D3.1 Prototype Description

V2.3

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Authors:	Daniele Fantin, S&T NO	
Approval (internal)	Ton Peters (Deltares)	
Reviewer		
Approval (ESA)	Zoltan Bartalis	
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Table of Contents

List of Figures ... 4

List of Abbreviations and Acronyms ... 5

1 Introduction ... 6

2 Selection of EO products ... 7

2.1 Selection Criteria ... 7
2.2 The Questionnaire ... 7
2.3 Questionnaire Summary ... 8
2.4 Final Selection ... 8

3 Description of mock-up EO products ... 11

3.1 Stockpile Measurement ... 11
3.1.1 Test Sites ... 15
3.2 Ground Stability ... 16
3.2.1 Test Sites ... 18

4 Platform for EO products showcase ... 20

5 Users feedback from workshop 2 ... 22

5.1 Stockpile measurement ... 22
5.1.1 Accuracy ... 22
5.1.2 Functionalities ... 23
5.1.3 Barriers for full-scale implementation ... 23
5.2 Ground Stability ... 24
5.2.1 Accuracy ... 24
5.2.2 Functionalities ... 25
5.2.3 Barriers for full-scale implementation ... 25

6 Conclusions ... 27

Appendices ... 28

Appendix A – Questionnaire : Form and Results ... 28

List of Figures

Figure 2-1: The top-20 products, including their potential (the sum of their gap scores) – From D2.2 (Gap Analysis Report) ... 9
Figure 2-2: Chart showing the cycle coverage of Stockpile Measurement and Surface Subsidence products ... 9
Figure 3-1: Time series analysis of radar data which indicates when a small (yellow), reasonable (orange) or definite (red) changes occurred. ... 12
Figure 3-2: Example of an optical image with detected stockpiles and their estimated volume. ... 13
Figure 3-3: Overview map of the mock-up application that shows an open pit mine as the location of interest with the detected stock piles highlighted in orange ... 13
Figure 3-4: The mock-up application presents the user with the acquired optical imagery for each location with stockpiles, which can be easily reviewed using a slider to review the progress over time. ... 14
Figure 3-5: The result of the time series analysis for each stock pile can be accessed in the mock-up application and shows the occurrence of small (yellow), reasonable (orange) or definite (red) changes at the stockpile over time. ... 14
Figure 3-6: Skorpion Open Pit Mine, Namibia. ... 15
Figure 3-7: Belgard Quarry, Ireland ... 15
Figure 3-8: InSAR measurements over an urban area, based on Sentinel-1. Every dot represents a deformation time series, with the color indicating the average velocity over the time span: green is stable, red is subsiding. ... 17
Figure 3-9: InSAR deformation time series. These time series are underlying every point in the figure above and show the movements per observation date. Left: a time series showing a decelerating movement, right: a time series showing a sinusoidal movement, which is often related to thermal expansion or water-related effects. ... 18
Figure 3-10: Skorpion Zinc Mine, Namibia, open pit mine. ... 18
Figure 3-11: Cadia gold mine, Australia, tailings dam collapse. ... 18
Figure 4-1: The platform mock-up interface, showing an interactive map. In the lower-right corner the legend is shown, and different data layers/products can be selected to add to the visualization. In the lower-left corner a pop-up screen is available to show additional information on the visualized data. In this example, an InSAR time series is visualized after clicking on a measurement point, together with some metadata. ... 20
Figure 4-2: Toggling the different data layers on the bottom right of the screen allows for visualizing different products. ... 20
Figure 4-3: The InSAR time series window is interactive and has various functions, such as zooming in and out, taking screenshots and showing the values of the observations and the fitted trend. ... 21
Figure 4-4: An example of the additional functionalities of the platform mock-up: measuring areas interactively, with an alternative background map. ... 21
Figure 5-1: Pie chart showing the required accuracy for an operational ground stability service, according to the webinar participants (63 voters). ... 23
Figure 5-2: Pie chart showing the required accuracy for an operational ground stability service, according to the webinar participants (74 voters). ... 24

List of Abbreviations and Acronyms

EO	Earth Observation
EO4RM	Earth Observation for the mining of Raw Materials
MSR	Movement and Surveying Radar
RM	Raw Materials

1 Introduction

Following on from the delivery of the product portfolio (D2.1: Current EO Capabilities Report), and the Gap Analysis (D2.2.: Gap Analysis Report), the next two goals of the project are:

- Identification of the prototype service(s) for showcasing during the 2nd EO4RM workshop.
- Selection of the most suitable virtual platform to be used for the showcase of the prototype services.

The goal of this document is to identify and provide a preliminary specification for the services/products having the best chance to make an immediate impact in increasing EO product usage in the mining sector. These services/products were showcased to an audience of potential users and stakeholders during the 2nd EO4RM workshop.

Chapter 2 describes the approach adopted for the selection of the services to be showcased. During the 2nd EO4RM workshop, the services/products described in Chapter 3 were showcased to potential users, using the platform described in Chapter 4. Chapter 5 presents the output of the 2 webinars hosted on the 23rd and 25th of June 2020. Finally, Chapter 6 summarize the content of the document.

Appendix A contains an overview of the questionnaire, including queries and summary of the results.

2 Selection of EO products

This chapter describes the procedure followed for the selection of the products demonstrated (as mock-ups) during the 2nd EO4RM workshop.

2.1 Selection Criteria

The selection of the services with the highest potential for showcasing was performed in two steps. First, a questionnaire was developed and send to both IBB members and other potential stakeholders within the mining industry. The assessment of the poll output based on the criteria defined below formed the second step.

The selection prioritised services that:

1. Address the identified critical challenges.
2. Rank high in the multi-criteria evaluation screening performed during task T2.2.
3. Are relevant for several mining cycles.

Within criteria number 2, particular attention was given to the services with high scores in demand and capability, filtering out the ones with large technology gaps between current RM needs and current EO capabilities.

The opinion of the LTMS' team and of the IBB, with their experience in mining across various raw material types and different geographies, had a crucial role in this phase and was always considered.

2.2 The Questionnaire

The goal of the questionnaire was to identify the most suitable candidate(s) for a demonstration of the capabilities and benefits that operational EO Services bring to the mining industry.

Specifically, it aimed in gathering the mining industry ́s perspective on the following:

a) Thematic Focus (key challenges for which you want to have a solution demonstrated)

b) Demonstration Mode (the preferred mode of the demonstration)

c) Target Audience (important target stakeholders to receive the demonstration).

The poll was built around the industry challenges, asking them to identify the most pressing challenges that they want a solution to. We also ask them about their preferred mode of demonstration.

THEMATIC FOCUS

Within the thematic focus, it was requested to select the 2 most important challenges from each of the four mining cycles and to recommend which challenges were seen as benefiting most from advancements in technology. In other words, to select challenges for which data/information using traditional methods are scarce or difficult (costly) to obtain.

DEMONSTRATION MODE

For finding the best demonstration mode for showcasing the services during the workshop, it was asked to the participant to choose the expected demonstration mode. Several options were proposed, including an online viewing portal (with or without the possibility to download a test data sample) and promotional videos. Finally, the importance of an in-person/onsite consultation and of assistance in analyzing the products were also explored.

TARGET AUDIENCE

In this section of the poll the participants were asked to recommend on key stakeholders likely to be interested in EO service demonstration.

2.3 Questionnaire Summary

The results of the questionnaire show the following preferences (divided per step of the mining cycle):

- Exploration: geological mapping, geochemical mapping.
- Permitting: infrastructure mapping, ground stability.
- Operations: ground stability, stockpile measurement.
- Closure & Aftercare: ground stability, environmental monitoring.

Ground Stability Monitoring was the highest in ranking in two categories (operations and closure & aftercare), and second in a third one (permitting). Given the high demand, it is considered as the primary candidate for showcasing. An EO-based service dedicated to the analysis of ground stability could be used for monitoring subsidence, open pit and tailings dam stability, covering a wide spectrum of mining activities.

Stockpile Measurement was the second and last primary candidate identified for showcasing. Even if relevant only during one operation cycle, stockpiles are a very important part of the mining business both operationally and financially.

In summary, the respondents show high interest in showcasing of the following products: ground stability monitoring and stockpile measurement, with good hands on demonstrations and some case studies, followed by engagement with the product providers. Geological and geochemical mapping, infrastructure mapping and environmental monitoring are other product for which the interest of showcasing is high.

In the next section, the 2 products for showcasing during the 2nd EO4RM workshop will be selected, according to the criteria defined in Chapter 2.1

A full overview of the questionnaire, including questions and a summary of the results, can be found in Appendix A.

2.4 Final Selection

The selection of the services with the highest potential for showcasing was performed following the procedure described in Section 2.2, with a further filtering to be based on the products ranking in the multi-criteria evaluation screening performed during T2.2 and described in the deliverable D2.2 – Gap analysis report.

The scores assigned to the top-20 products during the multi-criteria evaluation (Figure 2-1) clearly identify Ground Stability and Stockpile Measurement as the products with greatest potential for further development and/or those with a need for action to encourage utilization by the mining sector. These products are the ones with the highest chances for raising interest in the mining sector, given that user demand and technological capabilities are not far apart. For more details about the output of the multi-criteria evaluation and/or its scoring mechanism, refer to D2.2 – Gap analysis report.

Product Sheet	Total (potential)
Soil Structure and Chemistry	1,5
Surface Subsidence	1,4
Cultural Heritage	1,4
Air Quality TPM / Particulate Matter	1,35
Stockpile Monitoring	1,3
Monitoring of Infrastructure	1,15
Ground Water Monitoring	1,1
Lithology and Surficial Geology Mapping	1,1
Water Quality	1,1
Air Quality CH4	1,05
Land progressively rehabilitated	1
National Monuments	1
Topography / Elevation	0,95
Geophysical Assessment	0,9
Infrastructure Stability Monitoring	0,9
Air Quality CO2	0,8
Land disturbed by mining activities	0,75
Protected Areas	0,75
Orthophoto Map	0,7
Geological Mapping	0,65

Figure 2-1: The top-20 products, including their potential (the sum of their gap scores) – From D2.2 (Gap Analysis Report).

Finally, Ground Stability and Stockpiles Measurement do also cover the whole lifetime of a mine, from the exploration cycle to the closure and aftercare. This is clearly shown in the Chart below (Figure 2-2).

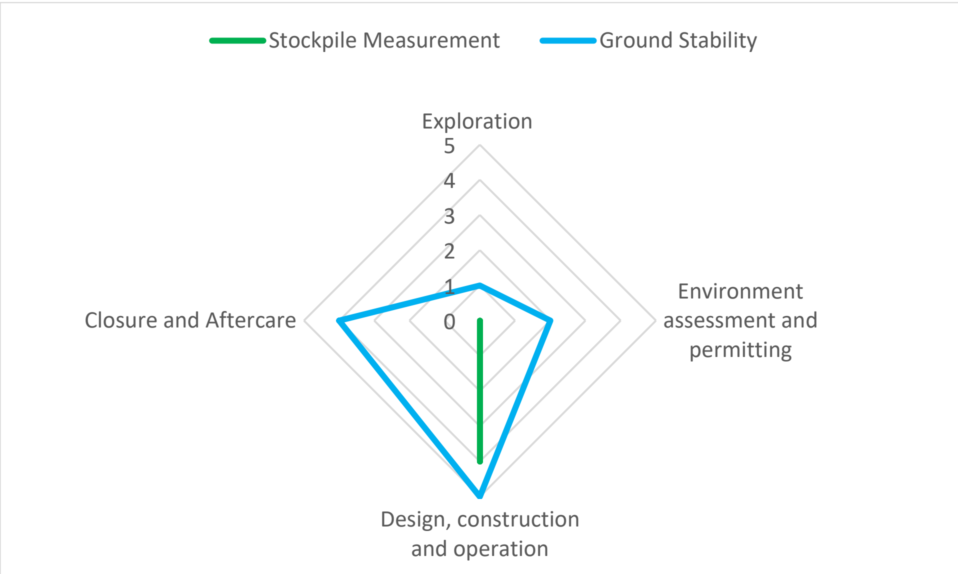


Figure 2-2: Chart showing the cycle coverage of Stockpile Measurement and Surface Subsidence products.

In conclusion, having taken into account all the criteria listed in Section 2.1, the following two services/products have been identified as having the best chance to make an immediate impact in increasing EO product usage in the mining sector:

- Stockpiles Measurement, where satellite-based technology will be able to measure stockpiles on a regular basis and calculate their volume. This has benefits for mining operational and financial management (month-end surveys), potentially replacing all surveying using standard techniques and drone technology. This application has significant potential as all open pit mines have stockpiles and many underground mines also have them. Stockpiles require measurement on a regular basis for both operational and financial purposes and as such are deemed to be of strategic importance to the industry.

- Ground Stability, which covers areas such as surface subsidence, tailings dam monitoring and pit slope stability. While some of this technology is already in place, we believe that many mining companies are not aware of the full potential of these EO-based services.

The selected services are described more in detail in the following chapter.

3 Description of mock-up EO products

3.1 Stockpile Measurement

General Description

Stockpiles are a very important part of the mining business from an operational and financial perspective.

As a part of open pit or underground mining operations, stockpiles are developed at strategic points for use in the next stage of the mining process. Rock is blasted in two forms, ore (mineral bearing rock) and waste. The ore is normally taken from the working faces and delivered to a crusher where it is reduced in size prior to delivery to the processing plant. This can be within the mine, at locations near the mine, or near the processing plant. Stockpiles are maintained for a variety of reasons, such as:

- The mining operation will normally work on a dynamic basis. The ore and waste will be removed from the blasted face as soon as possible after blasting. The crushing and processing plants normally operate on a steady state basis. Continuous feed to the plant is managed by using a stockpile.
- Excess capacity within the mine, greater than the crushing plant or processing plant.
- Strategic stockpile for steady state operation of processing plant or crushing plant.
- Storage from mining operations while crushing or processing plants are shut down.
- Grade variation stockpiles – either high grade or low grade.
- Impurities – mining operations may segregate ore that contains impurities / or penalty elements in separate stockpile and blend this ore into the feed for processing with other ore streams to ensure the final feed is within specification.

From a financial perspective, stockpiles are assessed at regular intervals as they often hold significant value on the company balance sheet. Large ore stockpiles hold significant value and the quantity of material and the grade of mineral within is directly relevant to the financial value.

Waste stockpiles are often stored at locations around mining operations, on a temporary or permanent basis. Volumes are required to ensure compliance, movement history and sometimes for regulatory requirements. The final arrangement of waste stockpiles (height, area, volume, and shape) are an important consideration with respect to mine closure. A mine will propose the final arrangement of the waste stockpiles that will be stable and cause the least amount of visual impact and this arrangement will need to be agree with regulatory authorities and verified once complete.

The ability to measure stockpiles is therefore a key part of most mining operations and any new technology that allows them to be measured accurately and timeously will likely be accepted favorably by the industry.

The technique

The technique to measure the volumes of stockpiles and to determine the occurrence of changes over time consists of two methods: a radar time series analysis and an optical (satellite photogrammetry) volume estimation. Each method will be individually addressed in the upcoming paragraphs.

The change detection method is based on radar images from satellites and consists of three steps:

(1) Processing
(2) Change-detection analysis
(3) Time series analysis.

First, the radar images are downloaded and processed. During the processing, the radar images are co-registered and georeferenced using a digital elevation model. Next, they are divided into manageable regions of approximately 1 km^2. These smaller images of the radar signal are ingested in the change detection analysis, which computes the coherent changes between image pairs of different dates and filters the detected changes to only report the significant and relevant changes. At the end, only significant changes related to activities and variations of the stockpiles remain. The filtering step is mainly focused on the application of land usage specific filters, such as industrial or parking filters. Specific features of the radar signal are analyzed per change to identify which changes relate to the movement or disturbance of stockpiles. These extracted features can be traced back to the physical interaction of the radar signal with a stockpile. Next, all significant changes are stored for every analyzed window within the time series. The time series analysis uses these stored changes to estimate the likelihood of the most impactful changes at a given location over time. The location of interest is bounded by individual stockpiles, which are identified during the analysis of the optical imagery, which is discussed in more detail in the next section. The timeseries effectively depends on four measures:

(1) The *significance* of the change.
(2) The *size* of the change.
(3) The *history* of other changes on the same location.
(4) The existence of other *nearby* changes.

Eventually, the time series analysis predicts when a small (yellow), reasonable (orange) or definite (red) change occurred during the analyzed period within the area of interest. An example of a time series analysis is shown in Figure 3-1, which indicates the historic changes over time at a given location of interest.

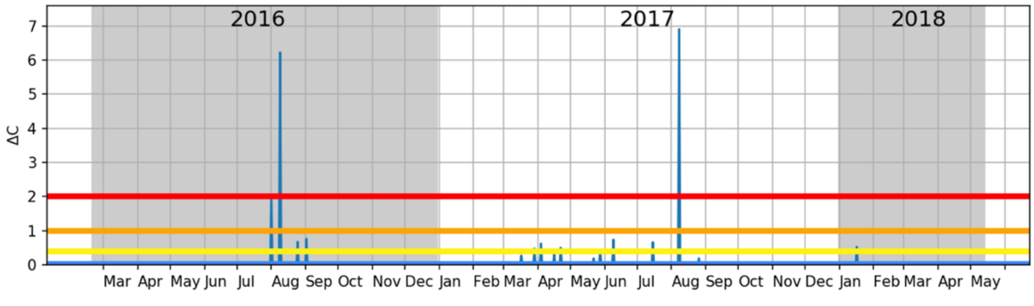


Figure 3-1: Time series analysis of radar data which indicates when a small (yellow), reasonable (orange) or definite (red) changes occurred.

Figure 3-2: Example of an optical image with detected stockpiles and their estimated volume.

The volume estimation is based on the analysis of optical imagery. An artificial intelligence model detects the location and outline of a stockpile in a satellite image and classifies it into a geometric shape. Currently, the classifier is trained to detect ridges, plateaus, and cones. The outline gives the area of the heap's footprint. This area is used together with the geometric relations from the classified shape to estimate the heap's volume. Figure 3-2 shows an example of the application of the volume estimation to a sample of an optical image with two stockpiles.

Mock-up set-up

For the mock-up, two sites with stockpiles were analyzed for a period of several months during 2019. Firstly, high resolution optical data were acquired for the areas in which the stockpiles are expected to enable the volume estimations. Secondly, Sentinel 1 radar data were downloaded for the time frames between the optical images to determine when changes have occurred between each optical image pair. The resulting stockpile analysis information can be presented to the user via a cross-platform GIS application or be exposed to the end user via a combination of a WMS (Web Map Service) and WFS (Web Feature Service) map layers. An impression of the data exposure via a GIS application is given in Figure 3-3 – Figure 3-5. Figure 3-3 shows an overview of the location of interest to the user, which in

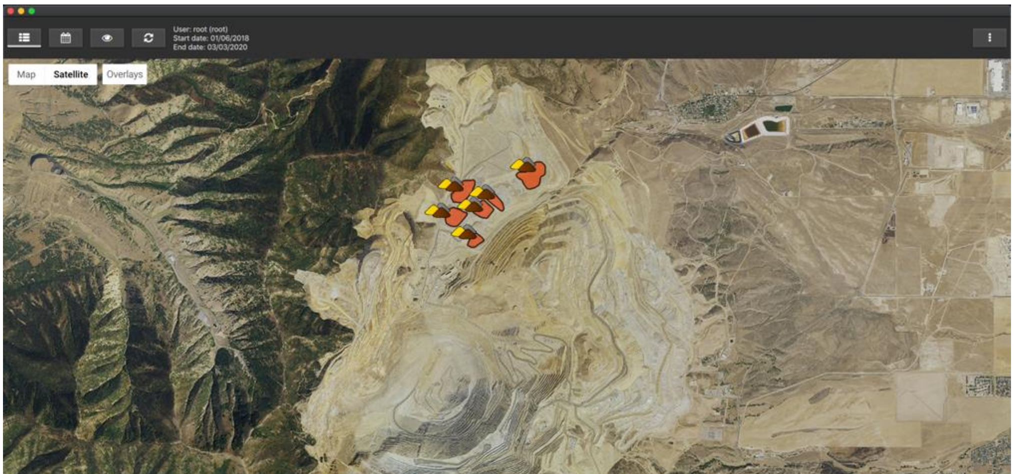


Figure 3-3: Overview map of the mock-up application that shows an open pit mine as the location of interest with the detected stock piles highlighted in orange

this example is an open pit mine. The locations of the detected stockpiles are highlighted on the map in orange and can be selected to access the volume estimation, optical images (Figure 3-4) and time series analysis (Figure 3-5).

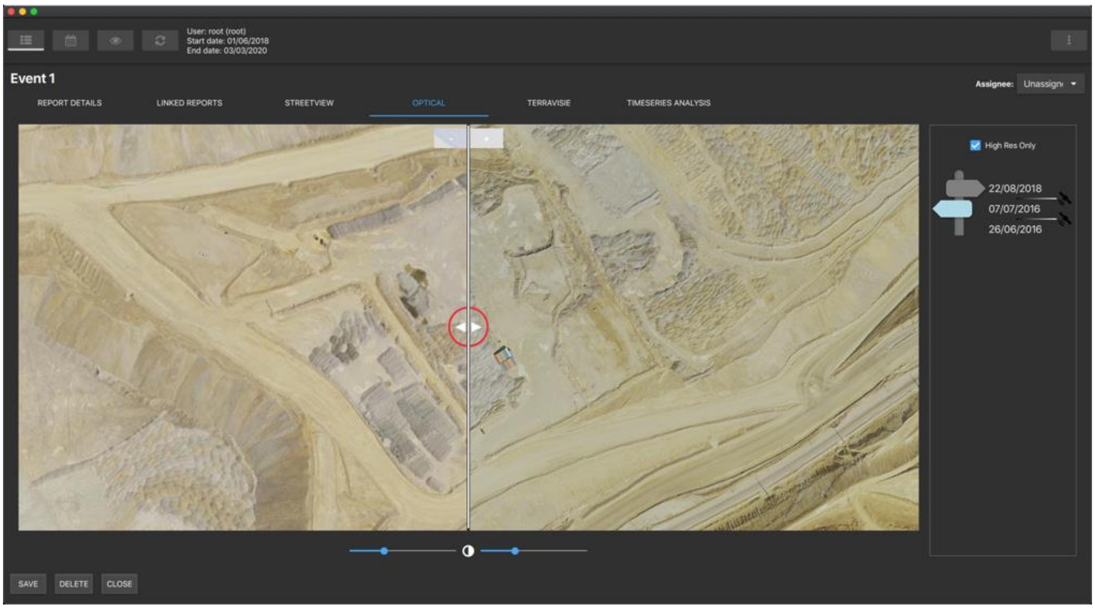


Figure 3-4: The mock-up application presents the user with the acquired optical imagery for each location with stockpiles, which can be easily reviewed using a slider to review the progress over time.

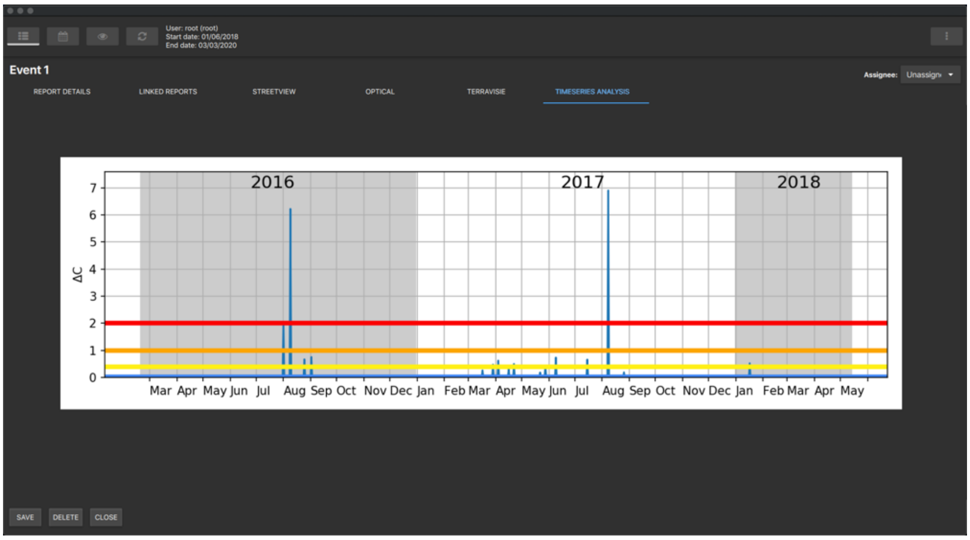


Figure 3-5: The result of the time series analysis for each stock pile can be accessed in the mock-up application and shows the occurrence of small (yellow), reasonable (orange) or definite (red) changes at the stockpile over time.

3.1.1 Test Sites

The two test sites for demonstration of the stockpile measurement service were:

- **Skorpion Zinc Mine, Namibia,** is an open pit mine which has several stockpiles located near the open pit – see Figure 3-6. The stockpiles which can be measured at different dates, to verify change and volume. Permission was obtained for the showcasing of this site, but it has not been possible to access to local stockpile ground-based values at specific dates.

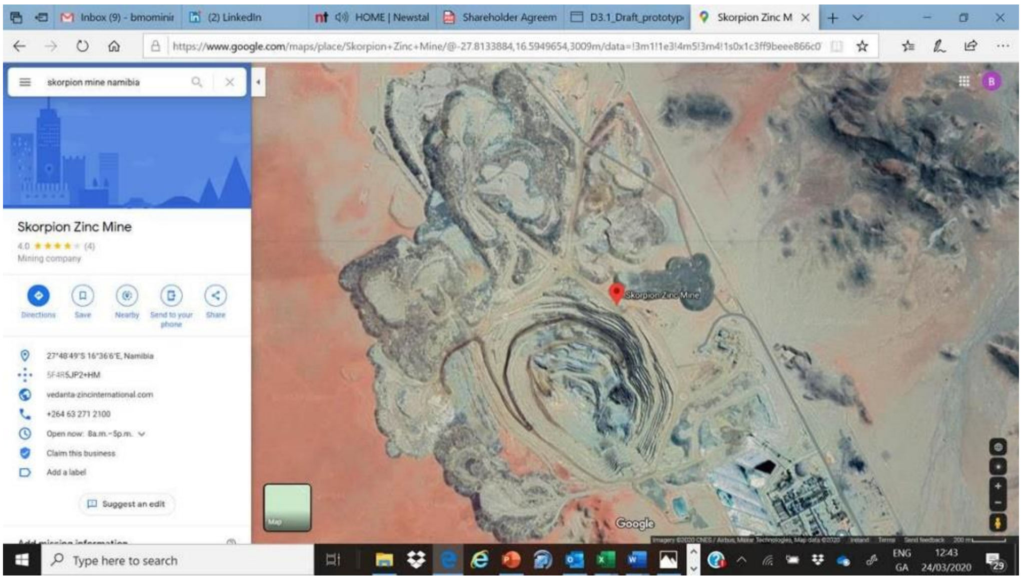


Figure 3-6: Skorpion Open Pit Mine, Namibia.

- **Belgard Quarry, Ireland,** is a large operation located near Dublin. There are several stockpiles which have verified stockpile volumes, which were obtained from the site managers of the quarry. These stockpiles can be measured and compared with ground truth volumes provided by the Company owning the Quarry. This procedure would allow to establish the accuracy level of the current EO technology.

Figure 3-7: Belgard Quarry, Ireland.

3.2 Ground Stability

General Description

Ground stability in the context of mining covers several areas related to the mining operation and the structures associated with the mining process.

Ground stability in this context covers three main areas: subsidence, pit slope stability and tailings dam stability.

Subsidence is either the gradual or dynamic sinking of land and can be the result of mining activities, but this is not always the case. Subsidence can also occur from movements within karstic features below the ground. In mining, there can be gradual subsidence of ground over a period of time and this can be predicted based on the mining design and rate of mining. Most mining operations carry out subsidence surveys on a regular basis, either using traditional surveying techniques or drones. Mining induced subsidence will not necessarily result in damage or loss to the lands that are affected. Provided the subsidence is gradual and distributed over a wide area it is unlikely that there will be loss or damage. Loss and damage can occur when the is rapid subsidence events or when there is variable subsidence over small areas (also known as differential settlement).

Pit slope stability is a major issue in open pit mines and while mining design can provide optimum mining methods, pit slope failure prediction is an integral part of good mining practice. Pit slope monitoring is normally carried out using traditional survey techniques in-situ monitoring and, ground based radar or drones. Pit slope failures can be gradual or dynamic and high-quality monitoring is essential to the safety of the operation. The ability to repetitively measure pit slopes to a high degree of accuracy is key to ensuring good practice.

Tailings dams are used to store the waste material from the processing plant and given the low proportion of minerals in ore and the high proportion of waste, tailings dams can be very large storage areas. For example, a mine operation at 1 million tons of ore per year at a grade of 2% copper, operating for ten years may need to store 9,800,000 tons of tailing material over this period. The structural integrity of tailings dams is absolutely crucial and though design will always include a large factor of safety, there have been a number of failures in the past. There are approximately 3,200 tailings dams around the world. Regular monitoring of tailings dams can be difficult and time consuming, using traditional surveying techniques or drones. Tailings dams must also be monitored following the closure of a mine for a significant period thereafter and this provides a significant opportunity for EO technology to provide a solution that has a high level of accuracy and resolution. The frequency of monitoring is also an important consideration, as the more frequently the facilities are monitoring the greater likelihood that an issue could be found before there is a failure. Because traditional techniques tend to be time consuming, they are not very suitable for frequent monitoring.

The technique

Ground stability can be measured remotely with the satellite-based InSAR technique. This technique uses radar images and is therefore able to measure throughout all weather conditions, as well as day and night. With InSAR, millimeter-scale movements of the surface can be measured for a wide range of applications, such as tailings dam stability, pit slope stability and surface subsidence.

The radar satellites record the radar's reflections that the earth, buildings and objects generate. By comparing multiple recordings of the same area or object, millimeter-level changes in height can be distinguished. The radar's reflections depend on surface characteristics and are best for solid objects such as urban areas, roads, or bare soil; vegetated or sandy surfaces are more challenging. Next to that, the trade-off with the technique is that it can track changes that are not visible to the human eye but cannot follow events that are significantly large than the radar's wavelength (~cm's). This means that the technique can generally measure effects leading up to a potential failure, but not (the extent of) the failure itself. For a more in-depth explanation, please refer to:

https://www.esa.int/About_Us/ESA_Publications/InSAR_Principles_Guidelines_for_SAR_Interferometry_Processing_and_Interpretation_br_ESA_TM-19

Mock-up set-up

Two separate mining areas were processed with the InSAR technique in order to showcase the possibilities of InSAR-related products for the mining industry. The relevant applications were monitoring the stability of tailings dams, pit slopes and the ground/infrastructure surrounding the mine. The mock-up was based on an already operational service, so actual results were showcased.

ESA's Sentinel-1 satellites were used as source data for these mock-ups, since they have a world-wide historical archive dating back to +/- 2015, are freely available and acquire new imagery generally every 6-12 days. The resolution (~20x5m) is lower than with commercial satellites, but for observing relatively large effects they provide a nice, low-cost, indication. For these mock-ups, the full-time span (~2015-now) was processed to provide a long-term view on the movements in and around the mine.

The result is a map, showing the performed deformation measurements, where the color indicates the average deformation over the measured time span (see Figure 3-8). Behind every measurement, there is a time series with observations, where the movements over time can be inspected in greater detail (see Figure 3-9), as input for risk assessment towards the future or for post-engineering and learning from failures that happened in the past. This map is visualized in a web environment, so any user can inspect the data interactively. The web environment is described in more detail in Chapter 4.

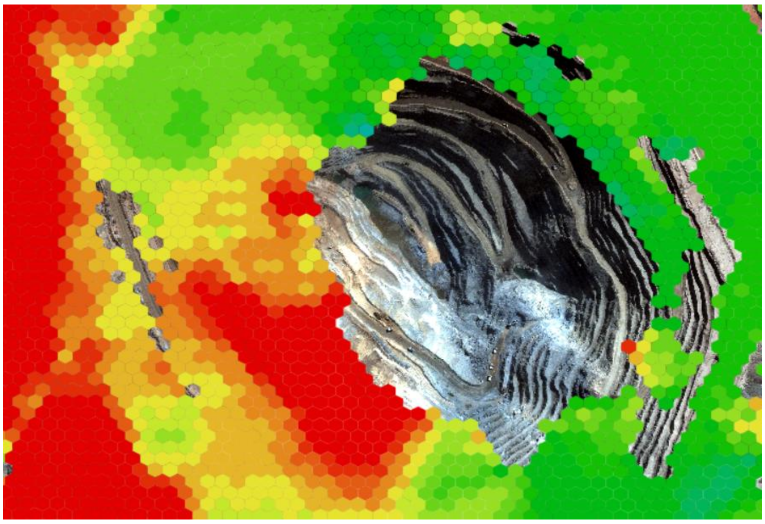


Figure 3-8: InSAR measurements over the Skorpion Zinc mine, based on Sentinel-1. Every cell represents a deformation time series, with the color indicating the average velocity over the time span: green is stable, red is subsiding.

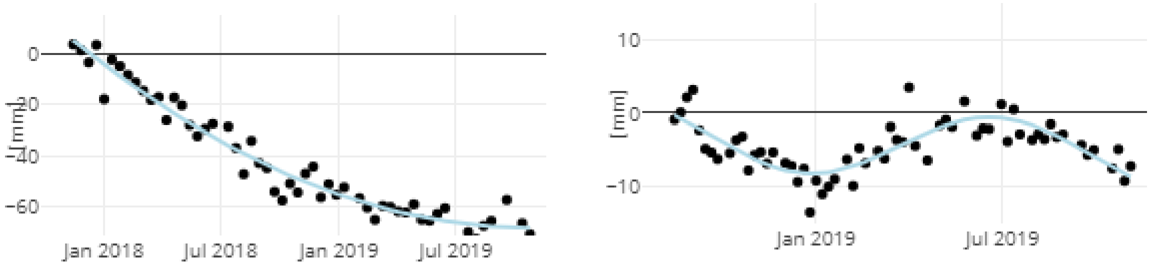


Figure 3-9: InSAR deformation time series. These time series are underlying every cell in the figure above and show the movements per observation date. Left: a time series showing a decelerating movement, right: a time series showing a sinusoidal movement, which is often related to thermal expansion or water-related effects.

3.2.1 Test Sites

The following test sites has been identified for showcasing:

- Skorpion Zinc Mine, Namibia (Open Pit Failure)* is an open pit zinc mine which experienced a major pit slope failure on May 9th 2019 and a smaller one in December that year. The first failure involved approximately 400,000 tons of rock and spanned an area of about 150x70m. As the first failure was the largest, this one is investigated for the showcase. An analysis of the pit in the days and weeks before the incident may show movement, which could have identified the potential for the failure to occur.

Figure 3-10: Skorpion Zinc Mine, Namibia, open pit mine.

- Cadia Hill Gold & Copper Mine, Australia (Tailings Dam Failure). An area of the Tailings Dam embankment slumped on 9th March 2018 following the identification of cracks earlier in the day in the dam wall during a regular inspection. In this case the failure was predicted in advance and the area was made safe. An assessment with EO technology was used in this study to try to identify movement in the days and weeks prior to the failure.

Figure 3-11: Cadia gold mine, Australia, tailings dam collapse.

* Unfortunately, it was not possible to source good satellite data to allow the Madenkoy Copper Mine to be used. This fact is a significant outcome of the EO4RM project itself. Indeed, it demonstrates that, at this time, good satellite data will not necessarily be available for all locations, at all times, on the planet. As back-up plan the project use two slope failures that occurred at the Skorpion Zinc Mine in Namibia.

4 Platform for EO products showcase

For showcasing the mock-ups described in Chapter 3 a web-based platform was chosen. This choice is in accordance with the output of the questionnaire described in Chapter 2. The platform allows interested parties from the mining industry to inspect the showcased products by themselves to assess the feasibility for their use case. This platform mock-up allows for interactive inspection of the results and can be accessed through any web browser. The interface is visualized in Figure 4-1.

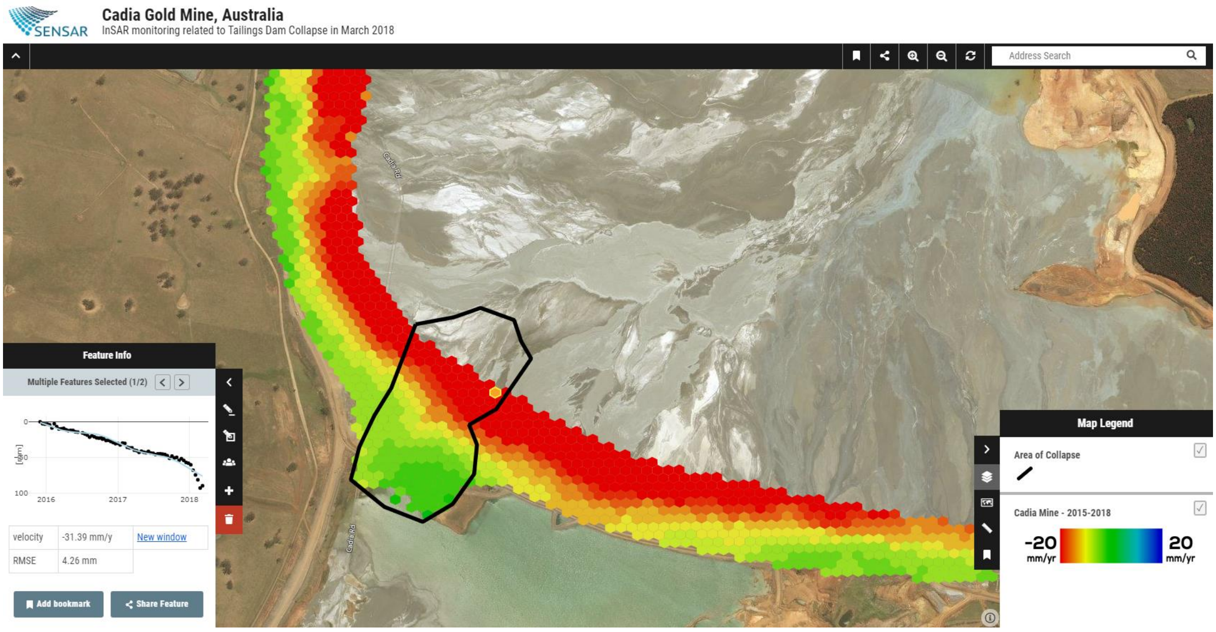


Figure 4-1: The platform mock-up interface, showing an interactive map. In the lower-right corner the legend is shown, and different data layers/products can be selected to add to the visualization. In the lower-left corner a pop-up screen is available to show additional information on the visualized data. In this example, an InSAR time series is visualized after clicking on a measurement, together with some metadata.

The strength of this interface is the ability to interactively visualize multiple products on a certain location at once and to find potential correlations. The different products can be toggled on/off via the panel on the bottom right (see Figure 4-2).

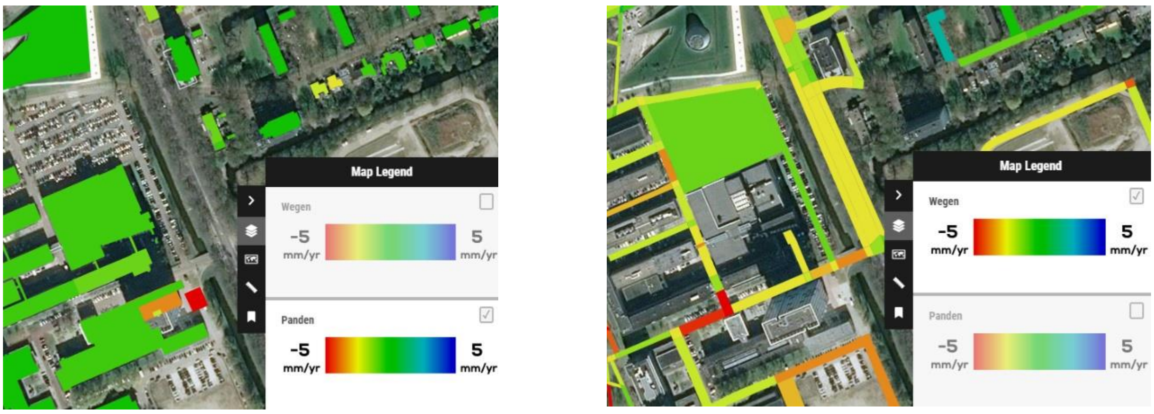


Figure 4-2: Toggling the different data layers on the bottom right of the screen allows for visualizing different products.

The InSAR time series can also be inspected interactively through the panel on the bottom left or in a separate window. This panel allows for various interactions with the time series (see Figure 4-3 for an example).

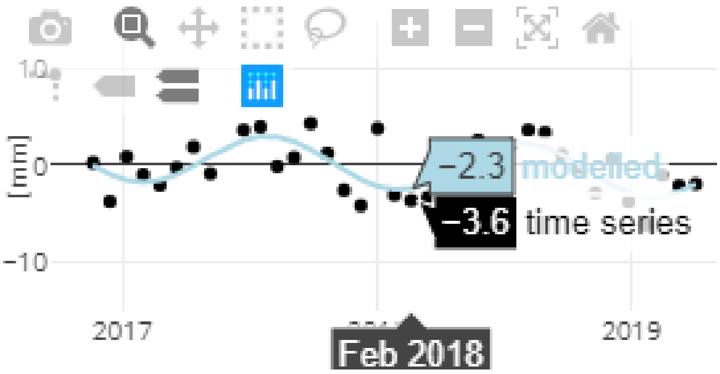


Figure 4-3: The InSAR time series window is interactive and has various functions, such as zooming in and out, taking screenshots and showing the values of the observations and the fitted trend.

Other functionalities include zooming in/out, searching addresses, changing the background map, adding bookmarks and measuring areas or distances (see Figure 4-4).

Figure 4-4: An example of the additional functionalities of the platform mock-up: measuring areas interactively, with an alternative background map.

The basis of this platform is already used operationally to visualize and inspect InSAR data. Since it works with open GIS-standards, it allows for the ingestion and visualization of all types of geo-products. For this showcase, the stockpile measurement, slope stability, tailings dam stability products were incorporated in the platform, but with the current set-up it is possible to add additional products in the future if needed. Because of the open data format, the services visualized in the platform can also be ingested in any GIS-system owned by the mining operator.

Next to that, there is the option to add customer-specific geo-data to the viewer to allow for combined interpretation of data and results, gathered with both EO as well as with other methods. For example, one could compare local GPS measurements on a tailings dam with the InSAR results at that location or have the amount of excavated material in the same interface as the stockpile measurement product. This requires provision of this local information in geo-data format by the mining operator.

The mock-ups and the interface platform showcasing them will be accessible until the end of the project and clearly advertised on the EO4RM portal.

5 Users feedback from workshop 2

The main goal of the two webinars organized on the 23rd and 26th of June 2020 was the presentation of the prototype services via the web-based platform to potential users within the mining sector. The attendees were requested to provide live feedback after each presentation on both the services and the platform. More specifically, several questions were addressed to the participants in relation to accuracy, desired functionalities, barriers, etc.

As an example, some of the most relevant questions addressed to the attendees were:

1. What accuracy is required for ground stability/stockpile measurements data?
2. What functionality should be added to the shown prototype?
3. Which barriers do you see for the full-scale implementation of the product?

The stockpile measurement prototype service was perceived as extremely user friendly (scoring 3.8/5 according to 63 voters) and perceived as adding value to current industry practices, once operational (3.7/5 according to 63 voters).

The ground stability prototype service received very similar scores. It was perceived as extremely user friendly (scoring 3.8/5 according to 81 voters) and perceived as adding value to current industry practices (3.7/5 according to 81 voters).

For more details, refer to the deliverable D2.3 (Workshop 2 Report). D2.3 discusses the approach to, participation and results and feedback from the workshop.

5.1 Stockpile measurement

A general description of stockpiles is given in Chapter 3.1 above and this outlines the operational and financial significance.

5.1.1 Accuracy

Accuracy of the stockpile monitoring service was identified during the workshops as the key feature for the product to succeed. The majority would consider the service, when an accuracy of at least 5% can be guaranteed (Figure 5-1**Error! Reference source not found.**). The verification study performed at the Belgard quarry showed that the current service achieves an accuracy of ~10% for cone and plateau shaped stockpiles, while only ~25% accuracy was achieved for ridges. Stockpiles that did not fit one of these geometries had inaccurate volume estimates, that only achieved ~40% accuracy.

As a result, the current service would be able to achieve at least on average 25% accuracy, when the current model is trained on ground truth stockpile data. If the current model is extended to include additional geometries of stockpiles and is trained on stockpile data, then the machine learning model should achieve at least a 10% accuracy. This statement is supported by the current accuracy of ~10% for cones and plateaus. The desired goal of achieving at least a 5% accuracy would involve additional research and development with a currently unknown result.

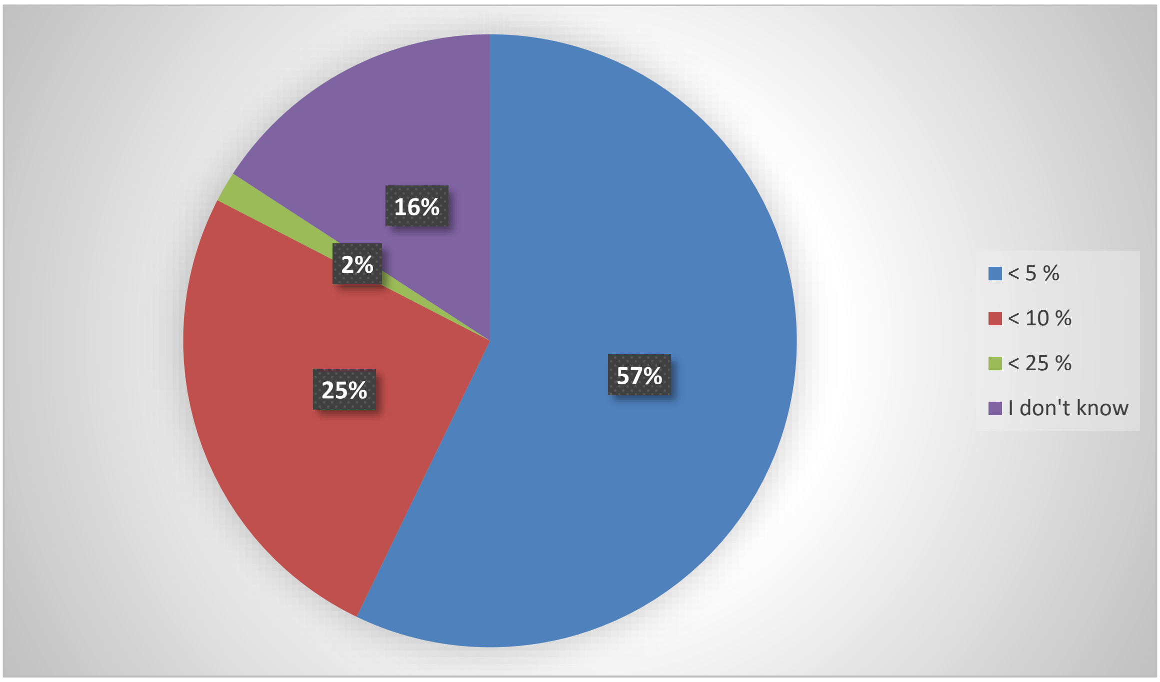


Figure 5-1: Pie chart showing the required accuracy for an operational ground stability service, according to the webinar participants (63 voters).

5.1.2 Functionalities

The participants were asked to identify useful functionalities that would make the showcased stockpile monitoring service more appealing to the market. The most desired functionalities were:

- Accuracy level (11 votes). The accuracy of stockpile measurement is the most critical factor and to compete with traditional techniques such as surveying and drones, the accuracy level needs to be 5% or better.
- Grade control (4 votes). Stockpiles on a mine site are sometimes used for grade control, as high grade and low-grade ores are often blended to provide a predicted grade for feed to the processing plant.
- Vegetation (2 votes). There is potential for vegetation to be problematic for stockpile measurement, but a fast-moving stockpile will not have vegetation. A stockpile with vegetation is indicative of no recent movement, so in general this should not be a major issue.
- Cross section (2 votes). As the capability of stockpile measurement develops, it may be possible to provide cross sections of the stockpile, for other uses such as slope stability, angle of repose calculations, etc.
- Material (2 votes).The identification of a material type would be difficult to achieve, and the mine operator is normally aware of the composition of the stockpile. It is worth noticing that the primary focus of stockpile measurement is to obtain a volume. A factor can then be applied to the volume to achieve a tonnage. The factor will vary for different materials and size fractions of the rock. The factors will be provided by the mine operators.

5.1.3 Barriers for full-scale implementation

During the workshop, the participants were also asked to identify potential barriers for full-scale implementation of the stockpile monitoring service. The barriers identified as most critical ones were:

- Accuracy (21 votes). Accuracy is the biggest challenge to stockpile measurement becoming a useful product for the mining industry. As stated above, 5% is the target and if this can be achieved at some stage, then the product will have the potential to be very marketable and to be widely accepted in the industry.
- Confidentiality/Privacy (9 votes). The only data that can be taken from EO measurement is volume and this alone may not be significant from a confidentiality perspective. The ore grade and size fraction are both very significant, but the amount of movement of a stockpile in a specific time frame can be indicative of a level of activity at a mine site. An indication of stockpile movement is currently available with current satellite technology.
- Cost (6 votes). Cost will be a factor and the industry will need to be able to compare the cost of an EO-based service with the one of traditional methods.

5.2 Ground Stability

Ground stability in the context of mining covers several areas related to the mining operation and the structures associated with the mining process. In this case it covers three main areas: subsidence, pit slope stability and tailings dam stability. This is described in detail in Section 3.2 above.

5.2.1 Accuracy

Similar to stockpile measurements, there is a minimum accuracy that is required for measuring structural stability. The data presented in Figure 5-2 shows the response from attendees of the webinar with respect to the required accuracy.

Almost 30% of the respondents indicated that they require the accuracy to be around 1mm, which is similar to conventional ground-based techniques (e.g. GPS, tachymetry, laser scanning). However, a significant number of respondents indicated that 5mm accuracy would be sufficient (49%).

Current capabilities of satellite-based ground stability monitoring allow for individual measurements with a precision in the mm-range. By using the high observation frequency of the satellites and combining a series of measurements, the deformation trends can often be derived with sub-mm precision. This means that the requirements set by the respondents are fulfilled for most use cases.

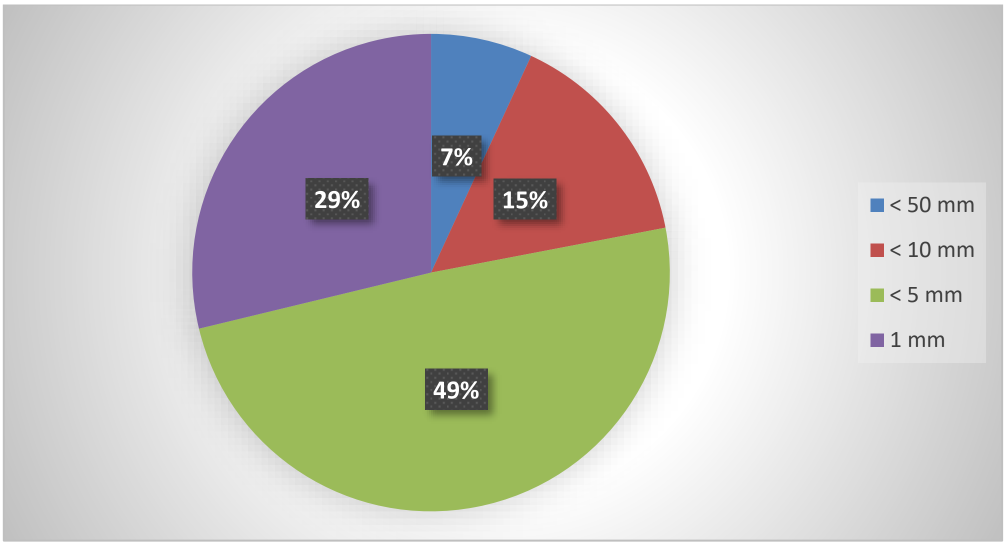


Figure 5-2: Pie chart showing the required accuracy for an operational ground stability service, according to the webinar participants (74 voters).

5.2.2 Functionalities

The participants were asked to identify useful functionalities that would make the showcased ground stability monitoring service more appealing to the market. The most desired functionalities were:

- Mapping geological structures (8 votes). While this is a separate EO function, it may be relevant to predicting and observing movement of geological features. This be can achieved by visualizing multiple EO capabilities in one interface.
- Estimated, high-resolution cross section (6 votes). Visualizing the deformation data in the form of a cross section, showing the variation over time, can be valuable for closer inspection of the effects visible in the dataset. This is a post-processing step of the InSAR dataset and is already commercially available.
- Flag up measurement error/uncertainty (4 votes). The graphs produced from ground monitoring should be able to identify movement at a particular time or over a time phase where several points are used. It may be therefore be possible to identify anomalous readings within a group of several readings. This is a post-processing step that is already commercially available.
- Early warning system (3 votes). The ability to show observed rates of change and flagging potential event precursors has very significant benefits to mining operations. This is a post-processing step that is already commercially available.
- Realtime Monitoring (2 votes). The potential downside is that the data is only available at pre-set time intervals, either several days or weeks. While in the event of an anticipated pit slope or tailings dam failure in the very short term, this time frame may not be sufficient. However, the frequency of observations will improve drastically in the near future, with new small satellites coming up. With these satellites, hourly-daily observations will become available.
- Groundwater or saturation (2 votes). This technology can assist mine operators to identify hazards in areas that are not normally considered by identifying changes in ground movement. Ground movement can sometimes be affected by changing groundwater profiles. Combined visualization/interpretation could aid the mining operation. This can be done relatively easy by implementing both datasets in the same interface.

5.2.3 Barriers for full-scale implementation

During the workshop, the participants were also asked to identify potential barriers for full-scale implementation of the stockpile monitoring service. The barriers identified as most critical ones were:

- Cost (12 votes). The cost of new or existing EO technologies will be a significant factor in the uptake from the industry. A cost-benefit analysis including temporal and spatial resolution will identify whether the product will be attractive. The showcases have been made with the freely available Sentinel-1 source data. This data is available on almost all locations world-wide and provides a cost-effective way of scanning mining locations in low resolution.
- Frequency of monitoring (8 votes). The satellite source data is only available at pre-set time intervals, either several days or weeks. While in the event of an anticipated pit slope or tailings dam failure in the very short term, this time frame may not be sufficient. However, the frequency of observations will improve drastically in the near future, with new small satellites coming up. With these satellites, hourly-daily observations will become available.
- Confidentiality/Privacy (5 votes). The data can be ordered by anyone, irrespective of the ownership of the respective mining location. The output of the service will be shared only with the customer using state-of-art security protocols.

- Resolution (4 votes). The resolution of the dataset depends on the satellite source data used, which in the end will boil down to a cost-benefit analysis. Source data up to a resolution of 0.5x0.5m is available on demand.
- Reliability and validation (3 votes). The InSAR technique exists since the 90's and its reliability has been proven over and over in multiple scientific papers, including validation with other (ground-based) measurement techniques. As with any measurement technique, the observations have to be interpreted while taking into account the strengths and weaknesses of the technique at hand.
- Accuracy (3 votes). Current capabilities of satellite-based ground stability monitoring allow for individual measurements with a precision in the mm-range. By using the high observation frequency of the satellites and combining a series of measurements, the deformation trends can often be derived with sub-mm precision.

6 Conclusions

Stockpiles Measurements and Ground Stability are the two services selected for showcasing to an audience of potential users and stakeholders during the 2nd EO4RM workshop.

These two services were selected because they fulfilled two main criteria:

- User interest. They were identified as two of the most suitable candidates for a demonstration by the pool respondents.
- Ranking high in the multi-criteria evaluation performed in Task 2.2.

Their relevancy was also confirmed by LTMS' team as products that may be of significant interest.

The following test sites has been identified for showcasing:

- Stockpiles Monitoring:
  - Skorpion Zinc Mine, Namibia.
  - Belgard Quarry, Ireland.
- Ground Stability:
  - Skorpion Zinc Mine, Namibia (Open Pit Failure).
  - Cadia Hill Gold & Copper Mine, Australia (Tailings Dam Failure).

The four mock-ups were showcased on a web-based platform. The platform was chosen in accordance with the output of the questionnaire described in Chapter 2. The platform allows interactive inspection of the results and will be accessible to the mining industry through any web browser.

User wishes and requirements were investigated during the workshop with dedicated interactive session. According to the output of the session, both services were perceived as extremely user friendly and providing adding value to current industry practices, once operational. For more details about the approach to, participation and results and feedback from the workshop, refer to the deliverable D2.3 (Workshop 2 Report).

Appendices

Appendix A – Questionnaire : Form and Results

Questionnaire Form

EO4RM - Service Demonstration Questionnaire

Over the last few months, the EO4RM project has gathered and analysed the needs and requirements of the mining industry and compiled a catalogue of Earth Observation (EO) Services that address the various challenges. We are now preparing one or more demonstration of the capabilities and benefits that operational EO Services bring to the mining industry. We kindly ask for your help in identifying the most suitable candidate(s) for demonstration. Specifically, we are interested in gathering the mining industry´s perspective on:

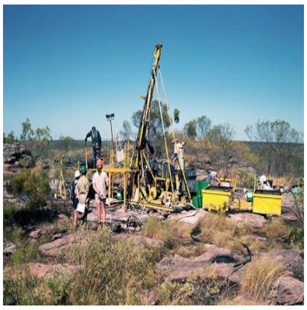
a) Thematic Focus (key challenges for which you want to have a solution demonstrated)
b) Demonstration Mode (the preferred mode of demonstration)
c) Target Audience (important target stakeholders to receive the demonstration)

Completing this survey will take 8-12 minutes and will greatly assist us in developing a convincing demonstration that addresses actual and prominent information needs of the mining industry.

Thematic focus

Please select the 2 (two) most important challenges from each (!) of the four mining cycles (i.e. total of eight selections). In particular your choice should take into account which of these challenges you see as benefiting from advancements in technology (i.e. if data / information is already easily available and does not pose a challenge to you - it is suggested you do not choose this challenge).

Exploration *



- ❑ Topographical Mapping
- ❑ Geological Mapping
- ❑ Geochemical Mapping
- ❑ Mapping Infrastructure
- ❑ Land Ownership Mapping
- ❑ Affected Stakeholders
- ❑ Weather
- ❑ Environmental Monitoring
- ❑ Other:

Permitting Process *

- ❑ Water Catchment
- ❑ Social / Demographics
- ❑ Topographical Mapping
- ❑ Air Quality
- ❑ Geochemical Mapping
- ❑ Flora and Fauna
- ❑ Restricted Lands
- ❑ Mapping of Infrastructure
- ❑ Land Ownership
- ❑ Land Usage
- ❑ Ground Stability / Geotechnical
- ❑ Site Layout
- ❑ Weather / Climate
- ❑ Other:

Development & Operations *

- ❑ Mapping of Infrastructure
- ❑ Site Layout Design
- ❑ Land Ownership Mapping
- ❑ Affected Lands Status
- ❑ Ground Stability / Geotechnical
- ❑ Structural Stability Monitoring
- ❑ Stockpile measurement
- ❑ Affected Stakeholders
- ❑ Environmental Monitoring
- ❑ Illegal Mining
- ❑ Weather

- ❑ Other:

Site Closure & Aftercare *

- ❑ Geochemical Mapping
- ❑ Environmental Monitoring
- ❑ Ground Stability / Geotechnical / Geochemical Mapping
- ❑ Affected Stakeholders
- ❑ Weather / Climate
- ❑ Mapping of Infrastructure
- ❑ Structural Stability Monitoring
- ❑ Other:

Demonstration mode

The demonstration will be presented at a conference in Berlin in June 2020. Please help us design the most convincing demonstration by answering the questions below.

Please choose the expected demonstration mode(s) - Videos will be hosted on common portals (YouTube, LinkedIn, etc.) *

- ❑ Online viewing portal
- ❑ Short promotional video (intro to EO solution, benefits, applications) [5-10 min]
- ❑ Extended promotional video (intro to workflow) [10-20 min]
- ❑ Sample data download
- ❑ Other:

If data download is required, which format(s) are commonly expected?

- ❑ [GIS data / Raster] - TIFF
- ❑ [GIS data / Vector] - Shapefile
- ❑ [Map] - PNG
- ❑ [Map] - PDF
- ❑ [Statistics] - XLSX
- ❑ Other:

In your view, how important is an in-person / onsite consultation for a successful demonstration? *

Not very important

- ○ 1

- 2
- 3
- 4
- 5

How important do you think is assistance to analyse this product / extract target information or indicators? *

Not very important

- 1
- 2
- 3
- 4
- 5

What other aspects do we need to consider for a convincing service demonstration?

____

Target audience

Please help us identify kex stakeholders that are likely interested in EO service demonstration(s)

Do you know other companies/stakeholders outside the IIB that would be interested in the demonstration?

____

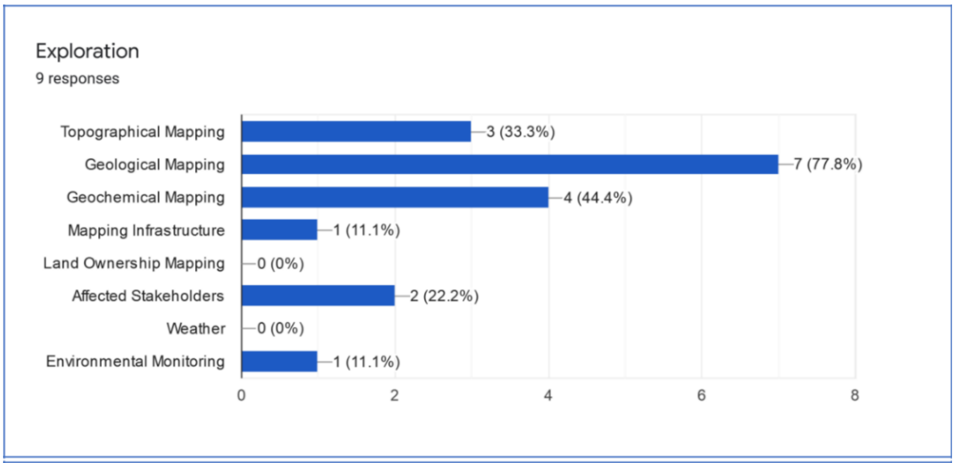
Do you have any additional comments?

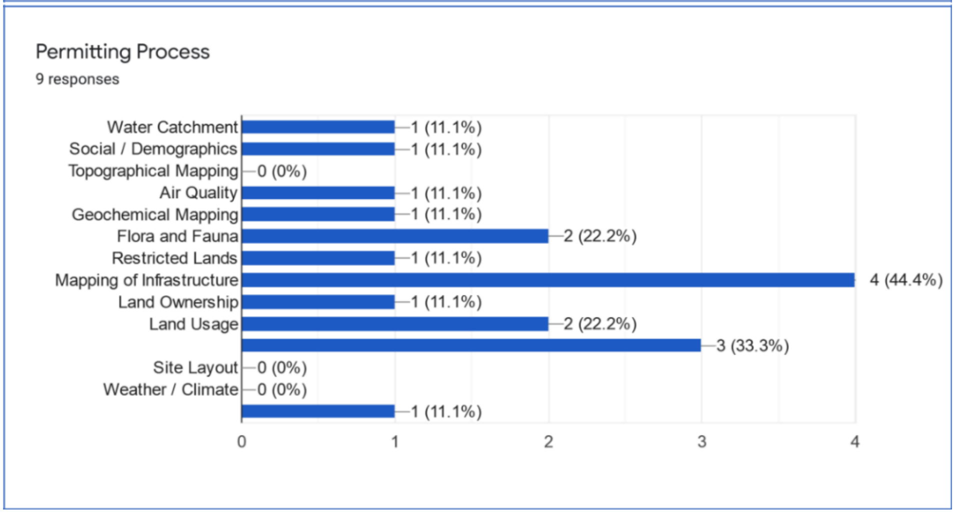
____

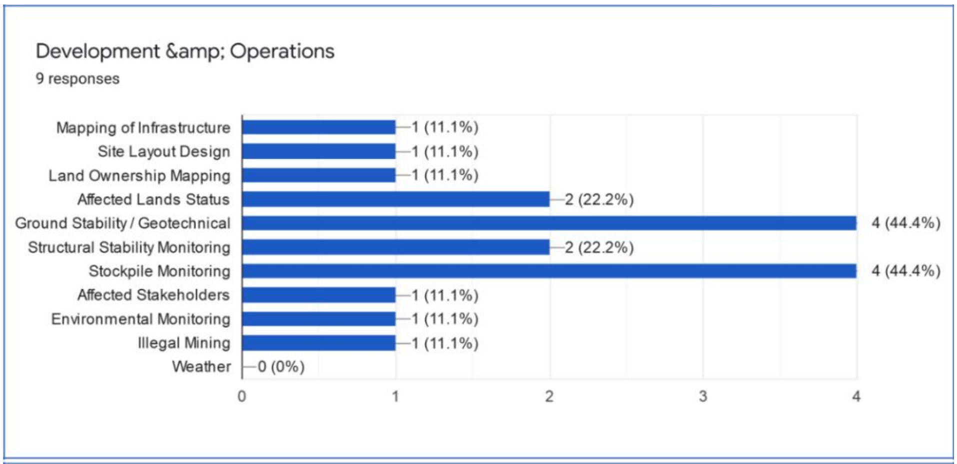
Questionnaire Results (Summary)

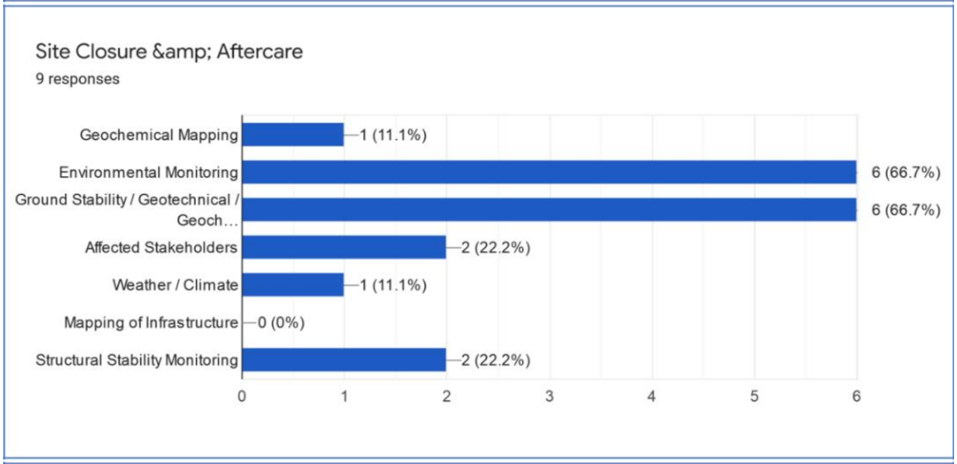
Last updated: 20.02.2020, 11:38

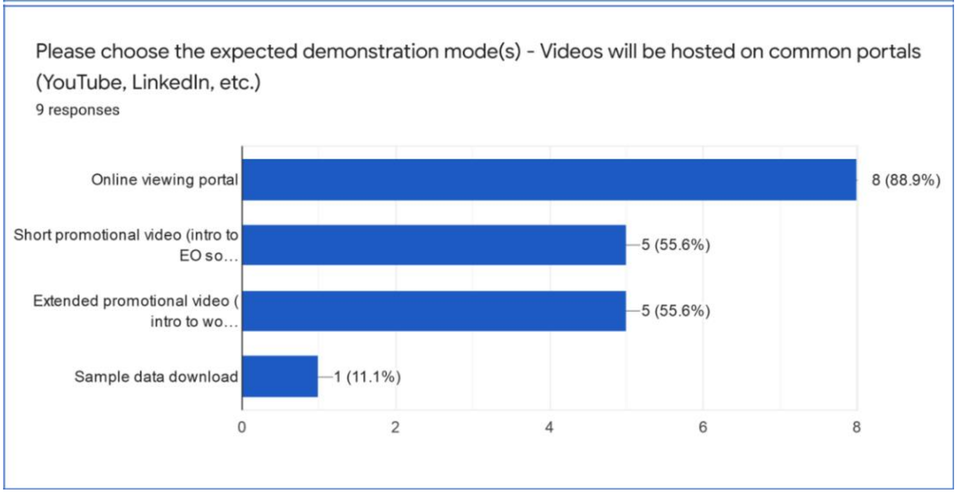
Number of responses: 9

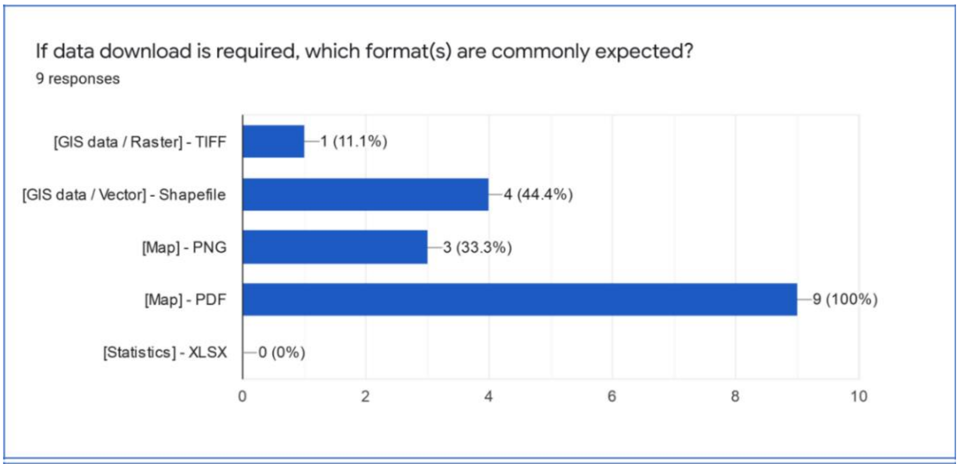


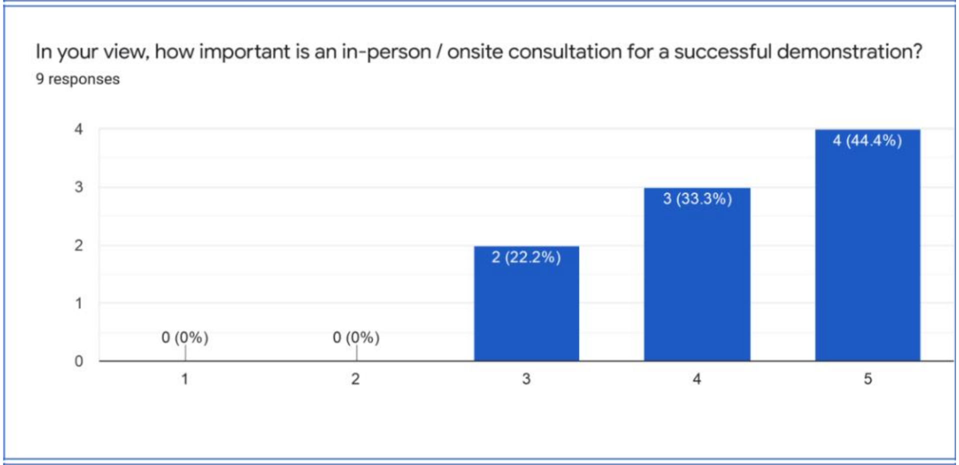


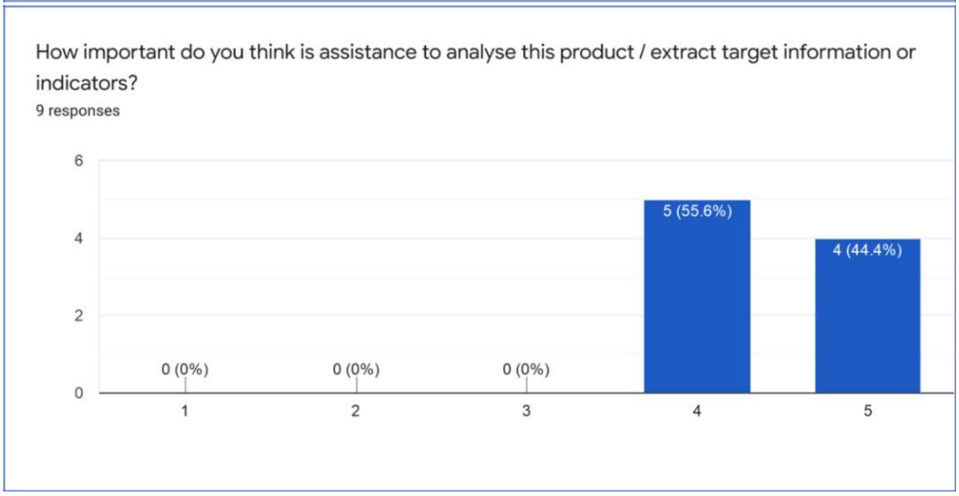

Development & Operations
9 responses
Mapping of Infrastructure
Site Layout Design
Land Ownership Mapping
Affected Lands Status
Ground Stability / Geotechnical
Structural Stability Monitoring
Stockpile Monitoring
Affected Stakeholders
Environmental Monitoring
Illegal Mining
Weather
1 (11.1%)
1 (11.1%)
1 (11.1%)
2 (22.2%)
4 (44.4%)
2 (22.2%)
4 (44.4%)
1 (11.1%)
1 (11.1%)
1 (11.1%)
0 (0%)
0
1
2
3
4

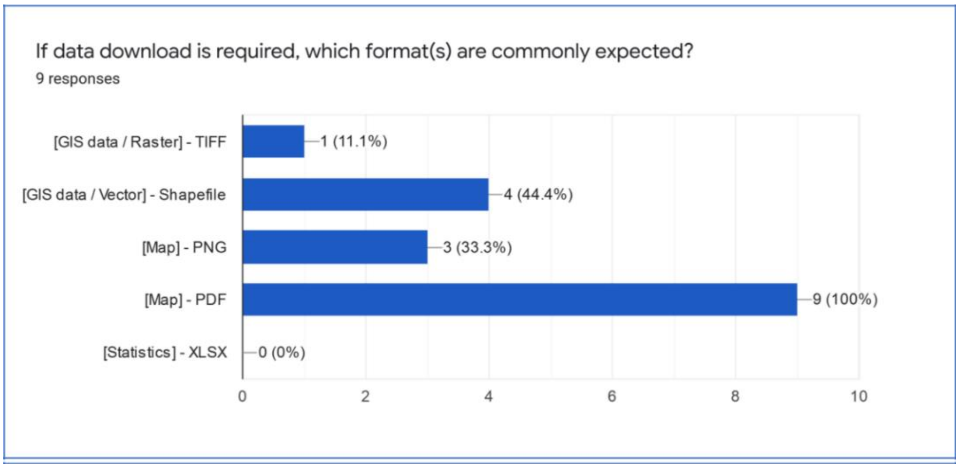

Site Closure & Aftercare
9 responses
Geochemical Mapping
Environmental Monitoring
Ground Stability / Geotechnical / Geoch…
Affected Stakeholders
Weather / Climate
Mapping of Infrastructure
Structural Stability Monitoring
1 (11.1%)
6 (66.7%)
6 (66.7%)
2 (22.2%)
1 (11.1%)
0 (0%)
2 (22.2%)
0
1
2
3
4
5
6

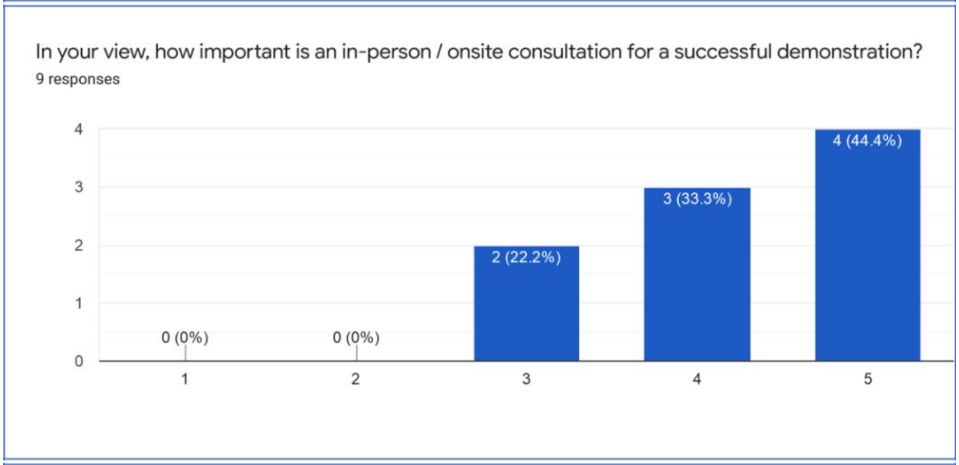

Please choose the expected demonstration mode(s) - Videos will be hosted on common portals (YouTube, LinkedIn, etc.)
9 responses
Online viewing portal
Short promotional video (intro to EO so…
Extended promotional video (intro to wo…
Sample data download
8 (88.9%)
5 (55.6%)
5 (55.6%)
1 (11.1%)
0
2
4
6
8

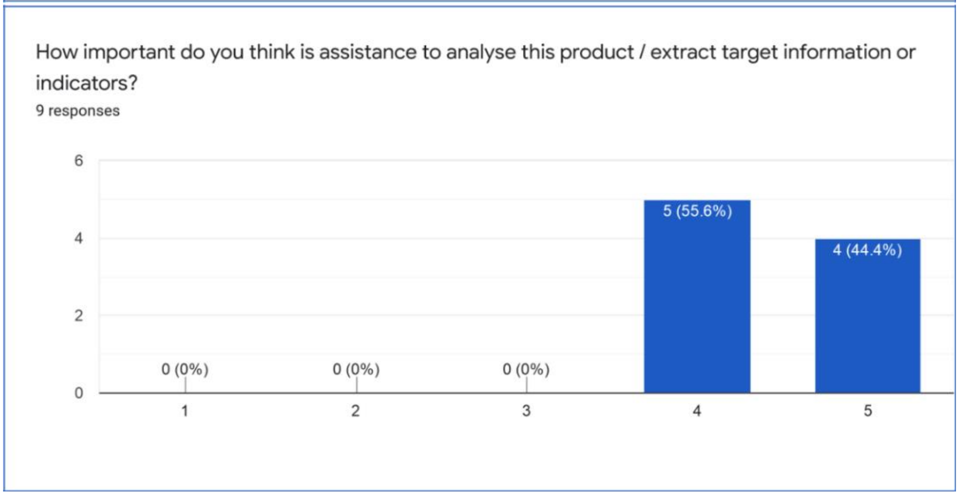

If data download is required, which format(s) are commonly expected?
9 responses
[GIS data / Raster] - TIFF
1 (11.1%)
[GIS data / Vector] - Shapefile
4 (44.4%)
[Map] - PNG
3 (33.3%)
[Map] - PDF
9 (100%)
[Statistics] - XLSX
0 (0%)
0
2
4
6
8
10


In your view, how important is an in-person / onsite consultation for a successful demonstration?
9 responses
0 (0%)
0 (0%)
2 (22.2%)
3 (33.3%)
4 (44.4%)
1
2
3
4
5


How important do you think is assistance to analyse this product / extract target information or indicators?
9 responses
0 (0%)
0 (0%)
0 (0%)
5 (55.6%)
4 (44.4%)
1
2
3
4
5







What other aspects do we need to consider for a convincing service demonstration?

6. responses
    - Trial at a surface and underground operation
    - Case studies
    - to be applied to convincing use cases
    - Depends on the product being demonstrated, but often consumers don't know the full capabilities and this is where expert assistance is required, both for analysis and extraction of information and when demonstrating the capabilities and applications.

- someone to introduce the product, but not necessarily do a demonstration

Target audience

Do you know other companies/stakeholders outside the IIB that would be interested in the demonstration?

7. responses
    - Building industry, waste sector and forestry / fishing
    - Exploration companies, service companies
    - Yes
    - Yes, to be provided via email
    - Tara Mines, Micon International
    - yes, consultants would be very interested in seeing "new" products that gives them an edge and something they can bring to their clients

Do you have any additional comments?

6. responses
    - looking forward to the on-line demonstration
    - The applications/tools need to compatible with industry platforms and require minimal training.
    - No
    - From the previous interaction my biggest take away was that having experts present the capabilities and applications of products was very important. I learned about latest advancements in EO technologies and could dream up new applications of my own. Whether the experts present in a face-to-face demonstration or in a promotional video is irrelevant in my opinion. Getting the information out as broadly as possible and with sufficient detail on the specifics is probably more key.
    - A demonstration that illustrates how it can be used in the mining industry, on a real project would be best.