Creating TSF Histories Using Modern Commercial and Declassified Cold War Satellite Photos

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ABSTRACT: Recent dam failures have brought the world's mine tailing facilities under intense scrutiny by governments, investors, and insurers. Published investigations into the causes of dam failures and experience at other mining operations worldwide shows that many mines lack comprehensive, reliable, as-built survey records even for recent operations.

In 2010 PhotoSat developed a geophysical process that is used to produce monthly time stamped engineering grade surveys of entire mines using modern satellites. This process has now been adapted to include declassified cold war spy satellite photos going back to the early 1960's.

This paper will present a demonstration case study using Glencore's Mufulira TSF in Zambia as an example. At this site 315 satellite photos including declassified US spy satellite photos from 1967 were used to create a tailings dam history.

Satellite derived deposition and construction histories enable an independent third-party view of tailings dam construction and operation over decades.

1 INTRODUCTION

Recent catastrophic dam failures have driven the need for independent, verifiable information about not only how the dam is being operated today but also a history showing how the dam was constructed.

Many mines lack comprehensive, reliable, as-built survey records even for recent operations. For mines where TSF construction began decades ago there is often a complete lack of records. Even when survey data exists it is often uncertain and incomplete – a situation which is exacerbated by staff turn-over or changes of mine ownership.

PhotoSat is producing independent, satellite photo based, historical records of the construction, operation, and volumes of tailings dams. PhotoSat has provided satellite data to assist with several recent dam failure investigations and has recognized that there is a need for independent, verifiable histories of the construction, maintenance, and depositional history of mine tailings dams.

Glencore's Mufulira TSF in Zambia makes an excellent case study. At this site, 315 satellite photos including declassified US spy satellite photos from 1967 were used to create a tailings dam history. A series of as-built topographic surveys of the entire TSF were produced. These provide a 3D view of the successive embankment wall lifts, pond boundaries, the probable distribution of coarse sands and fine tailings and the construction in the surrounding areas. The stratigraphic cross sections show the construction of the dam over a period of over 30 years. The volumes and locations of successive deposits of tailings can be tracked over time from the dam's commissioning in 1987 to the present day. This includes the measurement of the total current volume of tailings and water in the dam at 10:31 AM on March 20th, 2020.

2 THE NEED FOR INDEPENDENT TAILINGS DAM INFORMATION

Following the Brumadinho dam failure in Brazil in January 2019 that killed over 250 people, tailings dam safety is the subject of intense international scrutiny. For many of the world's tailings dams, "as-built" historical survey records are either inadequate or don't exist.

An Independent Investigation Report to the Vale Board of Directors on the Brumadinho dam failure was released on February 20, 2020. This report describes how government safety permits were obtained for the Brumadinho Dam when the dam had a Factor of Safety of only 1.09. This was far below the minimum industry standard, and Vale's own minimum standard, of a Factor of Safety of 1.3 for tailings dams.

The Vale Director of Iron Ore Operations and the independent engineering auditors did not inform the Vale CEO and Senior Executive Team nor the Vale Board of Directors of the very low Factor of Safety of the Brumadinho dam. Investors and insurers reading the February 2020 Vale report are recognizing the importance of developing independent, verifiable, sources of information for tailings dam safety. Mine owners should benefit by being able to provide their potential investors and insurers with independent, verifiable, satellite survey reports on the construction and depositional history of their tailings dams.

3 MUFULIRA MINE TAILINGS DAM IN THE ZAMBIA-DRC COPPER BELT

The Mufulira Copper mine in Zambia has been in operation since 1933. The mine is currently owned 73.1% by Glencore, 16.9 % by First Quantum and 10% by ZCCM-IH. Mine tailings have been deposited in the current active Mufulira tailings dam since approximately 1987.

3.1 *Satellite Photo record of the Mufulira tailings dam*

The record of archive cloud free satellite photos over the Mufulira mine site begins with a September 22, 1967 stereo pair of US Keyhole spy satellite photos (see Figure 1, which shows four of the mine tailings deposits used up until 1967, and the large tailings embankment and water dam to the north that appears to be new in 1967). The satellite record ends, as of the date of this report, with a March 23, 2020 stereo pair of 30 cm ground resolution Maxar WorldView-3 satellite photos.

Between September 22, 1967 and March 23, 2020 there are 315 cloud free satellite photos over the Mufulira mine site.

3.2 *PhotoSat Mufulira mine site surveys*

PhotoSat routinely surveys mine sites in all the world's major mining districts. Using stereo photos from the Maxar WorldView satellites, PhotoSat surveys mine sites to an accuracy of 15 cm in elevation. The PhotoSat team has completed over 1,200 survey projects globally, with over 600 since 2012.

PhotoSat produced 1 m survey grids accurate to 15 cm in elevation from stereo WorldView satellite photos for the Mufulira mine site for the following dates: March 23, 2020, July 13, 2017, and September 6, 2010.

The March 23, 2020 PhotoSat survey is shown in Figures 2-4 below.

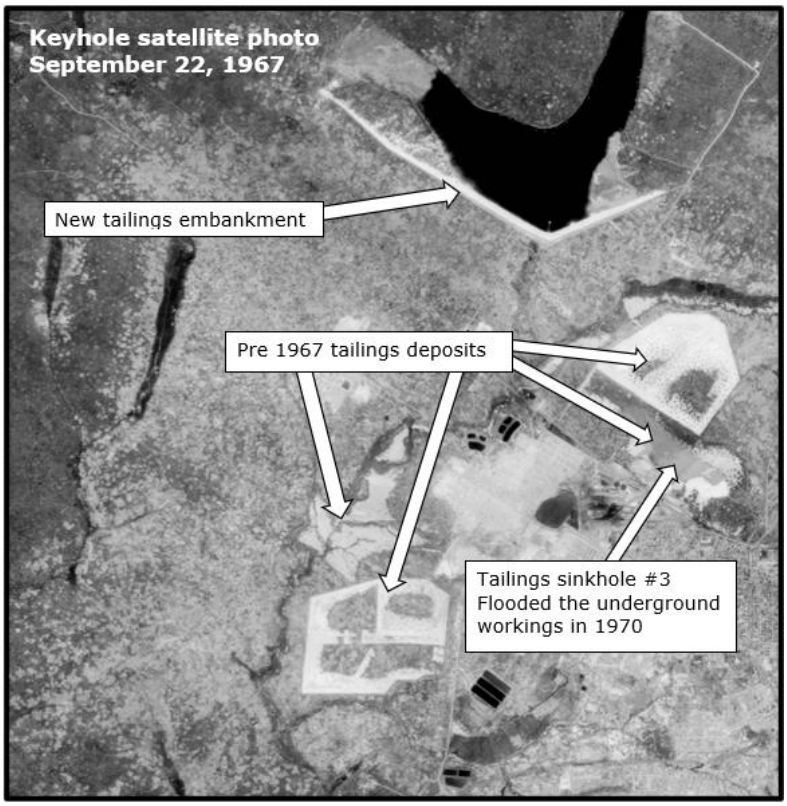

Figure 1. Declassified US Keyhole spy satellite photo of the Mufulira mine site and tailings dams taken on September 22, 1967.

Figure 2. WorldView-3 satellite photo of the Mufulira mine site and tailings dam taken on March 23, 2020.

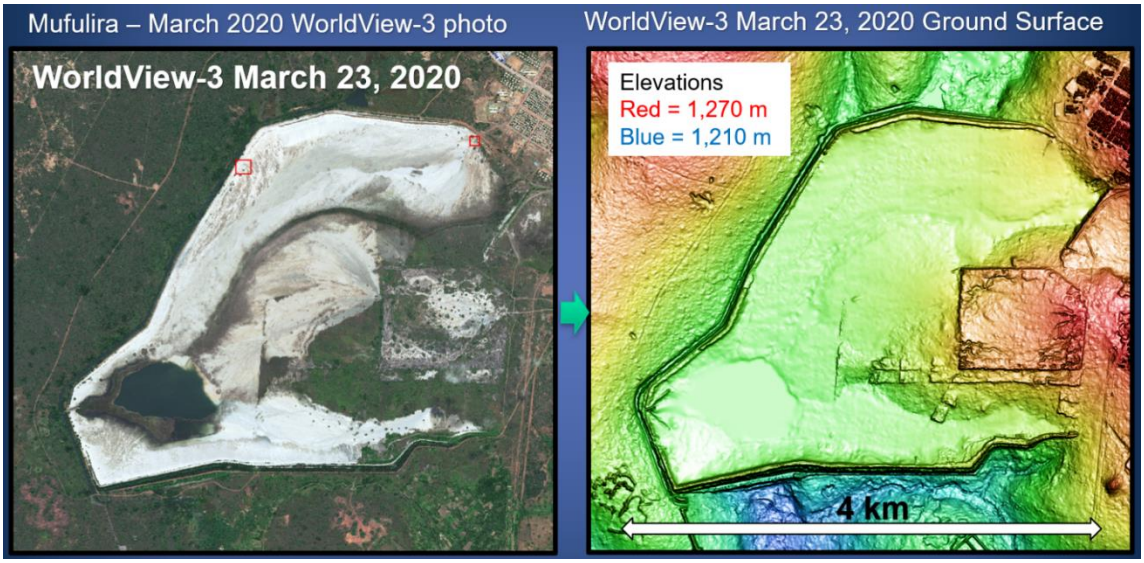

Figure 3. Elevation surface of the surface of the Mufulira tailings dam March 23, 2020 derived from WorldView-3 stereo satellite photos.

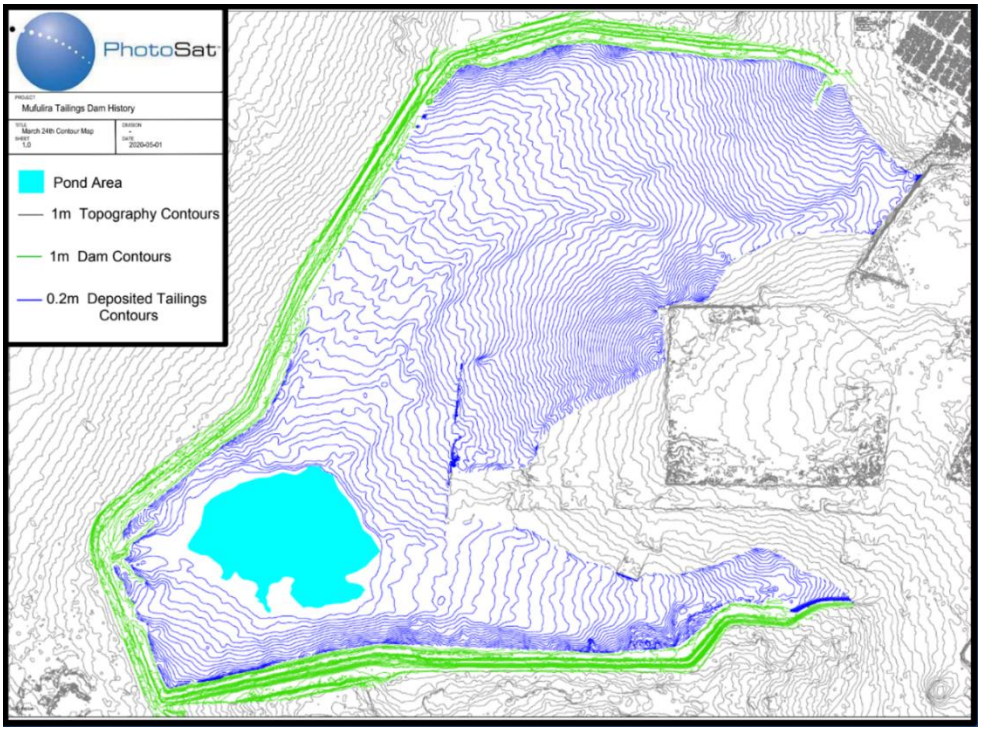

Figure 4. Elevation contours of the March 23, 2020 surface of the Mufulira tailings dam. Top of tailings 20 cm contours in blue. Surrounding area 1 m contours.

4 1967 STEREO KEYHOLE DECLASSIFIED US SPY SATELLITE PHOTOS OF THE MUFULIRA MINE SITE

In 1995 the US declassified archives of US spy satellite photos taken during the Cold War. This satellite photo program was designed to monitor the Soviet fleets of intercontinental nuclear bombers, the construction and launch sites for Soviet intercontinental nuclear missiles and Soviet and Chinese nuclear test sites.

4.1 *Topographic surface of the base of the Mufulira tailings dam produced from the 1967 Keyhole stereo satellite photos*

To measure the volumes and distribution of different fractions of the mine tailings in the Mufulira tailings dam over time, it is necessary to start with the topographic surface of the base of the tailings deposit. Fortunately, there are stereo US Keyhole spy satellite photos covering all the mines in the Zambia-DRC Copper Belt.

PhotoSat has developed a process and workflow to generate a topographic surface of the base of the tailings dam using the stereo Keyhole satellite photos. This is an extension to the proprietary stereo satellite elevation surveying system that PhotoSat first developed in 2008.

This 1967 topographic surface derived from the stereo Keyhole satellite photos has an estimated accuracy of one to two meters in elevation. The elevation grid of the base of the Mufulira tailings dam derived from the 1967 stereo Keyhole satellite photos is show in Figure 5.

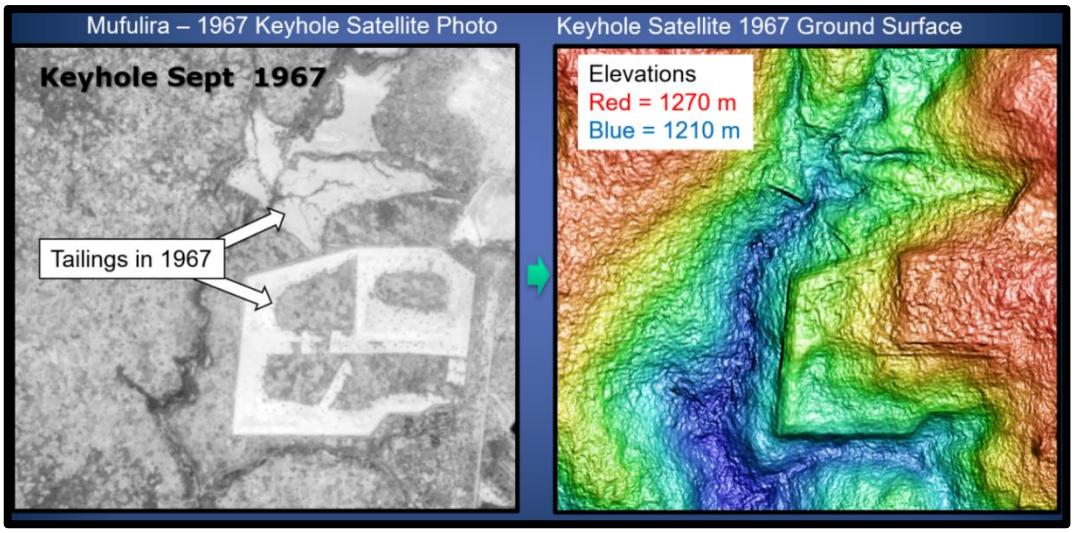

Figure 5. Elevation surface of the base of the Mufulira tailings dam derived from September 22, 1967 stereo Keyhole satellite photos.

4.2 *Measurement of the current thickness and volume of tailings in the Mufulira tailings dam derived from the satellite surveys*

PhotoSat has measured the current thickness and volume of mine tailings and water in the Mufulira dam. The current volume of tailings and water in the dam is 50,000 m3. This measurement is made by comparing the 1967 topographic surface, of what is now the base of the Mufulira tailings dam, with the present topographic surface created from the March 23, 2020 WorldView-3 stereo satellite.

The March 23, 2020 topographic surface of the Mufulira tailings dam is shown in Figure 6.

4.3 *Stratigraphic cross section of the Mufulira tailings dam*

The stratigraphic cross section of the Mufulira tailings dam shown in Figure 7 was created using the PhotoSat WorldView 2010, 2017 and 2020 surveys and the nearly 300 satellite photos taken between 1987 and 2020. The probable distribution of coarse sands, fine sands and tailings deposited beneath the pond is shown in the cross section.

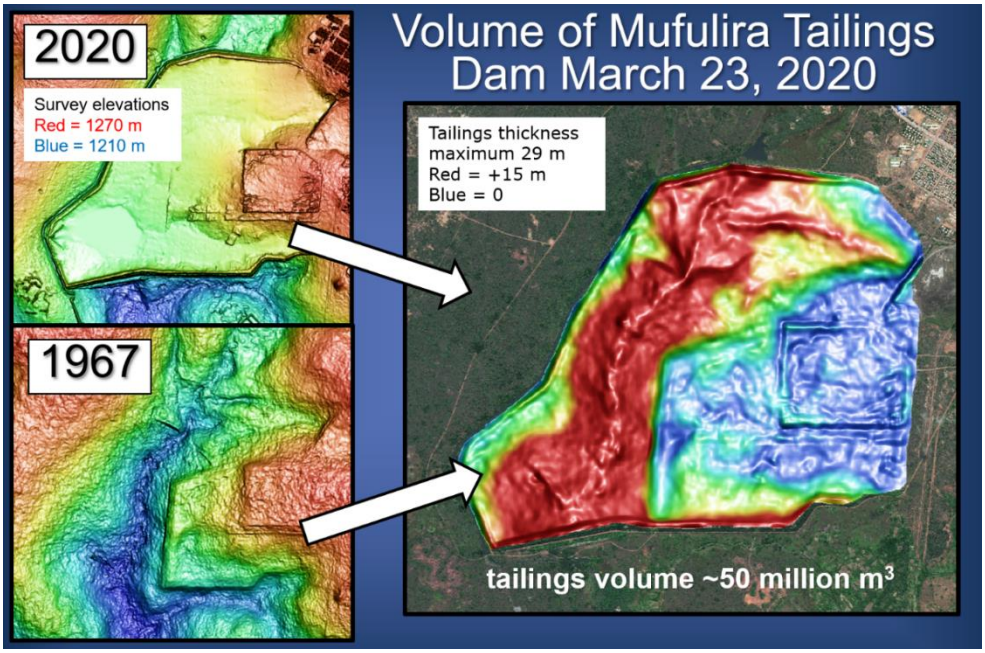

Figure 6. The tailings thickness and the volume of tailings and water in the Mufulira Tailings Dam on March 23, 2020. Maximum tailings thickness 29m.

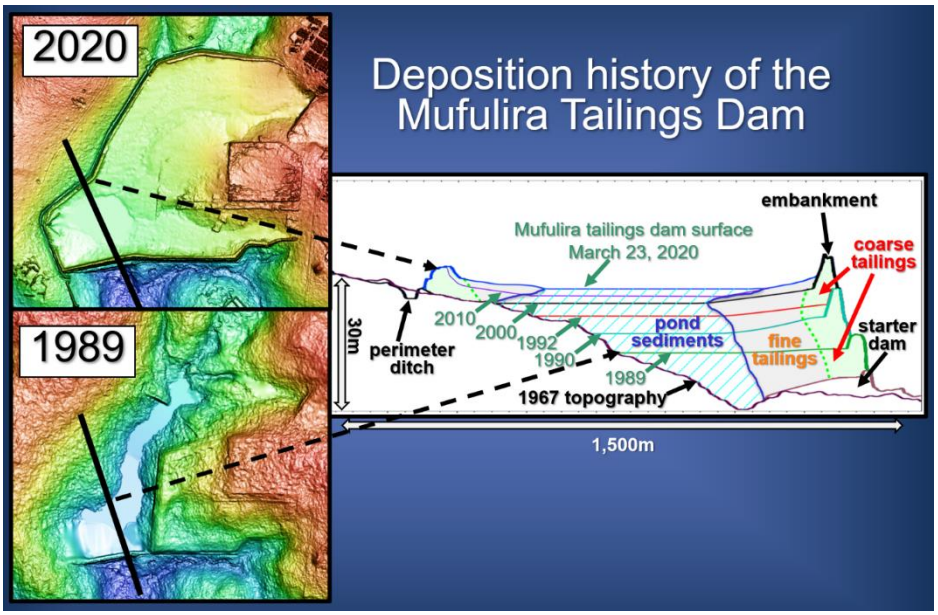

Figure 7. The Mufulira tailings dam topographic surfaces for March 23, 2020 and August 21, 1989. Cross section showing the tailings dam topographic surfaces for different years.

5 CONCLUSION

There is an urgent need for independent, verifiable information on tailings dams, and recent failures have brought the world's mine tailings dams under intense scrutiny by governments, investors, and insurers.

PhotoSat's independent satellite-based measurements show a current volume of 50 million m3 of mine tailings in the Mufulira tailings dam with an error of approximately 10%. In comparison, the Glencore response to the Church of England reports 79 million m3 of tailings for this tailings dam.

PhotoSat's 3D historical reconstruction of the Mufulira tailings dam shows the most probable current 3D distribution of coarse tailings, fine tailings and tailings deposited within the tailings pond.

From the total record of 315 satellite photos, it appears that the Mufulira tailings dam was probably well designed, carefully constructed, and well maintained over its history. More than 290 satellite photos taken between 1989 and 2020 show that the tailings pond was never allowed to come closer than 200 m to the Mufulira tailings dam embankment. This indicates that this upstream tailing dam embankment most probably consists entirely of coarse sands. This would give the dam a lower risk of failure than if the embankment was built on top of fine tailings and pond sediments, as was the case for Vale's Fundeo and Feijão failed tailings dams in Brazil.

This study does not determine the probable location of the current phreatic surface within the dam. Therefor this study cannot indicate whether the tailings dam embankment actually consists of unsaturated or water saturated sands.

The satellite survey history is only one component of the determination of a tailings dam Factor of Safety. An engineering determination of the Factor of Safety of a tailings dam requires on site investigations, probably including drilling, cone penetration testing, and measurements of the current phreatic surface, supervised and interpreted by qualified tailings dam engineers. However, satellite derived deposition and construction histories enable an independent third-party view of tailings dam construction and operation over decades.

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