Use of Groundwater-flow Models in Mine Permit Evaluations

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Understanding the Impacts of Mining in the Western Lake Superior Region

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mod•el |ˈmädl|

noun

• a simplified description, esp. a mathematical one, of a system or process, to assist *calculations* and *predictions*.

ORIGIN late 16th cent. (denoting a set of plans of a building): from French ***modelle***, from Italian ***modello***, from an alteration of Latin ***modulus*** (see **modulus**).

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from: New Oxford American Dictionary

Models are ubiquitous

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Outline

Overview of groundwater modeling

- *Conservation of Mass*
- *Conservation of Energy*

  } honor the physical/chemical laws

- *Hydrologic Cycle*
- *Calibration to on-site conditions*

  } honor the specific site

The importance of calibration and uncertainty analysis

Types of mining-permit related issues models can help with

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The value of models

conceptual model

A cohesive framework to consolidate and interpret data

computer simulation

A platform on which to test scenarios, evaluate responses, add margin of safety

decision making

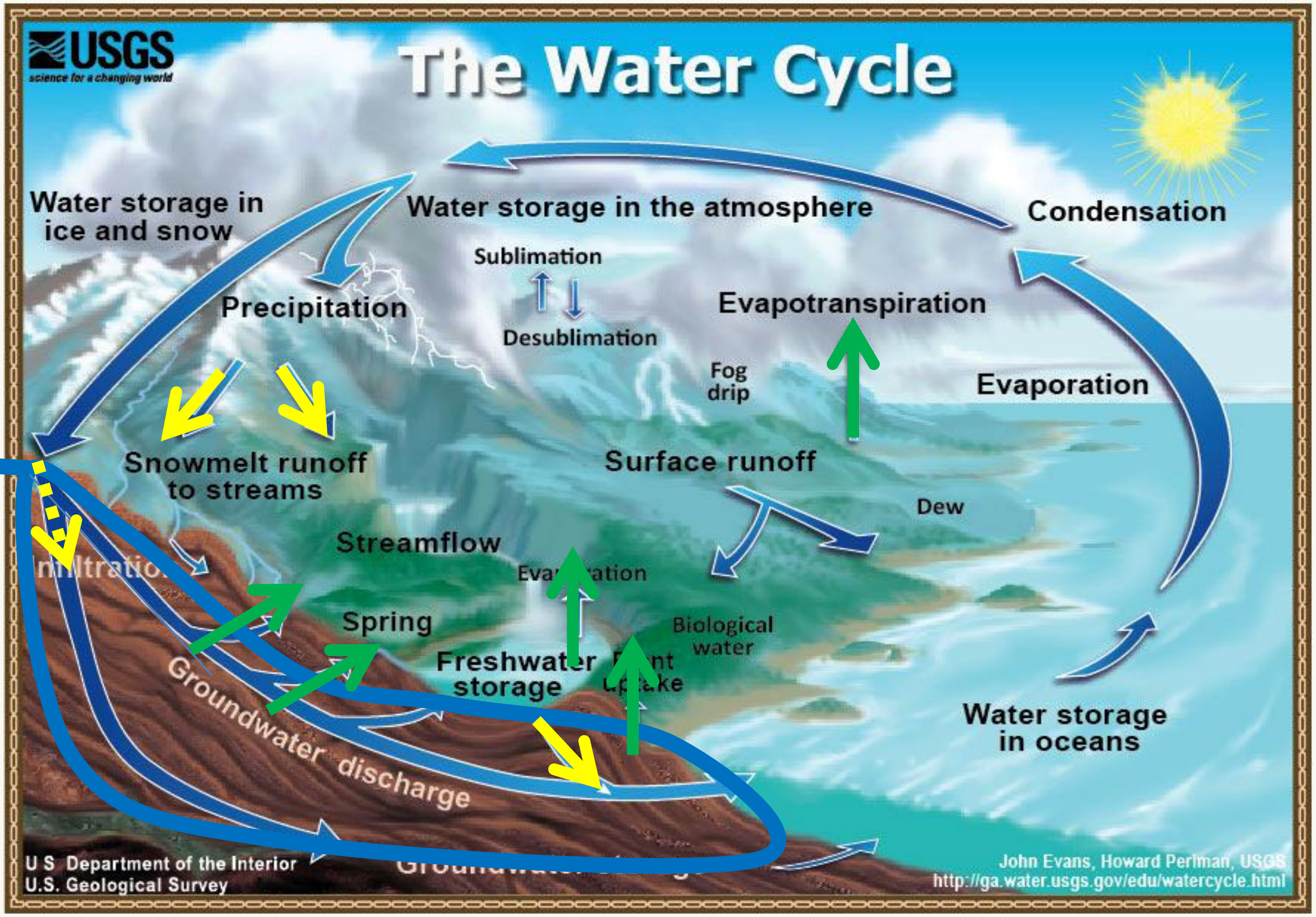
A feedback mechanism to revise interpretation and guide future work

Groundwater in the Hydrologic Cycle

Groundwater System

Water Entering the System

Water Exiting the System



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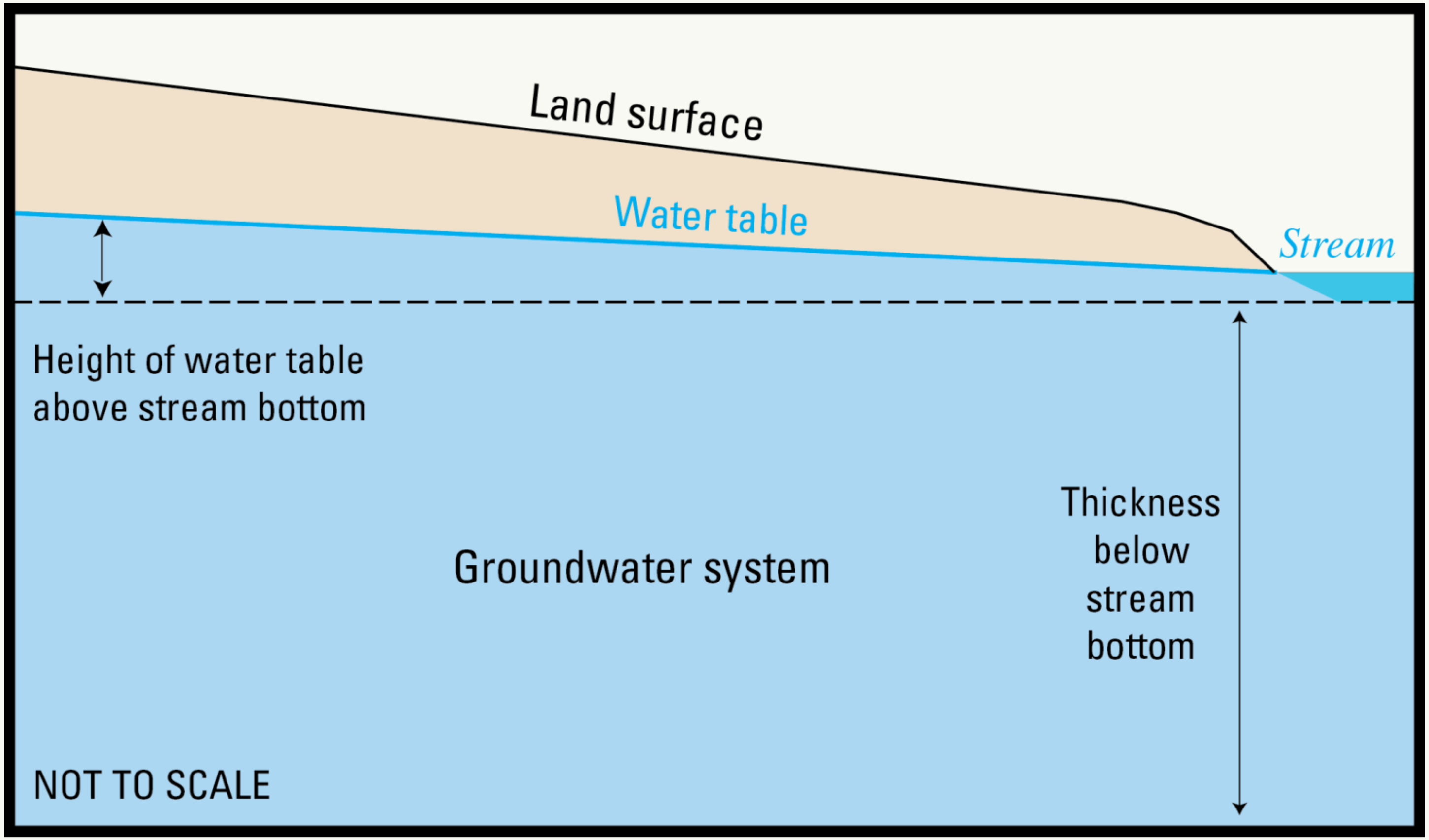
An aside: the myth of sustainable yield



http://pubs.usgs.gov/circ/1323/

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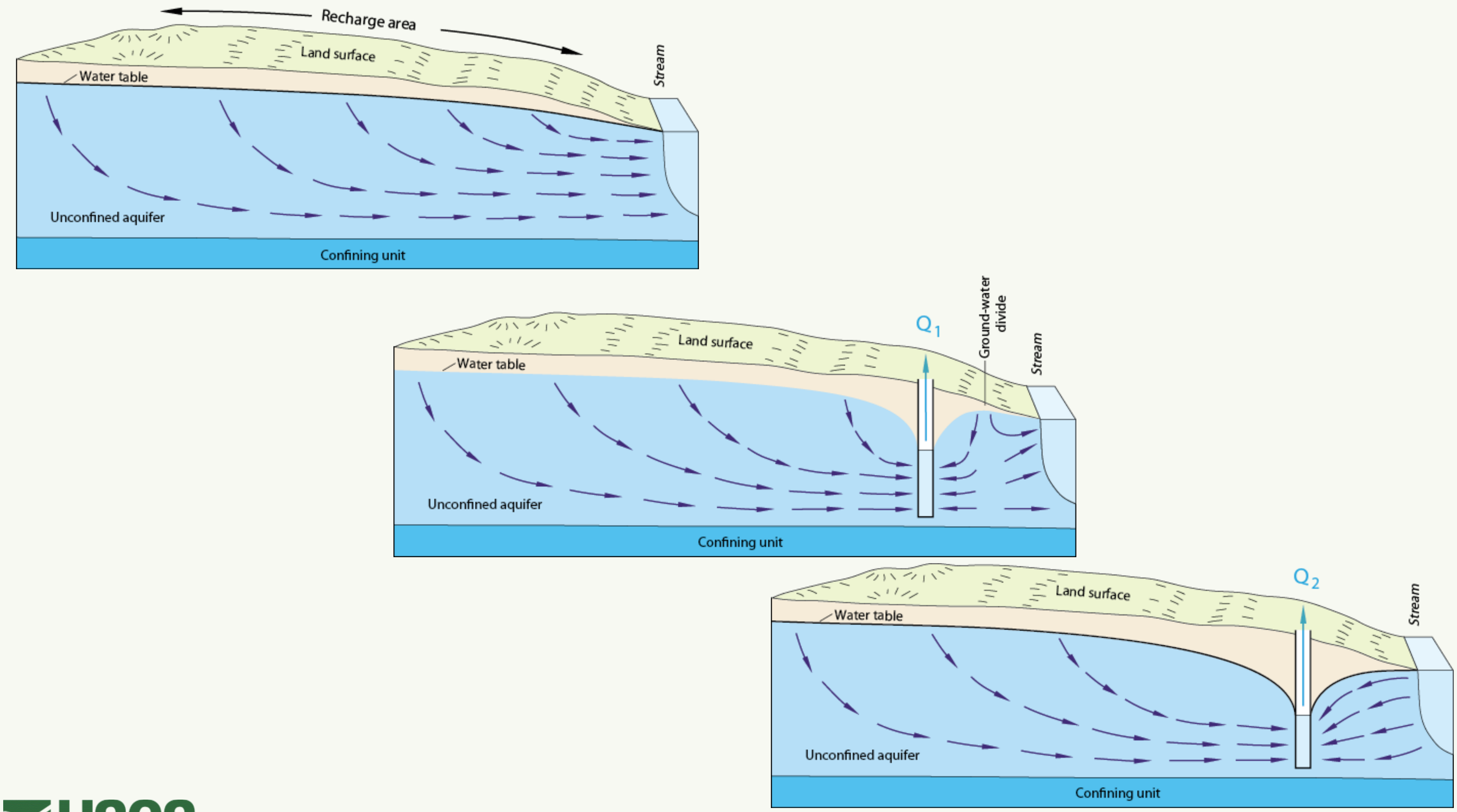
Interaction with streams is dynamic



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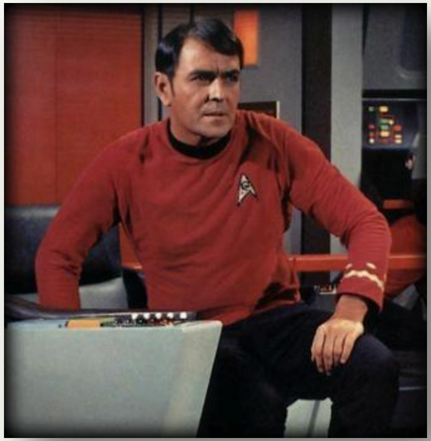
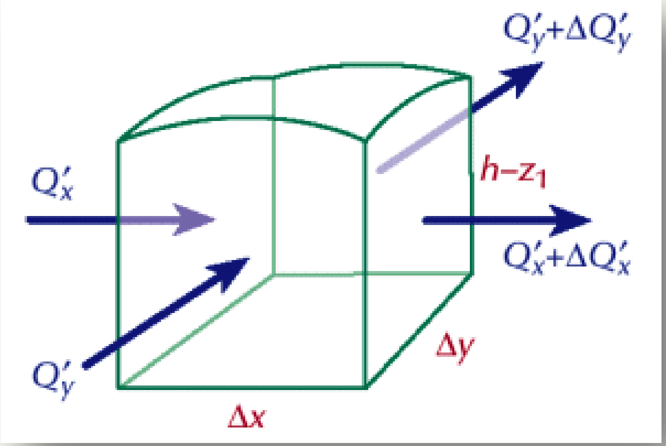
from Alley, Reilly, and Franke, USGS Circular 1186, 1999

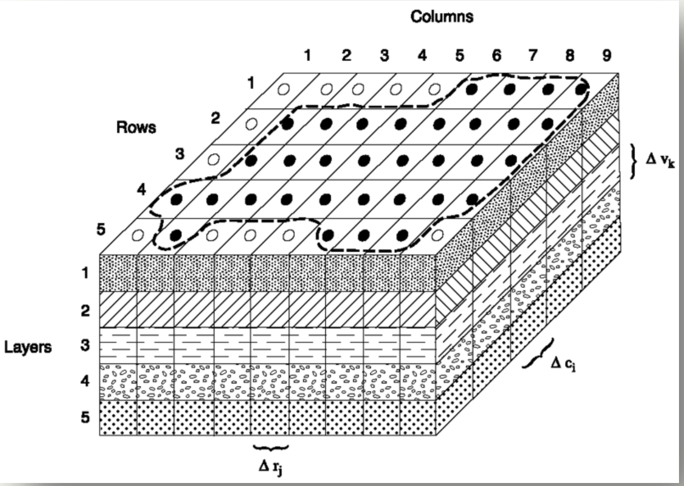
Conservation of Mass—Scotty's Rule

Matter cannot be collapsed—
water is incompressible

Must balance water inflow and outflow







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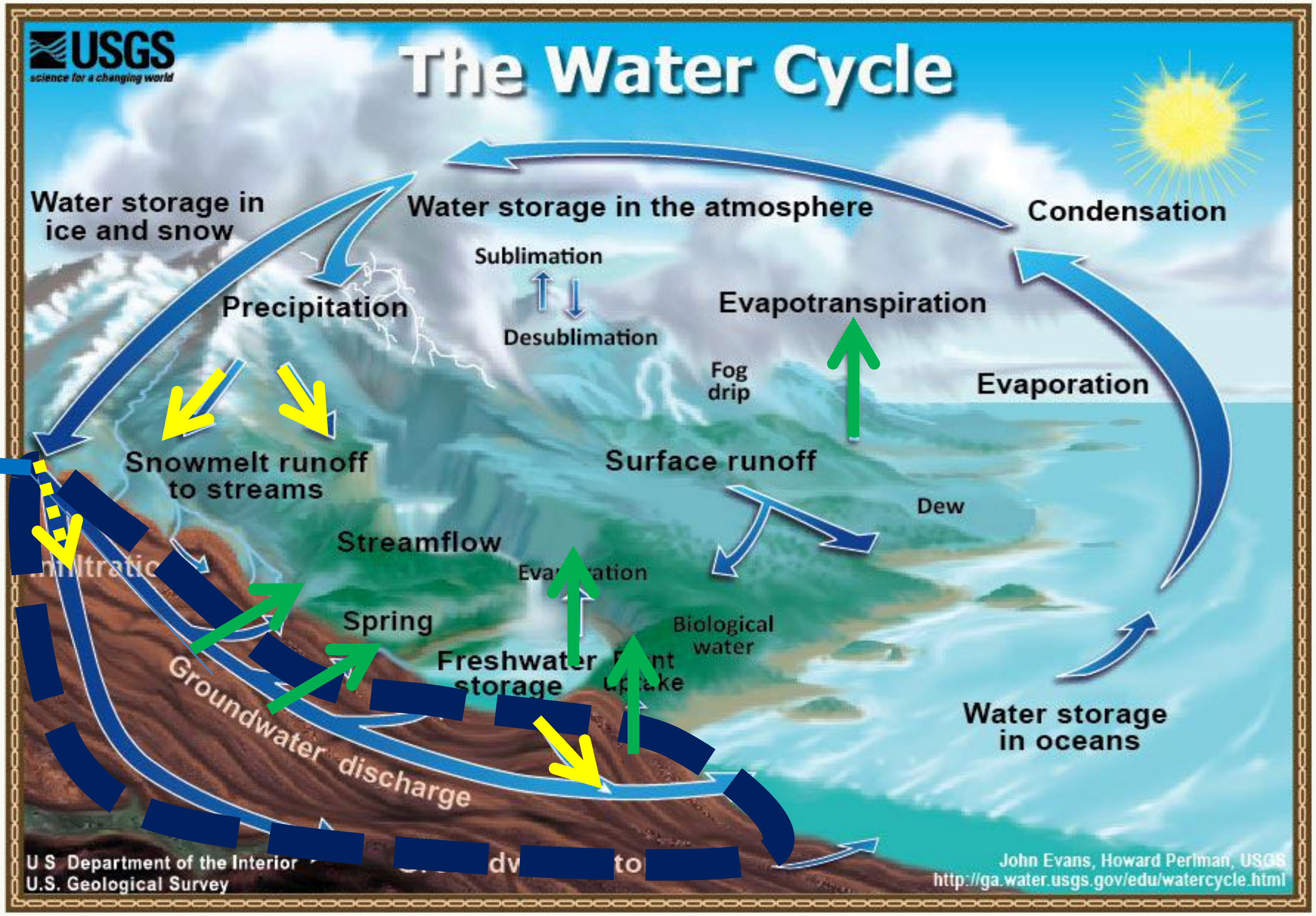
Control volume over which to balance inflows and outflows.

Groundwater System

Water Entering the System

Water Exiting the System



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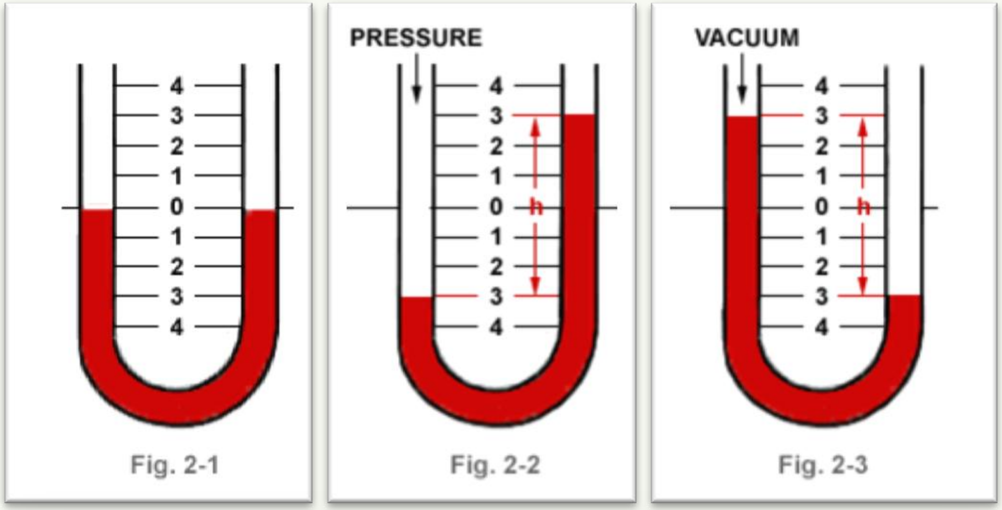
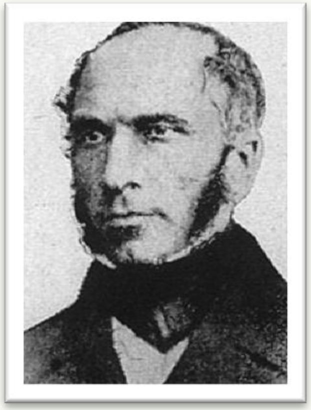
Conservation of Energy—Plumber's Rule

Water flows "downhill"

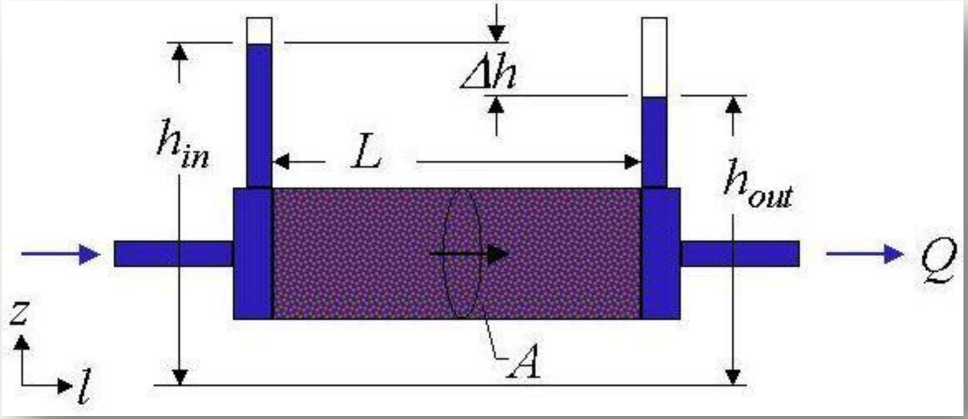
Energy entering the system must
either leave the system or
get converted to heat through friction.

“downhill”, pressure, and Darcy’s Law





Henry Darcy
1803-1858



flow is a function of:

- geometry (area)
- resistance (hydraulic conductivity)
- energy in/out (boundary conditions)

manometer image from: http://www.dwyer-inst.com/Products/ManometerIntroduction.cfm
Henry Darcy image from: Wikimedia commons
Falling head experiment image from: http://bioen.okstate.edu/Darcy/LaLoi/basics.htm

Conceptual model and choice of techniques

The choice of modeling technique and data acquisition are motivated by the nature of the question being asked.

nearby streamflow impact
groundwater levels
water quality in mine water
water supply to wetlands

The results of all models are contingent on conceptual, technique and data choices made.

A model designed to answer one question with a margin of safety may be at odds with another.

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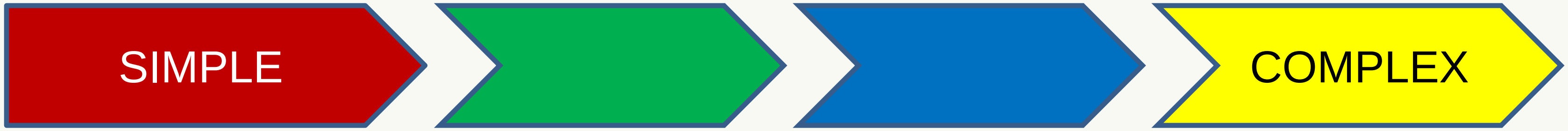
Choosing a model

What kind of model is required?



Tools:

Hand calculations — Analytic Elements — Fully Numerical

spreadsheet/paper — GFLOW — MODFLOW

FEFLOW

FEMWATER

Computational/Accuracy Issues:

Patience — Complexity of Geometry — Node/Element Size

Timing:

"Steady State" or "Transient"?

In all cases, an important consideration is track record/legal history

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Parameters controlling the model

Groundwater flow models rely on several parameters

Within the groundwater system
hydraulic conductivity
water levels at boundaries
geometry
reaction kinetics
porosity

Hydrologic cycle connections
recharge
precipitation, infiltration, losing streams
discharge
springs, gaining streams, lakes, evaporation, plant uptake,

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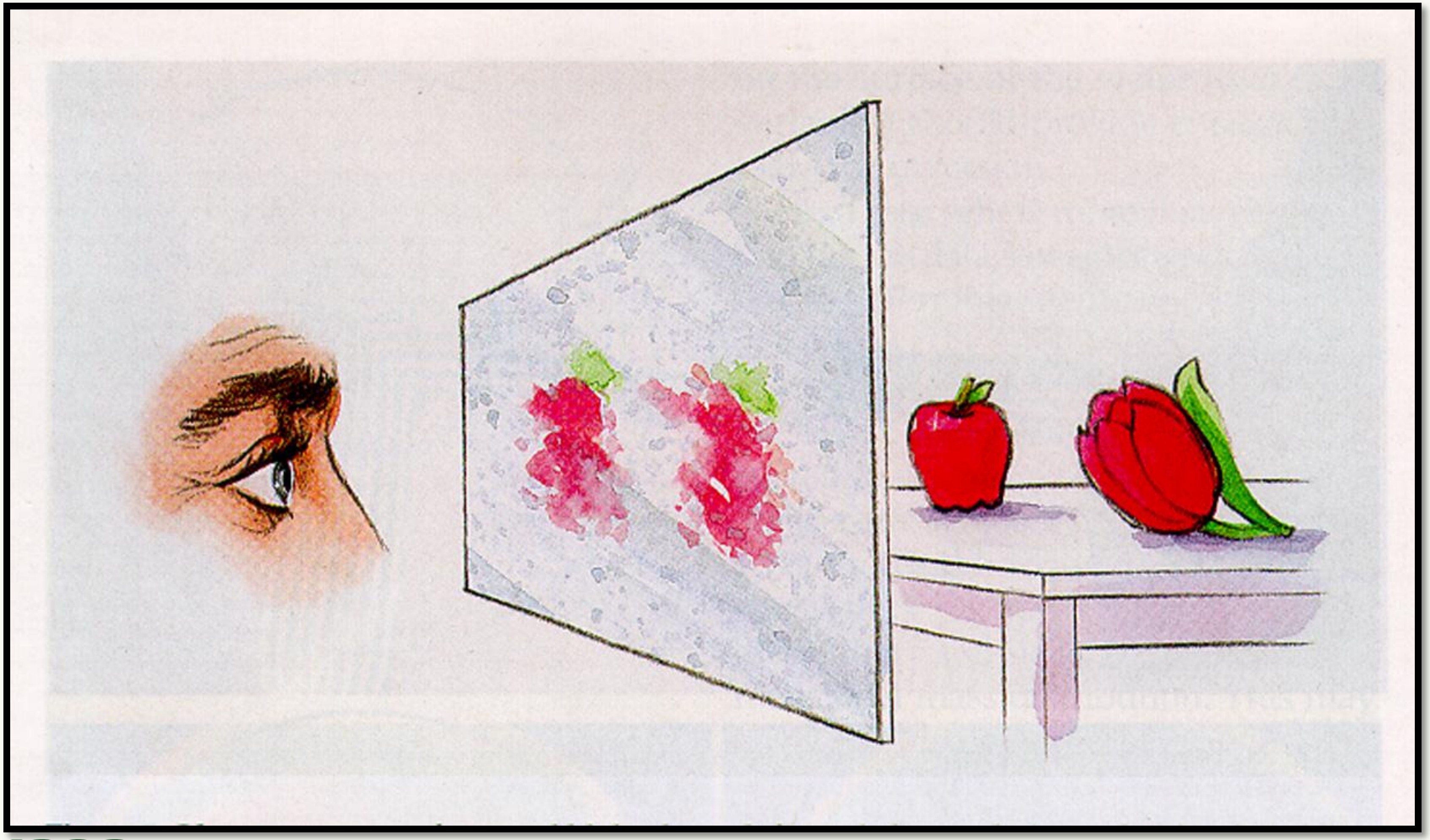
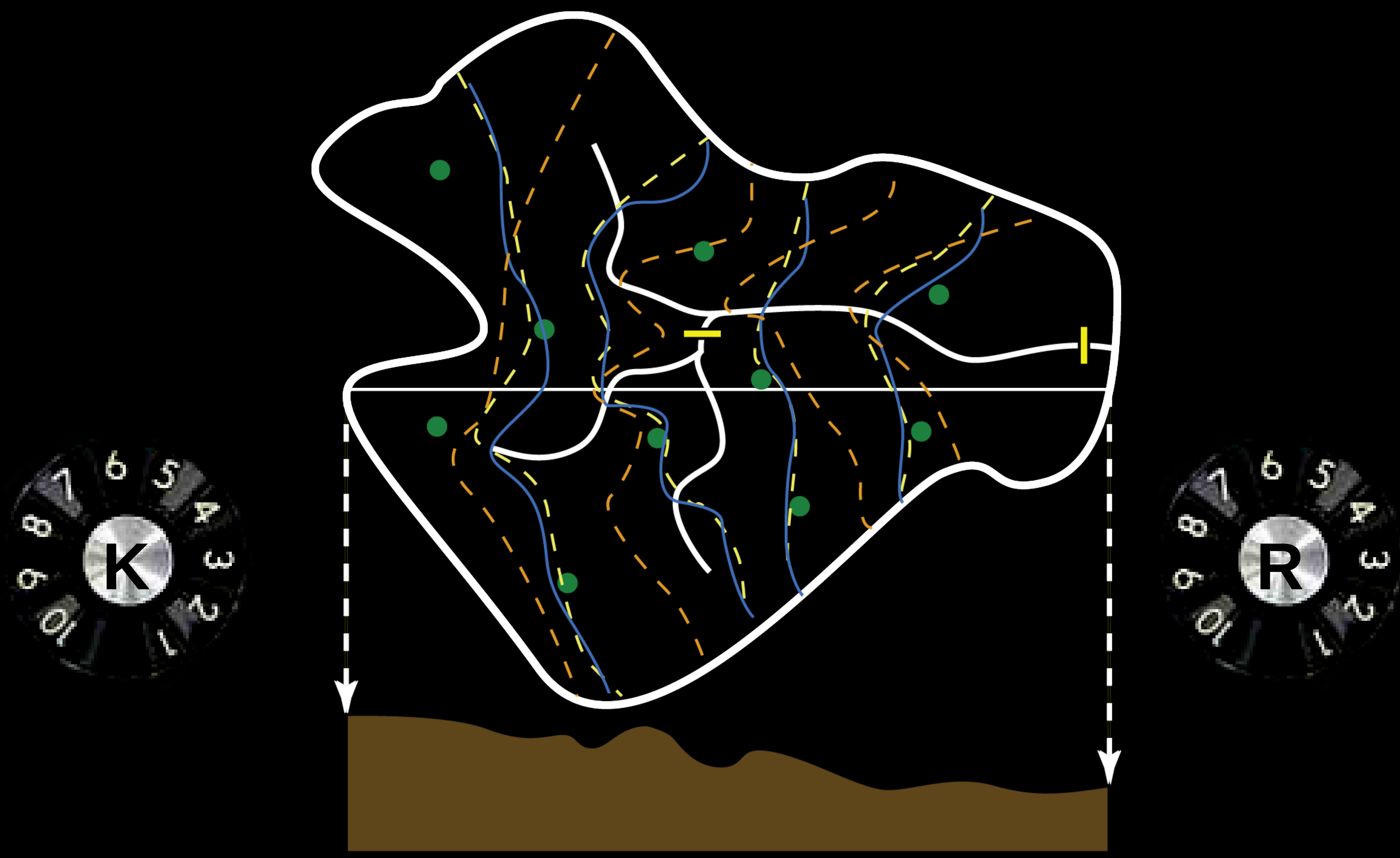
Parameters cannot be measured – they are inferred. But, the solution is not unique



Calibration and Uncertainty



Calibration and Uncertainty

More complex models → many parameters

Beyond Trial-and-Error → robust statistical techniques can help

Each parameter has some uncertainty associated with it

Predictions made using the model and these parameters will also have uncertainty to consider.

Models and uncertainty

"Essentially, all models are wrong,
but some are useful."

George E. P. Box

We should not expect to perfectly reproduce the measurements with a model.

We acknowledge that the model is imperfect.

We also acknowledge that our measurements are imperfect.

We thus rely on robust statistical techniques to quantify and explicitly consider these uncertainties.

Mine Inflows – outflows after abandonment

How much water enters the mine from storage vs. recharge/regional flow?

How much dilution of compounds in the mine will be achieved by ambient water?

What rates of transport back into host rock when the pumps are turned off?

image from http://diqky.blogspot.com/

Wetland and surface water impacts

How connected is a wetland to the underlying groundwater system?

How much flow in a stream is baseflow—relying on groundwater?

How is habitat impacted by differences in temperature or chemistry?

How is hydrologic function of a wetland impacted by changes in water chemistry if more/less groundwater interacts with the wetland?

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Water Quality Impacts

Flow model simulates movement of water through a system in terms of path.

Porosity quantifies water velocity.

Compounds can react (potentially transforming into others, degrading, and adhering to aquifer material).

A two-step approach is generally required, coupling a groundwater flow model with a transport model (MODFLOW + MT3D).

image from Keith Halford, USGS

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Summary

What can GW models do?
Provide a cohesive framework to interpret data.

Allow evaluation of potential scenarios.

Guide the need for further information and *help revise conceptual model of the site.*

What can GW models NOT do?
Perfectly simulate “Truth with a capital ‘T’”

Answer every type of question posed about the GW system.

A fully objective representation.

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Questions?