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
Water balance example

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

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

\[ P = \text{ET} + Q_S + Q_G \]  \[\text{[water balance or water budget]}\]

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

- 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

1) Shale bedrock folds and structure

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
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?

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

Discharge from Barrick Goldstrike Mine, Nevada