Introduction to Groundwater Modeling

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East Bay Plain Subbasin – Groundwater Sustainability Plan
Technical Advisory Committee Meeting

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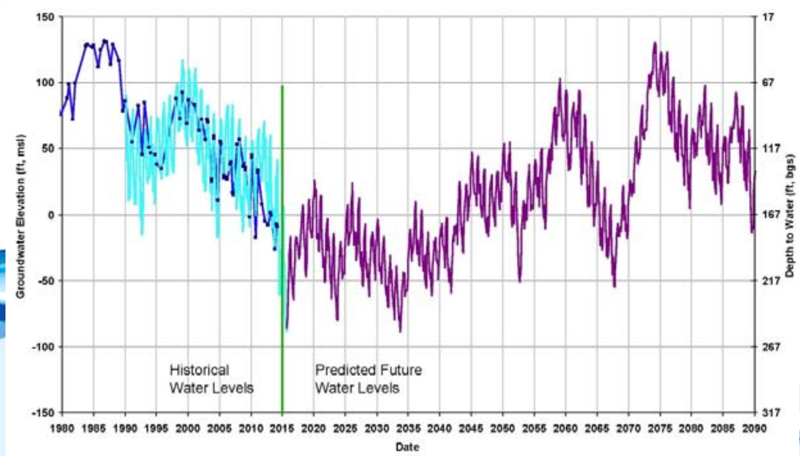
Topic of Discussion

- Why Use a Groundwater Model?
- What is a Hydrogeologic Conceptual Model?
- Groundwater Model Development
- Groundwater Modeling Platform Selection
- Groundwater Model Maintenance
- Key Takeaways
- Any Questions?

1. Why Use a Groundwater Model?

- To integrate many different types of data (e.g., aquifer parameters, water budget components, water levels)
- To study aquifer response to changes in GW system stresses (GW level fluctuations, GW flow directions/rates, GW storage change)
- To predict future changes in GW levels and fluxes from various management actions and changes in hydrologic regime (e.g., climate change)
- To be used as a tool in decision making

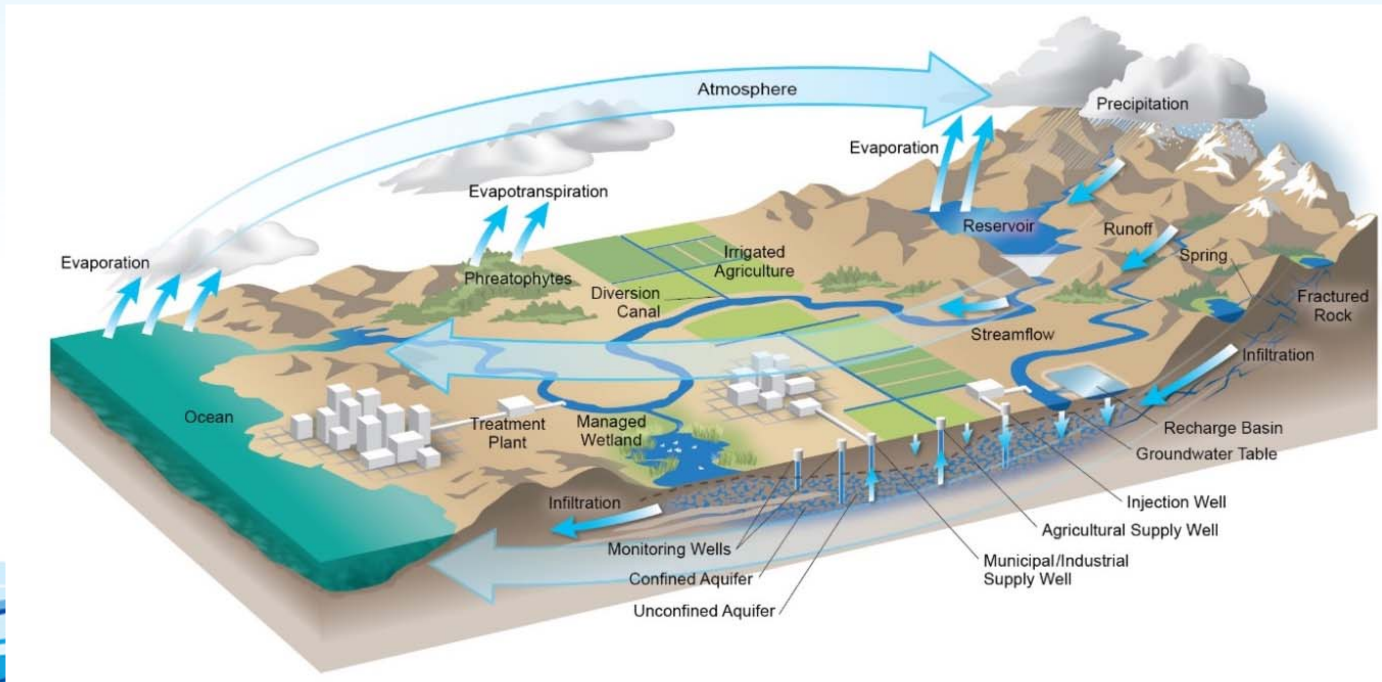


1. How can a groundwater model be used in a GSP?

- To develop a better understanding of historical, current, and future groundwater system dynamics (e.g., cones of depression, DTW, overdraft, GW–SW interaction)
- To evaluate sustainable management criteria (MTs and MOs)
- To evaluate effects of projects and management actions (prediction of future changes in GW levels)
- To evaluate sustainable yield of the subbasin

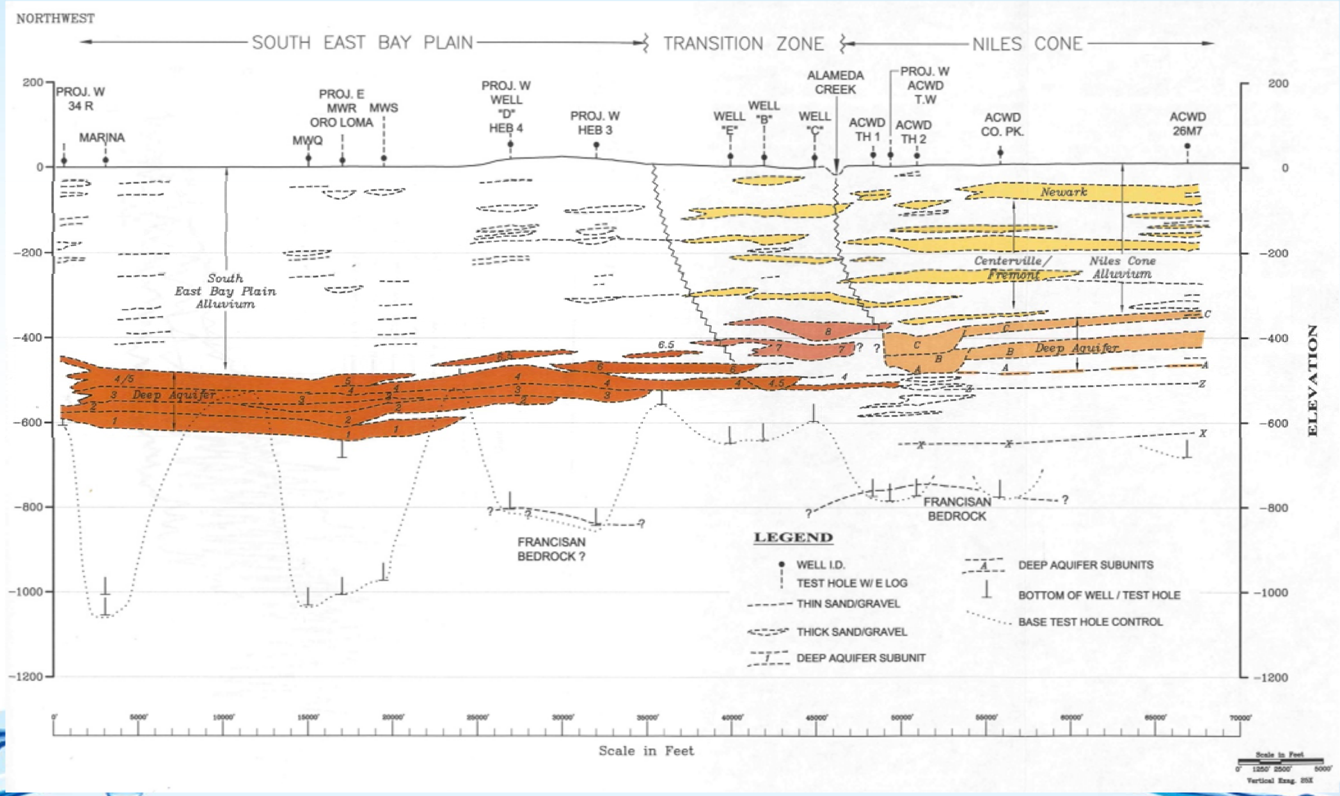
2. Hydrogeologic Conceptual Model

- A written and graphic depiction of the aquifer system, occurrence of groundwater, groundwater levels and flow, and water budget



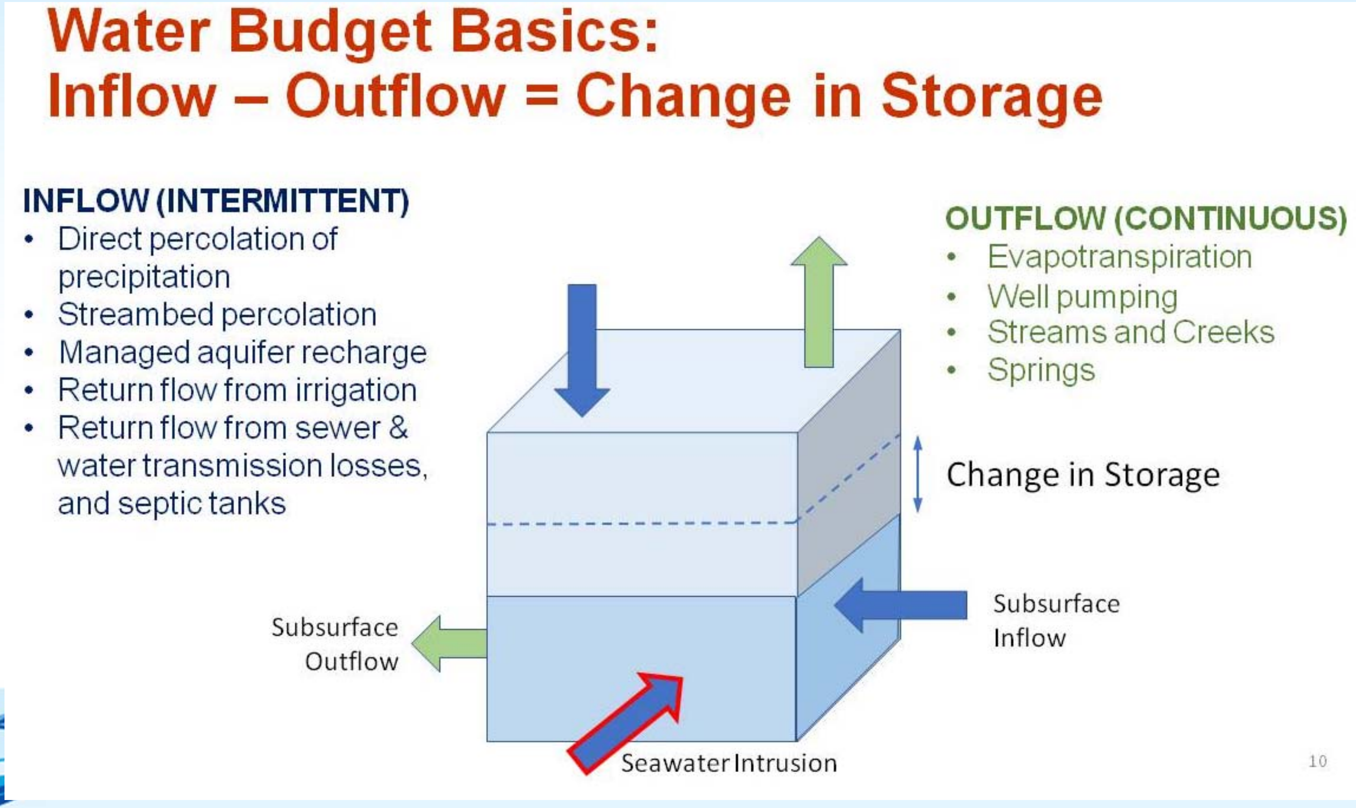
2. Hydrogeologic Conceptual Model (HCM)

- Characterize aquifer system based on available data and information

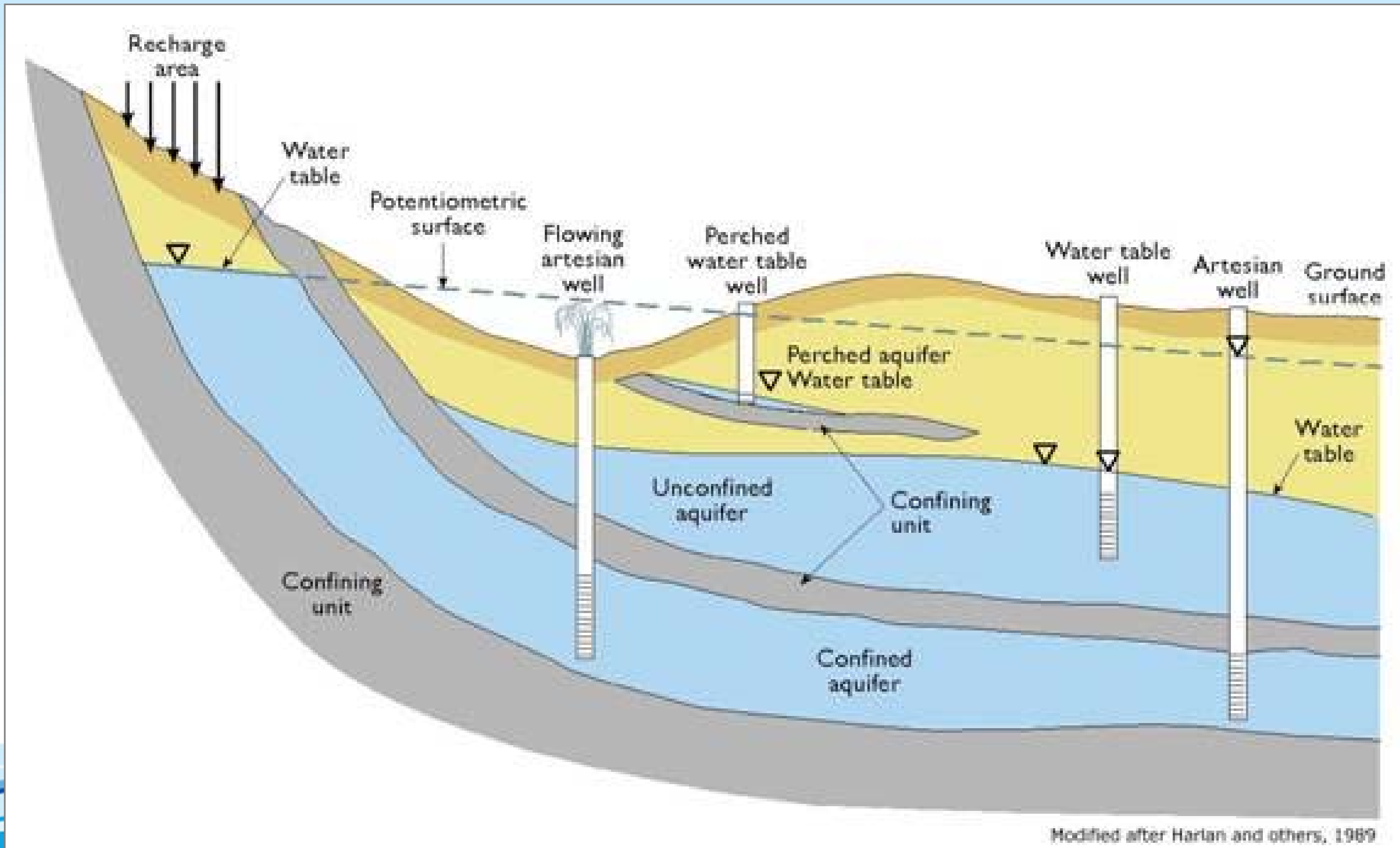


2. Hydrogeologic Conceptual Model

- Characterize Water Budget



2. Hydrogeologic Conceptual Model

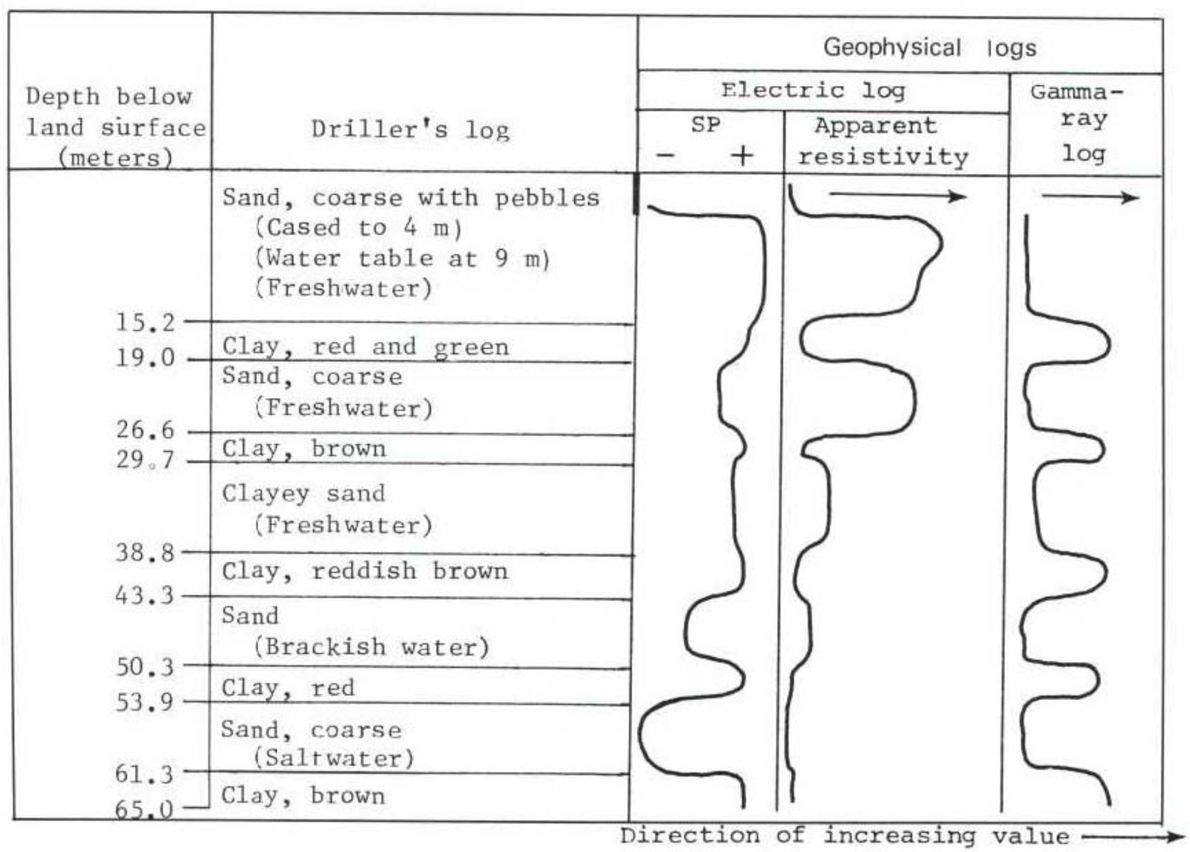


2. Hydrogeologic Conceptual Model

Field Sample Collection

2. Hydrogeologic Conceptual Model

Geophysical Logging



2. Hydrogeologic Conceptual Model

- GW flow directions and velocity based upon GW levels (known as heads)
- GW flow is considered in horizontal and vertical components
- Pumping wells and pumping rates influence GW flow rates and flow directions
- GW levels are used to construct GW contour maps (lines of equal elevation)

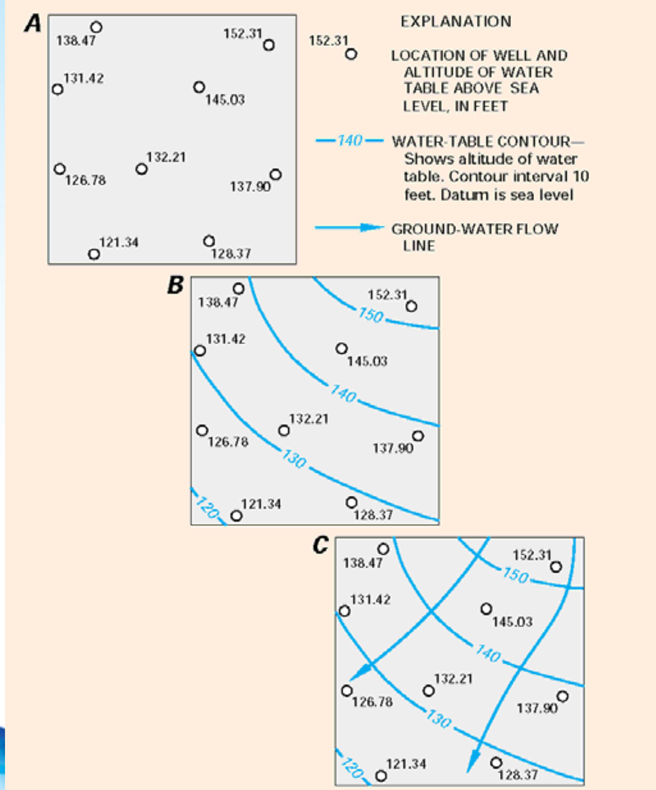
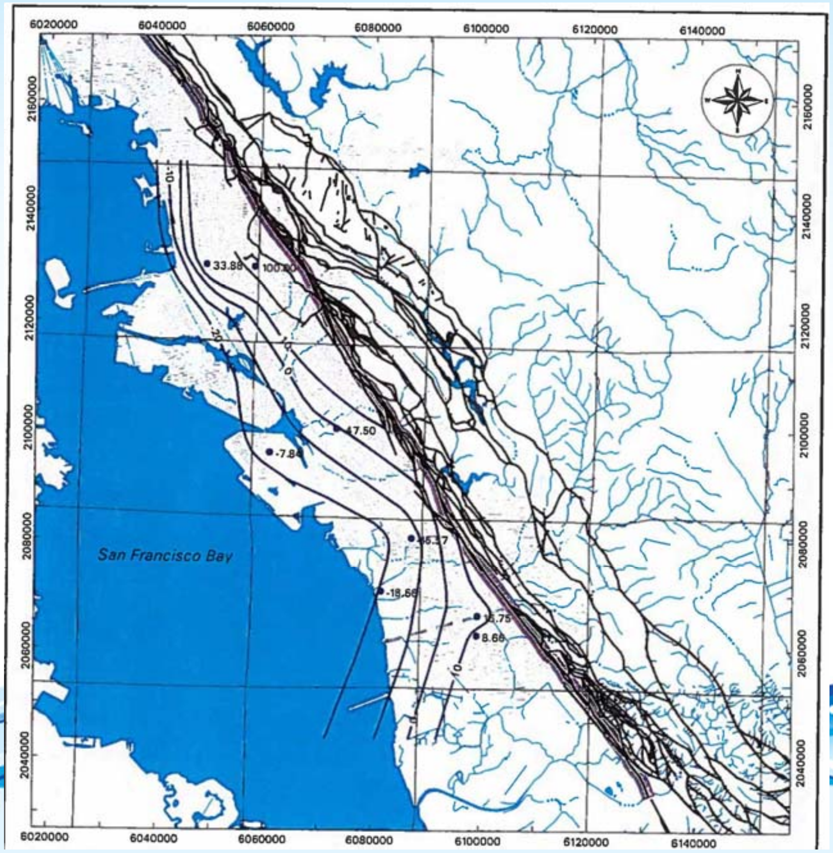


Figure A–2. Using known altitudes of the water table at individual wells (A), contour maps of the water-table surface can be drawn (B), and directions of ground-water flow along the water table can be determined (C) because flow usually is approximately perpendicular to the contours.

2. Hydrogeologic Conceptual Model

- Characterize Groundwater Levels and Flow



2. Hydrogeologic Conceptual Model

Darcy's Law

Q = KiA; where

- Q = volumetric rate of groundwater flow (L^3/T)
- K = hydraulic conductivity (L/T)
- i = hydraulic gradient (dimensionless)
- A = cross-sectional area of flow (L^2)

q = Ki/n; where

- q = velocity of groundwater flow (L/T)
- i = hydraulic gradient (dimensionless)
- n = porosity (dimensionless) – should use effective porosity, but only significant for fine-grained materials

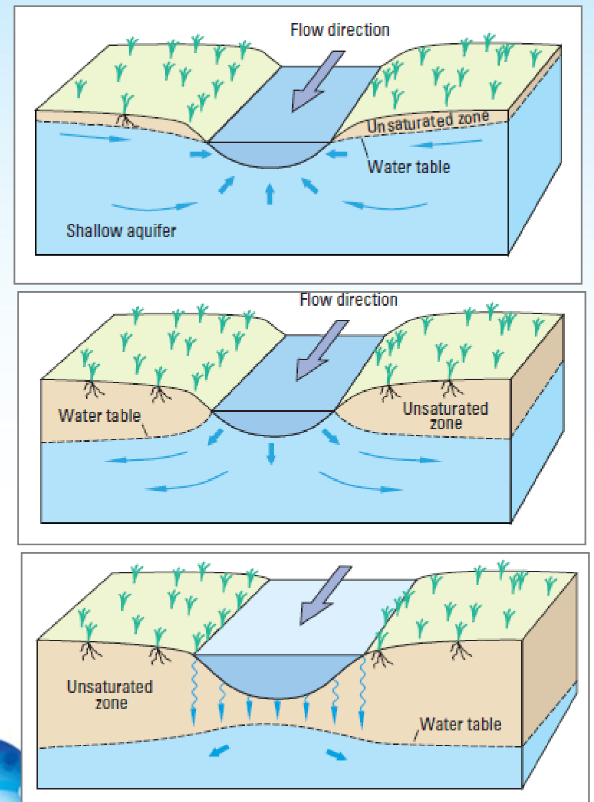
2. Hydrogeologic Conceptual Model

Groundwater – Surface Water Interaction

Gaining Stream - GW recharges stream

Losing Stream - Stream recharges GW

Disconnected Stream - Infiltration rate constant, recharge amount dependent on stream level, streambed/bank geometry, streambed K



USGS Circular 1376, Barlow and Leake (2012). Figure modified from Winter and others (1998).

2. Hydrogeologic Conceptual Model

Aquifer Parameters

- Hydraulic conductivity (K) defined as the rate of flow of water through a unit cross-section under a unit hydraulic gradient
- Transmissivity (T) defined as K times saturated thickness
- Specific yield (Sy) defined as ratio of volume of water drained by gravity from saturated material to total aquifer volume (0.01 to 0.3)
- Storage coefficient (S) defined as ratio of volume of water derived from aquifer skeleton compression and water expansion to total aquifer volume (0.005 to 0.00005)
- T, S, and pumping (amount/duration) are key variables that define lateral/vertical extent of pumping cone of depression
- Aquifer parameters most accurately defined by pumping tests

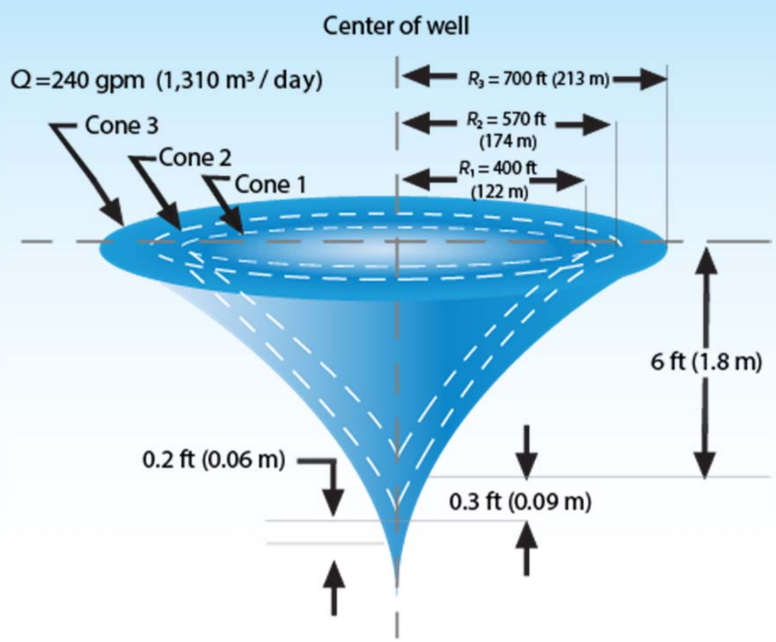


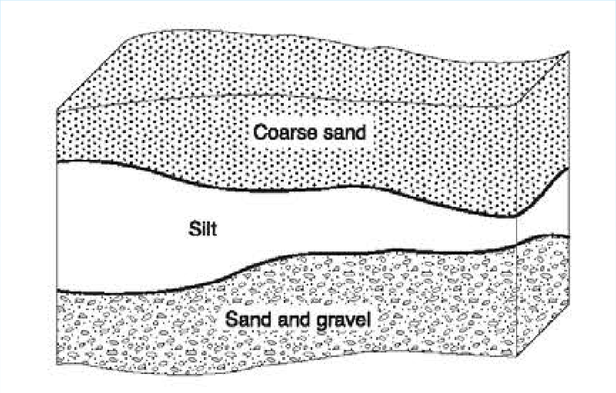
Figure 9.7. Changes in radius and depth of cone of depression after equal intervals of time, at constant pumping rate.

(from Driscoll, 1986)

3. Groundwater Model Development

<u>What is a Groundwater Model</u>

- Mathematical Representation of a Groundwater System
- Different Types of Models
  - Flow
  - Transport
- Simplified Representation of Complex Natural Conditions



Mathematical Model

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

3. Groundwater Model Development

Model Domain

- Define the horizontal and vertical boundaries of the aquifer system to be simulated by the model

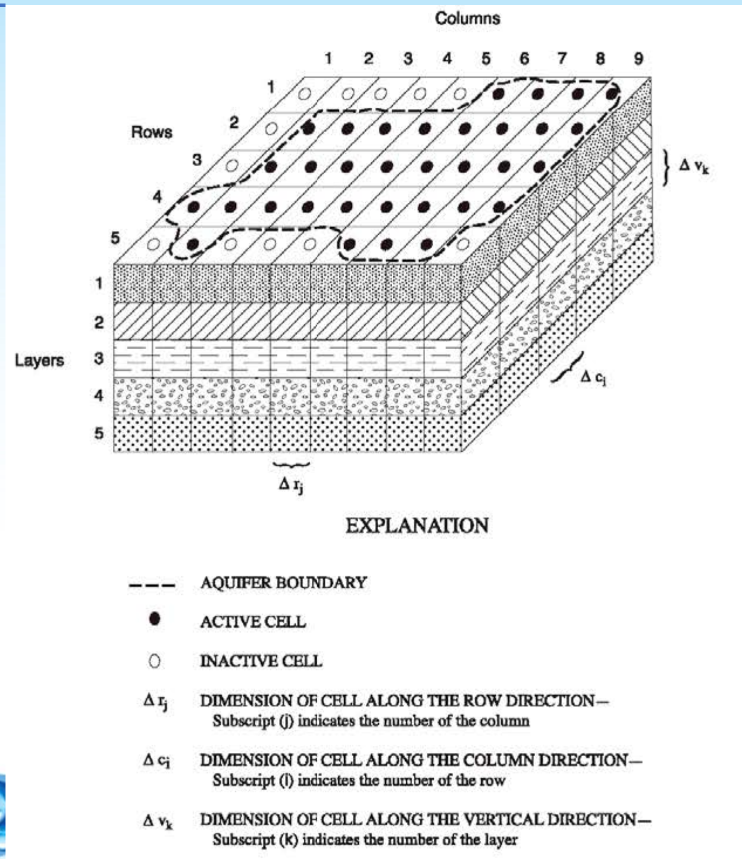


Figure 2–1. A discretized hypothetical aquifer system. (Modified from McDonald and Harbaugh, 1988.)

3. Groundwater Model Development

Model Grid/Layers

- Define spacing of model cells/nodes
- Define number and thickness of model layers

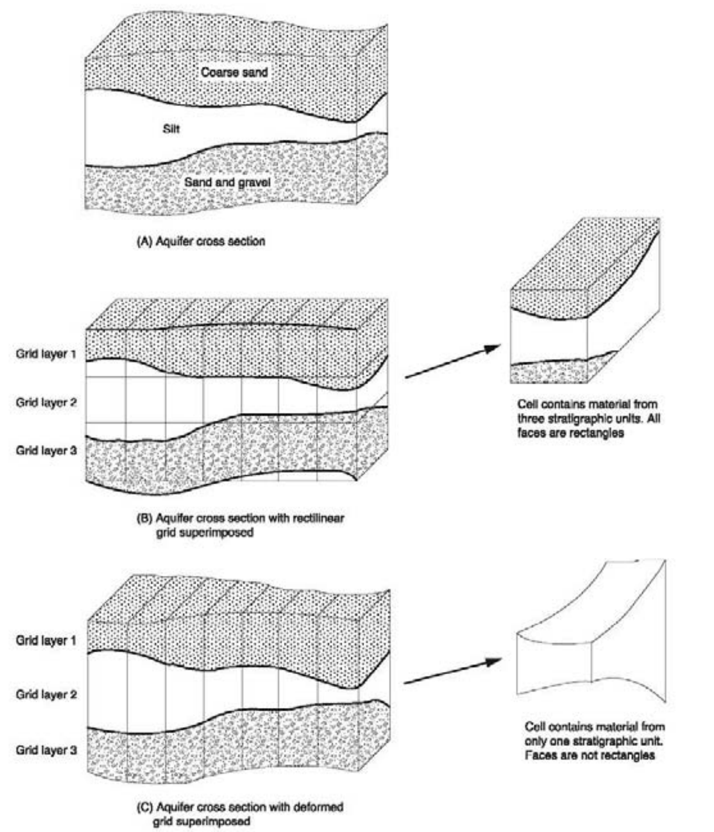
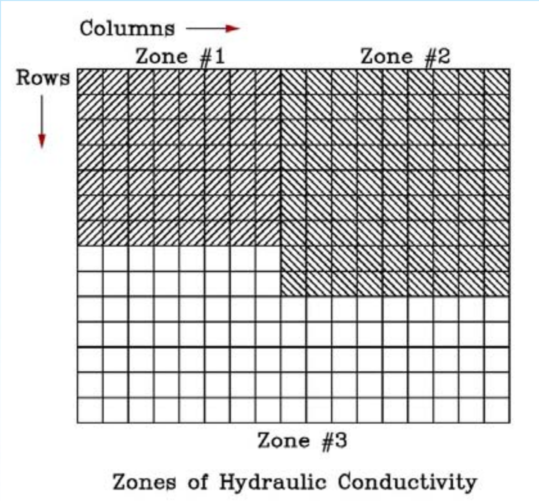


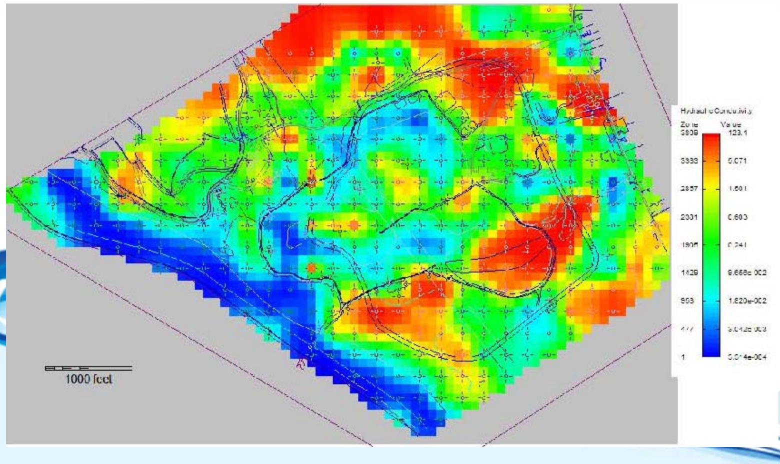
Figure 2-8. Schemes of vertical discretization. (From McDonald and Harbaugh, 1988.)

3. Groundwater Model Development

Model Inputs

- Define zones and values for initial aquifer parameters (e.g., T/K, Sy, Ss)
- Define location/magnitude of sources/recharge and sinks/discharge (e.g., precipitation recharge, streamflow infiltration, pumping)





3. Groundwater Model Development

Model Boundary Conditions

- Define nature of groundwater flow along boundaries of model domain (e.g., no flow vs. flow across boundary)
- Types
  - No Flow
  - Specified Flow
  - Constant Head
  - General Head
- Define water levels, conductance and/or fluxes along margins of model

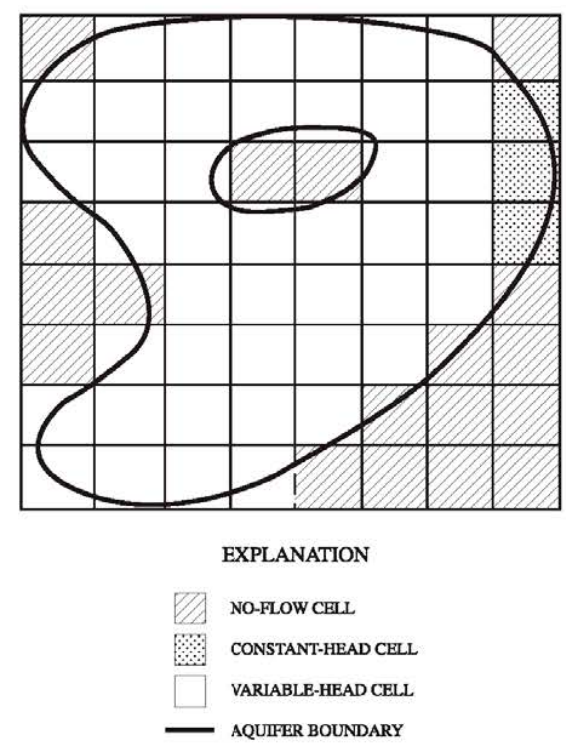
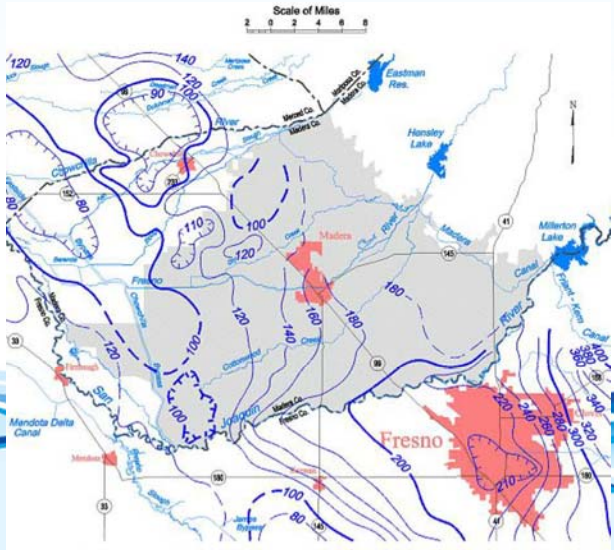


Figure 2–7. Discretized aquifer showing boundaries and cell designations. (Modified from McDonald and Harbaugh, 1988.)

3. Groundwater Model Development

Model Initial Conditions

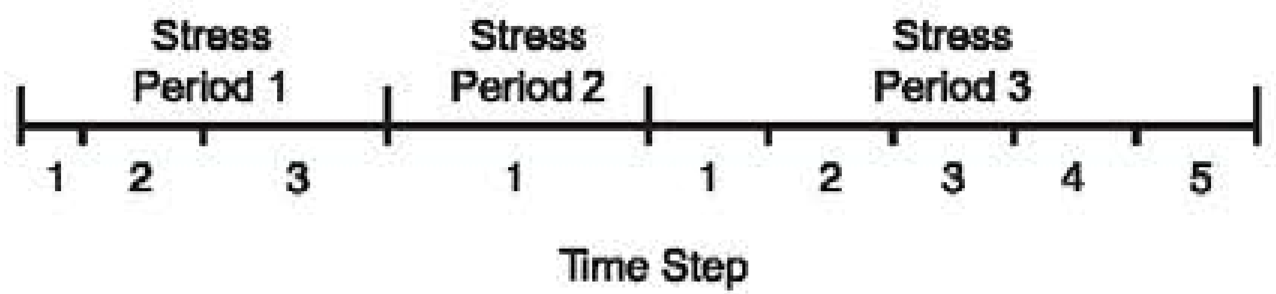
- Define water levels during initial year of model simulation within the model domain
  - Options include: steady state model run; groundwater contour map(s) for starting year



3. Groundwater Model Development

Model Stress Periods and Time Steps

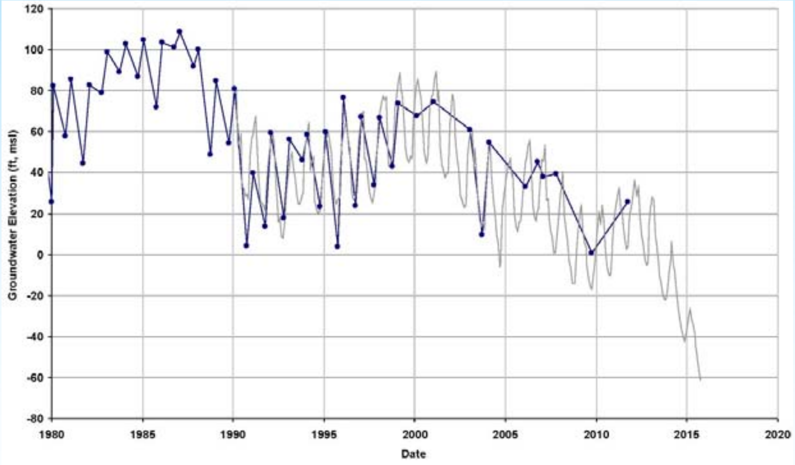
- Define time periods during which model stresses (recharge and discharge components) remain constant (Model Stress Periods)
- Define time periods within stress periods for which model calculates results (Model Time Steps)

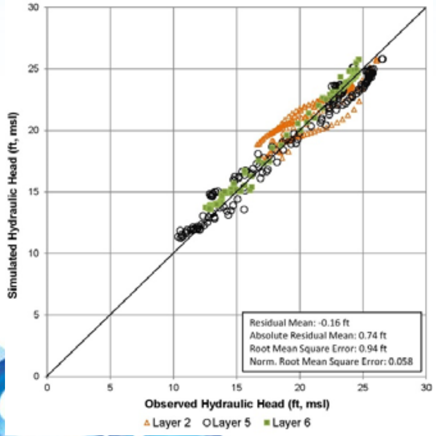


3. Groundwater Model Development

Model Calibration

- Conduct Manual and/or Automated Matching of Model Simulated to Observed Water Levels
- Adjust Selected Aquifer Parameters and/or Water Budget Components to Improve Match of Model Simulated to Observed Water Levels
- Evaluate Goodness of Fit
- Conduct Sensitivity Analyses





3. Groundwater Model Development

Groundwater Model Limitations

- All models are non-unique
- Models are simplifications of natural conditions
- Quality of model is highly dependent on input data
- All models have a degree of uncertainty; multiple inputs/parameters required
- Models best used as planning tools to evaluate relative differences of different scenarios/actions

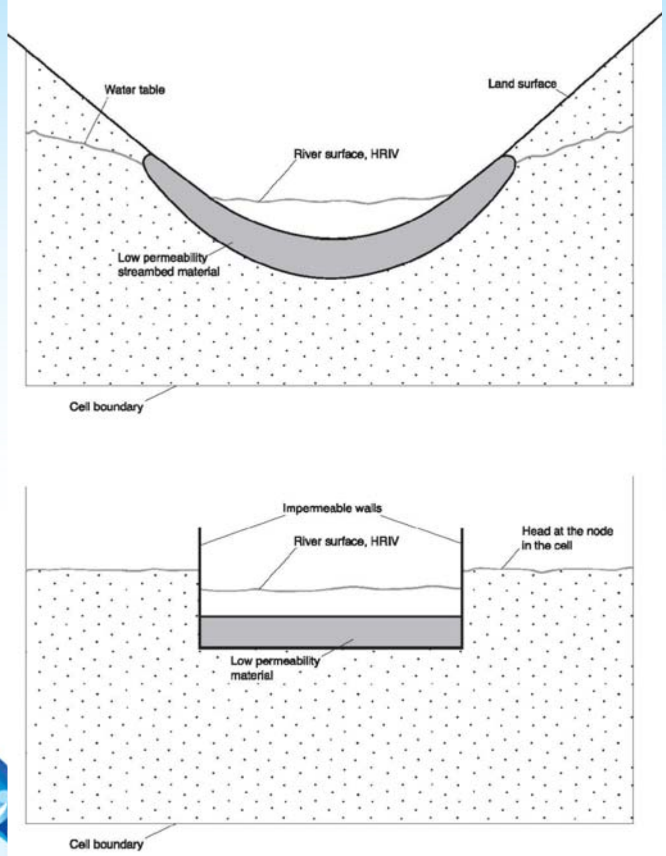


Figure 6–5. (A) Cross section of an aquifer containing a river and (B) conceptual representation of river-aquifer interconnection in a simulation. (From McDonald and Harbaugh, 1988.)

4. Groundwater Modeling Platform Selection

- Model Types
  - Physical (e.g., “Sand Box” Models)
  - Mathematical (Analytical vs. Numerical)
- Numerical Model Code/Platform Options
  - MODFLOW
  - IWFM
  - Others
- EBP Subbasin GSP Subtask 4.3 TM
  Model Objectives and Model Selection

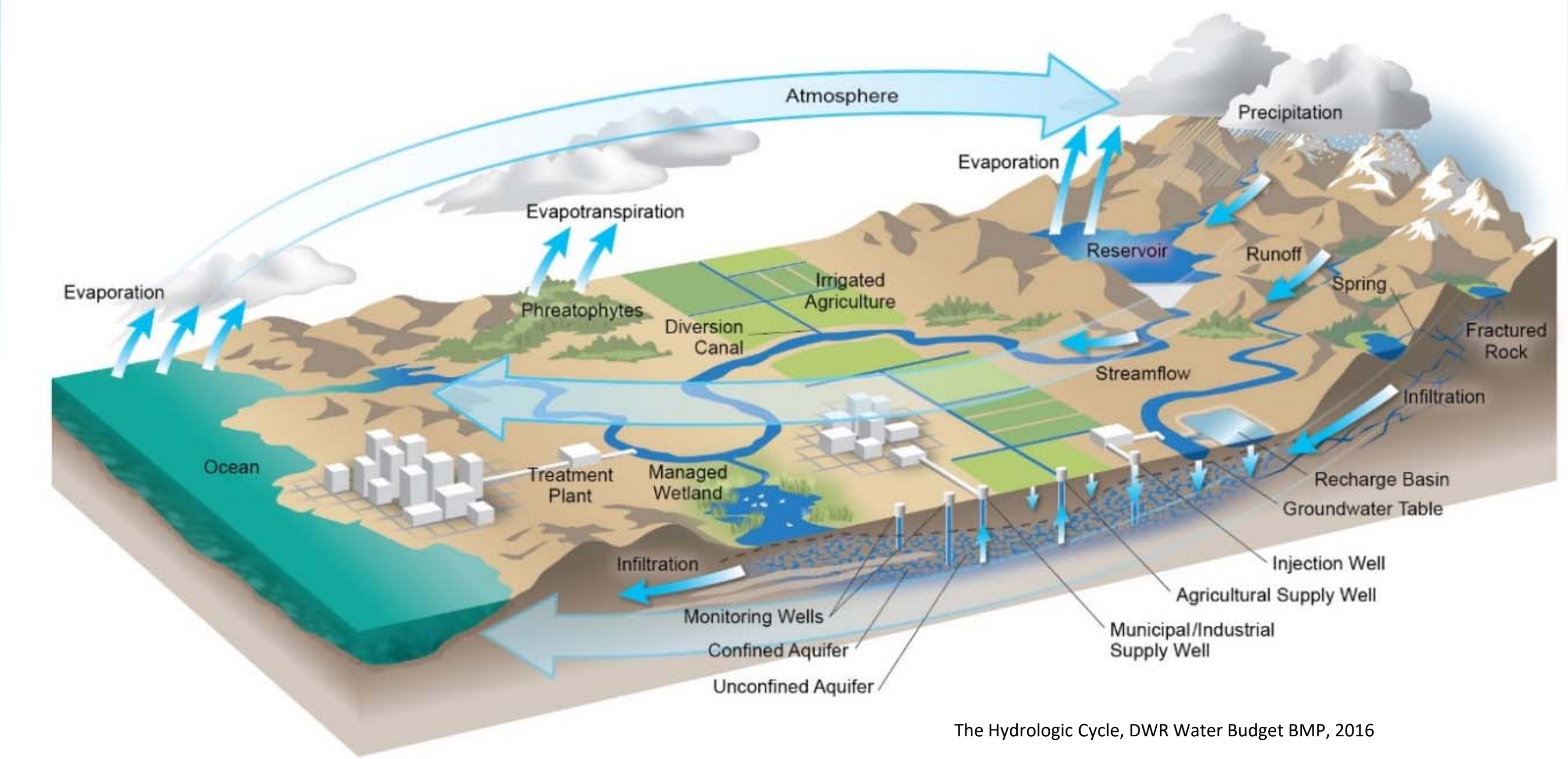
5. Groundwater Model Maintenance

- Models are meant to be updated, refined, and recalibrated in the future as additional data are collected and becomes available
- Consider periodic model updates
- Level of effort for future updates depends on construction (e.g., aquifer parameters) and performance of existing model compared to new data acquired; for example
  - Does new aquifer test data match existing aquifer parameter inputs reasonably well?
  - Can existing model provide reasonable simulation of water level fluctuations observed in recent data?

6. Key Takeaways

- A good and well developed hydrogeologic conceptual model is the foundation of a good numerical groundwater model
- Groundwater models support decision making
- The initial groundwater model developed for the GSP will evolve and improve over time as more data is collected

Any Questions?



The Hydrologic Cycle, DWR Water Budget BMP, 2016