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TECHNICAL MEMORANDUM

TO: **Andrew Burns - Southern Nevada Water Authority** **HCI-1827**
Jim Watrus - Southern Nevada Water Authority

FROM: **Houmao Liu**

SUBJECT: **Comparison between Calculations by *FEMFLOW3D* and *MODFLOW* for Contrived, Single Compartment Ground-Water Flow Problem**

DATE: **June 14, 2006**

INTRODUCTION

Hydrologic Consultants, Inc. (HCI) has previously submitted two Technical Memoranda to the Southern Nevada Water Authority (SNWA). The first one (HCI, 2006a) summarized our review of the document entitled "*FEMFLOW3D* - A Finite-Element Program for the Simulation of Three-Dimensional Groundwater Systems, Version 2". The second one (HCI, 2006b) summarized our review of the source code of *FEMFLOW3D* (written in *FORTRAN)* and comparisons between model-calculated and analytical solutions to some very simple problems (e.g., the Theis solution).

In addition to conducting those two reviews, SNWA also asked HCI to conduct numerical simulations of some other ground-water flow problems in order to compare the results obtained from *FEMFLOW3D* and *MODFLOW*, the popular finite difference-based code developed by the U.S. Geological Survey (HCI, 2006c). Because of the tight schedule for this work and the potential need for iterative discussion among SNWA, HCI, and Timothy J. Durbin, author of *FEMFLOW3D*, HCI has -- in consultation with SNWA -- decided to submit our findings from each of the model comparisons in a series of separate Technical Memoranda. This third Technical Memorandum compares our findings from simulations of the first contrived ground-water flow problem using both *FEMFLOW3D* and *MODFLOW*.

HCI will be submitting a fourth Technical Memorandum as soon as possible on the results of numerical simulations of a second contrived problem, one involving hydraulic barriers and conduits. Initially, it had been planned to do some two-dimensional modeling, specifically to address simulation of the water table. Based on the findings of the numerical testing described in this third Technical Memorandum, however, we do not think that modeling is now necessary. This should be discussed between SNWA and HCI as soon as possible.

DESCRIPTION OF CONTRIVED, SINGLE COMPARTMENT GROUND-WATER FLOW PROBLEM

Background

This contrived, so-called single compartment (i.e., with no internal barriers or conduits) ground-water flow is identical to the problem that was jointly designed by HCI and Sandia National Laboratories (SNL) as part of the review and verification of the HCI's proprietary ground-water flow code *MINEDW* that was conducted for the U.S. Bureau of Land Management by Sandia National Laboratories in 1998 as part of the Environmental Impact Assessment (EIS) process for several gold mines in northern Nevada (Corbet et al., 1998). It is noteworthy that *MINEDW* includes the core and several of the subroutines that were in the predecessor version of *FEMFLOW3D* developed by Mr. Durbin when he was with the U.S. Geological Survey (Durbin and Bond, 1998).

As shown in Figures 1 and 2, the contrived problem incorporates the following features and components.

1) A defined topographic surface including two streams separated by a topographic divide, forming two basins.

2) Orographically-controlled recharge to enable, together with the streams, a hydrologic divide to develop in at least the top layer of the model.

3) Two hydrogeologic layers, which are further sub-divided into more layers for numerical purposes, with a water table in the upper layer and with the lower layer significantly more permeable than the upper layer.

4) A set of defined hydraulic properties for the two geologic units and stream characteristics.

5) Boundary conditions such that the lower geologic unit could potentially transmit water between the two basins.

6) The ability to run both models (i.e., *FEMFLOW3D* and *MODFLOW* models) to steady-state conditions.

7) The ability to simulate a major, transient, hydraulic stress.

Description of Conceptual Hydrogeologic Model

Figure 1 is a schematic diagram of the contrived problem. The horizontal dimensions of the model domain for the problem are 90,000 by 90,000 ft, and the thickness ranges from 3,000 to 4,000 ft. There are two horizontal hydrostratigraphic units in the model domain, and the hydraulic conductivity of the lower unit is 10 times higher than that of the upper unit. The domain includes two valleys with mountains on the eastern, western, and northern side of each valley. Streams flow in each valley from north to south into a river at the southern edge of the domain. The larger river flows from east to west. The western valley contains an area of potential evapotranspiration (ET) near its southern end.

Description of Numerical Models

The domain of the contrived problem was incorporated into numerical ground-water flow models using *FEMFLOW3D* and *MODFLOW*. In each model, the eastern, western, and northern boundaries are no-flow boundaries (Figure 2). The southern boundary is a constant or specified head boundary in all layers, with the specified heads ranging from elevation 3,300 ft NGVD on the east side of the model to 2,980 ft on the west side. This represents a river flowing from east to west and allows inter-basin ground-water flow in the lower hydrogeologic unit. There is no vertical gradient assigned to the specified heads (i.e., the values of the specified heads do not vary in the vertical direction).

The hydraulic properties of the two hydrostratigraphic units are summarized in Table 1. The bottom unit has a uniform thickness of 1,500 ft; the top unit has a thickness ranging from 1,500 to 2,000 ft, depending on the elevation of the ground surface.

Recharge is applied to nodes (using *FEMFLOW3D)* or cells (using *MODFLOW*) along the mountain ranges, comprising a line source (Figure 2). The recharge rate for the *MODFLOW* model is 5.806 in/year. The equivalent flux is applied to each of the recharge nodes in the *FEMFLOW3D* model.

The two streams are represented in the models by using the stream routines of the respective codes. Each stream is assigned a width of 10 ft, a streambed thickness of 1 ft, and a vertical hydraulic conductivity of the streambed of 0.1 ft/day. The elevation of the streambed of the eastern stream decreases from 3,600 ft in the north to 3,200 ft at the river. The elevation of the streamed in the western stream similarly ranges from 3,400 to 3,000 ft. Since the last node (or cell) of each stream is a constant head node (cell), these nodes (cells) are not simulated as part of the stream.

ET is simulated in the southern part of the western valley. An “extinction depth” of 20 ft and a maximum ET rate of 0.8 ft/yr were assigned to the ET area.

A pumping "center" with a large extraction rate was purposely designed to simulate a large wellfield in the basin. This pumping center is represented as a single "well" at the center of the model domain (Point B, Figure 2). The model was simulated during the first 20 years of the transient simulations as pumping at a rate of 12.5 cfs (5,600 gpm) and then recovering for the next 60 years. The models attempted to simulate ground-water extraction from both layers of each model. *FEMFLOW3D* uses a "linking" feature to simulate a well penetrating multiple layers. With *MODFLOW*, the vertical conductivity values for the cells containing the well were set at very high values. During the simulation of recovery, the well linking and high hydraulic conductivity values were turned off in the respective models.

General Set-Up of Models

Figure 3 shows the meshes for the *FEMFLOW3D* and *MODFLOW* models. The set-up of the *FEMFLOW3D* model was done by Timothy J. Durbin, Inc. (TJDI). HCI used *VISUAL MODFLOW PRO* Version 3.1 from Waterloo Hydrogeologic for setting up the *MODFLOW* model. The *FEMFLOW3D* mesh has 3,249 nodes and 5,148 elements; the *MODFLOW* mesh has 3,040 cells. Both models contain eight model layers. The meshes were constructed so that all interior nodes are located in exactly the same location in plan view for both models. The nodes in the *FEMFLOW3D* finite-element model are located at the corners of elements. Nodes in the *MODFLOW* finite-difference model are located in the center of the cells, both horizontally and vertically.

Because of the difference in the fundamental location of the nodes in the two numerical methods (i.e., finite-element vs. finite-difference), the nodes in the two meshes are not in the same locations in the vertical dimension. There are eight nodes in each node column in the finite difference mesh, but nine in the finite element mesh. In this problem, six model layers are used to represent the upper hydrostratigraphic unit, and two model layers are used to represent the lower hydrostratigraphic unit.

Constant heads were assigned to the row of nodes at 5,000 ft North, as shown in Figure 3. Table 2 summarizes the locations and assigned heads of all constant heads used in the model.

Recharge was applied at a rate of 5.806 in/yr over the area associated with 62 *MODFLOW* cells (each cell is 5,000 x 5,000 ft in size) for a total of 2.05 x 10^6 ft^3/day. The same amount of recharge was applied to the 124 nodes in the first nodal layer of the *FEMFLOW3D* model mesh.

Streams were defined node by node with stream lengths of 5,000 ft in both the *FEMFLOW3D* and *MODFLOW* meshes. The locations and elevations of the stream nodes are summarized in Table 3.

The area of ET was represented by 20 nodes in the *FEMFLOW3D* meshes and 20 cells in the *MODFLOW* mesh, as shown in Figure 3.

RUNNING OF MODELS

Both steady-state and transient model simulations were conducted with *FEMFLOW3D* and *MODFLOW*. As previously stated, the model input files for *FEMFLOW3D* were prepared by TJDI. HCI used the executable *FEMFLOW3D* compiled from the source code that was provided by TJDI to conduct the model simulations. For the *MODLFOW* simulations, HCI used the *MODFLOW96* numeric engine in *Visual MODFLOW* Version 3.1 for the reason that *MODFLOW96* provided much faster convergence than *MODFLOW2000* during the 60 years of recovery simulation. It is obviously not the objective of this validation to evaluate the different versions of *MODFLOW*. Therefore, HCI just selected a *MODFLOW* numerical engine that is applicable to the test problem.

MODEL RESULTS

Presentation of Results

Results from these runs are compared in the form of tables summarizing the steady-state water budgets and a series of contour maps and hydrographs showing water levels calculated by the two models. The three levels in vertical extent of the models that were selected to compare the water levels were:

1) the water table,

2) the lower portion of the upper hydrostratigraphic unit at an elevation of 1,666 ft; and

3) the lower portion of the lower hydrostratigraphic unit at an elevation of 375 ft.

As previously noted, the nodes of the *FEMFLOW3D* and *MODFLOW* meshes coincide in plan view, but they do not coincide in the vertical dimension. Therefore, linear interpolation was used to report heads and drawdowns for the same vertical location.

For *FEMFLOW3D* the following interpolations were made.

1) Heads at the first nodal layer were used for the water table.

2) Heads at elevations of 1,666 and 375 ft were computed by linear interpolation of heads at nodes immediately above and below 1,666 and 375 ft, respectively.

For *MODFLOW*, the following procedures were used to report heads.

1) The water table was reported as the head in the uppermost saturated cell.

2) Heads at elevations of 1,666 and 375 ft were reported as the heads in the cell corresponding to that elevation.

After the heads were computed for each model simulation, they were imported with the Easting and Northing into Golden Software's *SURFER* contouring. The kriging routine of *SURFER* (using the default options) was used to produce the contour plots to be described below.

Comparison of Model Results

Before comparing the model results derived from each code, it is worth noting the following differences between *FEMFLOW3D* and *MODFLOW* that can cause slight discrepancies in the results.

1) Calculation of water table

   FEMFLOW3D uses grid collapsing to calculate the water table. *MODFLOW* uses the calculated head in the uppermost saturated cell as the water table. For a water table that fluctuates between different vertical layers, *MODFLOW* uses somewhat arbitrary parameters to control the wetting and drying of model cells.

2) Representation of the pumping well

   FEMFLOW3D uses a well "linking" feature to allow direct flow between specified well nodes with very little resistance. This was used in the contrived problem to represent a well penetrating several layers. *MODFLOW* does not have this feature; it uses a high vertical hydraulic conductivity value in the column of the cells to simulate a multi-layer pumping well.

The above differences are not expected to cause major discrepancies in the results of these two codes. However, minor discrepancies may be introduced by these differences, especially at the water table.

<u>Results of Steady-State Simulations</u>

Figures 4, 5, and 6 are contour plots showing the calculated hydraulic heads at the water table, at the 1,666 ft level, and at the 375 ft level, respectively, by both *FEMFLOW3D* and *MODFLOW* for the contrived problem under steady-state conditions. Figure 4 shows the two hydrologic basins clearly defined by both models. The “inter-basin” flow at depth is also clearly depicted in Figures 5 and 6. In all of these figures, the calculated hydraulic heads are essentially identical.

The water budgets under steady-state conditions calculated by the two models for the contrived problem are summarized in Table 4. Again, the values are essentially identical.

<u>Results of Transient Simulations</u>

Figures 7, 8, and 9 are contour plots showing the calculated hydraulic heads at the water table, at the 1,666 ft level, and at the 375 ft level, respectively, by both *FEMFLOW3D* and *MODFLOW* for the contrived problem under transient conditions -- specifically at the end of 20 years of pumping. At the 1,666 and 375 ft levels (Figures 8 and 9), the calculated hydraulic heads from the two models are essentially identical. As shown in Figure 7, there is a difference in the calculated water tables -- by about half a contour interval or 25 ft -- within a radius of about 15,000 ft from the pumping well with *MODFLOW* producing the higher levels. As indicated in Figure 10, this difference is even more noticeable when plotted in terms of drawdown at the water table (i.e., the difference in elevations of the water table between steady-state conditions and after 20 years of pumping). Consistent with the situation shown in Figure 7, *FEMFLOW3D* calculates more drawdown than *MODFLOW* in the model layer that contains the water table. The contours in Figure 10 also indicate that *MODFLOW* shows more “sensitivity” to the effect of recharge along the three line sources.

Figures 11, 12, and 13 are contour plots showing the calculated hydraulic heads at the water table, at the 1,666 ft level, and at the 375 ft level from both models at the end of 60 years of recovery. Again, the results are essentially identical.

Figures 14, 15, and 16 are hydrographs of the calculated hydraulic heads at three specific points (see Figure 2):

> Point A - at a relatively low elevation within the western basin,
>
> Point B - on the central divide at the location of the pumping well; and
>
> Point C - at a relatively high elevation within the eastern basin,

respectively.

As in the contour maps, each figure compares the calculated heads at the water table, at the 1,666 ft level, and at the 375 ft level. As shown in Figure 14, *MODFLOW* calculates a hydraulic head at the water table that is about 20 ft higher (maximum) than that calculated by *FEMFLOW3D* and the one from *MODFLOW* during the pumping period at Point A. There is also a time difference of about 2.5 years between when *FEMFLOW3D* (about 22 years) and *MODFLOW* (about 24.5 years) calculated the maximum drawdown.

As shown in Figure 15, the calculated heads in the pumping well (Point B) are similar at depth. However, *MODFLOW* shows a very unusual "recovery" for the first approximately 10 years after the well is turned off. This is attributable to wetting/re-wetting algorithm in *MODFLOW*, and HCI did not devote any significant effort trying to obtain the optimal wetting/rewetting parameters to produce a more reasonable "smooth" recovery curve (such as that produced by *FEMFLOW3D).*

Figure 16 shows the calculated hydraulic heads with time at Point C, beyond the zone of significant pumping-induced drawdown (Figure 10). Once again, the results are essentially identical at all three levels. Figure 17 shows the calculated streamflows at two points, the midpoint and the endpoint of the East and West Streams (Figure 2). Both models show the gaining nature of the both streams and the effects of pumping on decreasing streamflow over relatively long periods of time. Note that there is a difference in vertical scale on the two graphs in Figure 17. We have purposely expanded the scale for the East Stream whose flow is lower because of its higher elevation and less contribution (to baseflow) from ground water.

Finally, Figure 18 graphically depicts the components of the water budget calculated by each model through time. This includes fluxes from the constant head nodes, changes in storage, recharge, pumping discharge, ET fluxes, and the total streamflows (which are baseflows from ground water because we have not simulated direct precipitation or runoff to the streams) through time. As previously noted in Table 4, both models calculate essentially identical water budget components.

CONCLUSIONS

Based on our comparison of the results derived from *FEMFLOW3D* and *MODFLOW* for the contrived single compartment problem, HCI concludes -- assuming that the public domain code *MODFLOW* produces a "correct" solution -- the following:

1) *FEMFLOW3D* properly calculates hydraulic heads and water budgets under steady-state conditions; and

2) *FEMFLOW3D* properly calculates hydraulic heads and water budgets under transient conditions (simulated by a pumping stress of finite duration).

However, it should be noted that there were significant differences -- in the range of 20 ft -- between the elevations of the water table calculated by the two codes near (but, ironically, not within) the pumping well (see Figured 10 and 14). Mr. Durbin should be asked to comment upon these differences.

CLOSURE

Please contact us if you have any questions regarding any of the findings in this Technical Memorandum**.**

REFERENCES

Corbet, T., Ho, C., Knupp, P., and Ramsey, J., 1998, Review and verification of the *MINEDW* groundwater flow code, Sandia National Laboratories: report submitted to Greystone, Inc., December 4.

Durbin, T.J., and Bond, L.D., A finite–element program for the simulation of three-dimensional aquifers: U.S. Geological Survey Open-File Report 97-810, 338 p.

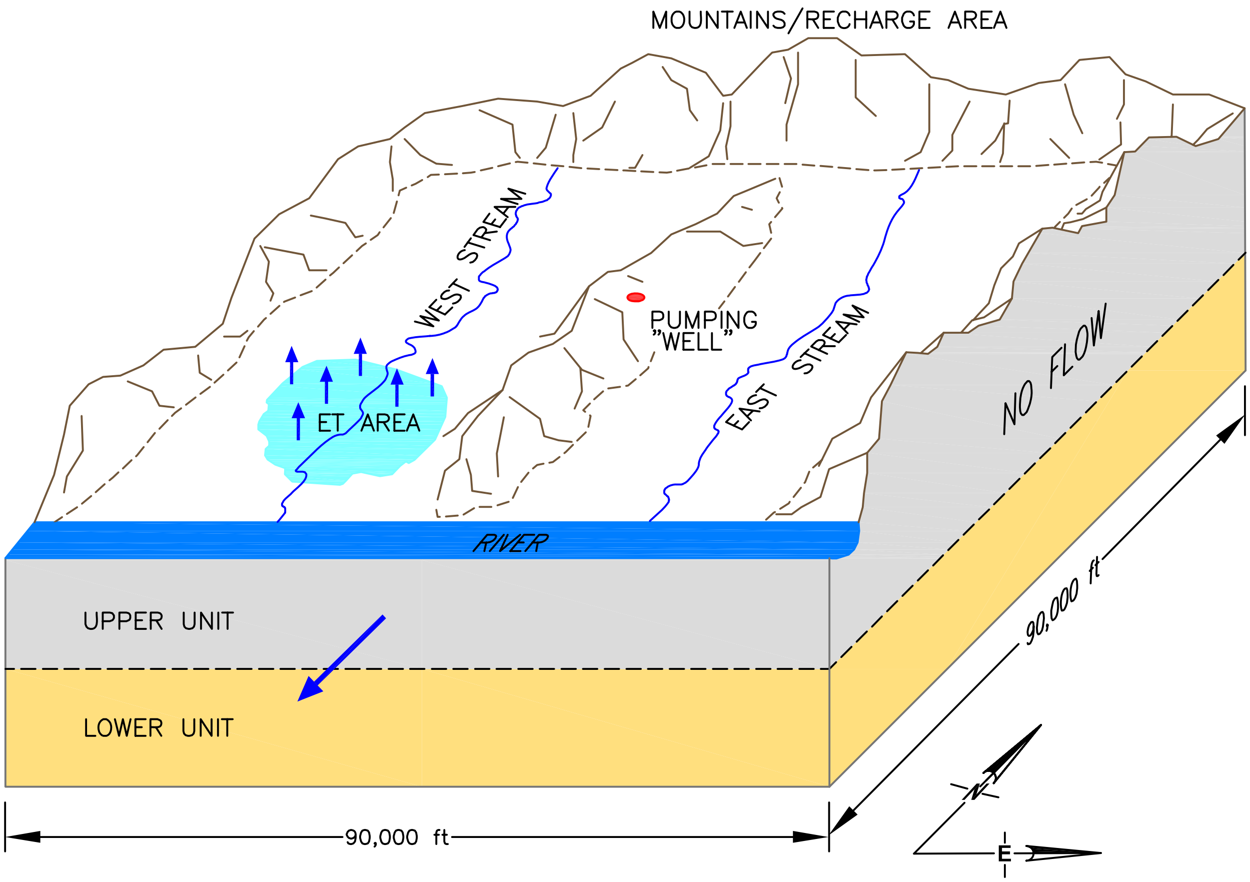
Hydrologic Consultants, Inc., 2006a, Preliminary comments on *FEMFLOW3D* documentation: Technical Memorandum submitted to SNWA, May 5.

Hydrologic Consultants, Inc., 2006b, Additional comments on *FEMFLOW3D* documentation and review of the source code: Technical Memorandum submitted to SNWA, June 5.

Hydrologic Consultants, Inc., 2006c, Revised scope of work and cost estimate - review of *FEMFLOW3D* ground-water flow code: submitted to SNWA, April 19.

Attachments:
- Figure 1 - Schematic Diagram of Contrived Single Compartment Problem
- Figure 2 - Boundary Conditions and Features of Numerical Models for Contrived Single Compartment Problem
- Figure 3 - Model Meshes and Boundary Conditions for Contrived Single Compartment Problem
- Figure 4 - Calculated Water Tables under Steady-State Conditions for Contrived Single Compartment Problem
- Figure 5 - Calculated Hydraulic Heads at Elevation 1,666 ft under Steady-State Conditions for Contrived Single Compartment Problem
- Figure 6 - Calculated Hydraulic Heads at Elevation 375 ft under Steady-State Conditions for Contrived Single Compartment Problem
- Figure 7 - Calculated Water Tables after 20 Years of Pumping for Contrived Single Compartment Problem
- Figure 8 - Calculated Hydraulic Heads at Elevation 1,666 ft after 20 Years of Pumping for Contrived Single Compartment Problem

Figure 9 - Calculated Hydraulic Heads at Elevation 375 ft after 20 Years of Pumping for Contrived Single Compartment Problem
Figure 10 - Calculated Drawdown of Water Table after 20 Years of Pumping for Contrived Single Compartment Problem
Figure 11 - Calculated Water Table after 60 Years of Recovery for Contrived Single Compartment Problem
Figure 12 - Calculated Hydraulic Heads at Elevation 1,666 ft after 60 Years of Recovery for Contrived Single Compartment Problem
Figure 13 - Calculated Hydraulic Heads at Elevation 375 ft after 60 years of Recovery for Contrived Single Compartment Problem
Figure 14 - Hydrographs of Calculated Hydraulic Heads at Point A at Three Different Elevations
Figure 15 - Hydrographs of Calculated Hydraulic Heads at Point B (Pumping Well) at Three Different Elevations
Figure 16 - Hydrographs of Calculated Hydraulic Heads at Point C at Three Different Elevations
Figure 17 - Calculated Streamflows at Midpoints and Endpoints of Streams
Figure 18 - Calculated Water Budgets
Table 1 - Hydraulic Properties of Hydrostratigraphic Units Used in Contrived Problem
Table 2 - Locations and Specified Elevations of Constant Head Nodes
Table 3 - Locations and Specified Elevations of Stream Nodes
Table 4 - Calculated Water Budgets under Steady-State Conditions



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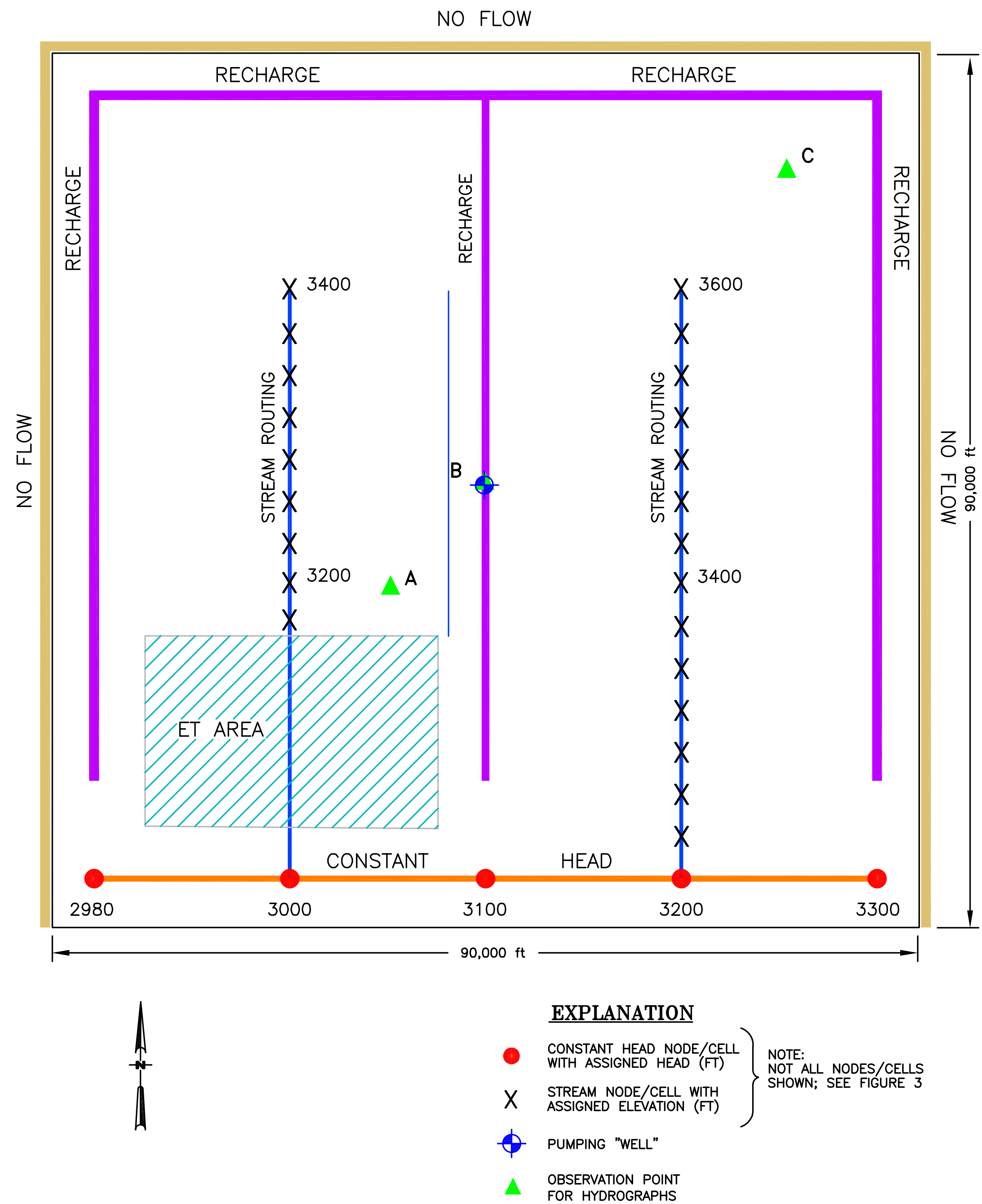
Schematic Diagram of Contrived Single Compartment Problem

FIGURE 1



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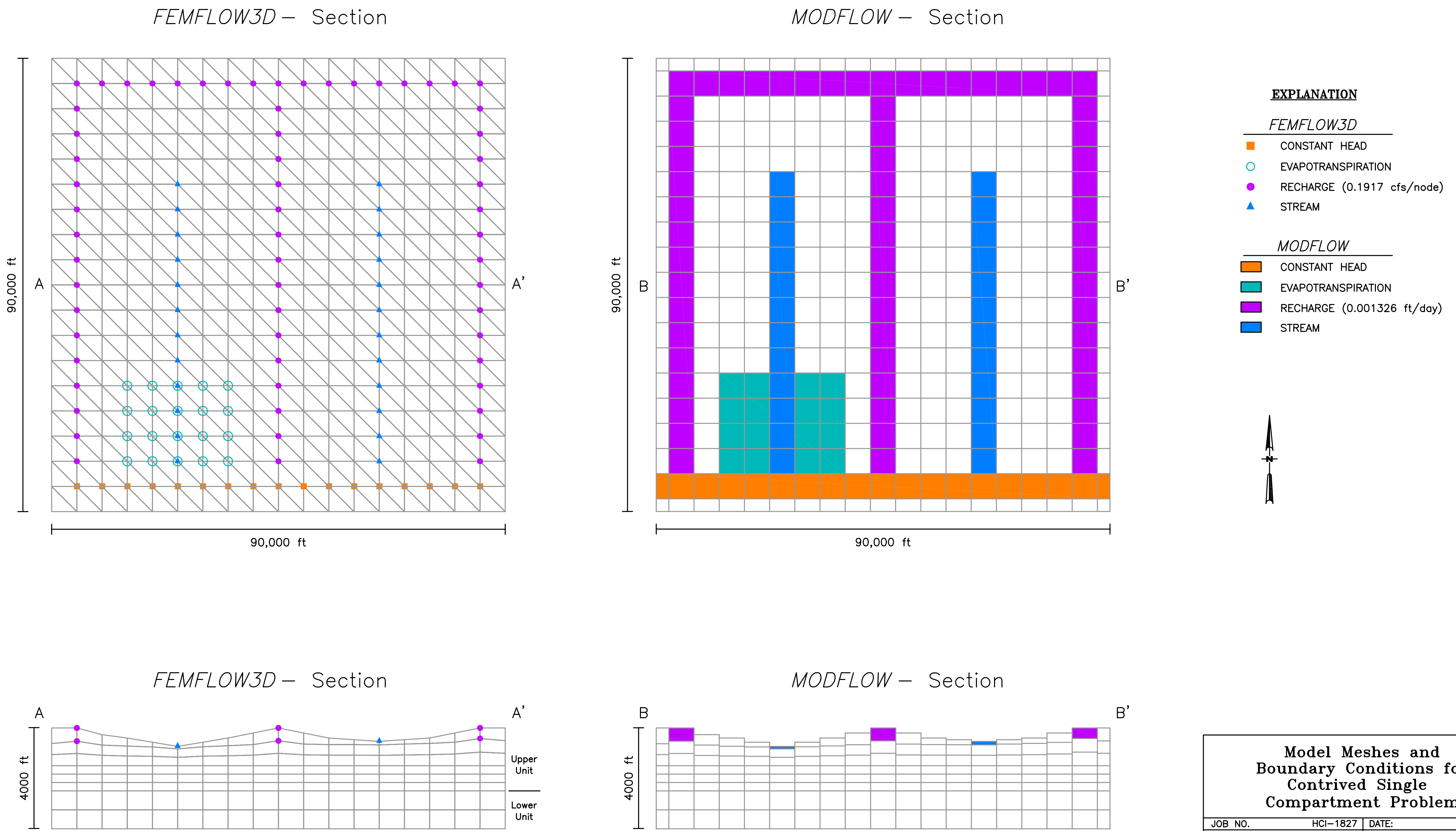
Boundary Conditions and Features of Numerical Models for Contrived Single Compartment Problem

FIGURE 2



Model Meshes and Boundary Conditions for Contrived Single Compartment Problem

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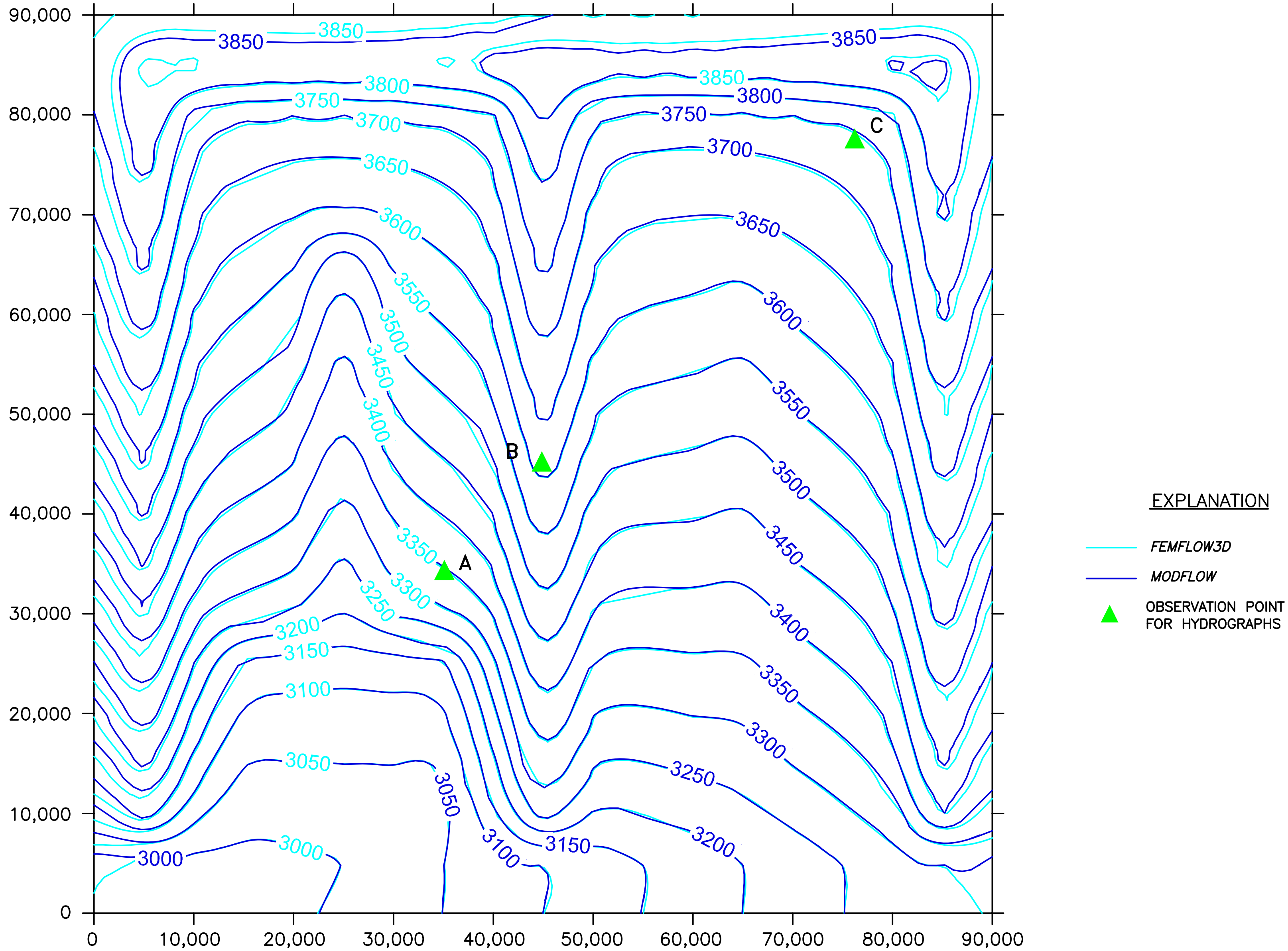
FIGURE 3



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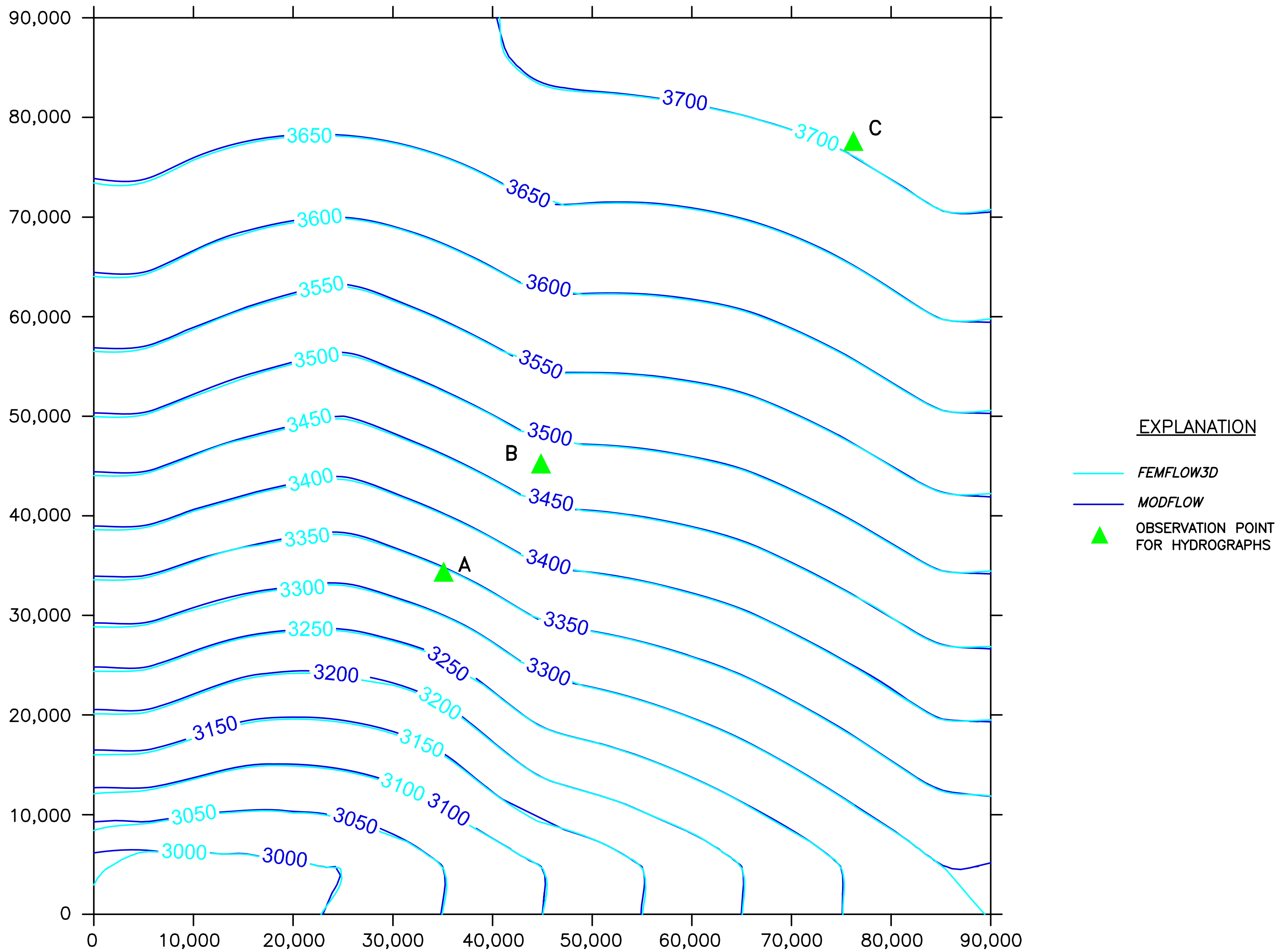
Calculated Water Tables under Steady-State Conditions for Contrived Single Compartment Problem

FIGURE 4



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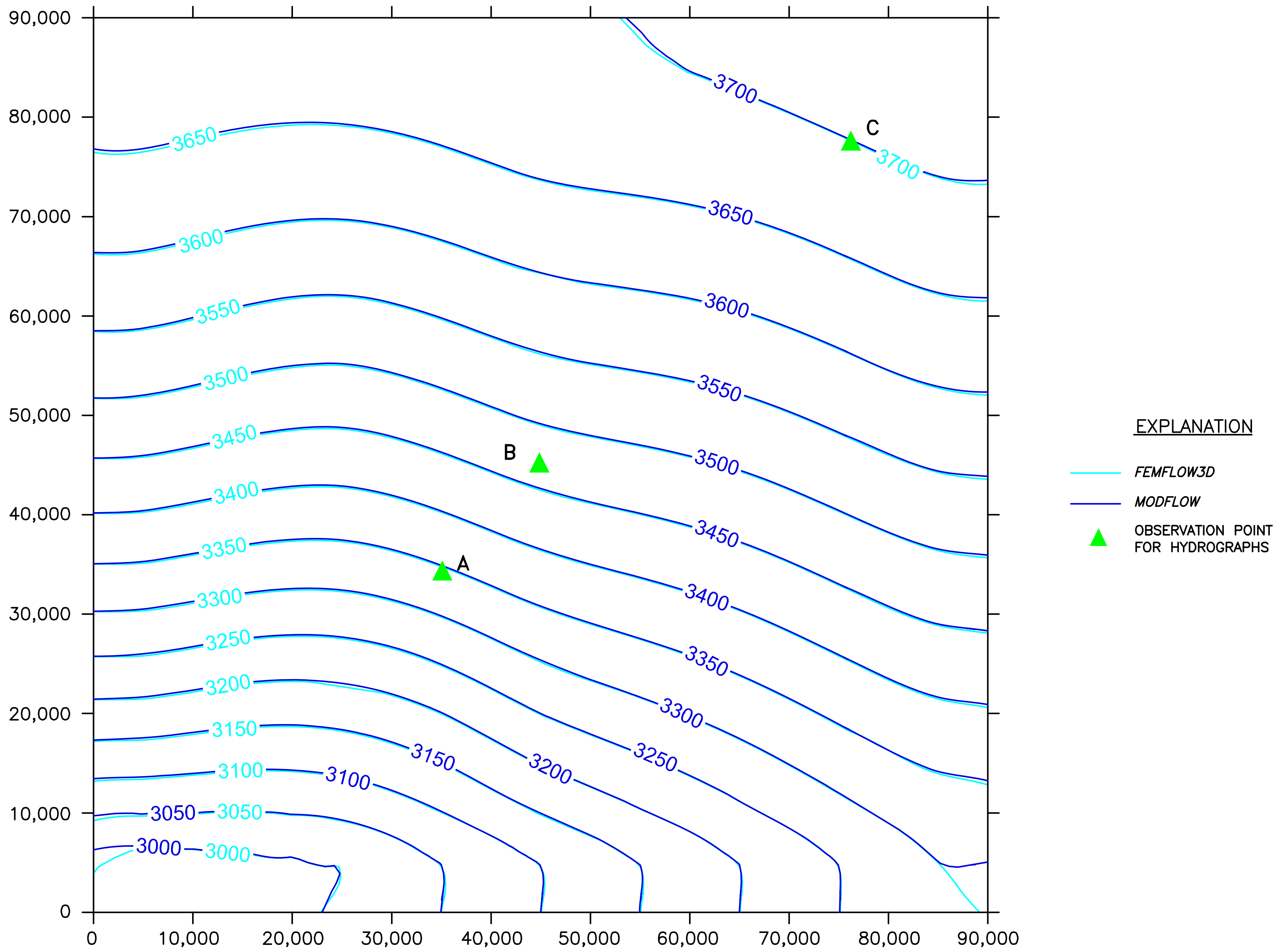
Calculated Hydraulic Heads at Elevation 1,666 ft Under Steady–State Condtions for Contrived Single Compartment Problem

FIGURE 5



HCI HYDROLOGIC CONSULTANTS, INC. HC ITASCA an company	JOB NO. HCI–1827	DATE: 25 MAY 06	Calculated Hydraulic Heads at Elevation 375 ft Under Steady–State Condtions for Contrived Single Compartment Problem	FIGURE 6
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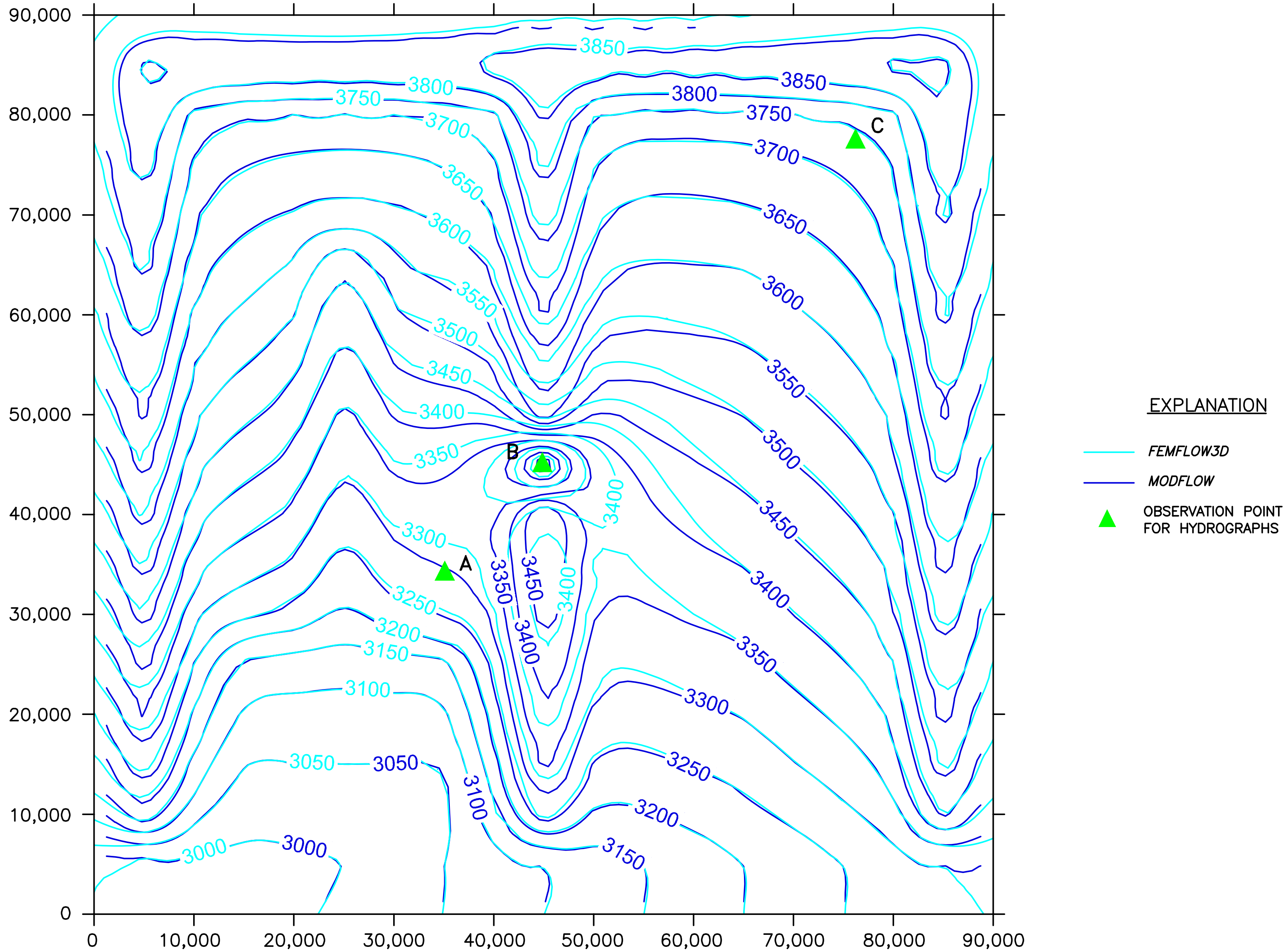

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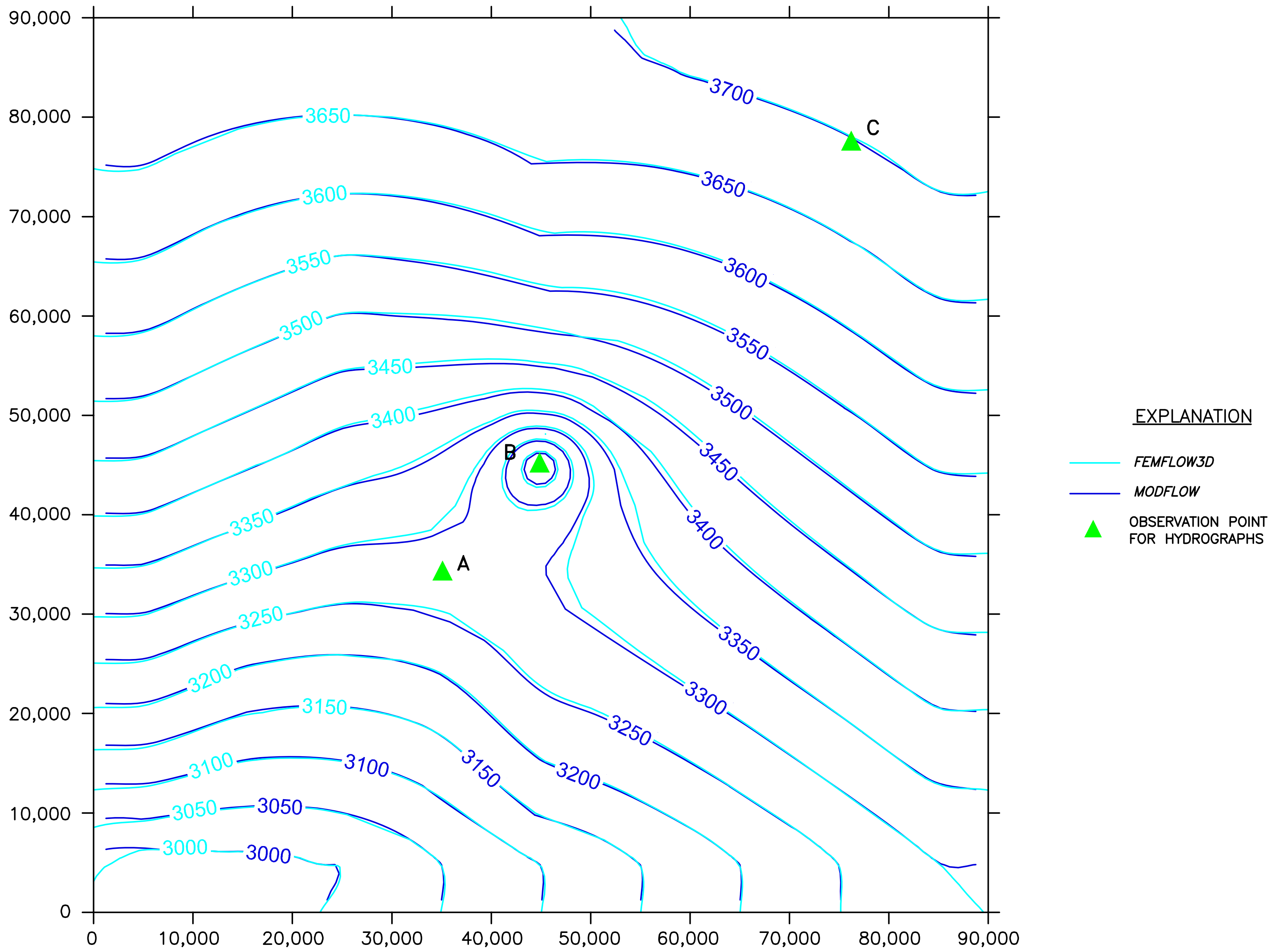
Calculated Water Tables after 20 Years of Pumping for Contrived Single Compartment Problem

FIGURE 7



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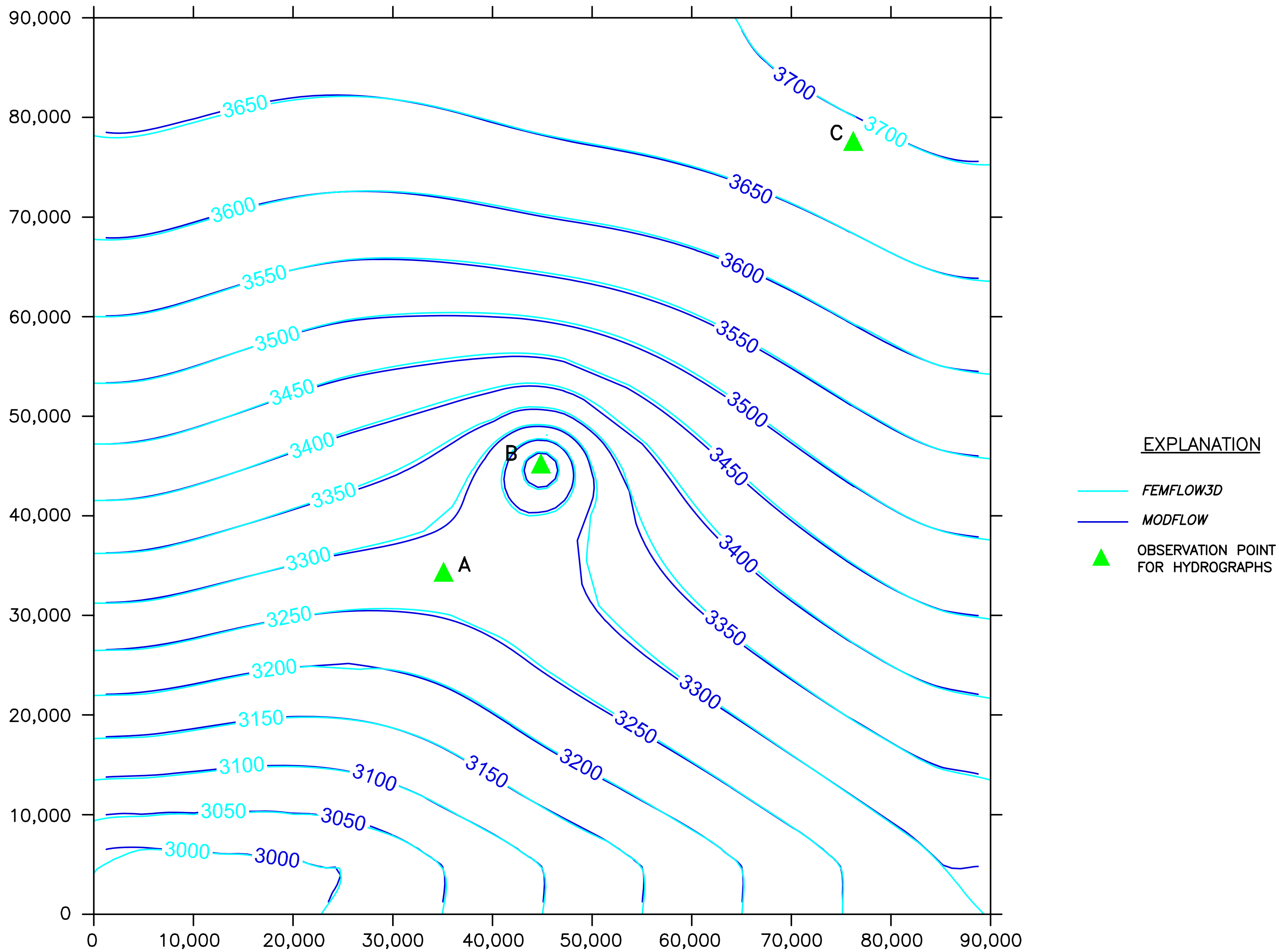
Calculated Hydraulic Heads at Elevation 1,6666 ft after 20 Years of Pumping for Contrived Single Compartment Problem

FIGURE 8



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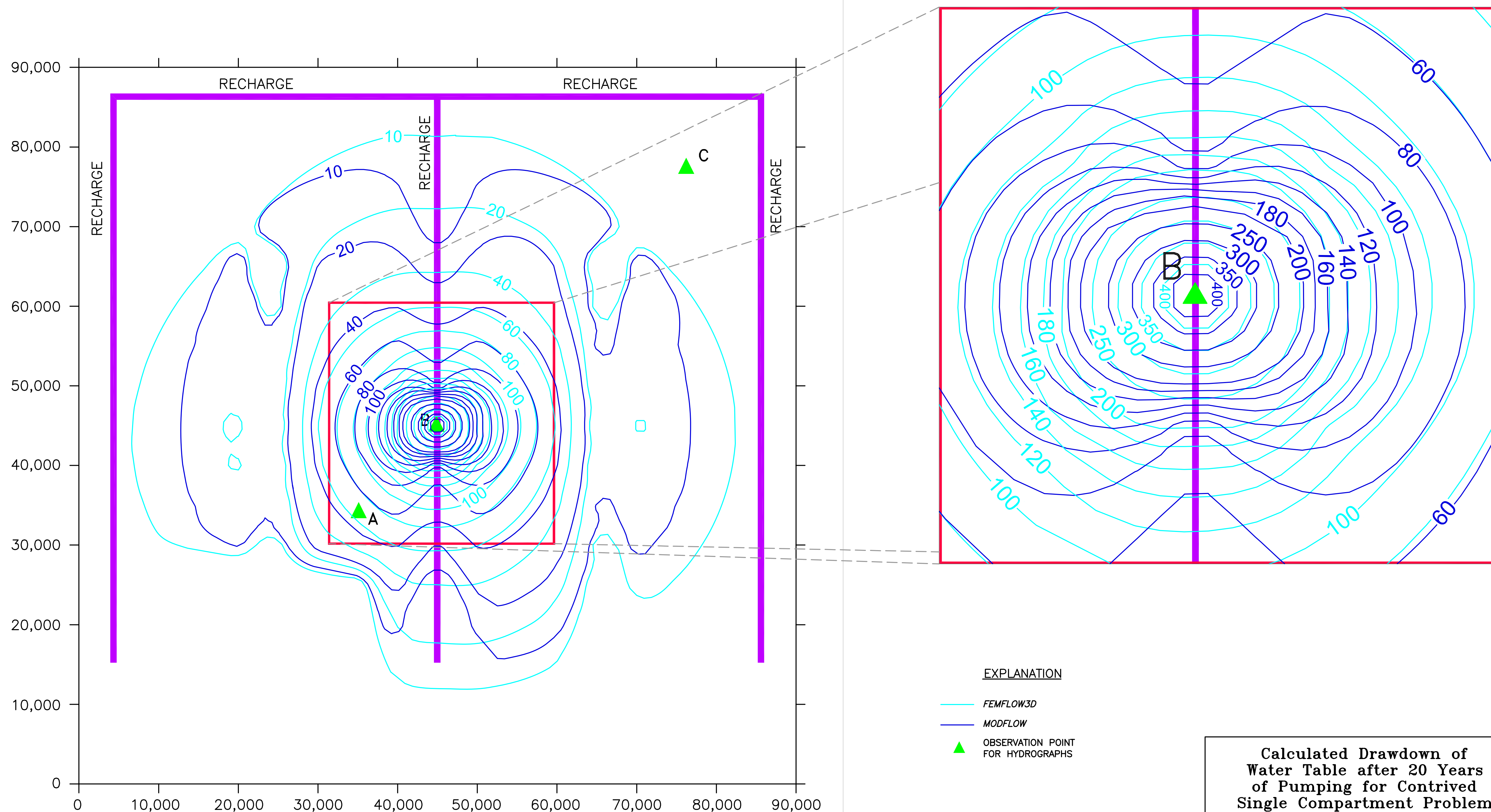
Calculated Hydraulic Heads at Elevation 375 ft after 20 Years of Pumping for Contrived Single Compartment Problem

FIGURE 9



Calculated Drawdown of Water Table after 20 Years of Pumping for Contrived Single Compartment Problem

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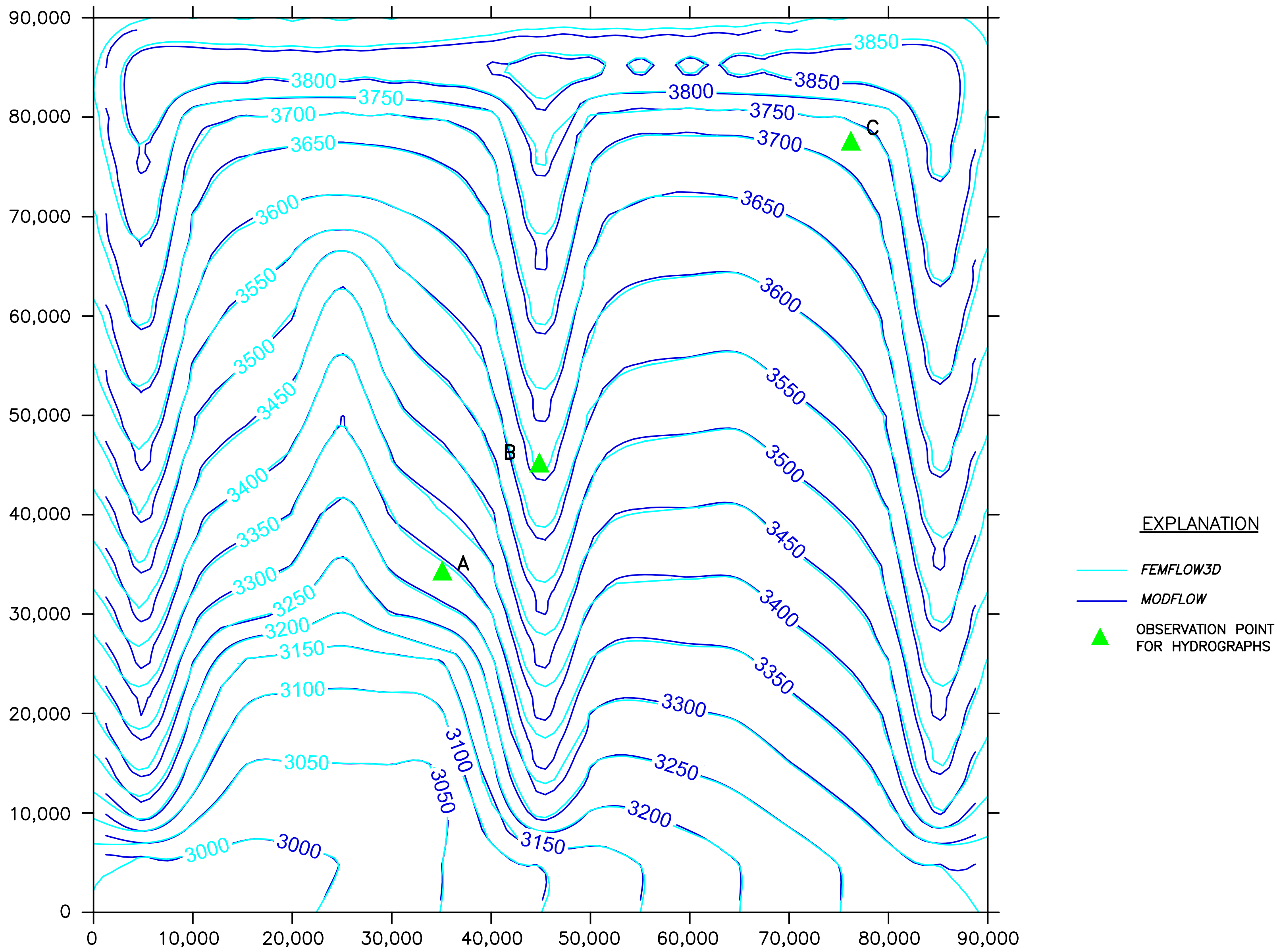
FIGURE 10



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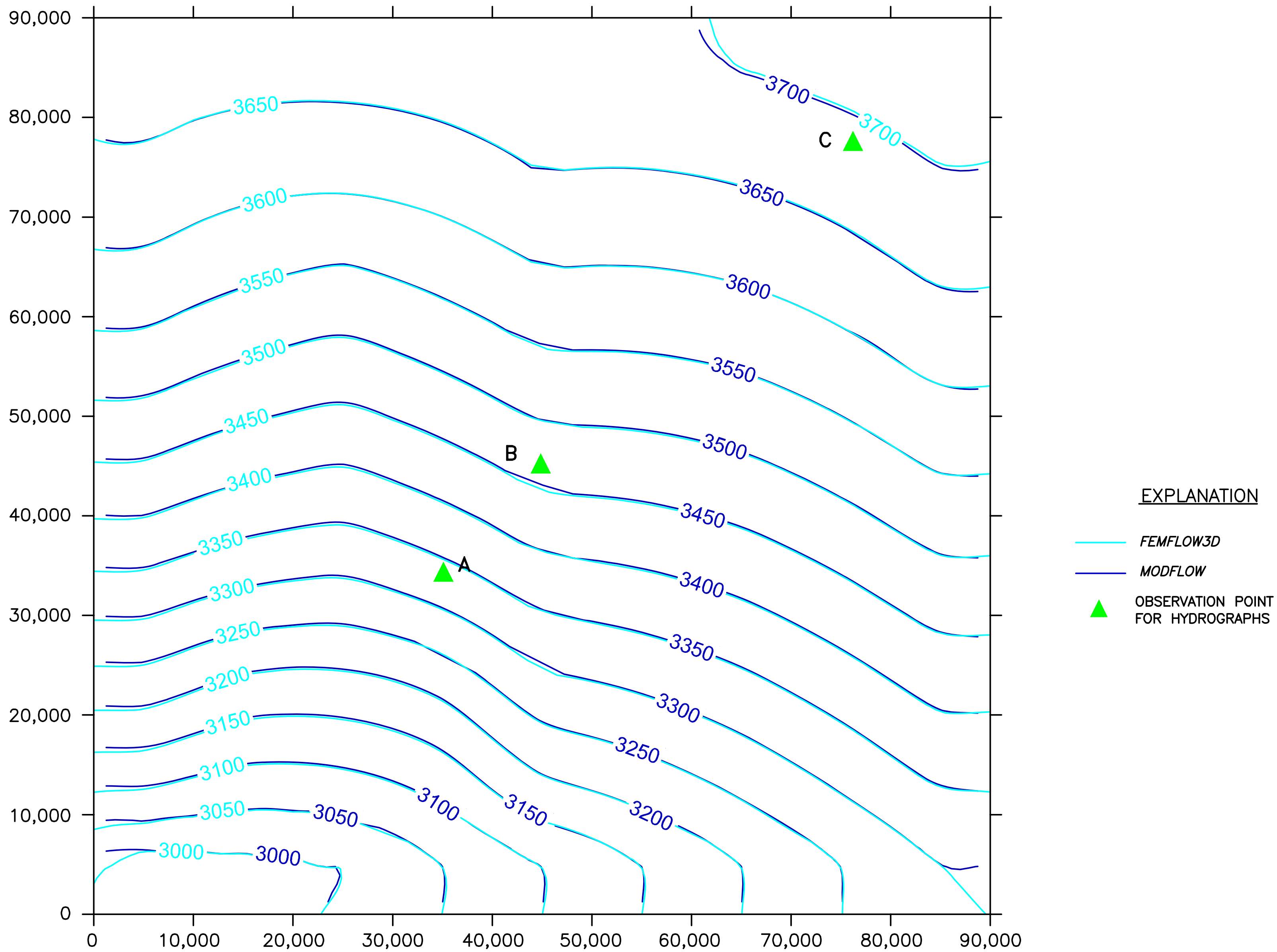
Calculated Water Table after 60 Years of Recovery for Contrived Single Compartment Problem

FIGURE 11



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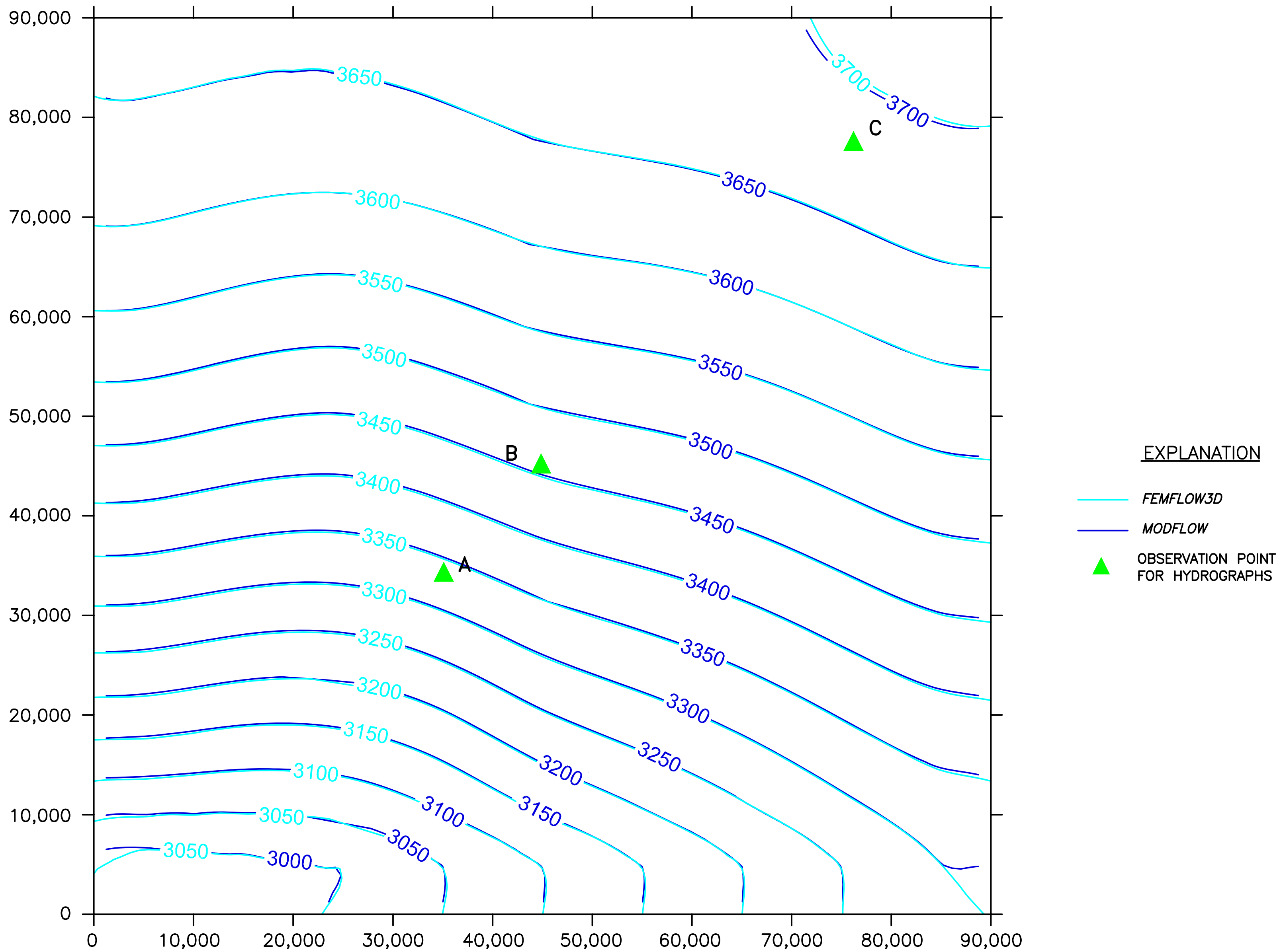
Calculated Hydraulic Heads at Elevation 1,6666 ft after 60 Years of Pumping for Contrived Single Compartment Problem

FIGURE 12



HCI HYDROLOGIC CONSULTANTS, INC.

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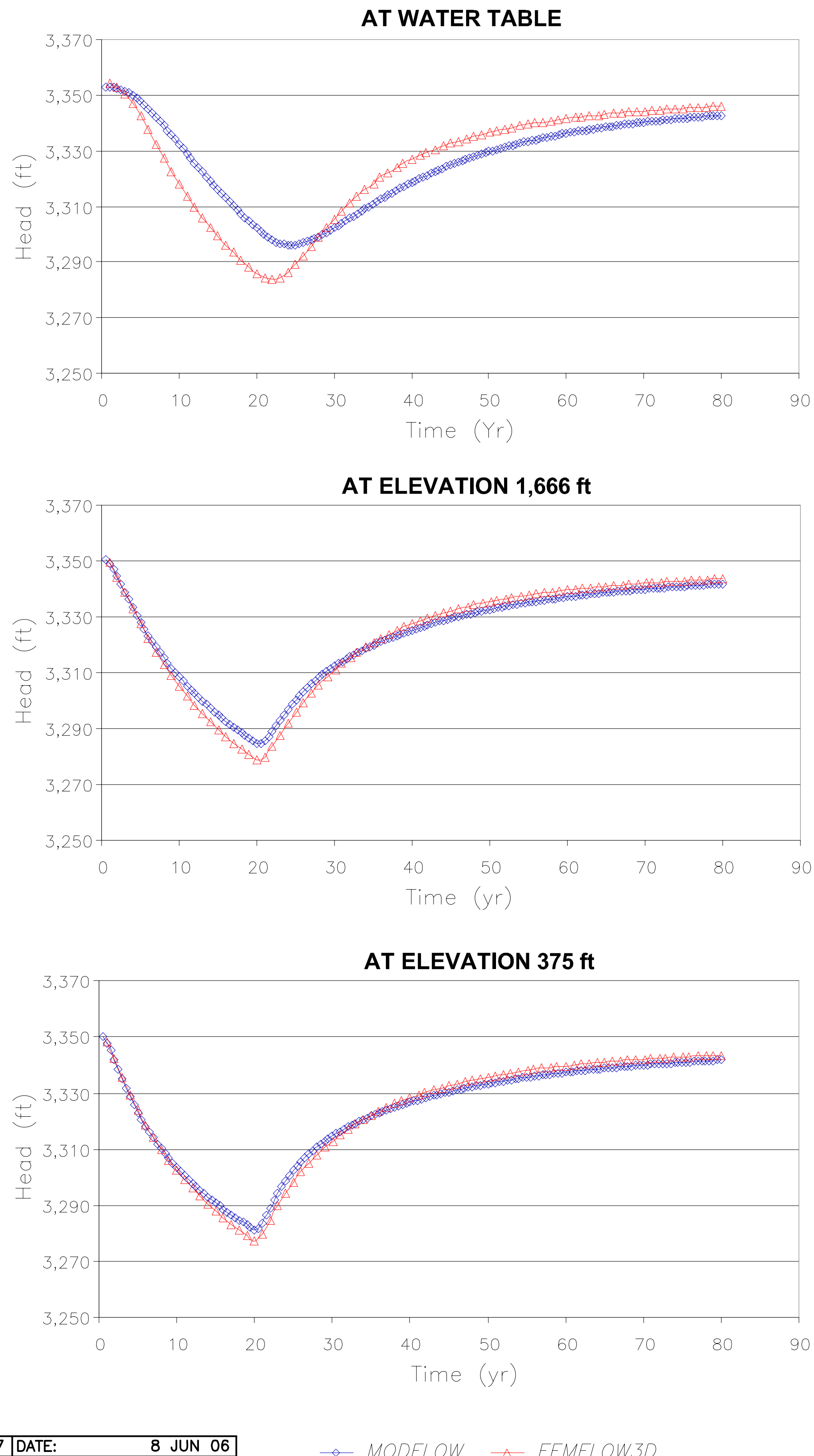
JOB NO.	HCI-1827	DATE:	8 JUN 06
BY:	HL	DWG FILE:	HEAD-375-60YRS
DRAWN:	SAC	PLOT FILE:	HEAD-375-60YRS
CHECKED:		PLOT DATE:	12 JUN 06

Calculated Hydraulic Heads at Elevation 375 ft after 60 Years of Recovery for Contrived Single Compartment Problem

FIGURE 13



JOB NO.	HCI–1827	DATE:	8 JUN 06
BY:	HL	DWG FILE:	HYDROGRAPH–A
DRAWN:	SAC	PLOT FILE:	HYDROGRAPH–A
CHECKED:		PLOT DATE:	12 JUN 06

HCI HYDROLOGIC CONSULTANTS, INC.

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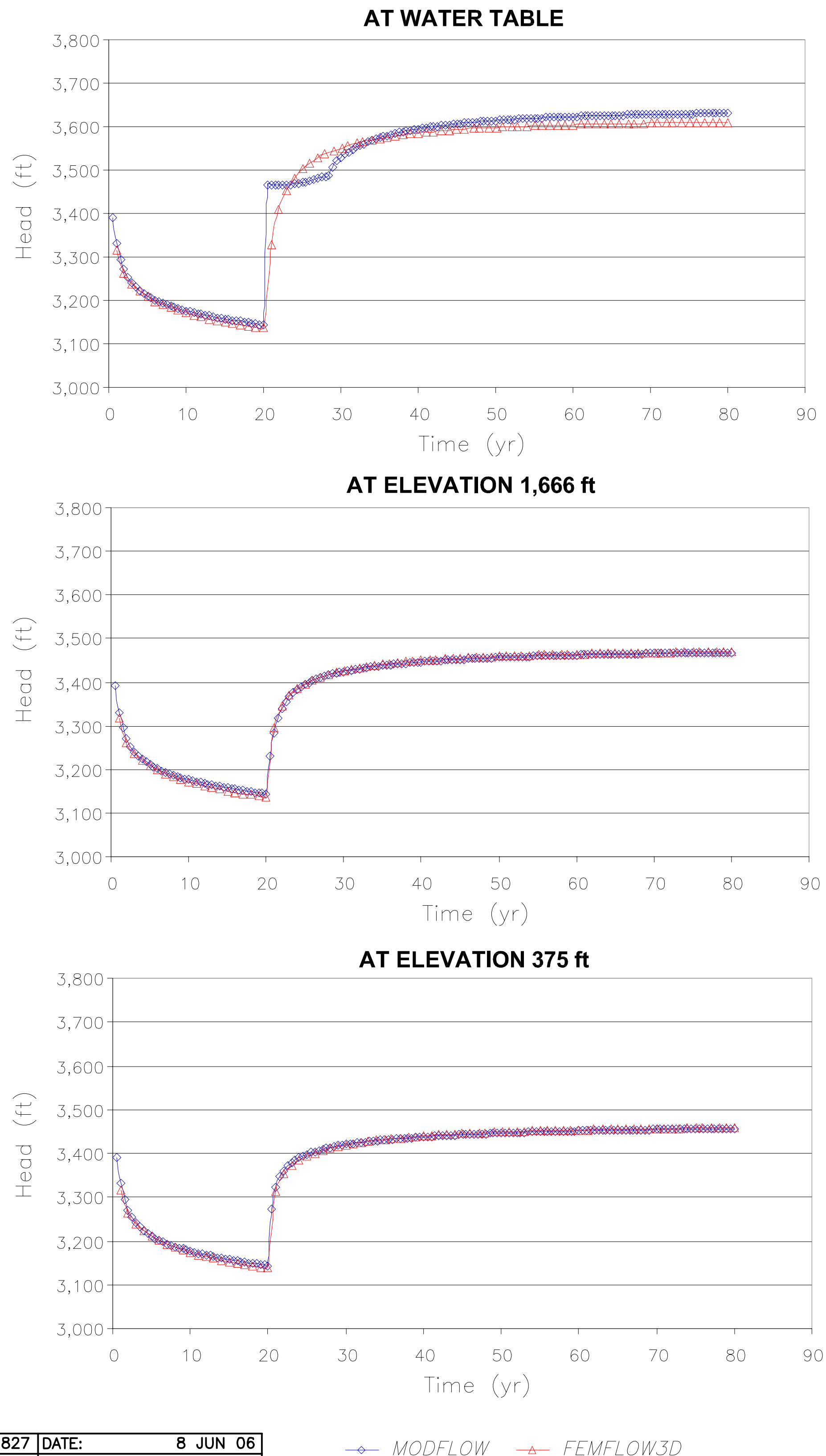
Hydrographs of Calculated Hydraulic Heads at Point A at Three Different Elevations

FIGURE 14



JOB NO.	HCI–1827	DATE:	8 JUN 06
BY:	HL	DWG FILE:	HYDROGRAPH–B
DRAWN:	SAC	PLOT FILE:	HYDROGRAPH–B
CHECKED:		PLOT DATE:	12 JUN 06

HCI HYDROLOGIC CONSULTANTS, INC.

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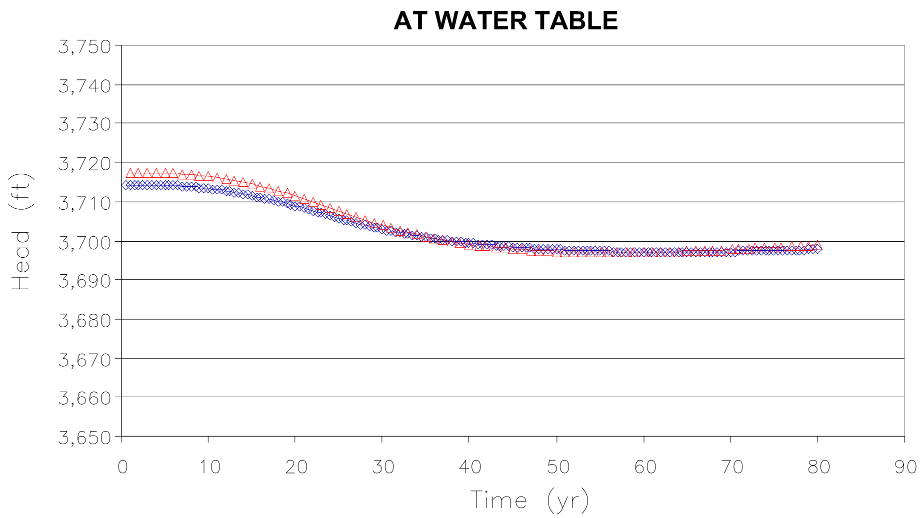
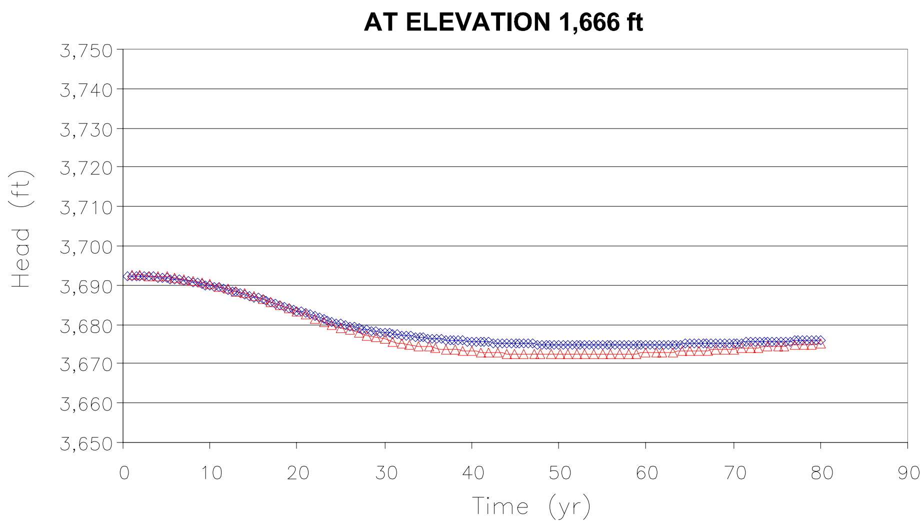
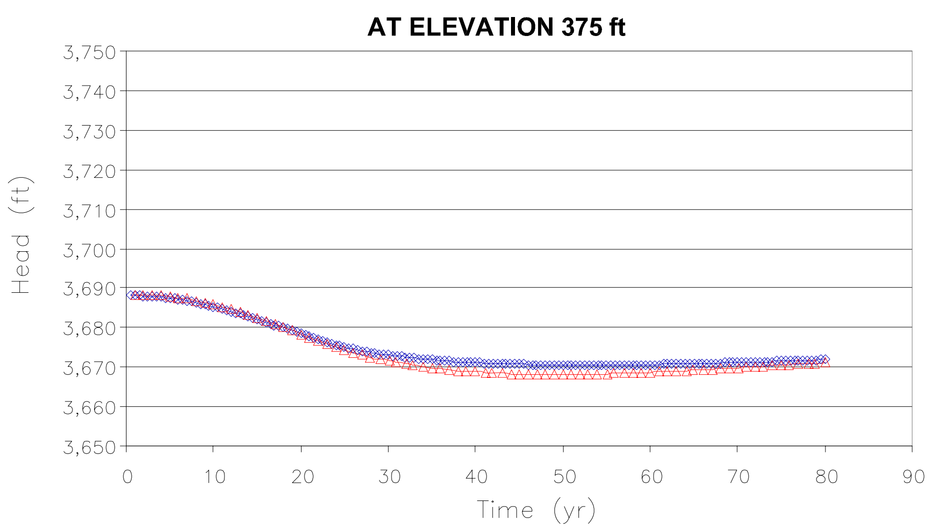
Hydrographs of Calculated Hydraulic Heads at Point B (Pumping Well) at Three Different Elevations

FIGURE 15





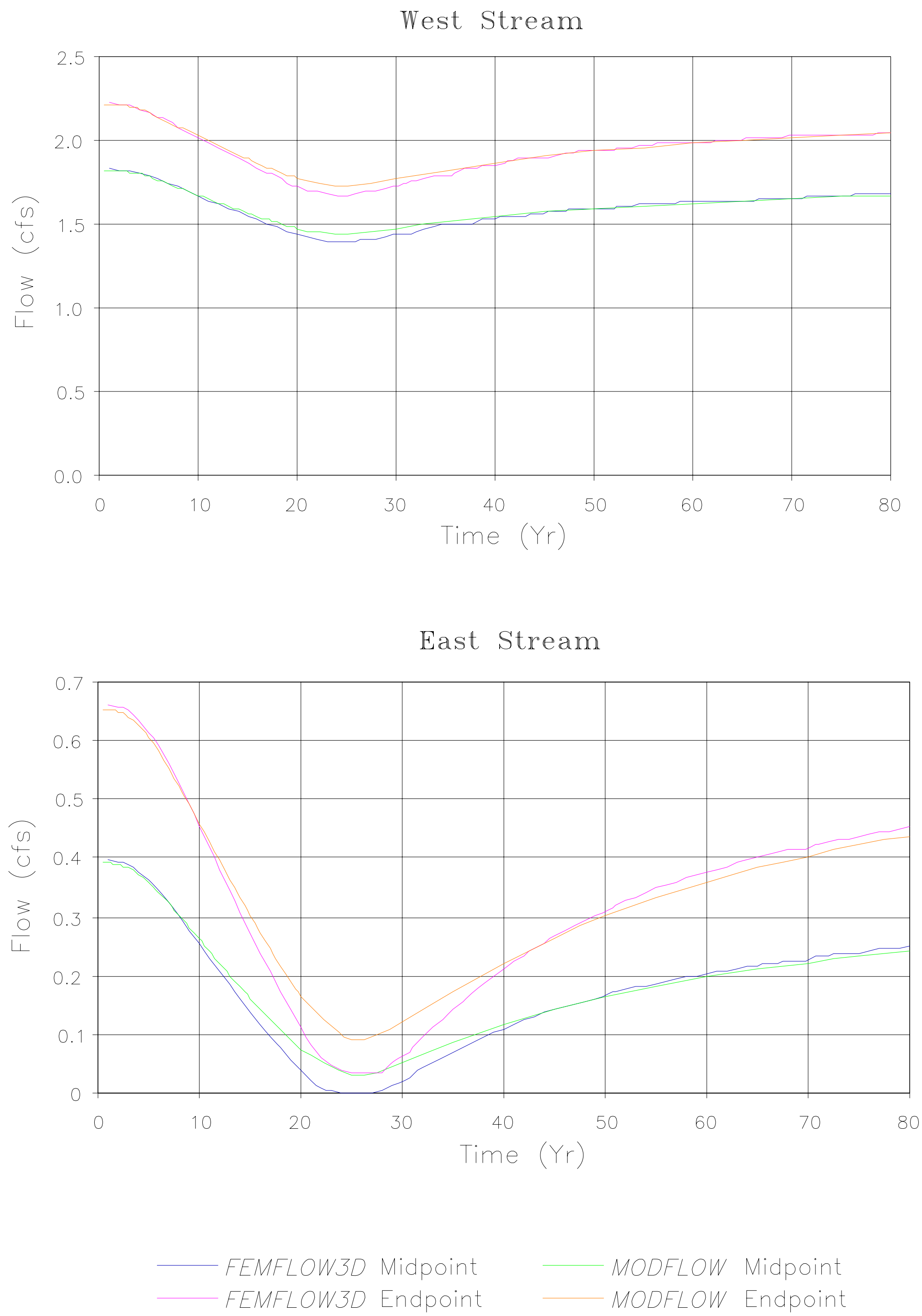


JOB NO.	HCI–1827	DATE:	8 JUN 06
BY:	HL	DWG FILE:	HYDROGRAPH–C
DRAWN:	SAC	PLOT FILE:	HYDROGRAPH–C
CHECKED:		PLOT DATE:	12 JUN 06

HCI HYDROLOGIC CONSULTANTS, INC. — HCI TASCA an company

Hydrographs of Calculated Hydraulic Heads at Point C at Three Different Elevations

FIGURE 16

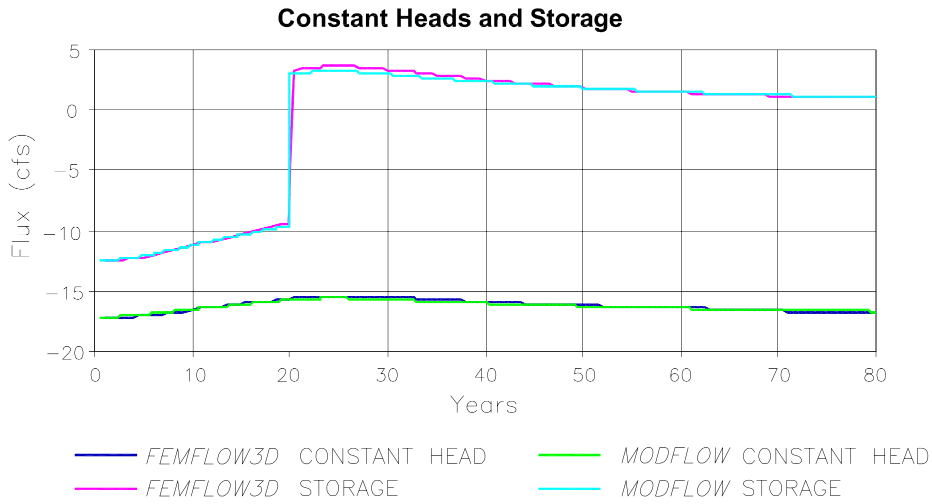


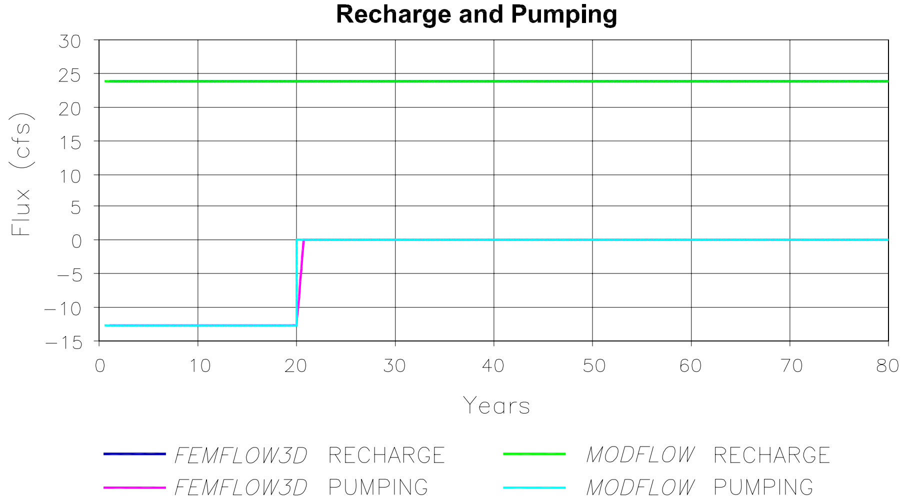
JOB NO.	HCI–1827	DATE:	8 JUN 06
BY:	HL	DWG FILE:	STREAM–FLOW
DRAWN:	SAC	PLOT FILE:	STREAM–FLOW
CHECKED:		PLOT DATE:	12 JUN 06

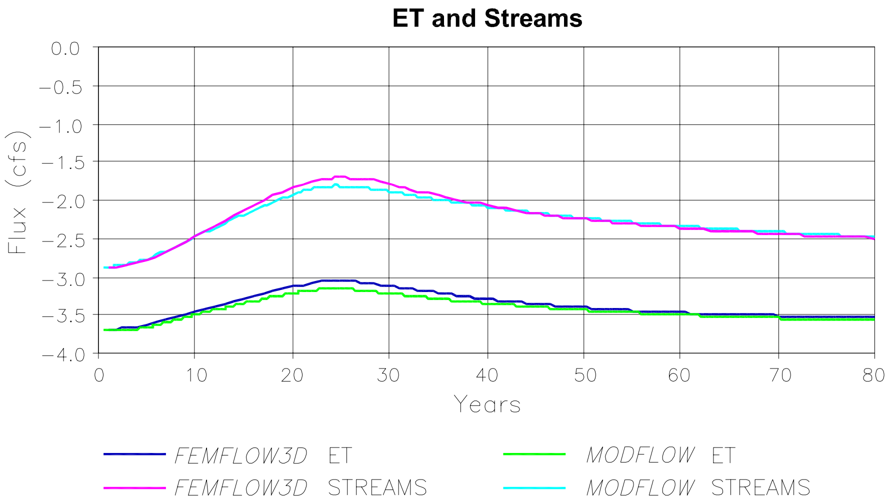
HCI HYDROLOGIC CONSULTANTS, INC. — HC|TASCA an company

Calculated Streamflows at Midpoints and Endpoints of Streams

FIGURE 17







JOB NO.	HCI–1827	DATE:	8 JUN 06
BY:	HL	DWG FILE:	WATER–BUDGETS
DRAWN:	SAC	PLOT FILE:	WATER–BUDGETS
CHECKED:		PLOT DATE:	12 JUN 06

HCI HYDROLOGIC CONSULTANTS, INC. HC|TASCA an company

Calculated Water Budgets

FIGURE 18

TABLE 1

Hydraulic Properties of Hydrostratigraphic Units Used in Contrived Problem

Parameter	Units	Upper Unit	Lower Unit
K_{xx}	ft/day	0.1	1
K_{yy}		0.1	1
K_{zz}		0.01	0.1
Specific Yield	dimensionless	0.01	0.01
Specific Storage	ft^{-1}	1×10^{-5}	1×10^{-5}

TABLE 2

Locations and Specified Elevations of Constant Head Nodes

FEMFLOW3D			***MODFLOW***		
Easting (ft)	**Northing (ft)**	**Elevation of Node (ft, NGVD)**	**Easting (ft)**	**Northing (ft)**	**Elevation of Node (ft, NGVD)**
Layer 1					
			1,250	5,000	2,980
5,000	5,000	2,980	5,000	5,000	2,980
10,000	5,000	2,985	10,000	5,000	2,985
15,000	5,000	2,990	15,000	5,000	2,990
20,000	5,000	2,995	20,000	5,000	2,995
25,000	5,000	3,000	25,000	5,000	3,000
30,000	5,000	3,025	30,000	5,000	3,025
35,000	5,000	3,050	35,000	5,000	3,050
40,000	5,000	3,075	40,000	5,000	3,075
45,000	5,000	3,100	45,000	5,000	3,100
50,000	5,000	3,125	50,000	5,000	3,125
55,000	5,000	3,150	55,000	5,000	3,150
60,000	5,000	3,175	60,000	5,000	3,175
65,000	5,000	3,200	65,000	5,000	3,200
70,000	5,000	3,225	70,000	5,000	3,225
75,000	5,000	3,250	75,000	5,000	3,250
80,000	5,000	3,275	80,000	5,000	3,275
85,000	5,000	3,300	85,000	5,000	3,300
			88,750	5,000	3,300
Layer 2					
			1,250	5,000	2,980
5,000	5,000	2,980	5,000	5,000	2,980
10,000	5,000	2,985	10,000	5,000	2,985
15,000	5,000	2,990	15,000	5,000	2,990
20,000	5,000	2,995	20,000	5,000	2,995
25,000	5,000	3,000	25,000	5,000	3,000
30,000	5,000	3,025	30,000	5,000	3,025
35,000	5,000	3,050	35,000	5,000	3,050
40,000	5,000	3,075	40,000	5,000	3,075
45,000	5,000	3,100	45,000	5,000	3,100

TABLE 2

Locations and Specified Elevations of Constant Head Nodes

FEMFLOW3D			*MODFLOW*		
Easting (ft)	**Northing (ft)**	**Elevation of Node (ft, NGVD)**	**Easting (ft)**	**Northing (ft)**	**Elevation of Node (ft, NGVD)**
Layer 2 (cont.)					
50,000	5,000	3,125	50,000	5,000	3,125
55,000	5,000	3,150	55,000	5,000	3,150
60,000	5,000	3,175	60,000	5,000	3,175
65,000	5,000	3,200	65,000	5,000	3,200
70,000	5,000	3,225	70,000	5,000	3,225
75,000	5,000	3,250	75,000	5,000	3,250
80,000	5,000	3,275	80,000	5,000	3,275
85,000	5,000	3,300	85,000	5,000	3,300
			88,750	5,000	3,300
Layer 3					
			1,250	5,000	2,980
5,000	5,000	2,980	5,000	5,000	2,980
10,000	5,000	2,985	10,000	5,000	2,985
15,000	5,000	2,990	15,000	5,000	2,990
20,000	5,000	2,995	20,000	5,000	2,995
25,000	5,000	3,000	25,000	5,000	3,000
30,000	5,000	3,025	30,000	5,000	3,025
35,000	5,000	3,050	35,000	5,000	3,050
40,000	5,000	3,075	40,000	5,000	3,075
45,000	5,000	3,100	45,000	5,000	3,100
50,000	5,000	3,125	50,000	5,000	3,125
55,000	5,000	3,150	55,000	5,000	3,150
60,000	5,000	3,175	60,000	5,000	3,175
65,000	5,000	3,200	65,000	5,000	3,200
70,000	5,000	3,225	70,000	5,000	3,225
75,000	5,000	3,250	75,000	5,000	3,250
80,000	5,000	3,275	80,000	5,000	3,275
85,000	5,000	3,300	85,000	5,000	3,300
			88,750	5,000	3,300

TABLE 2

Locations and Specified Elevations of Constant Head Nodes

FEMFLOW3D			*MODFLOW*		
Easting (ft)	**Northing (ft)**	**Elevation of Node (ft, NGVD)**	**Easting (ft)**	**Northing (ft)**	**Elevation of Node (ft, NGVD)**
Layer 4					
			1,250	5,000	2,980
5,000	5,000	2,980	5,000	5,000	2,980
10,000	5,000	2,985	10,000	5,000	2,985
15,000	5,000	2,990	15,000	5,000	2,990
20,000	5,000	2,995	20,000	5,000	2,995
25,000	5,000	3,000	25,000	5,000	3,000
30,000	5,000	3,025	30,000	5,000	3,025
35,000	5,000	3,050	35,000	5,000	3,050
40,000	5,000	3,075	40,000	5,000	3,075
45,000	5,000	3,100	45,000	5,000	3,100
50,000	5,000	3,125	50,000	5,000	3,125
55,000	5,000	3,150	55,000	5,000	3,150
60,000	5,000	3,175	60,000	5,000	3,175
65,000	5,000	3,200	65,000	5,000	3,200
70,000	5,000	3,225	70,000	5,000	3,225
75,000	5,000	3,250	75,000	5,000	3,250
80,000	5,000	3,275	80,000	5,000	3,275
85,000	5,000	3,300	85,000	5,000	3,300
			88,750	5,000	3,300
Layer 5					
			1,250	5,000	2,980
5,000	5,000	2,980	5,000	5,000	2,980
10,000	5,000	2,985	10,000	5,000	2,985
15,000	5,000	2,990	15,000	5,000	2,990
20,000	5,000	2,995	20,000	5,000	2,995
25,000	5,000	3,000	25,000	5,000	3,000
30,000	5,000	3,025	30,000	5,000	3,025
35,000	5,000	3,050	35,000	5,000	3,050

TABLE 2

Locations and Specified Elevations of Constant Head Nodes
Page 4 of 6

FEMFLOW3D			***MODFLOW***		
Easting (ft)	**Northing (ft)**	**Elevation of Node (ft, NGVD)**	**Easting (ft)**	**Northing (ft)**	**Elevation of Node (ft, NGVD)**
Layer 5 (cont.)					
40,000	5,000	3,075	40,000	5,000	3,075
45,000	5,000	3,100	45,000	5,000	3,100
50,000	5,000	3,125	50,000	5,000	3,125
55,000	5,000	3,150	55,000	5,000	3,150
60,000	5,000	3,175	60,000	5,000	3,175
65,000	5,000	3,200	65,000	5,000	3,200
70,000	5,000	3,225	70,000	5,000	3,225
75,000	5,000	3,250	75,000	5,000	3,250
80,000	5,000	3,275	80,000	5,000	3,275
85,000	5,000	3,300	85,000	5,000	3,300
			88,750	5,000	3,300
Layer 6					
			1,250	5,000	2,980
5,000	5,000	2,980	5,000	5,000	2,980
10,000	5,000	2,985	10,000	5,000	2,985
15,000	5,000	2,990	15,000	5,000	2,990
20,000	5,000	2,995	20,000	5,000	2,995
25,000	5,000	3,000	25,000	5,000	3,000
30,000	5,000	3,025	30,000	5,000	3,025
35,000	5,000	3,050	35,000	5,000	3,050
40,000	5,000	3,075	40,000	5,000	3,075
45,000	5,000	3,100	45,000	5,000	3,100
50,000	5,000	3,125	50,000	5,000	3,125
55,000	5,000	3,150	55,000	5,000	3,150
60,000	5,000	3,175	60,000	5,000	3,175
65,000	5,000	3,200	65,000	5,000	3,200
70,000	5,000	3,225	70,000	5,000	3,225
75,000	5,000	3,250	75,000	5,000	3,250
80,000	5,000	3,275	80,000	5,000	3,275

TABLE 2

Locations and Specified Elevations of Constant Head Nodes
Page 5 of 6

FEMFLOW3D			*MODFLOW*		
Easting (ft)	**Northing (ft)**	**Elevation of Node (ft, NGVD)**	**Easting (ft)**	**Northing (ft)**	**Elevation of Node (ft, NGVD)**
Layer 6 (cont.)					
85,000	5,000	3,300	85,000	5,000	3,300
			88,750	5,000	3,300
Layer 7					
			1,250	5,000	2,980
5,000	5,000	2,980	5,000	5,000	2,980
10,000	5,000	2,985	10,000	5,000	2,985
15,000	5,000	2,990	15,000	5,000	2,990
20,000	5,000	2,995	20,000	5,000	2,995
25,000	5,000	3,000	25,000	5,000	3,000
30,000	5,000	3,025	30,000	5,000	3,025
35,000	5,000	3,050	35,000	5,000	3,050
40,000	5,000	3,075	40,000	5,000	3,075
45,000	5,000	3,100	45,000	5,000	3,100
50,000	5,000	3,125	50,000	5,000	3,125
55,000	5,000	3,150	55,000	5,000	3,150
60,000	5,000	3,175	60,000	5,000	3,175
65,000	5,000	3,200	65,000	5,000	3,200
70,000	5,000	3,225	70,000	5,000	3,225
75,000	5,000	3,250	75,000	5,000	3,250
80,000	5,000	3,275	80,000	5,000	3,275
85,000	5,000	3,300	85,000	5,000	3,300
			88,750	5,000	3,300
Layer 8					
			1,250	5,000	2,980
5,000	5,000	2,980	5,000	5,000	2,980
10,000	5,000	2,985	10,000	5,000	2,985
15,000	5,000	2,990	15,000	5,000	2,990
20,000	5,000	2,995	20,000	5,000	2,995
25,000	5,000	3,000	25,000	5,000	3,000

TABLE 2

Locations and Specified Elevations of Constant Head Nodes

FEMFLOW3D			*MODFLOW*		
Easting (ft)	**Northing (ft)**	**Elevation of Node (ft, NGVD)**	**Easting (ft)**	**Northing (ft)**	**Elevation of Node (ft, NGVD)**
Layer 8 (cont.)					
30,000	5,000	3,025	30,000	5,000	3,025
35,000	5,000	3,050	35,000	5,000	3,050
40,000	5,000	3,075	40,000	5,000	3,075
45,000	5,000	3,100	45,000	5,000	3,100
50,000	5,000	3,125	50,000	5,000	3,125
55,000	5,000	3,150	55,000	5,000	3,150
60,000	5,000	3,175	60,000	5,000	3,175
65,000	5,000	3,200	65,000	5,000	3,200
70,000	5,000	3,225	70,000	5,000	3,225
75,000	5,000	3,250	75,000	5,000	3,250
80,000	5,000	3,275	80,000	5,000	3,275
85,000	5,000	3,300	85,000	5,000	3,300
			88,750	5,000	3,300
Layer 9					
5,000	5,000	2,980			
10,000	5,000	2,985			
15,000	5,000	2,990			
20,000	5,000	2,995			
25,000	5,000	3,000			
30,000	5,000	3,025			
35,000	5,000	3,050			
40,000	5,000	3,075			
45,000	5,000	3,100			
50,000	5,000	3,125			
55,000	5,000	3,150			
60,000	5,000	3,175			
65,000	5,000	3,200			
70,000	5,000	3,225			
75,000	5,000	3,250			
80,000	5,000	3,275			
85,000	5,000	3,300			

TABLE 3

Locations and Specified Elevations of Stream Nodes

FEMFLOW3D				*MODFLOW*			
Easting (ft)	**Northing (ft)**	**Length of Reach (ft)**	**Elevation of Streambed (ft, NGVD)**	**Easting (ft)**	**Northing (ft)**	**Length of Reach (ft)**	**Elevation of Streambed (ft, NGVD)**
Stream 1							
25,000	65,000	5,000	3,400.0	25,000	65,000	5,000	3,400.0
25,000	60,000	5,000	3,366.7	25,000	60,000	5,000	3,366.7
25,000	55,000	5,000	3,333.4	25,000	55,000	5,000	3,333.3
25,000	50,000	5,000	3,300.0	25,000	50,000	5,000	3,300.3
25,000	45,000	5,000	3,266.7	25,000	45,000	5,000	3,266.7
25,000	40,000	5,000	3,233.3	25,000	40,000	5,000	3,233.3
25,000	35,000	5,000	3,200.0	25,000	35,000	5,000	3,200.0
25,000	30,000	5,000	3,166.7	25,000	30,000	5,000	3,166.7
25,000	25,000	5,000	3,133.3	25,000	25,000	5,000	3,133.3
25,000	20,000	5,000	3,100.0	25,000	20,000	5,000	3,100.0
25,000	15,000	5,000	3,066.7	25,000	15,000	5,000	3,066.7
25,000	10,000	5,000	3,033.4	25,000	10,000	5,000	3,033.4
Stream 2							
65,000	65,000	5,000	3,600.0	65,000	65,000	5,000	3,600.0
65,000	60,000	5,000	3,566.7	65,000	60,000	5,000	3,566.7
65,000	55,000	5,000	3,533.4	65,000	55,000	5,000	3,533.3
65,000	50,000	5,000	3,500.0	65,000	50,000	5,000	3,500.0
65,000	45,000	5,000	3,466.7	65,000	45,000	5,000	3,466.7
65,000	40,000	5,000	3,433.3	65,000	40,000	5,000	3,433.3
65,000	35,000	5,000	3,400.0	65,000	35,000	5,000	3,400.0
65,000	30,000	5,000	3,366.7	65,000	30,000	5,000	3,366.7
65,000	25,000	5,000	3,333.3	65,000	25,000	5,000	3,333.3
65,000	20,000	5,000	3,300.0	65,000	20,000	5,000	3,300.0
65,000	15,000	5,000	3,266.7	65,000	15,000	5,000	3,266.7
65,000	10,000	5,000	3,233.3	65,000	10,000	5,000	3,233.3

TABLE 4

Calculated Water Budgets under Steady-State Conditions

Component (cfs)	**Calculated by**	
	FEMFLOW3D	***MODFLOW***
Recharge	23.73	23.78
Constant Head	-17.25	-17.18
ET	-3.68	-3.73
Streams	-2.88	-2.87