

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



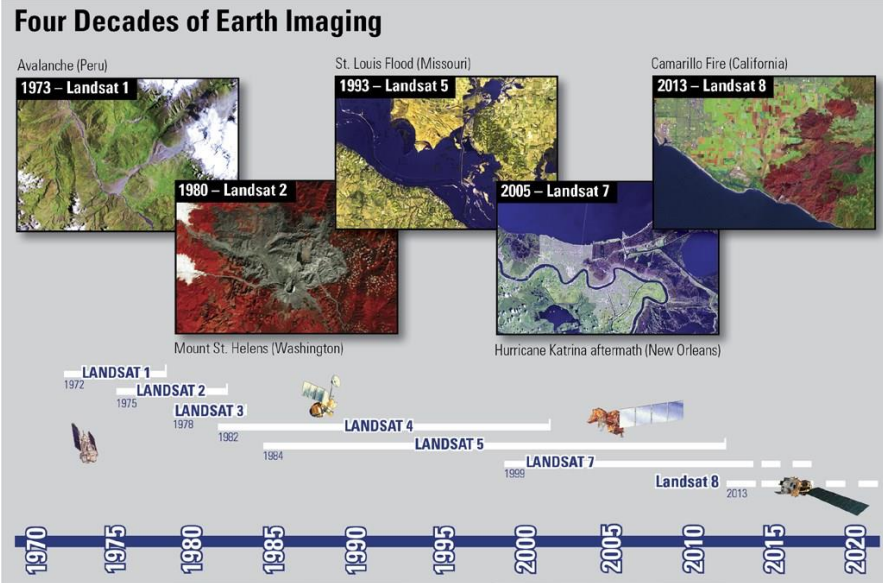
Project Background

- 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

Landsat Program



Graphic Courtesy of USGS/NASA Landsat

- 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

Band	Wavelength μm	Resolution m
Coastal/aerosol	0.43-0.45	30
Blue	0.45-0.51	30
Green	0.53-0.59	30
Red	0.64-0.67	30
Near IR	0.85-0.88	30
SWIR 1	1.57-1.65	30
SWIR 2	2.11-2.29	30
Panchromatic	0.50-0.68	15
Cirrus	1.36-1.38	30
TIRS 1	10.60-11.19	100
TIRS 2	11.50-12.51	100



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



Imagery - USGS/NASA Landsat



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

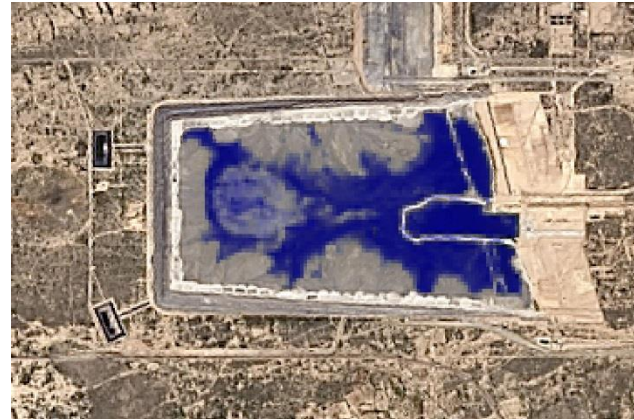


July 16, 2015 - PhotoSat/DigitalGlobe



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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 km² and elevation mapping area of 23 km²
- 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



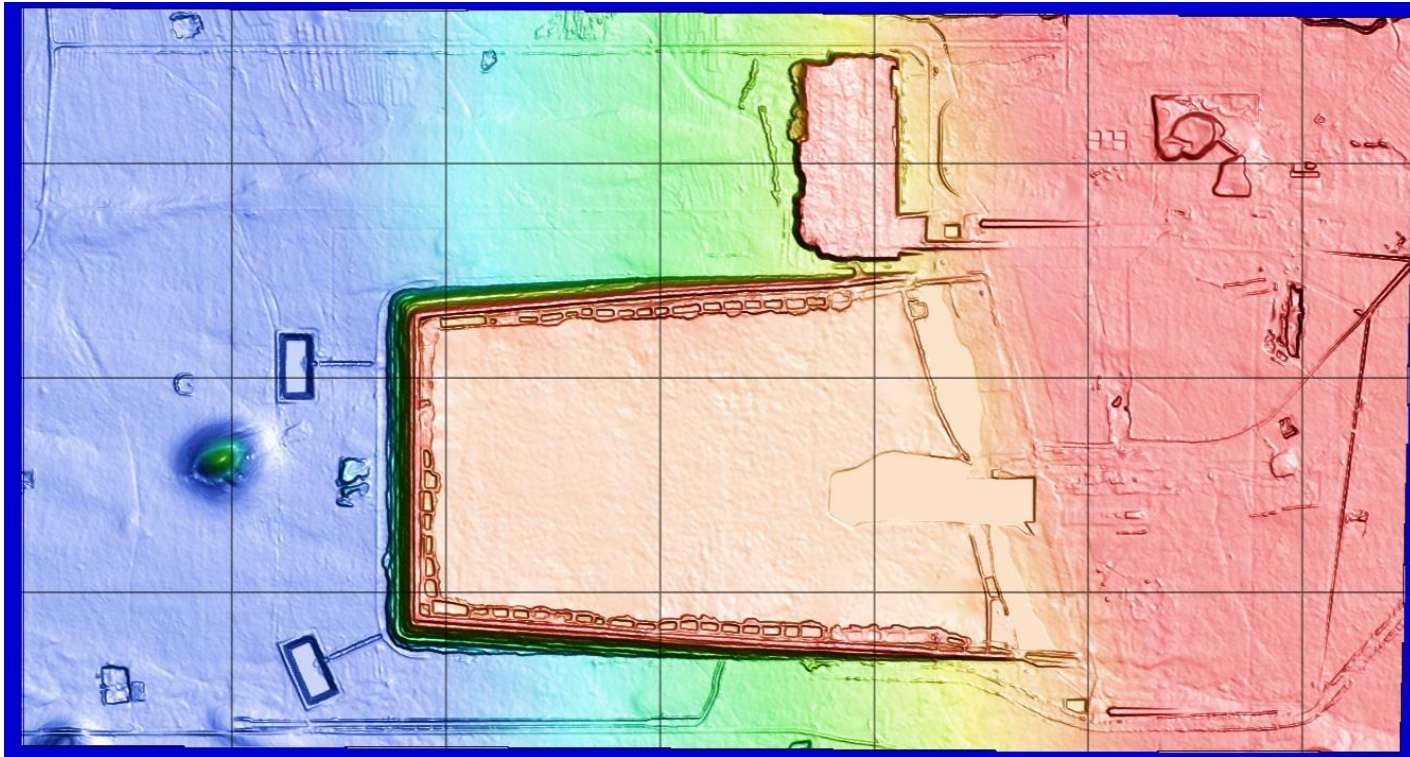
Topographic Survey at Minera Peñasquito



July 16, 2015 – PhotoSat/DigitalGlobe



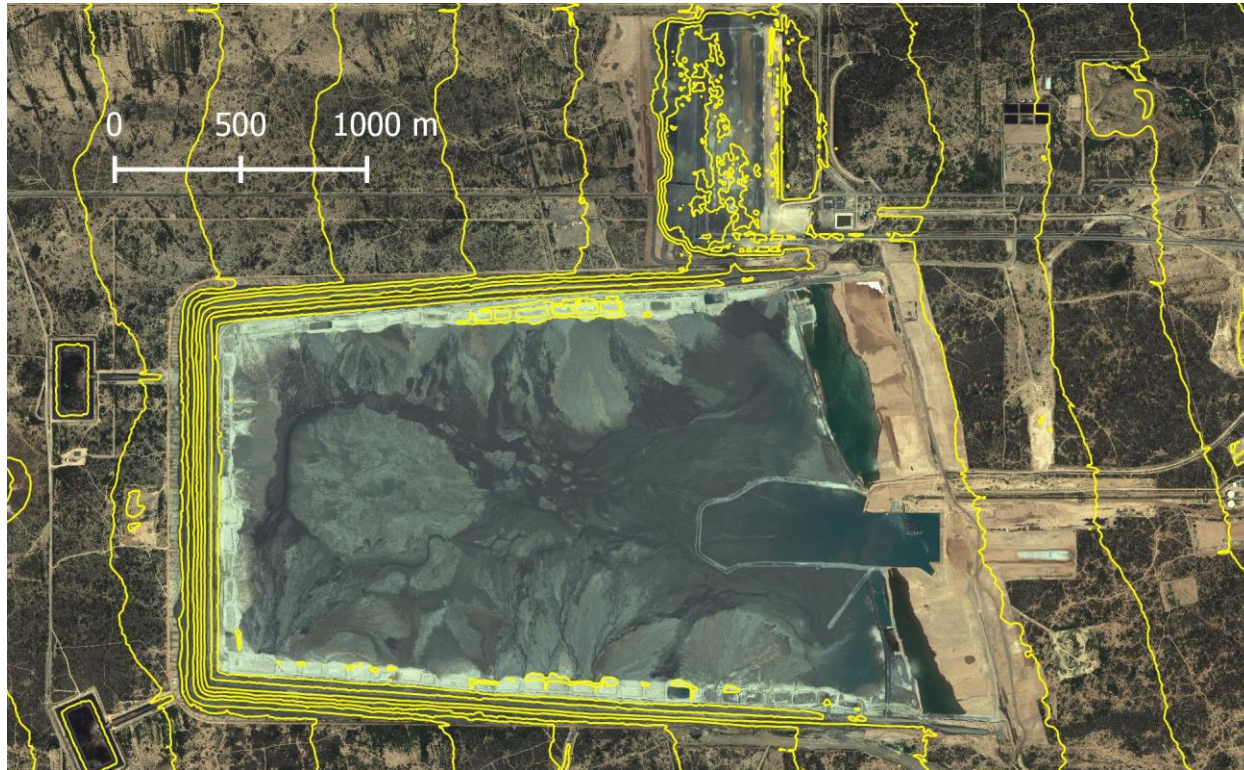
Stereo Satellite Elevation Model



July 16, 2015 Elevation Model - PhotoSat



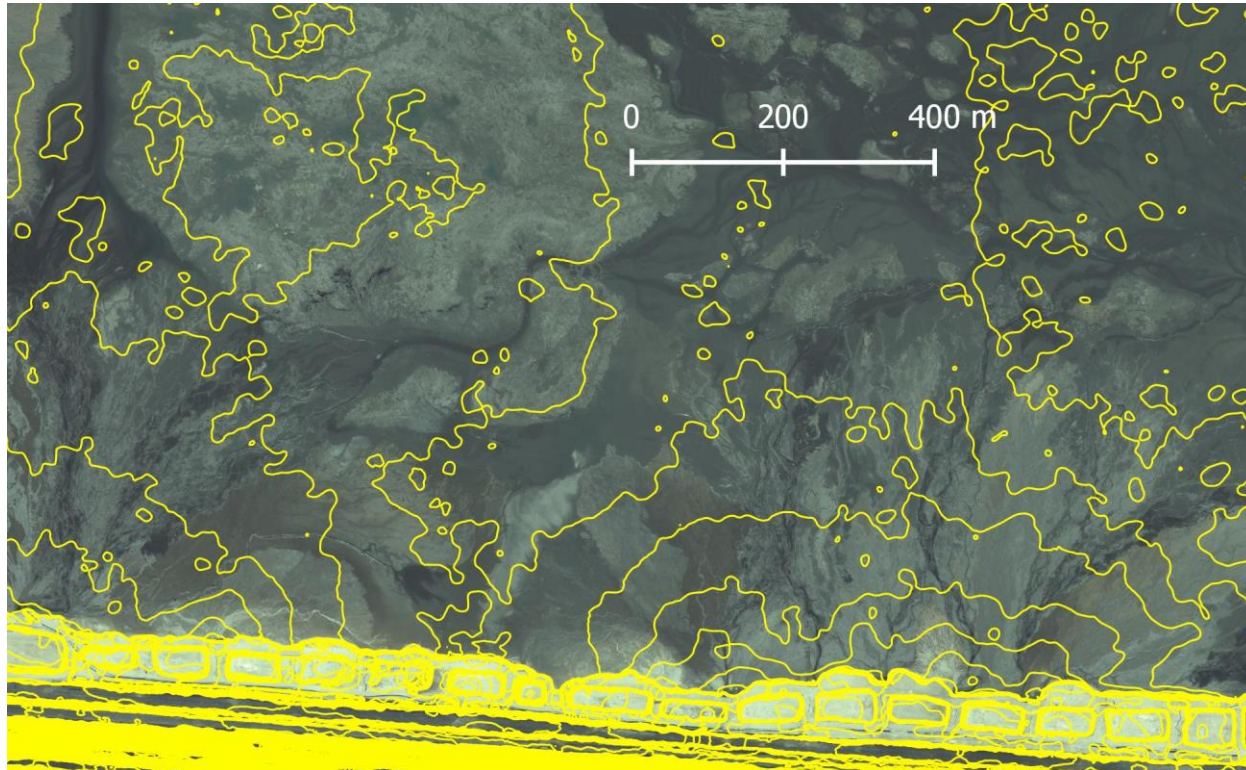
10 m Elevation Contours



July 16, 2015 Elevation Contours and Imagery – Golder & PhotoSat/DigitalGlobe

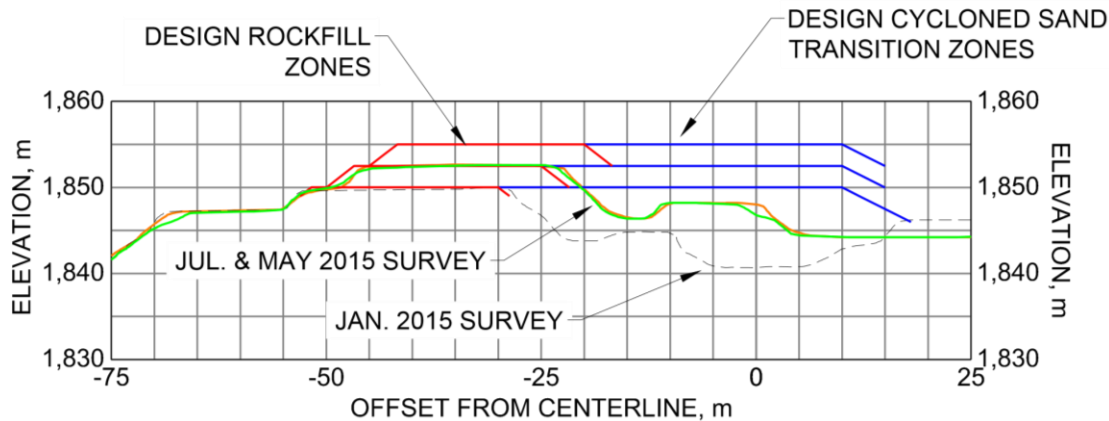


0.5 m Elevation Contours



July 16, 2015 Elevation Contours and Imagery – Golder & PhotoSat/DigitalGlobe

As-Built Survey

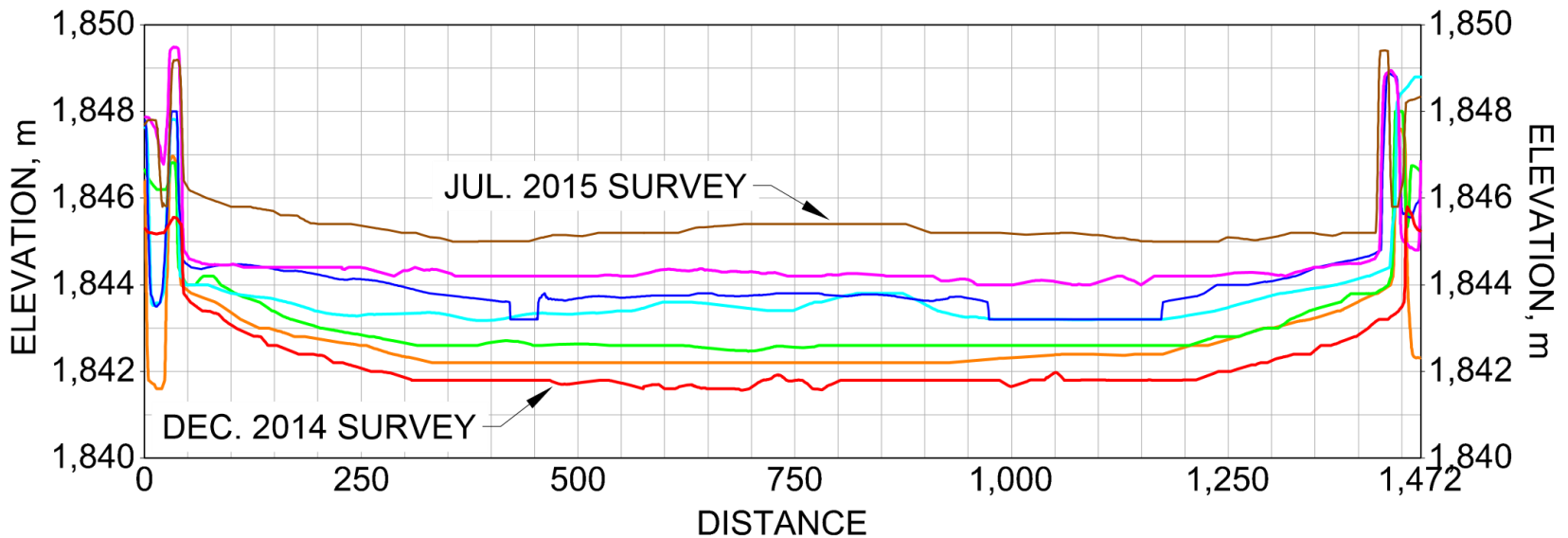


- Monthly survey is used to develop quality assurance as-built survey to:
 - Track overall construction progress
 - Evaluate conformance to design line and grade of the dam
 - Evaluate freeboard
 - Evaluate tailings beach lengths
 - Estimate construction volumes
 - Evaluate monthly rates of construction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

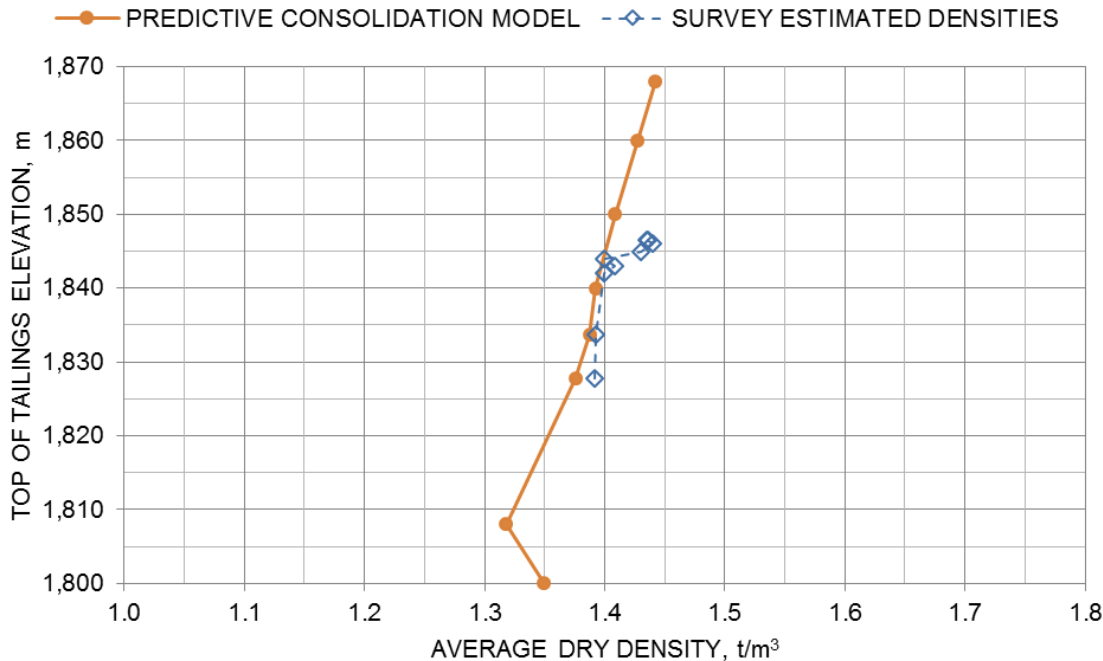


Tailings Deposition Monitoring

- 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 m³ this volume is used to track the remaining storage capacity of the TSF compared to the design stage-storage relationship of the facility.



Tailings Deposition Monitoring



- 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.



October 14, 2015, View of TSF



PhotoSat/DigitalGlobe

April 13, 2016

21



Questions?