



Characterizing, Predicting, and Modeling Water from Mine Sites

May 18-21, 2009
Sacramento, California

STRATUS CONSULTING

USGS science for a changing world

Kuipers & Associates, LLC

Training Academy

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

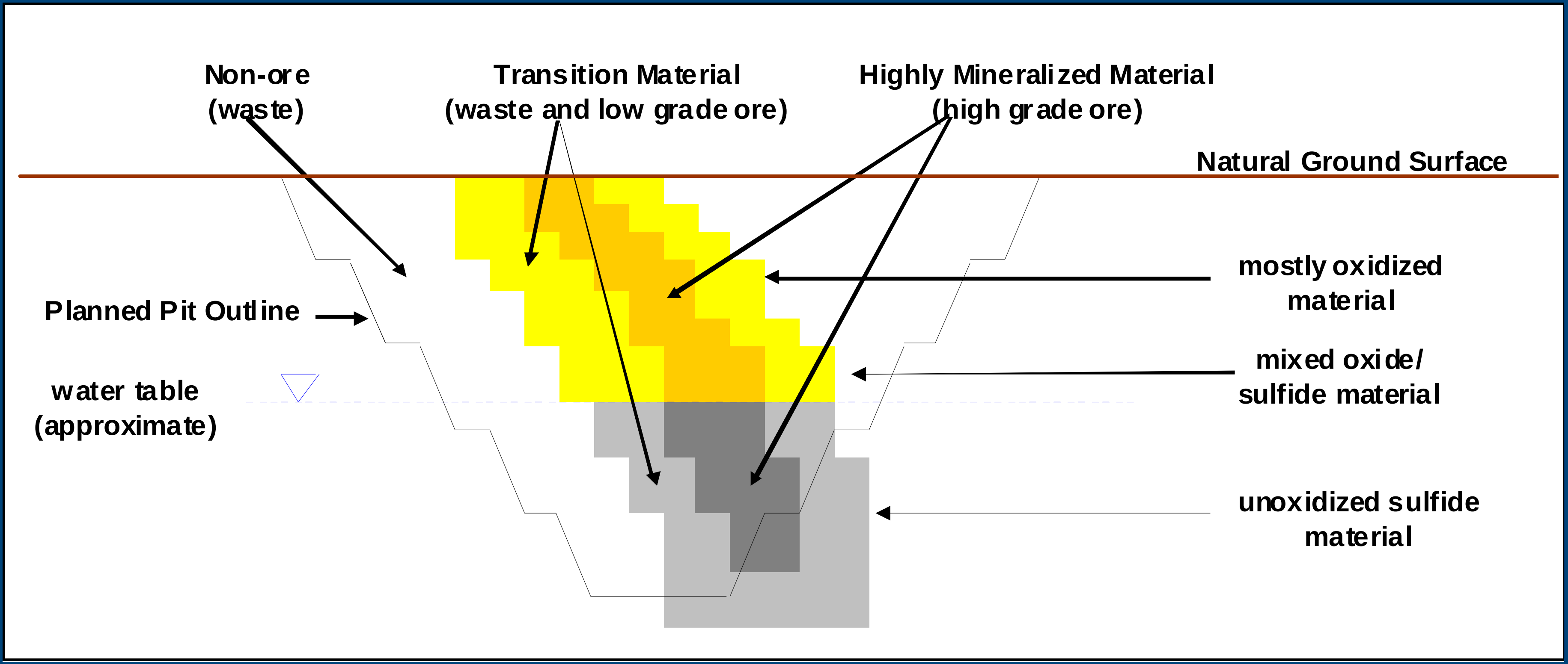
Mining Operations

- Phases of mining
  - Exploration
  - Development
  - Active Mining
    - Extraction
    - Beneficiation/processing
  - Reclamation, closure, post-closure

Cartoon of Mining Process at Yanacocha Mine, Northern Peru (Newmont)

http://www.yanacocha.com.pe/extrac/oro.asp

Ore Deposit



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

From World Wide Web

Underground Workings
Bastnäs Mine, Sweden

From World Wide Web

Waste Rock
Yanacocha Mine, Peru

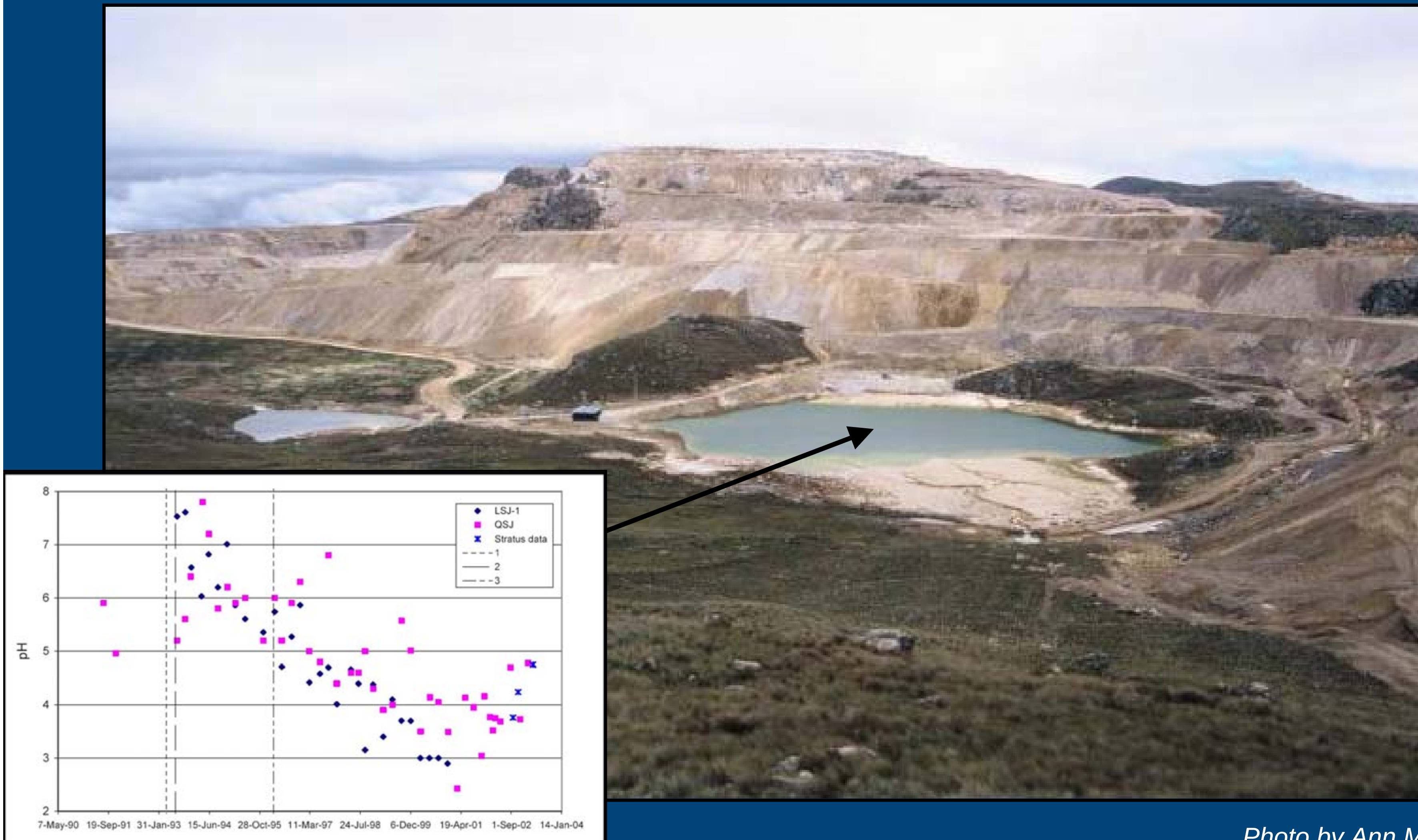


Photo by Ann Maest

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

Photo by Ann Maest

Tailings: Climax Mine, Colorado

http://www.airphotona.com/image.asp?imageid=1164&catnum=0&keyword=climax

Cyanide Heap Leach Pad, Rayrock, NV USA

Photo by Ann Maest

Cyanide Heap Leach, Marigold, Nevada USA

Photo by Ann Maest

Pregnant Solution Pond, Marigold Mine, Nevada USA

Photo by Ann Maest

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Copper Dump Leach
Silver Belle Mine, Arizona USA

From World Wide Web

Pregnant Solution Ponds (Cu): Cananea Mine, Mexico

Photo by Ann Maest

Smelter, La Oroya, Peru

Photo by Ann Maest

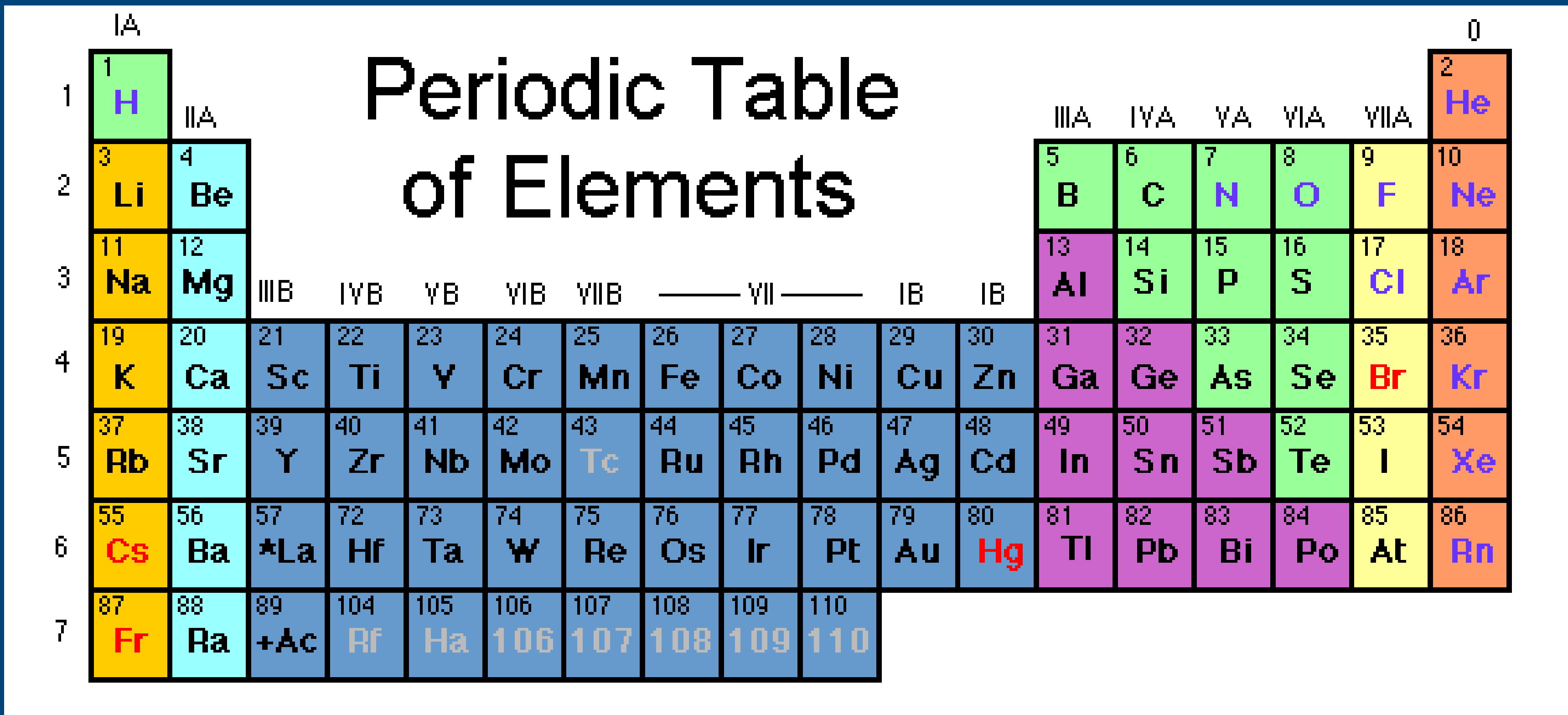
Slag – East Helena and Anaconda, Montana

http://formontana.net/ehelena.jpg; http://farm4.static.flickr.com/3493/3302640872_f057676ffc.jpg

Contaminants of Concern

- Metals
- Acid/base
- Radionuclides
- Sulfate, nitrate
- Extraction/beneficiation reagents

Periodic Table of the Elements



Metals and Metalloids

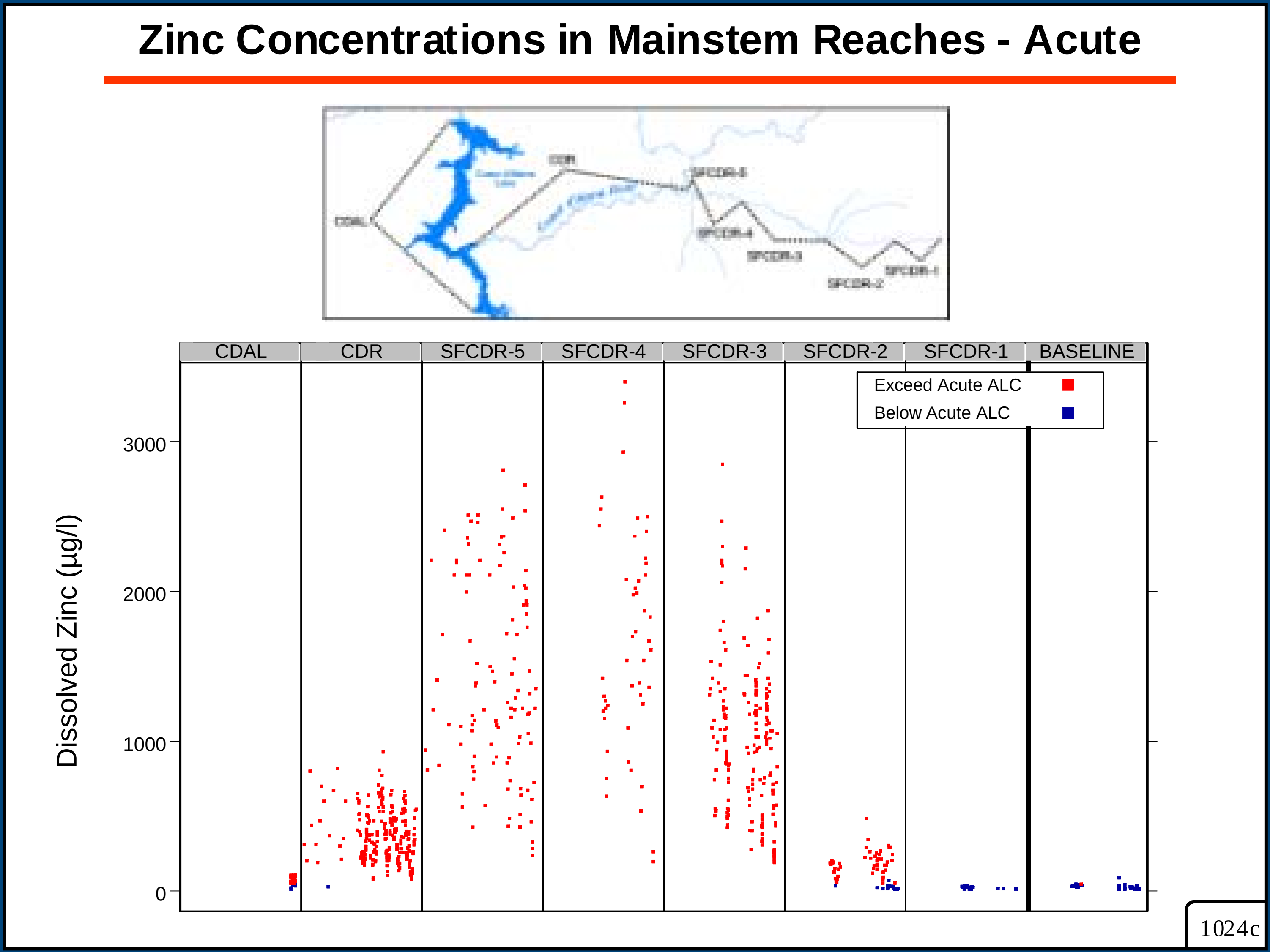
- Cadmium, copper, lead, zinc
  - Copper mines
  - Gold mines
- Iron, manganese
  - Potential baseline issues
- Thallium, beryllium
  - ‘rare’ contaminants that are toxic in low concentrations
- Metalloids/oxyanions
  - Arsenic
  - Selenium
  - Molybdenum…

Water Quality Standards (μg/l)

Standard	Cadmium	Copper	Lead	Zinc	Arsenic
Aquatic Life: Chronic (CCC)	0.25	9.0	2.5	118	150
Aquatic Life: Acute (CMC)	2.01	13.4	65	117	340
Drinking Water: MCL/SMCL	5	1,300 (action level)	15 (action level)	5,000	10
Drinking Water: MCLG	5	1,300	0	5,000	0

Aquatic life criteria @ 100 mg/l hardness

Zinc in Coeur d'Alene River, Idaho



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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

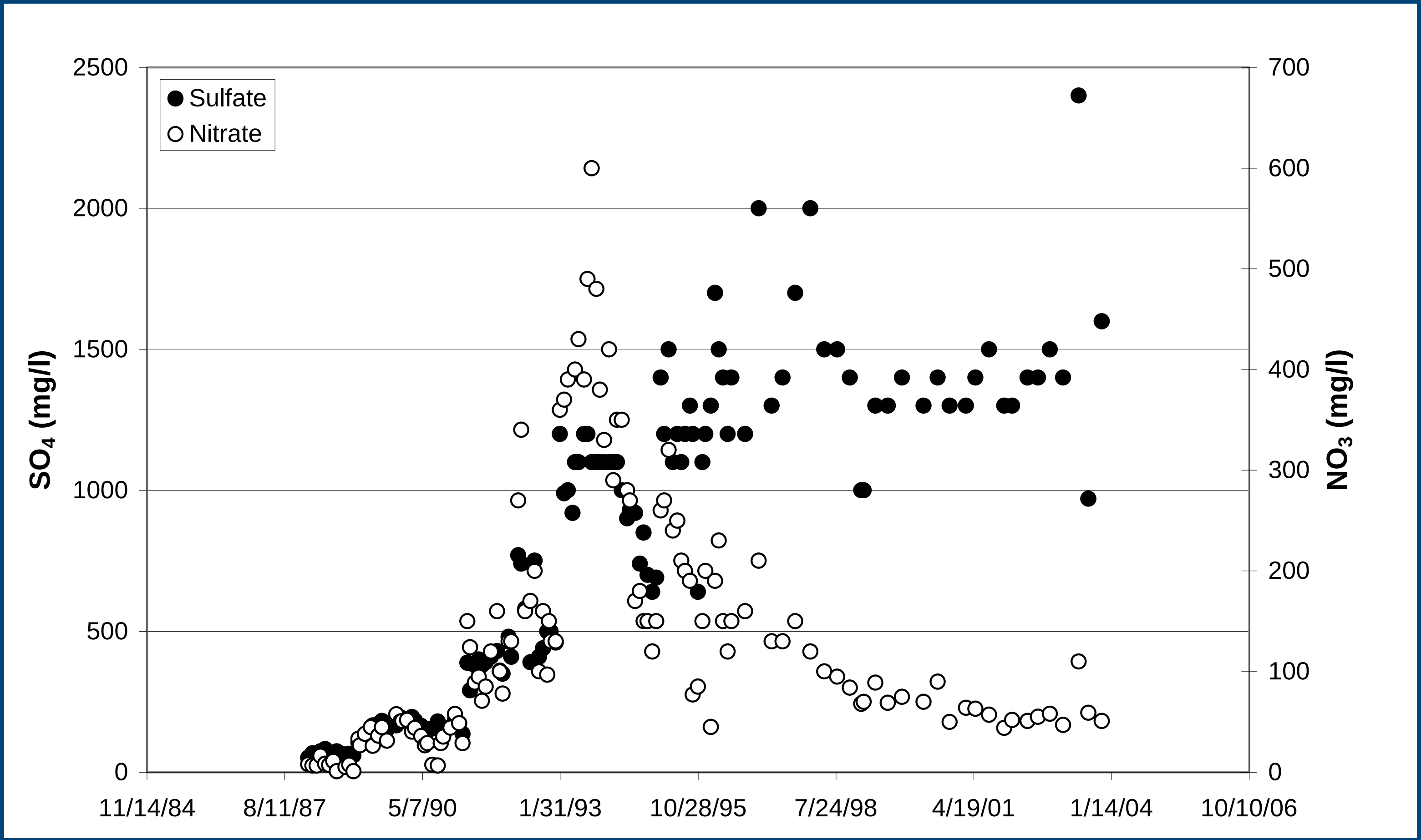
Radionuclides

- 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

Kuipers et al., 2006

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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

Montana Tunnels, MT (Pb, Zn) Flotation

Photo by Ann Maest

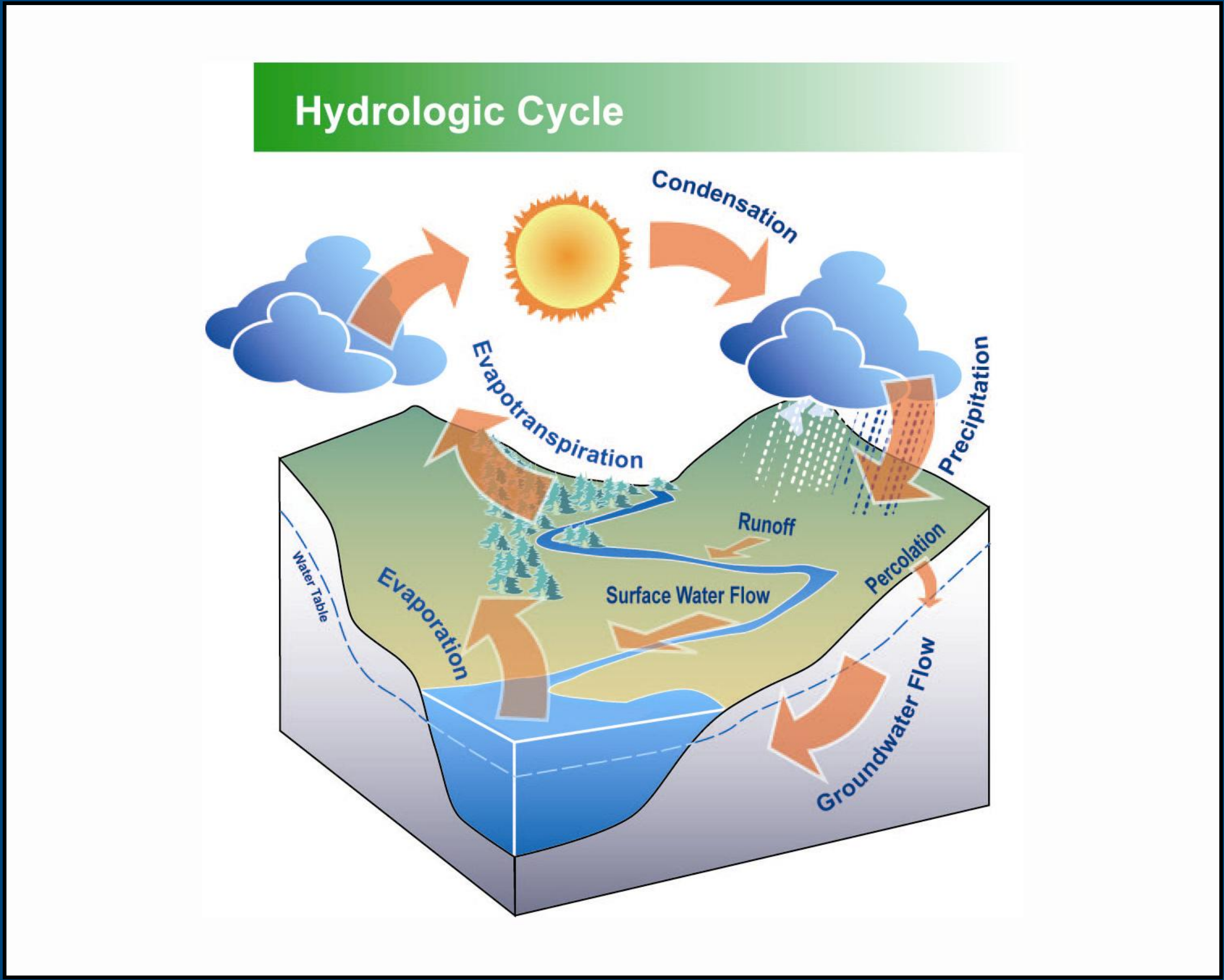
Transport of Contaminants from Mining Sources

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

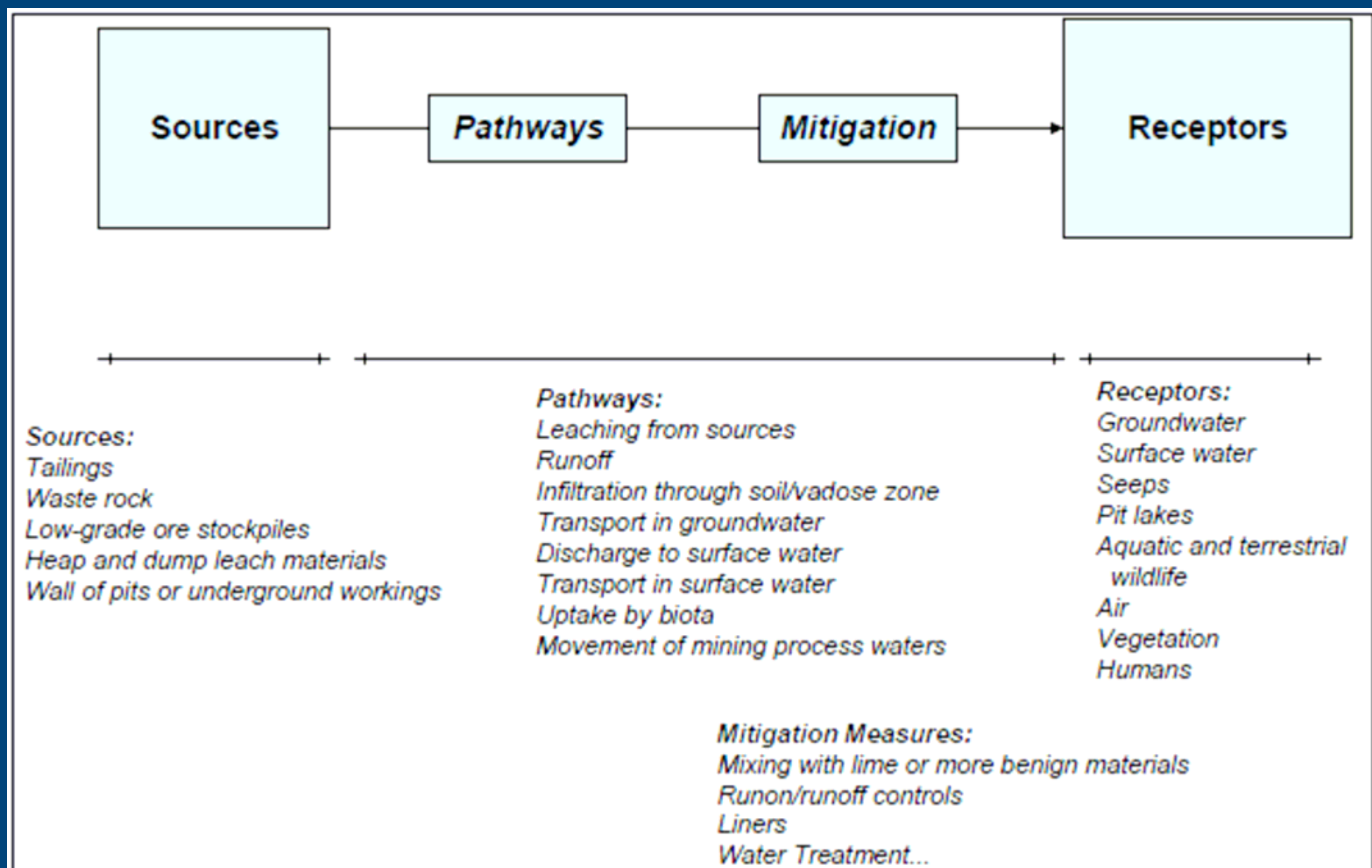
Pathways: Hydrologic Cycle



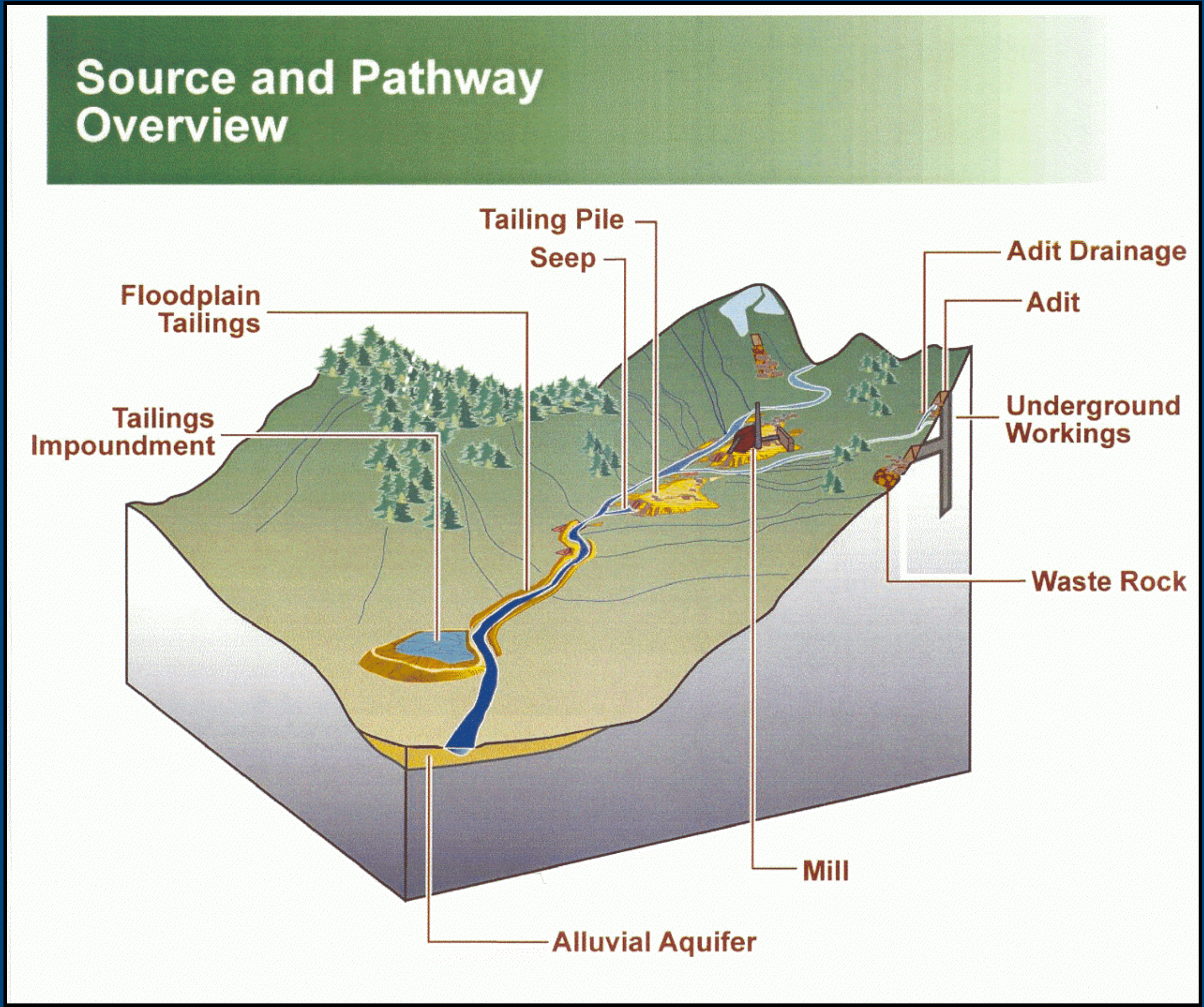
Primary Sources at Mine Sites

- Underground workings
- Open pits
- Waste rock
- Tailings
- Leach pads, solution ponds
- Stock piles
- Smelter emissions

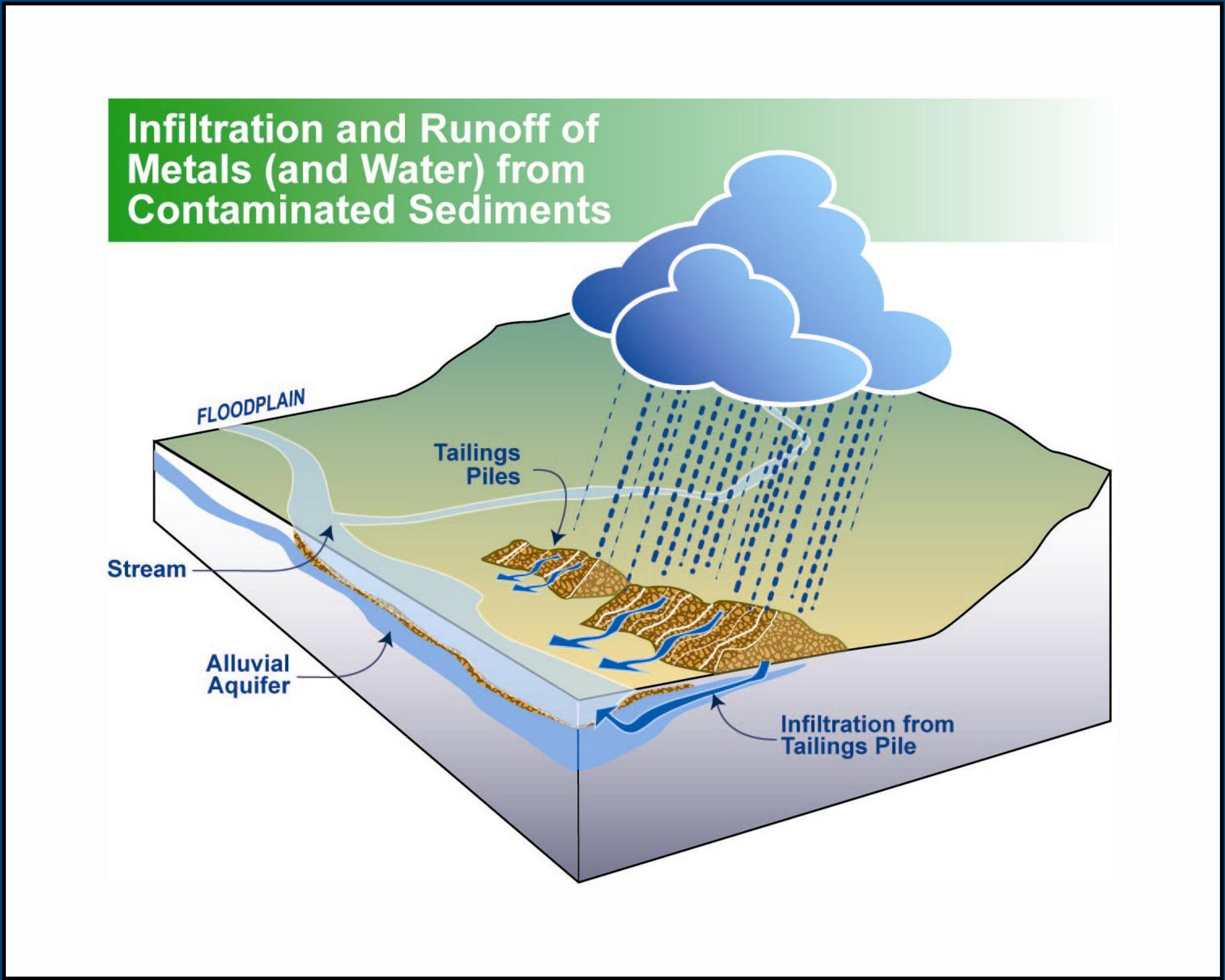
Generalized Mine Site Fate and Transport



Source and Pathway Overview



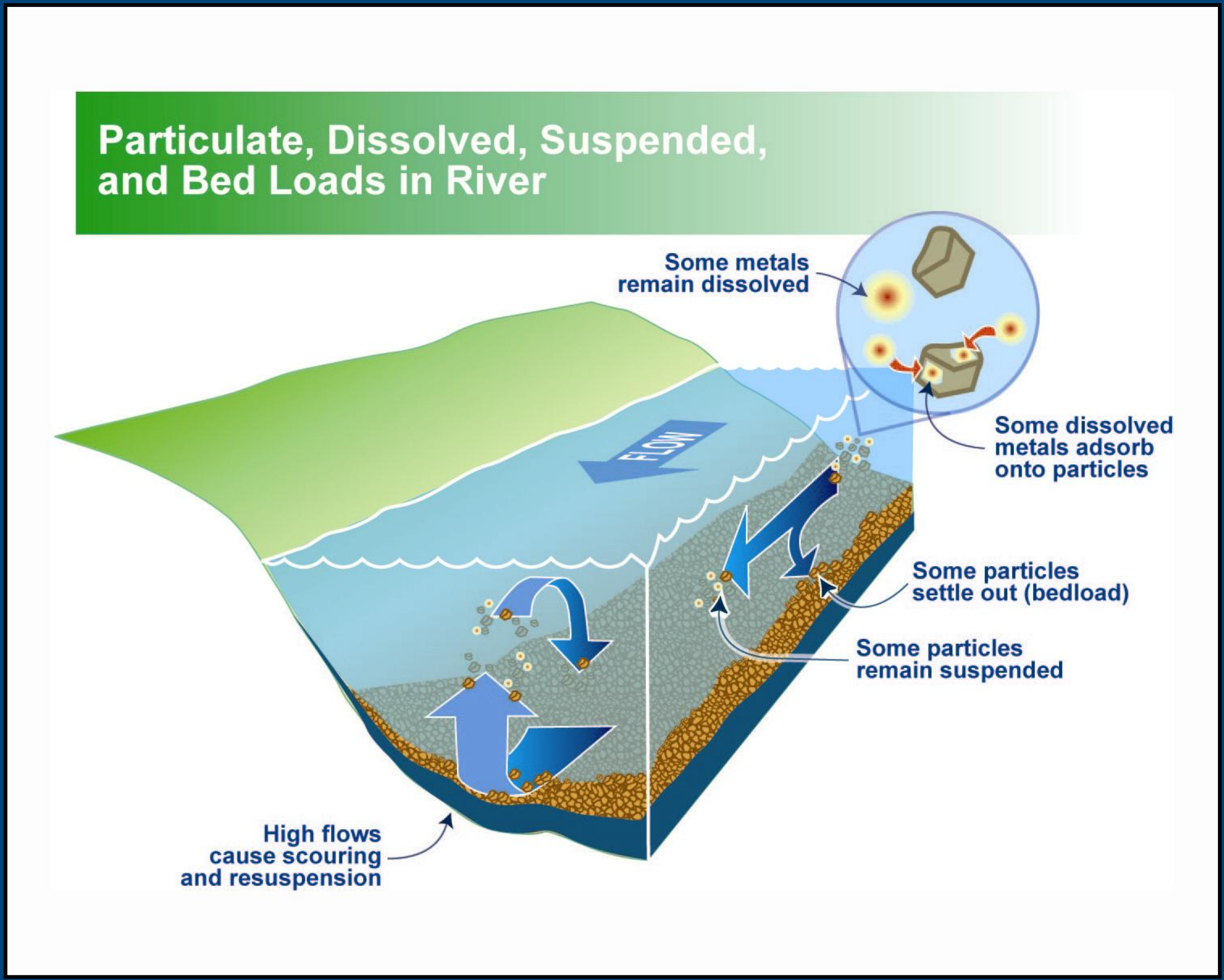
Pathways: Infiltration and Runoff



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



Receptor: Runoff from Blackbird Mine, Idaho – Panther Creek

Photo by Ann Maest