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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: **Additional Comments on *FEMFLOW3D* Documentation and Review of Source Code**

DATE: **June 6, 2006**

INTRODUCTION

On May 5, 2006, Hydrologic Consultants, Inc. (HCI) prepared a Technical Memorandum for the Southern Nevada Water Authority (SNWA) summarizing our preliminary review of the document entitled "*FEMFLOW3D* - A Finite-Element Program for the Simulation of Three-Dimensional Groundwater Systems, Version 2" (subsequently referred to as the "User Manual"). Since then, HCI has done an addition review of the source code of *FEMFLOW3D* (subsequently referred to as the "Source Code"), and compared the Source Code to the User Manual for consistency.

This Technical Memorandum summarizes our review and supplements our previous memorandum of May 5, 2006 (HCI, 2006). We hope this review arrives timely for SNWA to respond and meet the tight release schedule.

ADDITIONAL EDITS TO USER MANUAL

In addition to previous comments submitted to SNWA (HCI 2006), the following edits are based on our further review of the User Manual and Source Code:

P1-4, Figure 1-1: FAULT should be WFAULT

P1-4, Figure 1-1: WSHAPE is not included in the figure

P2-26, Equations 2-72 to 2-79: "," should be "*"

P2-26, Equations 2-73: should be $H_{12} = \sin \alpha_1 * \cos \alpha_3 - \cos \alpha_1 * \sin \alpha_2 * \sin \alpha_3$

P2-26, Equations 2-74: should be $H_{13} = \sin \alpha_1 * \sin \alpha_3 - \cos \alpha_1 * \sin \alpha_2 * \cos \alpha_3$

P2-26, Equations 2-79: should be $H_{32} = \cos \alpha_2 * \sin \alpha_3$

P2-26: $H_{33} = \cos \alpha_2 * \cos \alpha_3$ should be added to the manual as **Equation 2-80**

P2-36, Equation 2-111: $\sum C_w$ should be $\{C_w\}$

P3-2, Record 4: CNAME should be CNAME()

P3-4, Record 5: NC() should be NC

P3-5, line 3: COL should be COL()

P3-7 and P3-8, Record 3: KX(), KY(), KZ(), SS(), SY(), ITOP should be changed to XKX(), XKY(), XKZ(), XSS(), XSY(), XITOP

P3-8, Record 5: ALPHA1(), ALPHA2(), ALPHA3() should be changed to XALPHA1, XALPHA2, XALPHA3

P3-9: Record 6: does not exist in the code

REVIEW OF SOURCE CODE

General Comments

In general, the source code is very well designed and organized with good "readability". The author assigned variable names based on the intended application of that variable. The source code implements all the features described in the User Manual.

Although the description of each subroutine, along with variables, is provided in the User Manual, the readability of the code itself would be improved if the following were added -- as Comments -- to the Source Code:

1) A brief description of the purpose of each subroutine; and

2) A description of each key variable used in the subroutine.

Specific Comments

The following are comments related to specific subroutines:

BASIC

FEMFLOW3D has three alternative solvers for solving the system of equations. However, there are no recommendations or criteria included for selecting the most appropriate solver for a specific problem. HCI recommends providing users with some guidance on selection of the most apprpriate solver for a particular problem.

NODES

This subroutine includes the element pinch-out feature, but the feature is not described in the documentation. Based on HCI's own experience, preparation of pinch-out data is difficult. Thus, HCI recommends providing a detailed description of data requirements and showing a good example for a user to follow.

SITPACK

This subroutine can produce different levels of outputs from solver iterations with the variable ***Level.*** The User Manual, however, does not explain the meaning of ***Level*** and the range of values that should be used.

SAMG

The default parameters are hard-coded in the source code. Are these parameters the optimal parameters?

The User Manual should explain the meanings of ***LEVELX***, ***NCYC1***, ***NCYC2***, ***NCYC3***, and ***NCYC4*** and provide the recommended values of these variables.

PACK

In the subroutine ***PACK1,*** input data are required, if ***IMATRIX*** is 2. This input data, however, are not explained and included in the User Manual. The User Manual should provide instructions on how to create the input data for the input and output of the matrix structure.

WCHAED

This subroutine uses ***CHTAB()*** to identify the table of specified heads for a given node. The User Manual, however, does not explain that ***CHTAB()*** should be a global table ID or a local table ID in a given compartment.

WFLUX

This subroutine uses ***FXTAB()*** to identify the table of specified flux for a given node. The User Manual, however, does not explain whether ***FXTAB()*** should be a global table ID or a local table ID in a given compartment.

WEVAP

This subroutine uses ***ETTAB()*** to identify the table of specified evaporation rate for a given node. The User Manual, however, does not explain whether ***ETTAB()*** should be a global table ID or a local table ID in a given compartment.

WRIVER

Parameters used in the ***WRIVER*** code are not clearly described in the documentation. The code is set up to simulate tributary reaches, lateral inflow, and channel geometry. The description of these features, however, is not included in the documentation.

This module also has complicated input data that need more explaining and clarification. HCI recommends preparing a simple schematic diagram showing the meaning of the variables to help the user understand the following features:

- cross-section link,
- ***QXTB()***, the joint of the reach,
- width and depth of the river; and
- lateral inflow.

WFAULT

This module contains complicated input data that need more explanation and clarification. HCI recommends preparing a simple schematic diagram showing the meaning of the input data, such as NFL (number of fault link), In2(,1), and In2(,2), for the ***WFAULT*** subroutine.

MODEL VALIDATION

As part of the review and model validation, HCI re-ran the following three problems as documented in the User Manual to verify their reproducibility:

1. The Theis Problem

2. The Papadopulos Problem

3. The Neuman Problem

Good descriptions of the three problems are in the User Manual and are not repeated here. Using the exact input files prepared by the author, HCI was able to reproduce the results for the three problems. All three solutions were derived using the ***Point Over-Relaxation Method***.

In order to evaluate the solutions derived from the other two solvers (see comments above regarding the three alternative solvers), HCI also solved the problems using the ***Conjugate-***

Gradient (CG) Method and the ***Multi-Grid (MG) Method***. The convergence criterion for the ***CG Method*** is 1 x 10^{-7} ft. The default parameters were used for the ***MG Method***.

Figure 1 compares the drawdowns calculated by the three solvers from *FEMFLOW3D* with those from the Theis analytical solution. In general, the results from all three solvers are in close agreement with the analytical solution.

Figure 2 shows that the simulated results from the ***CG Method*** and ***Over-Relaxation Method*** are in close agreement with each other and in close agreement with the Papadopulos analytical solution. The simulated results from the ***MG Method*** with default parameters are not in as close agreement with the results from the analytical solution as those from the ***CG*** or the ***Over-Relaxation Methods***. It is not clear why the solution from the MG Method diverges from the analytical solution at 409 ft from the pumping well in comparison with those from 184 ft and 448 ft from the pumping well.

In Figures 3 and 4, results from the ***MG Method*** are in closer agreement with the Neuman analytical solutions than those from the ***CG*** and ***Over-Relaxation Methods***.

In summary, the comparison of results from the analytical solutions and numerical solutions using the ***Over-Relaxation Method***, the ***CG Method***, and the ***MG Method*** solvers indicate:

1) All three solvers work properly for the given problems.

2) Some solvers produce results that are closer to the analytical solution than the other solver(s) for the various problems.

As noted above, there are no suggestions from the author as to the applicability of the various solvers for problems in general.

CLOSURE

HCI appreciates this opportunity to work with SNWA on this project. If you have any questions or require further clarification about these comments, please do not hesitate to contact me.

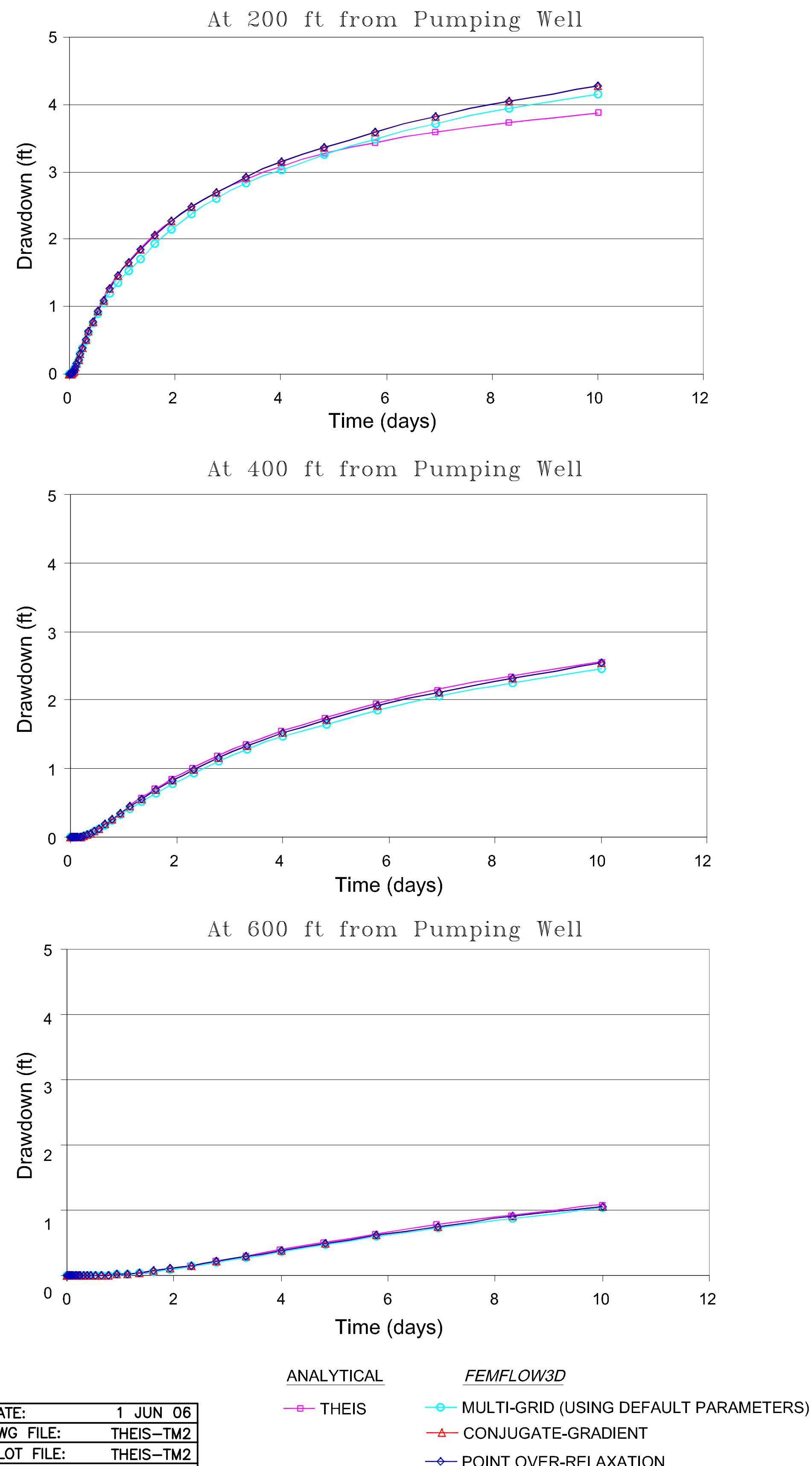
REFERENCES

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

Attachments: Figure 1 - Comparison of Drawdowns at Various Distances from Pumping Well Calculated by *FEMFLOW3D* Using Three Solvers to those Calculated by Theis Solution

Figure 2 - Comparison of Drawdowns at Various Distances from Pumping Well Calculated by *FEMFLOW3D* Using Three Solvers to those Calculated

by Papadopulos Solution
Figure 3 - Comparison of Drawdowns at Various Depths at Distance of 200 ft from Pumping Well Calculated by *FEMFLOW3D* Using Three Solvers to those Calculated by Neuman Solution
Figure 4 - Comparison of Drawdowns at Various Depths at Distance of 400 ft from Pumping Well Calculated by *FEMFLOW3D* Using Three Solvers to those Calculated by Neuman Solution



JOB NO.	HCI–1827	DATE:	1 JUN 06
BY:	HL	DWG FILE:	THEIS–TM2
DRAWN:	SAC	PLOT FILE:	THEIS–TM2
CHECKED:		PLOT DATE:	5 JUN 06

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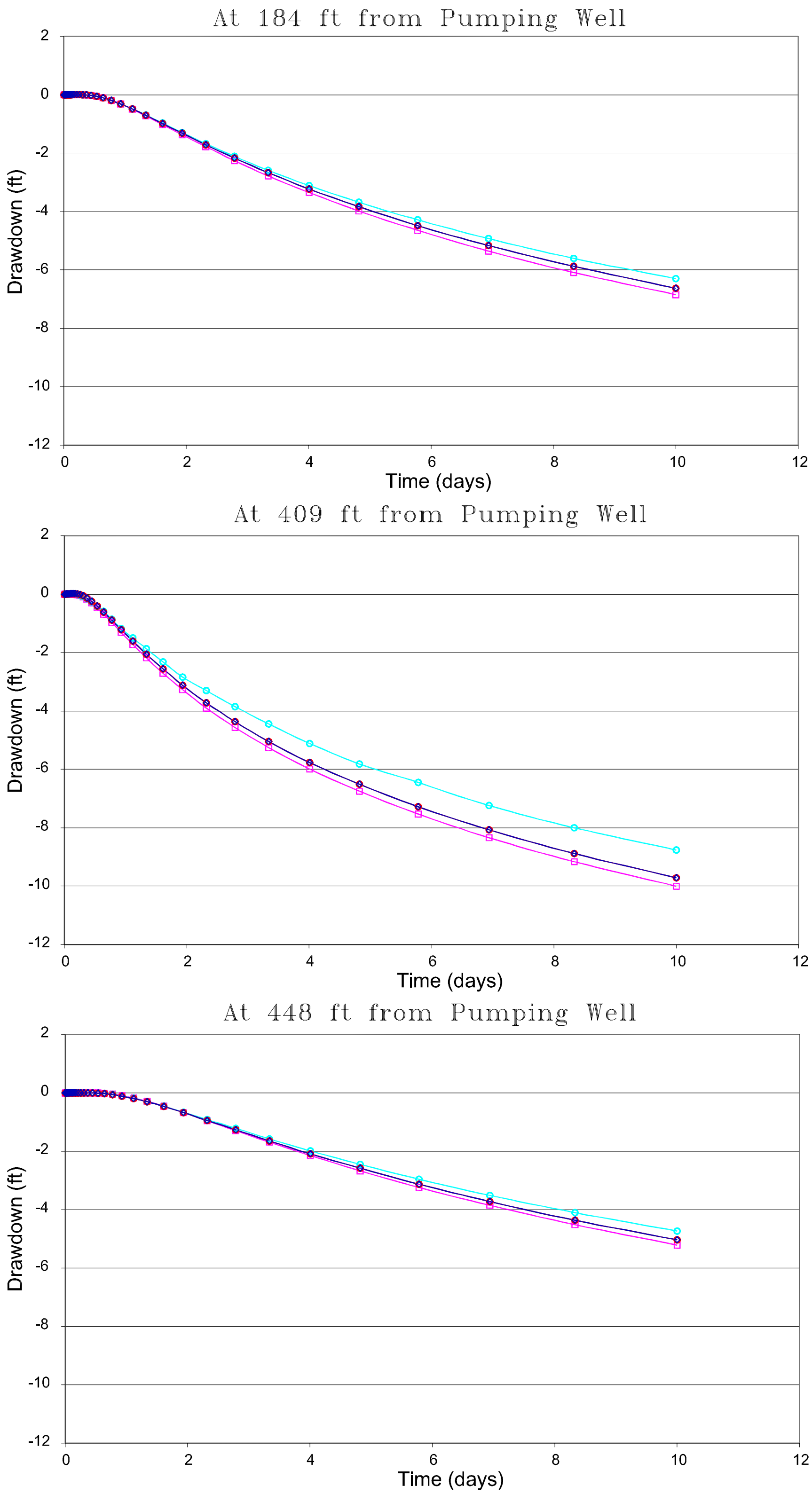
Comparison of Drawdowns at Various Distances from Pumping Well Calculated by *FEMFLOW3D* Using Three Solvers to those Calculated by Theis Solution

FIGURE 1



JOB NO.	HCI–1827	DATE:	2 JUN 06
BY:	HL	DWG FILE:	PAPADOPULOS–TM2
DRAWN:	SAC	PLOT FILE:	PAPADOPULOS–TM2
CHECKED:		PLOT DATE:	5 JUN 06

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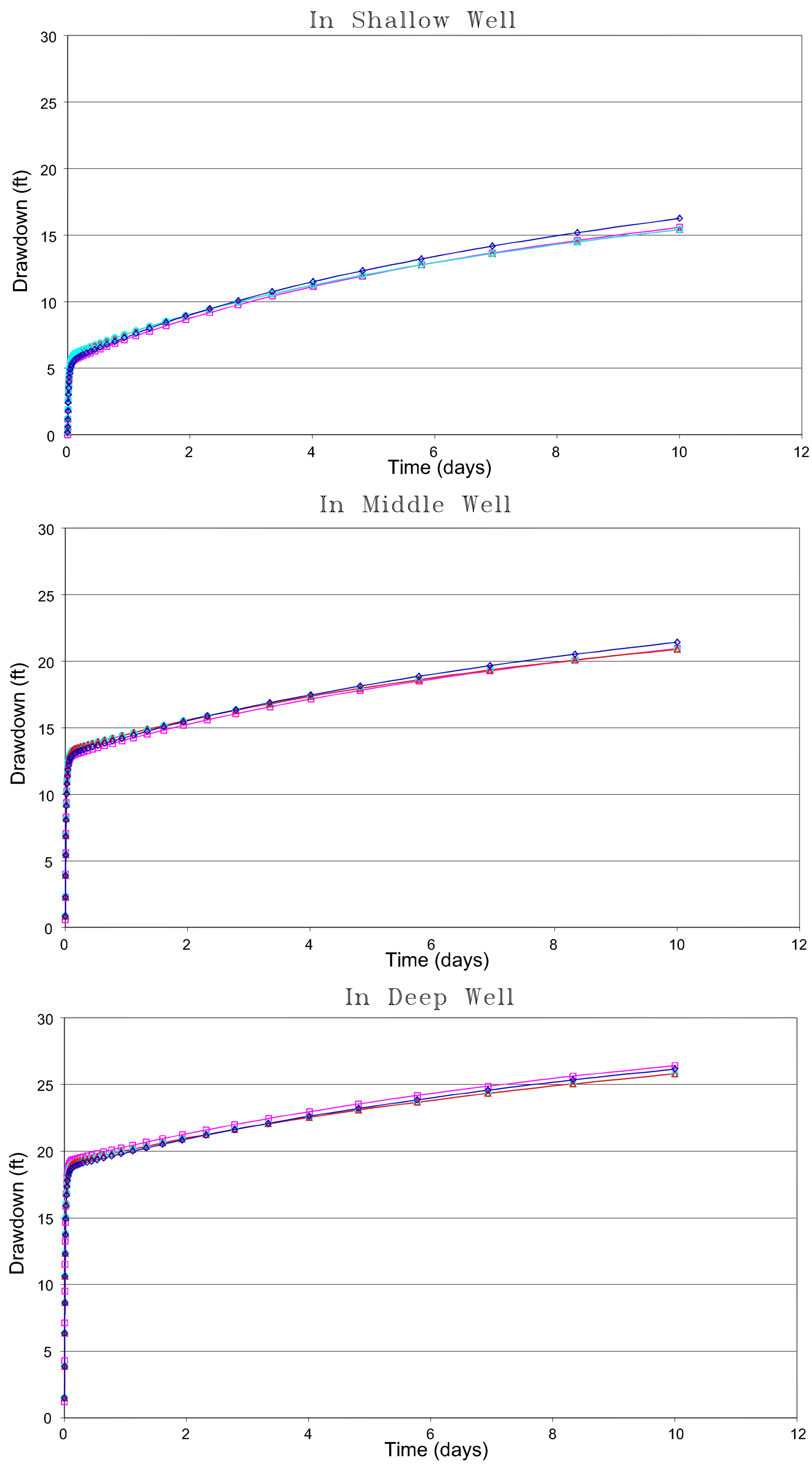
Comparison of Drawdowns at Various Distances from Pumping Well Calculated by *FEMFLOW3D* Using Three Solvers to those Calculated by Papadopulos Solution

FIGURE 2



ANALYTICAL

NEUMAN

FEMFLOW3D

MULTI-GRID (USING DEFAULT PARAMETERS)

CONJUGATE-GRADIENT

POINT OVER-RELAXATION

JOB NO.	HCI–1827	DATE:	2 JUN 06
BY:	HL	DWG FILE:	NEUMAN1–TM2
DRAWN:	SAC	PLOT FILE:	NEUMAN1–TM2
CHECKED:		PLOT DATE:	5 JUN 06

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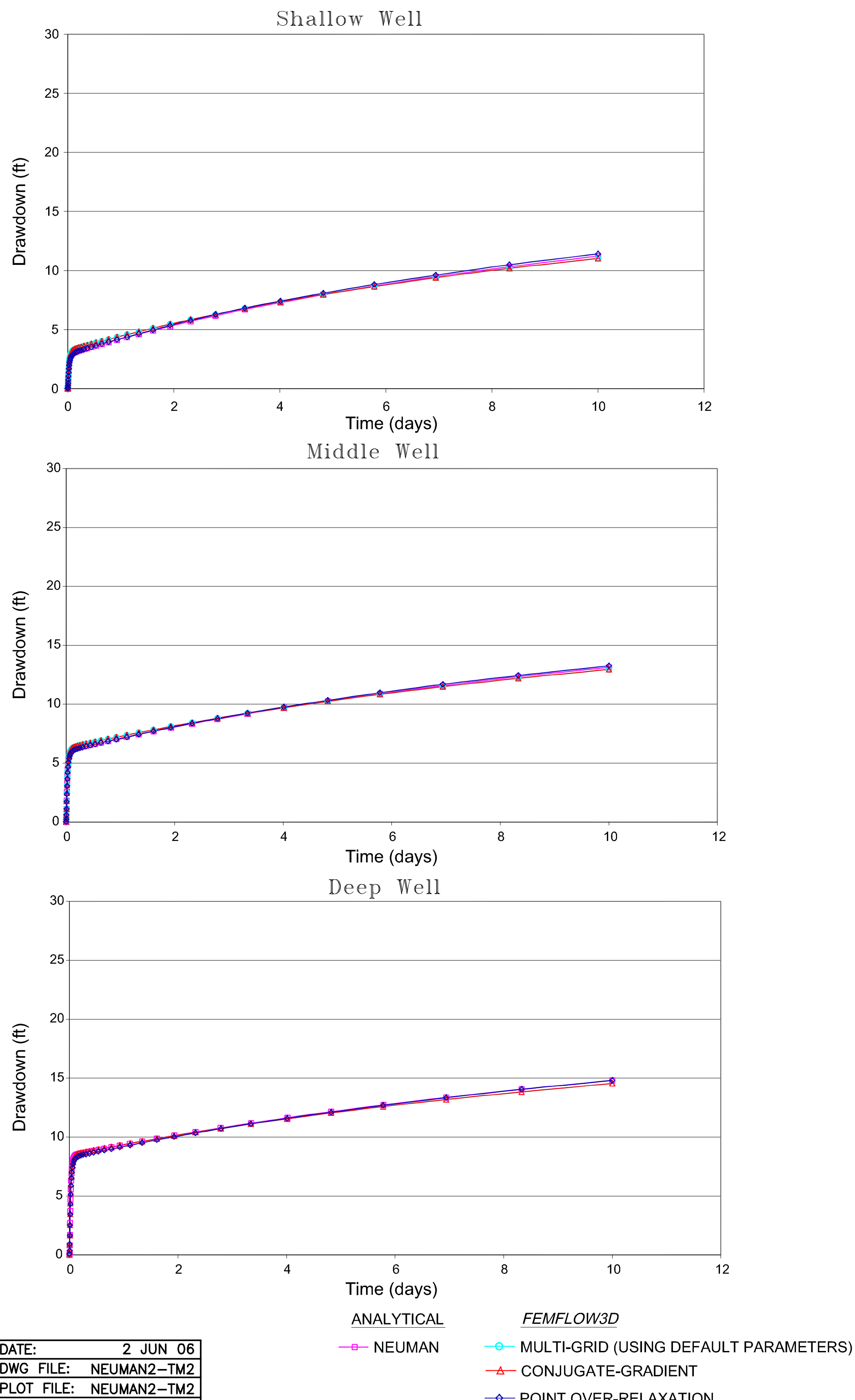
Comparison of Drawdowns at Various Depths at Distance of 200 ft from Pumping Well Calculated by *FEMFLOW3D* Using Three Solvers to those Calculated by Neuman Solution

FIGURE 3



JOB NO.	HCI–1827	DATE:	2 JUN 06
BY:	HL	DWG FILE:	NEUMAN2–TM2
DRAWN:	SAC	PLOT FILE:	NEUMAN2–TM2
CHECKED:		PLOT DATE:	5 JUN 06

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Comparison of Drawdowns at Various Depths at Distance of 400 ft from Pumping Well Calculated by *FEMFLOW3D* Using Three Solvers to those Calculated by Neuman Solution

FIGURE 4