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Comparison of Predicted and Actual Water Quality at Hardrock Mines

The reliability of predictions in
Environmental Impact Statements

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Project Background

- Project funded by Earthworks/MPC with grant from Wilburforce Foundation
- 2 year effort
- One additional report:

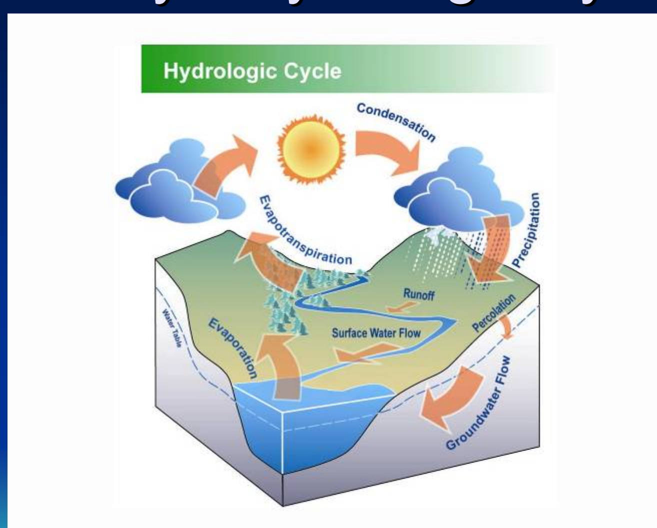
  Predicting Water Quality at Hardrock Mines: *Methods and Models, Uncertainties, and State-of-the-Art*
- Reports available at:

  www.kuipersassoc.com

Fate and Transport

- Physical movement of chemical constituents from sources to receptors
- Chemical changes and interactions along that pathway

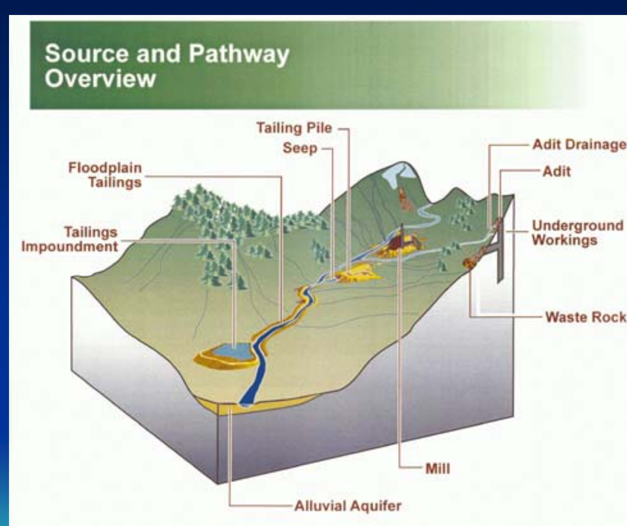
Pathways: Hydrologic Cycle



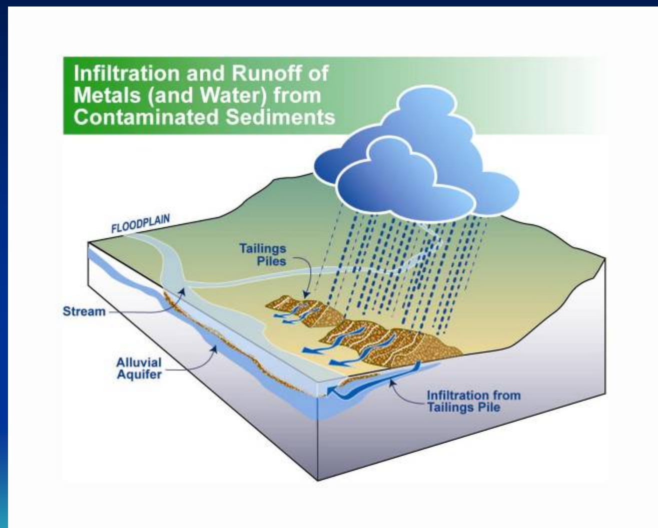
Primary Sources at Mine Sites

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

Source and Pathway Overview



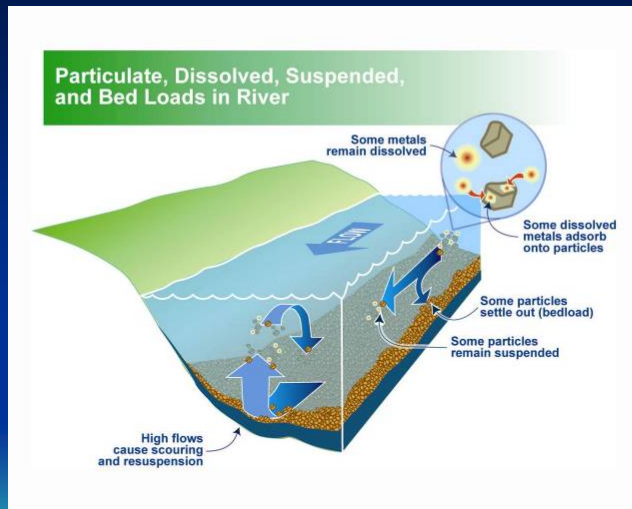
Pathways: Infiltration and Runoff



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

Pathways: Transport in Streams



Project Tasks

- Define and identify "major" hardrock mines in the U.S.
- Identify NEPA eligibility of major hardrock mines
- Identify and gather NEPA documentation for major mines
- Identify and compile water quality predictions information from NEPA documents
- Identify other water quality predictions information
- Conduct case studies analysis of NEPA process, predictions results, and actual water quality history
- Analyze NEPA predictions and water quality information on a comparative basis and in subgroups

Project Database

- Location
- Ownership
- Commodity
- Operation Type
- Operation Status
- Disturbance and Financial Assurance
- NEPA Documentation
- Record of NEPA document requests and retention
- NPDES Information

Data provided in Excel database form and statistically evaluated in appendices to report

Major Mines Identification

- Major Mines Criteria
  - disturbance area of over 100 acres, and
  - financial assurance amount of over $250,000, or
  - having a production history (1975 to current) of greater than 100,000 oz's Au, 100,000,000 #'s copper, or equivalent in other metal
  - In operation 1975 to present
- Sources
  - Kuipers, Randol, USGS, Infomine
- 182 major mines identified in U.S.
- 132 of those mines NEPA eligible

Methods

- Identified 182 major hardrock mines and 136 major mines eligible for National Environmental Policy Act (NEPA)
- Gathered information on:
  - geology/mineralization
  - climate
  - hydrology
  - field and lab tests performed
  - constituents of concern identified
  - predictive models used
  - water quality impact potential (pre-mitigations)
  - mitigations
  - predicted water quality impacts (after mitigations)
  - discharge information
- Information was scored numerically and entered into an Excel database

Methods

- Selected case study mines based on:
  - availability of water quality information after mining began
  - characteristics (commodities, mining types, and climates) similar to larger set of mines
  - mines with long histories and NEPA documentation from new project through reclamation and closure
  - mines with different proximities to water resources
  - mines that conducted some geochemical testing, and if possible, some water quality modeling
  - and mines with different potentials to generate acid and leach contaminants to water resources

Methods

- Obtained data/information on operational water quality for case study mines from NEPA documents, State agencies, and/or consultant or agency reports
- Compared potential (pre-mitigation) and predicted (after considering effects of mitigations) water quality from the EISs with actual water quality at the case study mines.
- Evaluated effects of geochemical and hydrologic characteristics on operational water quality.

Selected Case Study Mines

Case Study Mine	State	Case Study Mine	State
Greens Creek	AK	Golden Sunlight	MT
Pogo	AK	Mineral Hill	MT
Bagdad	AZ	Stillwater	MT
Ray	AZ	Zortman and Landusky	MT
Safford	AZ	Florida Canyon	NV
Jamestown	CA	Jerritt Canyon	NV
McLaughlin	CA	Lone Tree	NV
Royal Mountain King	CA	Rochester	NV
Grouse Creek	ID	Round Mountain	NV
Thompson Creek	ID	Ruby Hill	NV
Beal Mountain	MT	Twin Creeks	NV
Black Pine	MT	Flambeau	WI

Inherent Factors Affecting Water Quality

- Some characteristics that may influence environmental behavior of a mine include:
  - Ore type and association
  - Climate
  - Proximity to water resources
  - Pre-existing water quality
  - Processing chemicals used
  - Type of operation
  - Constituents of concern
  - Acid generation and neutralization potentials
  - Contaminant leaching potential

Inherent Factors - Summary Table

Site		State	Acid Drainage Developed on Site?	SW Impact?	Standards Exceeded in SW?	GW Impacts?	Standards Exceeded in GW?
Greens Creek	§ Ψ	AK	Yes	Yes	Yes	Yes	No
Bagdad		AZ	Yes	Yes	Yes	NA	NA
Ray		AZ	Yes	Yes	Yes	NA	NA
Jamestown		CA	No	NA	NA	Yes	Yes
McLaughlin	§ Ψ	CA	Yes	Yes	Yes	Yes	Yes
Royal Mountain King		CA	No	Yes	Yes	Yes	Yes
Grouse Creek	§ Ψ	ID	No	Yes	Yes	Yes	Yes
Thompson Creek	§ Ψ	ID	Yes	Yes	Yes	NA	NA
Beal Mountain	§ Ψ	MT	No	Yes	Yes	Yes	Yes
Black Pine	§ Ψ	MT	Yes	Yes	Yes	NA	NA
Golden Sunlight	Ψ	MT	Yes	No	No	Yes	Yes
Mineral Hill	§	MT	No	Yes	Yes	Yes	Yes
Stillwater	§ Ψ	MT	No	Yes	No	No	No
Zortman Landusky	§ Ψ	MT	Yes	Yes	Yes	Yes	Yes
Florida Canyon	Ψ	NV	No	No	No	Yes	Yes
Jerritt Canyon	Ψ	NV	No	Yes	Yes	Yes	Yes
Lone Tree	§ Ψ	NV	No	Yes	Yes	No? (baseline?)	Yes (baseline?)
Rochester	Ψ	NV	No	Yes	Yes	Yes	Yes
Round Mountain		NV	No	NA	NA	No? (baseline?)	Yes (baseline?)
Ruby Hill		NV	No	NA	NA	No (baseline)	Yes (baseline)
Twin Creeks	§ Ψ	NV	No	Yes	Yes	Yes	Yes (perched GW)
Flambeau	§ Ψ	WI	Yes	No	No	Yes	Yes

Ψ = mines with springs on site, or discharges to groundwater, and with moderate to high acid drainage or contaminant leaching potential

§ = mines with close proximity to surface water and high acid drainage or contaminant leaching potential

Inherent Factors
Surface Water Impacts

- **Surface Water:**
  - For the 13 mines with close proximity to surface water and high acid drainage or contaminant leaching potential (mines with § in Summary Table)
    - 12 (92%) have had some impact to surface water.
    - 11 (85%) have had exceedences of standards or permit limits in surface water as a result of mining activity.
      - Of the 11 with exceedences, ten (91%) predicted that surface water standards would not be exceeded.
    - 77% underpredicted actual impacts to surface water.

Inherent Factors
Groundwater Impacts

- Groundwater:
  - There are 15 mines with close proximity to groundwater, springs on site, or discharges to groundwater – and with moderate to high acid drainage or contaminant leaching potential (mines with ψ in Summary Table).
    - 14 (93%) have had mining-related impacts to groundwater, seeps, springs, or adit water.
    - 11 (73%) have had adverse mining-related impacts to groundwater
    - Of the remaining four mines
      - three have mining-related impacts to spring, seeps or adit water
      - only one has exceedences in groundwater that may be related to baseline conditions.

Inherent Factors Conclusions

- Mines with close proximity to surface water or groundwater resources and with a moderate to high acid drainage or contaminant leaching potential have an increased risk of impacting water quality.
- These combined factors at a mine appear to be a good indicator of future adverse water quality impacts.
- Mines in this category must rely on well executed mitigation measures to ensure the integrity of water resources during and after mining and are also the most likely to require perpetual treatment to guarantee acceptable water quality.

Failure Modes and Effects Analysis

Table 8.2 Failure Analysis Spreadsheet – NEPA/EIS Case Studies
Water Quality at Hardrock Mine Sites

Failure Mode		Effects	Consequences	Examples
Hydrological Characterization	Dilution overestimated	Surface water impacted in smaller upper watershed streams	M	Greens Creek, Jerritt Canyon
	Presence of water from springs or lateral flow not recognized	Ground and surface water impacts from contact with contaminant source	H	Black Pine, Mineral Hill, Royal Mountain King
	Amount of water underestimated	Load of contamination exceeds surface water discharge standards	M	Mineral Hill
			H	Ray, Zortman and Landusky
Geochemical Characterization	Sample representation, testing methods or interpretations inadequate	potential for acid drainage and other contaminants not recognized leading to failure to identify need for or type of mitigation	M	Greens Creek, Jamestown, McLaughlin, Royal Mountain King, Thompson Creek, Jerritt Canyon
			H	Grouse Creek, Beal Mountain, Black Pine
			S	Golden Sunlight, Zortman and Landusky
Mitigation	Mitigation Not identified identified, inadequate or not installed	inadequate mitigation identified to prevent impacts to water resources	M	Greens Creek, Jamestown, Thompson Creek, Jerritt Canyon
			H	Bagdad, Grouse Creek, Beal Mountain, Black Pine, Zortman and Landusky
	Waste rock mixing and segregation not effective	leachate contains acid drainage and other contaminants	M	Greens Creek, McLaughlin, Jerritt Canyon
	Liner leak, embankment failure or tailings spill	greater than design (e.g. exceedances) impacts to water resources	L	Stillwater, Florida Canyon, Lone Tree, Rochester, Twin Creeks
			M	Jamestown, Royal Mountain King, Jerritt Canyon, Mineral Hill
			H	Bagdad
			S	Golden Sunlight

Failure Modes and Effects Analysis

Hydrological Characterization Failures:

- 7 of 22 mines exhibited inadequacies in hydrologic characterization
  - At 2 mines dilution was overestimated
  - At 2 mines the presence of surface water from springs or lateral flow of near surface groundwater was not detected
  - At 3 mines the amount of water generated was underestimated

Failure Modes and Effects Analysis

Geochemical Characterization Failures:

- 11 of 22 mines exhibited inadequacies in geochemical characterization
  - Geochemical failures resulted from:
    - Assumptions made about geochemical nature of ore deposits and surrounding areas
    - Site analogs inappropriately applied to new proposal
    - Inadequate sampling
    - Failure to conduct and have results for long-term contaminant leaching and acid drainage testing procedures before mining begins.
    - Failure to conduct the proper tests, or to improperly interpret test results, or to apply the proper models

Failure Modes and Effects Analysis

Mitigation Failures:

- 18 of 22 mines exhibited failures in mitigation measures
  - At 9 of the mines mitigation was not identified, inadequate or not installed
  - At 3 of the mines waste rock mixing and segregation was not effective
  - At 11 of the mines liner leaks, embankment failures or tailings spills resulted in impacts to water resources

Failure Modes Root Causes Hydrologic Characterization

- Failures most often caused by:
  - Over-estimation of dilution effects
  - Failure to recognize hydrological features
  - Underestimation of water production quantities
- Prediction of storm events or deficiencies in stormwater design criteria is the most typical root cause of hydrologic characterization failures

Failure Modes Root Causes Geochemical Characterization

- Root causes of Geochemical Prediction Failures include:
  - Sample representation
  - Testing methods
  - Modeling/Interpretation
- Geochemical Characterization Failures can be addressed by:
  - Ensuring sample representation
  - Adequate testing
  - Interpretation

Failure Modes Root Causes Mitigation

- Hydrologic and geochemical characterization failures are the most common root cause of mitigation not being identified, inadequate or not installed
  - Most common assumption is that “oxide” will not result in acid generation
  - Mitigations are often based on what is common rather than on site specific characterization

Failure Modes Root Causes Mitigation

- Waste rock mixing and segregation not effective
  - In most cases, no real data is available (e.g. tons of NAG versus tons of PAG and overall ABA accounting)
  - Failures typically caused by:
    - Inadequate neutral material
    - Inability to effectively isolate acid generating material from nearby water resources

Failure Modes Root Causes Mitigation

- Liner leak, embankment failure or tailings spill
  - Mitigation frequently fails to perform and can lead to groundwater and surface water quality impacts
  - Failures are typically caused by:
    - Design mistakes
    - Construction mistakes
    - Operational mistakes

Failure Modes Root Causes Recommendations

- A more systematic and complete effort should be undertaken when collecting data
- Recognize the importance of thorough hydrological and geochemical characterization
- Utilize information in a conservative manner to identify and utilize mitigation measures
- Consider the likelihood and consequences of mitigation failures