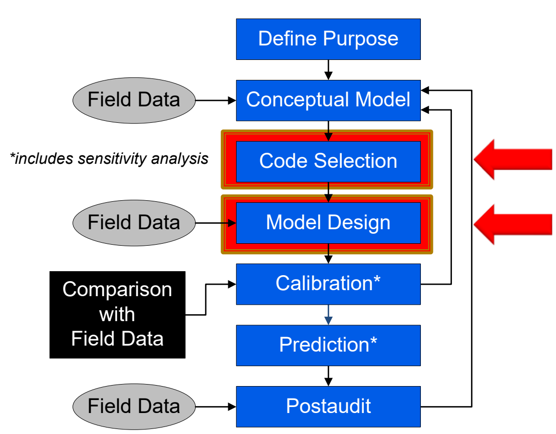
CE EN 547 – BRIGHAM YOUNG UNIVERSITY

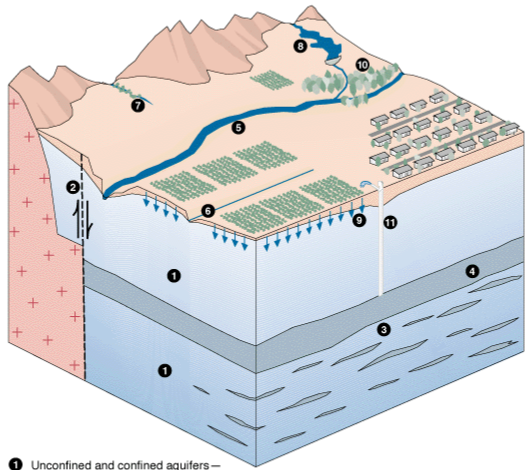
MODFLOW – Introduction Organization & Main Packages

Code Selection – Model Design

- We are now at this spot in the model development process
- MODFLOW is generally a safe and dependable choice for a model code
- Model design = construction of numerical grid and model inputs



- Developed by McDonald & Harbaugh of the USGS, 1983
- Public Domain
- Most widely used groundwater model
- Steady-state or transient saturated flow
- Versions:
  - MODFLOW 88
  - MODFLOW 96
  - MODFLOW 2000
  - MODFLOW 2005
  - MODFLOW-NWT
  - MODFLOW-USG

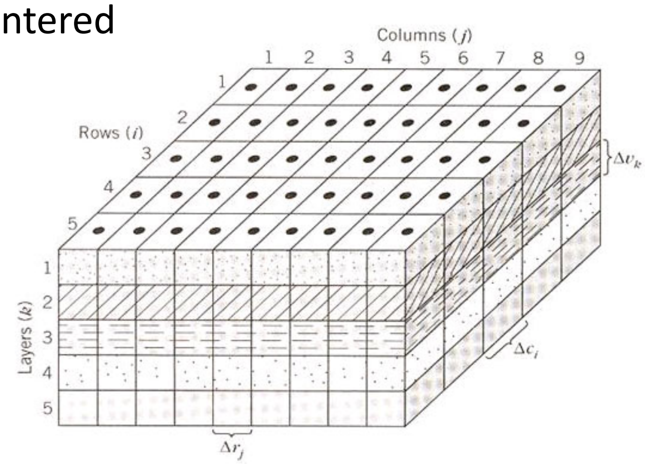


1. Unconfined and confined aquifers—Ground-water flow and storage changes
2. Faults and other barriers—Resistance to horizontal ground-water flow
3. Fine-grained confining units and interbeds
4. Confining units—Ground-water flow and storage changes
5. Rivers—Exchange of water with aquifers
6. Drains and springs—Discharge of water from aquifers
7. Ephemeral streams—Exchange of water with aquifers
8. Reservoirs—Exchange of water with aquifers
9. Recharge from precipitation and irrigation
10. Evapotranspiration
11. Wells—Withdrawal or recharge at specified rates

Figure 1. Features of an aquifer system that can be simulated by MODFLOW.

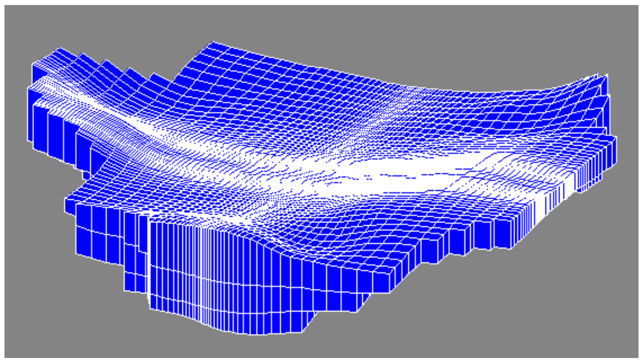
Finite Difference Model

3D Cartesian Grid
Cell-Centered



Grid Geometry

Orthogonal in xy
Thickness varies in z



Governing Equation

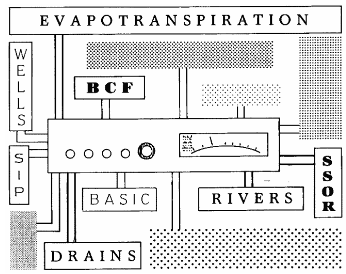
$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)-W=S_s\frac{\partial h}{\partial t}$$

where:

K_{xx}, K_{yy}, K_{zz}	= values of hyd. cond. along xyz axes
h	= total head
W	= Sources and sinks
S_s	= Specific storage
t	= time

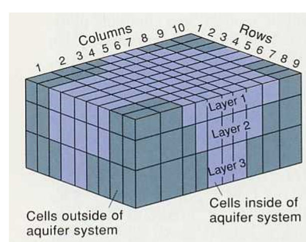
Processes & Packages

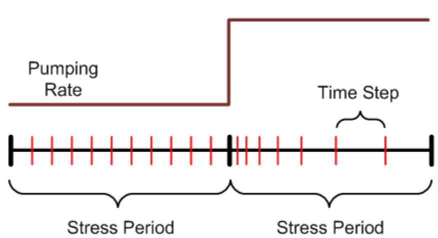
- MODFLOW is divided into a series of processes & packages
- Major tasks are organized as processes
- More specific tasks are performed by packages
- Each process may use one or more packages



Global Process

- Spatial discretization
  - # rows, cols, layers
  - Top/bottom elevations
- Temporal discretization
  - Stress periods
  - Time steps
- Units
- Package Selection



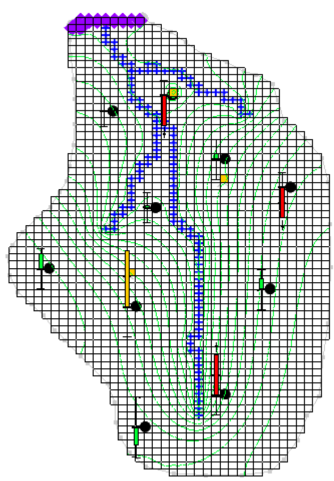


Ground Water Flow Process

- Formulation and solution of the ground water flow equation by the FD method
- Main part of MODFLOW code
- Includes
  - Flow package (BCF, LPF, or HUF)
  - Source/sink packages
  - Solvers

Observation Process

- Used for model calibration
- Calculates model-simulated heads and discharges to sources/sinks



Required Packages

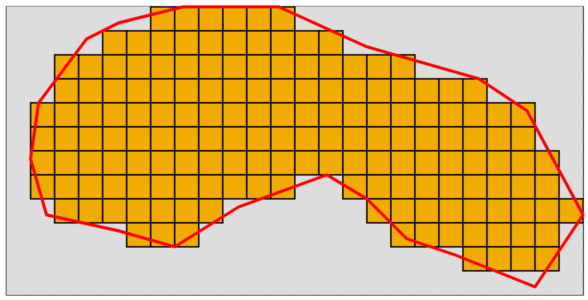
- Discretization
- Basic
- Output Control
- Flow Package (BCF, LPF, HUF, UPW)
- Solver (SIP, SSOR, PCG, GMG, etc.)

Optional Packages

- CHB – Time Variant Specified Head
- DRN – Drain
- DRT – Drain Return Flow
- ETS – Evapotranspiration Segments
- EVT – Evapotranspiration
- GAGE – Gage
- GHB – General Head
- HFB – Horizontal Flow Barrier
- LAK – Lake
- MNW – Multinode Well
- MNW2 – Multinode Well 2
- RCH – Recharge
- RIV – River
- SFR – Stream Flow Routing
- STR – Stream-Aquifer Interaction
- SUB – Subsidence
- WEL – Well
- UZF – Unsaturation Zone Flow

Active/Inactive Zones

Cells outside problem domain are marked as inactive



Controlled by IBOUND array
(1=active, 0=inactive, -1=specified head)

Virginia Coastal Plain Model

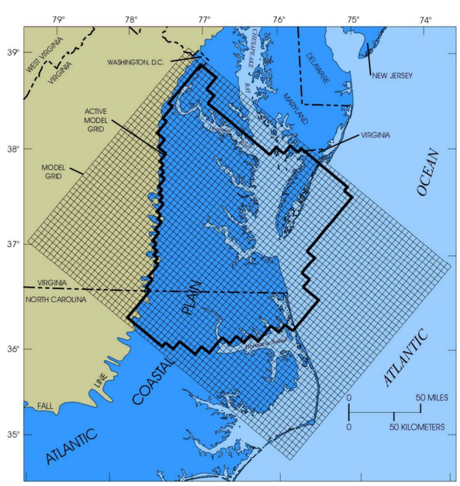


Figure 3. Ground-water-flow model grid in the Virginia Coastal Plain.

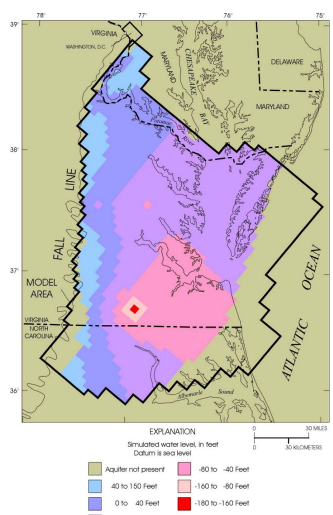
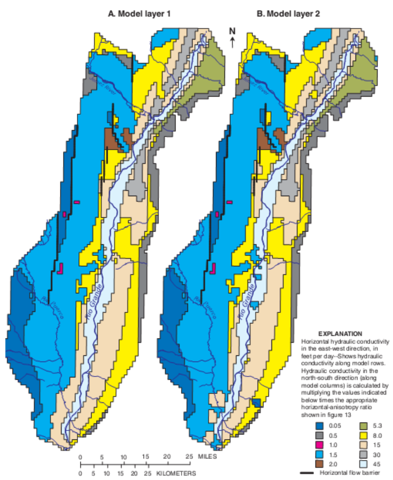


Figure 31. Simulated water levels for 1978-80 in the middle Potomac aquifer.

Flow Packages

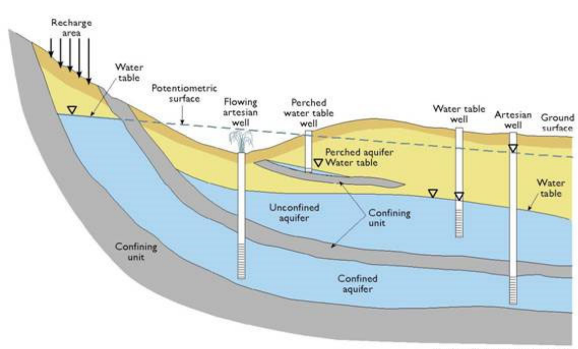


- Defines aquifer properties
- Four options
  - Block-Centered Flow (BCF)
  - Layer Property Flow (LPF)*
  - Hydrogeologic Unit Flow (HUF)
  - Upstream Weighting (UPW), MODFLOW-NWT

*We will use the LPF package in this course

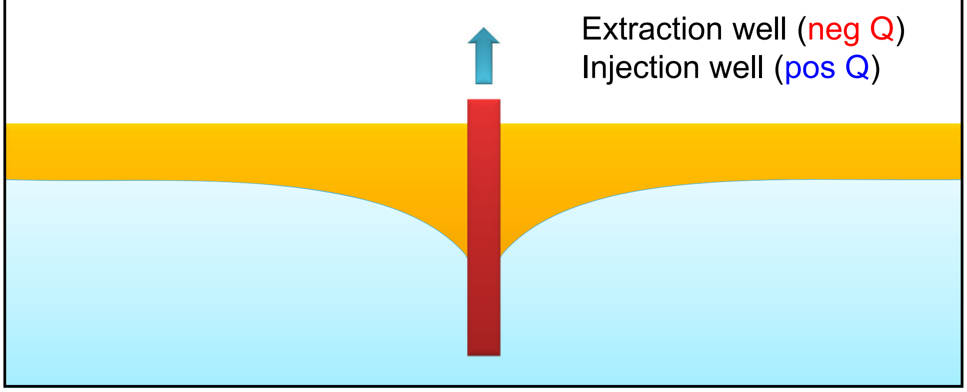
LPF - Layer Property Flow Package

- User enters Kh, Kv and storage terms for all layers
- Kv can be entered as directly or in terms of vertical anisotropy
- Horizontal anisotropy entered on a cell-by-cell basis
- Two layer types
  - Confined
  - Convertible



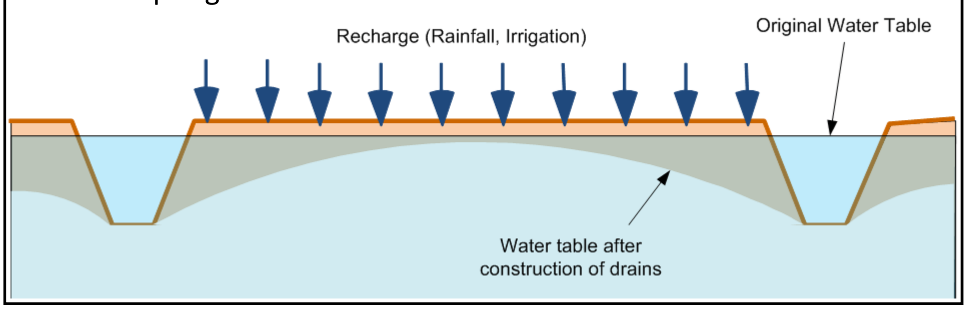
Well Package

- Assigned to individual cells
- Q can be steady state or transient

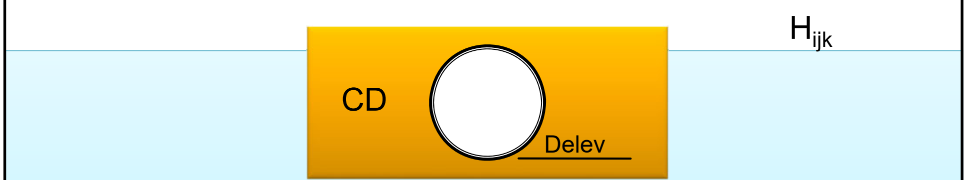


DRN - Drain Package

- Assigned to individual cells
- Used to simulate
  - Agricultural drains
  - Springs
- Required parameters
  - Elevation
  - Conductance



Drains

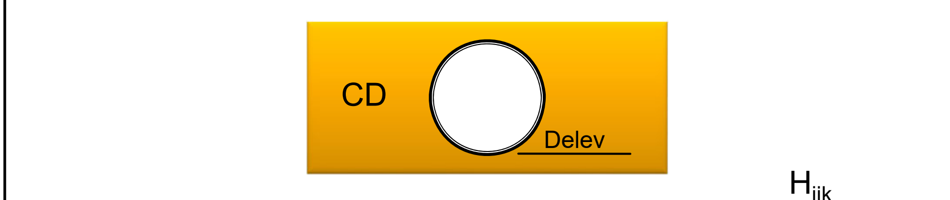


When the head is above the drain elevation:

$Q = CD\ (H_{ijk} - Delev)$ or

$Q = CD\ (Delev - H_{ijk})$ for proper sign on Q

Drains



When the head is below the drain elevation:

$Q = 0$

Conductance

Darcy's Law:

$$q = k \frac{\Delta h}{L} A$$

where

q = flow rate
k = hydraulic conductivity
Dh = head difference
L = flow length
A = gross cross-sectional area

Conductance, Cont.

Darcy's law can be rewritten as:

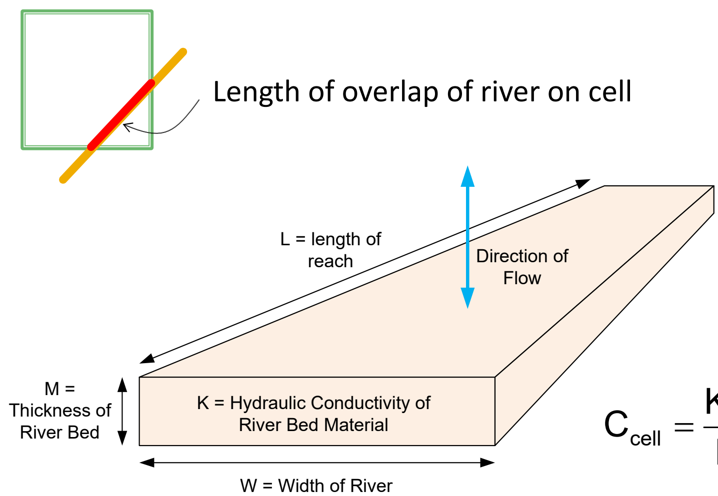
$$q = C \cdot \Delta h$$

where

$$C = \frac{kA}{L}$$

The appropriate values for k, A, and L must be determined on a case-by-case basis

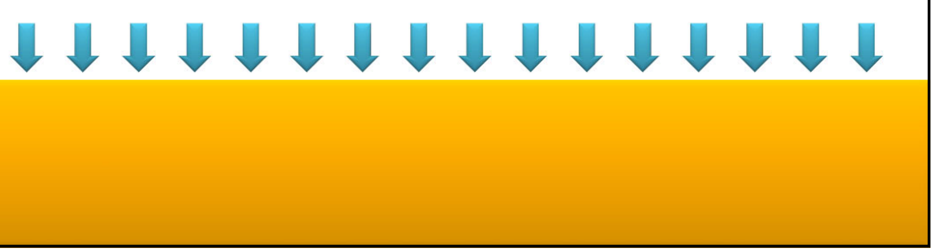
Sample Conductance Calculation



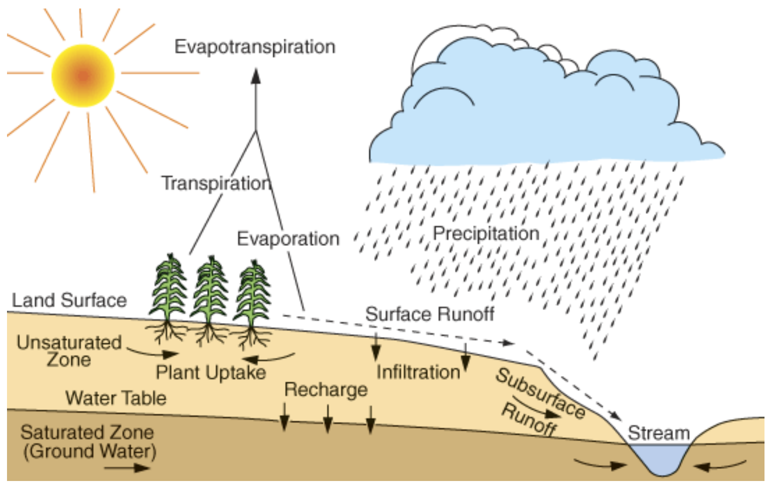
$$C_{cell} = \frac{KA}{M} = \frac{KLW}{M}$$

Recharge Package

- One value assigned to each vertical column
- Represents recharge due to precipitation
- Can be steady state or transient
- Infiltration rate must be assigned in correct units [L/T]



Factors Affecting Recharge Rate



Factors Affecting Recharge Rate

- Rainfall
- Runoff
  - Slope
  - Soil type
  - Land use
- Evapotranspiration
  - Soil type
  - Vegetation

Rule of thumb:
Recharge=~5-15% of precip.