



Characterizing, Predicting and Modeling Water from Mine Sites

May 18-21, 2009
Sacramento, California

STRATUS CONSULTING

Hydrologic Aspects

Basic hydrologic concepts and definitions

Hydrology of mine units

Hydrologic understanding is integral to predicting mine water quality

May be poorly characterized and uncertain

Water balance – natural system

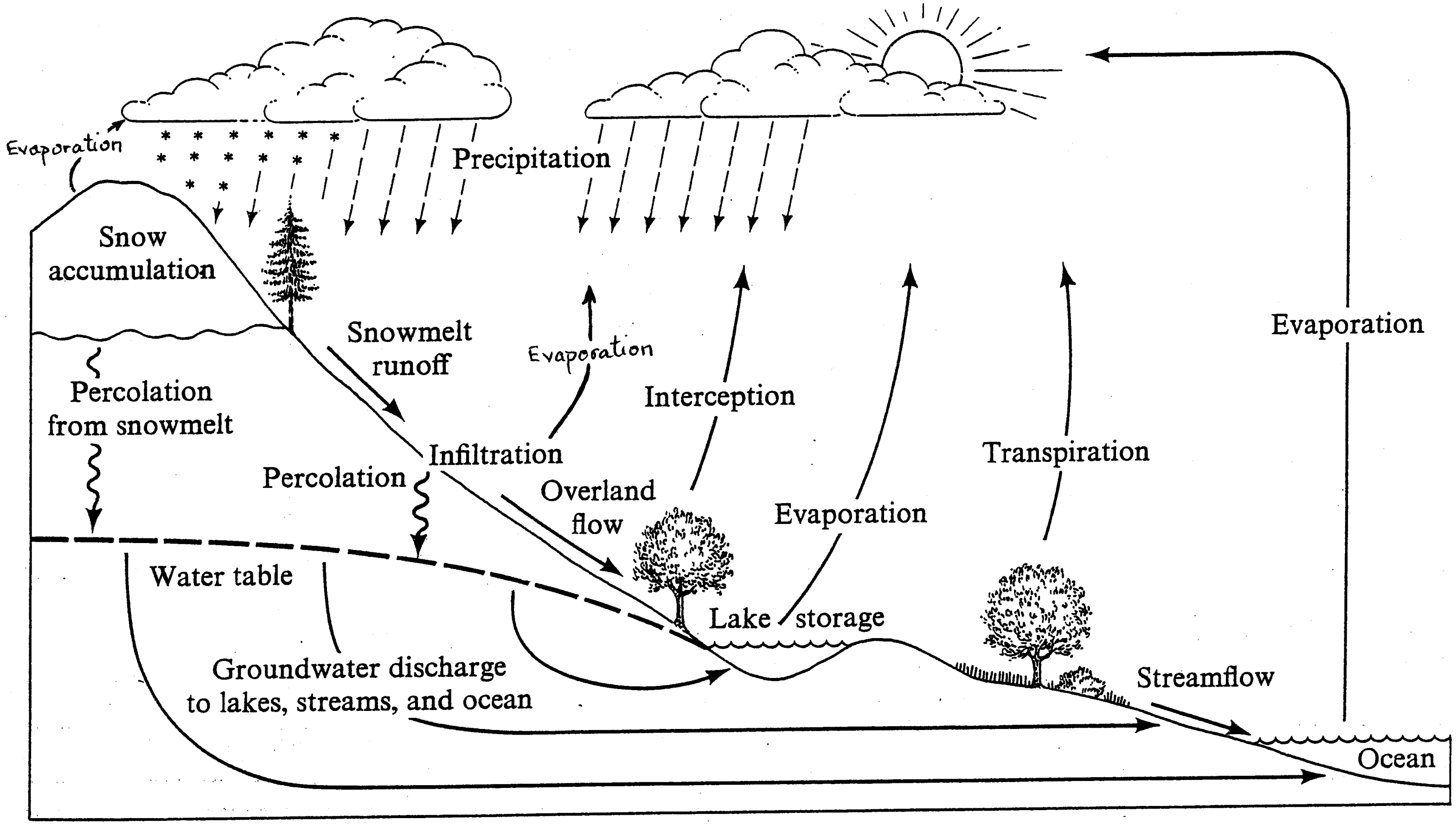
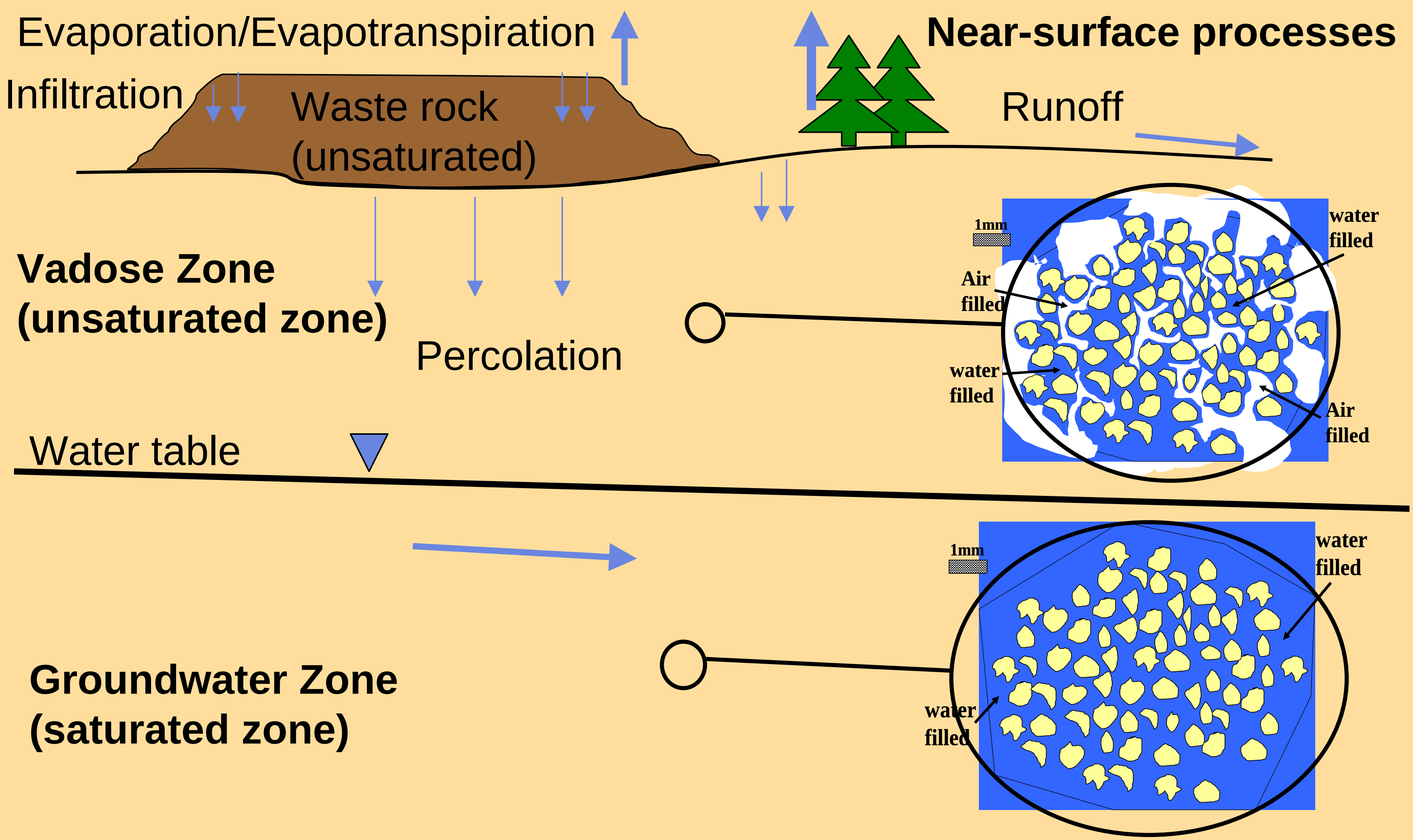


Figure 1-1 Schematic diagram of the hydrologic cycle.

Hydrologic zones at mine sites



Flow in porous media is described by Darcy's Law

$$Q = K\ i\ A$$

Q = discharge

K = hydraulic conductivity

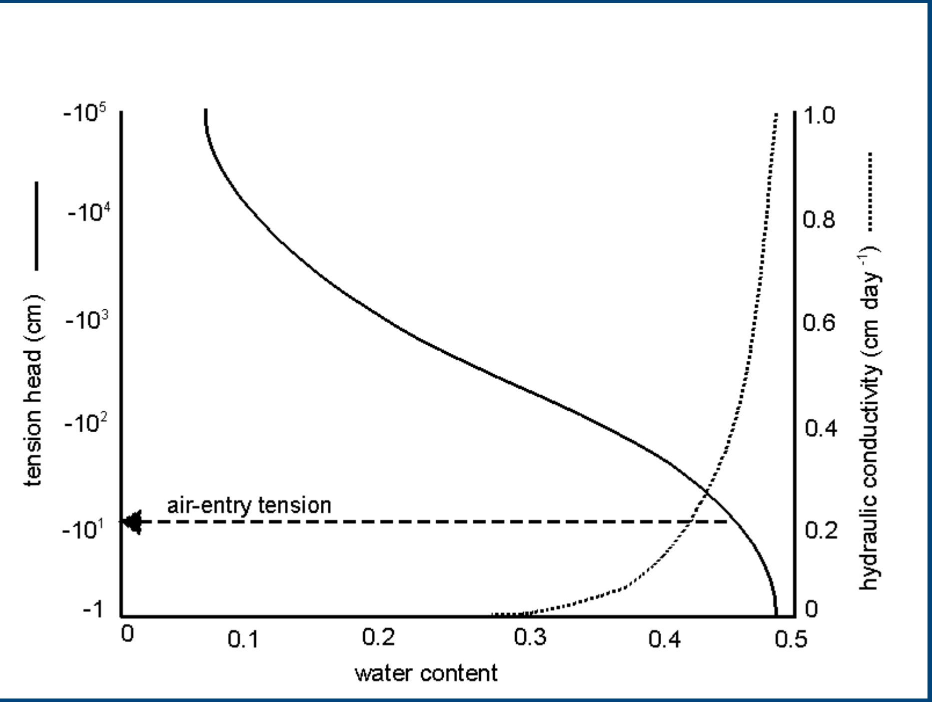
i = hydraulic gradient

A = cross sectional area

Parameters vary in space and time!

Unsaturated zone

- Tension head/suction is a function of saturation (water content) SWCC
- Hydraulic conductivity is a function of saturation (water content)
- Higher saturation = higher hydraulic conductivity



Saturated zone: Relationship between Hydraulic Conductivity and Groundwater Velocity (in porous media)

$$V = K\, i/n$$

V = groundwater velocity (units of length/time)

K = hydraulic conductivity (units of length/time)

i = hydraulic gradient [-]

n = porosity [-]

Hydraulic conductivity ranges over orders of magnitude

Relative hydraulic conductivities of major rock types

From Plumlee (1999)

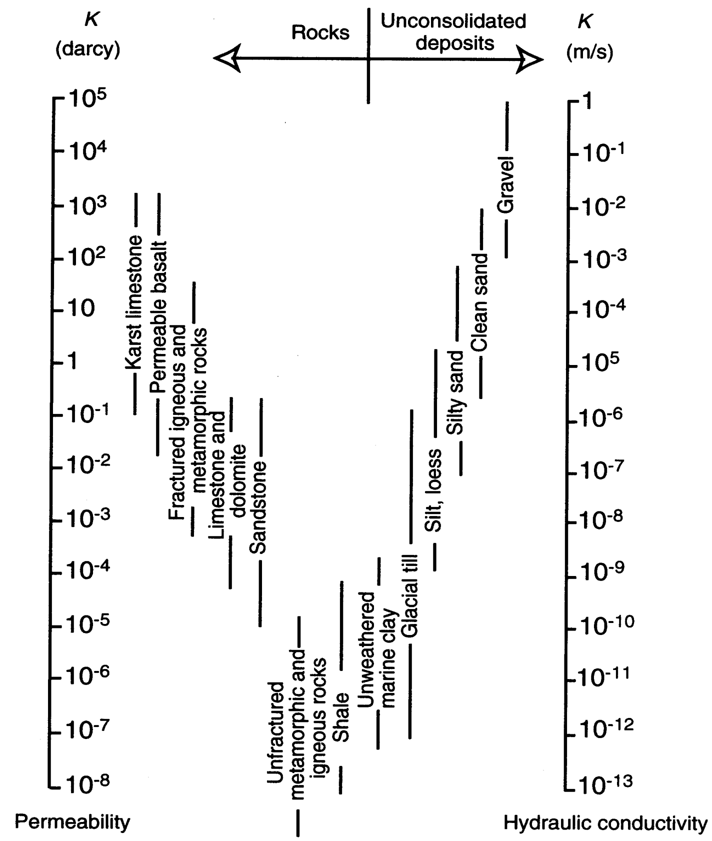
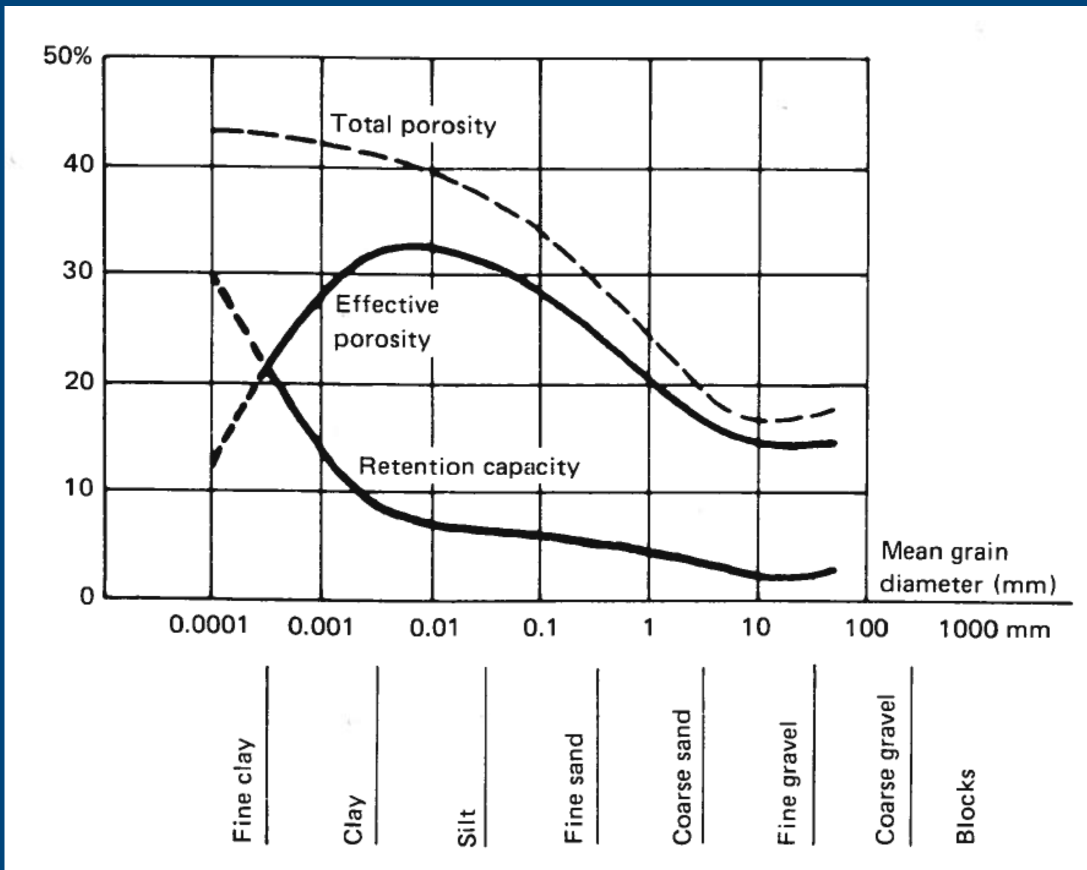


FIGURE 3.6—Hydraulic conductivities of various rock types. Modified from Freeze and Cherry (1979), and Cathles (1997).

Range in porosity



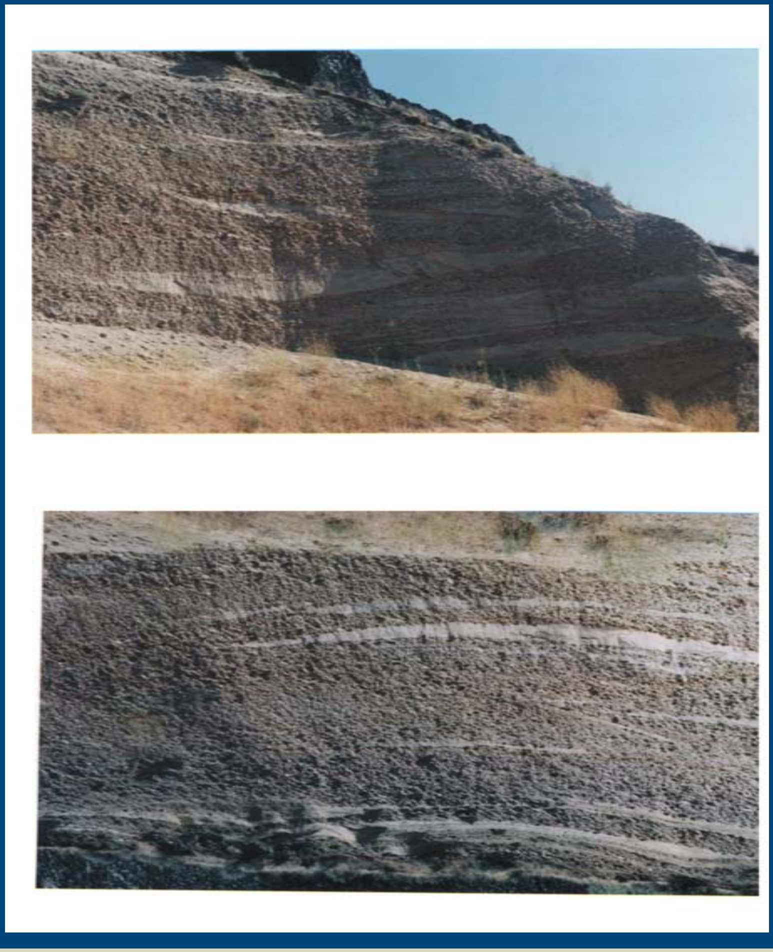
de Marsily 1986

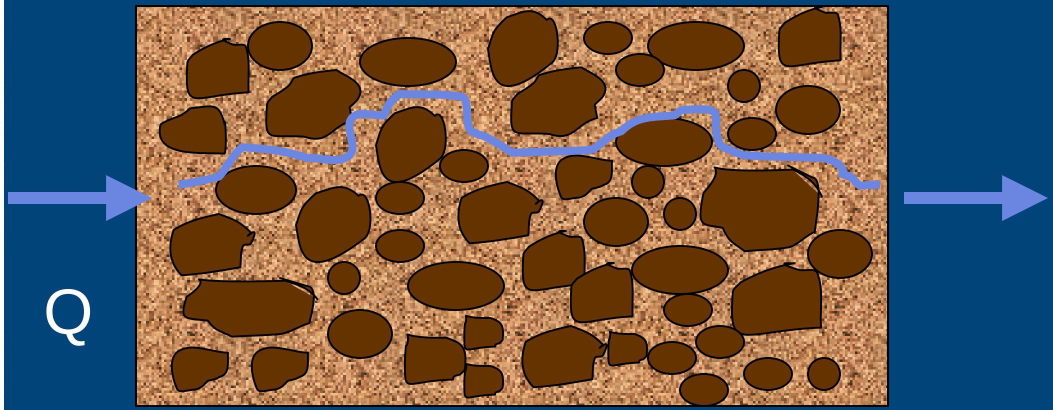
Table 2.4 Range of Values of Porosity

	n(%)
Unconsolidated deposits	
Gravel	25–40
Sand	25–50
Silt	35–50
Clay	40–70
Rocks	
Fractured basalt	5–50
Karst limestone	5–50
Sandstone	5–30
Limestone, dolomite	0–20
Shale	0–10
Fractured crystalline rock	0–10
Dense crystalline rock	0–5

Freeze and Cherry 1979

Groundwater flow in porous medium (intergranular flow)





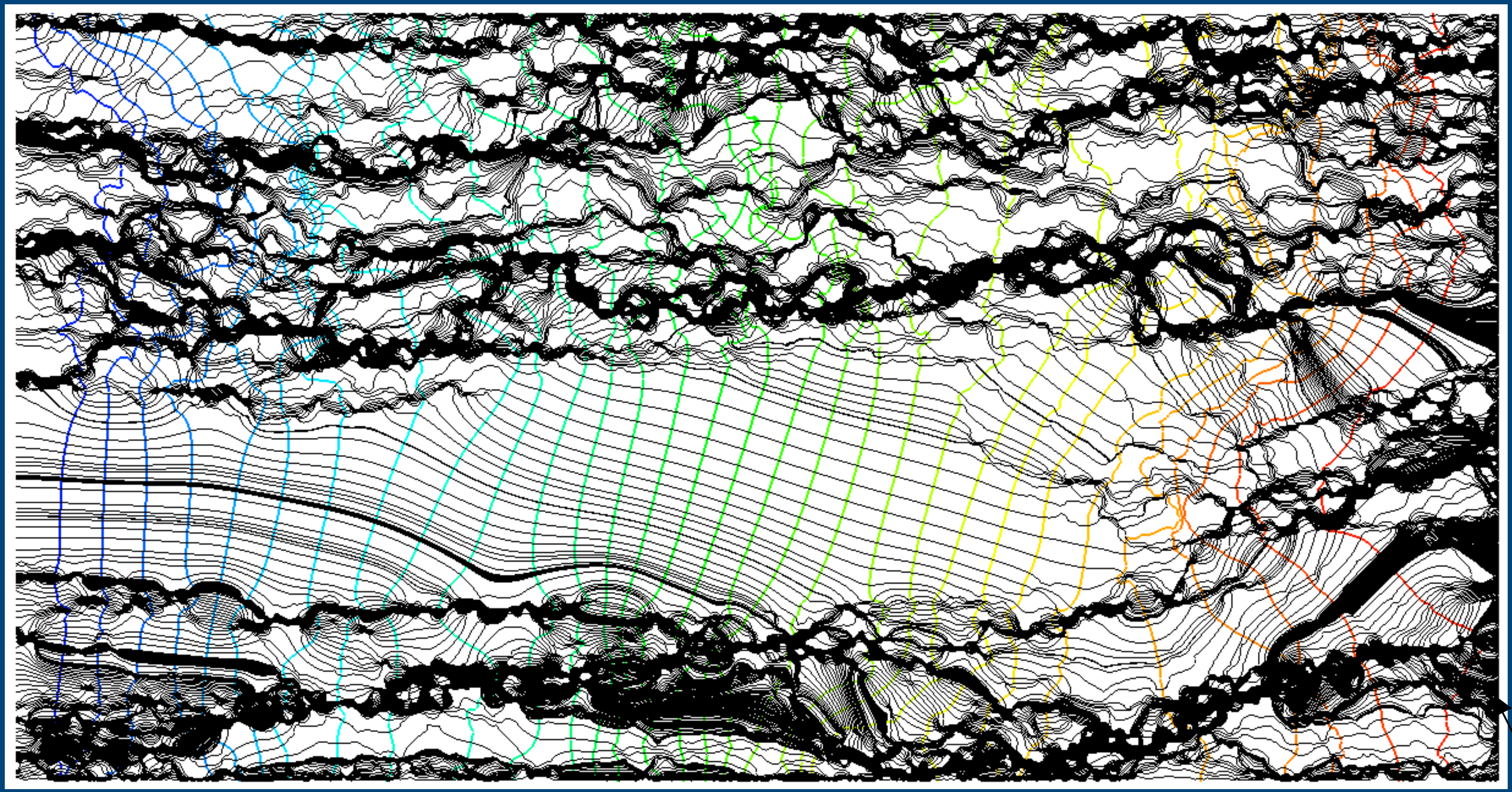
Example: Sandstone

Heterogeneity in porous medium flow

Klise et al. 2009

Heterogeneity in porous medium flow

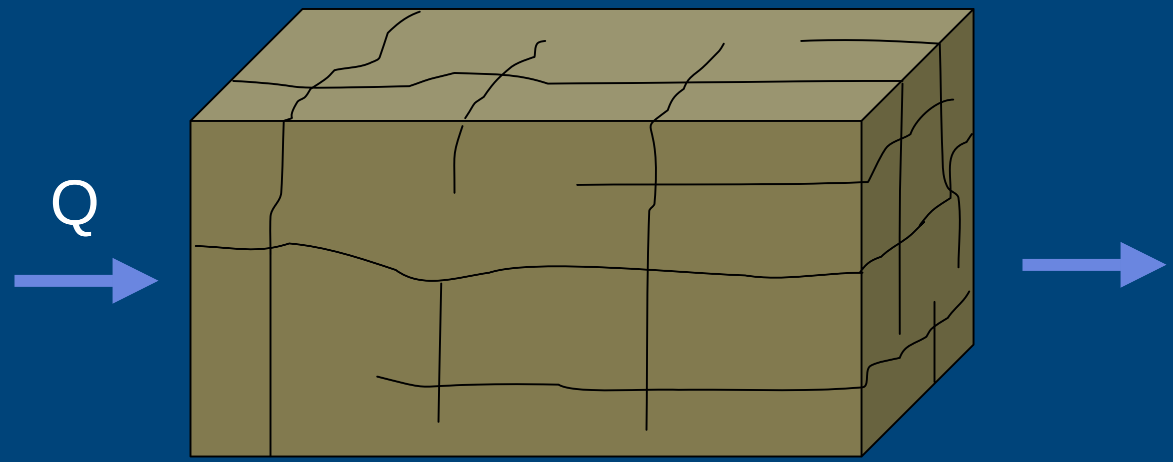
Two orders of magnitude difference for K field



K_{SAND} = 0.001 cm/s
K_{GRAVEL} = 0.1 cm/s
Geometric mean of K = 0.0046 cm/s

Klise et al. 2009
Single particle released from end column in each cell.

Groundwater flow in fractured rock

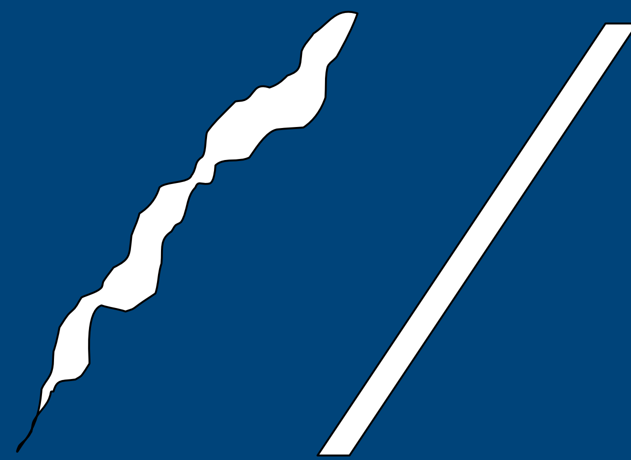


Examples: Shale, Granite, Gneiss

Fractured rock

Flow is dependent on fracture

- Connectivity
- Spacing
- Aperture (opening)
- Density



Real world fracture vs. ideal fracture

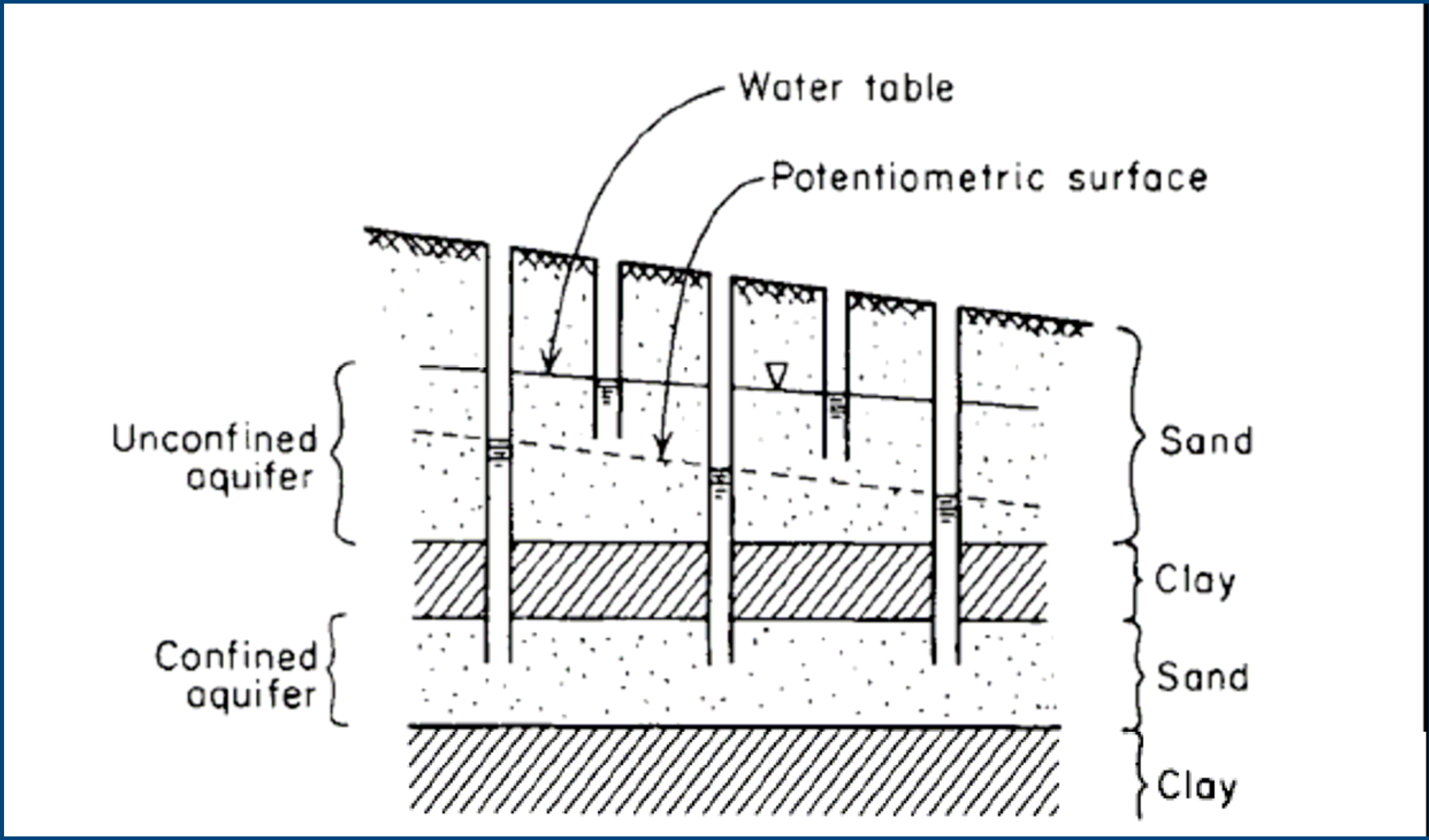
Such data are typically limited or absent at sites

"Equivalent porous medium" often assumed to simplify system

System may be highly anisotropic

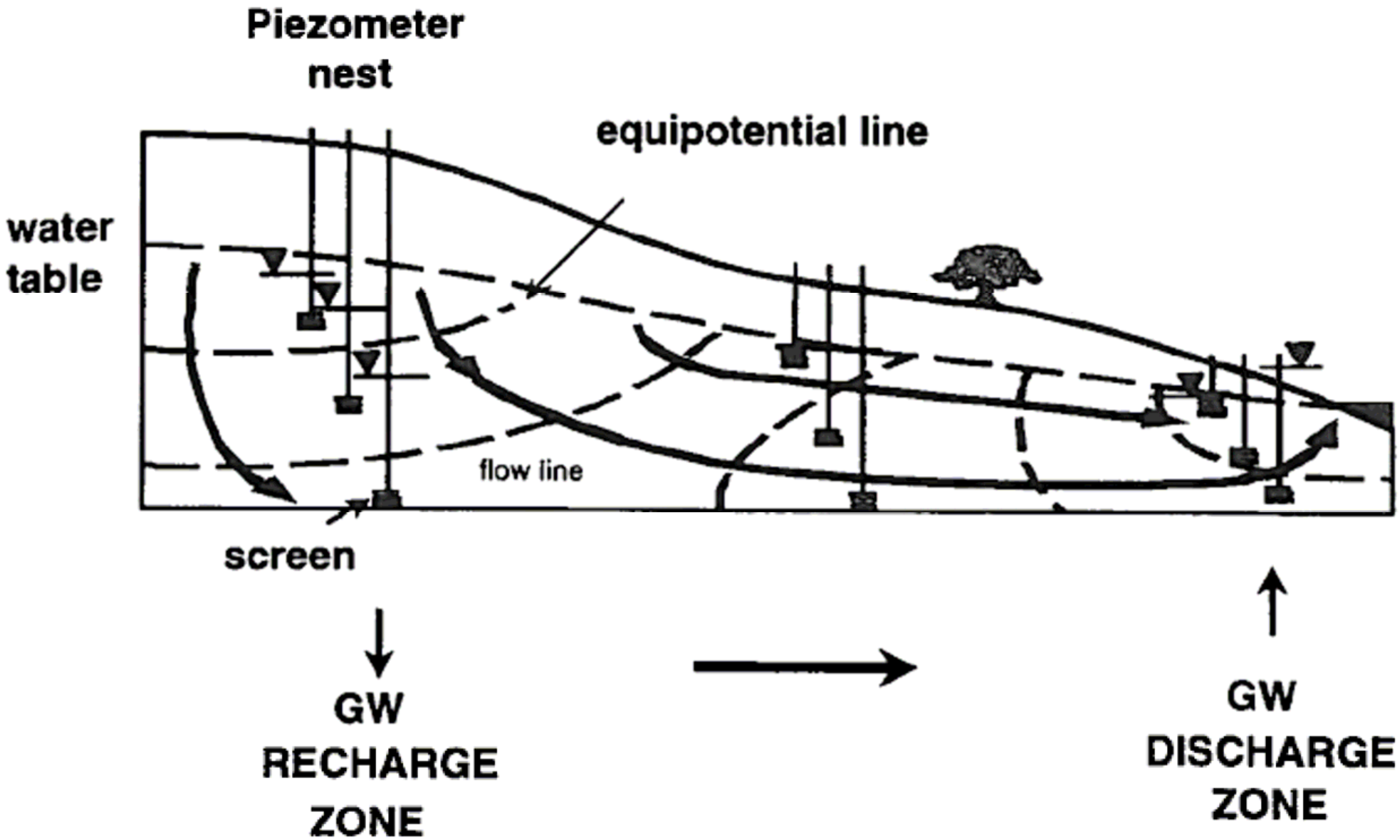
Flow and contaminant transport hard to characterize, understand and predict

Water table (unconfined) and confined aquifers – determination of hydraulic gradient and groundwater flow direction



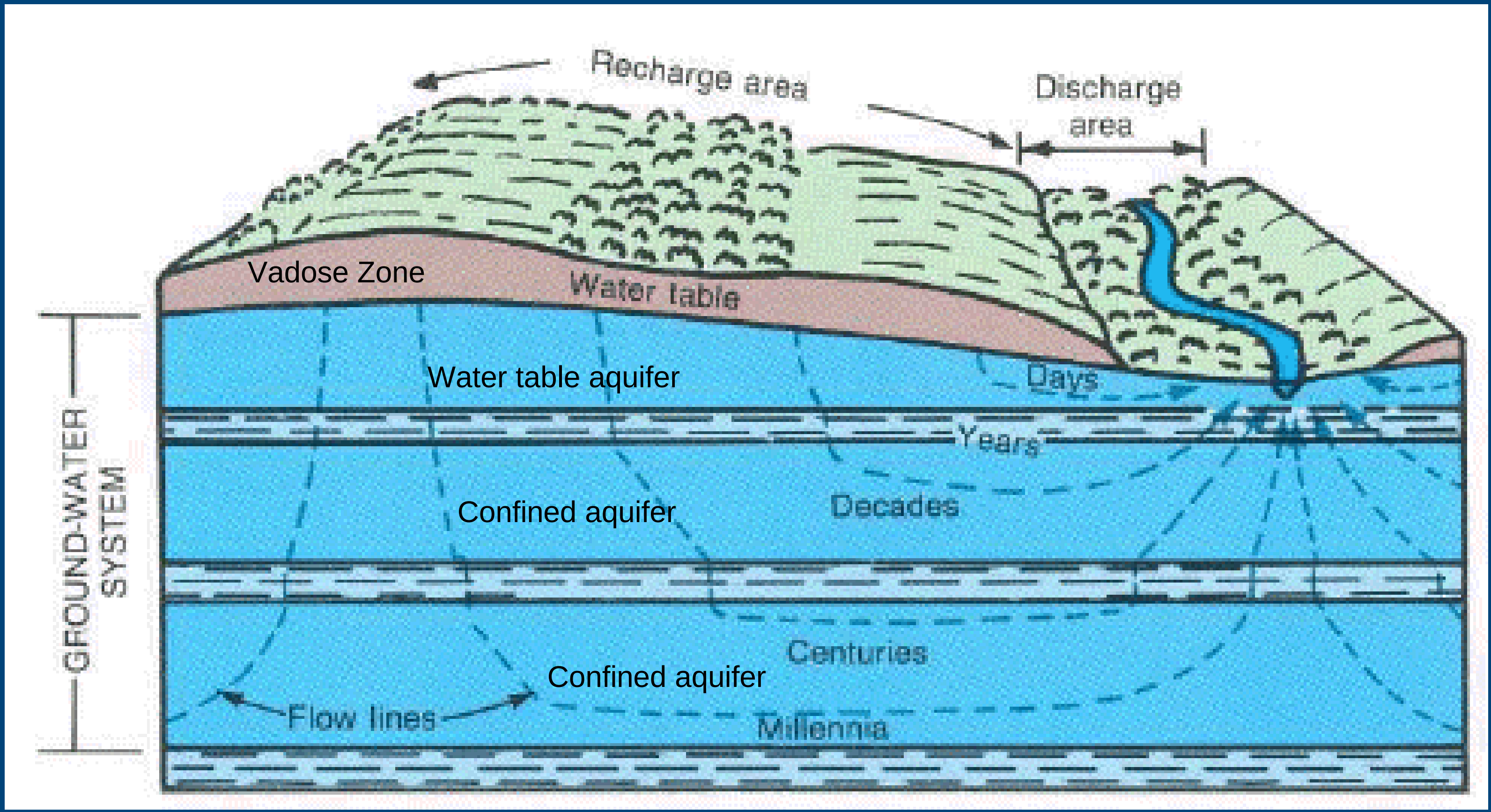
Freeze and Cherry 1979

HYDRAULIC HEAD IN NATURAL FLOW SYSTEM



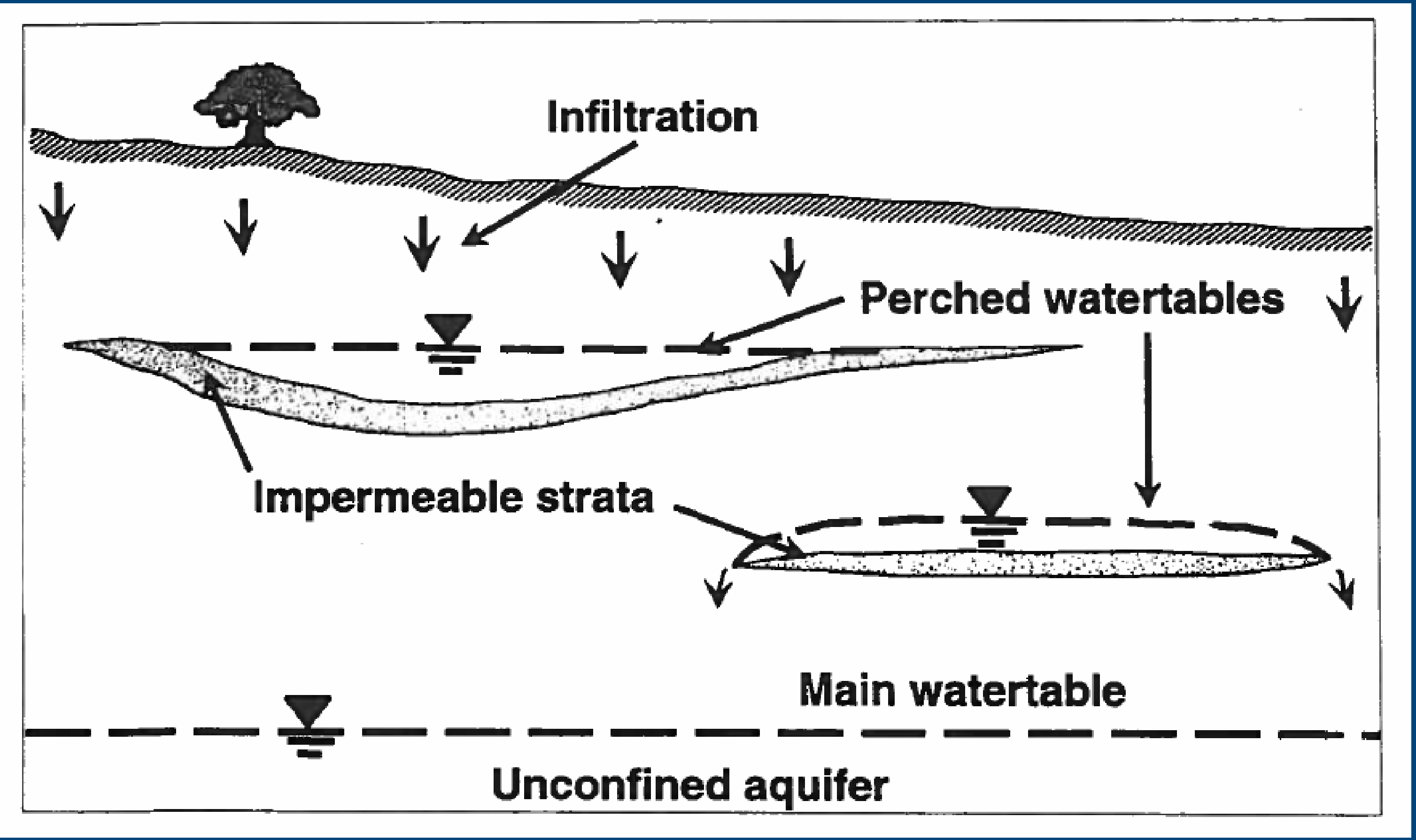
Cherry, J.A. 1999

Groundwater flow system - layered



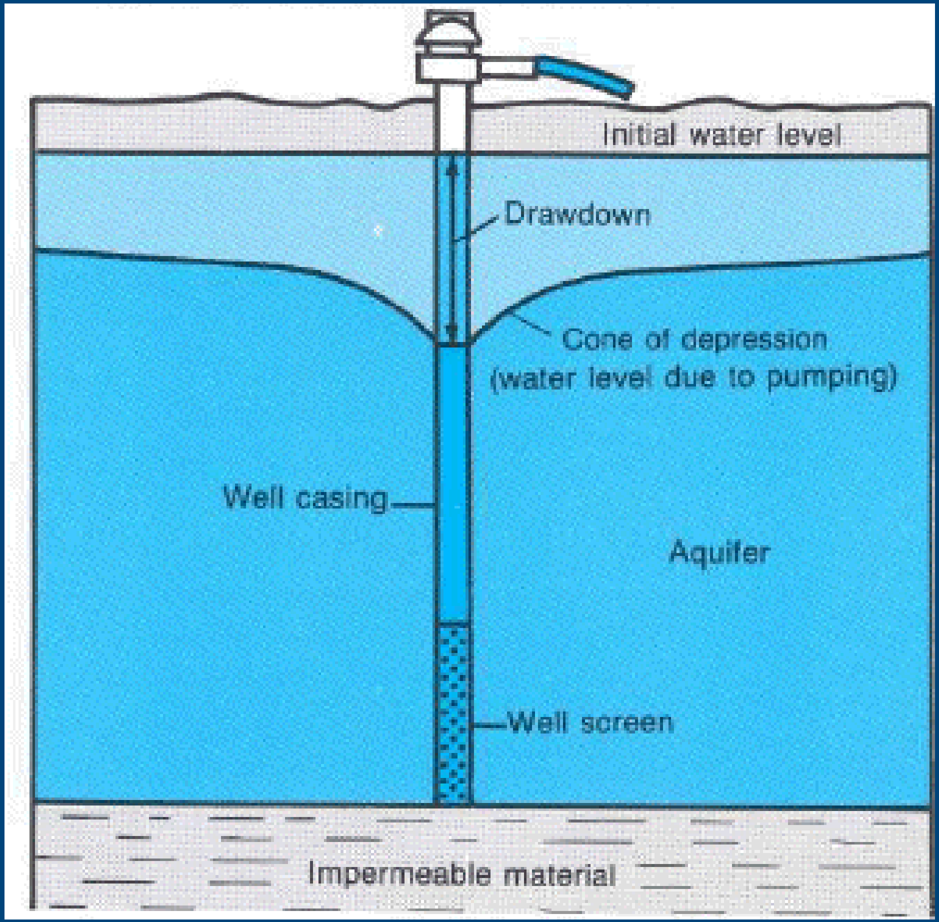
Graphic from Waller 2005

"Perched" water table



Cherry, J.A. 1999

Pumping: Drawdown at a well



Graphic from Waller 2005, USGS

Capture zone

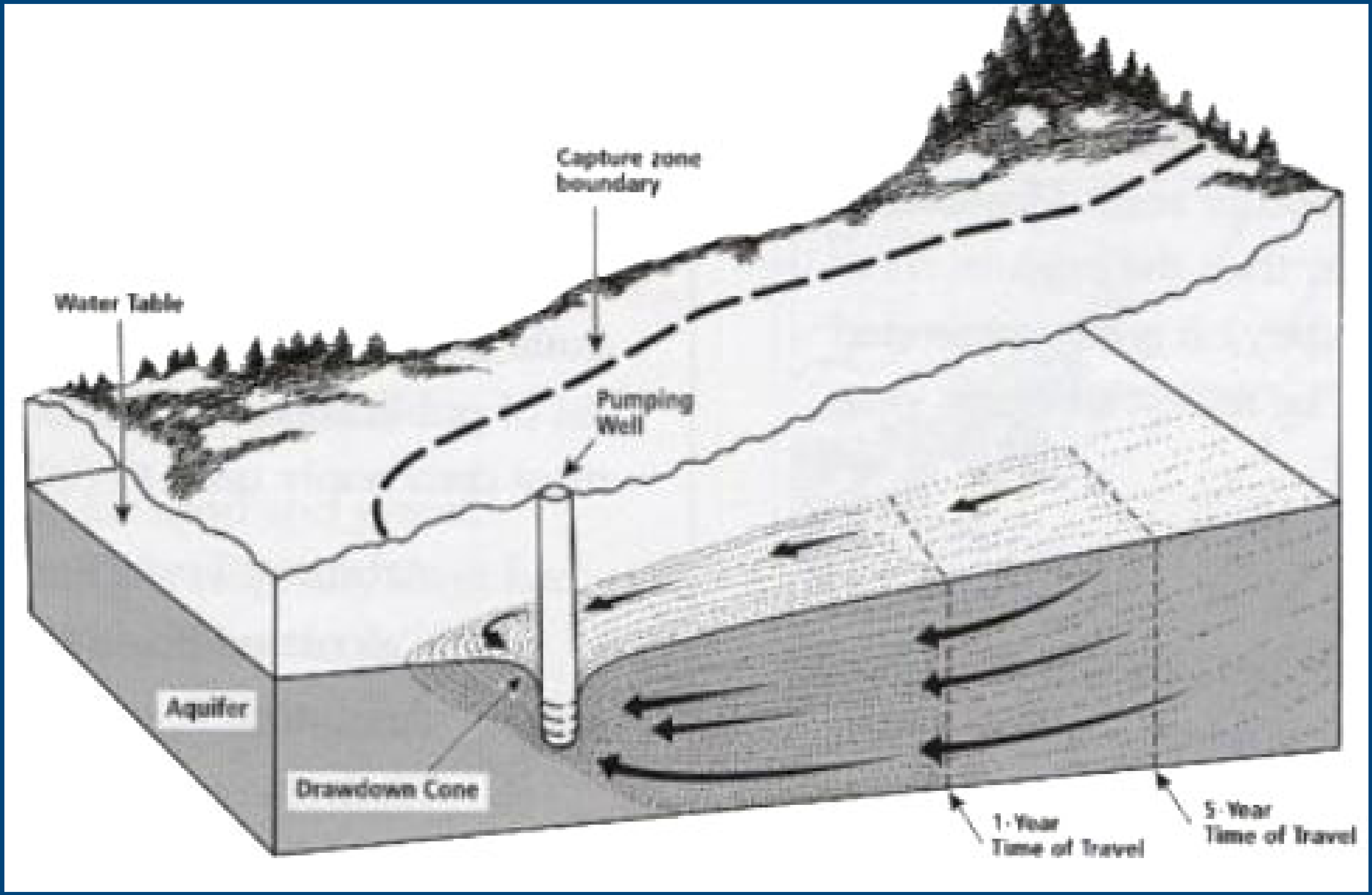
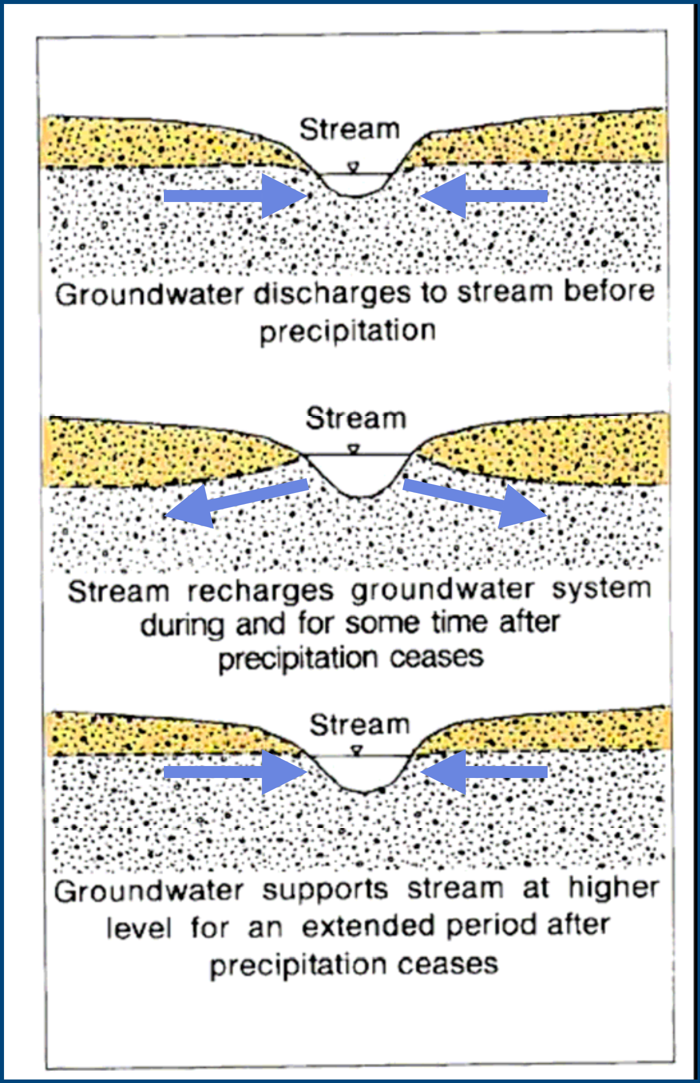


Image from mwwa.ca/education.htm

Gaining and losing streams

- Gaining reach/stream – groundwater discharges to the stream
- Losing reach/stream –stream discharges to groundwater

- Ephemeral: Flows only during storms and may or may not have a well-defined channel.
- Intermittent: Flows only during wet periods and flows in a continuous well-defined channel
- Perennial: Flows continuously



Graphic modified from Driscoll 1986

Influence of mine facilities on water balance

Round Mountain Mine, Nevada

photo credit: David Schumacher

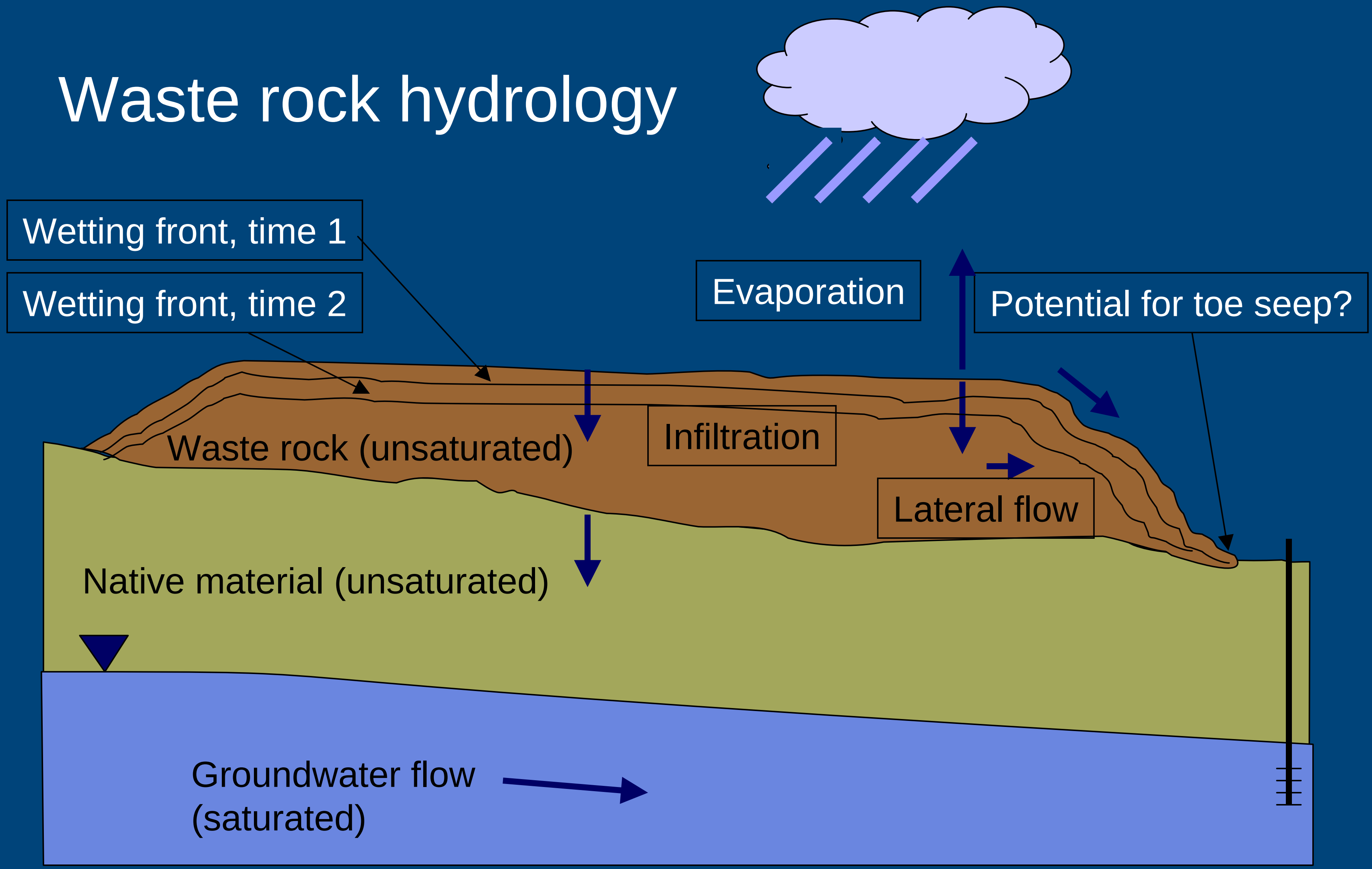
Influence of mine facilities on water

- Changes in near-surface processes (change in evapotranspiration, runoff, infiltration rates)
  - Interruption/change of areal recharge (waste rock, heap leach, tailings, Impoundments)
  - Infiltration of wetting front through waste rock, discharge/loading to groundwater
- Percolation from tailings impoundments – discharge/loading to groundwater
- Dewatering pits and underground mines – influence on springs, streams, allows oxidation of sulfides
- Flooding of underground workings - conduits for flow and transport
- Discharge of mine water – influence on water quantity and quality
- Creation of pit lakes and impoundments alters flow patterns

Waste rock hydrology

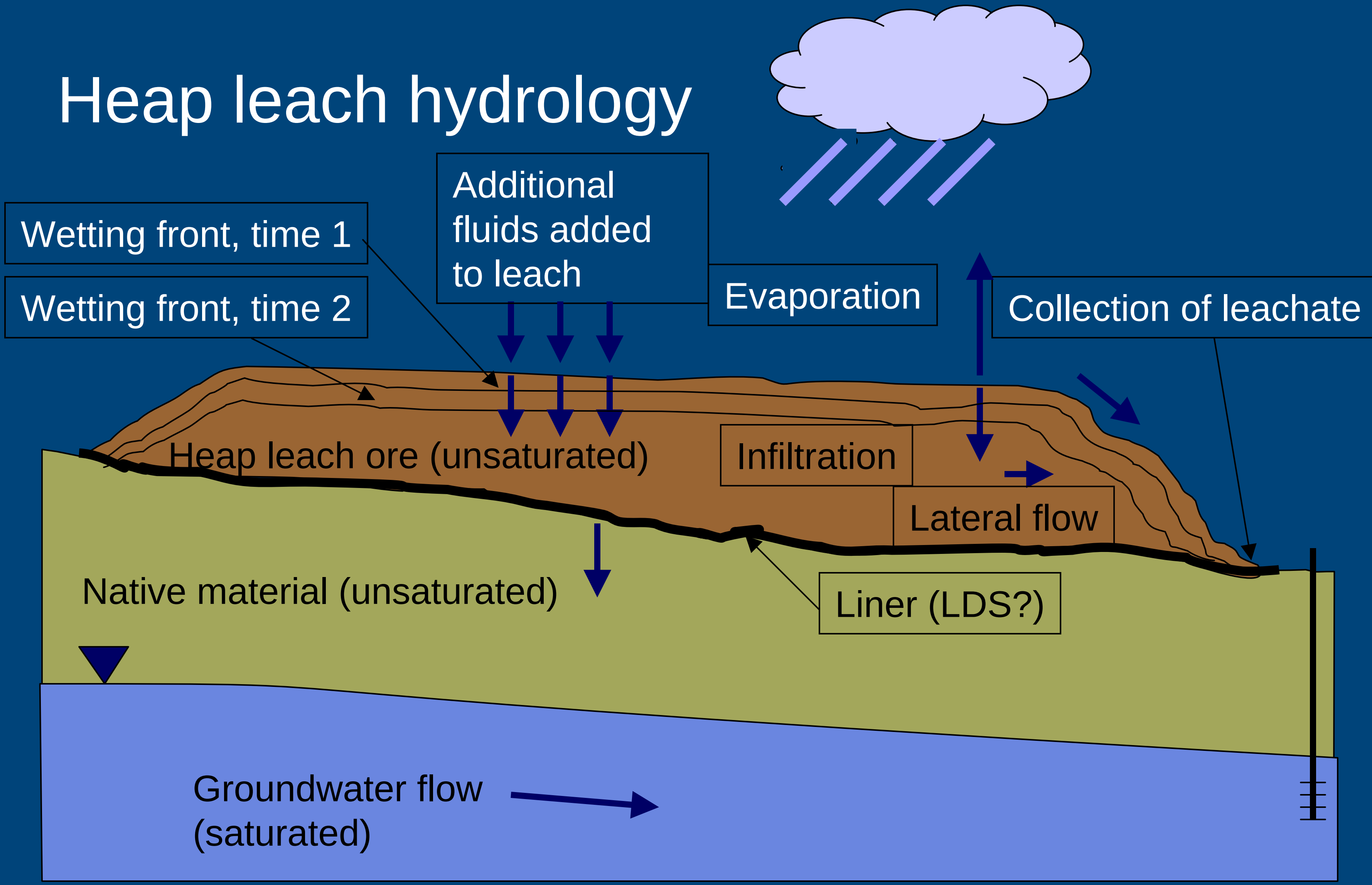
- Waste rock typically has low moisture content when deposited
- Water infiltrates during snow melt and precipitation events
- Wetting front migrates from surface of dump downward, in arid environments this may take tens to hundreds of years
- Dump may have low permeability layers (lifts) and macropores that influence hydrology
- Waste rock covers typically designed to increase evapotranspiration/decrease infiltration

Waste rock hydrology



Graphics: C. Travers

Heap leach hydrology



Graphics: C. Travers

Tailings impoundment hydrology

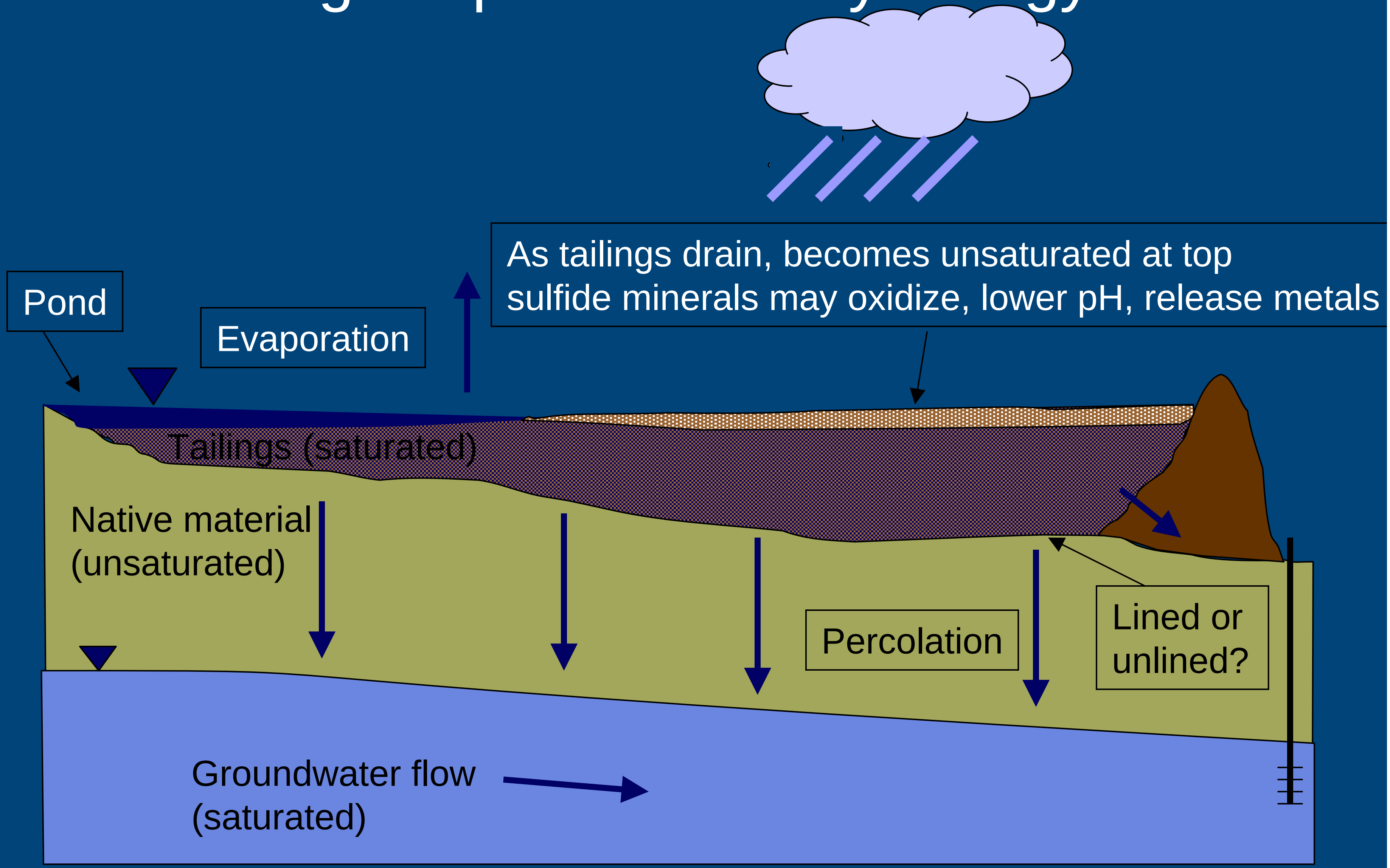
- Tailings slurry contains fine (typically small particle size, silt/clay range) materials
- Slurry has high water content
- Water migrating from the bottom of the tailings impoundment has driving head from impounded water
- Water chemistry of pore water at bottom may be very different than top of impoundment
- Fluctuating water levels in impoundment (wetting/drying, draining) can result in sulfide mineral oxidation and generation of acidic metal-rich pond
- Unlined tailings impoundment will drain slowly to groundwater

Tailings impoundments

Photo credit: Bullfrog tailings, NM
SARB Consulting 2009

Betze Pit tailings, Nevada

Unlined tailings impoundment hydrology

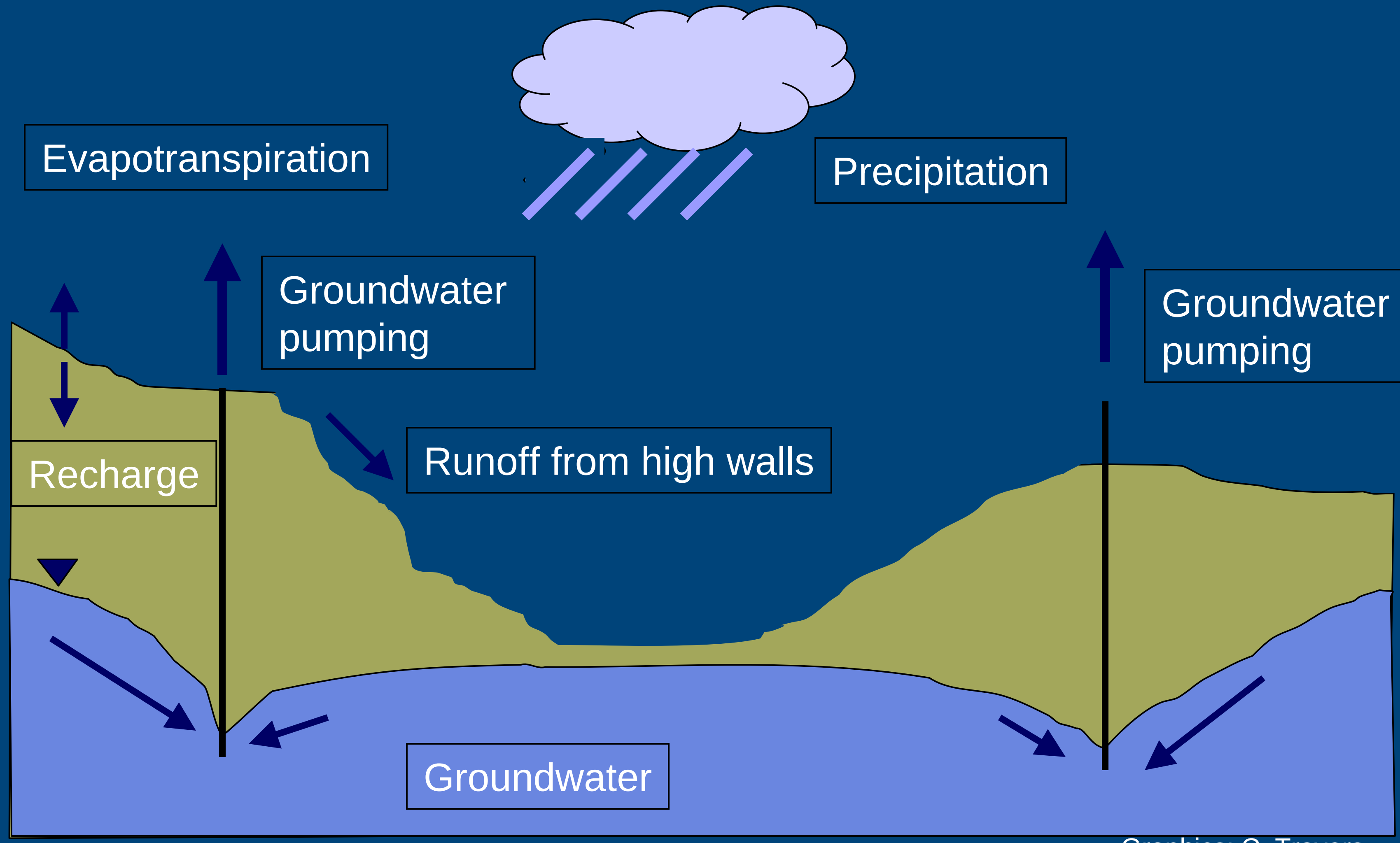


Graphics: C. Travers

Dewatering and flooding of open pits

- During life of mine, pit dewatering results in depression of water table, cone of depression
- Post-mining, as pit lake forms, evaporative losses may sustain a cone of depression
- Groundwater may inflow only, causing evaporative concentration of constituents in lake
- Groundwater may inflow and outflow, potential for degradation of downgradient water quality

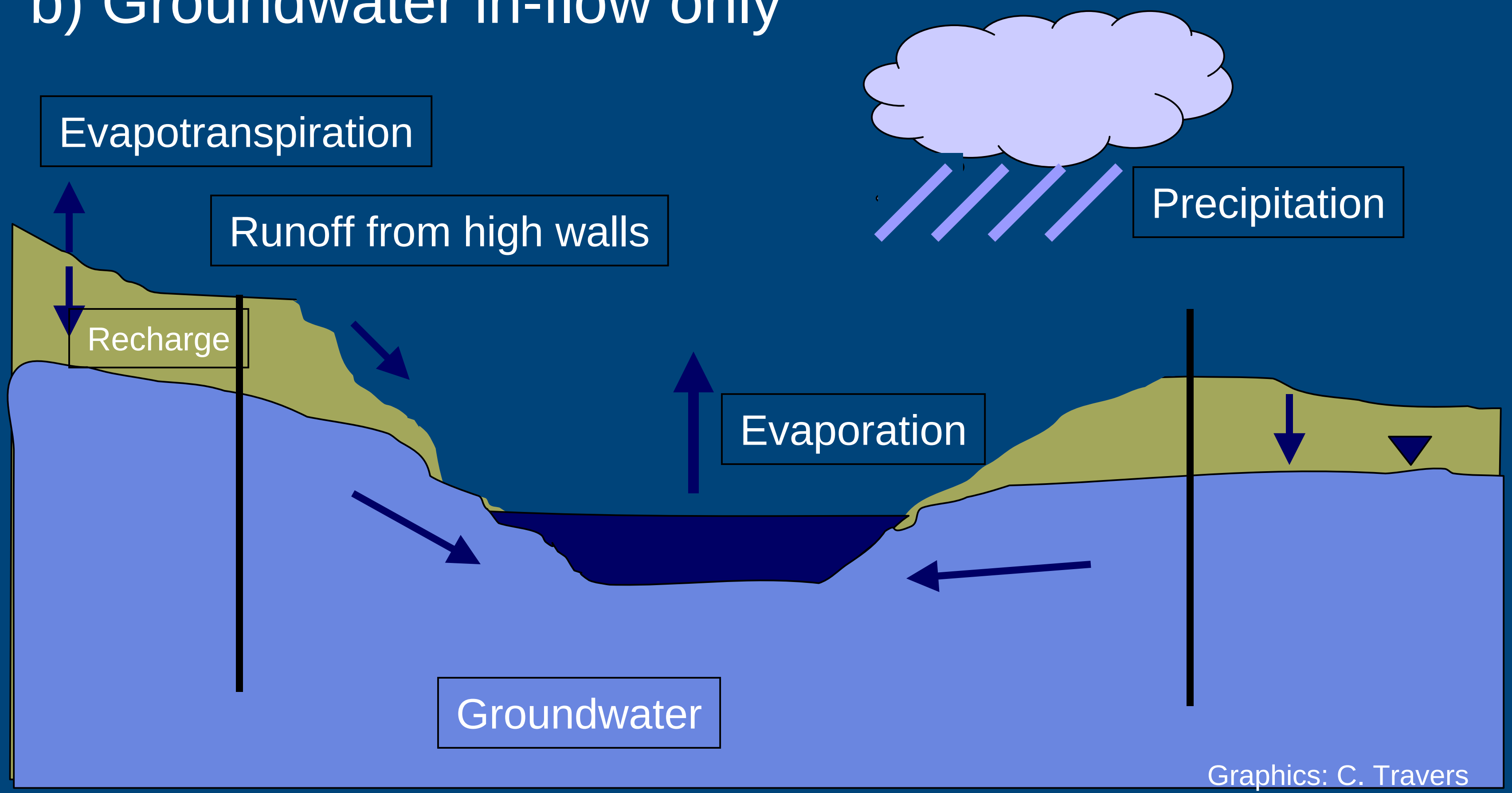
Dewatering of open pits



Graphics: C. Travers

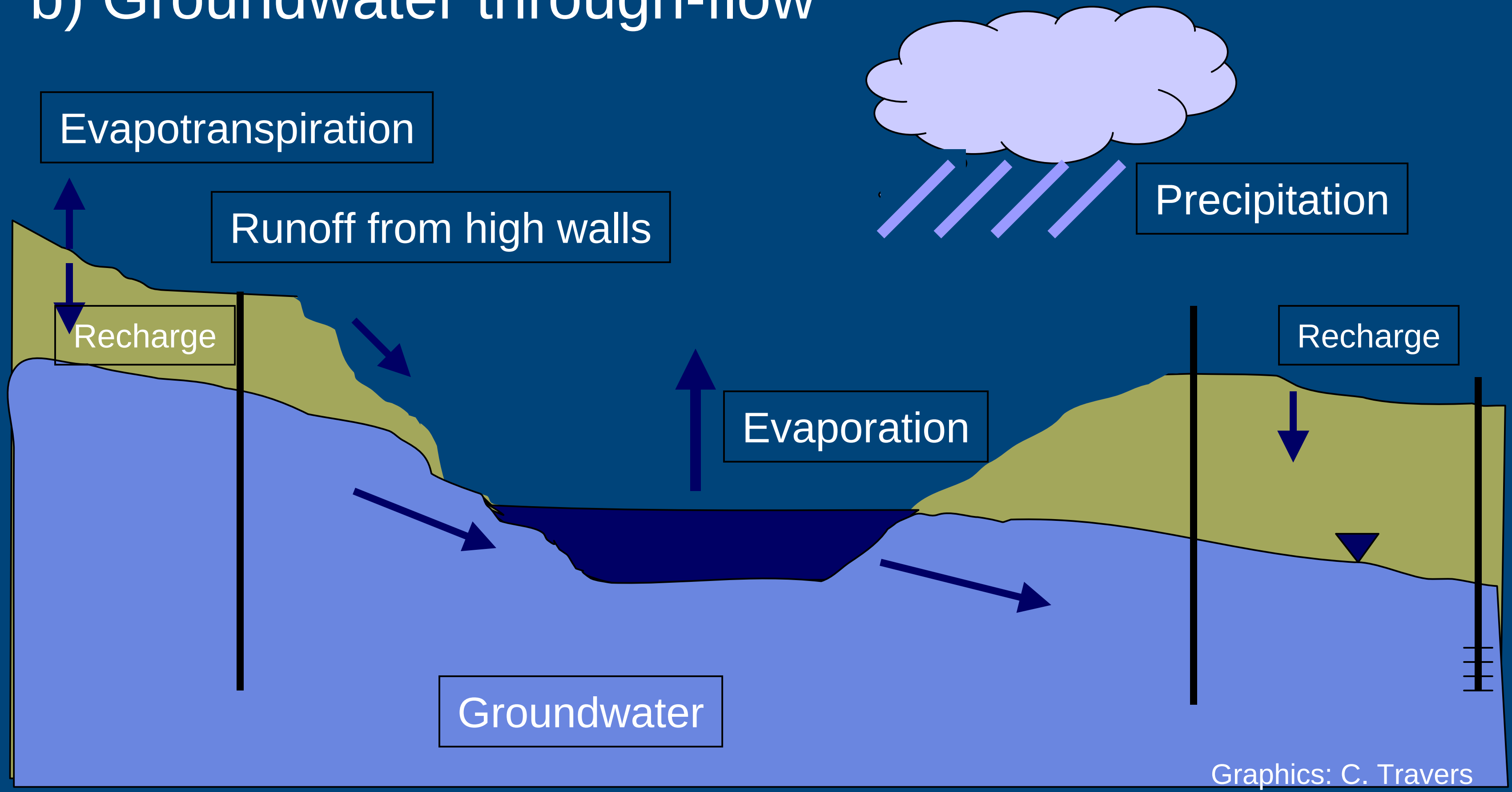
Post-mining, cessation of pumping, pit lake formation

b) Groundwater in-flow only



Post-mining, cessation of pumping, pit lake formation

b) Groundwater through-flow



Post-mining, cessation of pumping, pit backfilled with waste rock

Groundwater through-flow