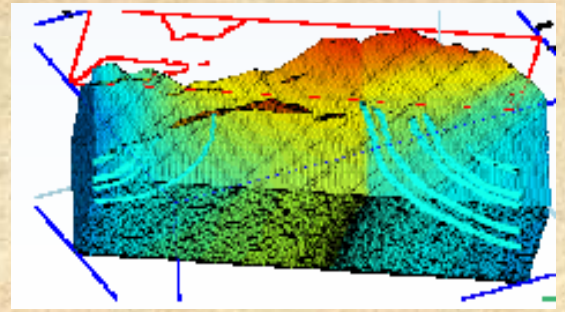
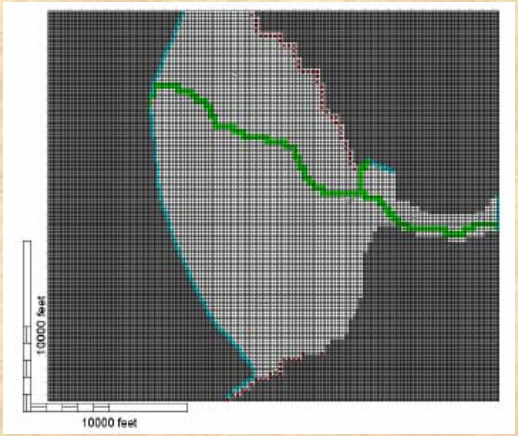
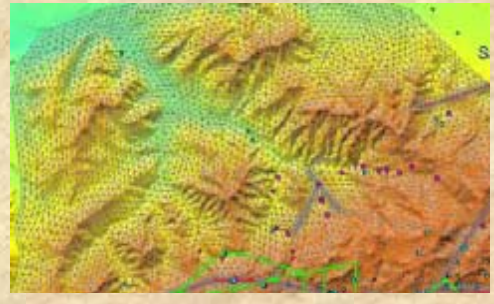
# Usefulness of Numerical Models to Address Impacts of Mitigation and Augmentation Actions on Groundwater and Surface Water Systems

Water Policy Interim Committee





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**September 12, 2007**

# Take Home Points

1. Numerical models can be developed to represent complex geological and hydrological systems.

2. Groundwater modeling is most useful when used to answer…How does the groundwater system work?

3. Analyses of impacts to water resources using ...What if scenarios… provide valuable information on the likely changes that will occur to hydrologic systems.

4. Quantitatively, forecasting short and long term impacts of specific proposed actions includes error and uncertainty.

## This Presentation

*Floyd Tries to Go On Line*

1. What is a model?
2. What types of models are there?
3. How is a numerical groundwater model developed?
4. What are the data needs?
5. Case study to illustrate model application
6. Challenges in using the results.

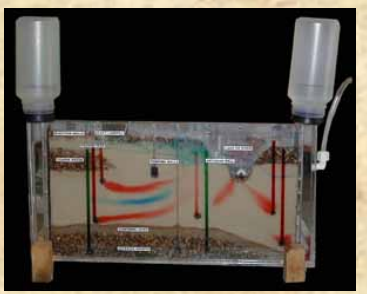
# What is a Model?

***Simplification of a real world setting.***

*Example*- Road map is a model of the earth's surface

## Types of Models

1. Physical Scale Model



2. Analog model

3. Mathematical Model

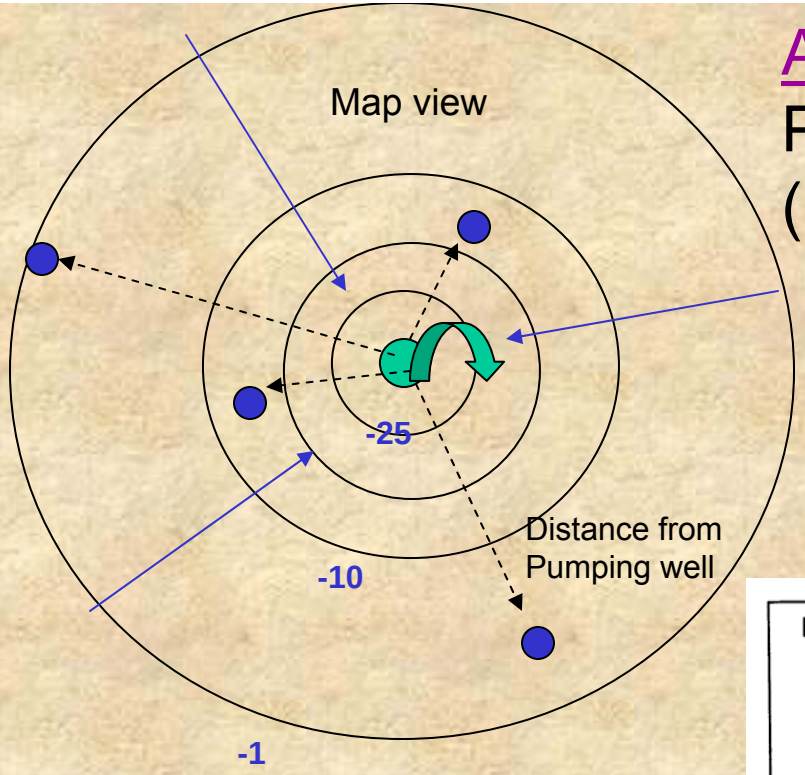
Use physics and math to describe the resource

Analytical Model

$$s = \frac{Q\,W(u)}{4\pi T}$$

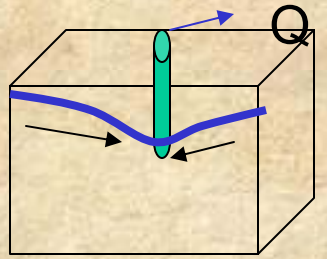
Numerical Model

Finite Differences
Finite Elements




## Analytical Model (equation)

Pumping Well- Predict drawdown(s) (reduction in GW levels)

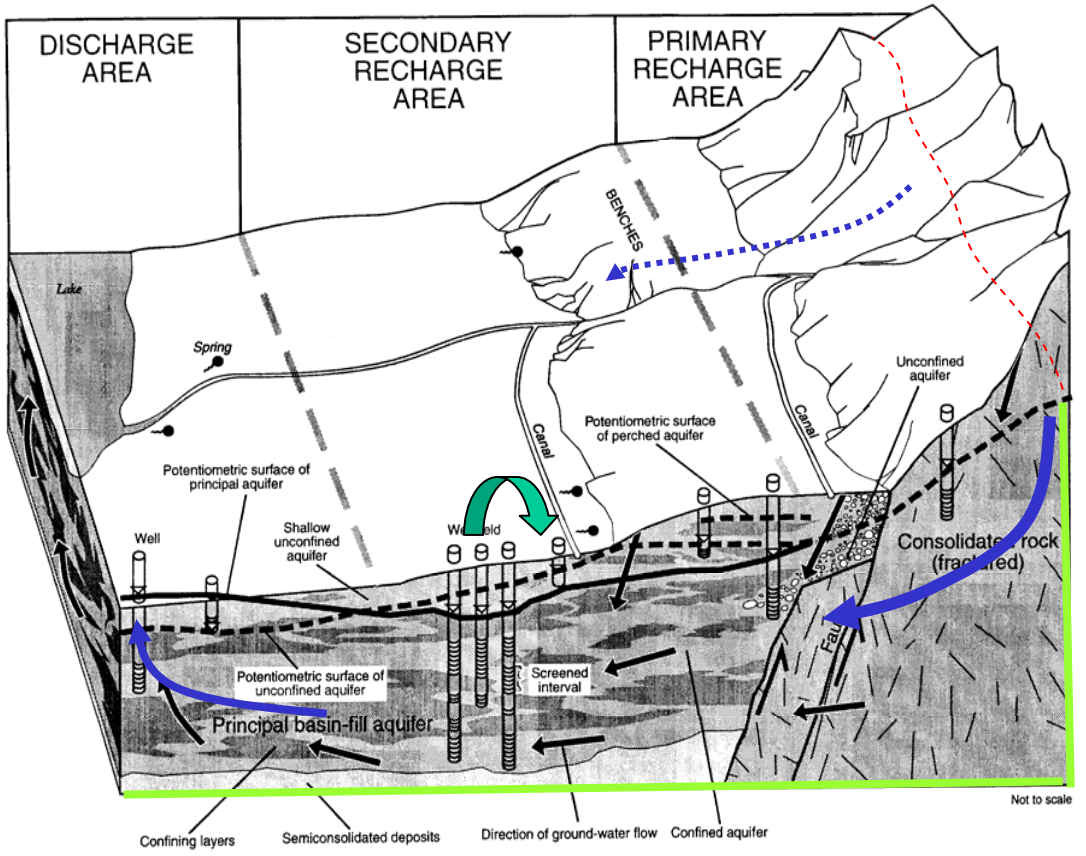



Many simplifying assumptions

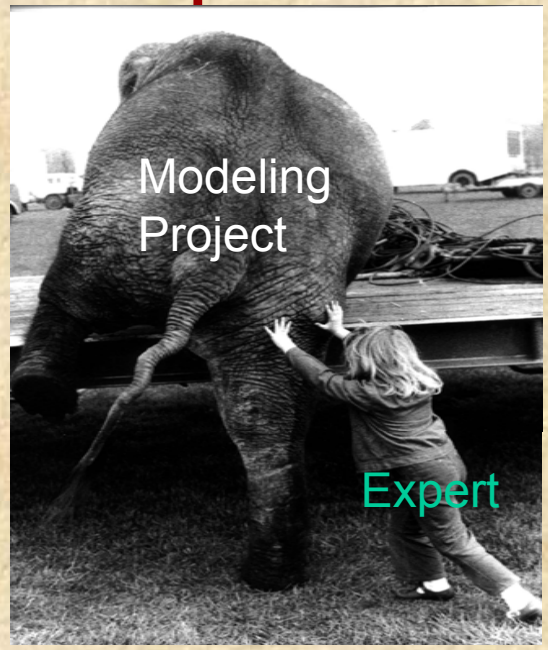
## Numerical Model

Handles More Complex GW Settings

Fewer simplifying assumptions



# Different amounts and distributions of data are required to solve specific problems.




***Increasing Data Needs***

***Increasing demand for Evidence of Simulation Match with Field Conditions***

## Generic Modeling

**Under general conditions**
**-how do components interact**

## Interpretative Modeling

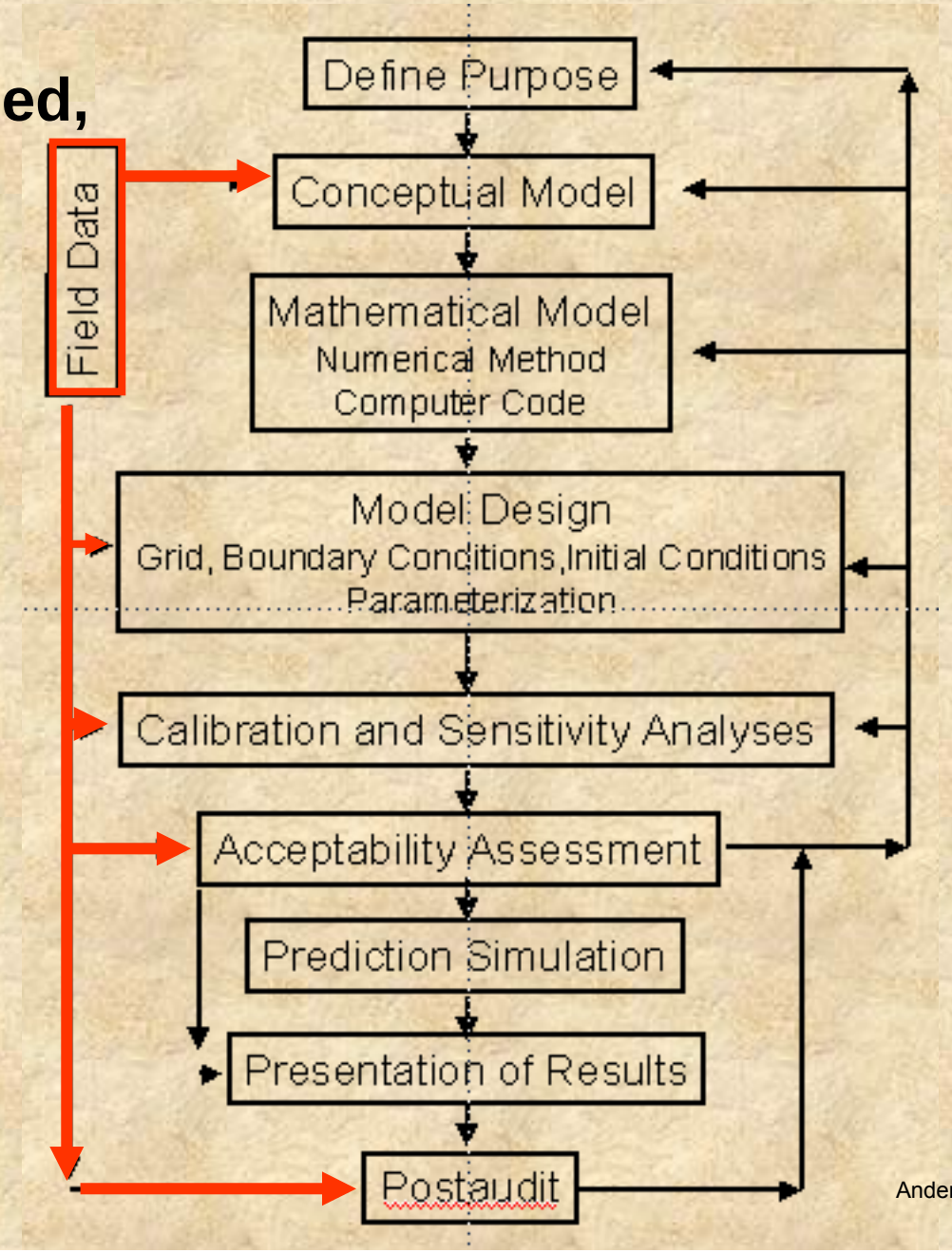
**Under field conditions**
**-how do components interact**

## Predictive Modeling

**Under field conditions**
**-what are likely outcomes**

# How are Numerical Models Developed?

**An Established, Recognized Method**




Anderson and Woessner, 2004

# What are the Data Needs?

Building the Conceptual Model

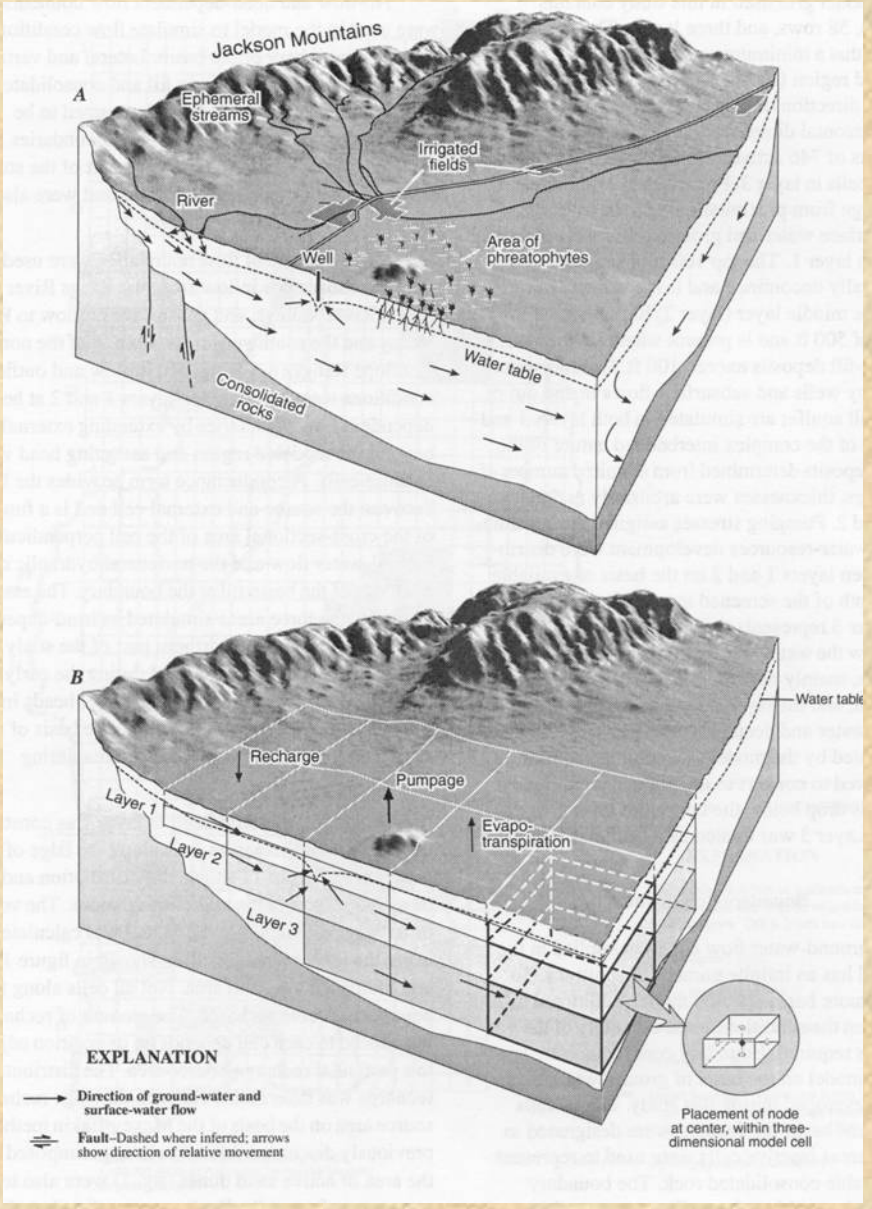
**Physical Framework**

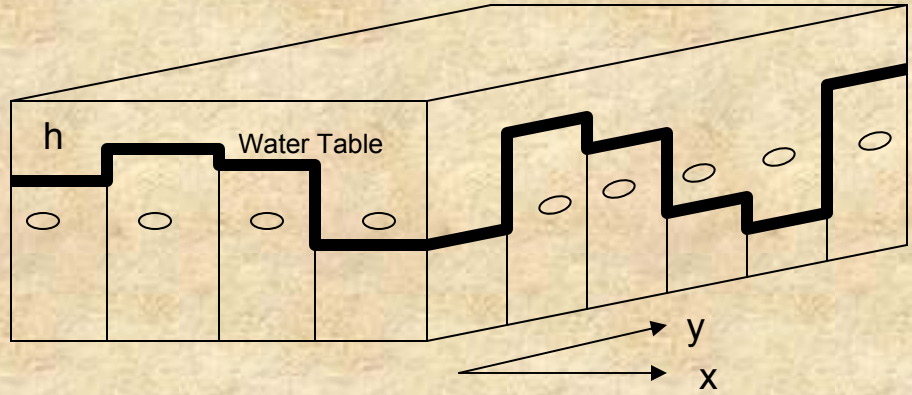
**Geology- nature, 3D extent**
**Surface topography and Soils**
**Hydrologic Features**

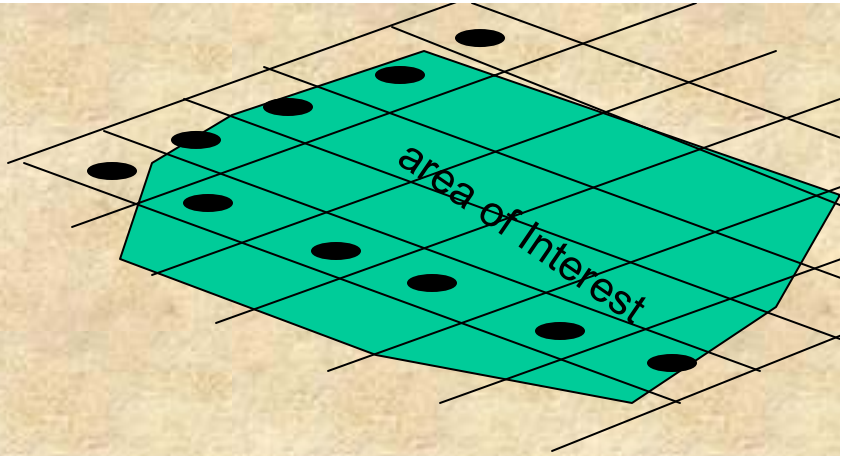
**Hydrologic Framework**

**Water Level Measurements**
**Surface Water Elevations**
**Surface Water Flows**
**Transmission and Storage**
**Properties of Earth Materials**
**Sources of Recharge and Discharge**
**Physical and Hydraulic Boundaries**
**Source and Sinks of Water**
**Water Quality Data**

It's the Hydrogeology!!

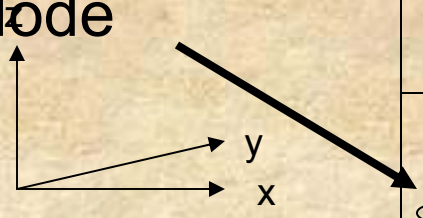


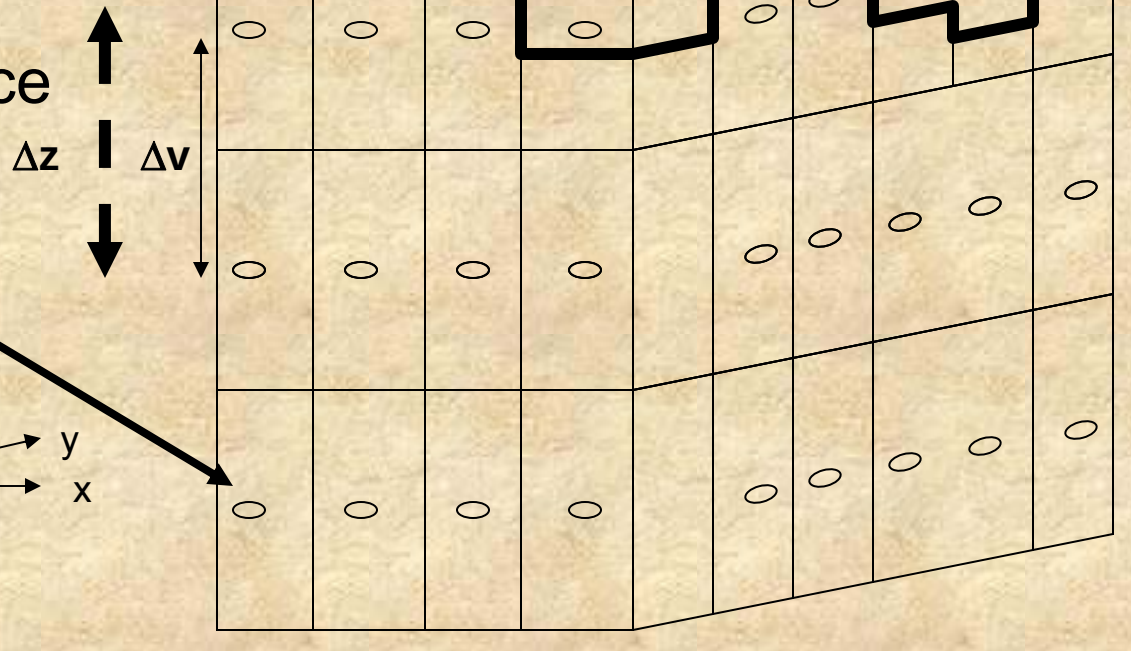


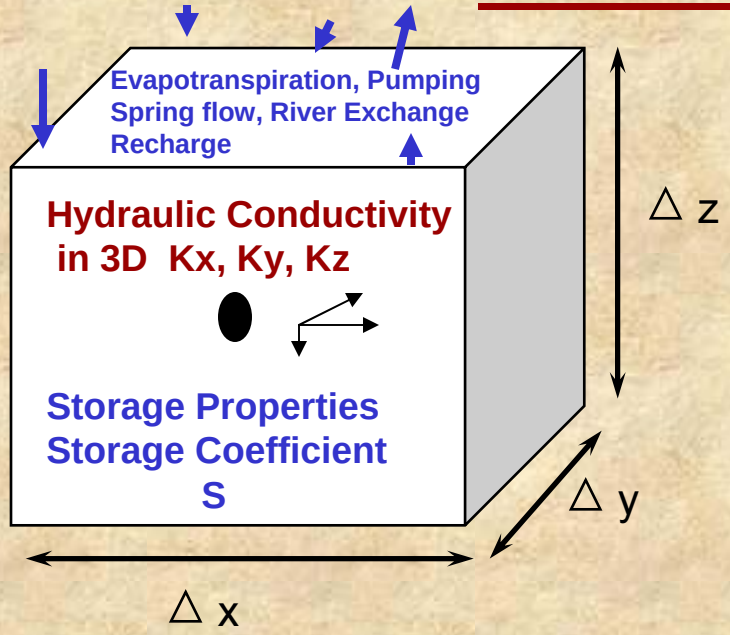

## Numerical Model

Break up the space and time into blocks and time Intervals. Node



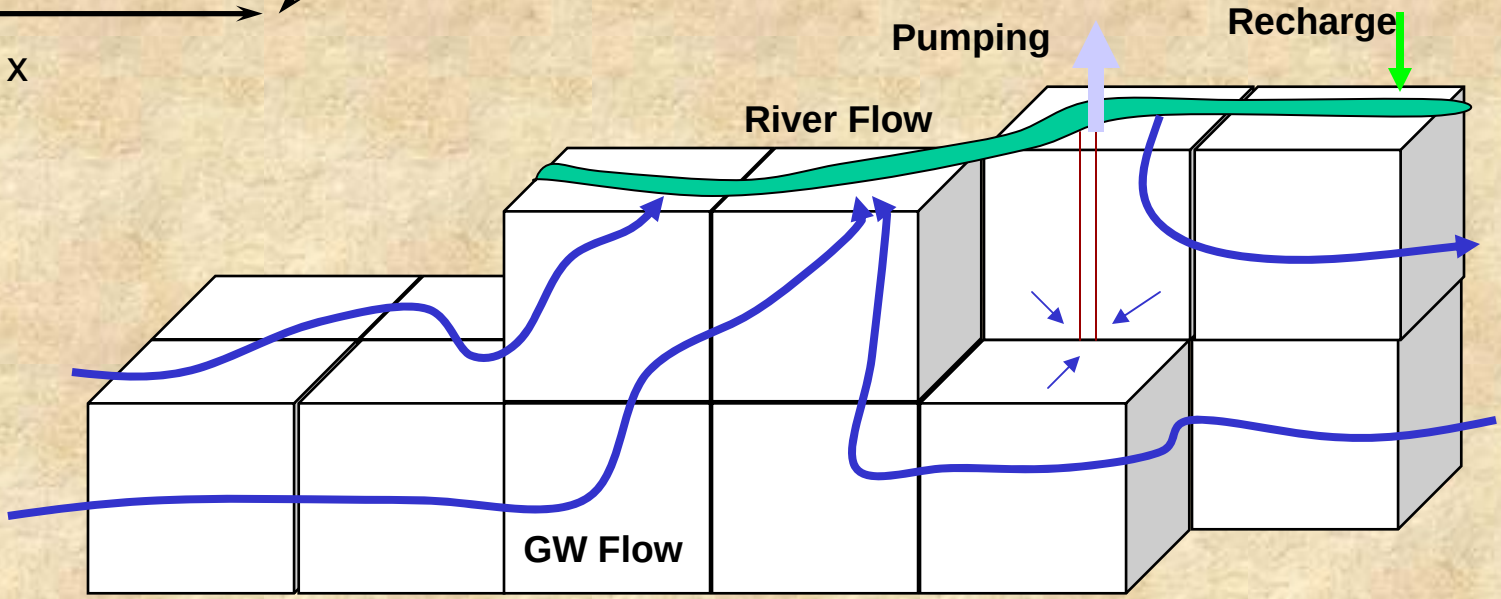



# Parameterizing the Model



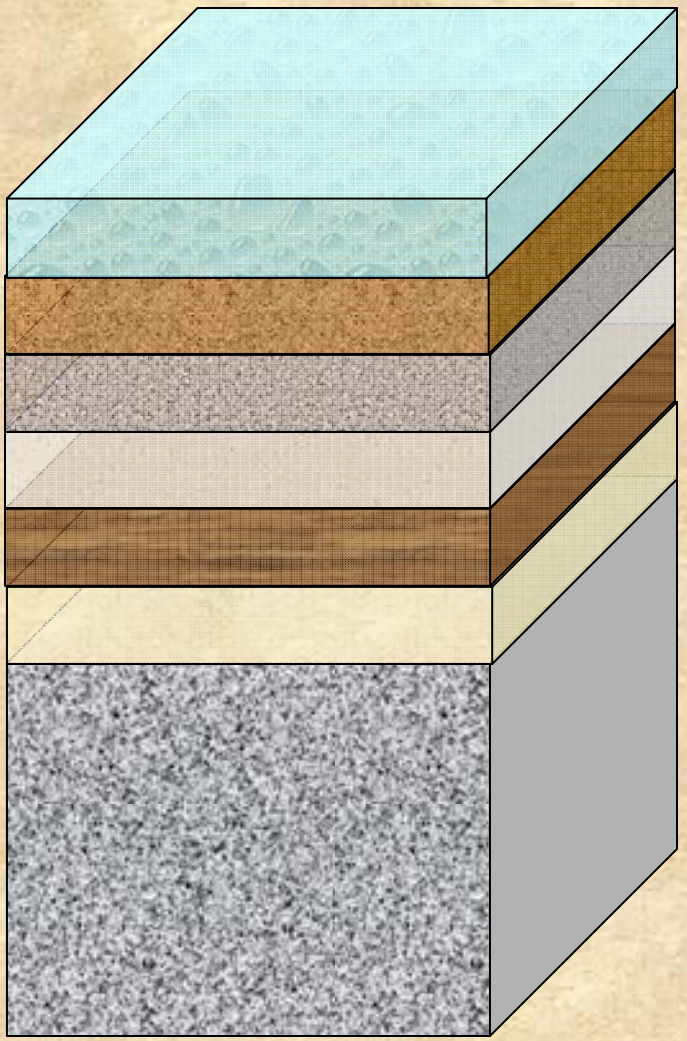

**Numerical Modeling Methods Assign Data to Cells or Elements that represent a Volume of Aquifer material**

Individual elements are then linked to adjacent cells and the GW model is created.



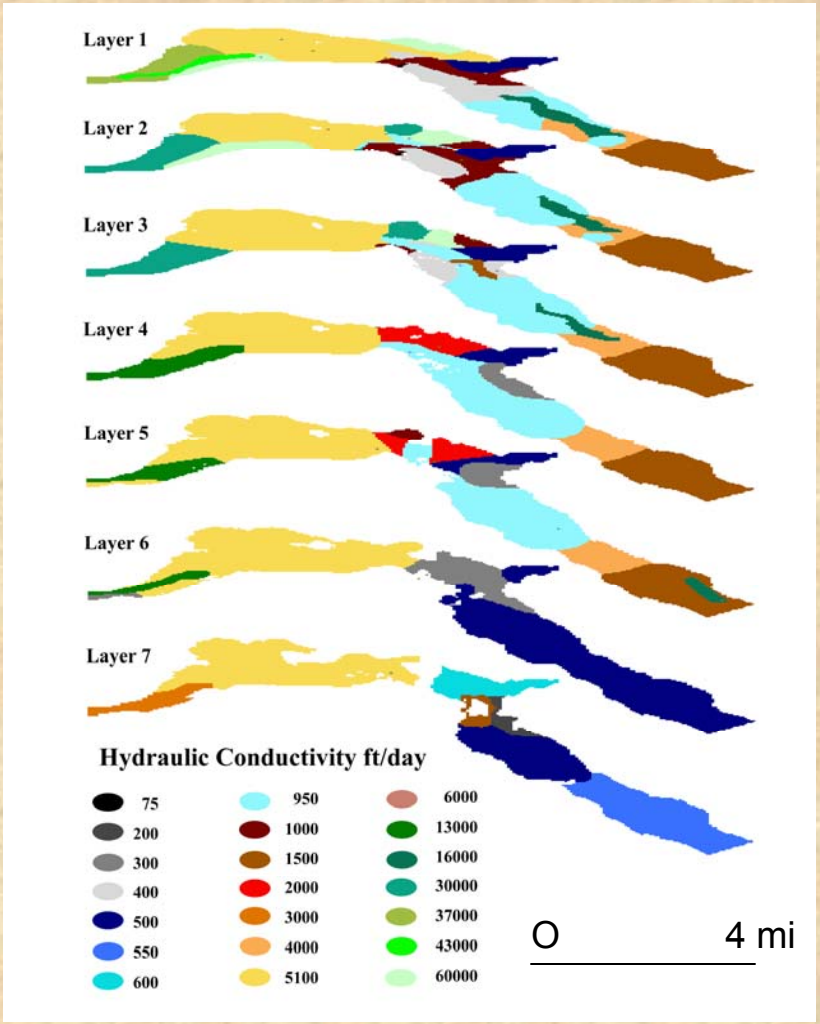
# Milltown GW Model example

## Seven Layers



Milltown (Berthelote et al., 2007)

## Distribution of Hydraulic Conductivity



# Case Study Example

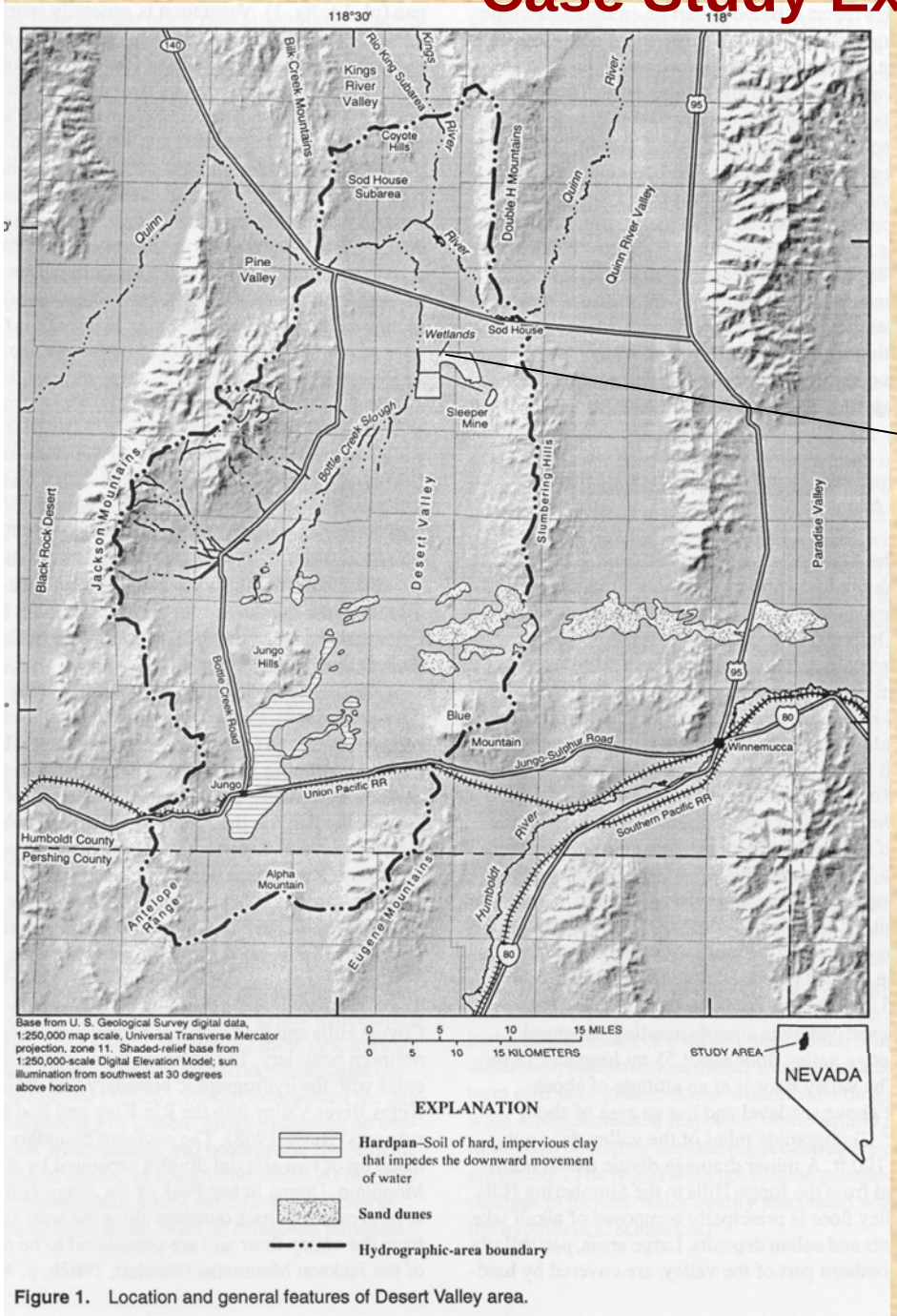
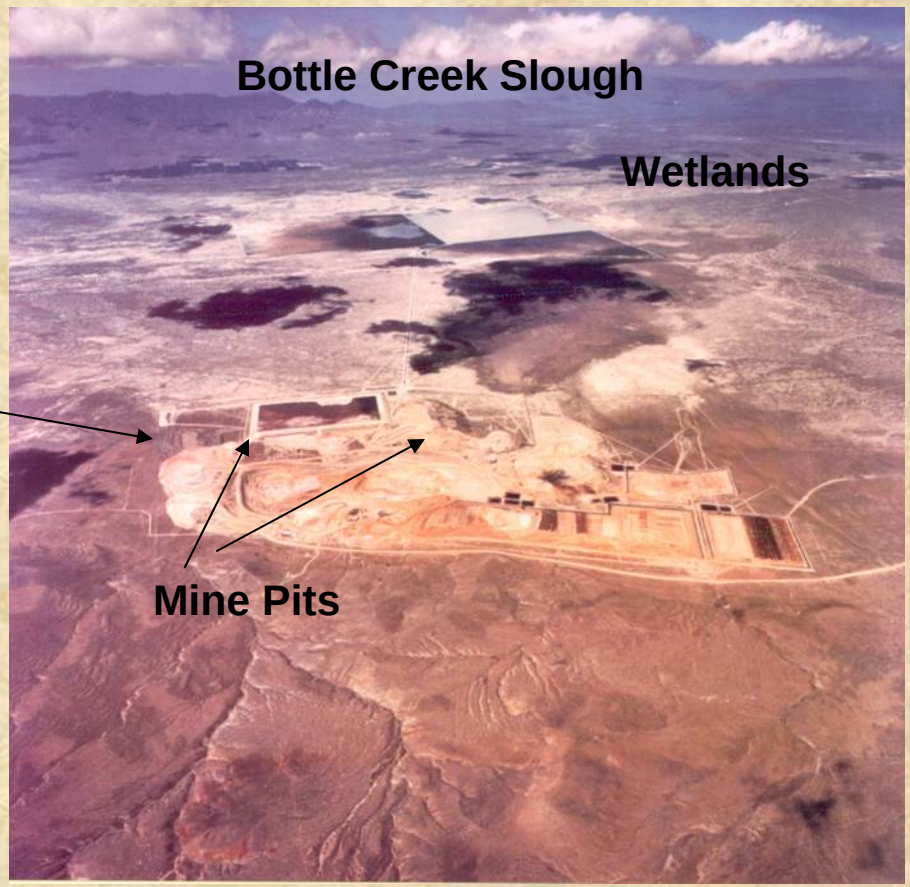



Figure 1. Location and general features of Desert Valley area.




**Purpose: Examine the effects of mine dewatering on the ground-water conditions in Desert Valley, NV**

***Purpose is not to build a model!!!***

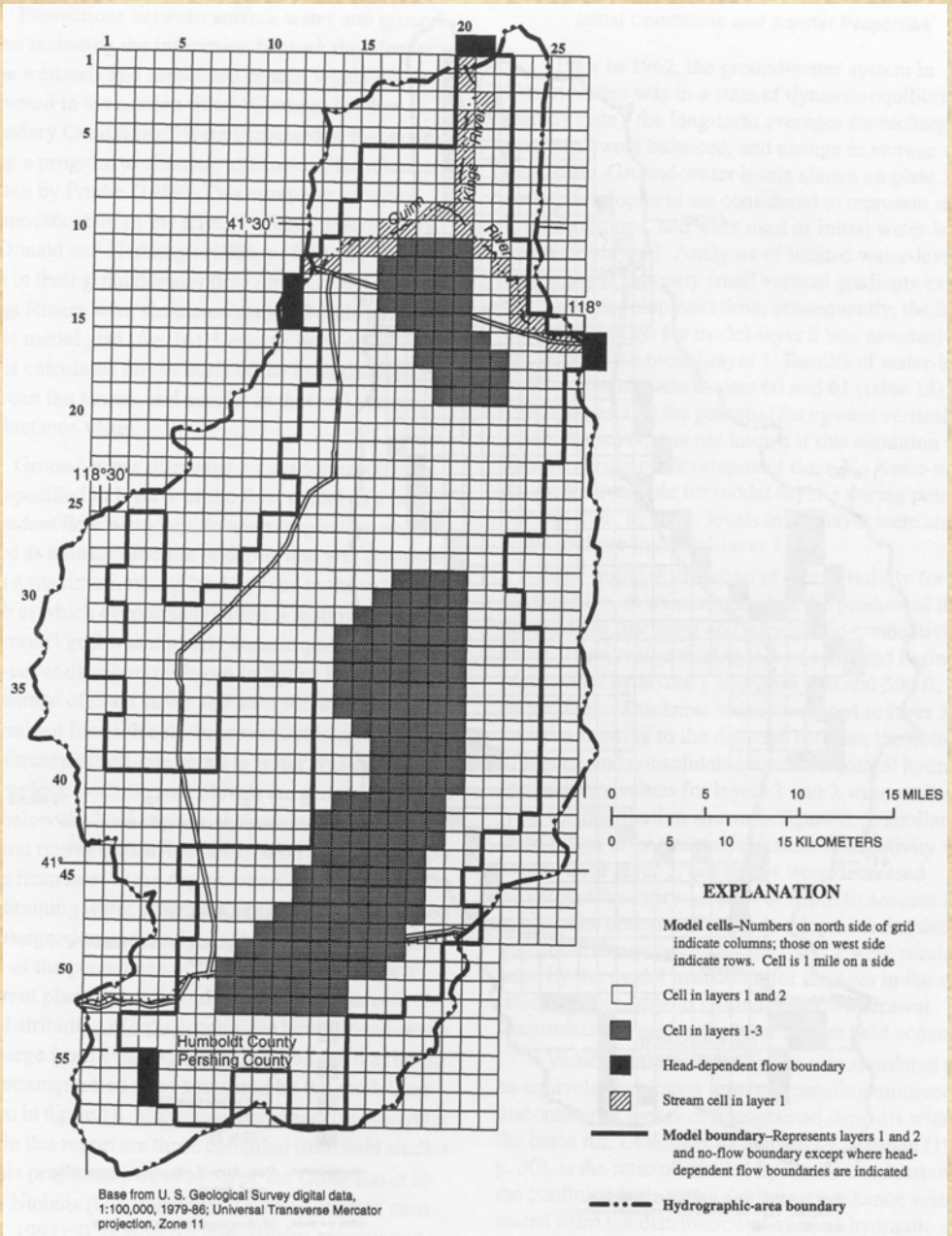



Figure 16. Block-centered finite-difference grid used for ground-water flow model of Desert Valley, Nevada.

## Formulate the GW Model

**Cells in the three layered model 4,524**

**Assign values to cells**

**Assign boundary conditions**

USGS MODFLOW Numerical Model

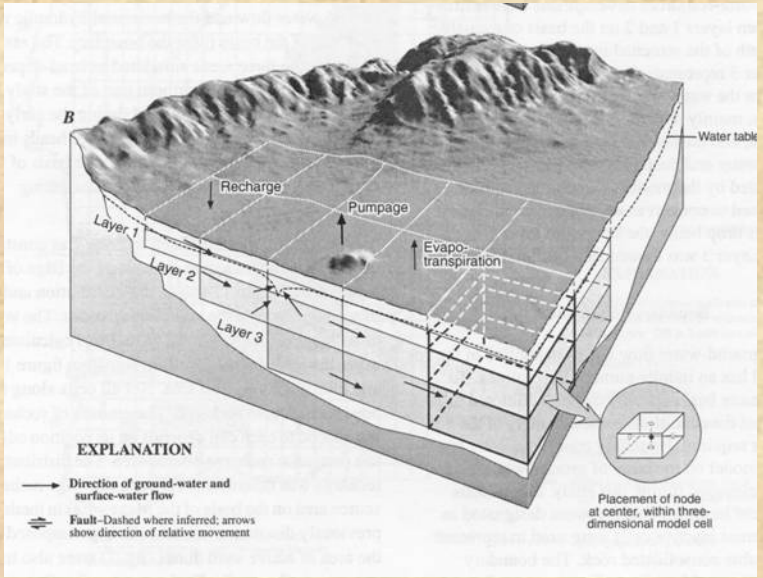


**Table 9.** Estimated ground-water budget for predevelopment conditions (pre-1962), Desert Valley, Nevada

[All values in acre-feet per year]

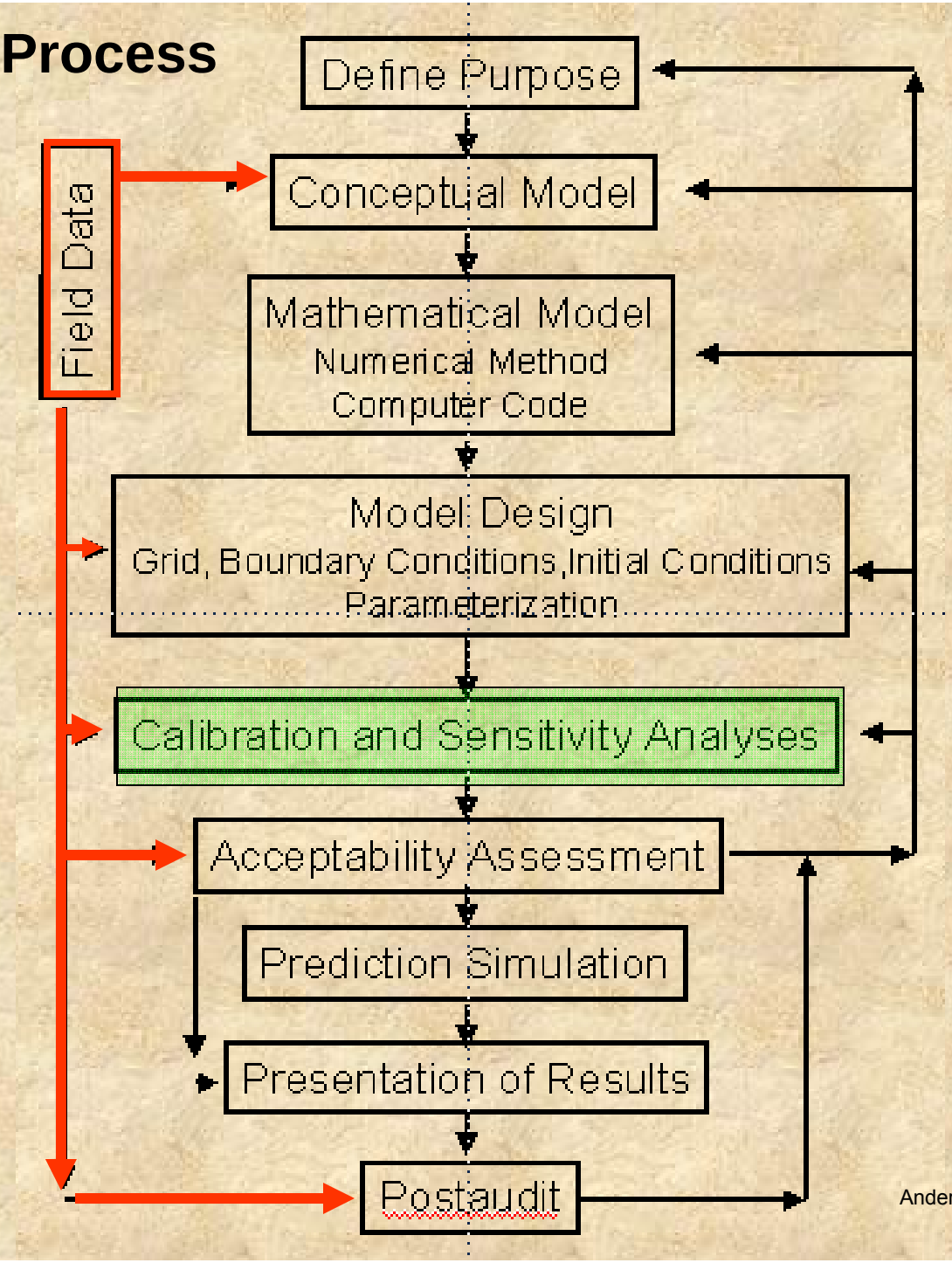
| Budget component | Estimated predevelopment conditions |
|---|---|
| **Inflow** | |
| Recharge from precipitation: | |
| From mountain block (p. 33, p. 34) | 3,300 - 6,800 |
| From sand dunes (p. 35) | 500 - 1,000 |
| Infiltration from rivers (p. 19) | 700 - 4,700 |
| Subsurface inflow: | |
| From Kings River Valley (p. 16) | 900 |
| From Quinn River Valley (p. 16) | 300 |
| Total inflow (rounded) | 5,700 - 14,000 |
| **Outflow** | |
| Evapotranspiration (p. 35) | 10,000 |
| Subsurface outflow: | |
| To Pine Valley (p. 19) | 100 - 400 |
| To Southwest (p. 19) | 120 - 1,200 |
| Total outflow (rounded) | 10,000 - 12,000 |

## Pre-simulation Water Balance

Critical!!!

In= Out +/- △Storage

# Modeling Process



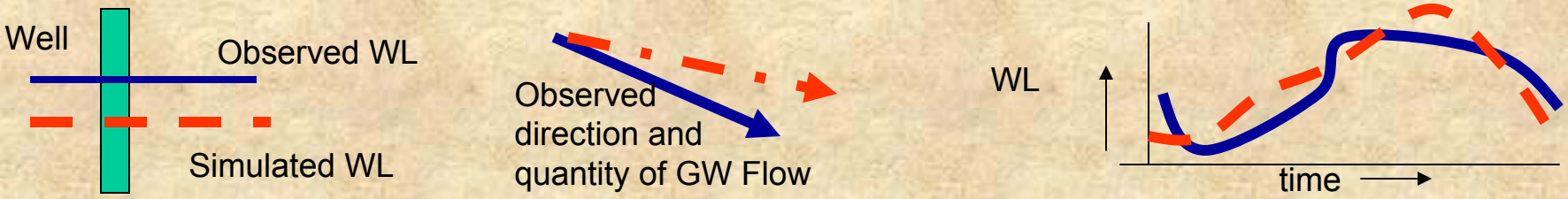

Anderson and Woessner, 2004

# Calibration Process

## Set Calibration Targets

1. **Differences between simulated and measured heads.**
2. **Differences between measured GW fluxes and simulated fluxes**
3. **Differences in the pre-simulation computed water balance and simulated water balance.**
4. **Differences in locations and rates of pre-simulation and simulation recharge and discharge**.

Using Trial and Error or Automated Parameter Estimation, the model is executed a number of times while adjusting model components such that differences between measured and simulated conditions are minimized



# Pre-development 1962 Calibration

## Pattern of water levels

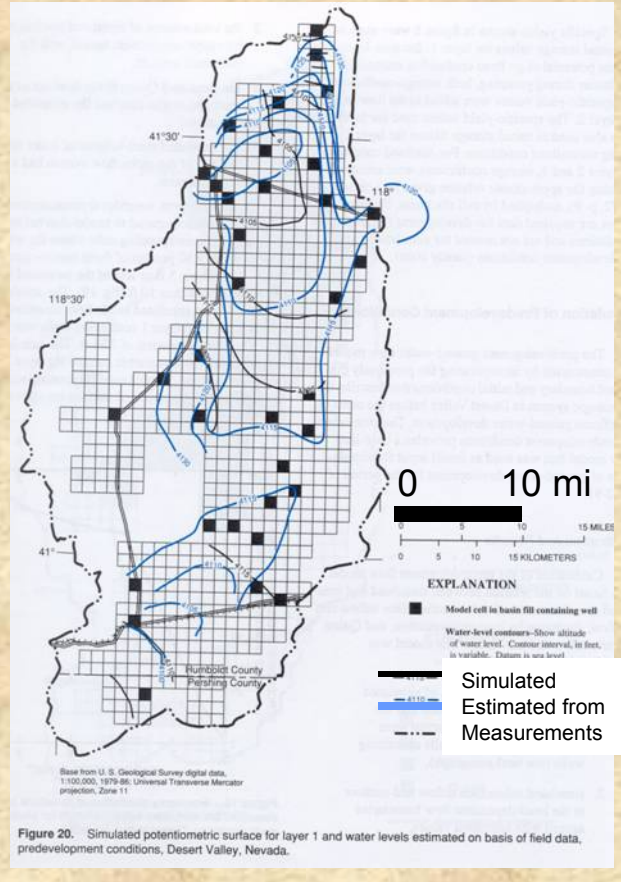



Figure 20. Simulated potentiometric surface for layer 1 and water levels estimated on basis of field data, predevelopment conditions, Desert Valley, Nevada.

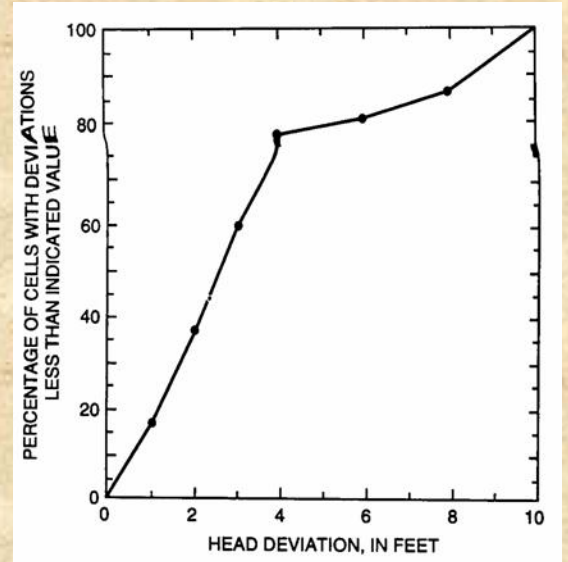



Figure 19. Frequency distribution of deviations between measured and simulated hydraulic heads for predevelopment simulation, Desert Valley, Nevada.

**Overall measured and simulated head match**

**Original Water Balance**
**5,700 -14,000 Inflow**
**10,000 - 12,000 Outflow**

**Simulated Flow at Boundaries Flow of Quinn River "agreed with estimates".**

## Simulated Water Balance

**Table 11.** Simulated ground-water budget for predevelopment conditions (pre-1962), Desert Valley, Nevada

[All values in acre-feet per year, rounded to two significant figures]

| Budget component | Simulated predevelopment conditions |
|---|---|
| **Inflow** | |
| Recharge from precipitation: | |
| From mountain block | 6,900 |
| From sand dunes | 440 |
| Infiltration from rivers: | |
| Quinn River | 2,600 |
| Kings River | 110 |
| Subsurface inflow: | |
| From Kings River Valley | 820 |
| From Quinn River Valley | 310 |
| Total inflow | 11,000 |
| **Outflow** | |
| Evapotranspiration | 9,100 |
| Subsurface outflow: | |
| To Pine Valley | 400 |
| To Southwest | 1,700 |
| Total outflow | 11,000 |

# 1962 to 1991 GW Development Simulation

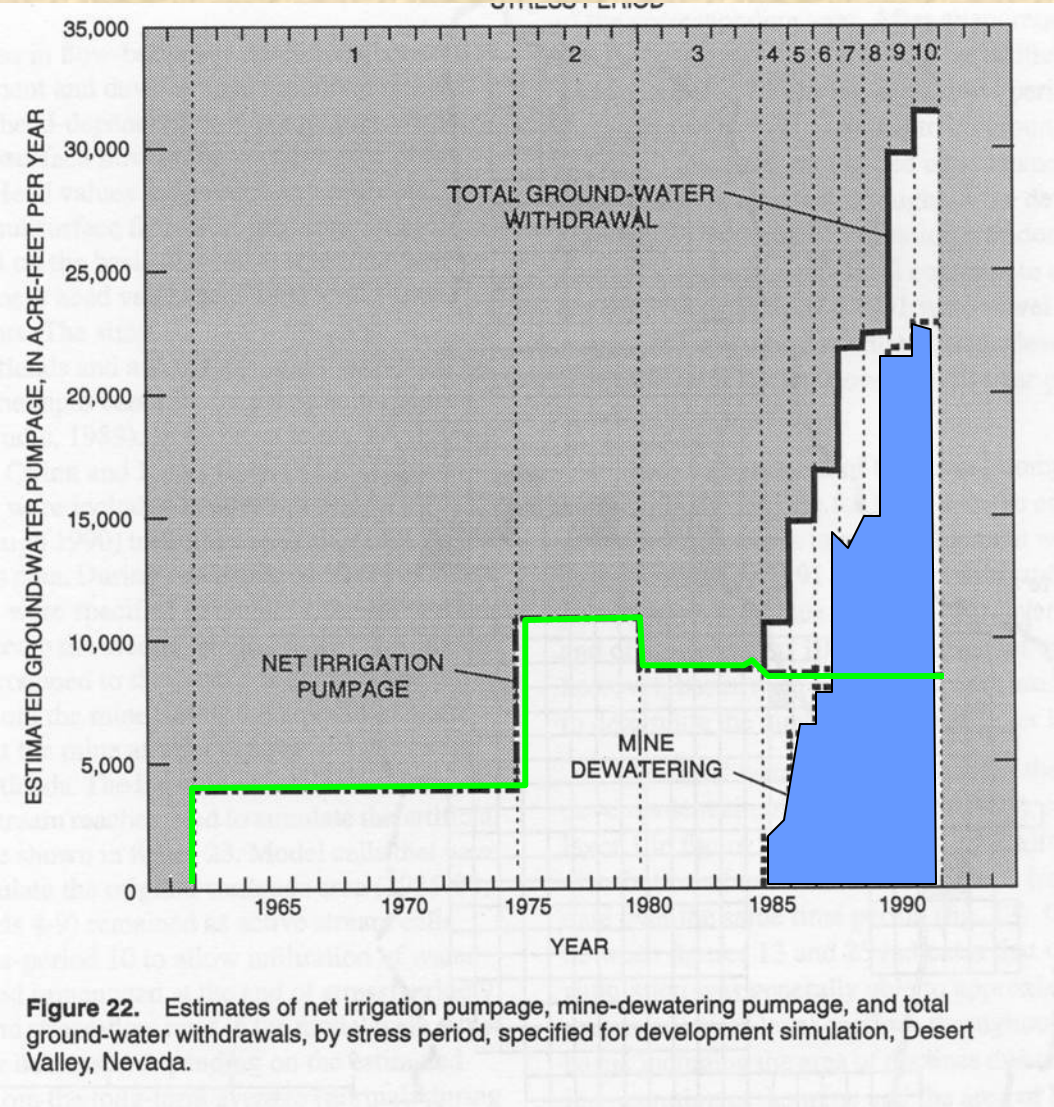
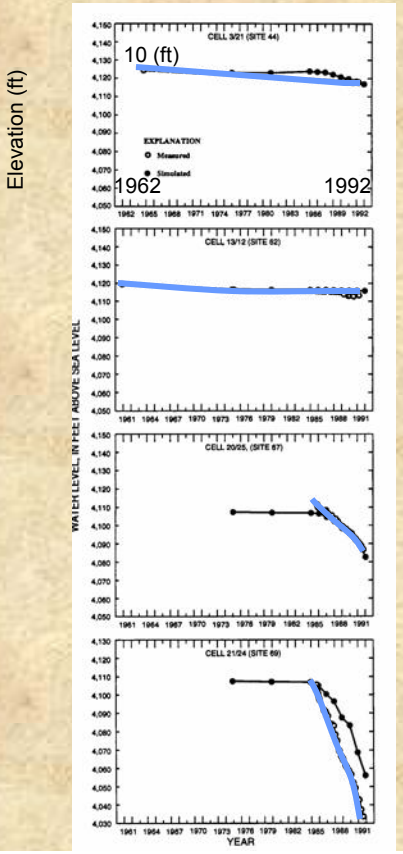



**Figure 22.** Estimates of net irrigation pumpage, mine-dewatering pumpage, and total ground-water withdrawals, by stress period, specified for development simulation, Desert Valley, Nevada.

## History Matching Transient Calibration

**During modeling additional calibration parameter adjustment was completed to yield:**

**Water level and flux values in "…matched fairly well**



# Sensitivity Analyses

**In this model:**

1. **Evaluated the sensitivity of model results to 5 hydrologic properties using 14 model simulations. Used head changes and calibrated flux rates at boundaries as baseline.**
2. **Halved and doubled parameter values.**

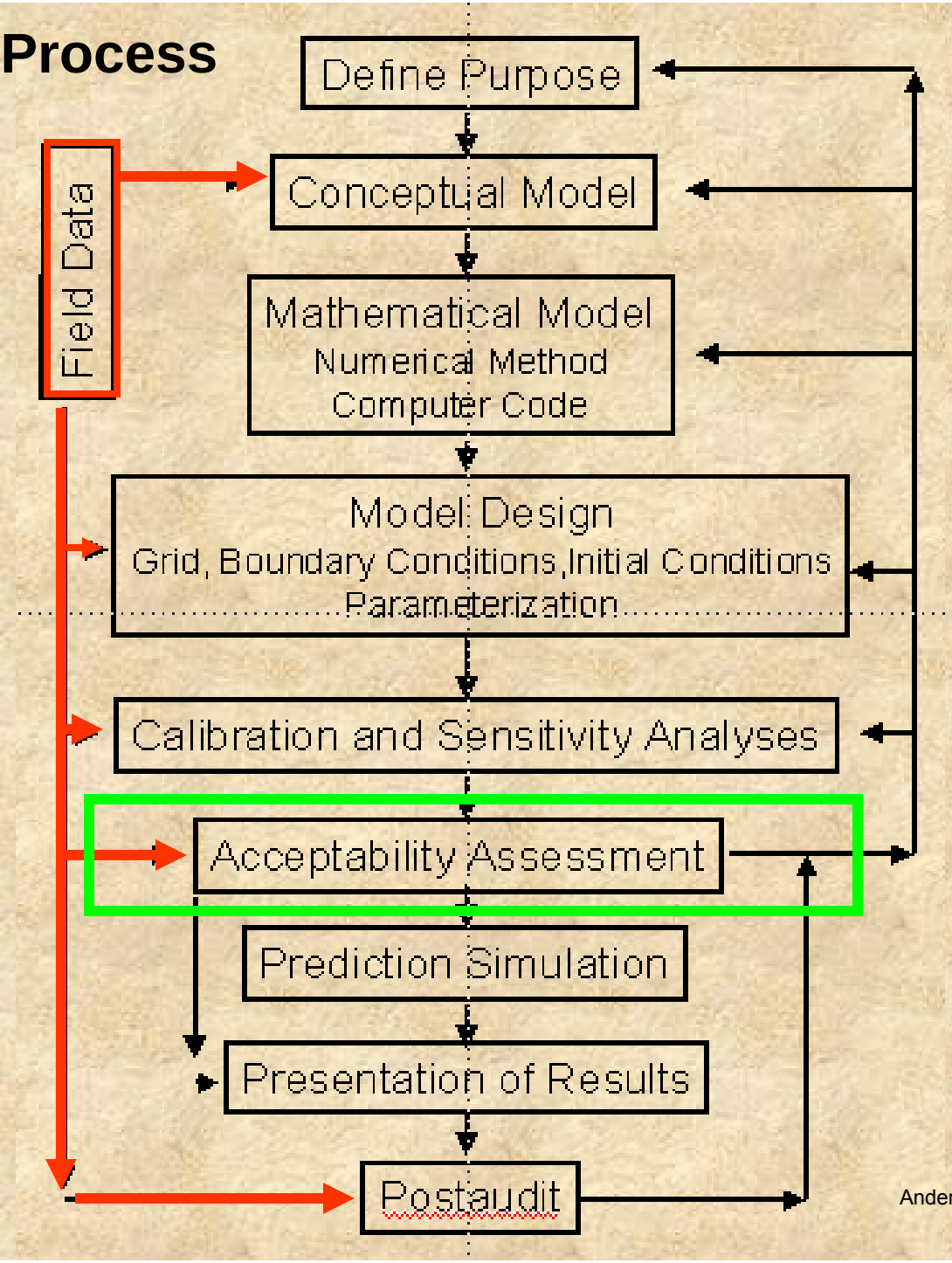
**Evaluation:**

**Model is most sensitive to recharge and plant use (ET) however absolute difference in mean head change is 10 ft.**

**Concluded :**

**Uncertainty in parameters does not effect general representation of the Gw system sufficiently to negate its use at this point.**

# Modeling Process




Anderson and Woessner, 2004

## Assessing the Calibration and Determining Acceptability

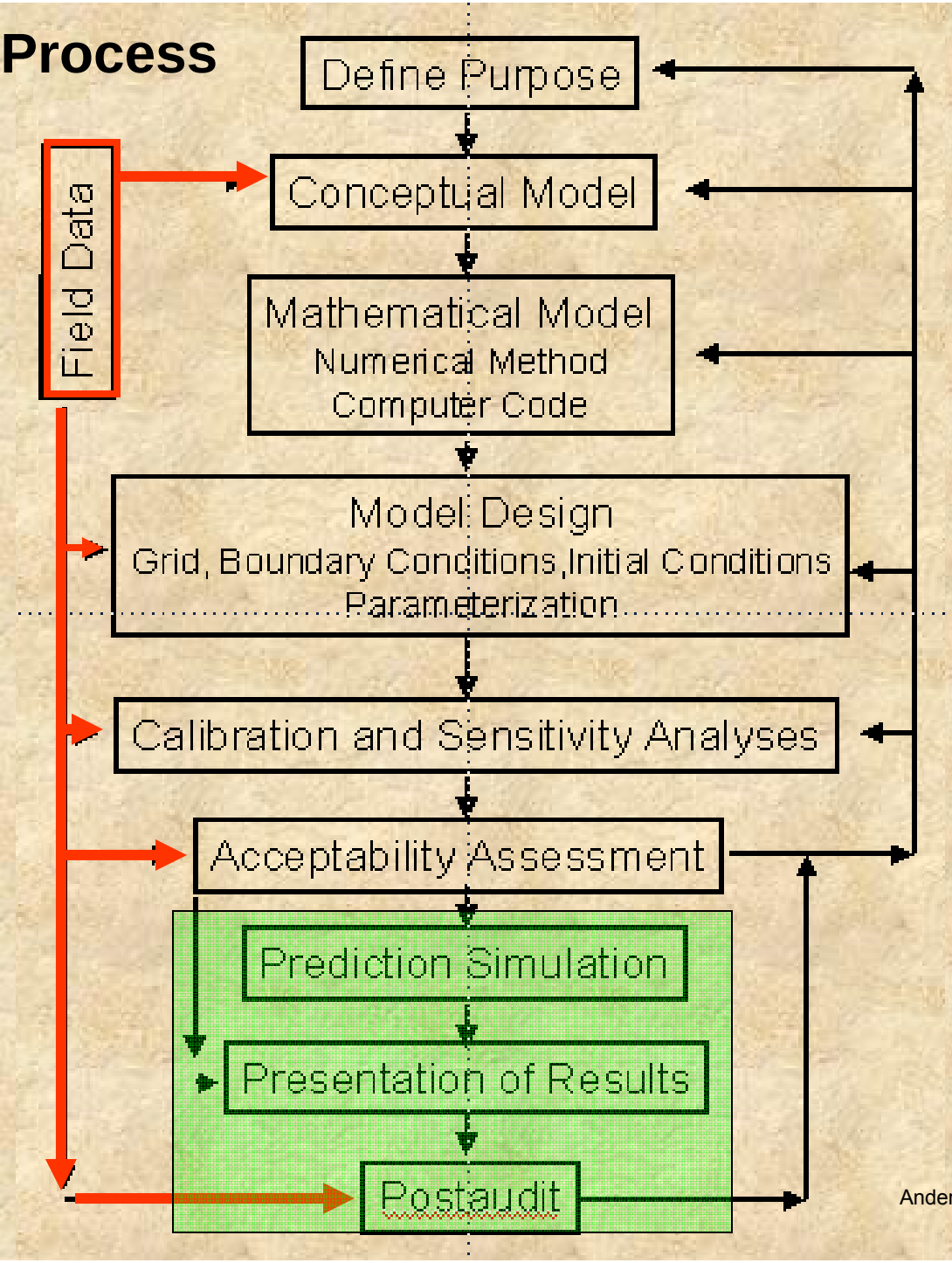
What evidence do you have that a “reasonable representation has been produced?”

**Preponderance of evidence /confirming observations documenting performance**

**Performance measured by closeness of fit with calibration targets and the character and nature of temporal and spatial data**

**Subjective judgment based on stated model purpose an supporting data.**

# Modeling Process




Anderson and Woessner, 2004

# Prediction or Testing of Three Future De-watering Scenarios (no additional calibrations as no history)

## Results of Predictions

1. Water level declines would not be localized around the mine.

2. Declines of 50 ft are simulated at 1 to 2 miles from the mine area.

3. The pumping discharge of water to the wetland retards the expansion of water level declines.

4. Subsurface inflow from the Quinn River Valley occurs.

5. Based on water budgets a new equilibrium may be approached after 100 yr from the time the mine de-watering ceases.

# Analyses of 11 Model POSTAUDITs (literature). How well do predictions match out comes?

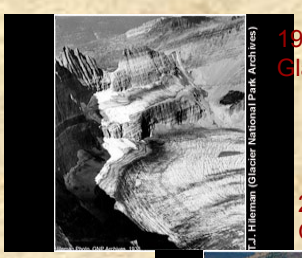
Reported Problems:

1. **Future Stress History and Distribution**

2. **Parameter Values and Distributions**

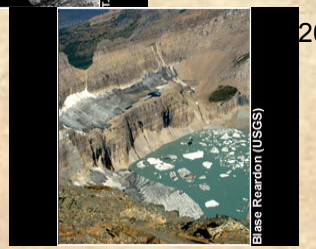
3. **Calibration Conditions Not Appropriate for Predictions,**

4. **Conceptual Model.**




1938 Grinnell Glacier Glacier NP.

2005 Grinnell Glacier Glacier NP.




2005

# How do You Reduce or Bracket Uncertainty In Model Predictions?

Step 1
Develop a site conceptual model and a calibrated numerical model

Step 2
Develop a number of additional site conceptual models incorporating uncertainties identified in the characterization of site GW/Hydrologic Conditions,
and a number of calibrated Numerical Models

Step 3
Use each calibrated model to predict outcomes.
The range of predictions suggests modeled uncertainty.

# Where Does That Leave Us?

Ground Water Models contain uncertainty, however, they are the only tool we have to assess complex settings!

**We need to assess uncertainty using multiple conceptual models and present ranges of likely results to decision makers!**