Comparison of Topography for Dam Breach Analysis

Impacts of Accuracy and Resolution on Flow Modeling Results

PhotoSat
Better Data for Better Decisions

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Abstract

With the release of the Global Industry Standard on Tailings Management, many mining companies are now required to conduct detailed dam breach analysis (DBA) for these tailings storage facilities (TSFs).

It is not uncommon for TSFs to have potentially large inundation areas, which may stretch hundreds of kilometres downstream of the TSF.

DBAs often begin with a dam breach simulation, where engineers use flow modeling software to define the potential inundation area. A complete set of topography for the area downstream of the TSF is a primary input for these simulations. Once the inundation area is defined, the full DBA can be completed with an impact assessment, emergency response plan, and more.

In this comparison, two sets of topographic data are used to produce flow models for a dam breach simulation: SRTM DEM and a PhotoSat survey. The results demonstrate the impacts of both low-resolution and low-accuracy on the flow model produced in the dam breach simulation.

For full results, read the report.

Contents

List of Tables

List of Figures

Introduction

In this report, PhotoSat completes a series of dam breach simulations to illustrate the impact of accuracy and resolution on the flow model.

Dam Breach Analysis

With the release of the Global Tailings Standard, mining companies around the world have completed dam breach analyses (DBA) for their tailings storage facilities (TSFs).

A DBA has many components, and most begin with defining the inundation area that lies downstream of the TSF. To define the inundation area, engineers produce a flow model using software.

A primary input into the flow modeling software is a complete topographic surface for the area downstream of the TSF. These areas can stretch hundreds of kilometers downstream and may cover thousands of square kilometers.

Dam breach simulations include several parameters, including the inflow location (starting point), amount of tailings discharged, and fluid dynamics.

In 2020, the Canadian Dam Association (CDA) published the Technical Bulletin: Tailings Dam Breach Analysis. This bulletin provides a framework for a DBA, with recommended software programs for flow modeling and guidelines on topography.

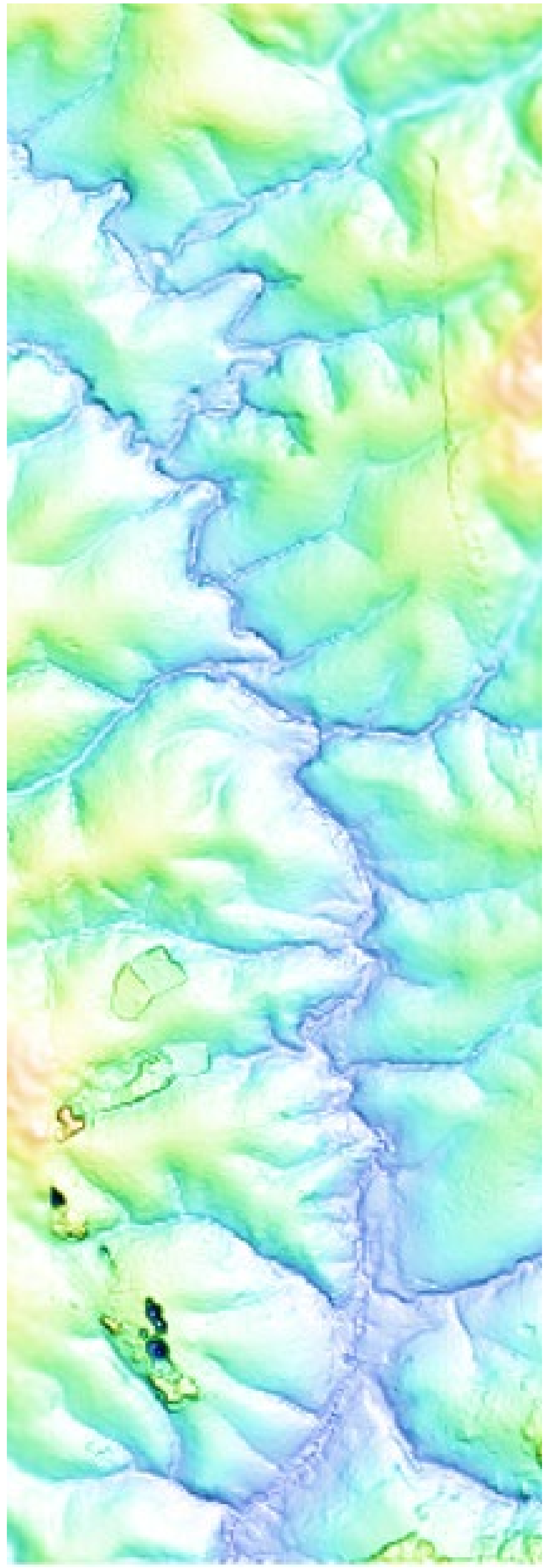
Flow Model Comparison

Previous studies have suggested that low resolution leads to larger inundation areas, greater flow volumes and more rapid flood streams. However, the results of this comparison show that resolution may in some circumstances cause underestimates of flood distance and inundation area.

The purpose of this comparison is to demonstrate how both accuracy and resolution influence the results of a flow model for a DBA.

Topographic Data for the Flow Model

These are some basic considerations when selecting topography for dam breach simulation:



Resolution

The spacing between points in the elevation grid—resolution—determines two things:

- Possible cell sizes for the flow model
- Level of detail in the topographic surface

A high-resolution elevation grid is desirable to ensure that important features in the downstream area are well-represented in the dam breach simulation.

Accuracy

Vertical accuracy, or absolute accuracy, is a measurement of how close to reality an elevation point is. When ground control is available, it is possible to measure the vertical accuracy of a topographic data set.

The CDA recommends using the best available topography, and also recommends conducting a sensitivity analysis on the results.

Area

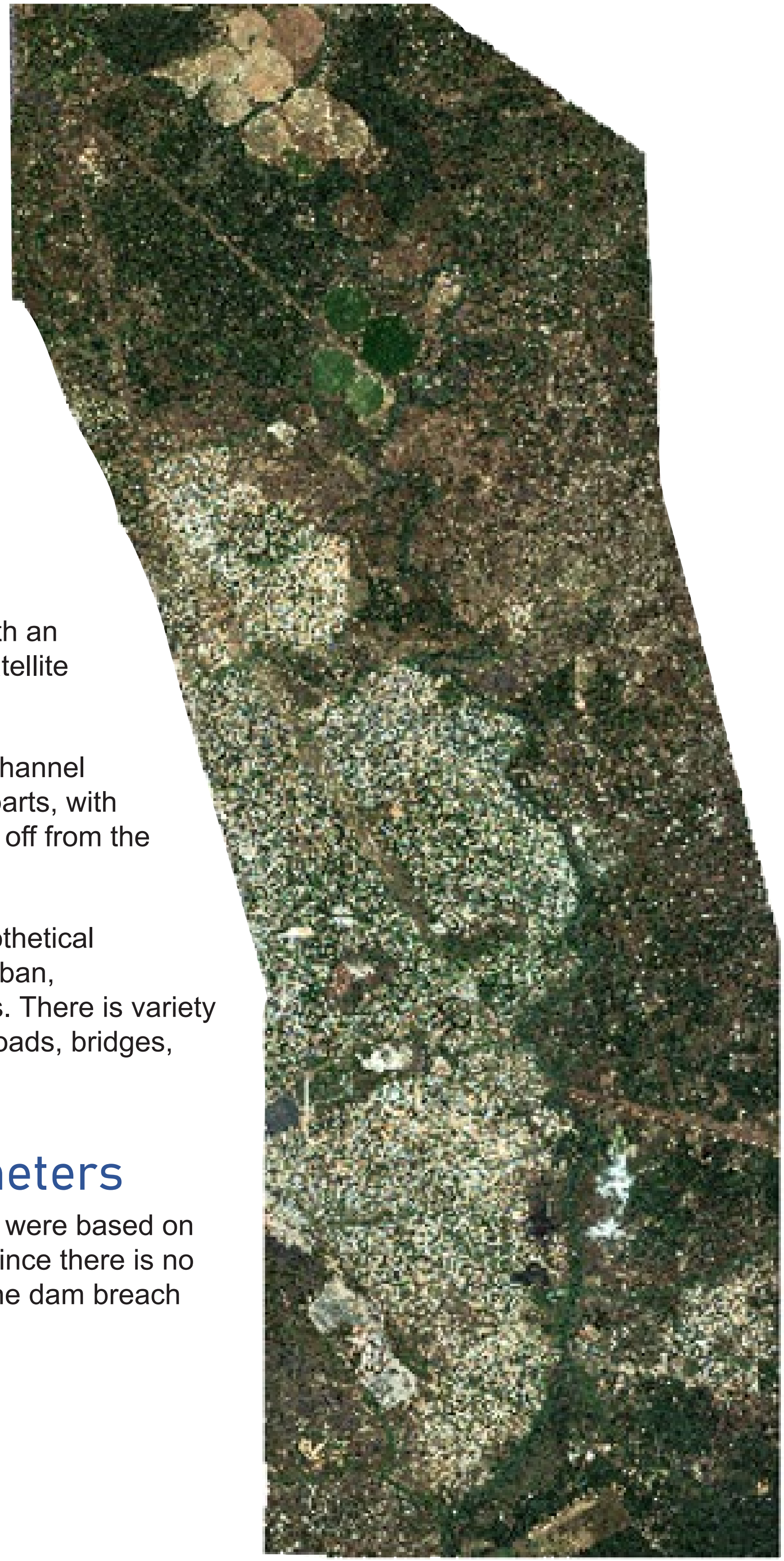
The topographic surface of the downstream area needs to be large enough to fully contain the flow of the discharged tailings.

Date

It is crucial that the topography used reflects the current state of the downstream area, with close attention to infrastructure, land use, and habitation.

Methods

In this comparison, PhotoSat has followed the recommendations in the CDA's Technical Bulletin: Tailings Dam Breach Analysis (CDA, 2020).



Site Selection

IMPORTANT: The site shown in this comparison does not lie in a potential dam breach inundation area.

The site was selected for these reasons:

- **Available topography.** Both an SRTM DEM and archive satellite imagery exist for the site.
- **Terrain variety.** The river channel includes narrow and wide parts, with smaller rivulets that branch off from the main river channel.
- **Inundation area.** The hypothetical inundation area includes urban, agricultural, and rural areas. There is variety of infrastructure including roads, bridges, and buildings.

Dam Breach Parameters

The parameters for the simulation were based on a real-world dam breach failure. Since there is no actual TSF, the starting point for the dam breach was arbitrarily selected.

- Dam breach duration: 7 hr
- Maximum flow: 2500 m^3/s
- Manning's roughness: 0.06
- Riverbed condition: dry

Topographic Data Sets

In this comparison, two sets of topographic data (Table 1) were used. The SRTM DEM (Fig 1) was selected because it is publicly available for most sites between latitudes of -60 to 60, and its accuracy and resolution are well-documented. The PhotoSat survey (Fig 2) was selected to represent a survey with high-accuracy and high-resolution.

Table 1. Specifications of topographic data sets

Specification	SRTM DEM	PhotoSat survey
Source	Shuttle Topography Radar Mission (SRTM)	WorldView-3 satellite imagery processed with proprietary deep learning algorithms
Date of Acquisition	Unknown dates in 2000	14:04 GMT March 23rd 2020
Resolution (m)	30	1
Vertical Accuracy (m RMSE)	2—3	<0.2

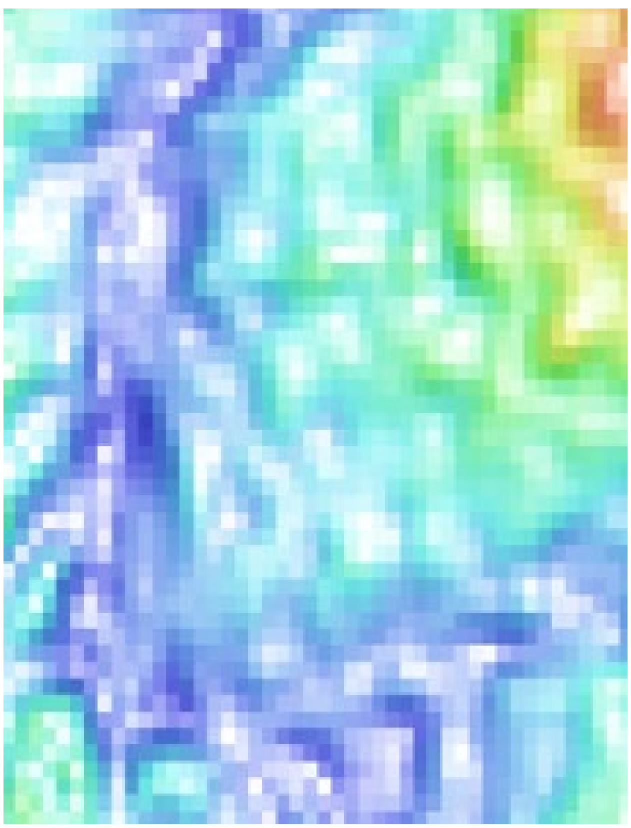


Figure 1. Example of the SRTM DEM

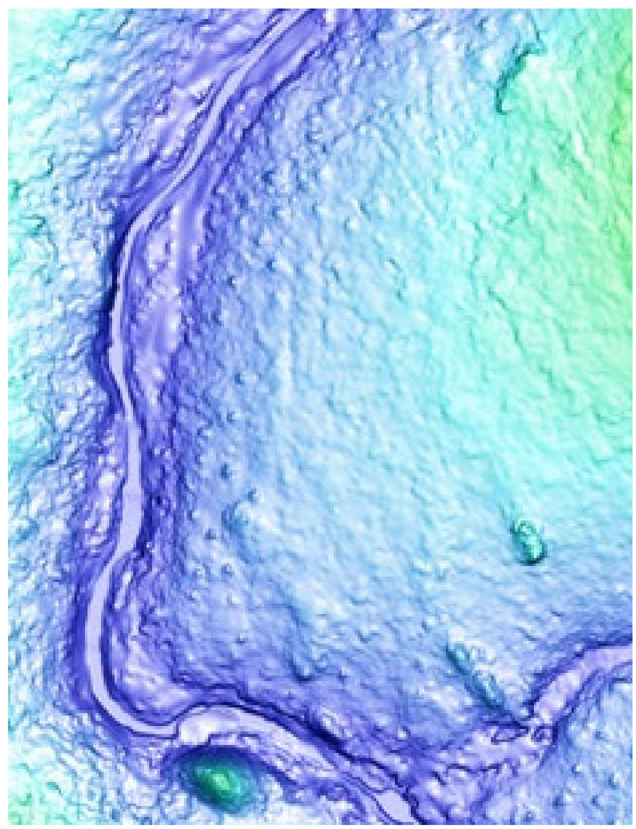


Figure 2. Example of PhotoSat survey

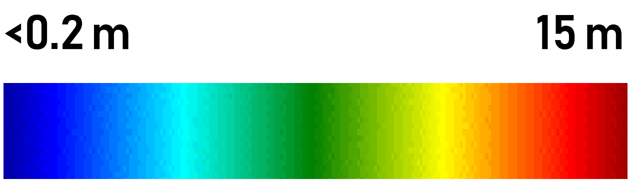
Dam Breach Simulations

For this comparison, Hydronia RiverFlow2D was selected from the CDA's list of recommended software programs.

PhotoSat ran three simulations using three different concentration by volume (Cv) values: 0.25, 0.38, and 0.50 (Fig 3 to Fig 5). The Cv value defines fluid behaviour, including its yield stress, density, and viscosity.

Flood Depth Scale Bar

The images that follow use this scale bar for flood depth:



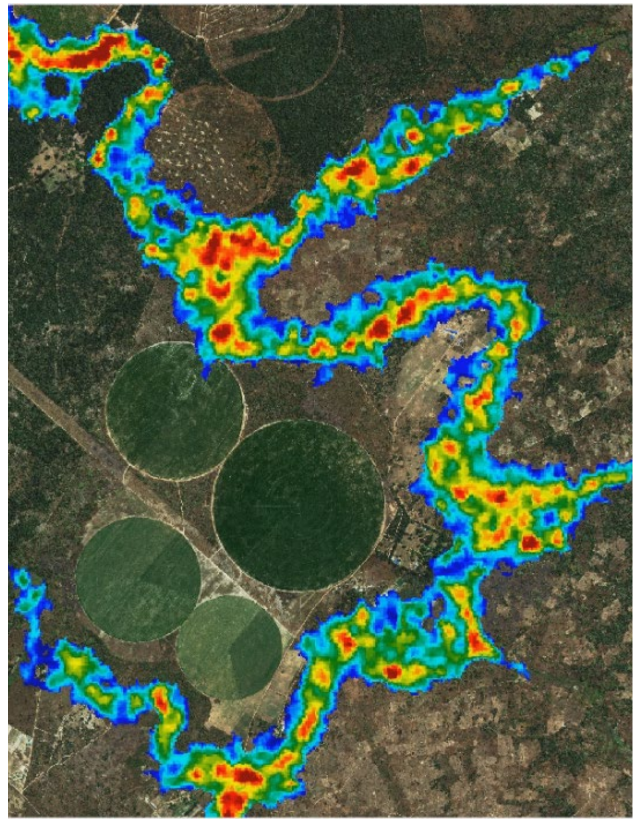


Figure 3. Flood depth with SRTM (Cv = 0.25)

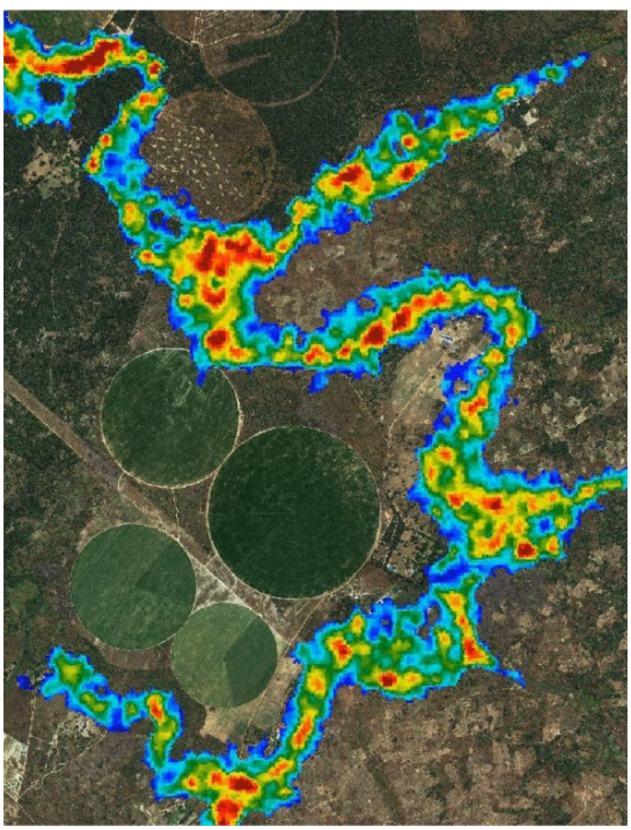


Figure 4. Flood depth with SRTM (Cv = 0.38)

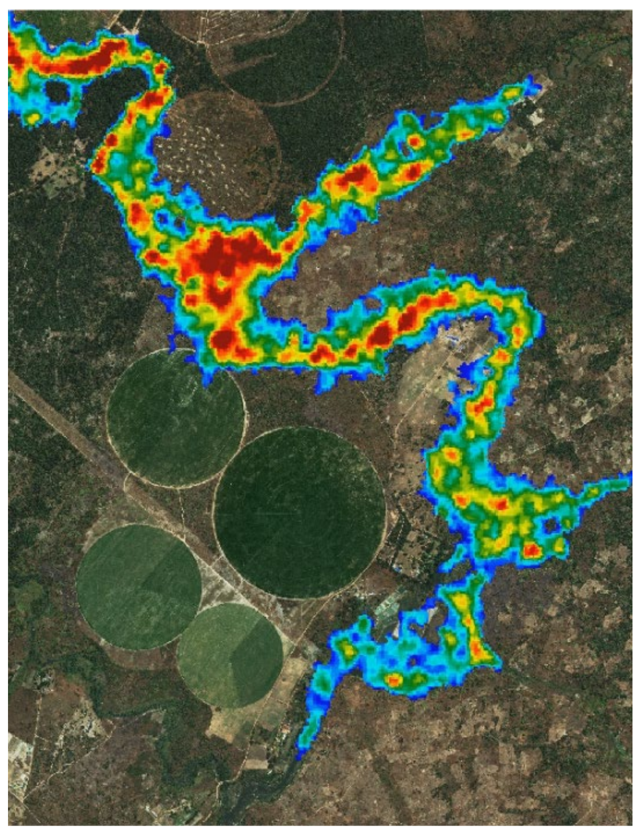


Figure 5. Flood depth with SRTM (Cv = 0.50)

Results

There are differences in location of the inundation area, the size of inundation area, flood depth, and flood distance.

Example 1: Different Inundation Area

In this example (Fig 6 to Fig 8), the river passes through an urban area.

The inundation area is highly irregular in Figure 7, likely due to vertical errors in the SRTM DEM.

In addition to producing different inundation areas, the flood depth in Figure 7 is inconsistent and does not follow the river channel as shown in Figure 6 or Figure 8.

Figure 6. Orthophoto of urban area

Figure 7. Flood depth in urban area with SRTM (Cv = 0.25)

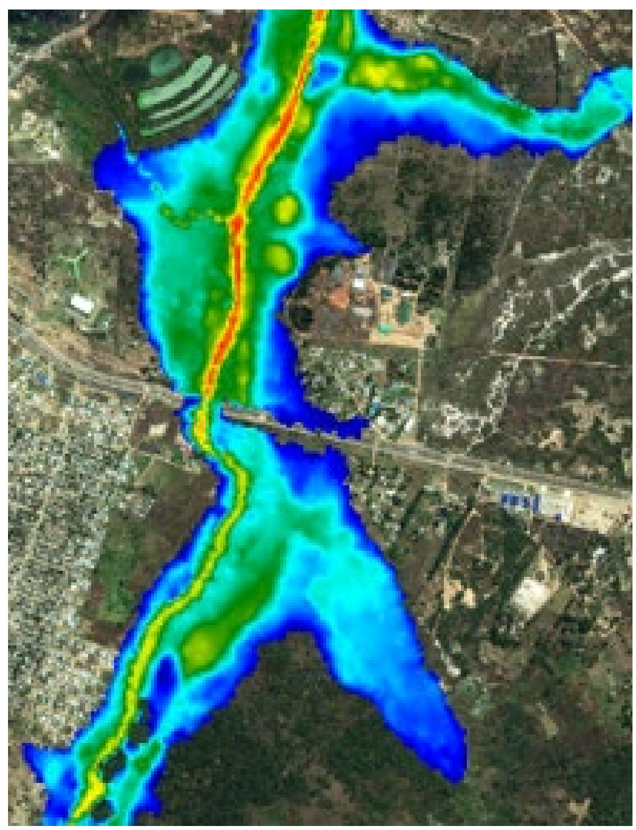


Figure 8. Flood depth in urban area with PhotoSat survey (Cv = 0.25)

Example 2: Different Flood Distance and Depth

This example (Fig 9 to Fig 11) shows a densely populated urban area on a bend in the river.

The difference in the flood distance (Fig 10) is significant, possible since SRTM does not define narrow channels well. In addition, the lower vertical accuracy of the SRTM surface creates artificial ‘holes’ within the channel that shorten the flood distance as tailings volume fills these holes rather than continuing downstream.

As a result, the flow model produced with SRTM does not extend as far as the flow model produced with a higher-resolution and higher-accuracy surface (Fig 11).

Figure 9. Orthophoto of river bend

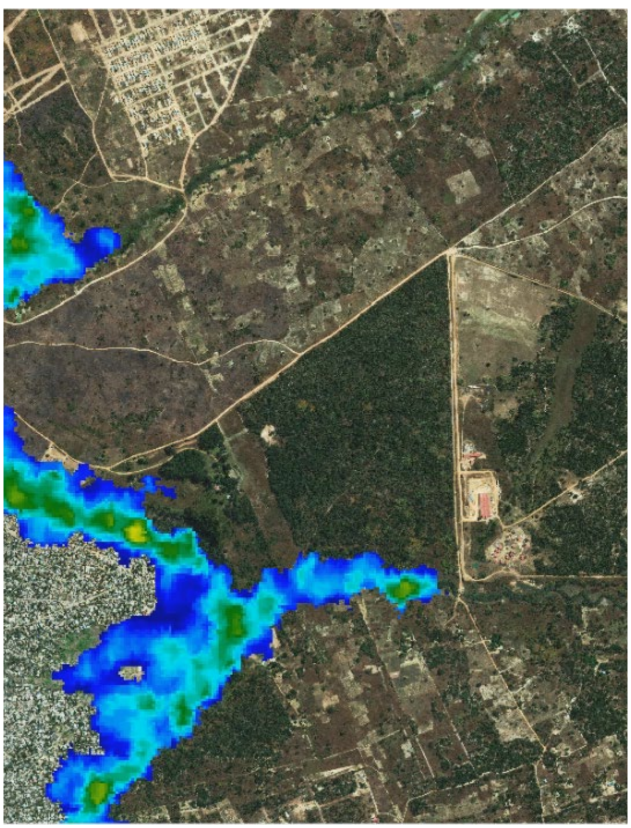


Figure 10. Flood depth at river bend with SRTM (Cv = 0.25)

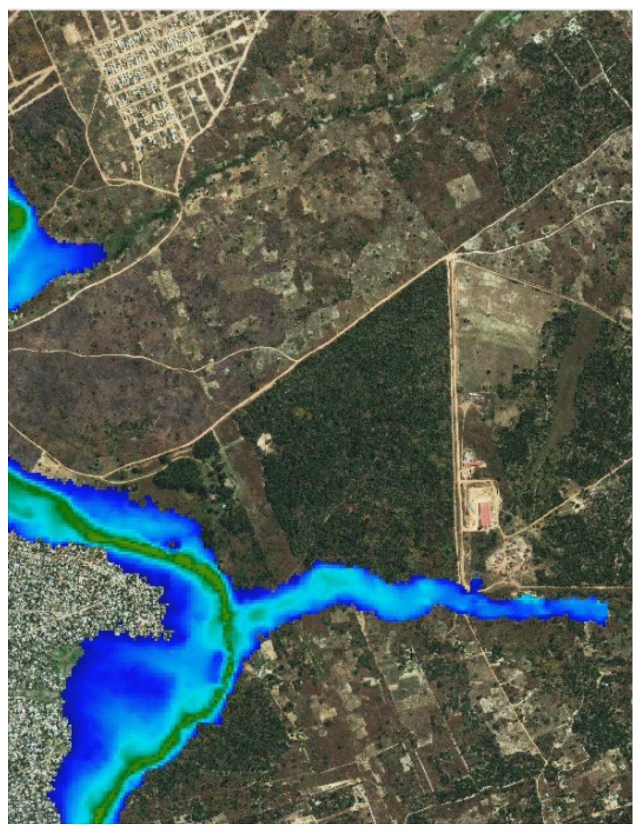


Figure 11. Flood depth at river bend with PhotoSat survey (Cv = 0.25)

Example 3: Different Inundation Area and Flood Depth

This example (Fig 12 to Fig 14) shows a wider section of the riverbed, with flat surrounding terrain.

In Figure 13, the inundation area covers a significantly different area as compared to Figure 14.

In addition, the estimated flood depth in Figure 13 is different, both in the extent of the depth and the location of the deeper inundation areas.

Like in example 2, the SRTM surface contains errors that create false pits or holes which affect the flow of tailings.

Figure 12. Orthophoto of wide river channel

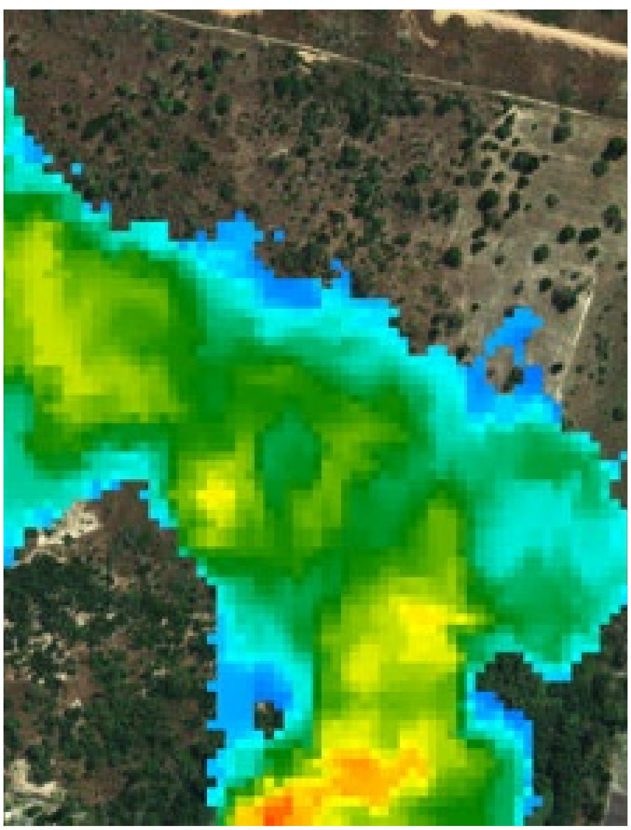


Figure 13. Flood depth at wide river channel with SRTM (Cv = 0.25)

Figure 14. Flood depth at wide river channel with PhotoSat survey (Cv = 0.25)

Example 4: Different Inundation Area

This example (Fig 15 to Fig 17) shows a narrow section of the riverbed, next to some steeper terrain.

In Figure 16, the inundation area covers a significantly different area as compared to Figure 17. The estimated flood depths are also different.

On page 16, the comparison of elevation profiles (Fig 18) shows vertical errors in the SRTM DEM.

SRTM has poor definition in the narrow sections of the river channel. A consequence of poor definition in topography is that the flow model cannot fill small spaces, which leads to an altered inundation area.

Figure 15. Orthophoto of narrow channel

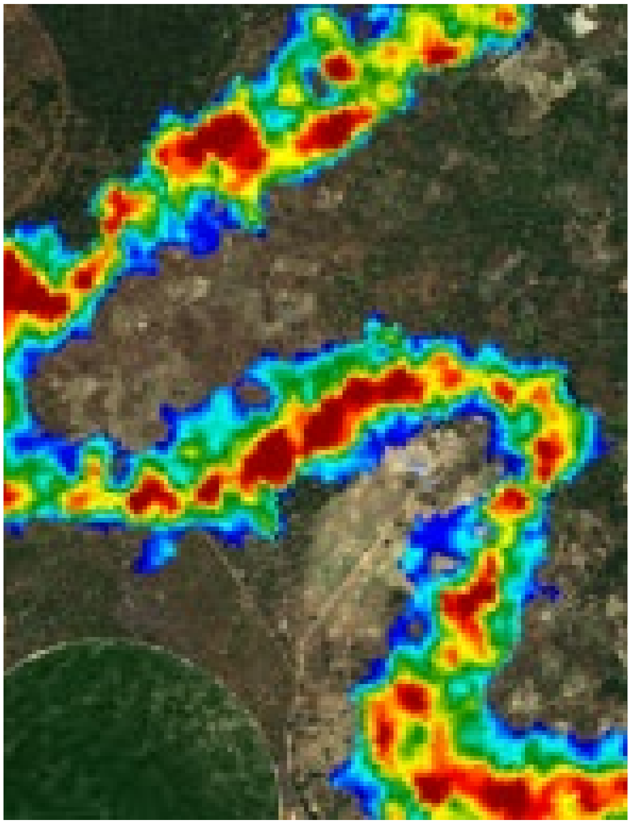


Figure 16. Flood depth at narrow channel with SRTM (Cv = 0.25)

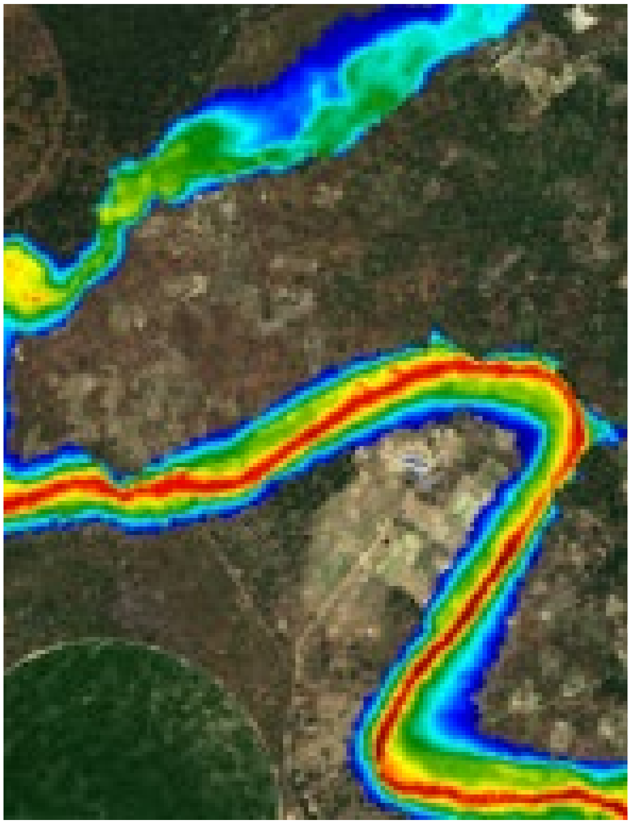


Figure 17. Flood depth at narrow channel with PhotoSat survey (Cv = 0.25)

Figure 18 shows the profiles of the SRTM DEM and the PhotoSat survey. The topography from SRTM (Fig 19) is visibly uneven, compared to the PhotoSat survey (Fig 20).

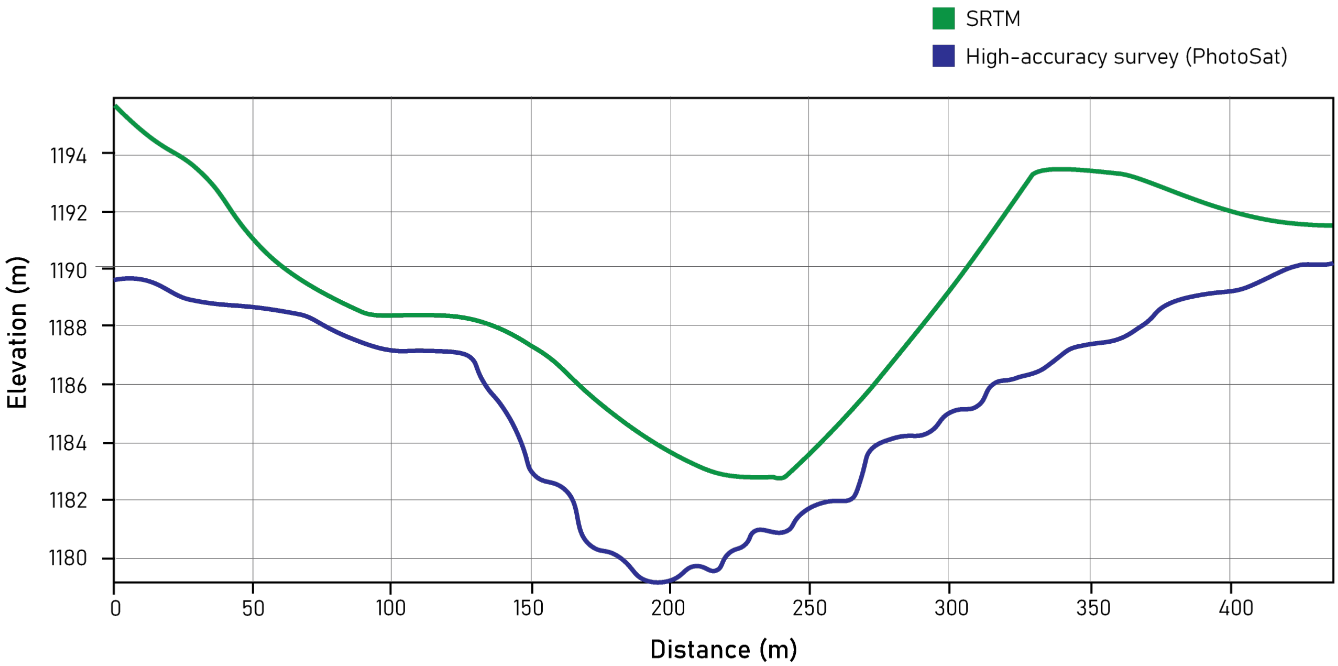


Figure 18. Comparison of elevation profiles at narrow river channel (at black line)

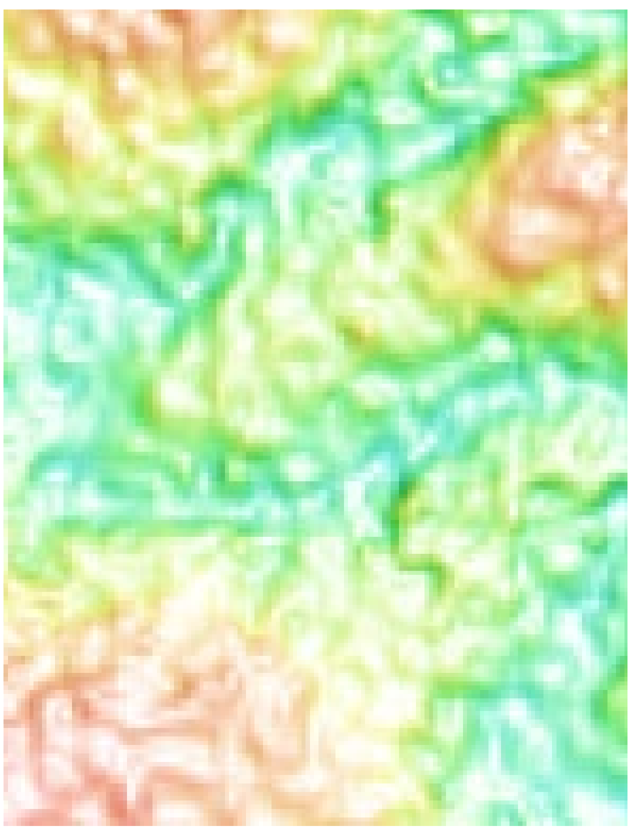


Figure 19. SRTM DEM at narrow river channel

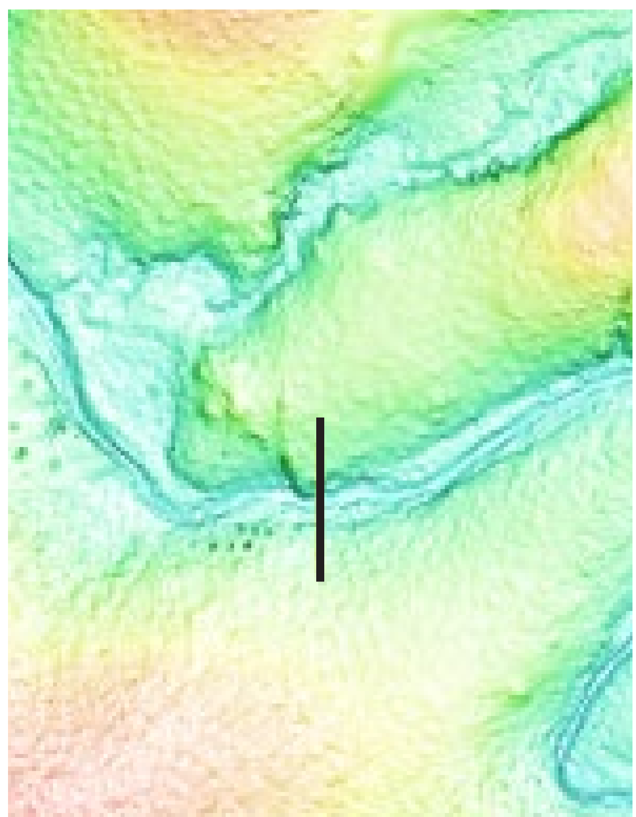


Figure 20. PhotoSat survey at narrow river channel

Example 5: Different Size and Location of Inundation Area

This example (Fig 21 to Fig 26) shows an agricultural area with flat terrain around the riverbed.

In Figure 22, the inundation area covers a significantly different area as compared to Figure 23, and the estimated flood depth is also different.

On page 18, the comparison of profiles shows that the SRTM DEM has a large vertical offset as compared to the PhotoSat survey. Here, low-accuracy and low-resolution have compounding effects. This results in a higher and more shallow topographic surface, which in turn results in a different inundation area.

Figure 21. Orthophoto of flat terrain near river

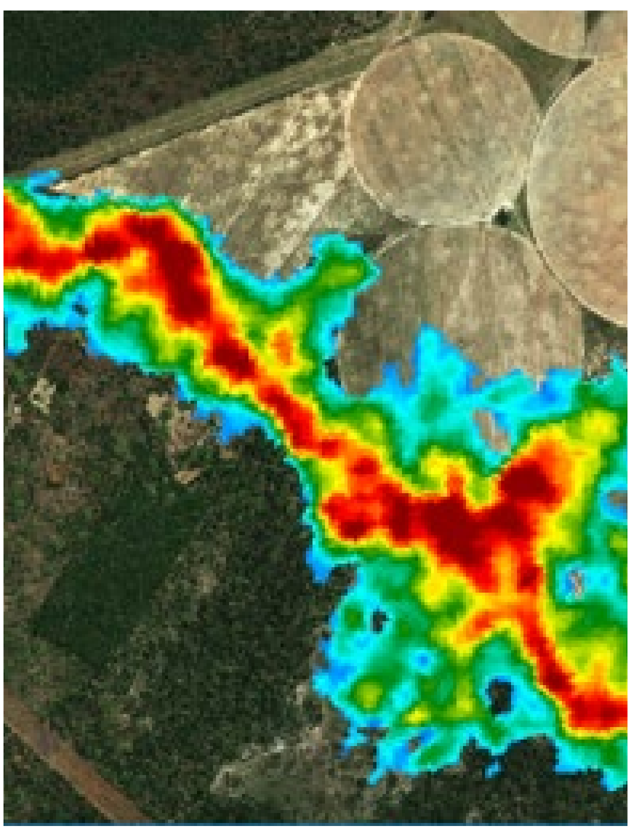


Figure 22. Flood depth at flat terrain near river with SRTM (Cv = 0.25)

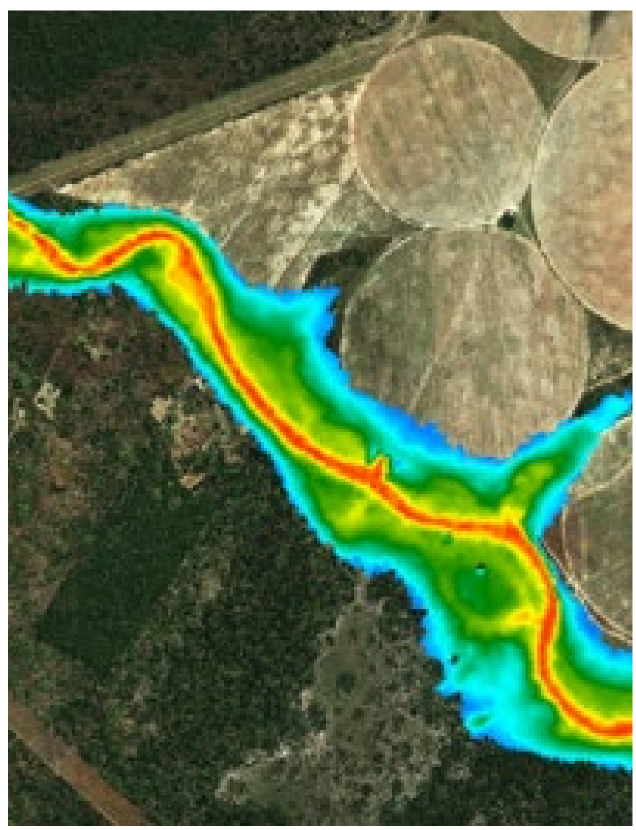


Figure 23. Flood depth at flat terrain near river with PhotoSat survey (Cv = 0.25)

Figure 24 shows the profiles of the SRTM DEM and the PhotoSat survey. The topography from SRTM (Fig 25) is visibly uneven, compared to the PhotoSat survey (Fig 26).

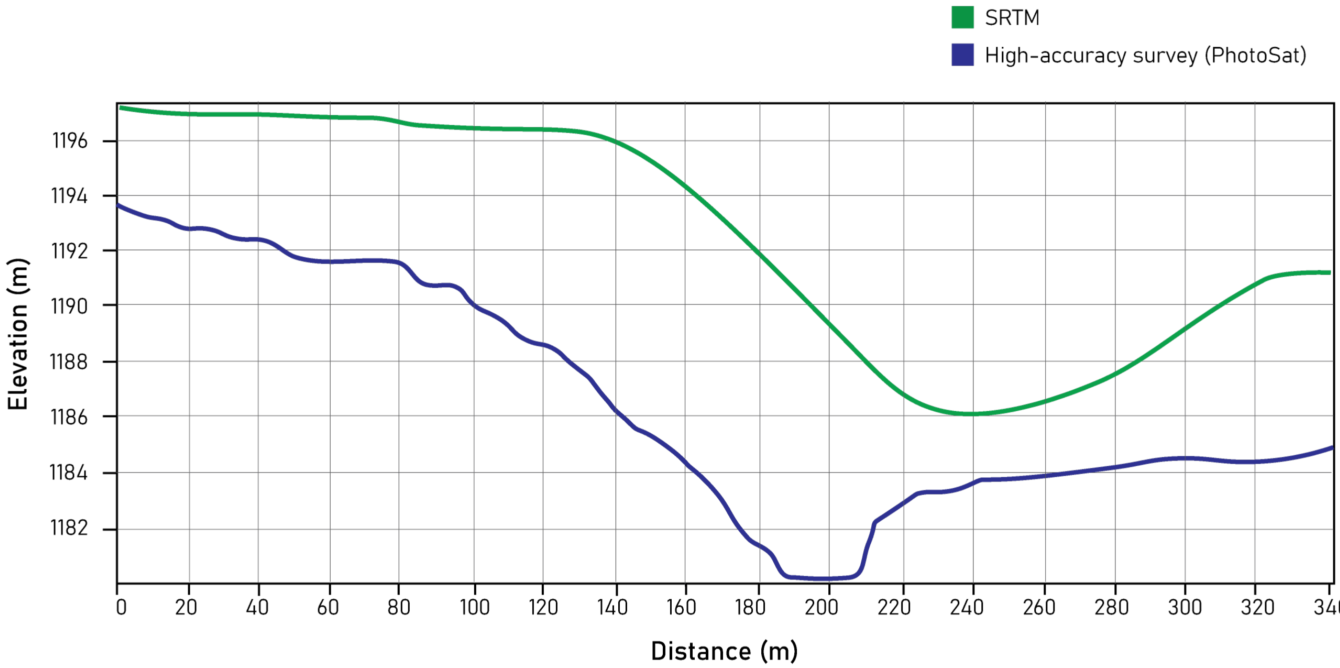


Figure 24. Comparison of elevation profiles of flat terrain near river (at black line)

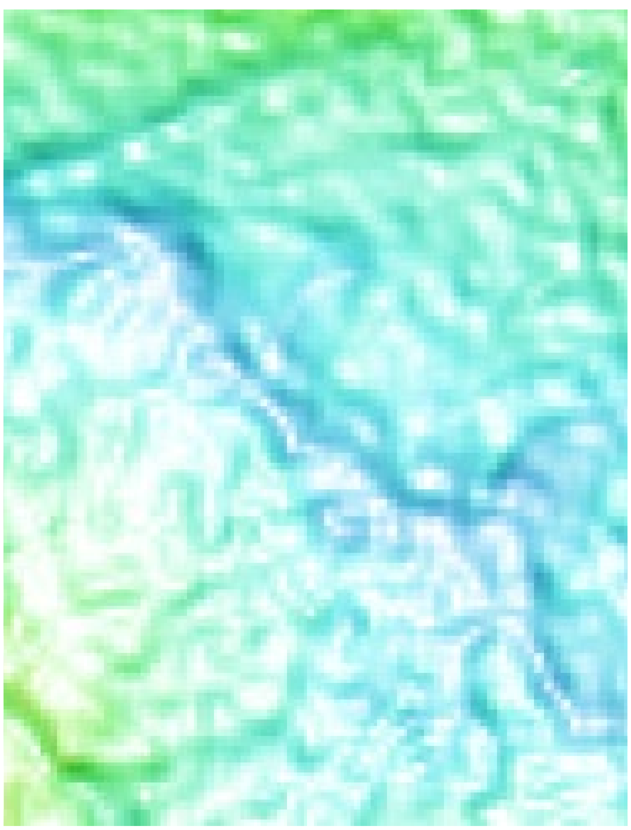


Figure 25. SRTM DEM of flat terrain near river

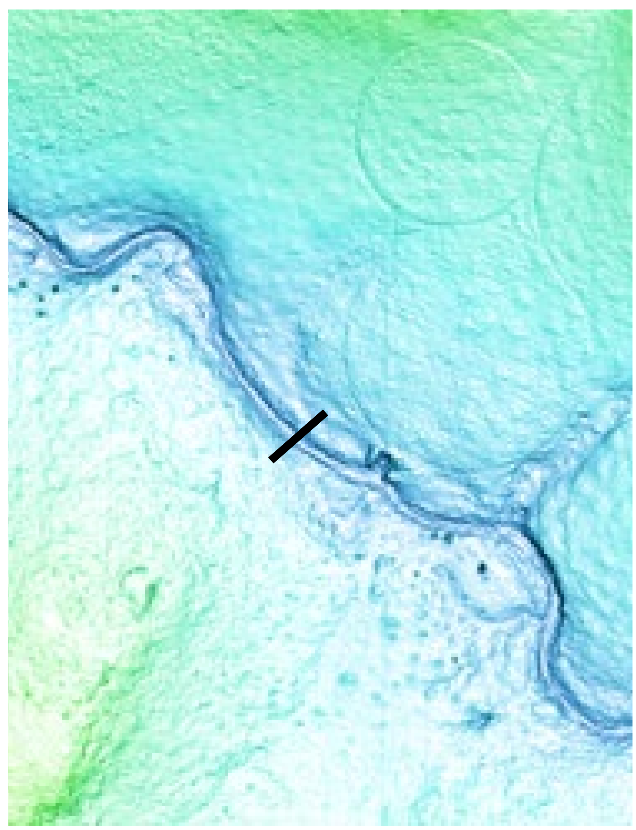


Figure 26. PhotoSat survey of flat terrain near river

Discussion

Accuracy and resolution are separate charactistics of topography. Both can affect the results of a flow model, but in different ways.

Resolution

Grid resolution influences the level of detail in a topographic surface and affects the possible cell size that can be used in a simulation. Flow models from low-resolution topography may show differences in the inundation area and flood distance.

Accuracy

Accuracy has both a vertical and a hortizontal component. Horizontal accuracy affects the location of features within an area, while vertical accuracy affects the elevation of the surface.

When vertical accuracy is low, flow models may show differences in inundation area size, inundation area location, and flood depth.

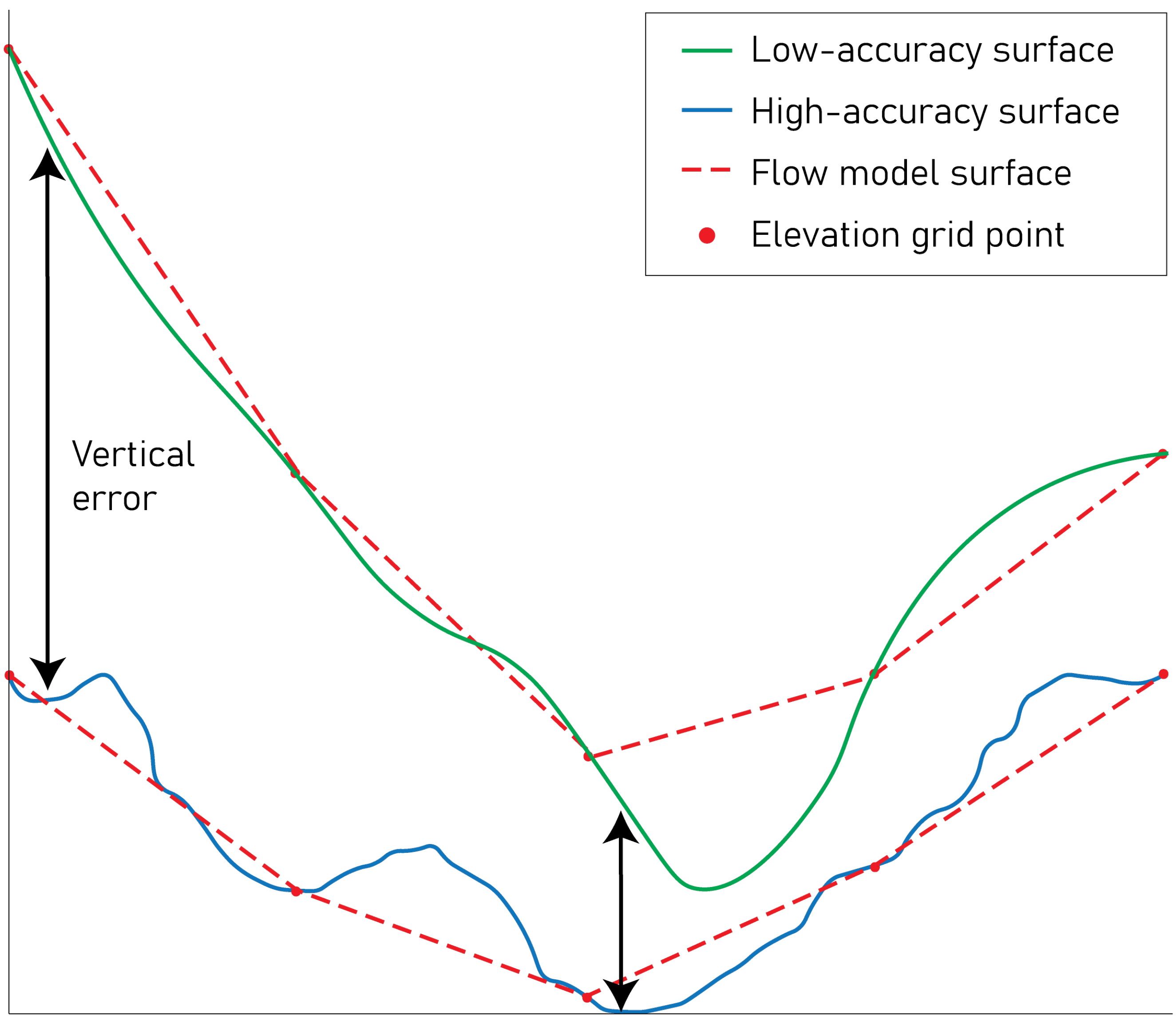


Figure 27. Combined effects of accuracy and resolution

Low Resolution

For many engineering applications, a high-resolution grid of 1 m or better is usually required.

The SRTM DEM has an elevation grid resolution of 30 m, and the PhotoSat survey was produced with an elevation grid resolution of 1 m.

NOTE: Accuracy and resolution are independent characteristics of topography. Resolution is not an indicator of accuracy, nor is accuracy an indicator of resolution. However, to accurately capture the features of variable terrain, it is important to have sufficient detail (i.e. resolution).

Impacts on Detail of Ground Features

Because there is a lower density of ground points, low-resolution topography shows limited detail particularly for small ground features.

Figure 28 shows a cross-section of a hypothetical surface with a low-resolution elevation grid and a higher resolution grid. The low-resolution grid loses detail because of the large grid spacing, whereas the higher-resolution surface is able to define smaller changes on the ground.

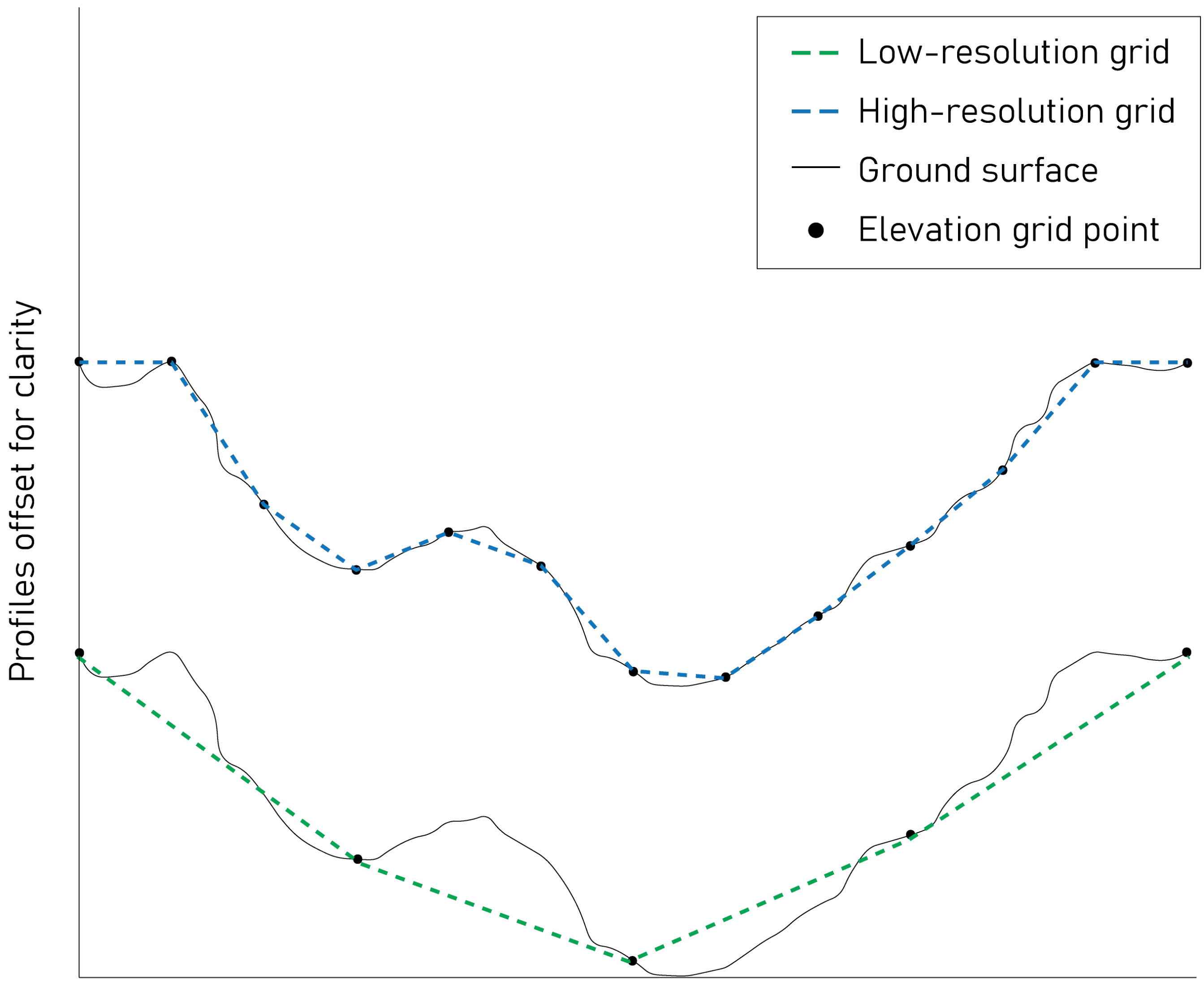


Figure 28. Effects of low-resolution versus high-resolution

Impacts on Flow Model Cell Size

In a dam breach simulation, the cell size of the flow model can be equal to or larger than the elevation grid spacing, but not smaller.

Low Resolution

The SRTM DEM has a known resolution of 30 m, allowing for a 30 m cell size in a flow model.

Large cell sizes, like those shown in Figure 29 and 30, leave unintended gaps that cannot be filled in the simulation.

High Resolution

When elevation grids have higher resolution, a smaller cell size as shown in Figure 31, can be used in the flow model. This lets the flow model closely follow the surface of the inundation area.

The flow models produced from high-resolution topography are a more plausible representation of what might actually occur in a real-world dam failure.

NOTE: High-resolution topography leads to larger file sizes, which may slow down the simulation time.

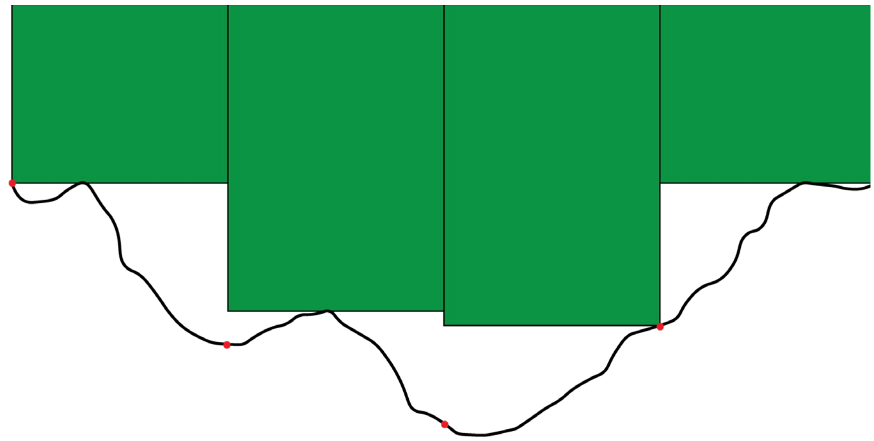


Figure 29. Cell size for a low-resolution elevation grid (spacing = 15n)

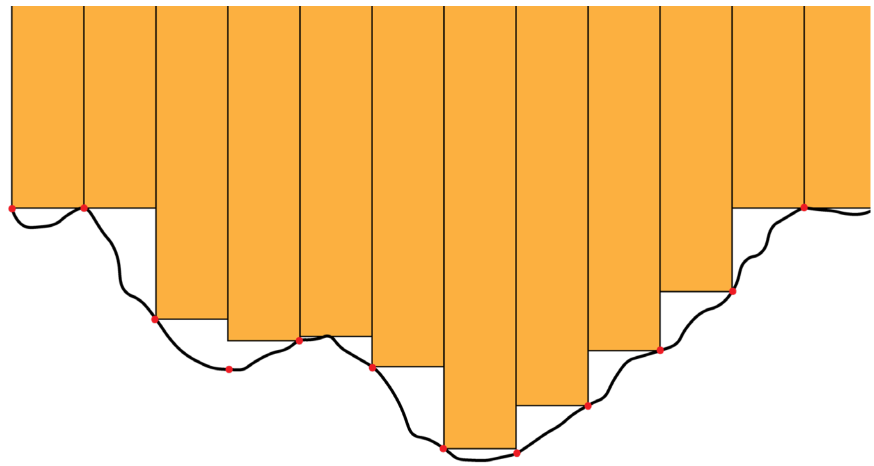


Figure 30. Cell size for a medium-resolution elevation grid (spacing = 5n)

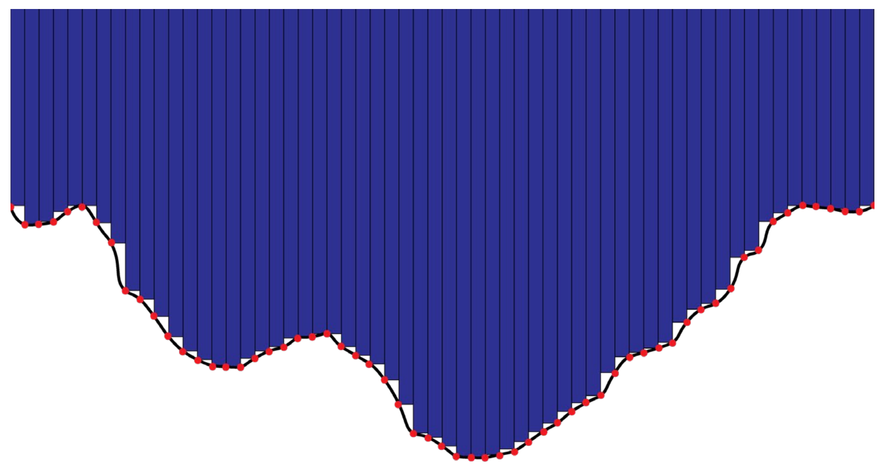


Figure 31. Cell size for a high-resolution elevation grid (spacing = n)

Low Accuracy

There are many different types of errors that can impact a flow model.

Offsets

When the same error affects all or a majority of points in an elevation grid, this is considered an offset. The entire elevation grid will appear shifted or "offset" in a specific direction.

Tilting

With this type of error, false slopes appear in the topography.

Vertical Errors

Vertical errors that are small and localized create false features in the terrain.

- **Positive errors:** These create false obstructions or islands. In a simulation, the tailings flow around these.

- **Negative errors:** These create false pits or depressions in the surface. In the simulation, the discharged tailings needs to fill these before continuing downstream.

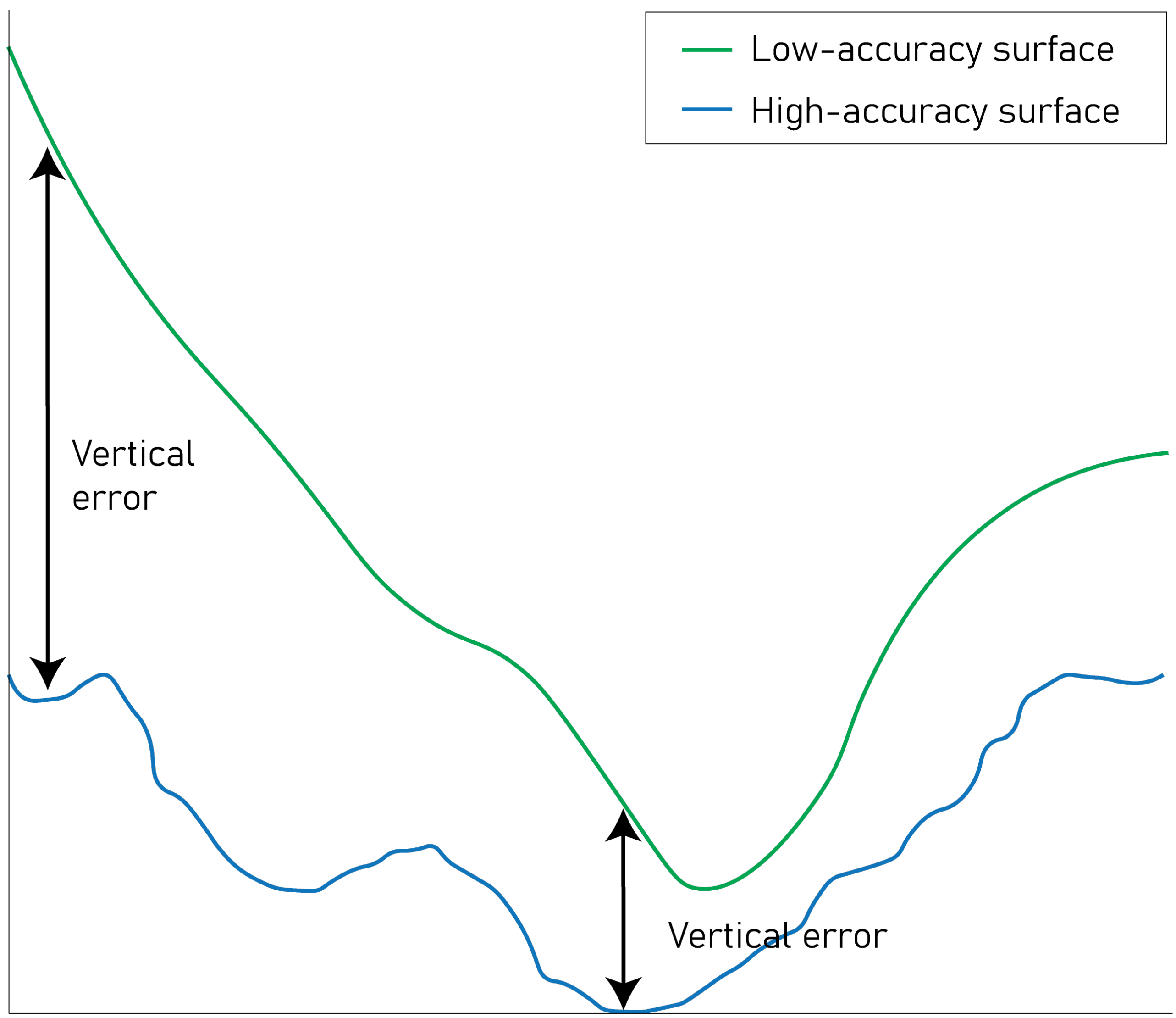


Figure 32. Effects of low-accuracy versus high-accuracy

Conclusions

This comparison demonstrates that both accuracy and resolution hold significant influence over flow model results.

The simulation results presented in this comparison show significant differences in:

- Size and location of the inundation area
- Estimated flood depth
- Estimated flood distance

These differences occurred across a variety of terrains, from wide flat areas to narrow channels and steeper areas.

DBA Cost and Timeline

For mining companies, a DBA is a significant investment in terms of cost, time, and effort.

Experienced engineers also know that "repairing" low-quality data is inefficient and in most cases ineffective.In reality, an early commitment to high-quality topography can reduce delays in completing the DBA and avoid potential problems in the dam breach simulations.

DBA Credibility

Estimates of inundation area, flood depth, and flood distance are key drivers in the development of the impact assessment, emergency response plan (ERP), and environmental remediation plan. These estimates may lead to potential limitations on land use or occupancy in the downstream area.

If using low-quality topography, engineers run the risk of introducing significant errors at the flow modeling stage that misinform the DBA.

Considering the wide-reaching social, environmental, and economic implications, it is reasonable to assert that a DBA should begin on a foundation of high-quality topography.

Ultimately, downstream topography requires a high-accuracy and high-resolution to ensure that the results of the flow model, and by extension the DBA, are realistic and credible.

About PhotoSat

PhotoSat produces elevation surveys from satellite imagery using proprietary deep learning algorithms.

Satellite Imagery

To produce each elevation survey, PhotoSat uses stereo pairs from high-resolution optical satellites.

Satellite imagery is captured from hundreds of kilometers above the earth's surface, potentially covering hundreds of square kilometers in a single pass. PhotoSat works with a range of commercial satellite operators, including Airbus and Maxar.

Deep Learning

PhotoSat's methods are based on geophysical processing, with proprietary deep learning technology.

An important feature of deep learning is that the convolutional neural network (CNN) is trainable. As a result, the process is continually improving.

Accuracy Testing

PhotoSat has published more than 50 accuracy studies, which are available at no cost. Each study examines the accuracy achieved using a specific satellite with a specific amount of ground control.