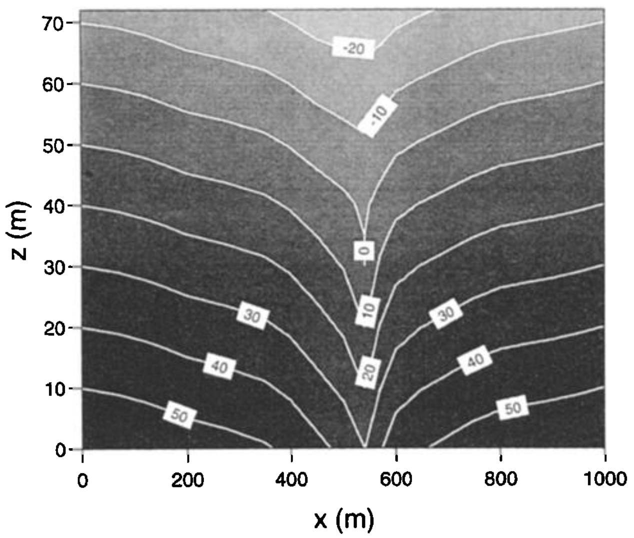

Figure 14. Steady state pressure head contours at cross section $y = 400$ m for test case 3S with the pumping well at $x = 540$ m, $y = 400$ m.

the Picard runs, displayed very similar behavior, converging in 9–13 iterations (Figure 15).

3.5.3. An aside. *Huyakorn et al.* [1986] reported that 177 min of CPU were needed for six Picard iterations in single precision on a VAX model 11/750 minicomputer. On the IBM 560 RISC workstation, 15 Picard iterations in double precision required 9 s of CPU, which is more than 3000 times faster than the simulations run a mere 8 years ago.

3.6. Test Case 3Ta

3.6.1. Description. The flow problem described in test case 3S is solved here under transient conditions. The simulations were run to $T_{max} = 5000$ days using the time discretization parameters given in Table 1. Very small time step sizes were needed initially ($\Delta t_0 = 2 \times 10^{-5}$ day), but as the solution approached steady state (after approximately 3000 days), the time step sizes increased to $\Delta t_{max} = 100$ days. Oscillations along the rapidly changing saturated/unsaturated interface near the seepage face caused convergence problems early in the simulations. Various strategies were tried in attempts to overcome these convergence difficulties.

3.6.2. Results. Only the backward Euler scheme ($\lambda = 1.0$) was effective in overcoming the nonlinear convergence oscillations near the seepage face. With $\lambda = 0.5$ both the Picard and Newton schemes failed to converge, with and without chord slope approximations and with and without mass lumping. The troubles occurred during the first two time steps, and included repeated nonconvergence of the seepage face exit point, regardless of the values of sf_1 and sf_{cvg}. With $\lambda = 1.0$, successful convergence was achieved for both iterative methods, again with no apparent effect of parameters sf_1 and sf_{cvg} (all four combinations of these two parameters were tried). Other strategies also had a minor effect on the performance of the Newton and Picard schemes. Mass lumping was slightly more efficient than the distributed case, and the chord slope approximations gave noticeably worse results than not using these approximations. For the chord slope methods a tolerance setting of 10^{-5} was used, and methods 1 and 2 gave identical results.

The results of several of the runs described above are summarized in Table 7. The BICGSTAB linear solver was used for the Newton runs reported in the table. Other nonsymmetric solvers were also tried (GRAMRB, GCRK, and TFQMR), but none of these was as efficient as BICGSTAB, requiring, in the best case, 50% more iterations and CPU time.

Overall, the Picard scheme converged faster and was more efficient than the Newton scheme. For this test case the CPU time per nonlinear iteration required for the Picard scheme was approximately 0.32 s, and for the Newton scheme approximately 0.60 s. The breakdown of the total CPU cost for one of the Picard and Newton runs for this test case is shown in Figure 16. This cost distribution, which is typical for the multidimensional transient simulations performed in this and other test cases, shows that for both the Picard and Newton schemes, over half the CPU time is used in solving the linearized system of equations. The next most intensive kernel, requiring about one quarter of the total CPU time, is the calculation and assembly of the finite element system matrices, including the Jacobian matrix for the Newton scheme. All the other tasks combined use up only 15–20% of the total CPU time.

3.6.3. Related results. *Putti and Paniconi* [1992] considered a variant of test case 3Ta. The test problem was modified to include prevailing flow along the x direction. Variable and fixed time step size simulations were run, and characteristic equations (7) and (8) were used in addition to (11) and (12). For some of the time steps in these tests the Picard scheme had trouble converging while the Newton method converged rapidly. Chord slope approximations applied to the Picard scheme increased its rate of convergence, although yielding very irregular or oscillatory convergence profiles.

3.7. Test Case 3Tb

3.7.1. Description. This test case involves the simulation of an evaporation event on a subcatchment of the Konza

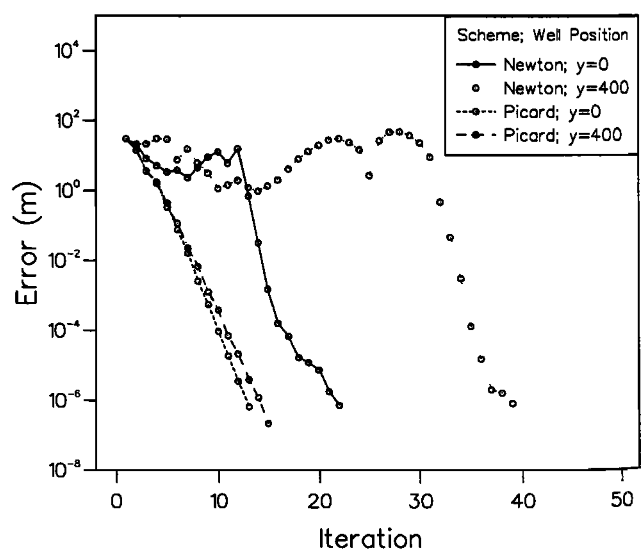

Figure 15. Convergence profiles for test case 3S showing the effect of pumping well position.