Mufulira Case Study

Producing a Record of Construction and Deposition from Archive Satellite Imagery

PhotoSat
Better Data for Better Decisions

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Contents

List of Figures

Abstract

In this case study, PhotoSat uses archive satellite imagery to produce a full historical record of construction and deposition for a tailings storage facility (TSF) at the Mopani Mine.

Located in the DRC-Zambian Copper Belt, the Mopani Mine lies approximately 30 km South of the town of Mufulira, Zambia.

The mine became operational in 1933, and multiple TSFs have been constructed and operated on the site throughout its life. Today, the TSF at the southern end of the site remains active.

A search of satellite archives—Keyhole, Landsat, and WorldView—yielded a total of 315 cloud-free images of the Mopani Mine spanning five decades.

From these, it was possible to either 1) produce a full topographic surface from stereo imagery, or 2) re-build the features of the dyke structure and tailings deposition from the information in the satellite images.

By accomplishing both, it established a detailed record of construction and operations, spanning from the pre-construction ground surface through to modern day.

For results, read the full report.

Introduction

In 2020, the Global Tailings Review released the Global Industry Standard on Tailings Management (GISTM).

Since its release, mining companies around the world have implemented new practices in TSF monitoring, and adopted management strategies to minimize risk across the lifecycle of each TSF.

Survey Records, Missing or Incomplete

Globally, more than 12,000 TSFs exist. But in reality, many of these TSFs lack comprehensive records of construction and deposition.

The GISTM provides detailed guidelines for site surveying and monitoring, and, many mining professionals—from managers to engineering consultants—have adopted the GISTM as a new set of best practices.

For newer TSFs, complying with the guidelines of the GISTM may be relatively straightforward.

But with older legacy TSFs, the situation may be different. The records may not have been kept in the first place. If records do exist, they may be incomplete or unverified.

For example, company records might include original site plans and designs. But without an as-built survey for comparison, engineers may still not have a clear picture of how the structure was built.

Tailings and geotechnical engineers rely on survey records to plan future modifications and determine the TSF Factor of Safety.

More Floods, More Storms

In the past, engineers planned and designed their structures to withstand major weather events, such as heavy rains and flooding. But weather patterns are evolving, and engineers are facing conditions like never before.

New data from the European Academies' Science Advisory Council (EASAC) shows that the frequency of floods and other hydrological events has doubled since 2004. Meteorological events, such as storms, have quadrupled since 1980.

Future TSFs can be designed differently, but existing TSFs must be carefully managed, monitored, or modified.

The Need for Retroactive Surveying

Many tailings dam failures—notably Brumadinho and Marianas—share certain characteristics.

Flawed Designs

In the last century, few mining companies saw the need to invest in mine waste infrastructure. Neither a source of income nor a valued asset, many TSFs were built quickly and cheaply, frequently by upstream construction.

Aging TSFs, particularly those with poor construction, pose a liability to mining companies.

Weather Events

Both Brumadinho and Marianas experienced unusually heavy rains shortly before their dams failed. The frequency of extreme weather events is increasing, further increasing the risk for many TSFs.

Missing Records

Subsequent investigations into Brumadinho and Marianas revealed that engineers may have had insufficient access to historical survey data on their respective TSFs.

Without reliable records on the construction and deposition, engineers cannot make fully informed decisions about a TSF's future or determine its Factor of Safety.

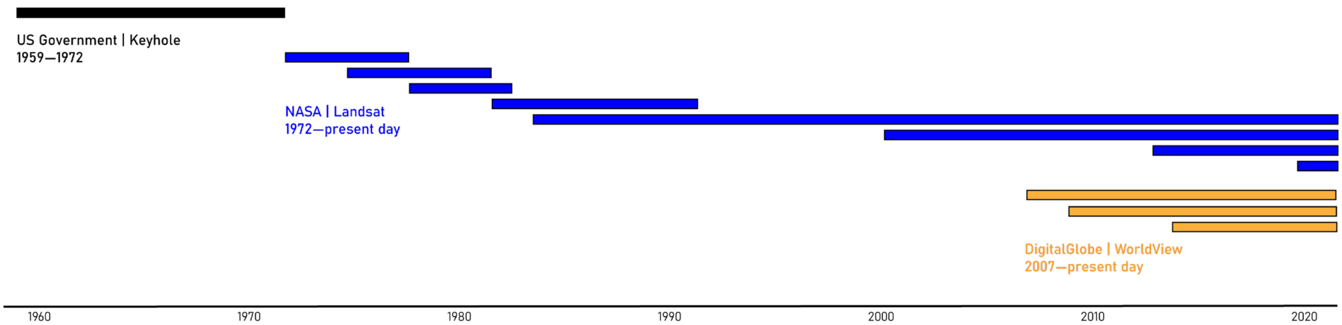
Six Decades of Earth Observation

The first satellites reached orbit in the late 1950's. Today, close to 3,000 satellites circle the globe; approximately 500 of those are Earth observation (EO) satellites.

Keyhole Satellite Program

In 1995, the US Government declassified the archive from the Keyhole satellite program. which ran from 1959 to 1972.

During the Cold War, military technology saw remarkable advancement, and Keyhole satellites had spatial resolutions of up to 0.61 m. Though decades old, Keyhole stereo imagery can be used for producing elevation surveys.



Timeline of Satellite Programs

Landsat Program

A NASA initiative, the first Landsat satellite was deployed in 1972. With the addition of Landsat 9 in 2021, the Landsat program now represents the longest running satellite program in history.

Landsat was designed to collect mono satellite imagery at a spatial resolution of 30 m; its archives span five decades.

WorldView Satellites

Powerful, agile, and highly accurate, the WorldView (WV) satellites are commercial equivalents of earlier military satellites. The WV constellation is currently owned and operated by Maxar Technologies.

With high spatial resolutions ranging from 50 cm to 15 cm, WorldView satellites are a preferred source of satellite imagery for producing elevation surveys.

Methods

The survey history was produced though the following methods.

I. Site Selection

The site was selected for specific reasons.

- **Site size.** The Mopani Mine is considered a medium-sized site.
- **Moderate climate.** The mine is located in a temperate zone, with a dry summer season and a moderately dry winter season. The areas sees an average annual rainfall of ~ 1200 mm, typically between December and March.
- **Operational site.** Built in 1987, Mufulira's southern TSF has grown to hold the copper mine's tailings.

Figure 1. 1967 Greyscale satellite photo of the Mufulira Mine

Source [Fig 1]: Keyhole, September 22, 1967

II. Original Ground Surface

To measure the volumes and distribution of different fractions of the tailings in the Mufulira TSF, it was necessary to recreate the original topographic surface. This surface now lies at the base of the TSF.

In the Keyhole satellite archive, there was stereo satellite imagery covering all the mines in the Zambia – DRC Copper Belt.

Using a proprietary software with deep learning technology, PhotoSat produced a topographic surface of the original ground surface, as it existed before construction. This process was based on PhotoSat's proprietary processing system that was initially developed in 2008.

Accuracy of Original Ground Surface

This 1967 topographic surface derived from the stereo Keyhole satellite photos has an estimated accuracy of one to two meters in elevation.

The orthophoto and 1967 original ground surface, which was derived from the 1967 Keyhole imagery, of the Mufulira TSF are shown below in Figure 2.

NOTE:

Vertical accuracy depends on the availability of high-accuracy ground control. The original surface of the Mufulira TSF was created without a site visit and without client-supplied ground control.

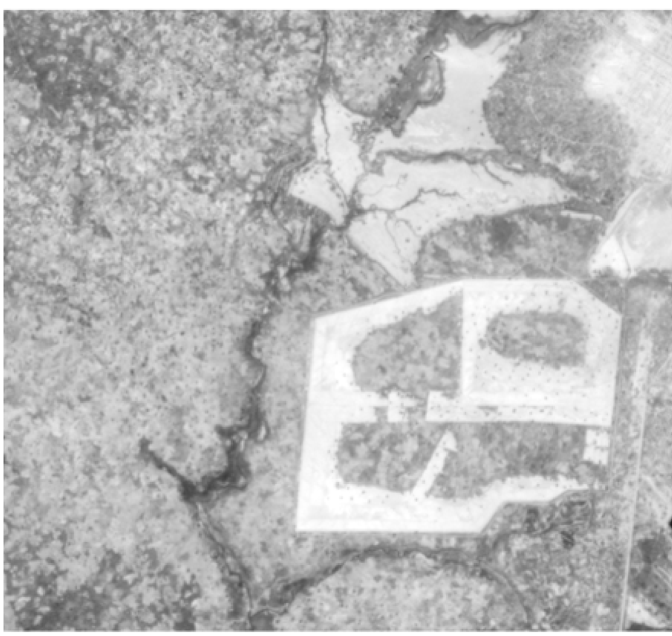


Figure 2a. 1967 Satellite photo of the Mufulira TSF

Source [Fig 2a]: Keyhole, September 22, 1967

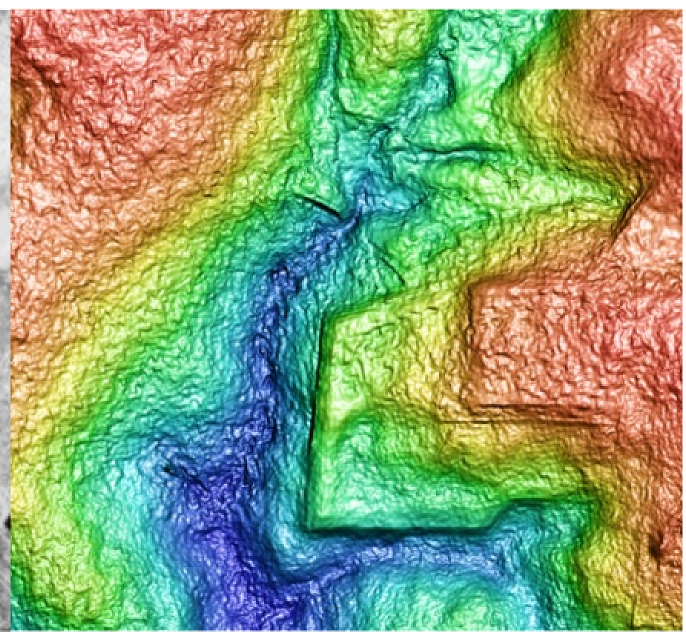


Figure 2b. 1967 Original ground surface of the Mufulira TSF

Source [Fig 2b]: Keyhole, September 22, 1967

III. Modern Elevation Surfaces

PhotoSat produced three elevation surveys from WorldView satellite imagery. These are described in the table below.

Accuracy of Surveys from WorldView

Without ground control, elevation surveys produced from WorldView satellite imagery have a horizontal accuracy of 3 m and a relative accuracy of 20 cm over 5 km.

When ground control is available, it is possible to achieve vertical accuracy in the range of 10 cm to 15 cm RMSE.

Date	Satellite	Image Resolution	Grid Resolution
September 6, 2010	WV-2 (Crosstrack)	50 cm	1 m
July 13, 2017	WV-2		
March 23, 2020	WV-3		

Figure 3a. 2020 Orthophoto of the Mufulira TSF

Source [Fig 3a]: WV-3, March 23, 2020

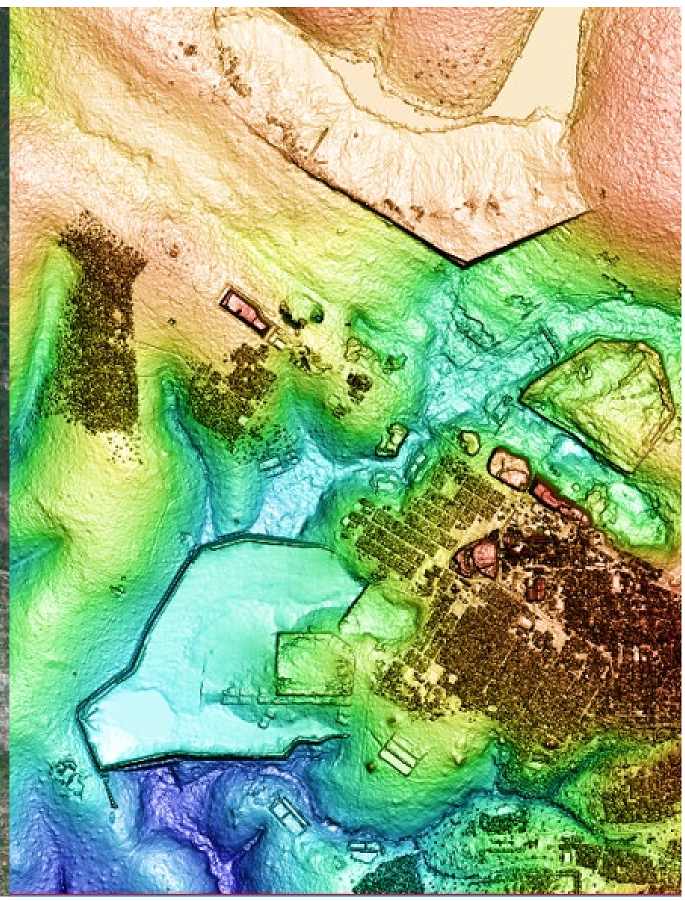


Figure 3b. 2020 Elevation survey of Mufulira TSF

Source [Fig 3b]: WV-3, March 23, 2020

Results

The satellite imagery dated between 1989 and 2020 shows that the tailings pond did not extend closer than 200 m to the Mufulira TSF embankment. This indicates that this upstream TSF embankment most probably consists entirely of coarse sands.

This study does not determine the probable location of the current phreatic surface within the TSF. Therefore this study cannot indicate whether the TSF embankment probably consists of unsaturated or water saturated sands.

Figure 4a. 1989 Pond edges

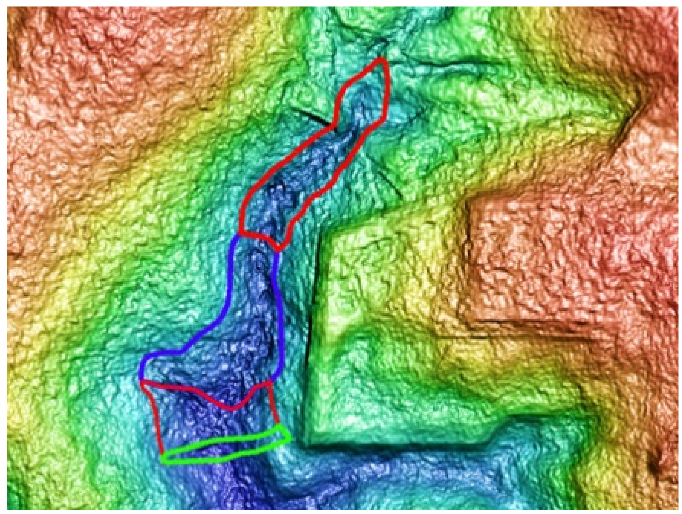


Figure 4b. 1989 Pond edges on original ground surface

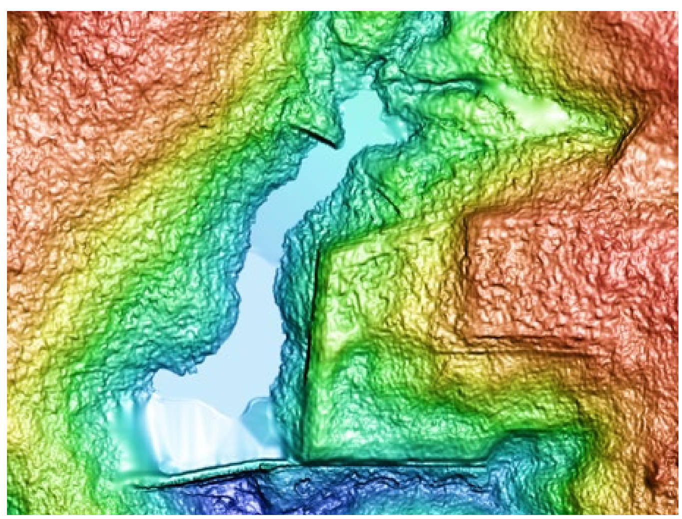


Figure 4c. 1989 Tailings on original ground surface

Source [Fig 4]: Keyhole, September 22, 1967 and Landsat 5, August 21, 1989

Pond Edges and Tailings Embankments

Tailings deposition can be observed in the Landsat 5 satellite imagery from these dates:

- Aug 21, 1989
- Sep 25, 1990
- Aug 29, 1992

From these, we can see the construction of embankments around the TSF, deposition of fine tailings, deposition of coarse tailings, and accumulation of water in the TSF.

Figure 4 shows the pond edges from the 1989 Landsat imagery overlaid on the 1967 original ground surface.

The ground features of the Mufulira TSF are shown for 1989, 1990, and 1992 in Figure 5 to Figure 8.

Mufulira TSF Pond Edges in 1989

These contours show the reconstructed surface of the Mufulira TSF for 1989. Contour intervals are 20 cm within the tailings cell, and 1 m in the surrounding area.

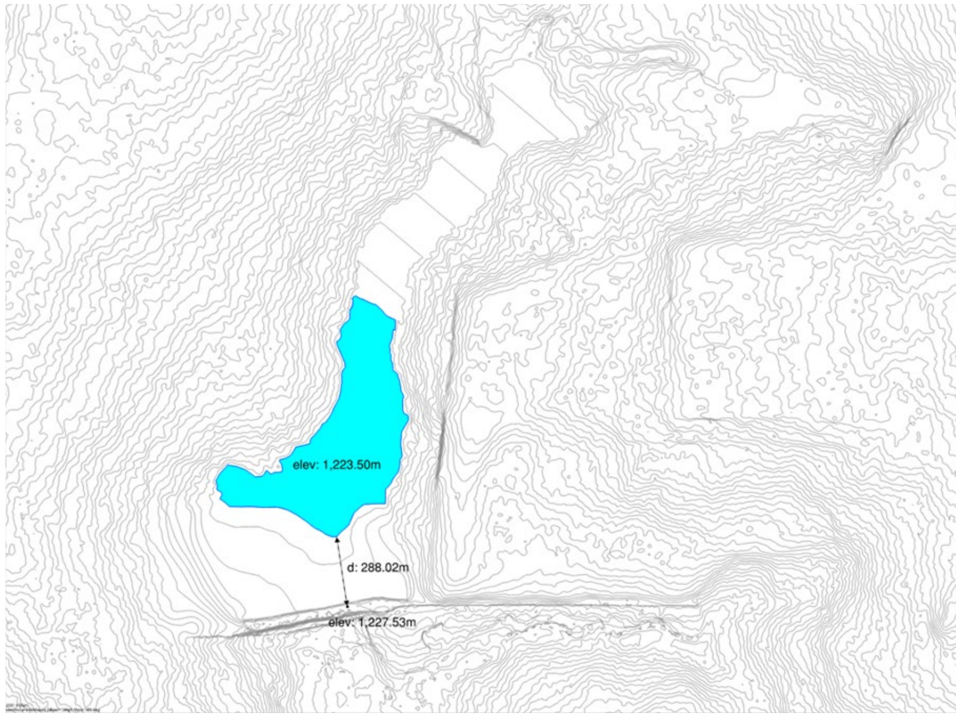


Figure 5. 1989 Contours with overlaid pond

Source [Fig 5]: PhotoSat, April 2020

Mufulira TSF Pond Edges in 1992

These contours show the reconstructed surface of the Mufulira TSF for 1992. Contour intervals are 20 cm within the tailings cell, and 1 m in the surrounding area.

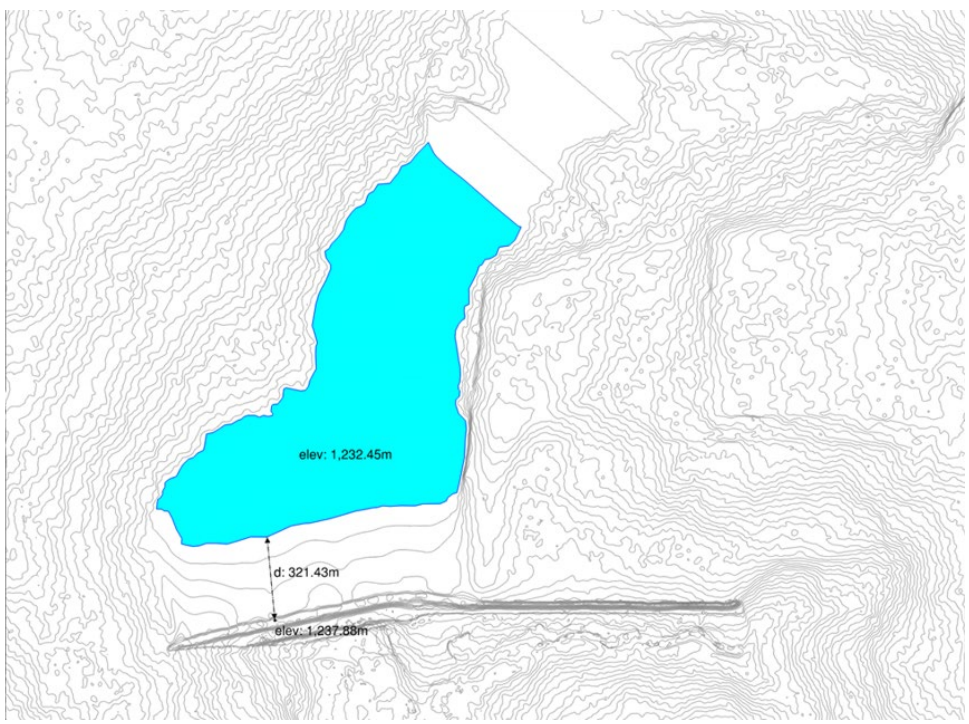


Figure 6. 1992 Contours with overlaid pond

Source [Fig 6]: PhotoSat, April 2020

Mufulira TSF Pond Edges in 2020

These contours show the elevation surface of the Mufulira TSF for 2020. Contour intervals are 20 cm within the tailings cell, and 1 m in the surrounding area.

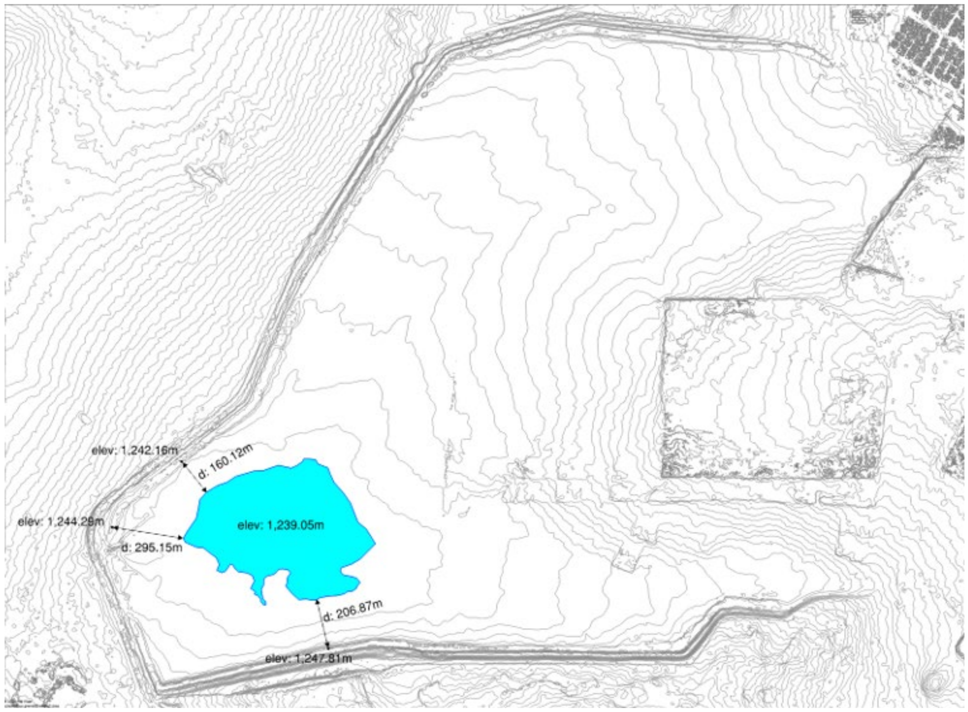


Figure 7. 2020 Contours with overlaid pond

Source [Fig 7]: PhotoSat, April 2020

Mufulira TSF Embankments in 2020

These contours show the elevation surface of the Mufulira TSF for 2020. Contour intervals are 20 cm within the tailings cell, and 1 m in the surrounding area.

The cross-section at line B is shown in Figure 9.

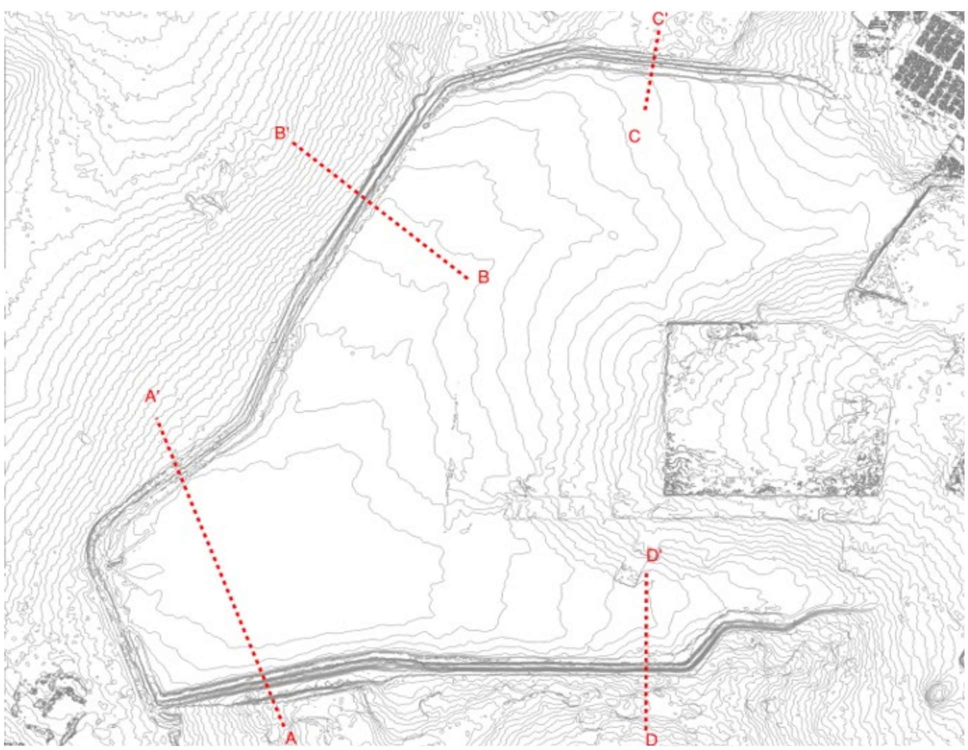


Figure 8. 2020 Embankments

Source [Fig 8]: PhotoSat, April 2020

Tailings Thickness and Volumes

It is possible to measure the current thickness and volume of tailings in the Mufulira TSF by comparing the:

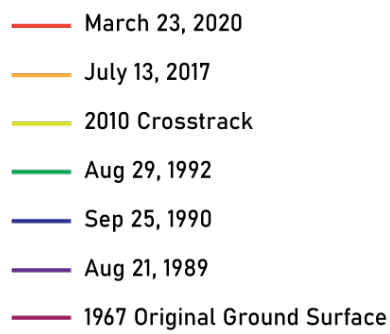
- **1967 original surface:** produced from the 1967 Keyhole satellite imagery (Fig 2)
- **2020 topographic surface**: produced from the March 23, 2020 WorldView-3 stereo imagery (Fig 3)

These measurements are:

- Current volume of tailings and water in the TSF: 50,000 m³
- Maximum tailings thickness: 29 m

Depositional History

The stratigraphic cross-section (Fig 9) of the Mufulira TSF was created by compiling the individual surfaces from the WorldView 2010, 2017 and 2020 surveys and reconstructed surfaces from the earlier Keyhole and Landsat 5 satellite imagery.



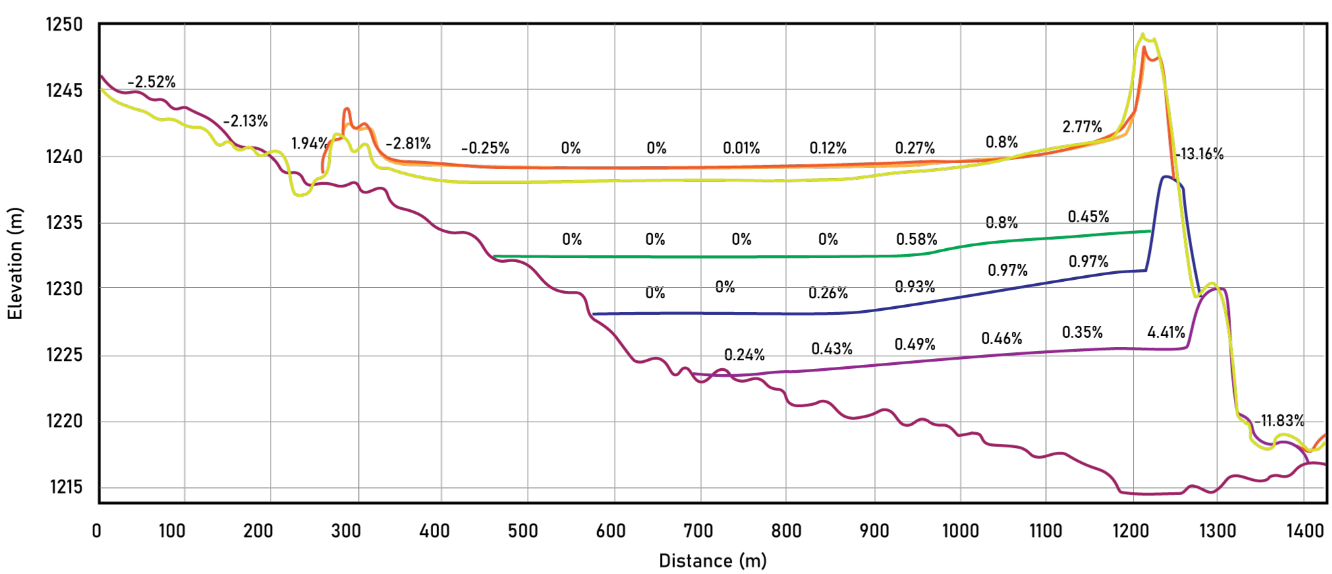


Figure 9. Tailings deposition by year

Source [Fig 9]: PhotoSat, April 2020

Distribution of Fine Tailings, Coarse Tailings, and Surface Water

The distribution of coarse sands, fine sands and tailings deposited around the pond is shown below.

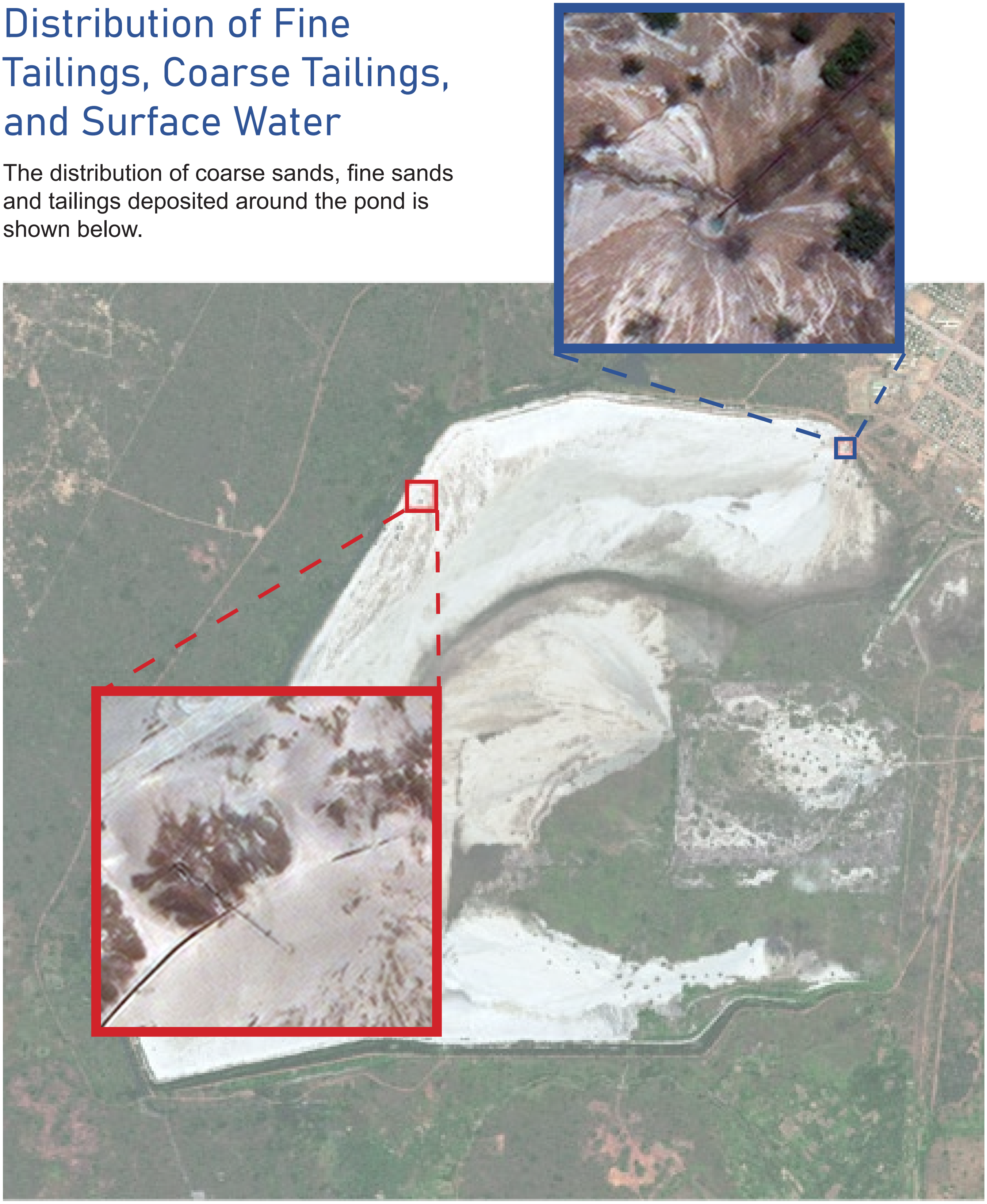


Figure 10. 2020 Fine and coarse tailings distribution

Source [Fig 10]: WV-3, March 23, 2020

Discussion

Although the Mufulira Case Study applies to the history of TSF construction and tailings deposition, archive imagery can be applied to a wider range of sites and projects.

Help Assess the TSF Factor of Safety

Determining the Factor of Safety for a TSF requires onsite investigations, likely including drilling, cone penetration testing, and measurements of the current phreatic surface, supervised and interpreted by qualified tailings engineers.

A complete record of construction and deposition is a valuable component in the determination of a TSF Factor of Safety.

Reproduce a Historical Ground Surface

Where the imagery exists, it may be possible to produce a reliable 3D surface of the site prior to construction or deposition.

Engineers can use historical ground surfaces to:

- Determine total tailings volume in a TSF
- Calculate total volumes and volume changes on leach pads and stockpiles
- Recreate key ground features in specific years
- Measure past cut and fill volumes for earthworks construction projects