Impact of topography errors on Tailings Dam Breach Analysis

Jim Turner (P.Eng.)
PhotoSat, Vancouver, BC, Canada

Angela Ellithorpe (E.I.T.)
PhotoSat, Vancouver, BC, Canada

Allan Ng (P.Geo.)
PhotoSat, Vancouver, BC, Canada

Andrea Krupa
PhotoSat, Vancouver, BC, Canada

ABSTRACT: Many mines conduct Tailings Dam Breach Analyses (TDBA) which include large potential inundation areas that may extend tens or even hundreds of kilometres downstream of the Tailings Facility. Simulations are done to calculate the size and location of the potentially impacted area if the dam were to fail. A primary input to the simulations is the topography downstream of the dam.

In some cases, simulations are attempted using free or low-cost publicly available topographic data. Alternatively, topography with unknown accuracy is sometimes derived from National or local Government contour maps. This type of topographic data may have a known resolution but unknown and potentially high levels of error.

Previous studies have focused on the resolution of the topographic survey and reported that lower resolution results in larger run-out areas, greater flow volumes and more rapid flood streams.

The Canadian Dam Association (CDA) has recently published a Technical Bulletin entitled "Tailings Dam Breach Analysis" (CDA, 2021). The bulletin recognises the survey resolution problem and recommends against the use of low-resolution or poor-quality surveys.

This study considers the impact of the vertical and horizontal accuracy of the survey in addition to the impact of resolution. Real-world survey data sets were used; however, the results of the modeling do not reflect an actual TDBA simulation and are intended only to illustrate the impact of topography accuracy on a hypothetical simulation.

The comparison concludes that the impact of survey errors (poor vertical accuracy) often exceeds the impact of poor resolution resulting in unpredictable impacts on simulation results.

More importantly, the comparison shows that different locations are impacted and with a different level of impact in these areas. The discrepancies occur in large flat areas and also in narrower, poorly defined channels.

The comparison refutes the conclusion that low-resolution results in larger run-out areas, greater flow volumes and more rapid flood streams. This comparison shows that the impact of poor accuracy can be more significant than topography resolution and that there can be no general rule about the impact of improving resolution unless the impact of survey accuracy is also considered. This paper agrees with the general guidance of the CDA bulletin in that the best available topography should be used and suggests that accuracy as well as resolution should be considered when choosing suitable topography. In order to ensure uniform style throughout the volume, all the papers should be prepared strictly according to the instructions set below.

1 INTRODUCTION

Many decisions and choices of parameters are made when producing a Tailings Dam Breach Analysis (TDBA). A detailed discussion of these and a suggested series of steps is provided in the Canadian Dam Association's Technical Bulletin "Tailings and Dam Breach Analysis" (CDA, 2021).

The CDA bulletin suggests that the "best available" topographic data should be chosen. It discusses the resolution of the survey and comments that the sensitivity analysis on topographic inputs cannot improve the level of detail that is available in the topographic data.

Previous studies have reported the impact of poor resolution and have concluded that lower resolution results in "larger run-out areas, greater flow volumes and more rapid flood streams" (Halliday, A., Arenas, A., 2019).

This paper considers the impact of not just the survey resolution but also its vertical and horizontal accuracy.

Further investigations have also been done to assess the impact of choosing a smaller cell sizes for the simulation. Since simulation software allows cell sizes smaller than the resolution of the topography to be chosen there is the risk that a user might choose to "improve" a low resolution topography simulation by reducing the simulation cell size.

The authors compared TDBA run-out analysis for surveys with different accuracies and resolutions to illustrate the impact on the simulated inundation area. The findings in this paper are also applicable to dam breach studies of water dams or any other flood inundation studies.

1.1 *Choosing topography for a TDBA*

The topography area required for a TDBA may cover tens or even hundreds of square kilometres downstream of the Tailings Storage Facility (TSF). For areas of this size, only new or pre-existing airborne LiDAR or satellite-based surveys are practical.

There are many sources for topography. These range from low-cost (or free), low-accuracy, low-resolution, publicly available satellite data such as Shuttle Radar Topography Mission (SRTM) through to a high-accuracy, high-resolution survey done using airborne LiDAR (flown with a manned aircraft) or using Geophysical Algorithms and data from high-resolution satellites. High-accuracy, high-resolution surveys from satellite have been available since 2014 for any part of the planet however, it is only in the past few years that they have been widely adopted for TDBAs.

Factors to consider when choosing topography are:

1.1.1 *Resolution*

Resolution is defined in terms of the horizontal grid spacing of the survey elevation grid. Low-resolution topography such as SRTM in the comparison area has a horizontal grid spacing of 30 m. High-resolution satellite surveys can have horizontal grid spacings of 1 m or smaller.

Better resolution does not necessarily correlate with better accuracy. For example, in other parts of the world, SRTM is available with 10 m grid spacing however the 10 m spaced grid has the same accuracy level as 30 m spacing. Similarly, surveys with 5 m grid spacing may have only marginal, if any, improvement in vertical accuracy when compared to a survey with 20 m grid spacing.

There is often confusion between photo "pixel size" and survey grid spacing. These are not the same. For example, a survey with 1 m grid spacing and 0.2 m Root Mean Squared Error (RMSE) vertical accuracy could be derived from satellite photos of any pixel size between 0.3 m and 0.5 m. Similarly, an airborne LiDAR survey with 0.2 m RMSE accuracy and a 1 m grid spacing may have an accompanying airborne orthophoto with a 0.15 m pixel size (or no orthophoto at all).

1.1.2 *Accuracy*

This is defined both horizontally and vertically, and it should be reported using standard methodologies such as the United States Geological Survey (USGS) survey accuracy standards. Users should be wary of using survey data if the accuracy level is not reported or does not use a National Standard for reporting.

As an example, the high-accuracy satellite surveys produced by PhotoSat have vertical and horizontal accuracies better than 0.2 m RMSE (LE90 0.3 m) reported using the USGS standards. These satellite surveys have a consistent accuracy level across entire survey areas covering hundreds of square kilometres, and the accuracy is publicly reported (Mitchell, G., 2016).

Lower accuracy topography such as SRTM or other "off the shelf" Digital Terrain Models (DTMs) have inconsistent accuracy and may include areas with large elevation errors. Errors can include:

- **General widespread errors which show up as "tilts".** For example, rivers may have sections where channel and surrounding area is tilted upward making the water in the river appear to flow up-hill.
- **Smaller areas with larger errors.** Examples of these are false "obstructions" or "holes" in the riverbed area.
- **Incorrect channel widths or depths.** These may be caused by poor resolution, however the errors are more frequently caused by local vertical errors associated with the difficulty of measuring elevations in narrow channels.

Examples of these error types are shown in the comparison.

Other sources of topography may be available depending on where in the world the TDBA is to be done. Commercial (not free) topography may claim better accuracy, however it may be costly and the actual accuracy may not be validated. In some cases, topography may be derived from contour maps; however, the user is cautioned that a smaller contour interval does not guarantee a higher accuracy level, and all contours are an approximation of the original topographic surface.

To the best of our knowledge, the highest accuracy produced from satellite is achieved using PhotoSat's geophysical algorithms. Airborne LiDAR can produce similar accuracy and may get better results in densely vegetated areas.

1.2 *Infrastructure, land use, vegetation, and hydrography*

The location of infrastructure, land use and vegetation can be determined using satellite orthophotos or airborne photos. For infrastructure purposes, a photo with a pixel size of 0.5 m may be adequate. Satellite photos with pixel sizes of 0.3 m are available, and Airborne LiDAR can provide photos with 0.15 m pixel size or smaller.

Digitized "footprints" of buildings, centerlines of roads and hydrography (digitized stream channels) can also be derived, however a high-accuracy topographic surface with vertical accuracy better than 0.5 m RMSE is generally required for this.

To be useable, the infrastructure photos should be geolocated and matched to the topography within at least 1 m RMSE horizontally.

1.3 *Current data*

For some TDBAs recent survey data may be essential. Examples include:

- Areas where there is changing human infrastructure such as buildings, bridges, construction etc.
- Large flat areas such as the deserts or river flood plains where the river channels may have changed due to the impact of flash floods or landslide events.

1.4 *Practical considerations*

Other considerations may include how complete the data coverage for the area is, its format, the co-ordinate system and availability of an accuracy assessment and documentation for the survey. In many cases, it may be faster and hence less expensive to acquire fresh satellite surveys rather than attempting to assemble and "repair" legacy survey data.

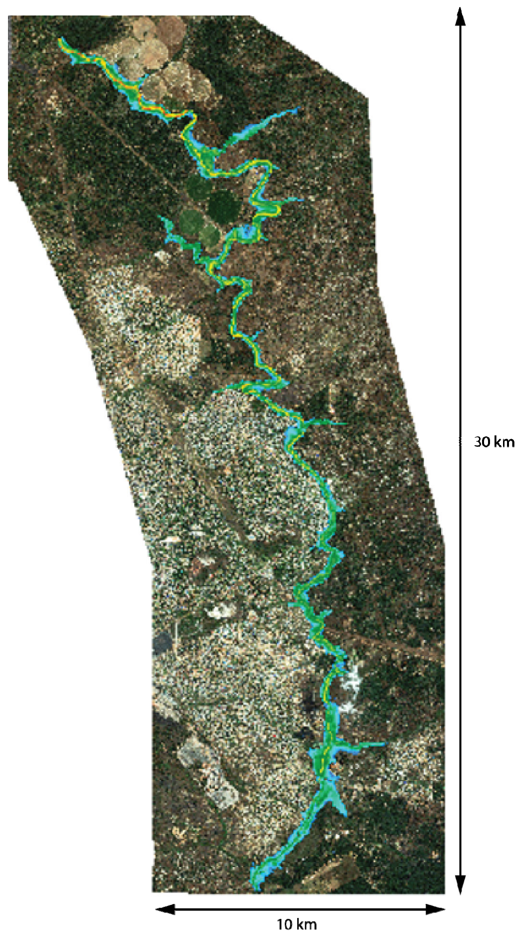

Figure 1. TSF downstream area

2 CASE STUDY ASSESSING THE IMPACT OF TOPOGRAPHY ERRORS ON A TDBA

2.1 *The topography data sets used for comparison*

This study compared dam breach run-out simulations for an area in Africa downstream of a mid-sized tailings facility. The area includes residential and commercial neighbourhoods and large, flat areas of un-developed African thorn scrub and agricultural land upstream of the urban areas.

It should be stressed that the results of the modeling do not reflect an actual TDBA simulation for this TSF or this area. They are intended only to illustrate the impact of topography accuracy for a hypothetical simulation.

An orthophoto of the area with an example DBA simulation is shown in Figure 1. The photo area is over 400 square kilometres in size.

For comparison, SRTM was chosen as a low-resolution data set, while a PhotoSat satellite survey was used for the high-accuracy survey. Satellite surveys are available for any part of the earth. STRM is available for most areas between latitudes -60 to 60. Both have well-documented accuracy levels and can be obtained without the need for a site visit. The comparison topography data sets used are summarised below:

Table 1. Specifications of topography used for comparison

Specification	SRTM	High-accuracy survey
Source	Shuttle Radar Topography Mission (SRTM)	High-resolution satellite photos processed with PhotoSat Geophysical processing algorithms
Elevation grid spacing (m)	30	1
Vertical accuracy (m RMSE)	2—3 (Gesch, D. 2019 USGS)	<0.2 (Mitchell, G., 2016 PhotoSat)
Accuracy Reporting standard	USGS	USGS
Vertical accuracy consistency	Varies with terrain and location.	Specific tools are used to ensure reliable accuracy in river channels.
Survey date	Various dates in 2000	14:04 GMT March 23rd, 2020
Associated orthophoto resolution for infrastructure, land use, vegetation, and hydrography	SRTM does not provide a high-resolution orthophoto. For this comparison, the geo-located high-resolution satellite photo with 50 cm pixel size from the high-accuracy survey was used to show the areas modeled. This photo was precision orthorectified to match the topography of the high-accuracy survey.	

2.2 *Dam breach outflow hydrograph*

Since the purpose of this study was to assess the impact of topography errors on run-out modeling, rheological parameters were selected from literature, and a modified hydrograph derived from the Mount Polley dam breach (Petkovšek et al, 2020) was used instead of modeling an actual breach.

The modified hydrograph represents a dam breach lasting approximately seven hours with a maximum flow rate of 2500 m³/s. An arbitrary inflow location in the north of the river corridor was selected.

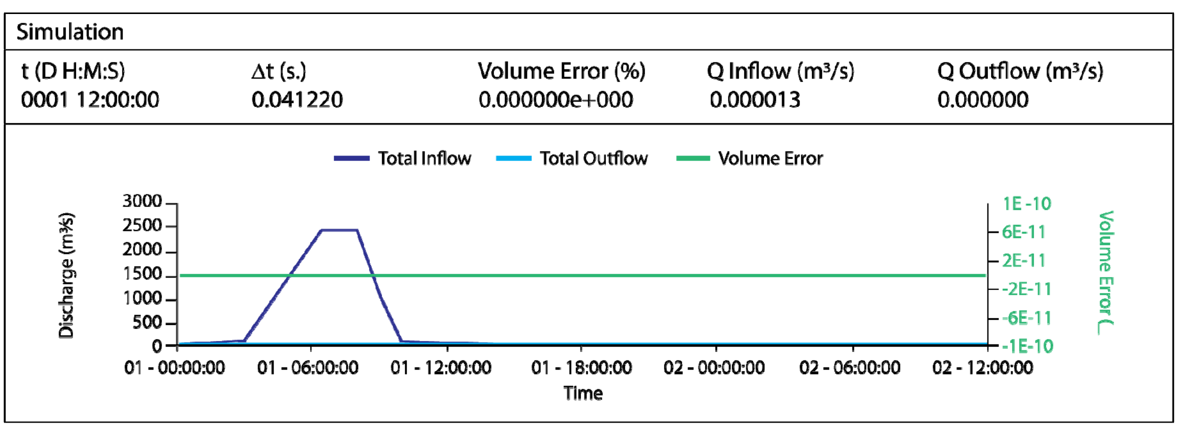

Figure 2. Hydrograph used for dam breach simulations

2.3 *TDBA modeling*

The inundation results were simulated using the Hydronia RiverFlow2D software, which is one of several modeling tools frequently used for this type of analysis.

RiverFlow2D is a finite-volume engine that allows visualization of two-dimensional hydraulic and hydrologic mesh models. The Mud and Tailings Flow module of the software allows flow simulations with varying rheological parameters.

The non-Newtonian tailings behavior was simulated using a Full Bingham flow resistance relation. Yield stress, viscosity, and density for three solids concentration by volume (Cv) values of 0.25, 0.38 and 0.50 were calculated using the equations derived by O'Brien & Julien (1988) for the Glenwood 1 sample. The examples were chosen to highlight the differences related to survey accuracy and resolution for various Cv values.

Other parameters were held constant including a Manning's roughness coefficient of 0.06 for the simulations. The initial conditions in the river were modeled assuming a dry riverbed.

Since the resolution of SRTM is 30 m, an initial simulation cell size of 30 m was chosen for the comparison. The high-accuracy survey has a resolution of 1 m which allowed simulations with smaller cell size to be done and compared.

2.4 *Modeling outcomes – key differences*

Key differences caused by differences in the accuracy and resolution of the topography are:

- Differences in the size and location of inundation areas.
- Differences in the maximum depth of predicted inundation.
- Differences in the total length of the inundation path.
- Differences in flood arrival time.
- Differences in depth-velocity product.

Examples to highlight and quantify these differences are shown for urban and rural areas below:

2.4.1 *Example 1 - Run-out area differences - urban area*

Figure 3 shows the predicted maximum depth using a Cv of 0.38. There are significant differences in the results. In some places, the SRTM simulation predicts a depth of over 15 m, while the high-accuracy survey predicts a depth of 9 m.

A possible cause of the depth differences are large, localized vertical errors in the SRTM data. These errors result in holes or obstructions in the river channel which do not actually exist.

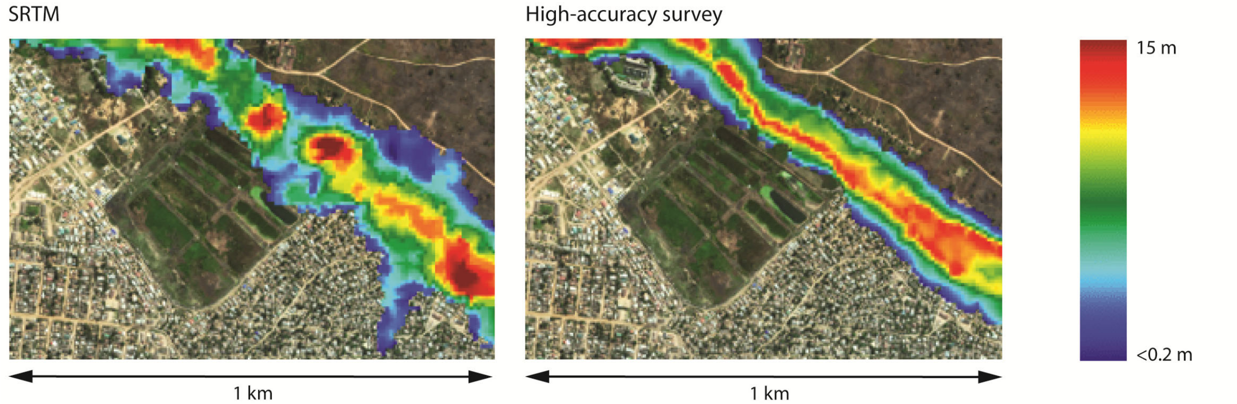

Figure 3. Comparison of inundated areas and maximum flow depths in an urban area

There are also significant differences in the location and size of the predicted inundation areas. Figure 4 shows colour-coded areas where the simulations were different. In this case the SRTM simulation predicts that significant additional areas with urban development would be inundated which may result in an inappropriate or misdirected emergency response plan.

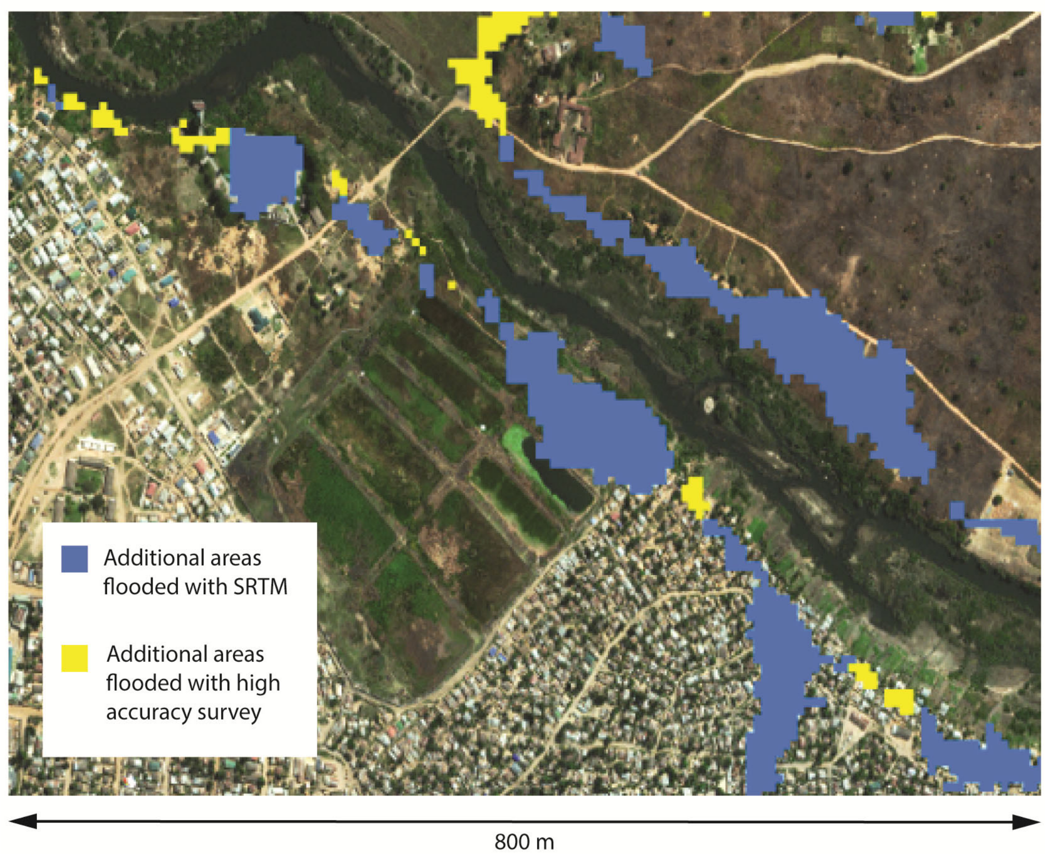

Figure 4. Inundated area differences

2.4.2 *Example 2 - Run-out area differences – Flat, rural area*

Differences can also be seen in the simulations done in a rural area using a Cv of 0.38. This is shown in Figure 5.

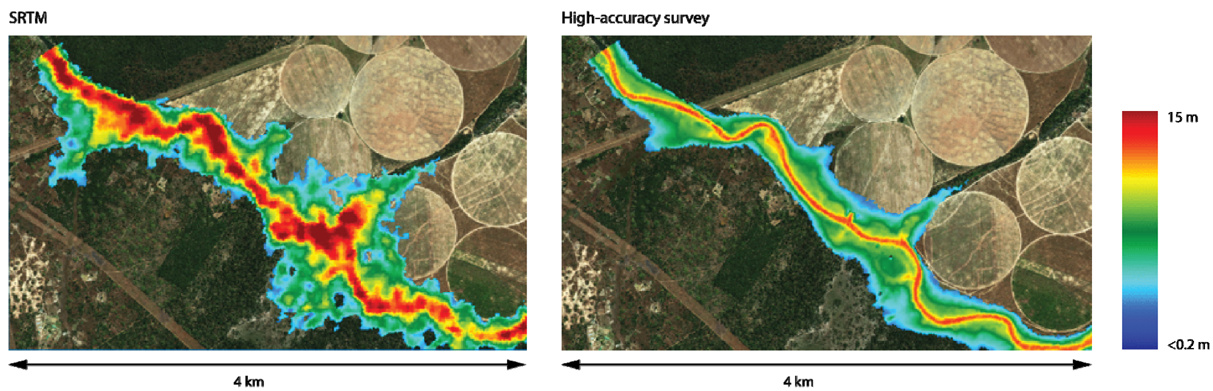

Figure 5. Comparison of inundated areas and maximum flow depths in flat rural areas

Similar to example 1, both the predicted depth of inundation and the area covered differ between the simulations. In this case the SRTM simulation predicts that large additional areas would be flooded with some areas flooded to a depth of up to 15 m.

2.4.3 *Example 3 – Differences in channel width and depths*

The cross section shown in Figure 6 shows the shape of the river channel along the cross section line shown in yellow in the photo.

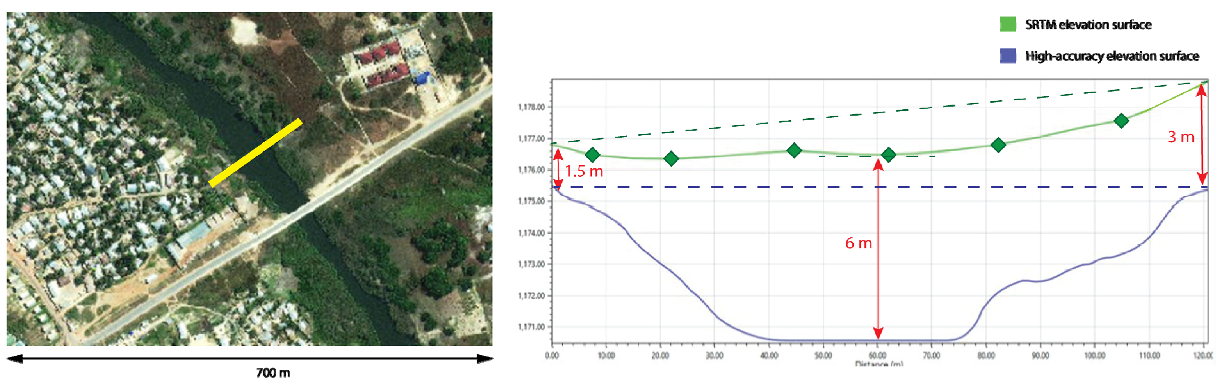

Figure 6. Comparison of SRTM and high-accuracy survey along yellow profile line

In both cases, the cross section shows the top surface of the water in the channel; neither data set shows the below-water surface. As a result, a wider or deeper river would have a more inaccurate cross section in both cases.

The high-accuracy survey, however, shows a much better definition of the shape of the channel. As was reported in previous studies (Halliday, A., 2019), the channel width is affected by resolution and in this case the high-accuracy survey constrains the flow to a narrower channel in this area.

However, the cross section also shows that the SRTM in this area has local tilt and elevation offset making the terrain 1.5 m – 3 m higher on the banks and 6m higher in the channel. This significant elevation difference impacts the simulation as shown in Figure 7.

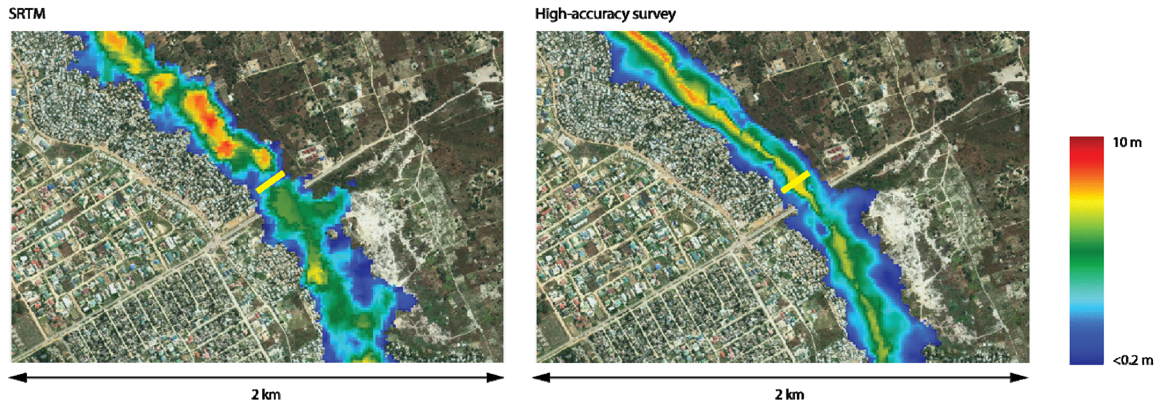

Figure 7. Comparison of maximum depth and areas covered in the vicinity of the black profile line

Similar elevation errors were seen in many locations along the river channel. It should be noted that the errors in the SRTM data were detectable only because a high-accuracy reference surface was available for comparison.

2.4.4 *Example 5 - Differences in Depth-Velocity product*

Depth-Velocity product (DV) is often used as an indicator of the flood severity and degree of damage that may be caused by an arriving flood wave. In the same area as the profile line shown in Figure 7, a comparison of DV using a Cv of 0.25 is shown in Figure 8. The considerable local differences in the DV results could be caused by elevation errors at this location or by differences in depths and velocities due to elevation errors further upstream or a combination of both.

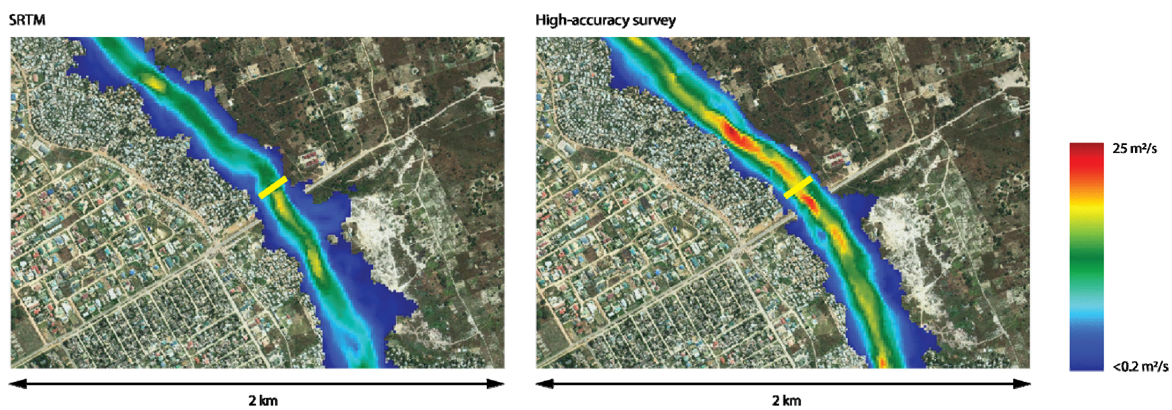

Figure 8. Comparison of Depth Velocity (DV) in the vicinity of the black profile line

2.4.5 *Example 6 – Differences in flood length*

Figure 9 shows the tailings run-out area for the model run using the highest solids concentration of Cv of 0.5, which had the rheology representing the least flowable material. In this case, the high-accuracy, high-resolution topography results in an inundation area that extends an additional 1.5 km further down the channel. This is contrary to the idea that lower resolution results in longer flood lengths. The shorter flood length for the SRTM simulation is probably caused by vertical errors in the riverbed which result in "holes" which have to be filled by the arriving tailings material before it continues downstream.

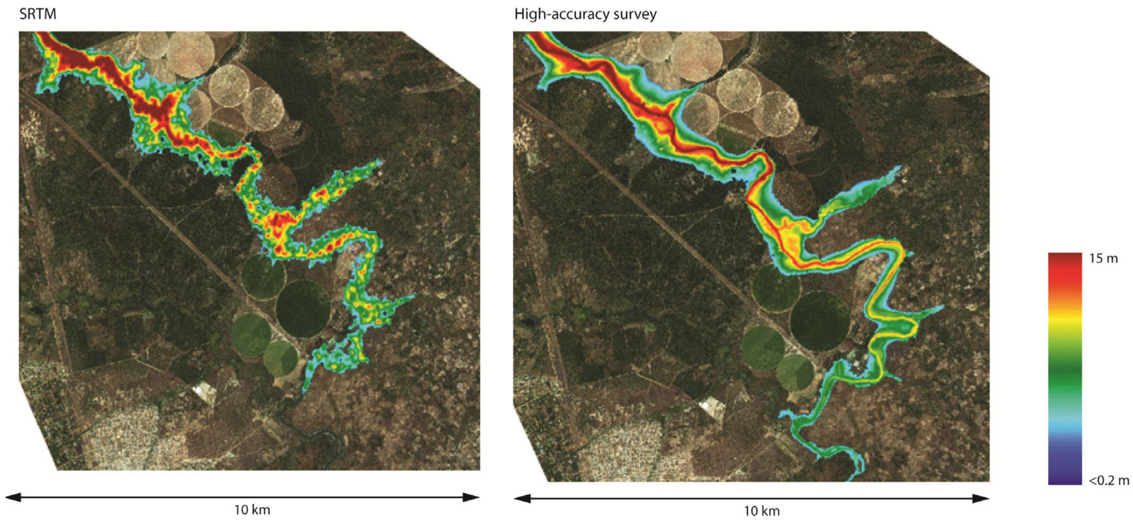

Figure 9. Comparison of flood distance

Note that in addition to a different overall flood length, different areas are flooded, and the depths are different. In general, in the high-accuracy survey the simulation of the tailings run-out appears to be more accurately constrained by the river channel.

2.4.6 *Example 7 - Differences flood arrival time*

Flood arrival times were simulated. The difference in arrival time with a Cv of 0.25 is shown in Figure 9. This shows that the arrival times differ by up to 7 hours at the furthest downstream end of the channel. The low-resolution SRTM in this simulation predicts a later arrival time in the urban areas which refutes the general conclusions that lower resolution results in faster flows reported in previous studies. This can have a major impact on emergency response planning and highlights the importance of high-resolution topography requirements when the flood wave propagates through areas with populations at risk.

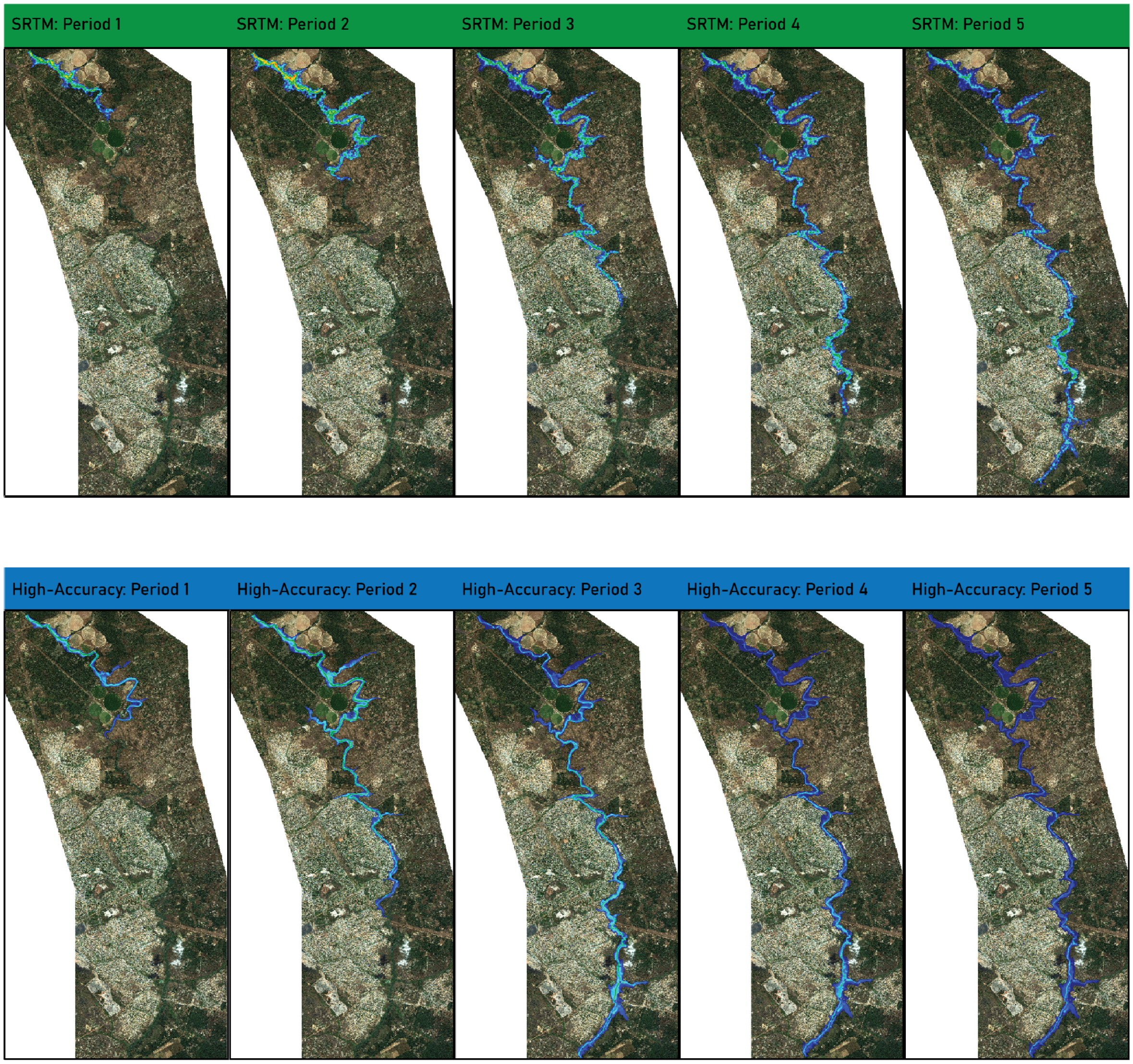

Figure 10. Difference in flood arrival time

2.5 *Impact of smaller simulation cell size*

Smaller cell size results in an intuitively better simulation, however a smaller cell size is only possible if the topography has sufficient initial resolution and accuracy to support the smaller cell size.

The high-accuracy survey would allow cell sizes as small as 1 m while the SRTM would be limited to a minimum size of 30 m. Previous studies have noted that choosing a smaller simulation cell size does not repair low-resolution topography (Halliday, A., Arenas, A. 2019).

3 CONCLUSIONS

Both accuracy and resolution of the topography significantly impact the results of the TDBA simulation results. Differences in results were noted for the size and location of inundation areas, the depth of predicted inundation, the total length of the inundation path, and the flood arrival time. These differences were apparent in both narrow valleys and wide flood plain areas.

In some areas the impact of vertical accuracy errors were more significant than the impact of lower resolution. These differences were significant, particularly in urban areas.

The outcome of this study supports the general conclusion of previous studies and the CDA (2021) recommendation that the best quality topography should be used; however, it also highlights the importance of accuracy versus resolution in the topography used. The results of this study are applicable for any flood mapping study including dam breaches of water and tailings dams.

4 ACKNOWLEDGEMENTS

PhotoSat would like to thank Dr. Violeta Martin of Knight Piésold for her support and in particular her advice in selecting suitable parameters for the simulations.

5 REFERENCES

ASPRS and USGS standards – for example “Positional Accuracy Standards for Digital Geospatial Data.”

Canadian Dam Association (2021). Technical Bulletin: Tailings Dam Breach Analysis.

Gesch, D. (2019) Accuracy Assessment of Elevation Data. USGS (EROS).

Gesch, D., Oimoen, M. Evans, G. (2019) Accuracy Assessment of the U.S. Geological Survey National Elevation Dataset, and Comparison with Other Large-Area Elevation Datasets—SRTM and ASTER.

Halliday, A., Arenas, A. (2019) Impacts of Topography Quality on Dam Breach Assessment Golder Associates

Halliday, A., (2019) The Value of Detailed Topographic Surveys for Consequence Classifications Using Dam Breach Assessments - Golder, Chile

Mitchell, G., (2016) Accuracy assessment – WorldView 3, Garlock Fault, 1GCP, 13cm RMSE 22cm LE90.

O'Brien, J.S., & Julien, P.Y. (1988). Laboratory Analysis of Mudflow Properties. *Journal of Hydraulic Engineering, 114*, 877-887.

Petkovšek, Gregor & Hassan, Mohamed & Lumbroso, Darren & Roca, Marta. (2020). A Two-Fluid Simulation of Tailings Dam Breaching. Mine Water and the Environment. 40. 1-15. 10.1007/s10230-020-00717-3.