Satellite Monitoring of a Large Tailings Storage Facility

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Presentation Topics

- Introduction and Project Background
- Photographic and Topographic Satellite Monitoring
- Use of Satellite Data for the Minera Peñasquito Project
Introduction

- Visual observation and as-built survey are an important aspect of tailings stewardship programs and tailings storage facility operation, maintenance and surveillance plans.

- With very large facilities, these programs can be challenging to execute:
  - Long site distances, shallow relief
  - Safe access concerns

- Unmanned aerial systems are an option, however:
  - Operator/pilot and spotter must be present
  - Multiple flights to cover large areas
  - Costly to complete regularly
  - May be restricted by government regulation
Introduction

Satellite monitoring is largely unencumbered by these limitations

- Completely remote monitoring
- High temporal resolution
- Potential for high visual resolution
- Can be used to develop topographic survey

Golder has been using satellite-based monitoring for Minera Peñasquito since 2013:

- Weekly moderate-resolution satellite imagery
  - Overview of entire mine site operations
  - Visual performance monitoring of the tailings facility development
  - Monitoring of the tailings beach and water reclaim pond management

- Monthly high-resolution satellite imagery and topographic mapping
  - Monitoring of deposited tailings volumes
  - Quality assurance as-built survey production and construction volumes analysis
  - Storage capacity monitoring and assessment

Graphic Courtesy of USGS/NASA Landsat
Project Background

- Mine operations:
  - Gold, silver, lead, and zinc produced from a mixed sulfide and oxide ore body
  - Oxide ore leached, sulfide ore processed by grinding and flotation
  - 130,000 tpd sulfide circuit capacity

- Tailings Storage Facility
  - 11-km long hybrid rockfill and cycloned sand tailings dam
  - 750 ha
  - Centerline-raise construction
  - Tailings transport water recovered for process reuse

July 16, 2015 View of Mine Site – PhotoSat/DigitalGlobe
Since 1972, the USGS and NASA have launched and successfully orbited seven earth-observing satellites under the Landsat Program.

Landsat 8 was launched on February 11, 2013 and became fully operational on April 11, 2013.

Mission objectives are to provide data for long-term monitoring of earth features.

Landsat 8 orbits the earth once every 99 minutes, collecting 185-km wide imagery, and provides a revisit time of 16 days.

Landsat 7 follows and offset orbit providing a combined global revisit time of 8 days.

Data available at no charge and without user restrictions, typically within 24 h of acquisition.
### Landsat 8

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<thead>
<tr>
<th>Band</th>
<th>Wavelength µm</th>
<th>Resolution m</th>
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<tbody>
<tr>
<td>Coastal/aerosol</td>
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<td>30</td>
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<tr>
<td>Blue</td>
<td>0.45-0.51</td>
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</tr>
<tr>
<td>Green</td>
<td>0.53-0.59</td>
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<tr>
<td>Red</td>
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<td>Near IR</td>
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<tr>
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<td>SWIR 2</td>
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<tr>
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<td>Cirrus</td>
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<tr>
<td>TIRS 1</td>
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</tr>
<tr>
<td>TIRS 2</td>
<td>11.50-12.51</td>
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</tr>
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</table>

October 22, 2015 View of Mine - USGS/NASA Landsat
Long-Term Performance Monitoring at Minera Peñasquito

- Data from Landsat 7 has been used to develop a complete imagery history of the TSF dating back to pre-construction starting in 2008.
- Landsat 8 is used for new imagery – allowing for new images every 7 or 9 days due to Minera Peñasquito’s position in the overlap area between two adjacent flight paths.
Enhanced Visualization of Water in the TSF

- Historically, the flat tailings beaches (0.5%) at Minera Peñasquito have resulted in large areas of shallow water that are relatively transparent in the natural color imagery.

- As water is a poor reflector of infrared light, it can be used to better delineate water-covered and wet areas in the TSF. 

October 15, 2015 - USGS/NASA Landsat

July 16, 2015 - PhotoSat/DigitalGlobe
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October 15, 2015 – Golder and USGS/NASA Landsat

July 16, 2015 – Golder and PhotoSat/DigitalGlobe
Satellite Topographic Mapping

- Photogrammetric techniques are commonly used to develop elevation models using high resolution satellite imagery, but are typically limited to ±1 meter vertical accuracy.
- Revisit times less than 1 day can be achieved using multiple satellites. Archival imagery is also available.
- PhotoSat Ltd applies advanced signal processing techniques derived from oil and gas seismic data processing and correction for the optical performance of various satellites.
  - Results in vertical accuracy better than 30 cm – achieving better than 15 cm in some cases.
  - Rapid survey of areas exceeding 100 km².
  - Survey tied to photo-identifiable ground control points.

Images - PhotoSat/DigitalGlobe
Satellite Topographic Mapping

- Stereo imagery for the Peñasquito project is acquired monthly using DigitalGlobe’s WorldView-1, -2 and -3 satellites, with panchromatic resolution of 0.31 to 0.5 m.
- Elevation models are tied to four ground control points – elevations match control survey data to an average of 13 cm and maximum difference of 29 cm.
- Survey costs are less than $12,000US for an imagery area of 100 km$^2$ and elevation mapping area of 23 km$^2$.
- Data is typically delivered to Golder within 1 week of acquisition from the satellite operator.

July 16, 2015 WorldView-2 Image of Construction Equipment and Deposition Piping at the Peñasquito TSF - PhotoSat/DigitalGlobe
Topographic Survey at Minera Peñasquito

July 16, 2015 – PhotoSat/DigitalGlobe
Stereo Satellite Elevation Model

July 16, 2015 Elevation Model - PhotoSat
10 m Elevation Contours

July 16, 2015 Elevation Contours and Imagery – Golder & PhotoSat/DigitalGlobe
As-Built Survey

- Monthly survey is used to develop quality assurance as-built survey to:
  - Track overall construction progress
  - Evaluate conformance to design line and grade of the dam
  - Evaluate freeboard
  - Evaluate tailings beach lengths
  - Estimate construction volumes
  - Evaluate monthly rates of construction
  - Evaluate remaining available tailings storage volume for each raise

- This data is used by the mine to improve forecasts and schedule future construction activities
The accuracy of the PhotoSat survey allows for detailed monitoring and profiling of the tailings beach.

The total volume of tailings contained behind the dam in July 2015 was estimated to be 119.7 million m$^3$; this volume is used to track the remaining storage capacity of the TSF compared to the design stage-storage relationship of the facility.
The volume estimates are compared to production data to evaluate the average in-place density of the tailings deposit.

These density estimates are compared to the design consolidation model that was used to estimate the operating life of the TSF.

The estimated densities compare favorably with the results of a geotechnical drilling and sampling and cone penetration test program of the tailings beach completed by Golder in 2014 and 2015.
Summary

- Satellite monitoring has provided a valuable, cost-effective, and timely source of data for observing, evaluating, and managing the development of the Minera Peñasquito TSF.
- Public data (Landsat) is used to produce weekly, moderate resolution imagery, including enhanced visualization of the water-covered and wet surface of the TSF.
- Monthly high-resolution satellite imagery and topographic mapping is used to:
  - Monitoring of deposited tailings volumes
  - Quality assurance as-built survey production and construction volumes analysis
  - Storage capacity monitoring and assessment
- The use of satellites eliminates a significant amount of field labor compared to traditional ground, light aircraft, or even unmanned aerial imagery system survey methods.
Questions?