Aquifer thickness map reflecting the difference between the water table elevation and the elevation of the upper contact of the trambt layer in the DOE GFM 3.0 model.

From the data used to generate the above figure, the geometric mean aquifer thickness is calculated to be 421 m. The aquifer thickness map was generated using the following script, written in the nawk programming language:

```
##########################################################
#! /bin/sh
# nawk script to create a file of aquifer thickness over the GFM 3.0 model area. By Jim Winterle, 03/22/99.

# concatenate data files with trambt layer elevation and water table elevation, extracted from GFM 3.0 file.
cat ../Geodata/trambt.xyz ../Geodata/wtrtbl.xyz > temp

nawk '
 BEGIN { i=1; j=1; lag=1800; factor=0.35 }
# write array of trambt elevations
 /begin-trambt/, /end-trambt/ {
   if($1~/[0-9]/) { tramx[i]=$1; tramy[i]=$2; tramz[i]=$3*0.3048; ilast=i; i++ }          }

# convert nevada state plane coordinates to UTM and subtract the layer elevations from the water table elevations and
# write to a file called aq_thick.xyz
 /begin-wtrtbl/, /end-wtrtbl/ {
   if($1~/[0-9]/ && $1==tramx[j] && $2==tramy[j]) {
     X=$1*0.30472-0.0010625*$2+378169.76  #convert eastings to UTM
     Y=$1*0.001061+$2*0.30472+3844636.03 # convert northings to UTM
     Z=$3*0.3048
     print X, Y, Z-tramz[j]
     j++ }            }'< temp > ../aq_thick.xyz
 rm temp # remove temporary file
#####################################################################
```

The next step is to take the aquifer thickness map and use it to scale the transmissivity values assigned to each node in the 2D MicroFem model. We do this by calculating a scaling factor equal to the thickness at a point in the model divided by the mean thickness of 421 m. The aquifer transmissivity at each model node is scale by this calculated factor. Unfortunately, the GFM 3.0 model area does not cover the entire model area of our 2D flow model; thus for areas outside of the GFM model, we use an constant aquifer transmissivity. The calculations are done using the following nawk program used to rewrite an existing .fem file:

```
#########################################################
#! /bin/sh
#Program to write a micro fem model input file that uses transmissivity values for each node that are
# scaled to be proportional to the aquifer thickness at that location. This program starts with an initial
# Micro-Fem file that has some arbitrary Transmissivity assigned to each node and re-writes the file with the
# scaled transmissivities as specified in the code below. Written by Jim Winterle 3/22/99.

# concatenate the aquifer thickness file and the .fem file: write to temp file
 cat aq_thick.xyz $1 > temp # merge thickness and MicroFem files

nawk '
 BEGIN {i=1; errlast=99e99; Tavg=1299; avgthick=421}
```

```
# Modify the NR-values below to find the right locations in the merged temp file. NR is the line number of the file.
# Read in location and thickness data from temp file
 NR<=45756 { locx[i]=$1; locy[i]=$2; thick[i]=$3; i++}
 NR==45757, NR==45775 {print} # read and print Microfem header lines
 NR==45776, NR==51595 {        # modify node data in Fem file
   if((NR-45773) % 3 == 0) {      #perform the following on every third line
     print
     if($3>4070100) {
     for(j=1; j<i;j++) {          # for-loop finds GFM location closest to MicroFem model location
       err=((locx[j]-$2)**2)+((locy[j]-$3)**2)
       if(err<errlast) {errlast=err; lowj=j}        }
       scale=thick[lowj]/avgthick                   }
     else scale=1                                  }
   if((NR-45774) % 3 == 0)                    #perform the following on every third line
    {print $1, Tavg*scale+1; errlast=99e99}
   if((NR-45775) % 3 == 0) {print}           #perform the following on every third line
                  }
 NR>51595 {print}                             # print the remainder of .fem file unmodified
'< temp > out.fem
rm temp                                       # remove temporary file
####################################################################
```

Results with Scaled Transmissivity:

The isotropic model with a drain (GRID3.FEM) was revised to incorporate scaled transmissivities (to represent varying aquifer thicknesses) for the northwest corner of the model. The area of the model within which T values were varied in this way is shown in Figure 8, where the map of aquifer thickness is overlain on the grid. The revised model (ISOSCALE.FEM) was run and results were compared to those of GRID3. Only slight differences in contour lines were noted, showing that incorporating the detailed aquifer thickness data did not produce major changes in output.

C-wells Pump Testing:

The 1996 pumping test at the C-wells was simulated in both an isotropic model (ISOSCALE.FEM) and an anisotropic one (GRID7.FEM). Well C#3 had been pumped for 322 days at an average rate of 821 m^3/d. Geldon et al. (1997) describe details about this test. The simulations assume that steady-state conditions were obtained. In reality, two observation wells during the actual test showed that drawdown had ceased to increase with time, a condition that may be steady-state. Four principal wells responded: H-4, ONC-1, WT-14, and WT-3. In the isotropic model, transmissivities were estimated to be about 1300 m^2/day. For the anisotropic model the principal axis of anisotropy was assumed to be oriented along azimuth 5 degrees with T in the north south direction of 5600 m^2/d and about 310 in the east-west direction. This yields a T_{min}/T_{max} ratio of about 6%.

Model Type	Pumping Head (m)	Non-Pumping Head (m)	Simulated Difference	Actual Test Drawdown (m)
Isotropic				
H-4	730.69	730.74	0.05	0.20
ONC-1	730.35	730.47	0.12	0.26
WT-14	729.94	730.00	0.06	~ 0.15
WT-3	729.32	729.36	0.04	0.12
Anisotropic				
H-4	730.63	730.65	0.02	0.20
ONC-1	730.13	730.23	0.10	0.26
WT-14	729.96	730.00	0.04	~ 0.15
WT-3	728.47	728.53	0.06	0.12

The results of the C-wells testing are important when comparing the output from the model to a real-world response of the aquifer. Neither the isotropic nor the anisotropic solutions satisfactorily duplicated the actual test drawdowns, but the isotropic solution was somewhat better. Drawdowns as large as obtained in the actual test could not be obtained. It was suspected that the relatively large diameter of the pumping zone, corresponding to an element, would cause lesser drawdowns in the simulation. This was checked using an analytical solution, the so-called Papadopulos method for analyzing tests in large-diameter wells. But it was found that the adverse affect of a large well diameter would decrease with time and become negligible at long times, greater than 200 days for the test case. As an alternative, numerical discretization may still be too coarse despite the use of a finer mesh around the C-wells and this could contribute to the discrepancies. Future work should try adding a third region of even finer scale, or even produce a radial pattern of nodes around the pumping well. Also, the constant-head boundaries may have been close enough to the observation wells to affect the results, resulting in underestimates of drawdown.

File Descriptions

A series of files have been placed in electronic format to make it easy to review and duplicate the work performed here. They are briefly described by disk number:

Disk 1 This scientific notebook

Disk 2 Validation test information for the MICRO-FEM code

Disk 3 Grid 2 - anisotropic model; max. T = 3500 m^2/d; direction = 30; ratio (T_{min}/T_{max}) = 6% and includes a central drain

Grid 3 - isotropic model (tuff T = 1300 m^2/d) with a high-T drain

Grid 4 - anisotropic model; max. T = 5600 m^2/d; direction = 5 deg; ratio = 6%; alluvium T = 2600 m^2/d; figures are included that show the effects on potentiometric contours of using different T values for the alluvium (500, 1000, 1500, and 2600 m^2/d)

Grid 5 - anisotropic model; max. T = 5600 m^2/d; direction = 5 deg; ratio = 20%; alluvium T = 2600 m^2/d
Grid 6 - anisotropic model; max. T = 5600 m^2/d; direction = 5 deg; ratio = 50%; alluvium T = 2600 m^2/d
Grid 7 - anisotropic model; max. T = 5600 m^2/d; direction = 5 deg; ratio = 6%; alluvium T = 1000 m^2/d
Grid 8 - isotropic model with a drain and area in northwestern corner of model with areally distributed recharge of 10 mm/yr

Preliminary Conclusions:

Aquifer anisotropy which may exist in the tuff aquifer system at Yucca Mt has the potential to alter groundwater flow paths to a more southerly direction. However, the flow paths in both isotropic and anisotropic simulations appear to intersect at distance of ~19 km from Yucca Mt.

The hydraulic properties of alluvium have a substantial effect on water levels and hydraulic gradients in Jackass Flats.

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7. Czarnecki, J. B., et al., 1997. *Hydrogeology and Preliminary Calibration of a Preliminary Three-Dimensional Finite-Element Ground-Water Flow Model of the Site Saturated Zone, Yucca Mountain, Nevada.* U.S. Geological Survey, Yucca Mountain Project Milestone Report SP23NM3, Denver, CO, 115 p.

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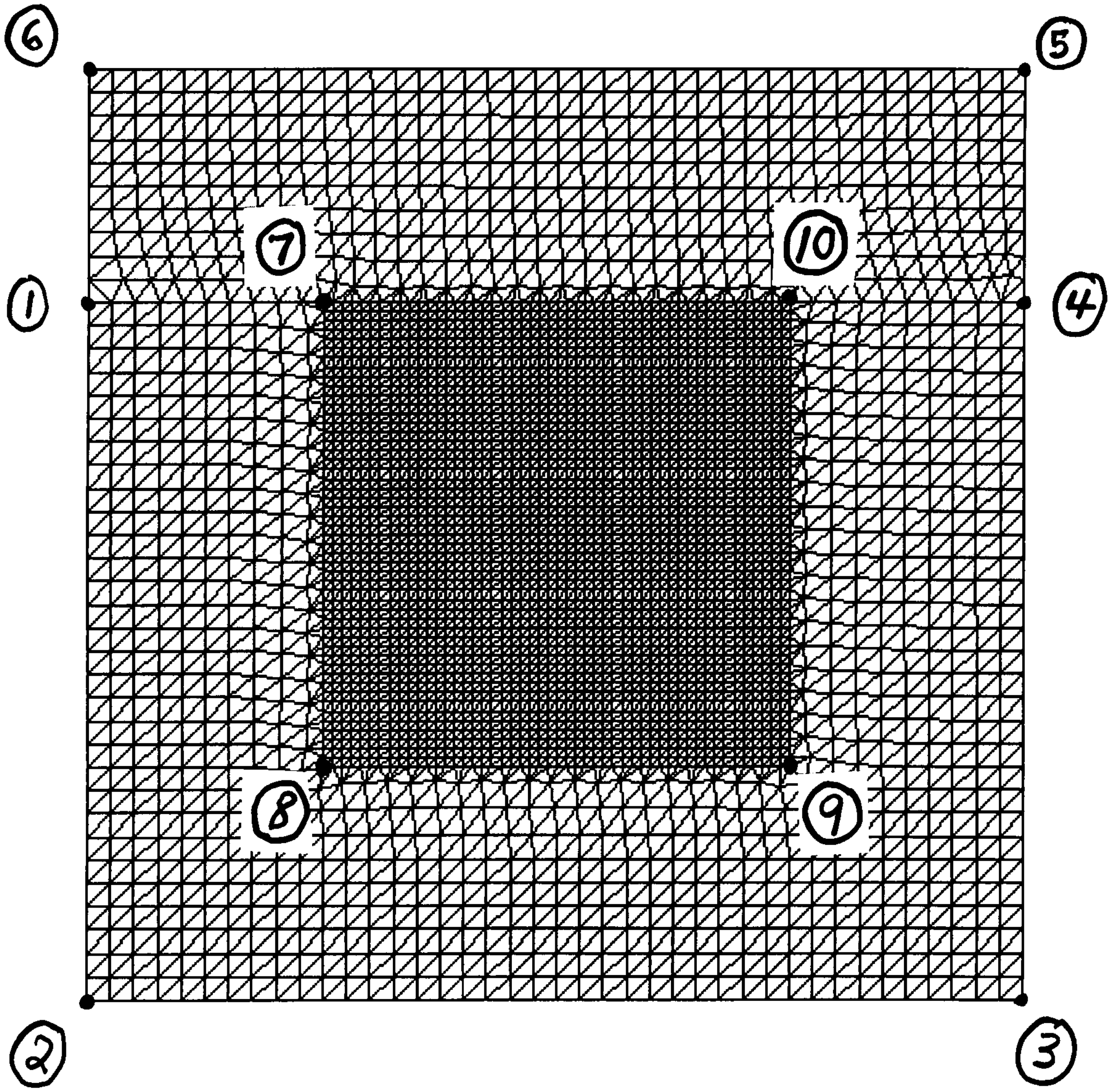
9. Kruseman, G. P. and N. a. de Ridder, 1994. *Analysis and Evaluation of Pumping Test Data.* Publication 47, 2nd Edition.. International Institute for Land Reclamation and Improvement, 6700 AA Wageningen, The Netherlands.

10. Plume, R. W. and R. J. La Camera, 1996. *Hydrogeology of Rocks Penetrated by Test Well JF-3, Jackass Flats, Nye County, Nevada.* Water-Resources Investigations Report 95-4245, U. S. Geological Survey, Carson City, Nevada, 21 p.

11. Bish, D.L., and S.J. Chipera. 1989. *Revised Mineralogic Summary of Yucca Mountain, Nevada.* LA–11497–MS, Los Alamos, NM: Los Alamos National Laboratory.

12. Cuttings Sample Log for borehole NC-Washburn-1X prepared by Bent Aaquist and Jamie Walker. Nye County Nuclear Waste Repository Project Office, Nye County, Nevada. January 4, 1999. 11 pages.



Approved ECP 8/22/2000

I believe This use of "Cross out Tape" is appropriate although There can be questions regarding compliance To QAP-001, Scientific Notebook Control. [signature] CNWRA QA 8/16/2000

FIGURE 1. VALIDATION TEST GRID.

SCIENTIFIC NOTEBOOK # 311

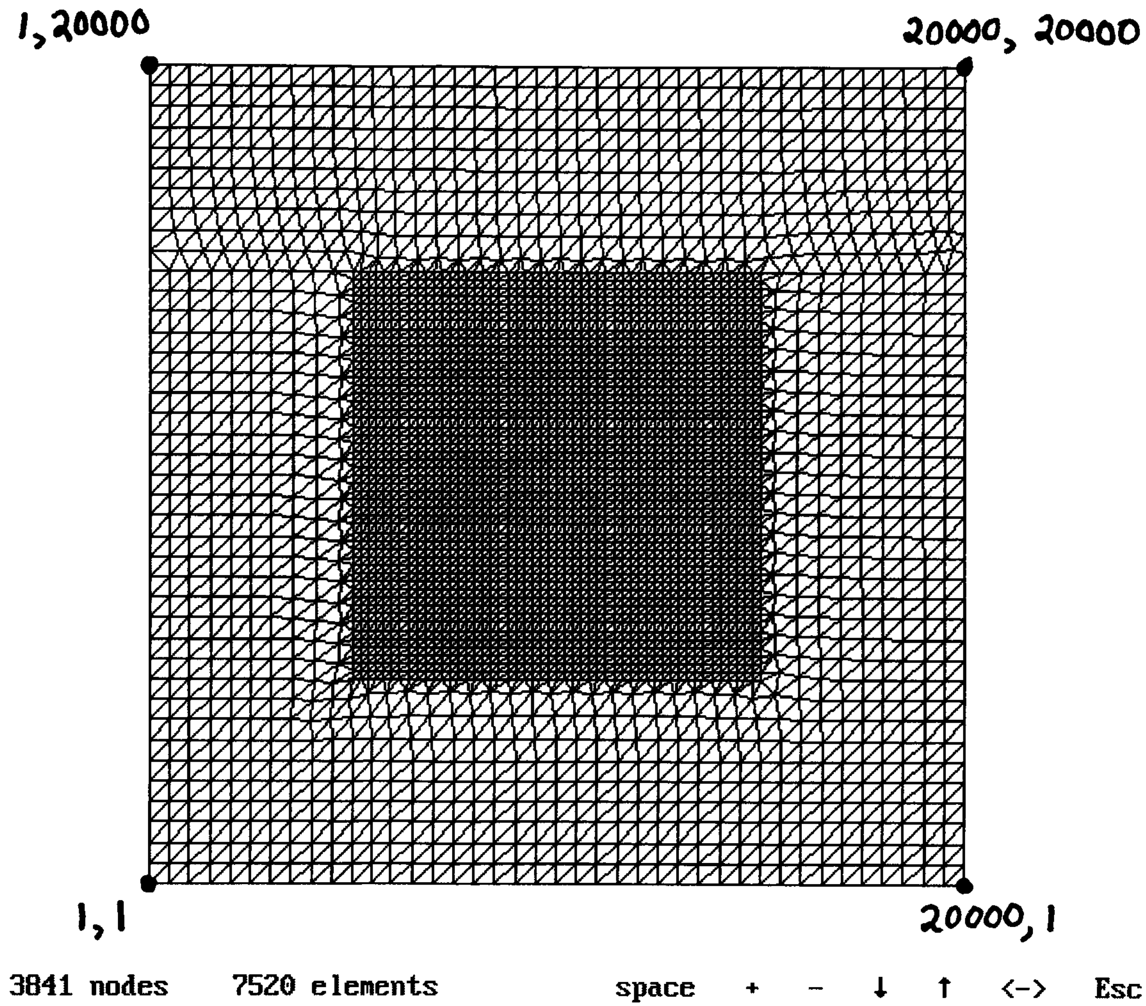
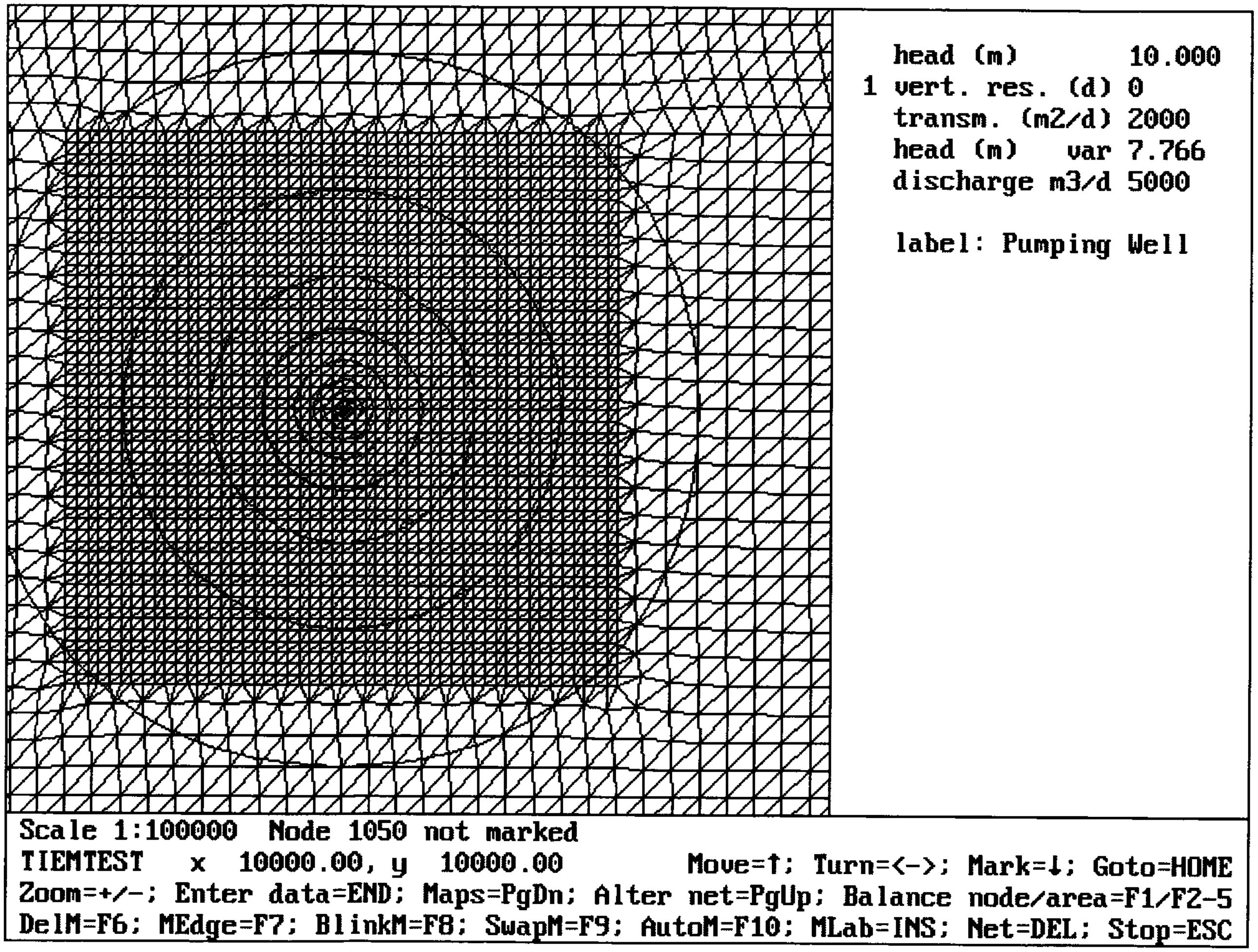


FIGURE 2. TEST GRID

SCIENTIFIC NOTEBOOK # 311

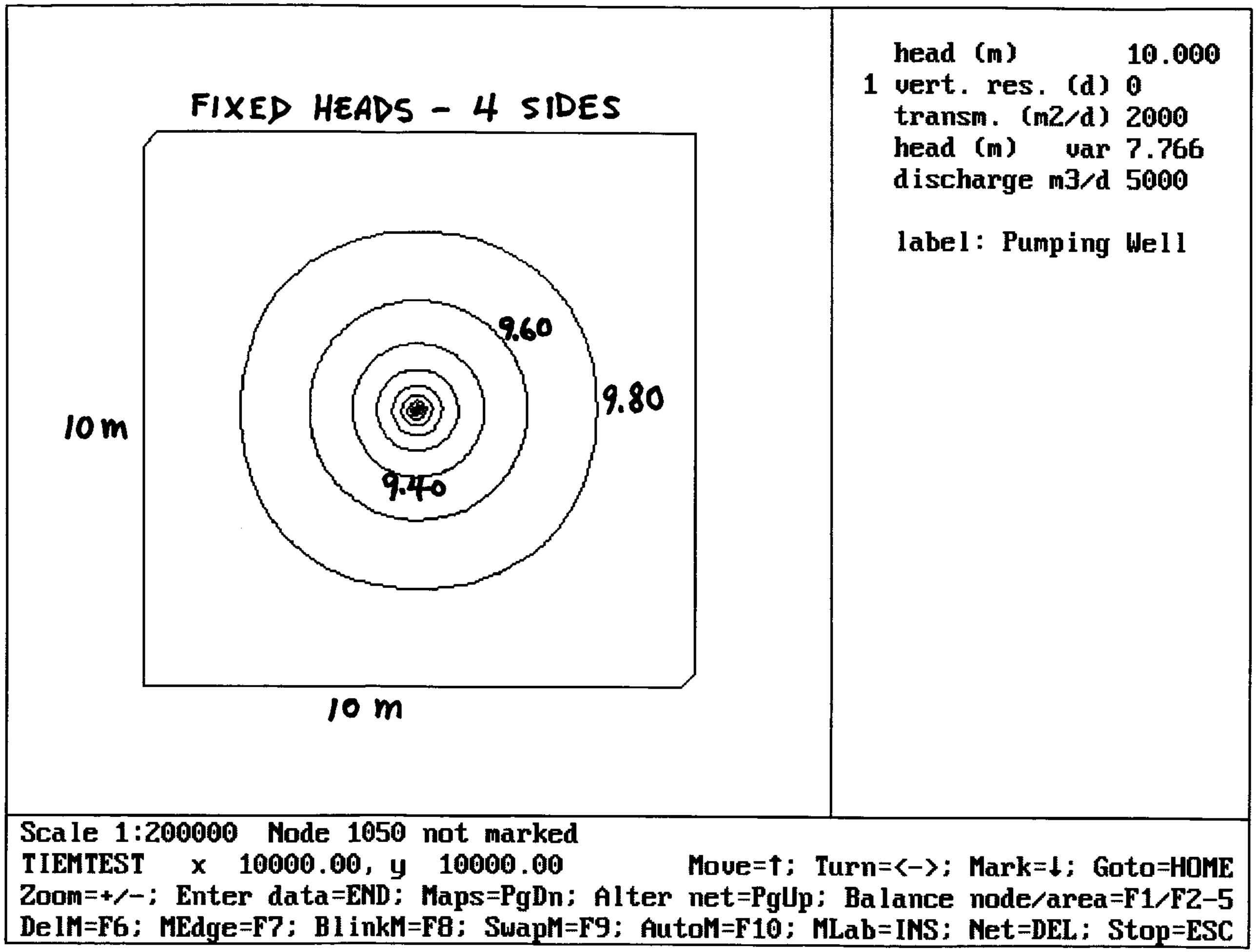
8/22/2000



8/22/00

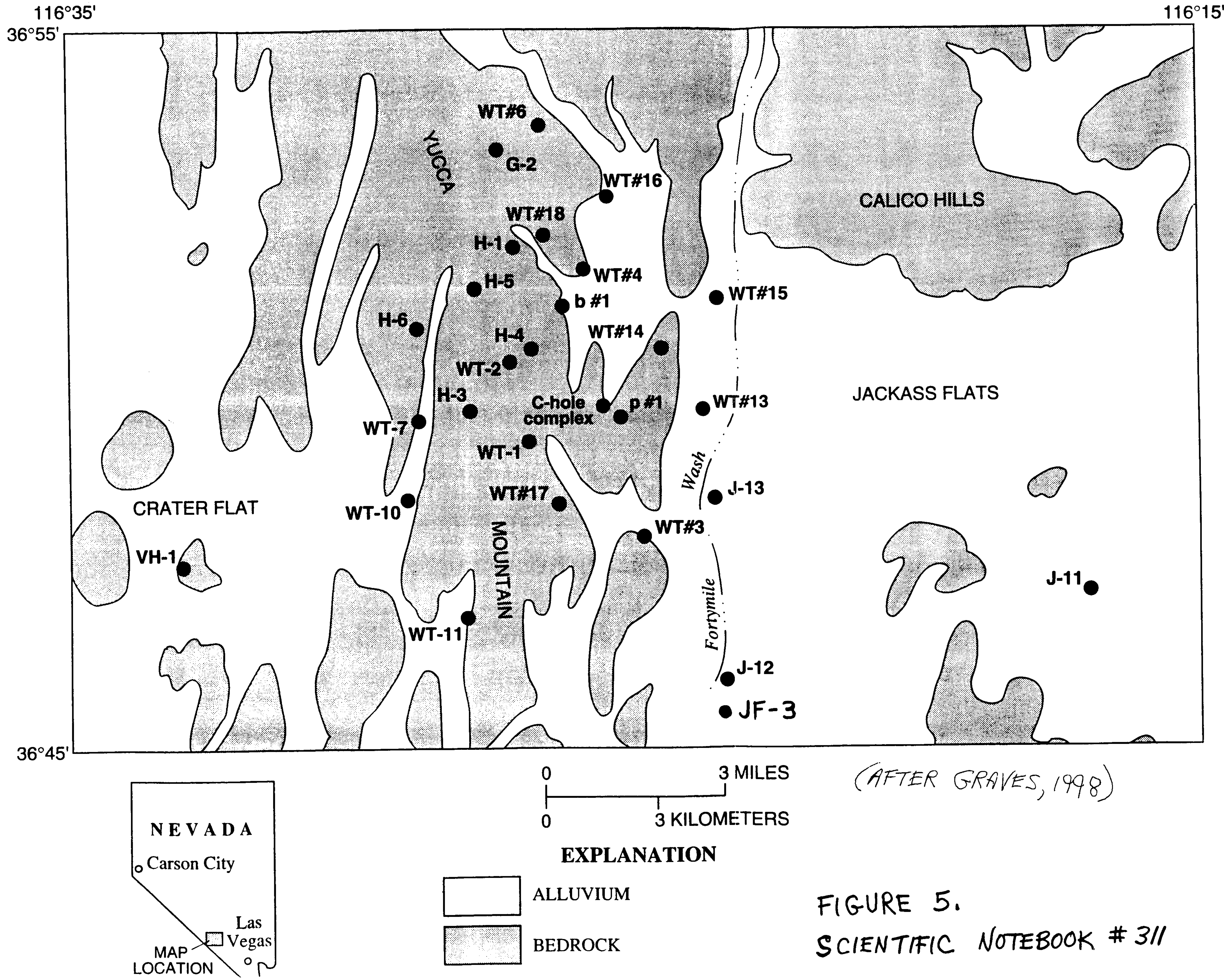
FIGURE 3. DRAWDOWN TEST. $Q = 5000\ m^3/d$.

SCIENTIFIC NOTEBOOK #311



ECP
8/22/00

FIGURE 4.
SCIENTIFIC NOTEBOOK #311



EXPLANATION

ALLUVIUM

BEDROCK

FIGURE 5.
SCIENTIFIC NOTEBOOK # 311

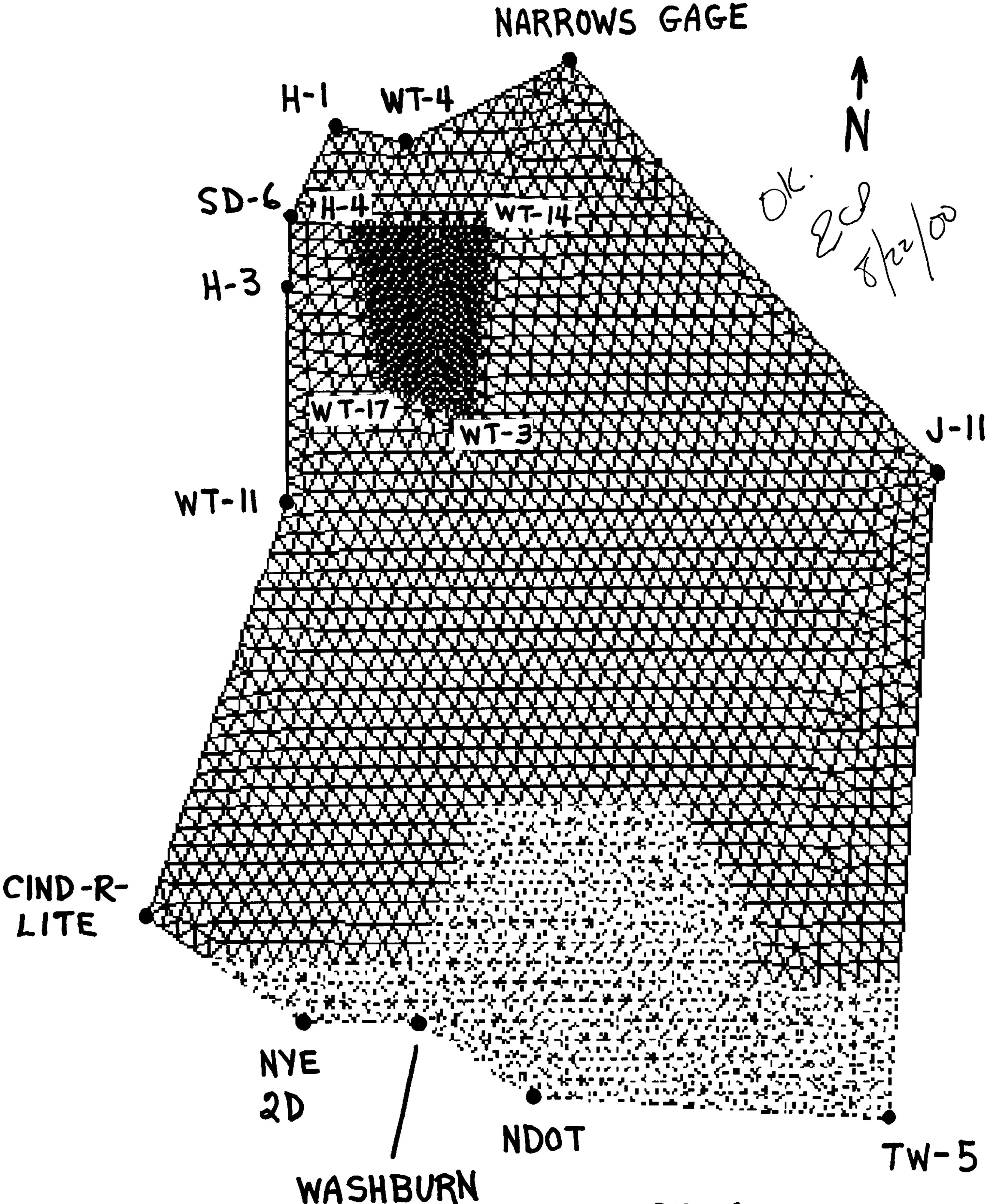


FIGURE 6.
SCIENTIFIC NOTEBOOK 311

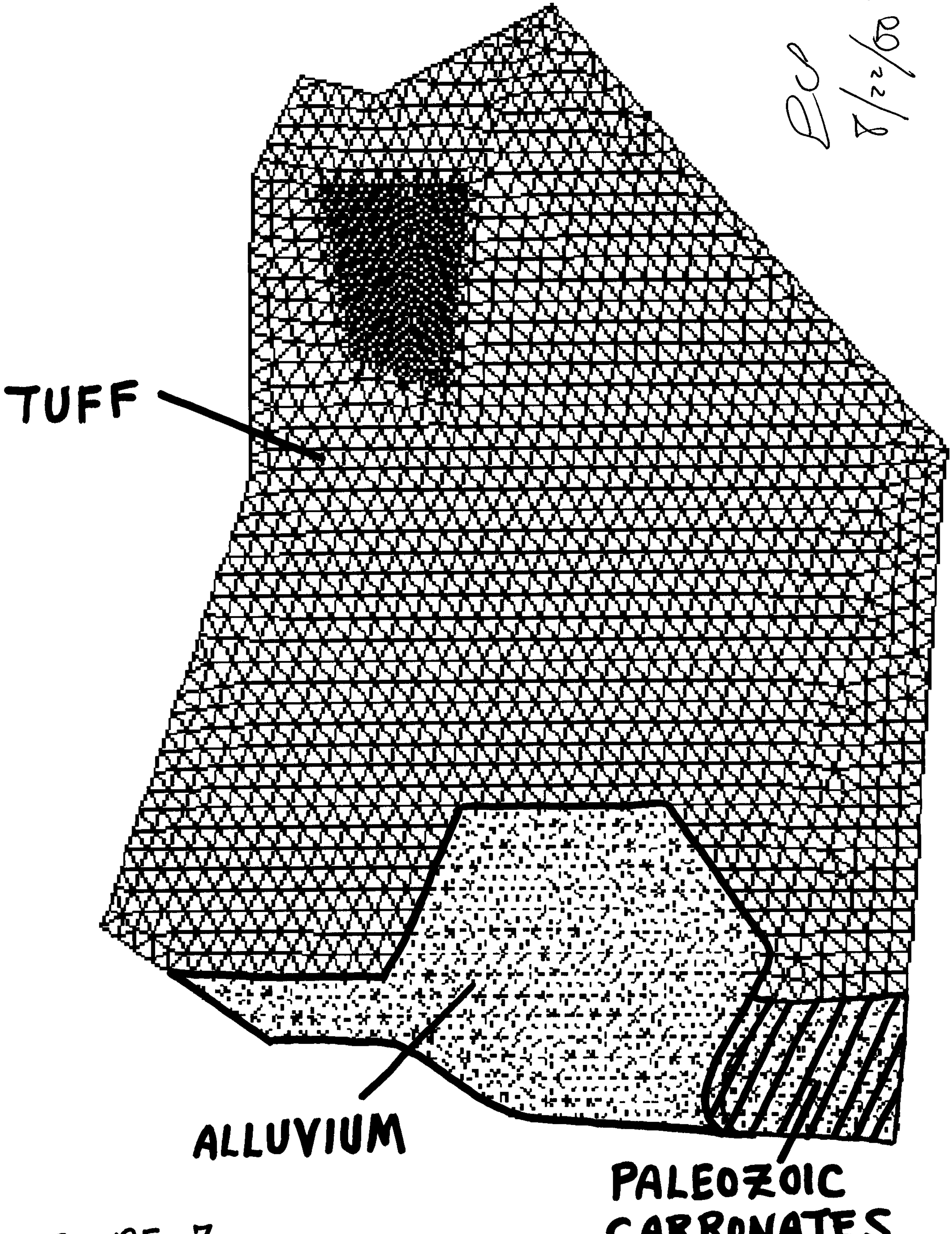
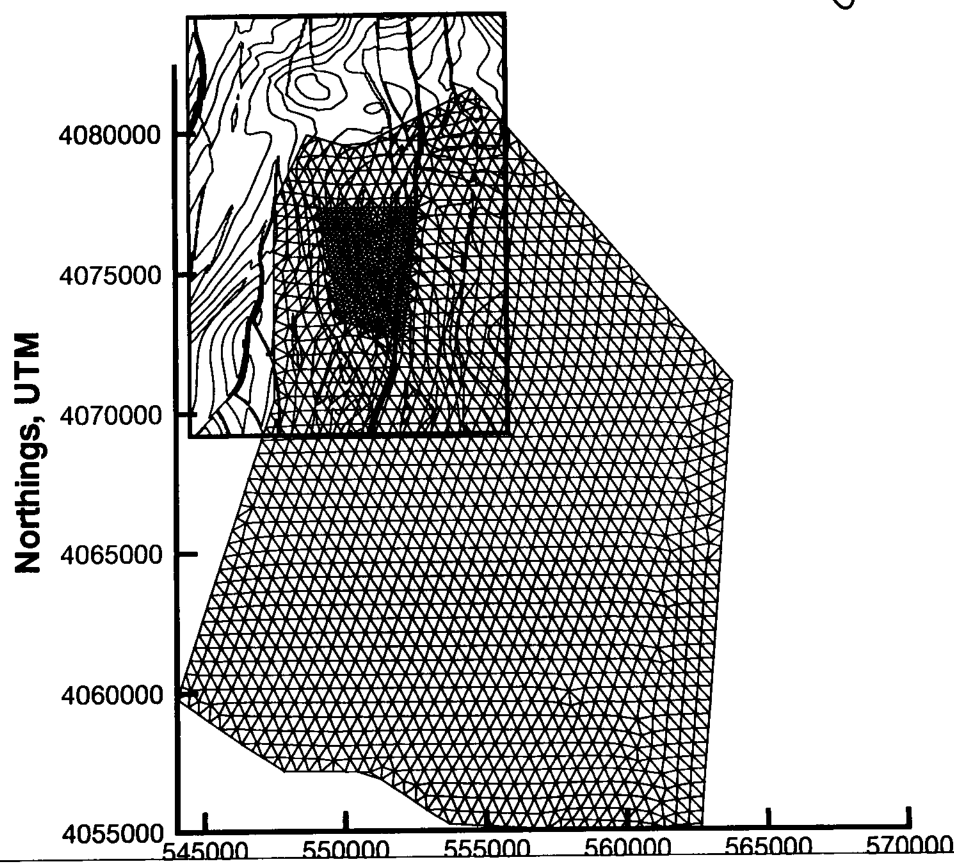


FIGURE 7.
SCIENTIFIC NOTEBOOK #311



Why was this page not marked by the Auditor?

OK. [initials] 8/22/2000

FIGURE 8.
SCIENTIFIC NOTEBOOK #311

Date: 3/23/99
Sender: Jim Winterle
To: Kick Hemker <microfem@xs4all.nl>
cc: N. (CNWRA) Coleman
Priority: Normal
Subject: Anisotrpic modeling with MicroFem

Dr. Hemker,

I recently purchased your MicroFem code. So far it is the only code I have found that allows the user to model the effects of various anisotropy directions without the need to regrid the model to be aligned with the principle directions of anisotropy. Although it is somewhat difficult to learn, I am quite pleased with the capabilities of the model. I am having one problem, however, and I hope that you can help.

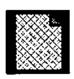
I have used femodel! to create a single-layer model, grid4.fem. The only way that I have been successful in making the model anisotropic is by (1) adding ANISO to the file label, using the Update command, and (2) writing the parameter files by assigning dummy parameters to all nodes in Mode 2, and writing them to files grid4.ad1 and grid4.af1 from Mode 3. The problem is that when I save the file grid4.fem and exit MicroFem, I cannot reopen the file as an Anisotropic model. It seems that the model does not automatically look for the .ad1 and .af1 parameter files as it should, even though "ANISO" is contained on the first remarks line in the file lable of the .fem file.

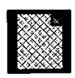
After quitting MicroFem and then returning to the same model, the only way I have found to use anisotropy in an existing model is to re-create the parameter files (ad1 and af1) during the MicroFem session. As I am building a quite complex model, it is troubling to have to do this each time. Why is MicroFem unable to read in my existing .ad1 and .af1 parameter files?

I have included the grid4.fem and the two parameter files as attachments to this email.

I would appreciate any help.


grid4.fem


Grid4.af1


Grid4.ad1

++
Jim Winterle, Hydrologist

phone: (210) 522-5249
fax: (210) 522-5155

Center for Nuclear Waste Regulatory Analyses
Southwest Research Institute
6220 Culebra Road Bldg 189
San Antonio, TX 78253-5166
++

Date: 3/24/99
Sender: Jim Winterle
To: N. (CNWRA) Coleman
Priority: Normal
Subject: Fwd:Re: Anisotrpic modeling with MicroFem

Forward Header

Subject: Re: Anisotrpic modeling with MicroFem
Author: Kick Hemker <microfem@xs4all.nl>
Date: 3/24/99 10:22 AM

Dear Jim,

You are completely right. There appeared to be a tricky bug in the code, but this never gave trouble when running under DOS.
I fixed it and attached you will find Femodel.zip with the new PC and EM versions.
If you meet other problems, or have questions, don't hesitate to email me.

There wouldn't have been problems if you had used the Windows version.
I hardly use the DOS version myself nowadays. Is there any reason for you to run the DOS version under Windows?

Kick Hemker

FileItem.txt   RFC822.TXT   femodel.zip

Date: 3/22/99
Sender: Kick Hemker <microfem@xs4all.nl>
To: "Neil Coleman" <ncoleman@swri.edu>
cc: "Jim Winterle" <jwinterle@swri.edu>, "Neil Coleman" <nmc@nrc.gov>
bcc: N. (CNWRA) Coleman
Priority: Normal
Subject: MicroFEM

Dear Mr Coleman:

Thanks for your interest in MicroFEM.
I received both your fax and phone-message.

There is no theoretical background in the manual, but the manual does contain the full FemCalc code (in Pascal), just in case someone wants to see how heads are computed.

I obtained the required theory from two books that explain exactly how to code steady-state and transient groundwater flow.
These books are:

1 - A.Verruijt, 1982, Theory of groundwater flow,
    Chapter 8 (p. 105-121)
    The MacMillan Press
    ISBN 0 333 32958 9
2 - W.Kinzelbach, 1986, Groundwater Modelling, (p. 91-99)
    Developments in water science 25, Elsevier
    ISBN 0 444 42582 9

The code was originally written in 1986, and improved several times afterwards (for faster computations and for larger models).

It is interesting to know (and mentioned in the manual) that only lateral flow components are computed by finite elements, vertical components are included by finite difference terms.

Recharge, wells and leakage are just part of the water balance computations (and partial differential equations, if you go back to the theory).

Of course I could have copied parts of the mentioned books into the manual, but this is all well known theory, while most readers of the manual (not so many) are not interested in theory at all. Actually, I'm a lecturer at the Amsterdam University (groundwater hydraulics and groundwater modeling), but my research topics happen to be analytical solutions (well flow in layered aquifer systems: see the MLU software at my web site). At the university I only use MicroFEM for teaching groundwater modeling, but some collegues use MicroFEM for their PhD research.

If you need more specific information, please let me know.

Sincerely,

Kick Hemker

================================

from: C.J. (Kick) Hemker
Elandsgracht 83
1016 TR Amsterdam
The Netherlands
phone: +31 20 6228 711

fax: +31 20 6234 628
email: microfem@xs4all.nl
http://www.xs4all.nl/~microfem

=================================

RFC822.TXT

MicroFEM

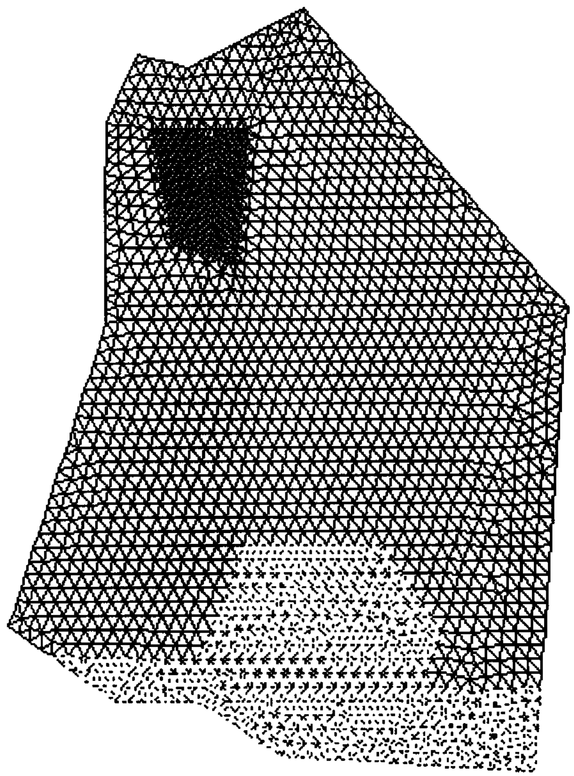
Program Characterization

MicroFEM is an integrated large-capacity finite-element microcomputer program for multiple-aquifer steady-state and transient groundwater flow modeling

Information potentially subject to copyright protection was redacted from this location. The redacted material (about MicroFEM) may be found at:

http://www.xs4all.nl/~microfem/program.html

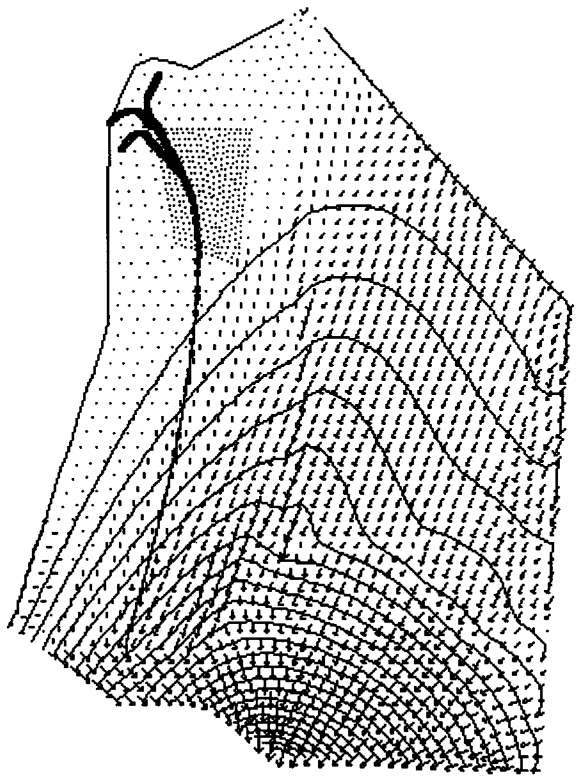
Program Parts



```
head (m)        6.000
1 vert. res. (d) 0
transm. (m2/d) 5600
head (m)    var 724.619
discharge m3/d 0

label:
```

```
Scale 1:200000  Node 1176 not marked
GRID4       x 550055.88, y 4067620.75        Move=↑; Turn=<->; Mark=↓; Goto=HOME
Zoom=+/-; Enter data=END; Maps=PgDn; Alter net=PgUp; Balance node/area=F1/F2-5
DelM=F6; MEdge=F7; BlinkM=F8; SwapM=F9; AutoM=F10; MLab=INS; Net=DEL; Stop=ESC
```

GRID4. FEM



```
  head (m)        30.000
1 vert. res. (d) 0
  transm. (m2/d) 3500
  head (m)   var 730.999
  discharge m3/d 0

  label:
```

"GRID2"

ANISOTROPY

$T_{max} = 3500\ m^2/d$

azimuth $= 30^\circ$

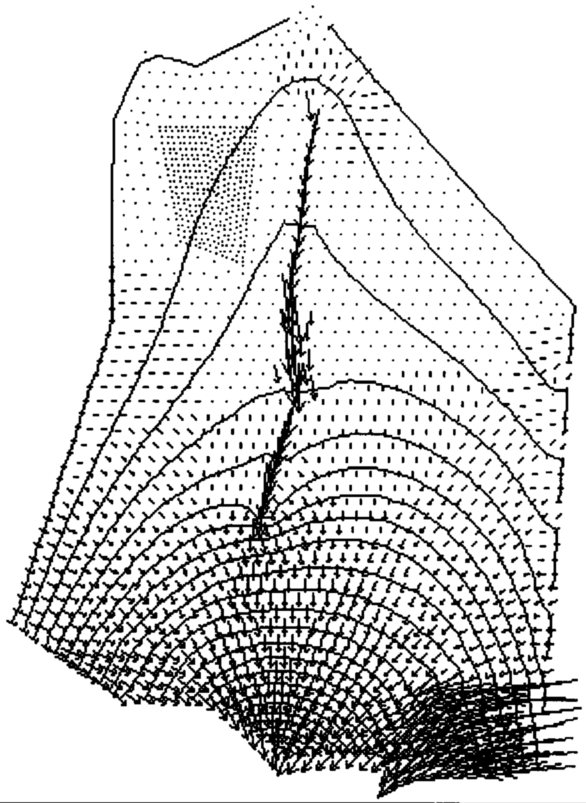
$T_{min}/T_{max} = 6\%$

Central drain

8/22/00

```
Scale 1:200000  Node  344 not marked
GRID2      x 548015.00, y 4076587.25      Move=↑; Turn=<->; Mark=↓; Goto=HOME
Zoom=+/-; Enter data=END; Maps=PgDn; Alter net=PgUp; Balance node/area=F1/F2-5
DelM=F6; MEdge=F7; BlinkM=F8; SwapM=F9; AutoM=F10; MLab=INS; Net=DEL; Stop=ESC
```

GRID2.FEM



```
  head (m)        30.000
1 vert. res. (d) 0
  transcm. (m2/d) 1300
  head (m)   var 729.243
  discharge m3/d 0

  label: fixed node 15
```

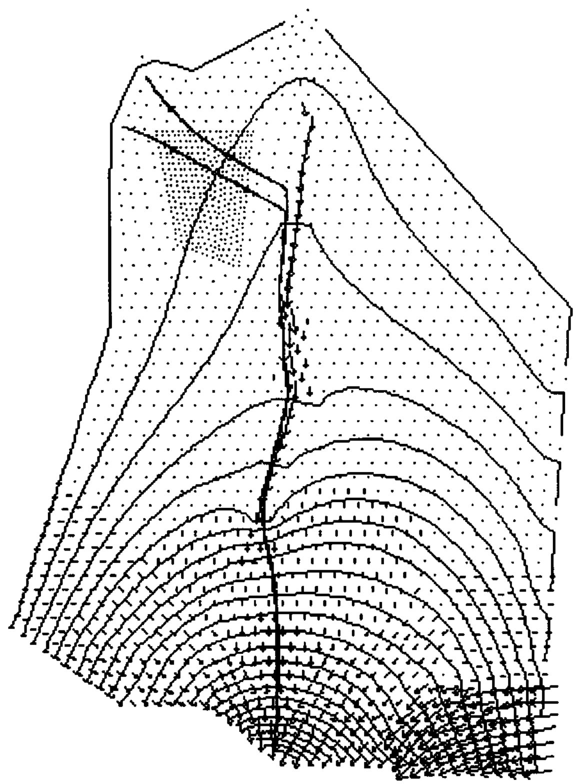
ISOTROPIC

CENTRAL DRAIN

8/22/08

```
Scale 1:200000  Node  718 not marked
GRID3      x 552090.00, y 4072550.00       Move=↑; Turn=<->; Mark=↓; Goto=HOME
Zoom=+/-; Enter data=END; Maps=PgDn; Alter net=PgUp; Balance node/area=F1/F2-5
DelM=F6; MEdge=F7; BlinkM=F8; SwapM=F9; AutoM=F10; MLab=INS; Net=DEL; Stop=ESC
```

GRID3.FEM



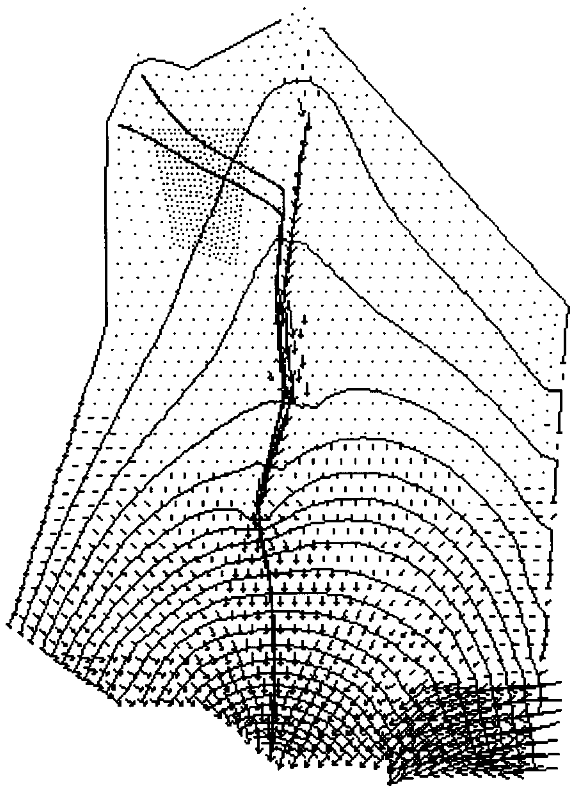
head (m)
1 vert. res. (d)
transm. (m2/d)
* head (m)
discharge m3/d

label:

Scale 1:200000   Downstream   time step (y) 100
GRID3   thickness 500   porosity (<1) 0.01   Colors=f,w,y,r,g,b,0-9
*↓↑=PgUp/Dn; CLS=<->; Zoom=+/-: All=F1; Marks=F2; Mconnect=F3; Edge=F4; Net=F5
↑↑=F6; M<0=F7; Grid=F8; FileI/O=F9/10; Draw/non-M=↓/↑; FL↓/↑=END/HOME; Stop=◄┘

8/22/00

GRID3. FEM



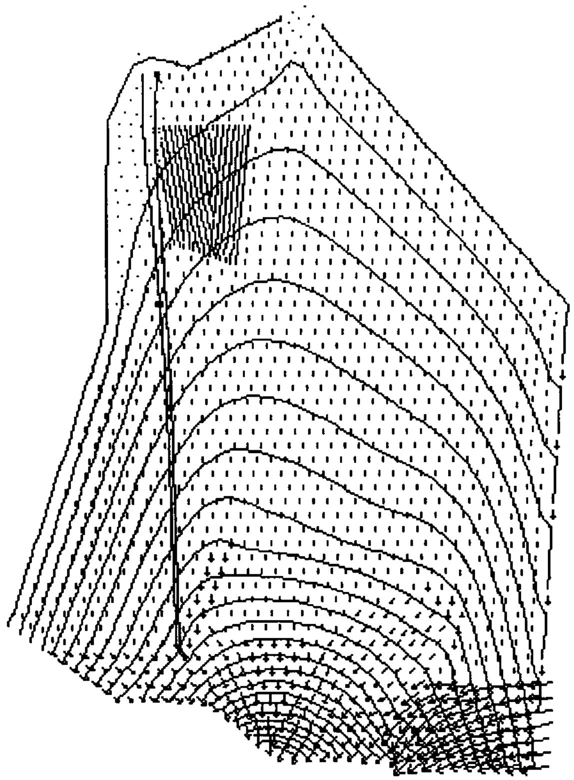
head (m)
1 vert. res. (d)
transm. (m2/d)
* head (m)
discharge m3/d

label:

Scale 1:200000 Downstream time step (y) 100
ISOSCALE thickness 500 porosity (<1) 0.001 Colors=f,w,y,r,g,b,0-9
*↓↑=PgUp/Dn; CLS=<->; Zoom=+/-: All=F1; Marks=F2; Mconnect=F3; Edge=F4; Net=F5
↑↑=F6; M<0=F7; Grid=F8; FileI/O=F9/10; Draw/non-M=↓/↑; FL↓/↑=END/HOME; Stop=↵

8/22/00

T VALUES SCALED
TO VARYING THICKNESS
IN NW CORNER (YM).
"ISOCALE.FEM"



```
  head (m)          6.000
1 vert. res. (d) 0
  transm. (m2/d) 5600
  head (m)   var 730.898
  discharge m3/d 0

  label:
```

anisotropic

$T_{max} = 5600\ m^2/d$

azimuth = 5°

$T_{min}/T_{max} = 6\%$

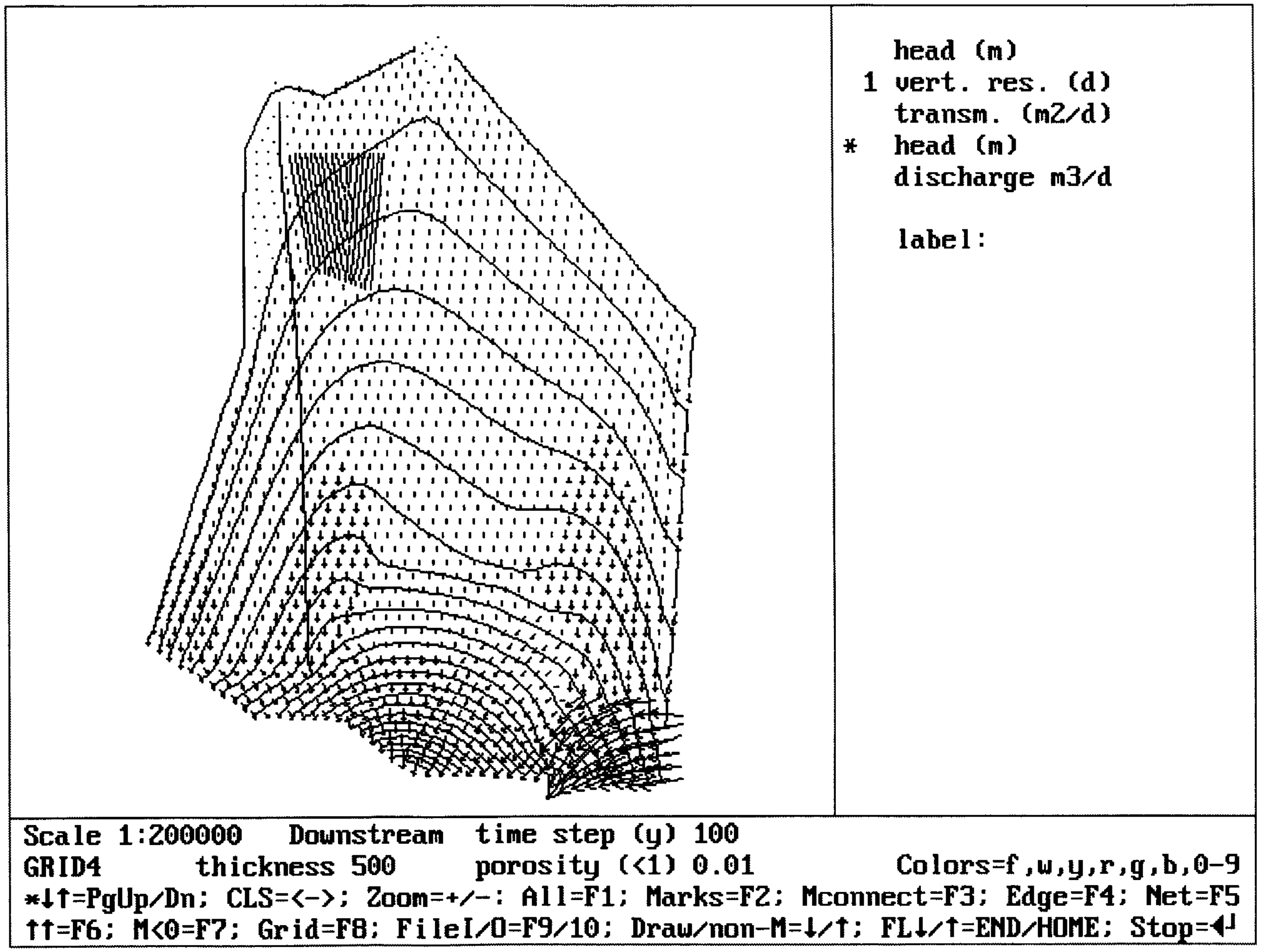
No drain

```
Scale 1:200000   Node   65 not marked
GRID4       x 549343.31, y 4079194.00       Move=↑; Turn=<->; Mark=↓; Goto=HOME
Zoom=+/-; Enter data=END; Maps=PgDn; Alter net=PgUp; Balance node/area=F1/F2-5
DelM=F6; MEdge=F7; BlinkM=F8; SwapM=F9; AutoM=F10; MLab=INS; Net=DEL; Stop=ESC
```

EP
8/22/00

ALLUVIUM $T = 2600\ m^2/d$

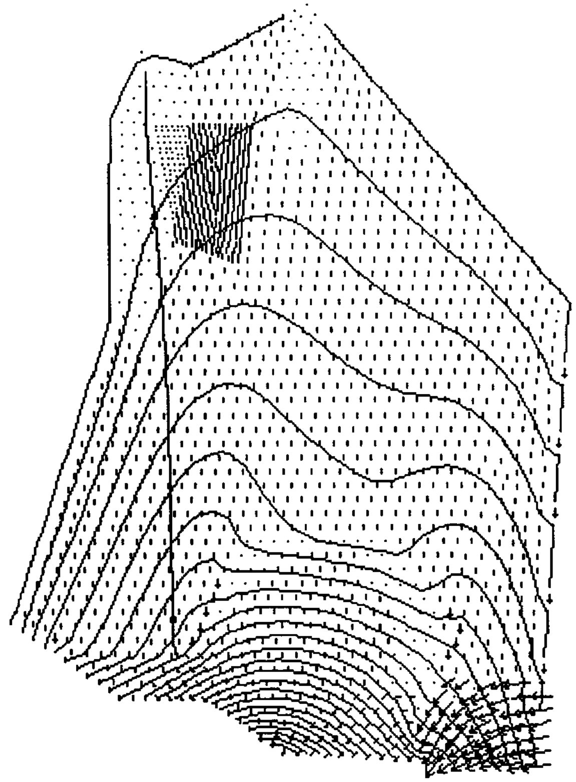
GRID4. FEM



CP
8/22/00

ALLUVIUM T= 1500 m^3/d

GRID4. FEM



head (m) 6.000
1 vert. res. (d) 0
transm. (m2/d) 5600
head (m) var 729.997
discharge m3/d 0

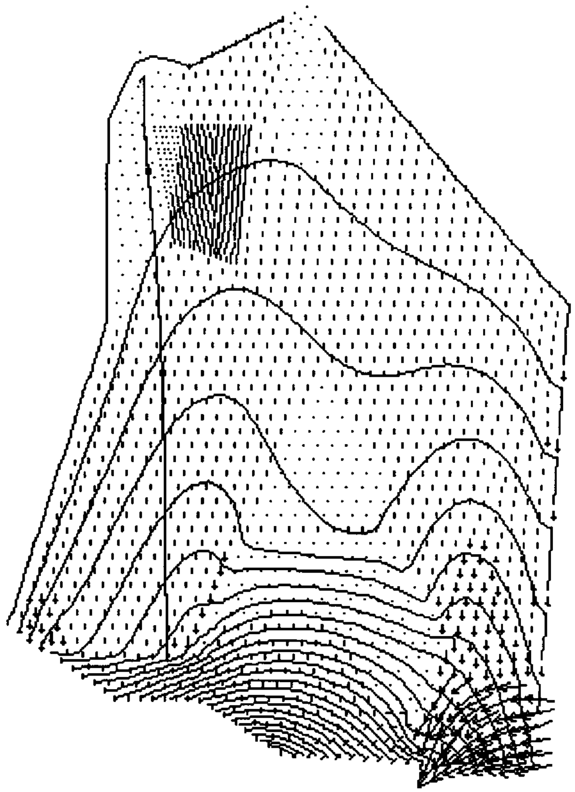
label: fixed node 16

Scale 1:200000 Node 236 not marked
GRID4 x 552630.00, y 4077330.00 Move=↑; Turn=<->; Mark=↓; Goto=HOME
Zoom=+/-; Enter data=END; Maps=PgDn; Alter net=PgUp; Balance node/area=F1/F2-5
DelM=F6; MEdge=F7; BlinkM=F8; SwapM=F9; AutoM=F10; MLab=INS; Net=DEL; Stop=ESC

8/22/00

ALLUVIUM $T = 1000\ m^2/d$

GRID4.FEM



head (m) 6.000
1 vert. res. (d) 0
transm. (m2/d) 5600
head (m) var 730.961
discharge m3/d 0

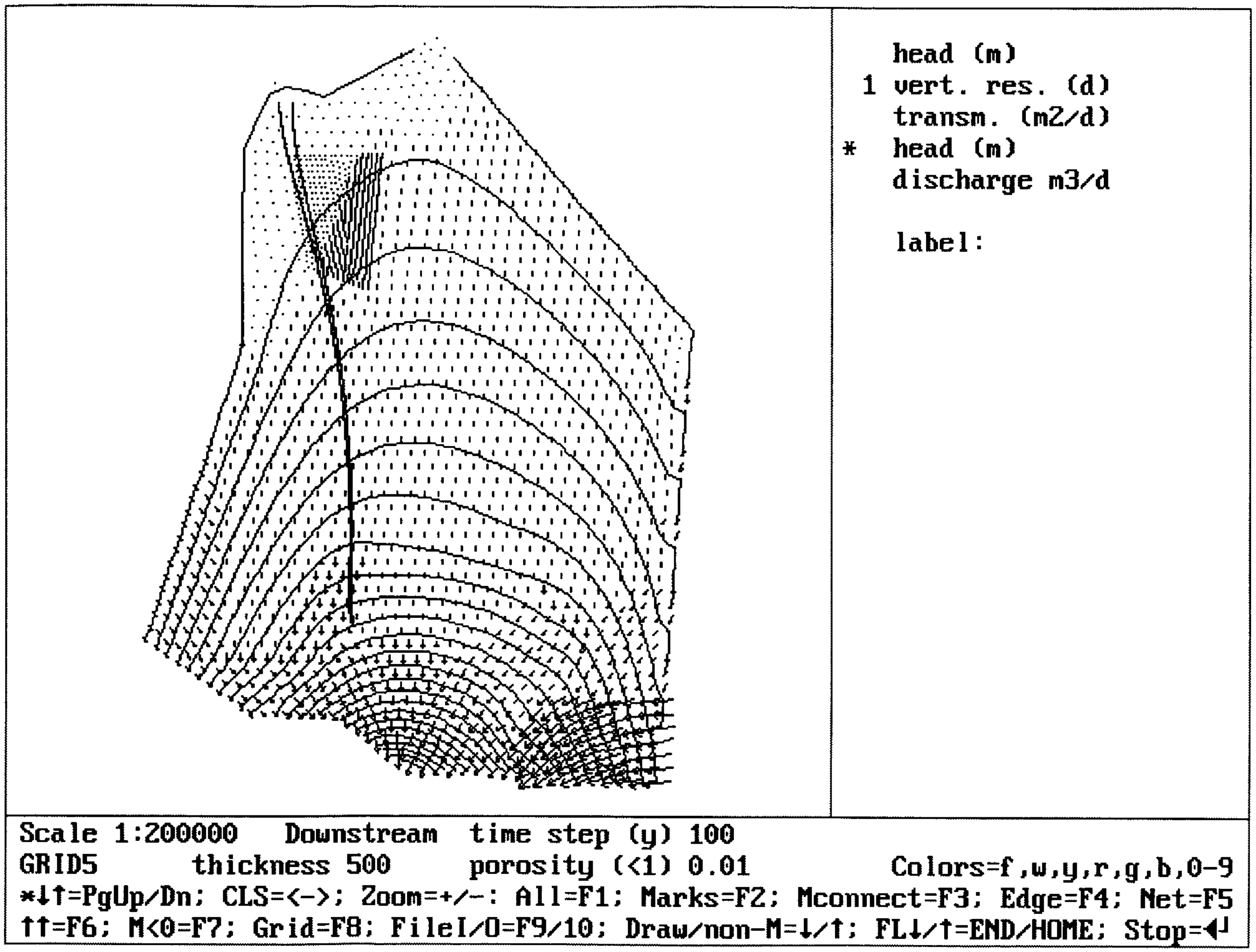
label:

Scale 1:200000 Node 64 not marked
GRID4 x 548850.81, y 4079175.00 Move=↑; Turn=<->; Mark=↓; Goto=HOME
Zoom=+/-; Enter data=END; Maps=PgDn; Alter net=PgUp; Balance node/area=F1/F2-5
DelM=F6; MEdge=F7; BlinkM=F8; SwapM=F9; AutoM=F10; MLab=INS; Net=DEL; Stop=ESC

8/22/02

ALLUVIUM T = 500 m^2/d

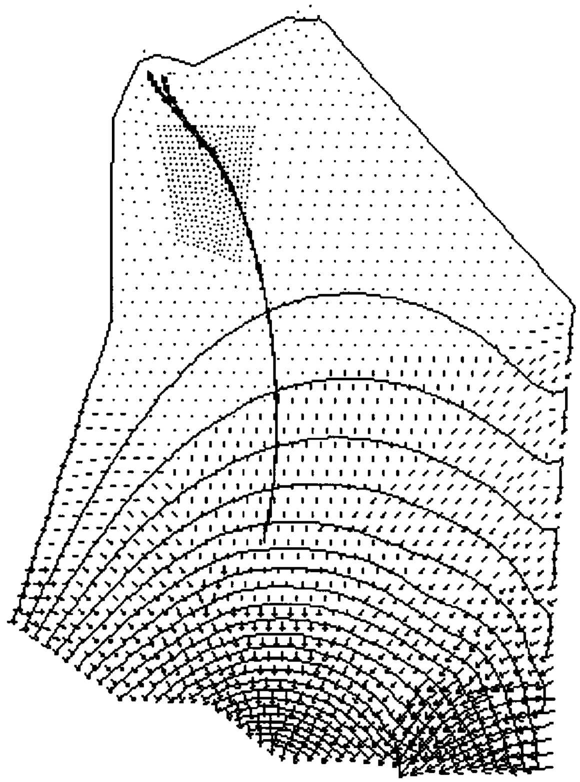
GRID 4. FEM



8/22/08

AZIMUTH = 5°

GRID5.FEM RATIO = 20%



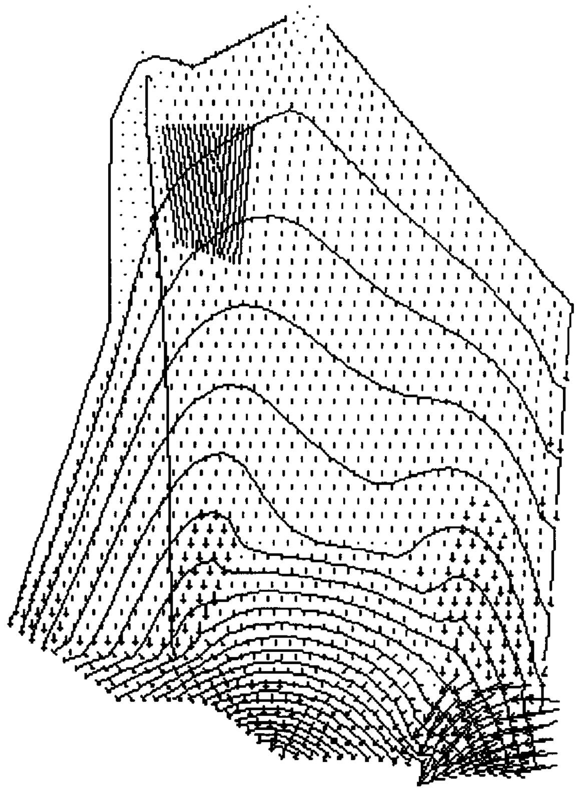
```
  head (m)        50.000
1 vert. res. (d) 0
  transm. (m2/d) 5600
  head (m)   var 730.996
  discharge m3/d 0

  label:
```

```
Scale 1:200000  Node   65 not marked
GRID6      x 549343.31, y 4079194.00       Move=↑; Turn=<->; Mark=↓; Goto=HOME
Zoom=+/-; Enter data=END; Maps=PgDn; Alter net=PgUp; Balance node/area=F1/F2-5
DelM=F6; MEdge=F7; BlinkM=F8; SwapM=F9; AutoM=F10; MLab=INS; Net=DEL; Stop=ESC
```

8/22/00

AZIMUTH = 5°

GRID6.FEM RATIO = 50%



```
  head (m)        6.000
1 vert. res. (d) 0
  transm. (m2/d) 5600
  head (m)   var 730.948
  discharge m3/d 0

  label:
```

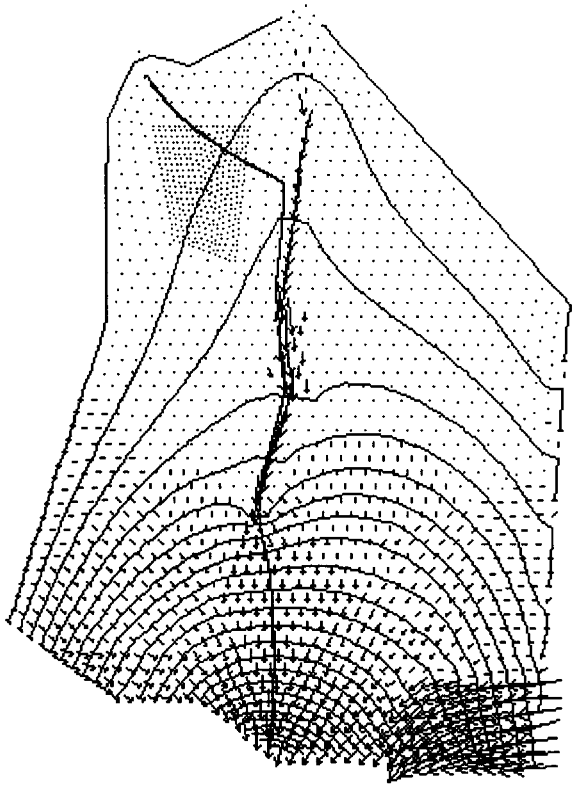
Anisotropic
$T_{max} = 5600\ m^2/d$
azimuth = 5°
$T_{min}/T_{max} = 6\%$

8/22/00

```
Scale 1:200000  Node   64 not marked
GRID4      x 548850.81, y 4079175.00       Move=↑; Turn=<->; Mark=↓; Goto=HOME
Zoom=+/-; Enter data=END; Maps=PgDn; Alter net=PgUp; Balance node/area=F1/F2-5
DelM=F6; MEdge=F7; BlinkM=F8; SwapM=F9; AutoM=F10; MLab=INS; Net=DEL; Stop=ESC
```

ALLUVIUM $T = 1000\ m^2/d$

GRID7.FEM



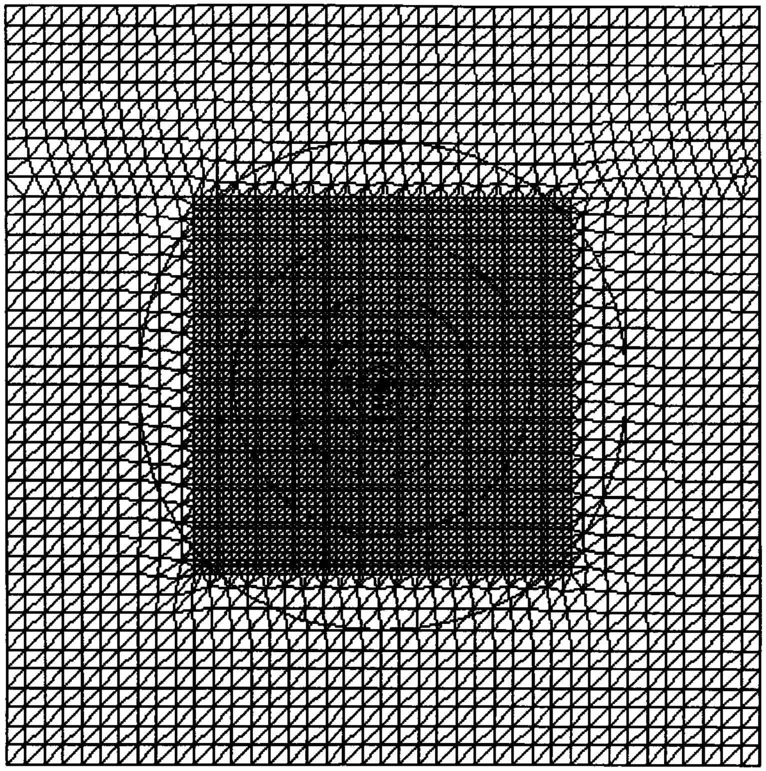
```
head (m)          30.000
1 vert. res. (d)  0
transm. (m2/d)    1300
head (m)     var  730.969
discharge m3/d    -6.75

label:
```

```
Scale 1:200000  Node   64 not marked
GRID8      x 548850.81, y 4079175.00        Move=↑; Turn=<->; Mark=↓; Goto=HOME
Zoom=+/-; Enter data=END; Maps=PgDn; Alter net=PgUp; Balance node/area=F1/F2-5
DelM=F6; MEdge=F7; BlinkM=F8; SwapM=F9; AutoM=F10; MLab=INS; Net=DEL; Stop=ESC
```

LP
8/22/00

areally - distributed recharge in NW corner of model (10 mm/yr).

GRID8.FEM



```
  head (m)         10.000
1 vert. res. (d)  0
  transm. (m2/d)  2000
  head (m)    var 7.767
  discharge m3/d  5000

  label: Pumping Well
```

```
Scale 1:150000  Node 1050 not marked
THIEMTST   x  10000.00, y  10000.00        Move=↑; Turn=<->; Mark=↓; Goto=HOME
Zoom=+/-; Enter data=END; Maps=PgDn; Alter net=PgUp; Balance node/area=F1/F2-5
DelM=F6; MEdge=F7; BlinkM=F8; SwapM=F9; AutoM=F10; MLab=INS; Net=DEL; Stop=ESC
```

8/22/00

SEE FILE "TIMETEST.JPG"

Entries into this scientific notebook No. 311 for the period from 3/4/99 to 3/24/99 have been made by Neil Coleman (USNRC).

Neil Coleman 3/24/99

No original text entered into this Scientific Notebook has been removed.

Neil Coleman 3/24/99

ADDITIONAL INFORMATION FOR SCIENTIFIC NOTEBOOK #: 311E

Document Date:	03/04/1999
Availability:	Southwest Research Institute® Center for Nuclear Waste Regulatory Analyses 6220 Culebra Road San Antonio, Texas 78228
Contact:	Southwest Research Institute® Center for Nuclear Waste Regulatory Analyses 6220 Culebra Road San Antonio, TX 78228-5166 Attn.: Director of Administration 210.522.5054
Data Sensitivity:	■"Non-Sensitive" □ Sensitive □"Non-Sensitive - Copyright" □ Sensitive - Copyright
Date Generated:	04/03/1998
Operating System: (including version number)	Windows NT 4.0
Application Used: (including version number)	Microfem
Media Type: (CDs, 3 1/2, 5 1/4 disks, etc.)	3 - 3½ disks
File Types: (.exe, .bat, .zip, etc.)	.fem, af1, exe, jpg, wpd, txt, ad1
Remarks: (computer runs, etc.)	Media contains: Yucca Mountain model parameters; validation tests.