Characterizing, Predicting, and Modeling Water from Mine Sites

May 18-21, 2009
Sacramento, California
Course Outline

- Day 1: Mine site overview, Advanced acid generation, Mine site characterization
- Day 2: Modeling and case studies
- Day 3: Site Tour of Jamestown Mine
- Day 4: Use of prediction information in mine permitting and case studies
Introduction

- Instructors
- Objectives
- Participants
Course Instructors

- Instructors
  - Charlie Alpers, USGS
  - John Hillenbrand, EPA Region 9
  - Rick Humphreys, SWRCB
  - Jim Kuipers, Kuipers & Associates
  - Ann Maest, Stratus Consulting
  - Kirk Nordstrom, USGS
  - Connie Travers, Stratus Consulting

- Field Trip Leaders
  - Roger Ashley, USGS
  - JC Isham, Shaw Environmental
  - Victor Izzo, RWQCB
Objectives of Course

- Increased scientific understanding of one of the biggest challenges at mine sites – predicting long-term geochemical and hydrologic behavior
  - Unlike other industrial facilities, contaminant discharges from mine sites can take years, decades, or longer to develop and are subject to climatic and seasonal variability in concentrations and flow
  - Hydrologic conditions difficult to predict over long-term
  - Costs of poor predictions can be high
- Learn how to design a characterization, modeling, and mitigation program that has the best chance of protecting the environment and minimizing costs of future remediation
What would you like to get out of the course?
Any specific questions?
Hardrock Mines
Mining Operations

- Phases of mining
  - Exploration
  - Development
  - Active Mining
    - Extraction
    - Beneficiation/processing
  - Reclamation, closure, post-closure
Cartoon of Mining Process at Yanacocha Mine, Northern Peru (Newmont)

Ore Deposit

Non-ore (waste)
Transition Material (waste and low grade ore)
Highly Mineralized Material (high grade ore)

Planned Pit Outline

water table (approximate)

Natural Ground Surface

mostly oxidized material
mixed oxide/sulfide material
unoxidized sulfide material

Maest et al., 2005
Exploration

- Exploration
  - Mapping and sampling to define extent of ore body; drilling and access roads
  - Potential impacts: land rights/use; noise; surface disturbance and water quality
Development

- Development: preparing deposit for extraction
  - Roads, power, water, mineral processing facility; remove overlying soil, waste rock/overburden; drill drifts, crosscuts; mitigation
- Potential impacts: erosion, water quality, noise, dust, loss of vegetation, water quantity changes
Extraction

- Extraction: removing ore from the ground
- Drilling, blasting, mucking, hauling
- Potential impacts: noise, nitrate from blasting, dust, start of accelerated leaching of ore, water quality, water quantity changes
Processing/Beneficiation

- Processing/beneficiation: concentrating metals from ore
  - Crushing, grinding, physical/chemical separation of concentrate (flotation, leaching)
  - Final product (smelting, SX/EW, Carbon-in-Leach for Au)
- Potential impacts: cyanide/acid spills, leaching of tailings and spent heap leach, smelter emissions, slag leaching, water quality, water quantity changes
Reclamation

- Reclamation: returning to beneficial use after mining
  - lessening slopes, capping, removing buildings and roads, revegetation
- Potential impacts: temporary construction impacts, introduction of non-native plants, rising groundwater levels after dewatering
Closure/Post-closure

- Closure/post-closure: ongoing period after mining and reclamation are completed
  - Can last for tens of years (CERCLA = 30 yrs) and requires bonding for water treatment (if necessary), maintenance, monitoring, and unexpected environmental impacts
- Potential impacts: ongoing groundwater/surface water quality impacts
Types of Mines and Sources of Contamination at Mine Sites

- Open pits
- Underground workings
- Waste rock
- Tailings
- Smelters and smelter slag
- Cyanide heap leach piles
- Acid leach piles
- Liquid and solid storage facilities
Open Pit/Blasting: Tintaya Copper Mine, Peru

Photo by Ann Maest
Open Pit: Equity Silver Mine, Canada

Photo by Ann Maest
Underground Workings
Bastnäs Mine, Sweden
Underground Workings
Bastnäs Mine, Sweden

From World Wide Web
Waste Rock
Yanacocha Mine, Peru

Photo by Ann Maest
Waste Rock
Yanacocha Mine, Peru

Photo by Ann Maest
Waste Rock – Blackbird Mine, Idaho

Photo by Ann Maest
Tailings
Ball Mill, Tintaya, Peru

Photo by Ann Maest
Tailings: Flotation

Photo by Ann Maest
Tailings: Laguna Huascacocha, Peru

Photo by Ann Maest
Tailings: Toquepala and Quajone Copper Mines, Peru
Tailings: Climax Mine, Colorado

http://www.airphotona.com/image.asp?imageid=1164&catnum=0&keyword=climax
Cyanide Heap Leach Pad, Rayrock, NV USA
Cyanide Heap Leach, Marigold, Nevada USA

Photo by Ann Maest
Pregnant Solution Pond, Marigold Mine, Nevada USA

Photo by Ann Maest
Pregnant Solution Ponds (Cu): Cananea Mine, Mexico

Photo by Ann Maest
Smelter, La Oroya, Peru

Photo by Ann Maest
Slag – East Helena and Anaconda, Montana

Contaminants of Concern

- Metals
- Acid/base
- Radionuclides
- Sulfate, nitrate
- Extraction/beneficiation reagents
Periodic Table of the Elements

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Periodic Table of Elements

STRATUS CONSULTING
Metals and Metalloids

- Cadmium, copper, lead, zinc
  - Copper mines
  - Gold mines
- Iron, manganese
  - Potential baseline issues
- Thallium, beryllium
  - ‘rare’ contaminants that are toxic in low concentrations
- Metalloids/oxyanions
  - Arsenic
  - Selenium
  - Molybdenum...
### Water Quality Standards (μg/l)

<table>
<thead>
<tr>
<th>Standard</th>
<th>Cadmium</th>
<th>Copper</th>
<th>Lead</th>
<th>Zinc</th>
<th>Arsenic</th>
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<td>1,300 (action level)</td>
<td>15 (action level)</td>
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<td>10</td>
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<tr>
<td>Drinking Water: MCLG</td>
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<td>5,000</td>
<td>0</td>
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</tbody>
</table>

Aquatic life criteria @ 100 mg/l hardness
Zinc in Coeur d’Alene River, Idaho

Zinc Concentrations in Mainstem Reaches - Acute

Dissolved Zinc (µg/l)

Exceed Acute ALC
Below Acute ALC
Acid/Base

- Acid (mine/rock) drainage (pH <1 to 6)
  - One of largest water quality problems at hard rock mine sites (groundwater, surface water, aquatic biota, wildlife)
  - Pyrite + air + water = acid + sulfate + iron
  - Leaches more metals
- Basic mine drainage (pH 8.5 to 12+)
  - Tailings, cyanide, weathering of rocks, oxyanions
Acid Drainage: Eagle Mine, Colorado

Photos by Ann Maest
Acid Drainage: Colorado

http://www.mines.edu/fs_home/jhoran/ch126/amd.htm
Radionuclides

- Gamma emissions from adits
- Uranium, thorium, radon
- Humans most sensitive species
Sulfate and Nitrogen Compounds

- Sulfate in groundwater and surface water
  - Sources: pyrite and other sulfides
  - Delayed reaction – can take years for acid drainage and sulfate to impact waters
- Nitrate and ammonia in groundwater and surface water
  - Main source: blasting (TNT or ammonium nitrate)
  - Usually dissipates in 5 to 15 years after blasting stops
Jamestown Mine, California

Groundwater downgradient of tailings and waste rock

Kuijpers et al., 2006
Extraction/Beneficiation Reagents

- Flotation reagents
  - Xanthates, carbamates, thiophosphates, mercaptobenzthiazole, frothing reagent, cyanide
  - Toxic to microorganisms, aquatic biota, but concentrations generally low

- Beneficiation reagents
  - Cyanide
  - Cyanide alternatives
  - Bacteria
Transport of Contaminants from Mining Sources

Grasberg Open Pit, New York Times, 12/27/05
Fate and Transport

- Physical movement of chemical constituents from sources to receptors
- Chemical changes and interactions along that pathway
Pathways: Hydrologic Cycle
Primary Sources at Mine Sites

- Underground workings
- Open pits
- Waste rock
- Tailings
- Leach pads, solution ponds
- Stock piles
- Smelter emissions
Generalized Mine Site Fate and Transport

Sources:
- Tailings
- Waste rock
- Low-grade ore stockpiles
- Heap and dump leach materials
- Wall of pits or underground workings

Pathways:
- Leaching from sources
- Runoff
- Infiltration through soil/vadose zone
- Transport in groundwater
- Discharge to surface water
- Transport in surface water
- Uptake by biota
- Movement of mining process waters

Mitigation Measures:
- Mixing with lime or more benign materials
- Runon/runoff controls
- Liners
- Water Treatment...

Receptors:
- Groundwater
- Surface water
- Seeps
- Pit lakes
- Aquatic and terrestrial wildlife
- Air
- Vegetation
- Humans
Source and Pathway Overview

- Floodplain Tailings
- Tailings Impoundment
- Tailing Pile Seep
- Adit Drainage
- Adit
- Underground Workings
- Waste Rock
- Mill
- Alluvial Aquifer
Pathways: Infiltration and Runoff

Infiltration and Runoff of Metals (and Water) from Contaminated Sediments

FLOODPLAIN

Tailings Piles

Stream

Alluvial Aquifer

Infiltration from Tailings Pile
Pathway: Leaching of Mine Materials

- Moving from solid to liquid
  - Acid and/or metal-rich drainage, metal salts/crusts
- How to test or predict/simulate
  - Before mining begins: leach tests – short term, long term
  - Active mining: sample drainage
Pathway: Transport in Streams

Particulate, Dissolved, Suspended, and Bed Loads in River

Some metals remain dissolved

Some dissolved metals adsorb onto particles

Some particles settle out (bedload)

Some particles remain suspended

High flows cause scouring and resuspension
Receptor: Runoff from Blackbird Mine, Idaho – Panther Creek

Photo by Ann Maest