Integrated Closure Planning for Waste Rock and Tailings in an Arid Climate

Björn Weeks, PhD, P.Eng, Golder Associates
Gabriel Lopez Vasquez, Glencore Argentina
Arnaldo Santander, Golder Associates

December 4, 2014
Overview - Site Characteristics

- Located in Northwestern Argentina
- Open pit copper-gold mine 2,600 masl
- Production:
  - Copper: 180,000 ton/year
  - Gold: 600,000 troy ounces/year
- Nearing the end of its productive life
Climate Setting

- Arid/Perarid Climate
- Annual Precipitation of 160 mm/year, ranging from 80 to 350 mm
- Precipitation concentrated in period December – March
- Typically short, high-intensity rain events
- Pan evaporations in the order of 1,400 mm/year

- Estimated precipitations for 24 hour events:
  - 50 year: 52 mm
  - 200 year: 63 mm
  - 1000 year: 75 mm
Watershed total = 11,500 ha

Waste Rock – 620 ha at closure

Tailings – 940 ha at closure
Closure Planning Elements for the Site

- Avoid impacts downstream in Vis Vis (Chemical Stability)
  - Geochemical Characterization
    - Waste rock, tailings
    - Alternative cover materials
  - Understand transport systems
    - Water balances
    - Groundwater (calibrated models)
    - Surface water flow
- Evaluate downstream water quality under different closure scenarios
  - Alternative surface water diversion schemes
  - Cover studies
    - Alternative cover configurations
    - Field tests for tailings and waste rock
Other Closure Planning Studies

- Physical Stability
  - Dam and Dump Stability
  - Landform erosion
    - Alluvial fan upstream of TSF
    - Waste Rock Facilities – long term slopes
  - Tailings consolidation

- Aesthetics
  - Pilot scale revegetation studies (direct revegetation on waste rock)
  - Seed bank development for successful species
Geochemical Characterization
Geochemical Characterization

- **Waste Rock**
  - Some waste rock is potentially acid generating.
  - Visual evidence of oxidation (steam venting, limited areas)
  - Other waste rock types identified as potential cover material

- **Tailings**
  - Potentially acid generating (in long term)
  - Contact water currently not acid

- **Alluvial materials upstream of TSF**
  - Inert (potential cover material)
Elements of Characterization Program

- Lab testing and field evaluation
- Long-term column tests
- Long-term irrigated field lysimeters
- Drilling program (2013) for the collection of in-situ tailings samples
- Installation of thermistor strings for the measurement of temperature profiles in the waste rock dumps
  - Long-term monitoring
  - Newer strings for additional coverage, replacement of failed thermistors
- Preliminary (prior to 2009) and detailed (post 2012) characterization of upstream alluvial material (cover source characterization)
Pileta 1

Colas

Total Sulphur = 2.55 %
Sulphate Sulphur (SO₄) = 2.01 %
Sulphide Sulphur = 0.52 %
ANC (kg H₂SO₄/t) = 10.8
NAG (kg H₂SO₄/t) = 25.4
Understanding Flow Systems
Elevation Cross Section - Tailings

- Alluvial Fan Upstream of TSP
- Tailings – 940 ha at closure
- Vis Vis
Pit – Waste Rock – Tailings Profile
Site-Wide Water Balance (GoldSim)
Groundwater flow model

- Existing model re-structured
- Incorporating detailed topography
- Recharge flow input to groundwater model defined in GoldSim
- Groundwater model calibrated considering:
  - Well data from 66 points
  - Data back to 1997
  - Surface seeps
Calibration Results RMS < 5%
Closure Scenarios
Evaluating Closure Scenarios

- Evaluation Approach:
  - GoldSim used to simulate the water balance
  - Modflow used to simulate the groundwater flow
  - PHREEQC used to evaluate the impact of the measures on downstream water quality

- Scenarios modelled:
  - Historic (calibration of models)
  - No Closure
  - Closure configuration in EIA
  - Alternative Closure scenarios
Example Closure Scenarios

EIA
Case presented in original EIA
- Evaporation pond on TSF
- Spillway
- Surface channels to bring upstream flow to pond.
Example Closure Scenarios

Structures to retain and evaporate water upstream of TSF
Example Closure Scenarios

Diversion of surface water to pit for evaporation.
Example Closure Scenarios

Water diversion channels east and west of pond
Use of Models

- Models were all preliminary and investigative in nature
- The models are effectively “stacked” with water balance information used in the geochemical model (*not coupled*)
- Simulations in GoldSim used to provide inputs for a variety of conditions (wet and dry years over a 100 year cycle)
- Used to test the relative importance of elements in the system
- Examples:
  - How could alternative diversion schemes affect water quality from a mass balance point of view?
  - How much does infiltration through covers impact water quality downstream? (setting design goals – what is good performance? What do the covers need to achieve?)
Preliminary Results - Tailings

- Complete perimeter diversions provided best water quality downstream under most conditions

- Results were far more sensitive to variations in the quality of the tailings contact water than to the different flow diversion scenarios

- Future development of acidic conditions in all (or part) of the tailings would define downstream water quality
  - Motivation for more detailed tailings characterization
  - Upstream/downstream water characterization
  - Sampling of porewater in tailings
Preliminary Results – Waste Rock

- Waste Rock Contact water more important in low flow conditions

- Improving the quality of the tailings cover proportionally increases the importance of contact water from the waste rock dumps

For both Tailings and Waste Rock:

- Accurate infiltration predictions key to evaluate impacts
- Highlights the importance of field tested infiltration measurement
Cover Design – Infiltration Measurement
Cover Concept

GARD Guide, Ch. 6
Cover Design

■ Ongoing evaluation of covers at site since 2003

■ Limitations in locally available material for cover construction

■ General approach defined:
  ■ Encapsulation waste rock by “inert” waste rock
  ■ Use of alluvial material from upstream of TSF to construct tailings cover.
  ■ Revegetation where possible

■ Instrumented field tests to evaluate alternative cover configurations
Field Box – Alluvial material over tailings

- 0.5 m alluvial over tailings
- Non-acidified tailings
- Equivalent profile to field tests run since 2003
Salt Precipitation (flux from tailings)
Construction of Lysimeters
Construction (2013)
Eg Suction Profiles (1 m Aluvial over Tails)
Cover Profiles – Waste Rock

Diagram showing soil profiles with various layers and measurements.
Waste Rock Lysimeters
Monitoring of previous cover configurations show good performance in normal and dry years.

Despite generally dry conditions, periodic, high-intensity rainfalls are challenging for store-and-release covers built without a barrier layer.

In particularly wet years, the storage capacity can be overwhelmed, resulting in plug flow through cover.

Revert to water balance/geochemical modeling to see if these infrequent events are acceptable or not.
Summary

- Site owners have been involved with on-going closure studies since 2003:
  - Geochemical characterizations
  - Groundwater monitoring and modeling
  - Cover design for waste rock and tailings deposits
  - Erosion measurement and modeling
  - Revegetation studies, and seed bank development
  - Pit lake modelling and predictive studies
Summary

- Integration of water balance, hydrogeological, and geochemical models has provided a tool to evaluate alternative closure scenarios.

- Closure studies are well advanced, and many of the studies needed to define or justify closure measures have been completed.

- Site owners are in the process of completing the studies needed to finalize various aspects of the closure design.
Gracias
Erosion
Storm Events – Immense Erosive Power
Erosion of Upstream Alluvial Fan

- Alluvial Fan upstream of TSF has significant erosion potential
- Preliminary evaluation of erosion using RUSLE show that sediment from fan must be taken into account for long-term planning
- Alternatives:
  - Periodic maintenance of affected surface water diversions
  - Incorporate sediment accumulation over TSF into design.
Erosion Studies

- Studies conducted to define erosion properties for exposed waste rock (candidate cover materials)
- Eg- “Epidota Clorita” waste rock before synthetic precipitation (30%, 20% and 10% slopes (Flumes 2m long, 0.4 m wide)
After Runoff Event
Erosion Study Results

- Studies included
  - Field observations
  - Flume studies
  - Rainfall simulators
  - Numerical Models
- Results of early studies permitted ruling out need for more sophisticated erosion modeling (e.g., SIBERIA)
- Provided sufficient background information to demonstrate erosion resistance of cover rock to authorities
Revegetation
Waste Rock – Edge of Revegetation
Fully developed revegetation of waste rock