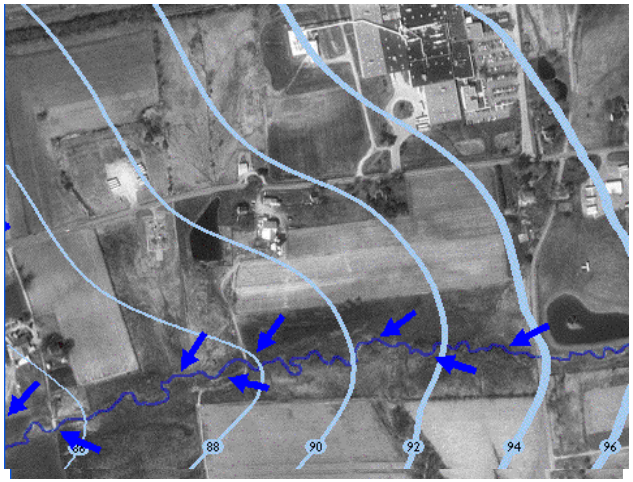
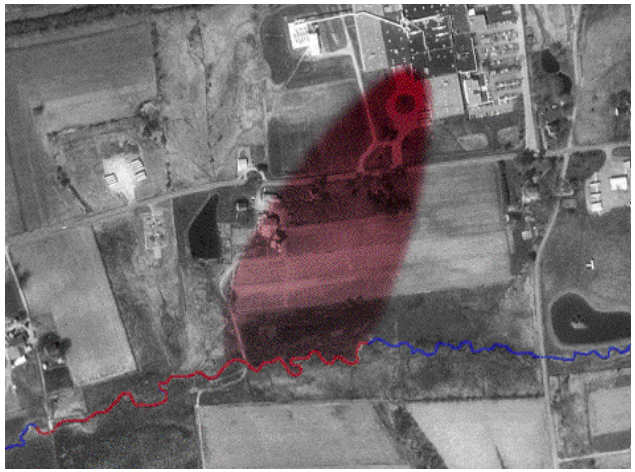
Introduction to Groundwater Modeling

Groundwater Flow and Contaminant Transport



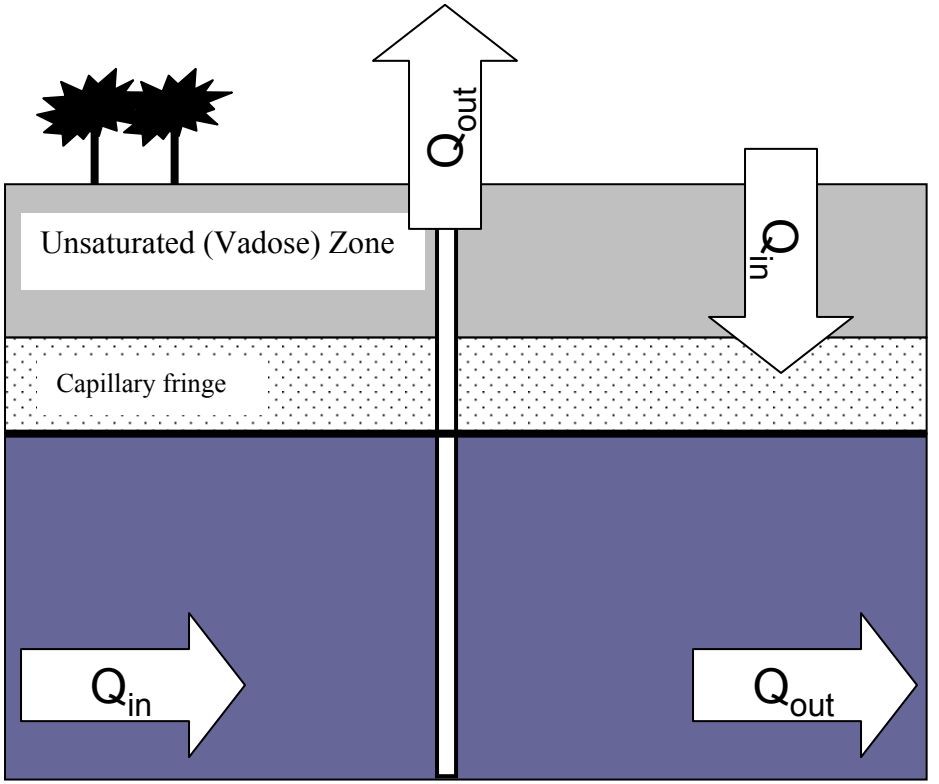


- Groundwater flow
- Contaminant Transport

Water Budget Equation

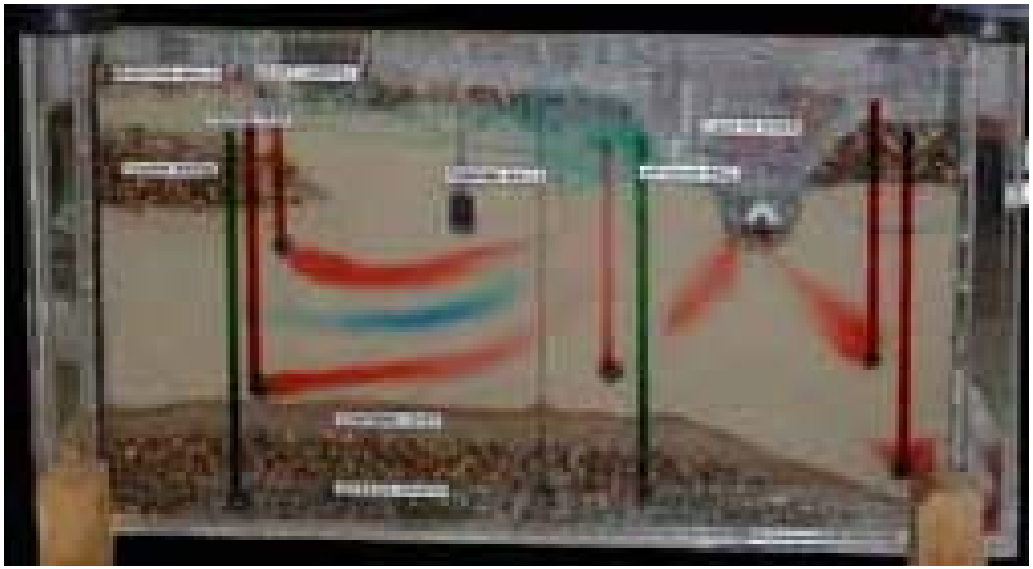
$$Q_{in} - Q_{out} = \Delta S$$

- How to explicitly show details about the impacts of specific **spatial and temporal water utilization patterns** on a groundwater system?
- How to consider **recharge distribution, complicated groundwater / surface water interaction, and complex aquifer geology**?



Complex Groundwater System and Models

- Analysis of complex systems requires the application of sophisticated **Numerical Models.**
- **Model**: a representation tool of a real system.



Why modeling?

- Understand the behavior of a flow system
- Predict the response of a flow system under different stresses
- Enhance groundwater productivity
- Choose the best scheme to install new wells
- Design plans to protect and remedy contaminated aquifers
- Realize critical properties that affect flow

The Governing Flow Equations

- Confined aquifer

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)\pm W=S_s\frac{\partial h}{\partial t}$$

- Unconfined aquifer

$$\frac{\partial}{\partial x}\left(hK_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(hK_{yy}\frac{\partial h}{\partial y}\right)\pm W=S_y\frac{\partial h}{\partial t}$$

Numerical Models and the Governing Flow Equations

- Numerical model provides a solution to the governing groundwater flow equations subject to boundary & initial conditions.
- It utilizes either the FDM or FEM to transfer the governing equation to a set of algebraic equations.
- The domain of interest (i.e. aquifer) is discretized by a mesh or grid network.
- The algebraic equations are solved, iteratively, at nodes for the unknown heads.

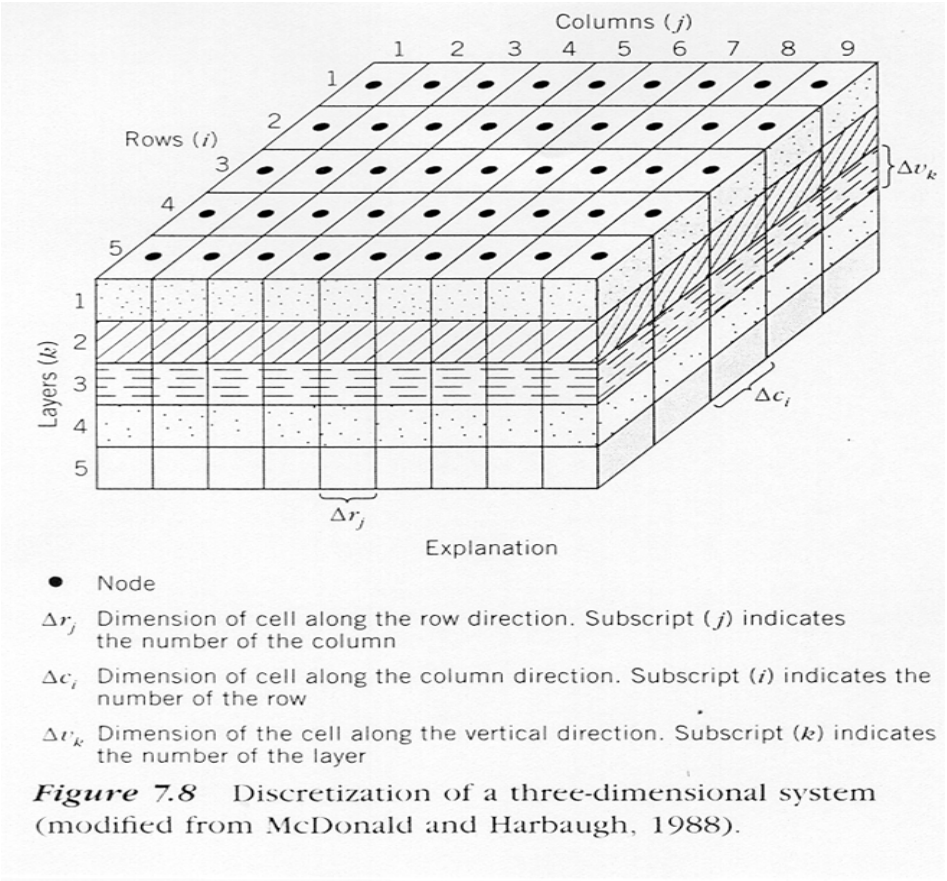
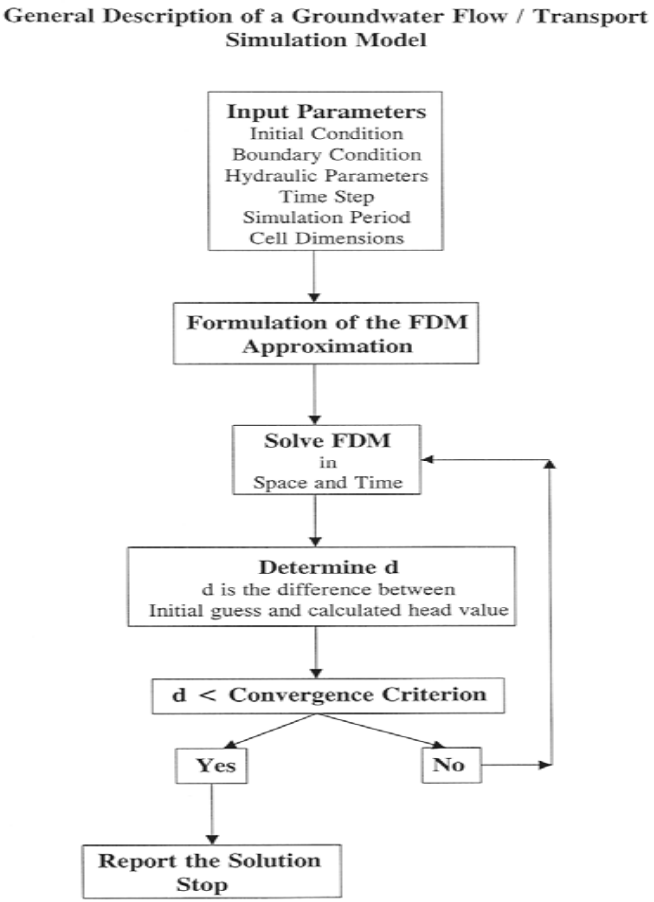


Figure 7.8 Discretization of a three-dimensional system (modified from McDonald and Harbaugh, 1988).

Model Mechanism



How to run a numerical model?

- Select the flow simulator (purpose of the model)
- Evaluate the available data / information
- Construct a conceptual model
- Divide the domain
- Run the simulator
- Calibrate
- Verify & analyze model sensitivity
- Run the simulator for forecasting purposes
- Post-audit

How to run a model?

Conceptual model

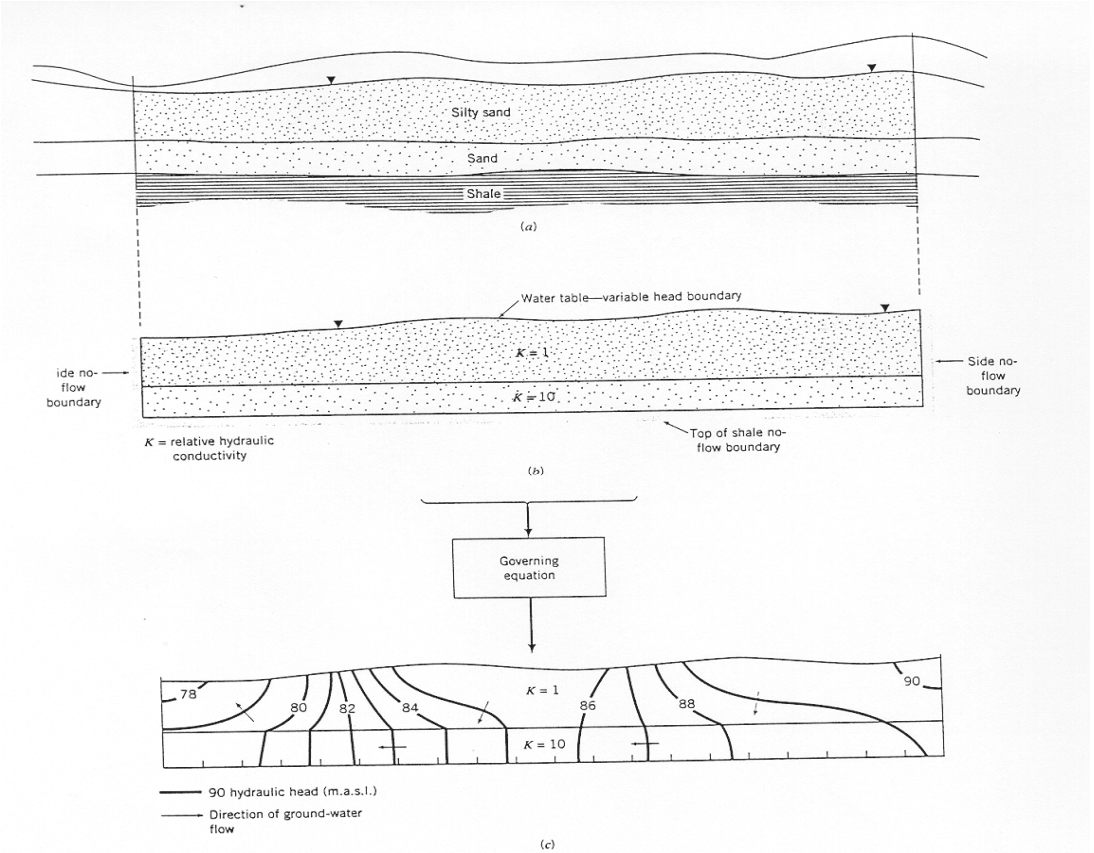


Figure 4.1 A geologic problem (*a*) is conceptualized onto a mathematical problem (*b*), which is ultimately solved in terms of the hydraulic head distribution (*c*).

How to run a model?

Divide the domain

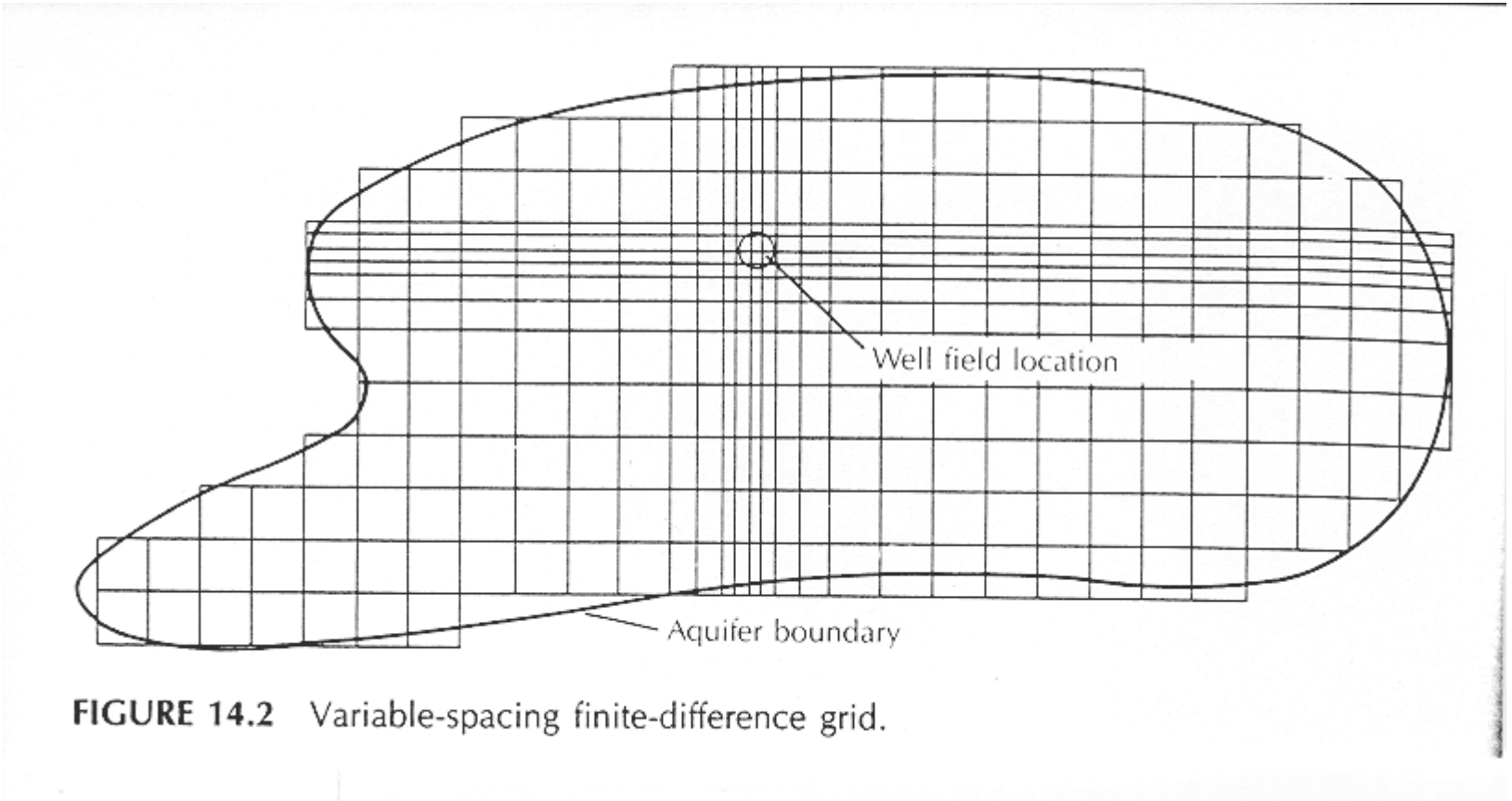


FIGURE 14.2 Variable-spacing finite-difference grid.

How to run a model?

Divide the domain

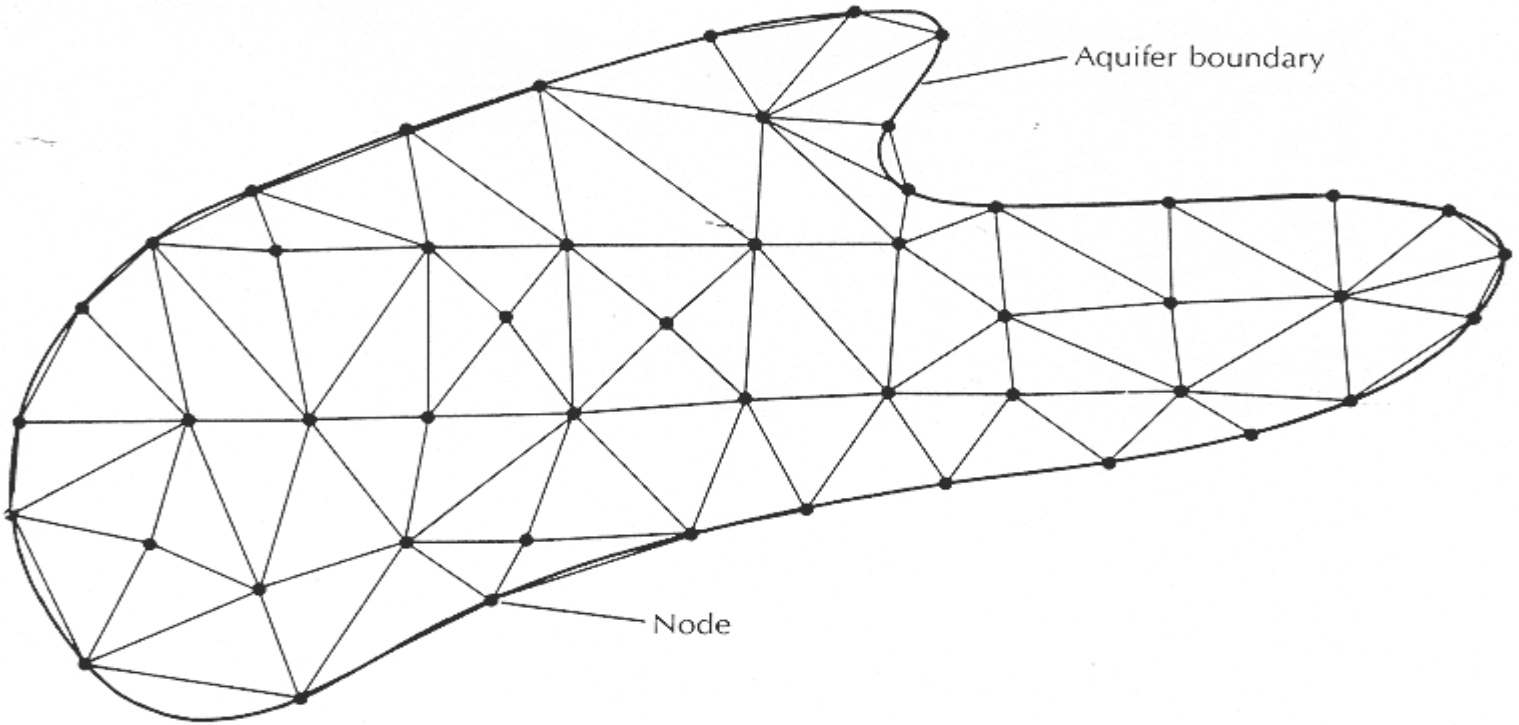
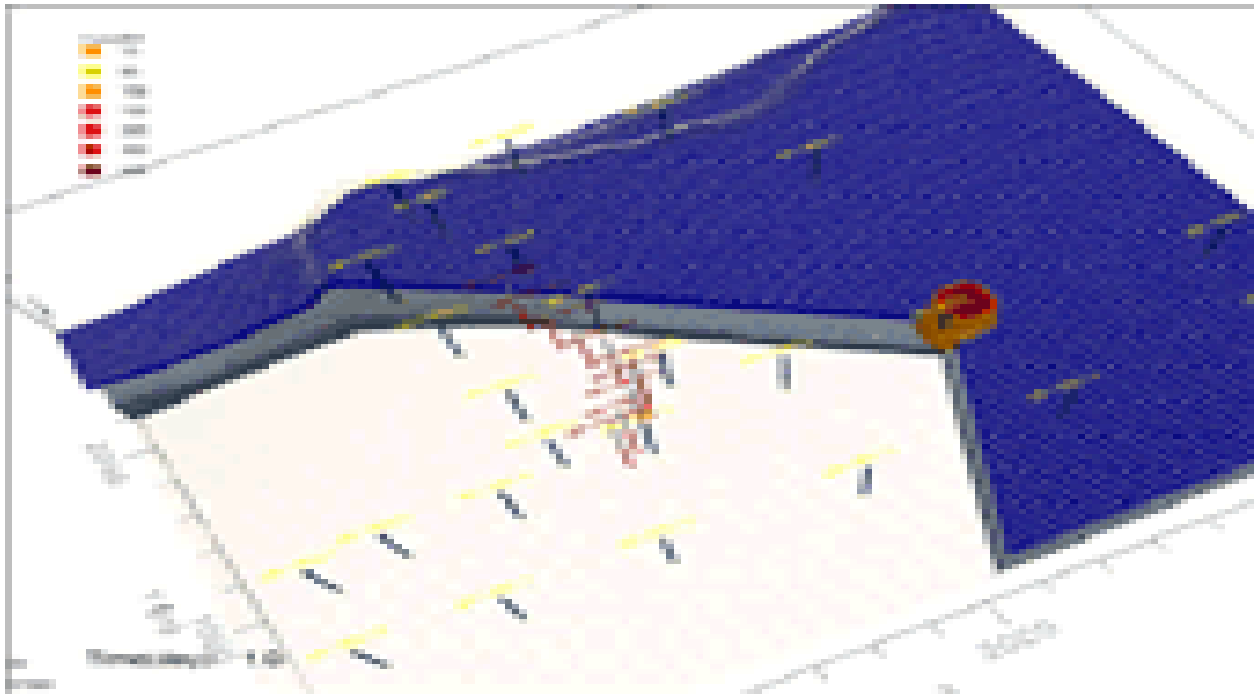


FIGURE 14.5 Finite-element grid for an aquifer.

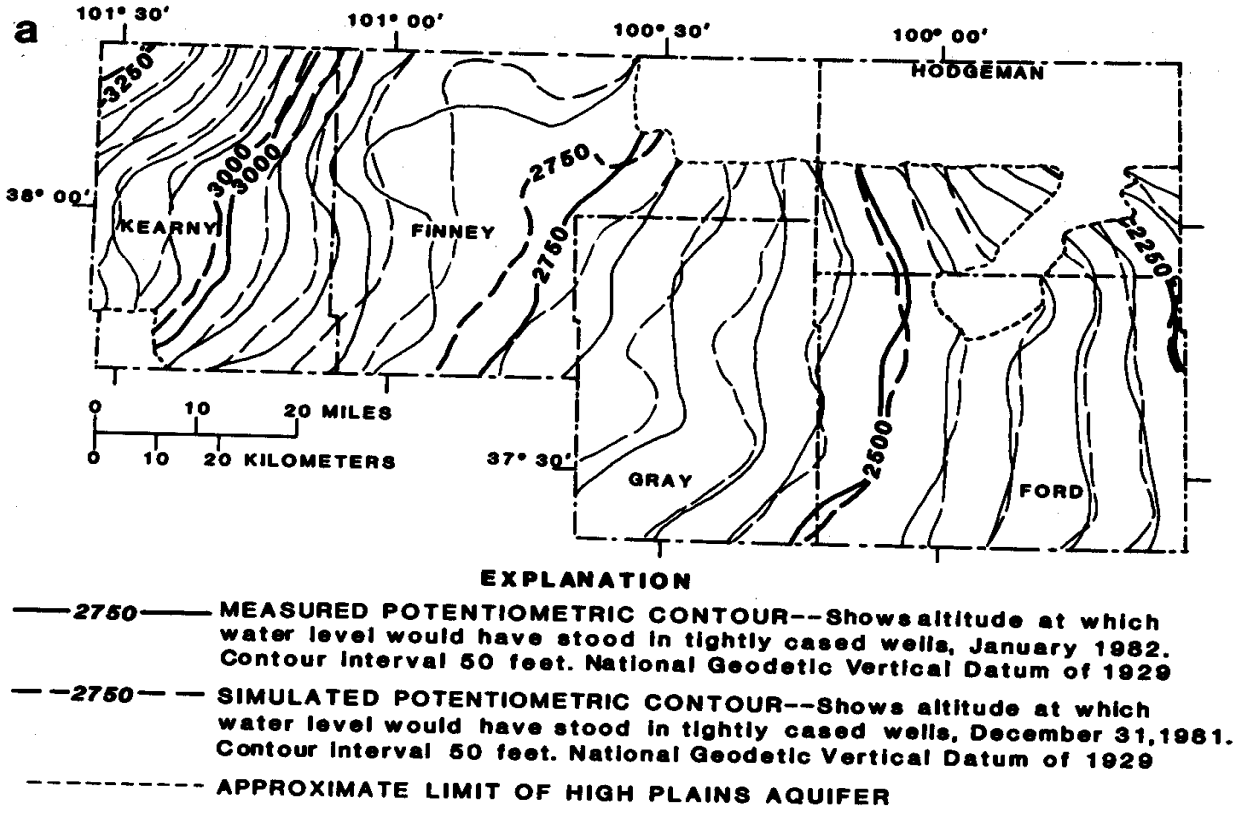
How to run a model?

Run the model



How to run a model?

Calibration: Head matching



How to run a model?

Calibration: Statistical analysis

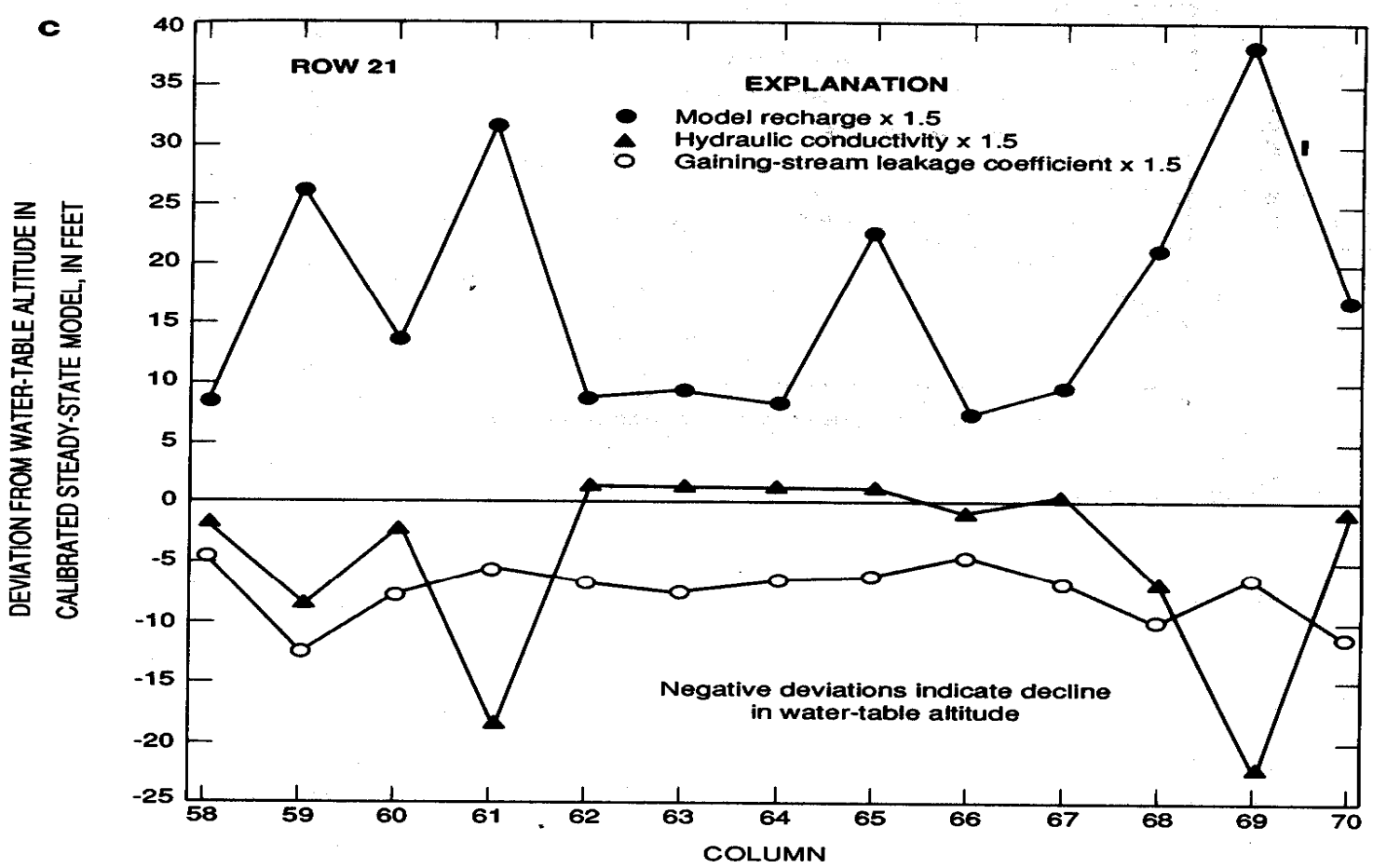
Measured and Simulated Heads for a model of a portion of Cape Cod, Massachusetts[a]

Node (i, j, k)	U.S. Geological Survey well no.	Water level (feet above sea level) Observed average 1963–76	Water level (feet above sea level) Calculated at center of grid block
6, 16, 7	WNW 78	2.7	3.4
11, 26, 7	TSW 216	4.1	5.3
15, 14, 7	WNW 30	6.6	6.7
16, 14, 7	WNW 30	6.6	7.4
16, 21, 7	TSP 17	6.8	7.2
16, 26, 7	TSW 198	7.6	7.1
17, 22, 7	TSP 16	7.6	7.9
18, 17, 7	WNW 34	8.0	8.0
21, 19, 7	TSP 18	6.4	6.5

ME = −0.34 ft
MAE = 0.40 ft
RMS = 0.55 ft

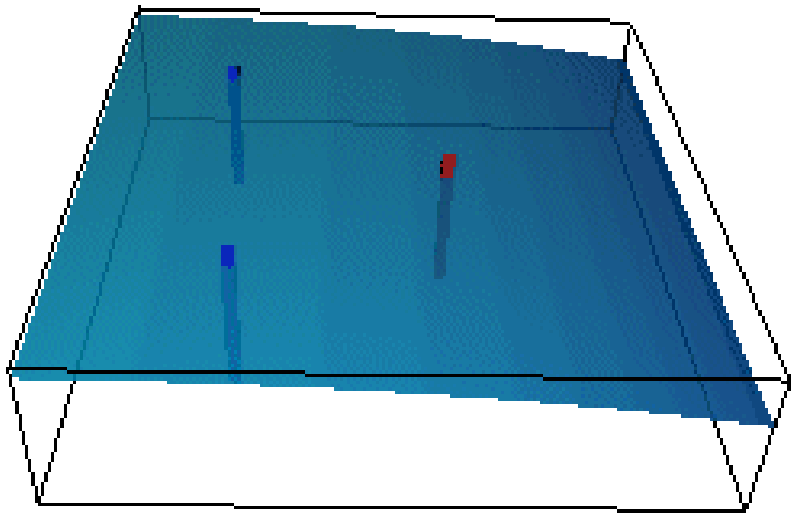
How to run a model?

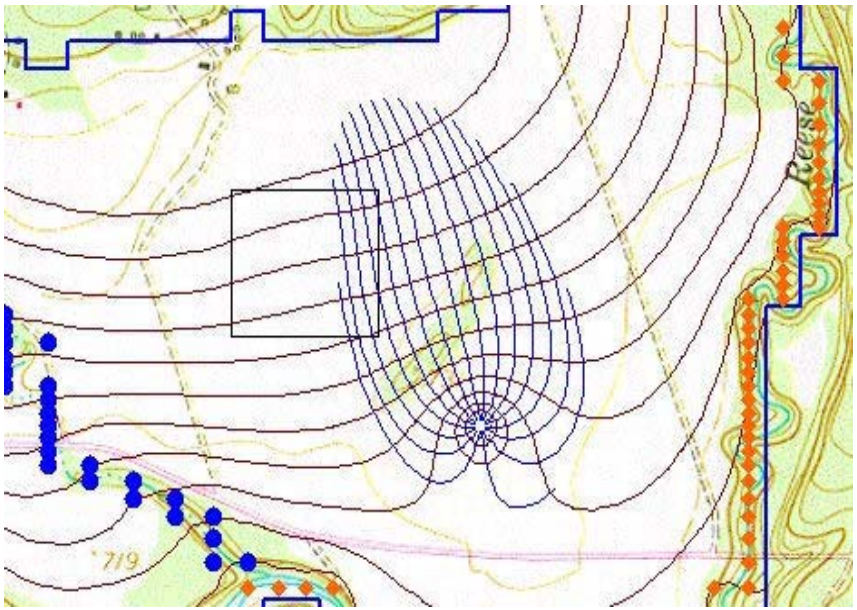
Sensitivity analysis



How to run a model?

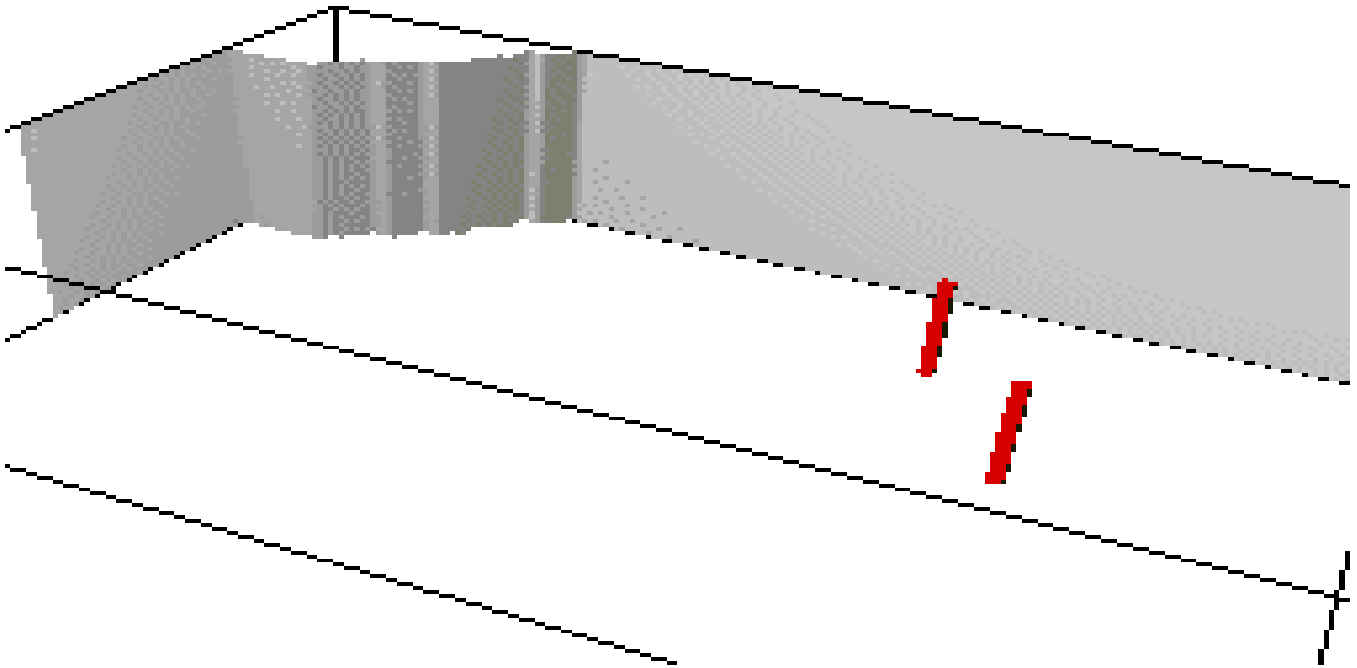
Predicting flow towards a well and capture zone





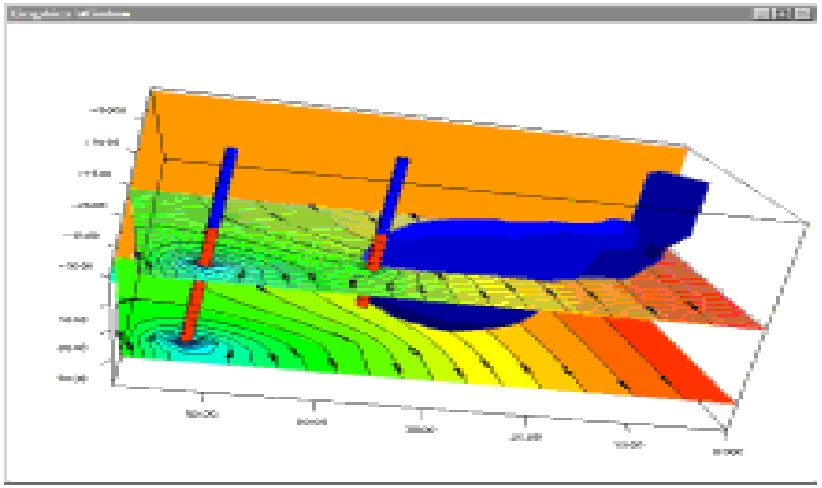
How to run a model?

Predicting contaminant transport towards pumping wells



How to run a model?

Predicting the behavior of a pump and treat remediation alternative



Examples of Groundwater Flow & Contaminant Transport Models

- Visual MODFLOW
- MODPATH
- MT3DMS
- RT3D
- SEAM3D
- FEMWATER
- SEEP2D
- UTCHEM
- PEST
- UCODE
- VS2DT
- VLEACH
- Visual HELP