Site Characterization: Hydrology

Collect and analyze data to understand water balance and water movement

Water Budget

- "Ins" minus "Outs", pre-mining, over life of mine, and post-closure
- Throughout mine site
- Within individual mine units

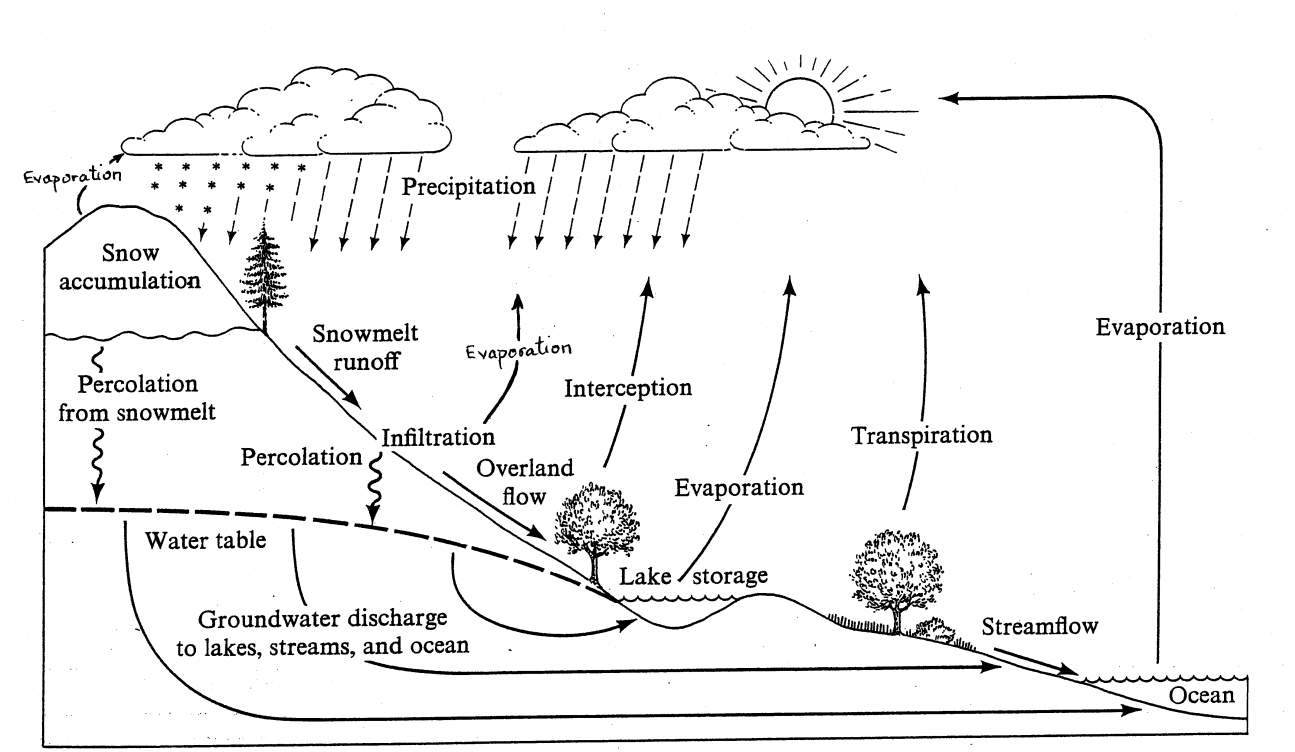


Figure 1-1 Schematic diagram of the hydrologic cycle.

Water balance example

Example from the Straight Creek catchment in the Red River Valley, New Mexico (Questa)

- P = 701 gpm
- ET = 540 gpm (77%)
- Q_G = 156 gpm (21.3%)
- Q_S = 5 gpm (0.7%)

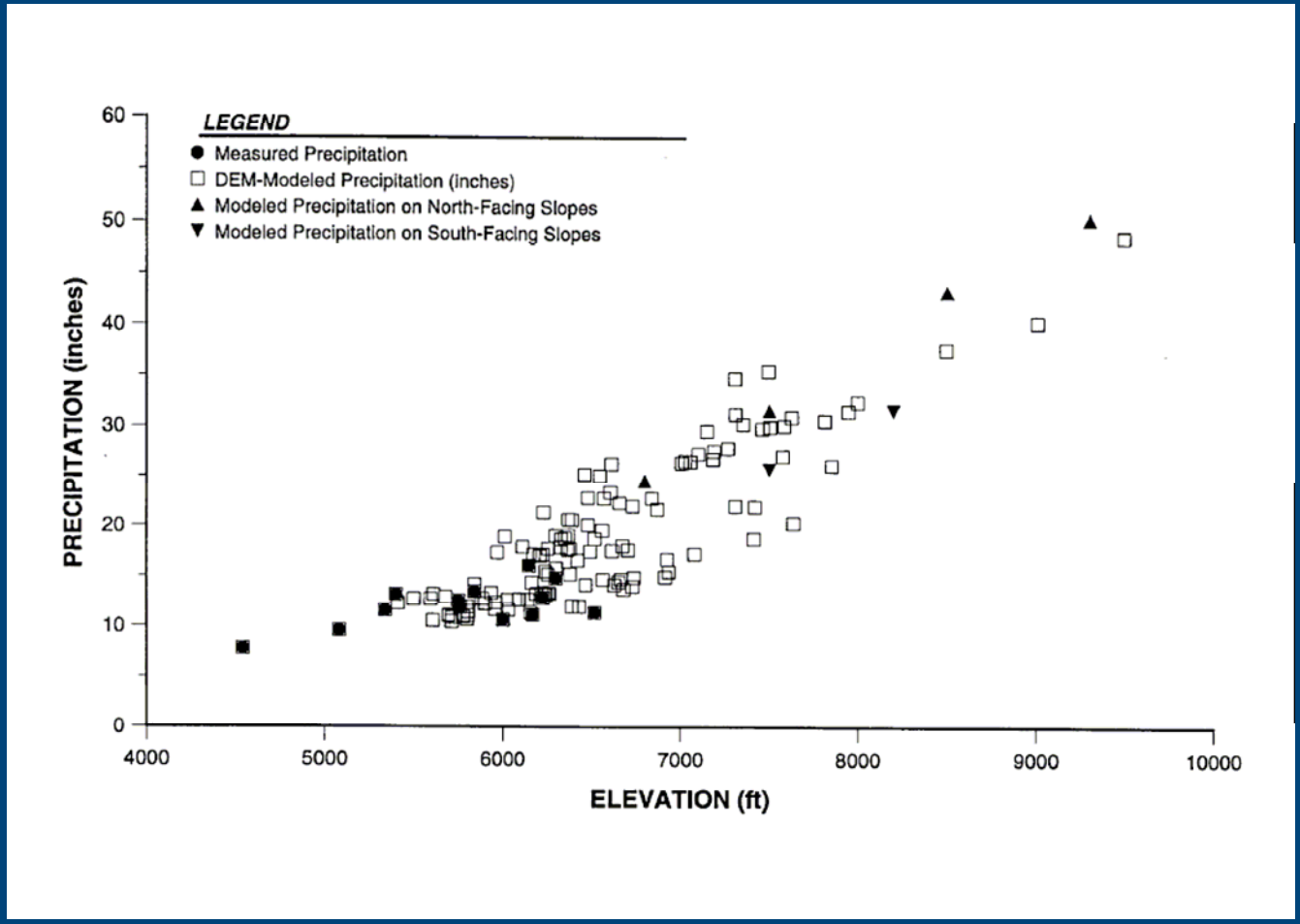
$P = ET + Q_S + Q_G$ [water balance or water budget]

McAda and Naus (2008)

Hydrologic characterization: near-surface processes

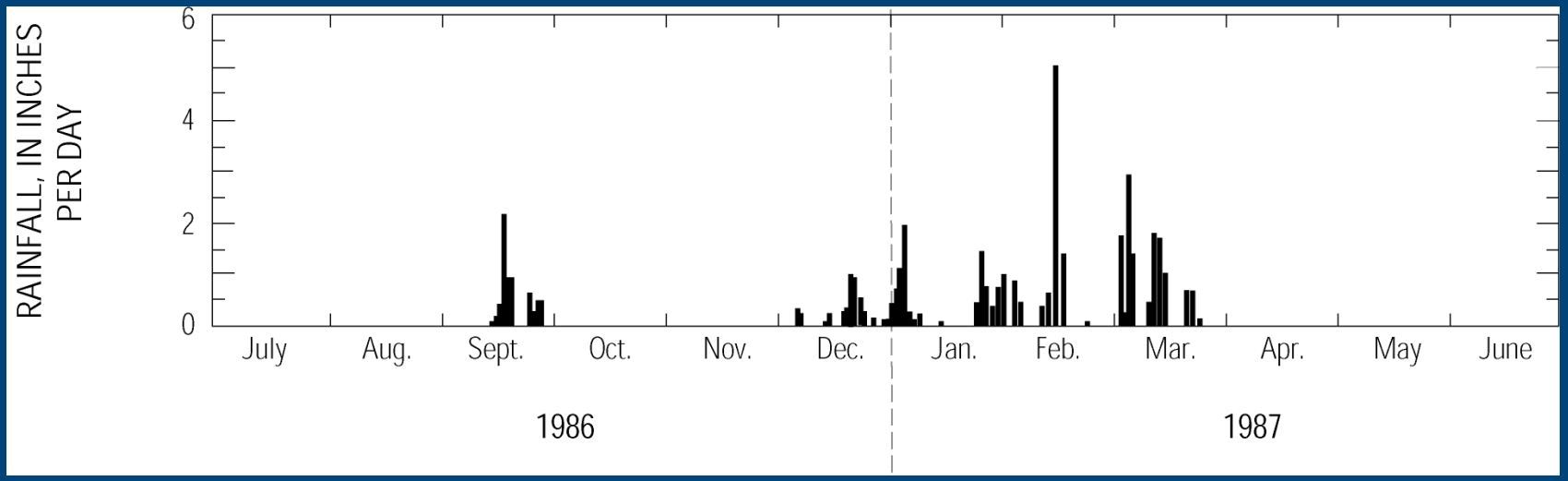
- Meteorological data – obtain from regional or mine-maintained stations
  - Precipitation – events and timing, orographic effects?
  - Evaporation/evapotranspiration (pan evaporation data, methods for estimating ET from temperature, precipitation, humidity, vegetative cover etc.)
- Runoff from native ground, covers, and mine wastes – estimate from topography, material type, testing of particle size (e.g., SCS runoff curve number)
- Infiltration/K– estimate from laboratory measurements of materials, or field infiltrometer tests

Average annual precipitation with land surface elevation – Big Springs Mine, Nevada



Exponent, 1998

Precipitation:



Example of precipitation recorded at Questa Mine, NM

Frequency, duration, intensity of individual events must be considered

Need long-term, continuous meteorological data record

Precipitation, infiltration and runoff

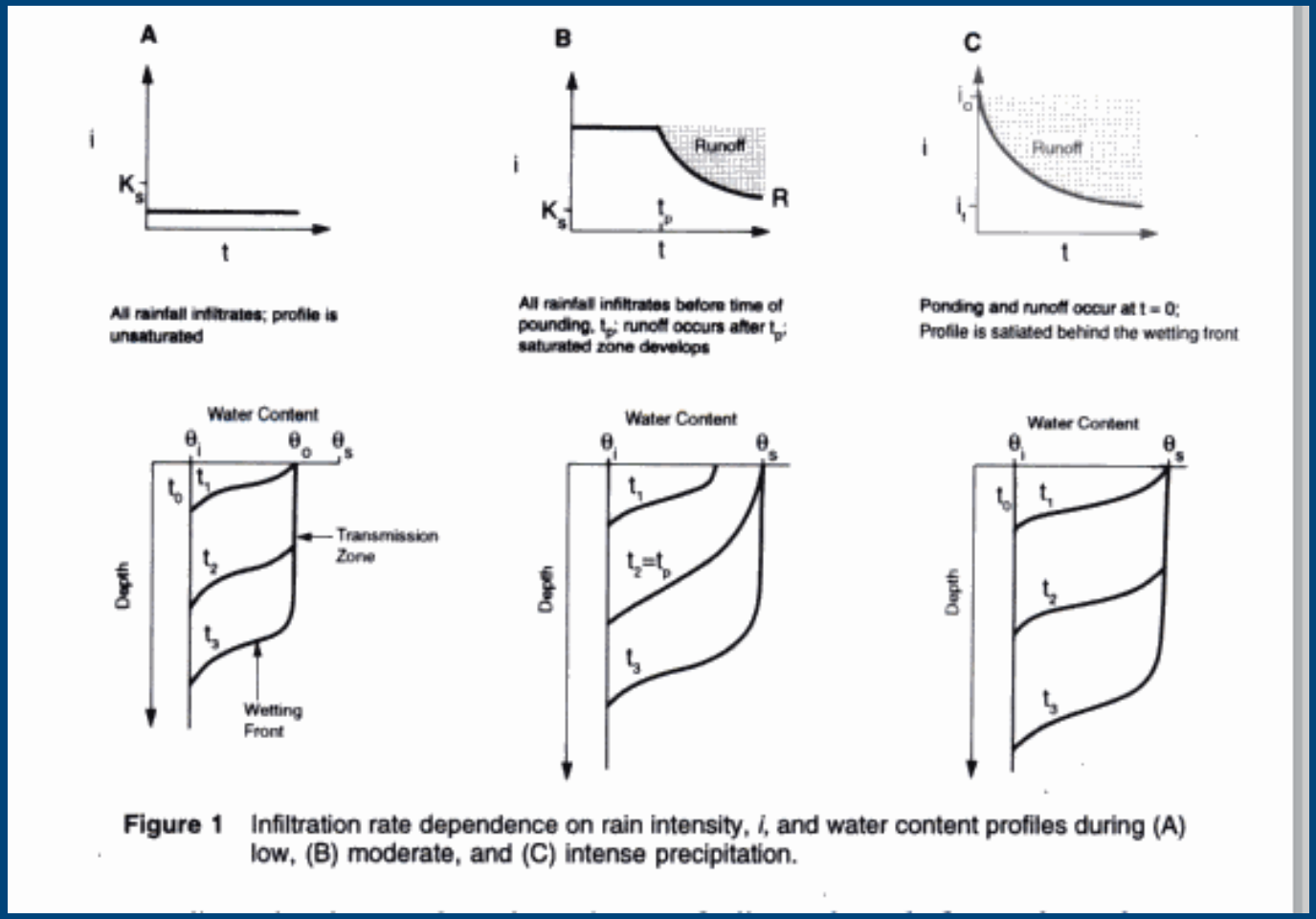
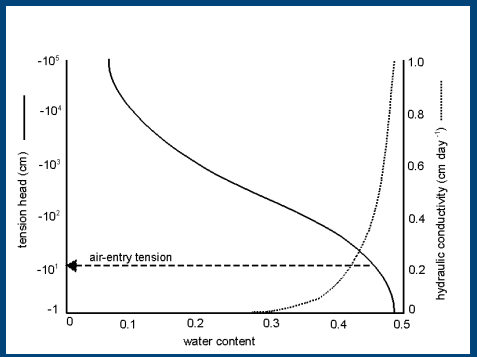


Figure 1 Infiltration rate dependence on rain intensity, *i*, and water content profiles during (A) low, (B) moderate, and (C) intense precipitation.

Stephens, 2006

Hydrologic characterization – mine wastes, native ground

- Hydraulic properties of mine wastes (e.g, waste rock) and native ground
  - Unsaturated flow properties (e.g., porosity, initial water content, relative permeability as a function of negative pressure)
  - Characterization methods: Can be measured in laboratory on mine waste and native materials [e.g., soil water characteristic curve])
  - May not adequately characterize presence of macropores? Internal layers?

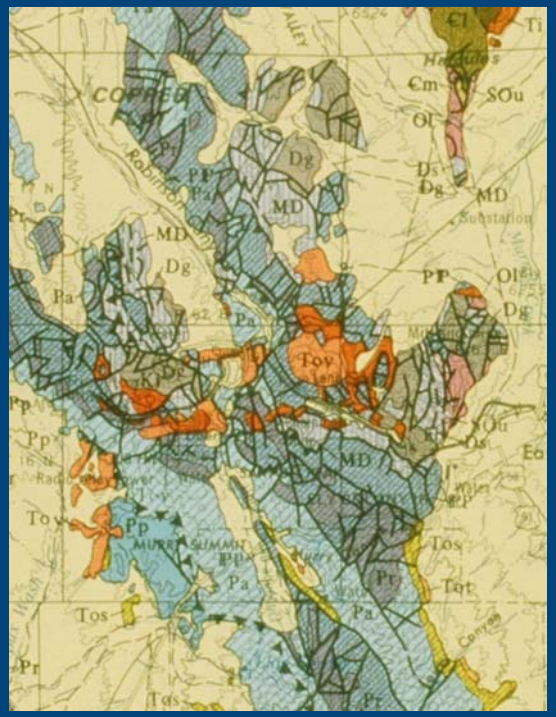


Example: Characterization of hydrologic properties of native material – collecting soil (aka “the sponge”) samples for hydraulic testing, Yanacocha Mining District, Peru

Photo credit: Connie Travers

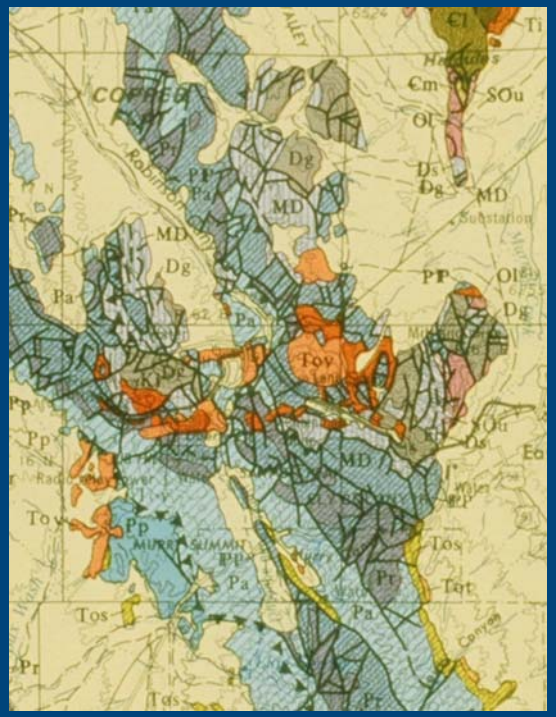
Hydrologic characterization – groundwater

Aquifers and aquitards



- Geologic units present, continuity of aquifers (vertical and lateral extent), presence of faults
- Characterization methods: Geologic surface mapping, drill hole logging, can obtain information from regional studies, mine block model, observations of aquifer response during aquifer testing

Hydrologic characterization – groundwater



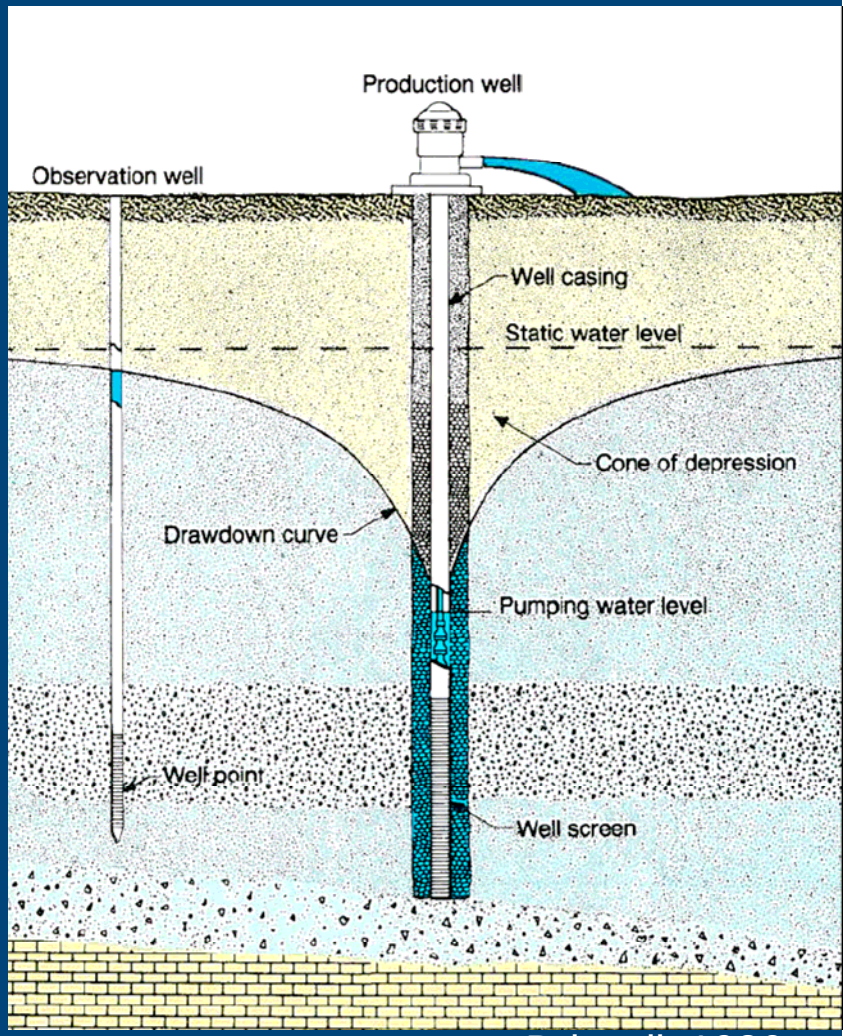
- Hydraulic properties of aquifers and aquitards – hydraulic conductivity, saturated thickness, storage coefficients, unconfined vs. confined units
- Characterization methods: determine from site-specific aquifer tests, water level data

Hydrologic characterization – groundwater

Methods for determining hydraulic conductivity

(in order of decreasing reliability):

- Pumping tests (multi-well gives storage too)
- "Slug" tests
- Laboratory permeability
- Literature values for similar geologic materials



Driscoll, 1986

Hydrologic characterization – groundwater

Monitoring Well near Robinson District, Ely Nevada Photo credit: Connie Travers

- Hydraulic conductivity ranges over orders of magnitude – need to capture heterogeneity
- Are data available for all significant aquifers/geologic units in mine area (unconfined, confined)?
- Are data grouped in space or time?
- Is flow channelized into higher permeability zones, fractures, conduits?

Hydrologic characterization – groundwater

Horizontal and vertical groundwater flow directions (gradients) and velocities

Groundwater recharge and discharge areas

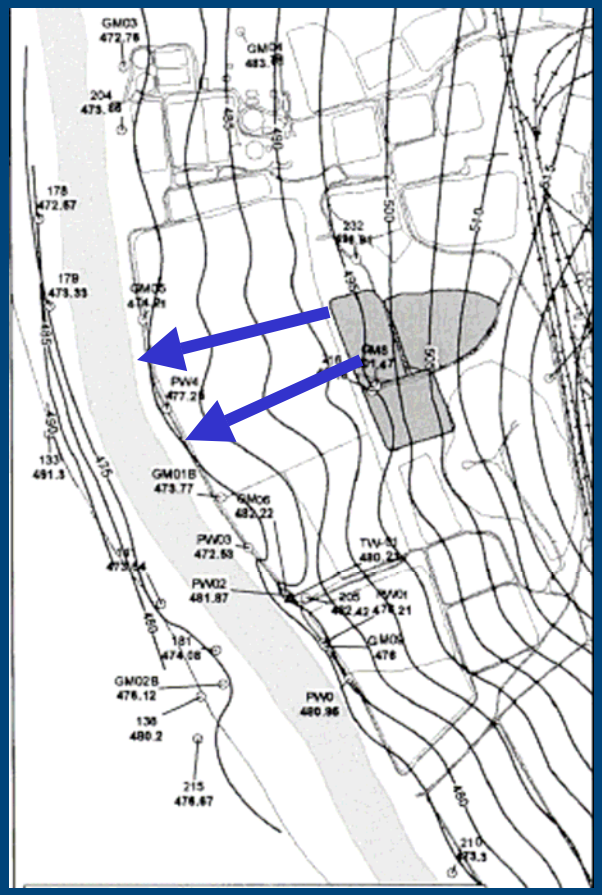
Characterization methods:

- Groundwater level measurements in wells/piezometers in aquifers
- Isotopic studies of water can indicate age of water, flow paths, travel time
- Tracer studies

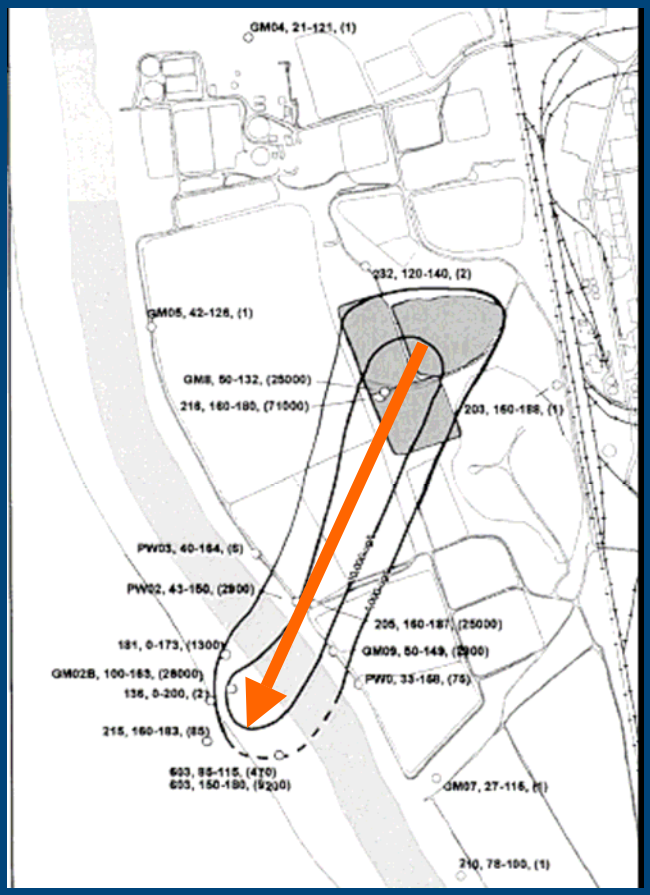
Is groundwater flow in fractured rock or flooded underground workings?

- Geologic mapping of fracture geometry at surface and in boreholes can provide information on regional fracture characteristics
- Fractures aperture, connectivity cannot be measured directly – need hydraulic or tracer tests.
- Historic mine maps of underground workings can provide insight into flow paths
- Individual fractures can be tested using packers in boreholes to isolate fractures
- Consider whether equivalent porous media assumption is warranted

Fractures can create unexpected flow paths and rapid travel times: Avtex Superfund Site



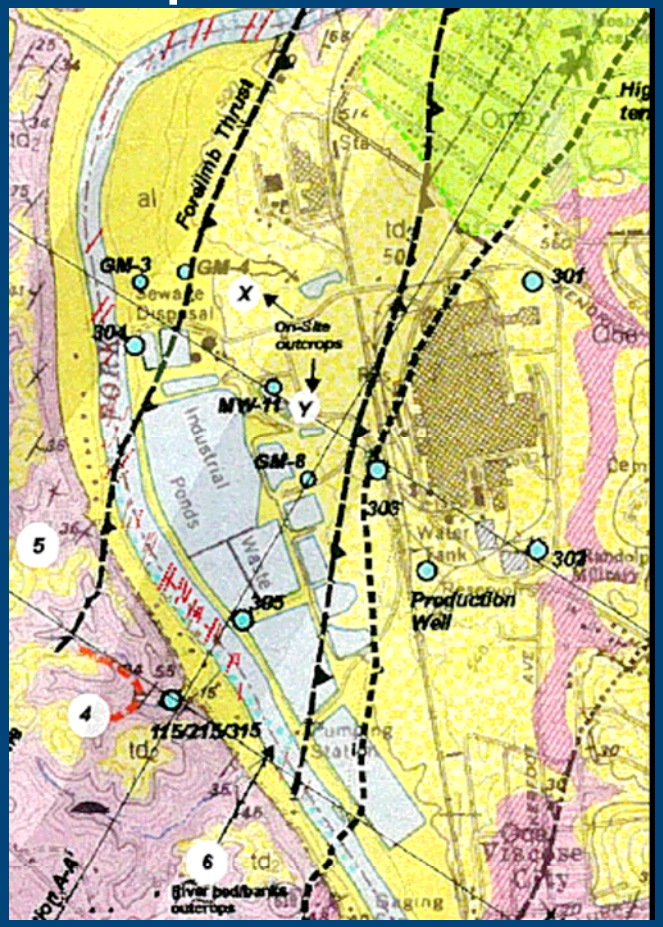
1) Groundwater gradient inferred from water level measurements



2) Direction of contaminant plume migration

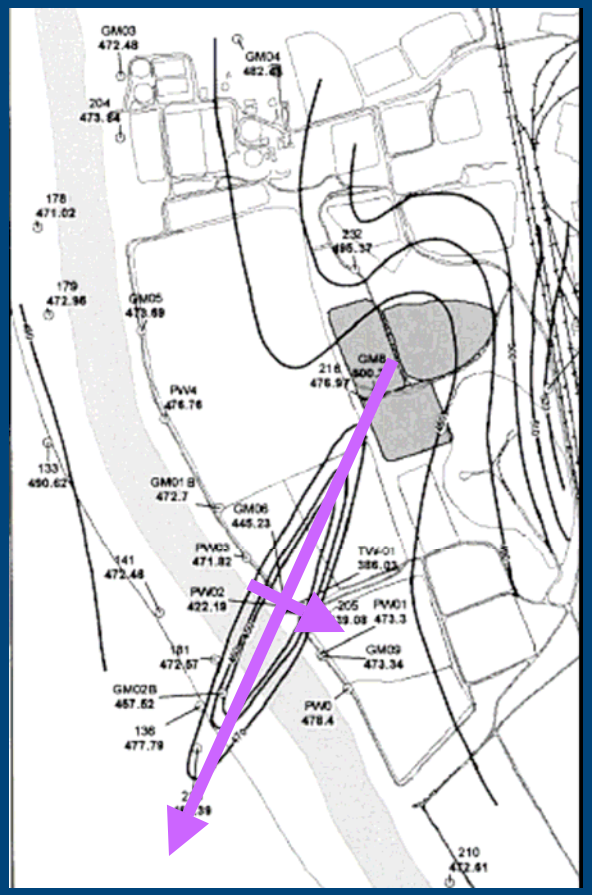
Exponent 2001

Fractures can create unexpected flow paths – example from Avtex Superfund Site



Golder Associates 2001

1) Shale bedrock folds and structure



Exponent 2001

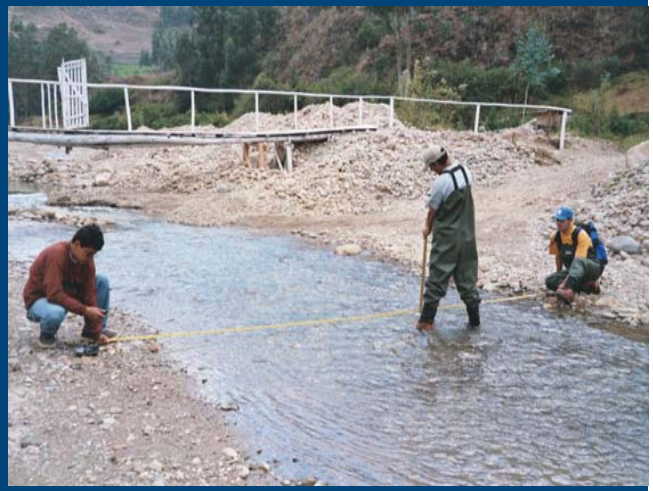
2) Anisotropy caused by fractures apparent in pumping test drawdown

Hydrologic characterization – surface water

Discharge measurements – stream and spring flow rates

- Manual measurements using flow meter, channel cross sections, or bucket and stop watch
- Dedicated gaging stations (mine installed or USGS) – develop rating curve

Need data sufficient to understand temporal nature of flows



Manual stream gaging, Yanacocha, Peru

Ephemeral stream gage near Betze Pit, Nevada

Photo credits: Connie Travers

Hydrologic characterization – surface water

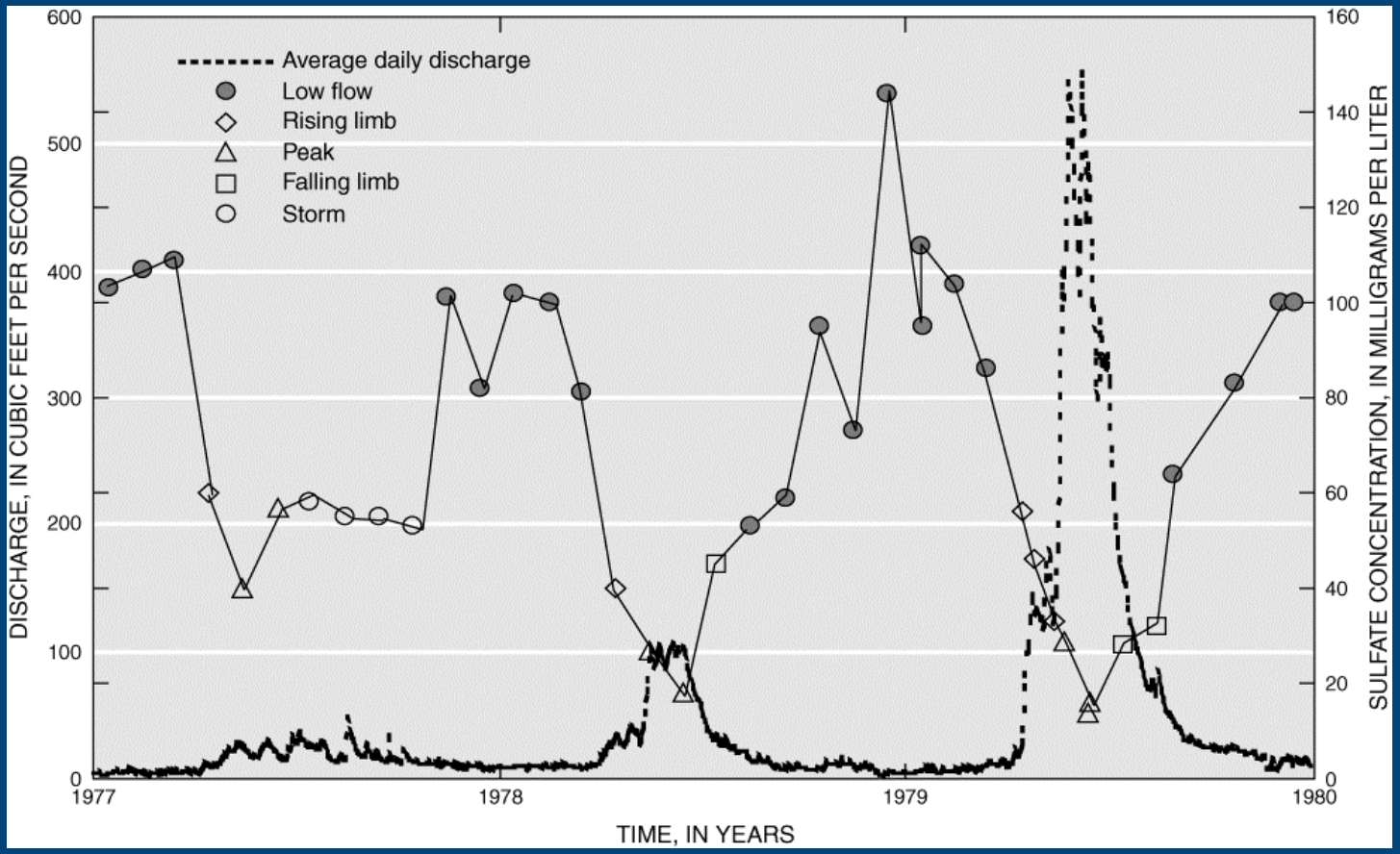
Groundwater/surface water interactions

- Characterization methods:
  - Determine gaining/losing reaches using discharge measurements along streams
  - Water level measurements in wells adjacent to streams and river stage can indicate flow directions variation in time
  - Water quality measurements – use with discharge measurements to characterize loading (in time and space) from groundwater, runoff, tributaries

- Consider: amount and reliability of measurements (e.g., are data sufficient to understand seasonal flow and /or water quality changes?)

Photo credit: Connie Travers

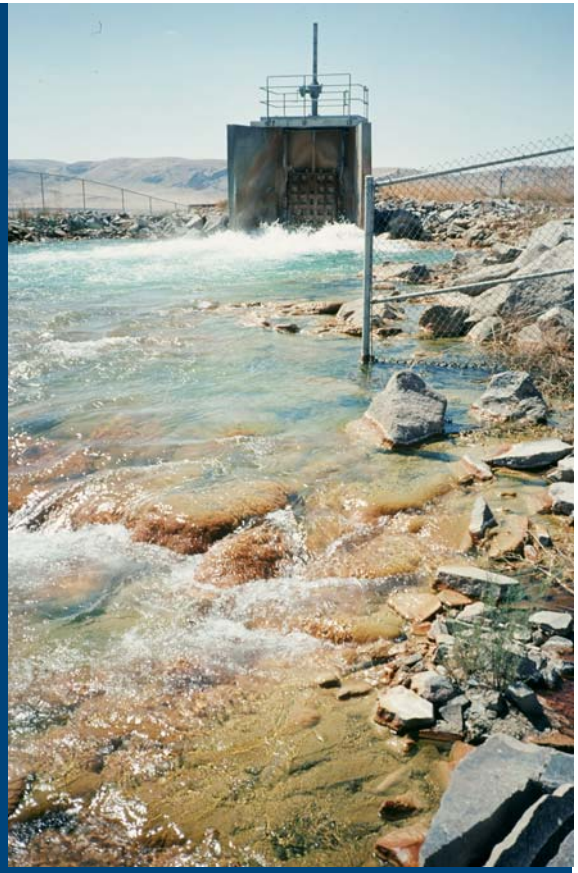
Seasonal variation: intensity, duration, frequency, timing of events



Red River, Questa Mine, NM

Hydrologic characterization: Mine plan over time

- Dewatering/flooding of open pit or underground workings?
- Discharge of water from dewatering?
- Infiltration of tailings water?
- Delayed recharge by construction of mine facilities such as waste rock dumps?
- Water management post-mining?



Discharge from Barrick Goldstrike Mine, Nevada

Note: Changes in mine plan often result in changes in hydrologic conditions – may need to re-evaluate as mine plan changes

Photo credit: Connie Travers