MINING AND EXPLORATION HYDROLOGY

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INTEGRATED APPROACH TO WATER RESOURCE CHARACTERIZATION FOR MINERAL EXPLORATION PROJECTS
THE MINING SEQUENCE

exploration  development  operations  closure
Early exploration...
Advanced exploration...
Essential Natural Resources for a Mine

Ore

Water

Land

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Mine Development

- Increasingly complex process
  - Changing federal, state and local environmental regulations
- Mine development/operation projects carry potential long-term environmental liabilities
- Every aspect of the mine development process must be considered in tandem
- Plan and design for closure
  - Requires comprehensive characterization and representative data sets
    - Hydrological characterization
    - Geochemical characterization
    - Geotechnical characterization

“*It’s the economy stupid!*”
Characterization/Baseline Studies for NEPA

- Jurisdictional Determinations for Waters of the U.S.
- Noxious Weeds, Invasive and Non-Native Species
- Cultural and Native American Resources/Values
- Surface Water and Groundwater Resources
- Minerals and Paleontological Resources
- Threatened and Endangered Species
- Social and Economic Values
- Wastes, Hazardous or Solid
- Human Health and Safety
- Land Use Authorization
- Special Status Species
- Grazing Management
- Climate/meteorology
- Visual Resources
- Migratory Birds
- Wilderness
- Air Quality
- Recreation
- Vegetation
- Soils

Long-lead items
Past experience has shown that:

- The development of water resource data is an extensive, costly and most time consuming endeavor

- To optimize the water resource characterization program, mining companies should be advised to collect characterization and baseline water resources data during exploration activities

- Data collection methods must be accepted/defensible with BLM, EPA and NDEP

* Data collection methods and water resource monitoring, management and mitigation (3M) plans must also be acceptable/defensible with NDWR, local government, and stakeholders per NRS 533.353
Program Design

• Designed to *piggy-back* with advanced exploration stage of mine development process
  • Reduce costs associated with hydrogeological, geochemical and geotechnical characterization programs
  • Streamline the planning, design and permitting phases of the mine development process

• **Must follow current federal, state and local statutes, codes, regulations, ordinances and policies**

• **Utilize accepted/defensible data collection, data management and analytical methods**
  • Only collect data sets that are necessary to support mine development (exploration, planning, design, permitting) mining operations, and mine closure
  • Optimize collection and quality of data required for permitting and compliance

• **Utilize state of the art software to process representative data sets**
WATER RIGHTS: where hydrologic science meets water law

- Mine water demand vs. availability
- Dewatering (consumptive vs. non-consumptive)
- Unappropriated water available?
  - Hydrographic Area (Basin) status
  - Perennial yield vs. committed water rights
  - Basin study vs. purchase/lease of existing rights
  - Water rights database
  - Pumpage inventories
  - Crop inventories

NDWR, 2015
BASIN-SCALE CHARACTERIZATION

- Climate
- Land cover
  - LandSAT
- Geology
  - Geophysics
- Hydrology
- Hydrogeology
Precipitation

• Models are sensitive to simulated precipitation distribution (spatial and temporal)
  – Multiple data sets and robust period of record often necessary
Evaporation/Evapotranspiration (ET)

- Models are sensitive to simulated ET distribution (spatial and temporal)
  - Multiple data sets and robust period of record often necessary
Precipitation and Evaporation

- Statistical relationships in terms of elevation

**Precipitation-Elevation Relation:**
Precip. (in/year) = 0.0052x - 16.601
where: x = Elevation (ft amsl)
$R^2 = 0.88$

**Evaporation-Elevation Relation:**
Evap. (in/year) = -0.0131x + 108.93
where: x = Elevation (ft amsl)
$R^2 = 0.90$
Land Cover

- Satellite imagery – thematic mapping
- Aerial imagery – color infrared (CIR)
Soil/Sediment

- Permeability
- Vadose zone hydrology / soil moisture balance

Maurer et al., 2004
Seismic Surveys

- Passive, low impact, non-invasive
- Based on material densities and gravitational effects

Modified from Maurer and Welch, 2001
CSEM/CSAMT Surveys

- CSEM (Controlled-source Electromagnetics)
- CSAMT (Controlled-source Audio-Frequency Magnetotellurics)
- Data utilized to define geologic structures, lithology, water table trends and fluid salinity
Gravity and Magnetic Surveys

- Data utilized to delineate subsurface geology, magnetic rocks, sedimentary basin depth, basement topography, and buried faults or contacts that can affect fluid flow.
Geology

- Geology
- Hydrogeology
Geology

- Site-specific
- Stratigraphic correlation
- Structural controls
  - Mineralization
  - Groundwater flow

Modified from Practical Mining LLC, 2014
Crafford, 2010
Geological Modeling

- 3D visualization of geologic units, structures, and other multi-element data sets
SURFACE WATER HYDROLOGY

- Flow/stage
  - Peak flow
  - Average flow
  - Base flow
Weirs

- Simple design and installation
- Low cost (<$500 fabrication)
- Raises head
- Requires freeboard and still pool
- Not self-cleaning
- Less accurate than a flume
- Work in Waterway Permit not required
Flumes

- More involved installation
- Higher cost (≥$2,000 fabrication)
- Moving flow
- Minimal raise in head
- Self-cleaning
- Submerged flow (certain types)
- Work in Waterway Permit often required
Velocity – Area

- Inexpensive and reliable method
- Most practical for large streams
- Used extensively
- Velocity measurement
  - Float
  - Current meter
  - Slope method
Bucket Testing

- Inexpensive and accepted method
- Size of container dictates range of flows
- Used extensively
Surface Water Models: Tools for Hydrogeology

- Precipitation statistics
- Spatial distribution of runoff and pit inflows
Potentiometric Surface

- Water level surface contours
- Hydraulic gradients and flow directions

Lopes, et al., 2006

Groundwater Contours  Groundwater Elevations  Depths to Water
Potentiometric Surface

- Combined data sets
  - Surface water rights/resources inventory/characterization
    * Stage/flow of seeps, springs, streams, lakes and ponds
  - Groundwater rights/resources inventory/characterization
    * Well logs, underground water rights and water levels
Geologic Models: Tools for Hydrogeology

- Targeting geologic units and structures for hydraulic testing from exploration coreholes
Geologic Models: Tools for Hydrogeology

- Targeting geologic units and structures for packer isolated hydraulic testing from exploration coreholes
Hydraulic Packers

- Hydraulic testing
- Monitoring
- Aquifer storage and recovery (ASR)
- Solution (ISR) mining
- Rock stress mechanics
- Hydraulic fracturing

Images courtesy of Inflatable Packers International
Packer Deployment/Retrieval

1. Deploy to target depth
2. Inflation/testing
3. Deflation/retrieval via rig wireline
Types of Packer Tests

- **Injection**
- **Discharge**
- **Falling Head**

* Straddle packers work with any test
Down-hole Geophysical Surveys

- Orientation/deflection
- E-log
- Spinner
- AT
Instrumentation Boreholes

- Vibrating Wire Piezometer (VWP)
- Water level monitoring
- Stability/deformation monitoring
- Licensed well driller not required
WELL DRILLING AND CONSTRUCTION

- Licensed well driller required
- Waiver required to:
  - Drill monitoring wells
- Water right permit required to:
  - Drill production well in designated basin, or
  - To use water from the well if in non-designated basin
Monitoring Wells

• Generally located upgradient and downgradient from process facilities
• Nested completions to assess vertical gradients
Air Lifting

- Common well development method
- The “Poor Man’s Pumping Test”
- Limited by:
  - Line submergence ($\geq 60\%$ ideal)
  - Pressure
  - Volumetric displacement rate
Slug and Injection Tests

- Small-scale test methods
  - Low permeability/yield
  - Shorter duration

- Large-scale test methods
  - Higher permeability/yield
  - Longer duration

- Large-scale behavior can be underestimated with small-scale tests

- Tests performed from piezometers or monitoring wells
  - Can alter ambient groundwater chemistry and cause future water quality samples to be unrepresentative
Pumping Tests

• Step drawdown
Pumping Tests

• Constant rate discharge
Well Purging and Sampling

- 3 well Volume
- Low-flow
- Minimum Purge
  - HydraSleeve™
  - Passive Diffusion Bag Sampler (PDBS)
  - Polysulfone Membrane Sampler (PSMS)
  - Regenerated Cellulose Sampler (RCS)
  - Rigid Porous Polyethylene Sampler (RPPS)
3-well Volume Purging and Sampling

- Cost limitations
- Water management and disposal
- Time limitations
Low-flow Purging and Sampling

- Water management and disposal
- Cost limitations
- Depth limitations
- Time limitations
**HydraSleeve**

- Discrete depth interval, no-purge groundwater sampler
- Independently tested to provide comparable results
- Simple and repeatable (3-steps)

1. **Deploy**
2. **Retrieve**
3. **Discharge**
HydraSleeve

- Facilitates **simultaneous** collection from discrete intervals
- Most cost effective groundwater sampling method
- Can reduce field labor, sampling and equipment costs by \( \geq 50\% \) and, in some cases, up to \( 80\% \)
WATER QUALITY / AQUEOUS GECHEMISTRY

- Piper plot / trilinear diagram
- Evaporative trends / isotopes
Conceptual Modeling – General Approach

Exploration Drilling and Geological Modeling

Hydrological Characterization

Geochemical Characterization

Geotechnical Characterization

Surface Water Modeling

Conceptual Hydrogeological Modeling

Maurer and Welch, 2001
Conceptual Hydrogeologic Model

- Selected components
Conceptual Hydrogeologic Model

- Selected components
Groundwater Modeling – General Approach

- Conceptual Hydrogeologic Model
- Numerical Model Construction and Calibration
- Incorporate Current Mining Plan
- Predict Inflows and Determine Mine Water Demand
- Develop Dewatering Plan and Water Supply Plan
- Dewatering Simulation and Impact Prediction
- Conduct Sensitivity/Uncertainty Analyses
Groundwater Models as Tools

- Planning, design, permitting, operations, reclamation and closure
- Prediction of pre-mining, operations/closure and post-mining conditions
  - Infilling rates for open pits and underground workings
  - Draindown from HL, TS, and WRS facilities and soil covers
- Optimization
  - Dewatering systems/programs, and
  - Mine water supply systems/programs
- Prediction of pore pressures
  - Slope stability (open pit), and
  - Roof stability (underground)
- Prediction of cumulative impacts to water resources
  - Dewatering, water supply and water disposal programs
  - Infiltration from HL, TS, and WRS facilities
QUESTIONS?

THANK YOU

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