flow or transport equations. For the solution of transport equations, cell dimensions more than 1.5 times larger than an adjacent cell may cause oscillations in the distribution of the transported quantity in space. In order to prevent such oscillations, Intercomp Resources Development and Engineering (1976) suggests that cell size should be restricted to less than twice the value of hydrodynamic dispersivity. For example, the hydrodynamic dispersivity of about 3 m used in this study restricts the maximum cell size to 6 m.

Although it is possible to construct a finite-difference grid that would encompass the entire area illustrated by Miller and Delin (1993, p. 46 and 47), the number of resulting cells and corresponding calculations would be impractical to model with the SWIP code. If cells were 6 m on a side, for example, 10,000 cells would be required to simulate the two-dimensional area shown by Miller and Delin. The flow-net analysis (Miller and Voss, 1986), makes it possible to reduce the modeled area and to simulate flow only in the area around production well A, the flow region where energy transport is of greatest concern (figs. 21–22). Flow outside this modeled region is represented by a specified flux at model boundaries, as determined by flow-net analysis.

The finite-difference grid for the ATES-site model was oriented such that the axis of maximum transmissivity was aligned with the horizontal-coordinate direction (Miller and Delin, 1993, p. 46 and 47). The origin of the field-coordinate system shown in figures 21 and 22 was arbitrarily chosen to be halfway between production wells A and B. A variably-spaced grid was designed because of restrictions on grid size for solution accuracy and stability inherent to the difference approximation used in the SWIP code (Intercomp Resources Development and Engineering, 1976). Cell sizes range from 0.3 m on a side at production well A to a maximum of 4.6 m on a side at the periphery of the model; cell sizes increase in all directions equally by a factor of 1.5 or less. The grid has 6 layers with 594 cells per layer (fig. 23). Vertical grid spacings were selected to correspond with aquifers and confining units (table 3). The lateral boundaries of the model correspond to the 10 m equipotential for the Ironton and Galesville Sandstones (fig. 21) and to the 2.9 m equipotential for the upper part of the Franconia Formation (fig. 22).

Flux calculation at model boundaries

Appropriate flux rates must be specified at the model boundaries such that the boundaries accurately represent ground-water flow and heat transport between the modeled area and the area outside the simulated region. The correct boundary fluxes can be determined by analysis of the flow net for steady-state conditions. The total flow crossing an equipotential (figs. 21 and 22) is equal to the injection rate and is thus known. In addition, an equal amount of flow is represented by each streamtube. Therefore, if quasi-steady-state flow is assumed, the distribution of fluxes along an equipotential is known for any injection rate.

One form of boundary-flux specification simulated by use of the SWIP code (Intercomp Resources Development and Engineering, 1976, p. B.11) is:

$$e_{w_{ij}}\Delta t = \alpha_{ij}V(P_I - P_{ij}^{n+1}) \qquad (11)$$

where

$e_{w_{ij}}$ = the fluid-influx rate at boundary cell i,j [L/T] (m^3/s),

α_{ij} = a constant factor that gives the fraction of the entire grid boundary that cell i,j represents [dimensionless],

V = an aquifer-flux coefficient [$L^3/(M/L\text{-}T^2)$] (m^3/kPa),

P_I = a fixed pressure at some distance outside the model boundary [$M/L\text{-}T^2$] (kPa), and

P_{ij}^{n+1} = the pressure in boundary cell i,j at time of the (n+1)th time step [$M/L\text{-}T^2$] (kPa), and

Δt = time [T] (s).

For an infinite aquifer, the pressure outside the model boundary (P_I) is maintained at the initial system pressure (P_{ij}^0) before pumping. For simulation of the doublet-well system, the initial pressure (P_{ij}^0) is held constant along a locus somewhere between the wells. In a homogeneous, isotropic aquifer, this locus would be the perpendicular bisector of the well axis; however, in the anisotropic Franconia-Ironton-Galesville aquifer, the locus is along a line at an oblique angle to the well axis (Miller and Delin, 1993, p. 46 and 47).

The aquifer-flux coefficient (V), is calculated by use of equation 11 for an equipotential by letting P_I equal the initial pressure (P^0_{ij}), α_{ij} equal 1 (representing the entire boundary), e_w equal the steady-state injection rate for each formation, and P_{ij}^{n+1} equal the steady-state pressure at the equipotential. Values of V were calculated for the 10-m equipotential (fig. 21) for the Ironton and Galesville Sandstones and the 2.9 m equipotential (fig. 22) for the upper part of the Franconia Formation, as 12.6 and 3.8 m^3/kPa (cubic meters per day-kilopascal), respectively. Because the 32 streamtubes illustrated in figures 21 and 22 represent