EO4RM

Earth Observation for the mining of Raw Materials

D1.2: Geoinformation Report

Version 5

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List of Abbreviations

2D / 3D	2 Dimensional / 3 Dimensional
AA	Atomic Absorption
AF	Acid Forming
AI	Artificial Intelligence
ARD	Acid Rock Drainage
CA	Closure / Aftercare (mining phase)
CAD	Computer-Aided Design
CIM	Canadian Institute of Mining
cm	centimetre
CNN	Convolutional Neural Networks
COx,	Oxides of Carbon
dB (A)	Decibel (A - Weighted)
DO	Design / Operation (mining phase)
DTM	Digital Terrain Model
E	Exploration (mining phase)
EO	Earth Observation
EO4OG	Earth Observation for Oil and Gas
EO4RM	Earth Observation for the mining of Raw Material
EQS	Environmental Quality Standard
ESA	European Space Agency
EU	European Union
EY	Company previously known as Ernst & Young
FS	Feasibility Study
g	Gravity (i.e. 9.8m/sec)
GIS	Geographic Information Systems
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GPS	Global Positioning System
GSI	Geological Survey of Ireland
ICP	Inductively Coupled Plasma
InSAR	Interferometric Synthetic Aperture Radar
JORC	Joint Ore Reserves Committee Code
K	Kelvin
kHz	Kilo hertz
km	Kilometre

LiDAR	Laser Imaging Detection and Ranging
m	Metre
m^2	Metre squared
m^3	Metre cubed
mg/L	Milligram per litre
mm	millimetre
NAF	Net Acid Forming
NOx	Oxides of Nitrogen
OCR	Optical Character Recognition
OS	Ordinance Survey
P	Permitting (mining phase)
PAF	Potential Acid Forming
PFS	Prefeasibility Study
PPV	Peak Particle Velocity
REE	Rare Earth Elements
SAC	Special Areas of Conservation
SOx	Oxides of Sulphur
TDR	Time Domain Reflectometry
TSF	Tailings Storage Facility
USGS	United States Geological Survey
w/w	Percentage by weight
WRD	Waste Rock Dump
XRF	X-Ray Fluorescence

1 Executive summary

The objective of the EO4RM project is to highlight the benefits and opportunities for Earth Observation (EO) in the Raw Materials (RM) sector. This report is the primary output from the first work package (WP1) of the EO4RM project. Information for this report has been attained by desktop review, mining expert interviews and the workshop that was held in Brussels (6th June 2019).

The objective of this report is to provide an overview of each phase of the mining cycle, catalogue what geoinformation is required for each of these phases, describe how this geoinformation is currently being attained and highlight the barriers and opportunities for EO in each of these phases.

The global demand for raw materials continues to grow and the extraction of these materials is placing pressure on the finite resources of the Earth. Mining companies must become more efficient at identifying and abstracting mineral resources and new 'digital' technologies such as EO have a role to play in this. Europe is becoming overdependent on outside jurisdictions for much of its raw material requirements and this is not sustainable from a security of supply perspective and indeed from an environmental perspective (environmental action must be global and not just local). Europe needs to address the imbalance of raw material supply and embracing new technologies will be an important step in this process.

There are five distinct phases of the mining cycle and they are; Exploration, Permitting, Design & Construction, Operation and finally, Closure & Aftercare. Each of these phases require specific data in order to progress. The data that is required is for the most part 'geoinformation' as it relates to the physical, structural, developmental / social and chemical properties of the Earth.

This report identifies 67 items of geoinformation that are required over the life of a mining project, it describes how they are currently achieved and the associated measurement resolutions that are required, to make them beneficial to the mining industry. These geoinformation requirements have been analysed and presented in a series of tables of challenges and needs.

There are 41 current techniques for attaining geoinformation for the mining industry described in Appendix 1. This includes a brief description of monitoring and measuring techniques including detail of the equipment required.

Specific elements of geoinformation may be required in more than one phase of the mining cycle. For example, geotechnical information is required for both exploration and for construction. During exploration the detail required is in relation to deep structural faults that might be indicative of a geological feature that could be mineralised, while during construction the focus is more in relation to the detection of shallow voids that could be problematic with respect to structural stability. Each item of geoinformation is catalogued and discussed individually within the relevant mining phase.

Geoinformation within the mining sector is acquired and used by many different organisations such as mining companies, regulatory authorities, consultancies, academic institutions, community groups and other stakeholders. The techniques and methodologies used by different organisations will not vary significantly, although academic organisations and consultancies will often lead the way in terms of the development of new techniques to attain geoinformation.

There are barriers and opportunities in relation to advancements in geoinformation acquisition and these are summarised within the report. Significant opportunities lie within digitalisation, while the barriers are typically the cost of the new technology and gaining the trust of stakeholders in the new technology.

Although satellite data is being used by the mining industry to attain EO data, it is concluded that it is being underutilised. The primary reason for this underutilisation is concluded to be an lack of awareness of the technology and its capabilities, a fear the possible costs that may be involved (without appreciating the cost savings that may be realised) and finally a 'fear of change' which is part of the psyche of most people.

Good geoinformation is fundamental to managing risk and preventing failures. Solutions are required to provide cost effective high-quality data for all phases of a mining operation to identify and manage risk; and EO can be part of the solution.

EO providers must engage closely with both mining companies and regulators to ensure that technologies advance in line with the requirements of the industry. Furthermore, EO providers must work with industry to educate them on new technologies and to ensure that employees have the requisite skills to effect the change.

The geoinformation needs presented in this report will form the basis of a mock-up virtual platform that will be created by the EO4RM team to demonstrate the benefits of using EO data.

This report does not make specific recommendations as this report is only the first phase of the EO4RM project, which provides the base for rest of the work to be completed. This report and, in particular the information included in chapter 6, will be used by the EO4RM team to identify gaps in relation to the use of EO and especially the use of satellite technology to gather geoinformation for the mining industry. This work will be presented as part of the ongoing EO4RM project.

2 Introduction to EO4RM

2.1 Project Overview

The European Space Agency (ESA) funded project 'Earth Observation for the mining of Raw Materials' (EO4RM), aims to establish industry best practices guidelines for the use of Earth Observation (EO) in the mining sector.

The vast volume of EO data available has triggered the need to find new ways of exploiting EO data in order to extract its full potential. Despite the improvements of EO technology, there are still various barriers that limit the use of EO in the mining sector. The natures of these barriers are diverse, e.g. limited technological knowhow, financial aspects / cost of services, organisational aspects, lack of education / understanding, and unawareness of the potential of EO.

The objective of the EO4RM project is to be able to showcase EO capabilities for geographic areas of interest to a user community. This is done by (i) identifying the geoinformation needs of the mining sector, (ii) identifying the opportunities EO services have to offer, (iii) analysing the barriers and (iv) proposing a strategy to overcome them.

For the purposes of this report Geoinformation, Earth observation and Raw Material are defined as follows:

<u>Geoinformation</u>
Geoinformation is a very broad subject and at minimum it includes; all physical, structural, developmental / social and chemical properties of the Earth. In the context of the EO4RM project the geoinformation of interest is the data that is required to find raw materials, to successfully extract and process these raw materials, and to demonstrate responsible closure of the mining operation.

<u>Earth Observation</u>
Earth Observation can be defined as; the process of collecting data about the properties of Earth, including physical, chemical and biological. It can be used to monitor and assess the state of the natural and built environments and the changes to them. Earth Observation data can be collected in a number of different ways. It can be collected from space using satellites, from the air using airplanes and balloons, and on the ground using specially designed instruments. All Earth Observation data are collected using specialised technology, called sensors. These sensors are carried on satellites, airplanes or carried by people on the ground.

<u>Raw material</u>
A 'raw material' can be considered to be a basic material from which a product is produced. Raw materials are wide ranging and include metals, minerals and forest-based materials to name but three. While the EO4RM project is looking at raw material as a whole, the focus of the project is on mining and as such the raw materials that are of releveance in this report are metals and minerals. A mineral is typically defined as a solid, naturally occurring inorganic substance and in many instances in this report mineral is used when refering to material that contains metal ore and both terms are used interchangably thoughout the report.

Project Team:
The EO4RM project was awarded to a consortium of European companies, headed by Stichting Deltares (Deltares) from The Netherlands. The four additional companies are:

1. LTMS (Lisheen Technical and Mining Services) from Ireland,

2. S&T Corporation from The Netherlands,
3. Science [&] Technology AS from Norway
4. Geoville from Austria.

The expected outputs of the EO4RM project are:

- Establish and elaborate the current and future uses for EO in the mining industry, also anticipate future development of EO sensors, systems and services.
- Define the current EO capabilities and uses based on the various available EO sensors and EO service provider capabilities to support the entire mining cycle.
- Develop EO service mock-up(s) on a virtual platform to demonstrate relevant EO capabilities for the mining sector.
- Develop an implementation roadmap to enhance the uptake of new, potentially beneficial EO capabilities, and to establish them as a part of the mining industry 'best practice' guidelines.

The EO4RM project will:

- Unlock current EO services and products for the mining sector
- Showcase these services and products in a virtual platform
- Build a roadmap towards EO services best practice guidelines

The project has five distinct Work Packages (WP), each led by a member company of the consortium, under the project management of Deltares, with the following WP title headings and responsibility:

- WP1 - Collection of geoinformation requirements - LTMS
- WP2 - Definition of current EO capabilities and use - Geoville
- WP3 - Development of a service mock-up – Science & Technology AS Norway
- WP4 - Development of a best practice roadmap – S&T Netherlands
- WP5 – Project Management – Deltares

As part of the project, this stakeholder consultation workshop was carried out at the start of the project to ensure that relevant stakeholders had the opportunity to provide their input at the earliest stage. The project started in April 2019 and has a life span of 18 months.

2.2 International Industry Board (IIB) - role / members composition

As part of the original proposal for the project, the consortium proposed that an IIB is established to act as a sparring partner to the EO4RM project team. The IIB has a spread across the globe involving the most important mining regions and also involves different types of players in the sector (i.e. mining company, governmental regulator, consultant firm, network platform and academia). Composition and tasks of the IIB are further detailed in the Management & Administrative proposal.

The IIB consists of individuals who occupy the following positions:

1) Senior Geologist from Black Mountain Mining South Africa, part of Vedanta Zinc International
2) Manager Technical Marketing – Iron Ore – Atlantic, Rio Tinto, mining activities in a.o. Australia and Canada
3) Vice President of Barr Engineering, a consultant firm active in mining in the US and Canada
4) State Secretary for Environment and Sustainable Development, Minas Gerais (Brazil)

5) Director at GeoScience Ireland (GI), is a network of 36 companies, delivering integrated expertise in water, minerals, environmental and infrastructure.
6) Director at the Geological Survey of Ireland
7) Partner at Survey Lab and Associate Professor at Sapienza Università di Roma.

The IIB is chaired by the representative from Geoscience Ireland who has an extensive, worldwide network throughout the mining industry in addition to critical experience in understanding the role of geo-information in the mining lifecycle.

Tasks of the IIB include:

- Active participation in the two workshops and in meetings/interviews by Skype,
- Provide access, where appropriate, to data and information to facilitate a high quality and demonstrable virtual platform and
- Comment, prioritise, validate and supplement interim findings and final project results.

2.3 Objectives of this report

This report is the primary output from work package 1 of the EO4RM project. The objective of the report is to:

- Introduce an overview of the mining industry, and what are the opportunities and challenges.
- Explain the mining process and the information that is required for each of the phases of the process.
- Provide detail on the specific geoinformation requirements for the mining cycle.
- Explain the different requirements for geoinformation for different professionals associated with the mining industry (from miners to regulators).
- Explain how mining geoinformation is currently attained.
- Provide a discussion on barriers and opportunities.

The geoinformation requirements are the key aspect of this report and are presented in in summarised in chapter 6 of the report.

3 Geoinformation report structure and information sources.

Chapters 4 and 5 provide an overview of the mining industry, which is important background information to appreciate the geoinformation detail that is presented in chapter 6.

Chapter 6 catalogues the geoinformation requirement of the mining industry. A description of various techniques currently used to attain geoinformation for the raw materials sector is included in Appendix 1.

Chapter 7 provides an overview of the barriers and opportunities associated with the attainment of geoinformation. Much of which is based on the discussions from the workshop in Brussels.

Chapter 8 gives some brief conclusions from the report.

Chapter 9 gives a brief introduction to the EARSC portal and the objectives of this workspace.

Appendix 1 describes the current techniques used by the mining industry to attain geoinformation. The questionnaire template and results are included as Appendix 2 and copies of the interviews with industry experts are included as Appendix 3 of this report. Appendix 4 includes a circumscribed bibliography of references used during completion of the report.

The information for this report was sourced by several means and these are briefly outlined below:

- A desktop literature review was completed. The bibliography provided in Appendix 4 lists a selection of the sources that were accessed to provide information used in the preparation of this report.

- A questionnaire was developed by the EO4RM team and distributed to over 200 people who work in the raw material / geological / mining sector. The number of completed questionnaires that were return to the EO4RM team was disappointing, being just 10% of the number that were distributed. However, those questionnaires that were returned did contain useful information and that information has been incorporated into the report. The questionnaire responses were sufficient to give the EO4RM team an initial sense of understanding of EO within the raw material sector and this was used to structure the workshop in Brussels. The questionnaire responses were used, in part, to decide who would be participants in the workshop.

  Information was also gleaned from the lack of responses. The people who did not complete the questionnaire may have been too busy. However, the EO4RM team took the view that the lack of response was also an indication in itself of the lack of engagement and/or awareness of EO within the mining sector and this is an important piece of information taken from the exercise. The questionnaire that was issued and a summary of the responses is included in Appendix 2 of this report.

  From the responses that were received it was possible to draw some conclusions.

Firstly, the sectors that are most aware of, and engaged in, EO are the academic and research institutions, followed by the geological surveys. Mining companies displayed a poor level of EO knowledge and a poor level of EO use. A question might arise about the profile of those selected to complete the questionnaire and might this have introduced a biase towards academic and research institutions (i.e. was the questionnaire was sent to more academic and research institutions, meaning there would be more responses from these groups). This point was considered but was discounted, because discussions during the workshop confirmed the assertion that; while some mining companies are using EO, as a group they are a laggard with respect to fully embracing the new technology.

The areas where EO is most widely used, at this time, were reported to be in stability/subsidence monitoring, environmental monitoring and geochemical / geological mapping. The same three aspects are highlighted as being suitable to benefit from EO technology advancements, although closure and rehabilitation is also specifically included in this response. The discussions at the workshop, the IIB interviews, and the literature reviews confirm that stability monitoring, environmental monitoring and geological mapping are the three areas where EO is most widely use within the mining sector.

- Four members of the IIB were interviewed by the EO4RM team and a summary of each of the interviews is included in Appendix 3. The interaction with the IIB members was vital to the attainment and validation of information that is included in this report.

  All four interviewees have significant knowledge and experience in their area of expertise. Three of the interviewees have personal experience in using EO technology, while the other interviewee had a more overarching view of the technology and its place within the industry. Of the four interviewees, one was particularly expert in the development of EO technology.

  The responses of the interviewees very much endorse the information that was attained at the workshop. The areas where the interviewees reported EO being used and having the greatest opportunity for growth were stability, exploration and environmental – similar to the workshop sentiment and the questionnaire findings.

  There were many barriers to the adaptation of EO given by the interviewees and again they corresponded with the workshop findings. Cost, lack of expertise and lack of awareness of the technology were the three themes that came out strongest.

  It was concluded that the EO technology providers would benefit from both engaging with junior mining companies and providing and entry-level EO product.

  The perceived lack of resolution, (temporal, spatial and spectral) was reported by the interviewees as not being as significant as was initially thought (prior to the commencement of WP1). While it was concluded that improvements can be made in resolution these were all application specific and did not represent a fatal flaw in the technology for its general use within the raw materials sector.

- Much of the information included in this report was attained from the knowledge of the LTMS team, who's three Directors and associate environmental expert have a combined experience of over 80 years in mining across various raw material types and different geographies.

- The Brussels workshop held on the 6th of June was a rich source of information for this report. A full account of this workshop can be found in the D1.1 workshop report. A brief overview of the workshop is provided in the following text:

The objectives of the workshop were:

1. To introduce and provide an overview of the EO4RM project, including objectives and anticipated key results.
2. To gather relevant inputs from EIP-RM OGs and IIB on their current geoinformation needs and gaps and potential use of satellite EO to fill these gaps.
3. To provide participants with an overview of current and future capabilities for EO in the mining sector and to give them access to world-class experts of EO capabilities relevant for the mining sector.

The workshop was attended by 38 persons, from various organisations. The workshop served the purpose as set out in the objectives, which are noted above. In addition, it was noted that participants had a range of knowledge of EO technologies, from expert level to virtually no knowledge. The workshop therefore provided a platform for all participants to either share their knowledge or learn about EO technology.

From the workshop it became clear that there are differing views on the status, levels of use, levels of interest and the potential of advancing the use of EO technology in the mining industry.

The information, data and opinions outlined in the full workshop report are used as input for the geoinformation tables presented in chapter 6 of this report.

4 Brief overview of the global mining industry

Raw materials are a fundamental aspect of the global economy and vital for growth and to maintain living standards for the Earth's ever-growing population.

Securing a sustainable supply of raw materials is a key priority for the EU. Raw materials, such as metals and minerals or forest-based materials, have become increasingly important to the EU's economy, growth, and competitiveness. More than 30 million jobs in the EU and many key economic sectors such as automotive, aerospace, and renewable energy are dependent on a sustainable supply of raw materials. Raw materials are particularly crucial for the development of modern environmentally friendly technologies and a strong European industrial base. Without them, there wouldn't be any smartphones, laptops, or cars.

Recent years have seen a major focus on the circular economy, with an increase in reuse, recycling and product substitution. However, the need to abstract raw materials from the ground is vital to meeting the demand.

Raw materials are critical to the advancement of new technologies including the decarbonising the worlds energy supply. For example, the lithium demand has increased significantly in the last decade to meet the demand for batteries needed by the electrical industry.

The graph below illustrates how mining has increased over the decades to meet the global demand.

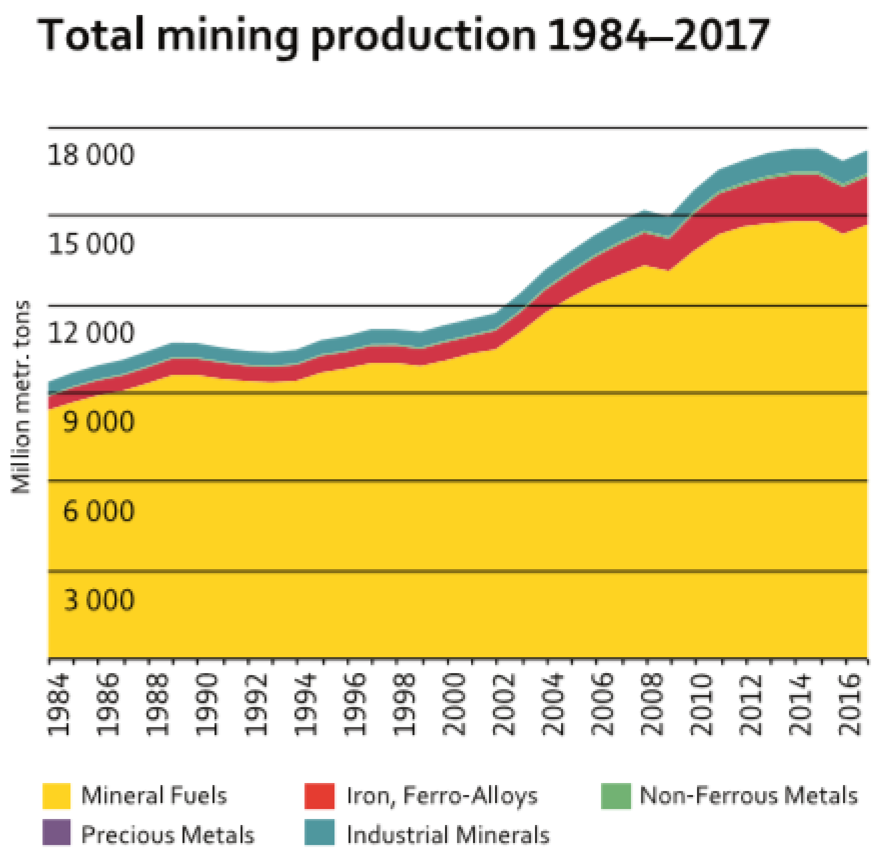


Figure 1 – 1984 to 2017 total mining production.

4.1 Global raw material demand and supply

The global population is forecast to reach 9 billion by 2030, including 3 billion new middle-class consumers. This places unprecedented pressure on natural resources to meet future consumer demand. Demand for raw materials has been growing decade on decade and this trend looks set to continue. The vast majority of commodity analysts project ongoing demand side pressure for raw materials. The figure below was produced by Wood Mackenzie and plots the historic and projected consumption rate for copper in kilotons. Copper is a key commodity and is very useful to track global development. The increasing supply side pressure for raw materials will force mining and exploration companies to be more innovative with respect to identifying new resources. Embracing and refining technologies such as EO can be part of this innovation.

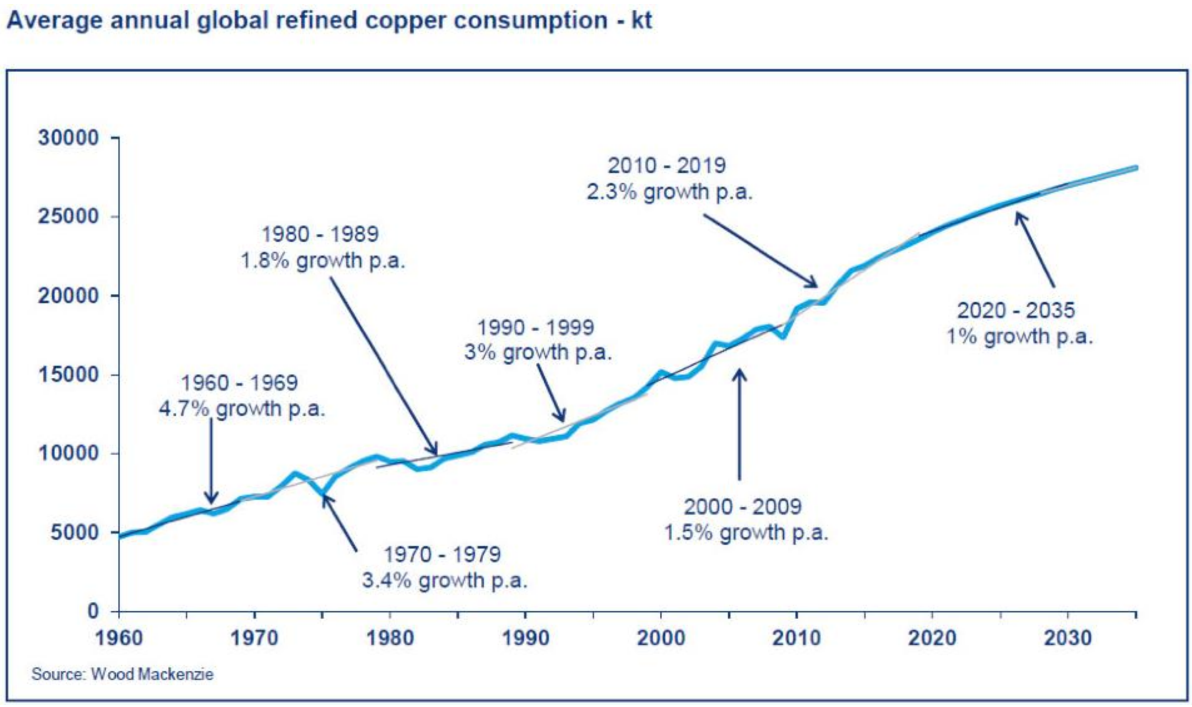


Figure 2 – Wood Mackenzie projected copper consumption.

4.2 Global raw material production and consumption overview

Minerals are deposited and mined all over the globe, with some countries having greater reserves than others. The chart in figure 4illustrates the variation in raw material abstraction (mining) between different countries around the world, with China being the main producer followed by the USA, Russia and Australia.

The quantity of mineral that is produced by a country is not just a direct measurement of how much mineral is present within a country, it is also very much dependant on the ease with which the mineral can be extracted. This is influenced by various factors including cost of production, climate conditions, political stability and regulatory requirements. The net result is that the cost of abstraction will vary depending on under what jurisdiction the mineral is being mined and it may in fact be prohibitively expensive to mine in certain geographic locations.

Figure 3 presents the different quantities of mineral being abstracted from different countries around the word. Figure 4 shows geographically where different minerals are present within Europe.

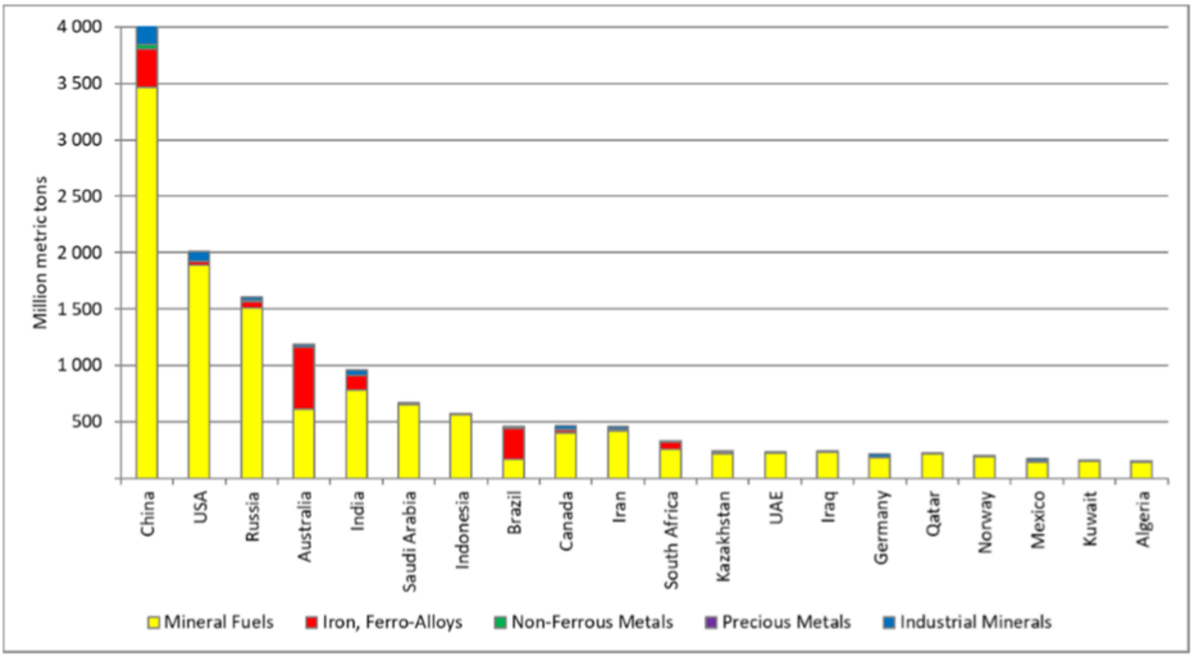


Figure 3 - Global commodities abstraction by country.

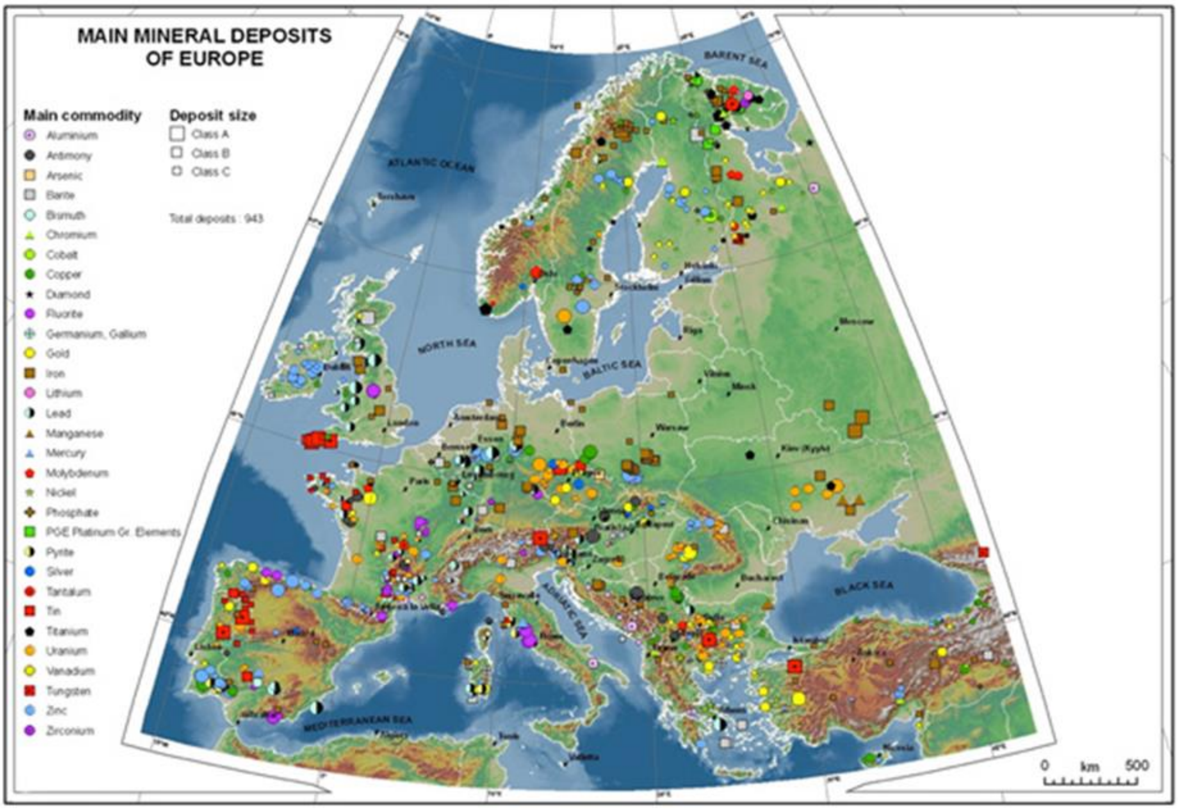


Figure 4 – Raw material resources within Europe (Euromines)

China has been, and remains, one of the key drivers of raw material demand. The figure below indicates the proportion of raw materials used by China when compared with the rest of the world. China's demand influence is very significant as commodities are traded globally, and all countries must compete for their share.

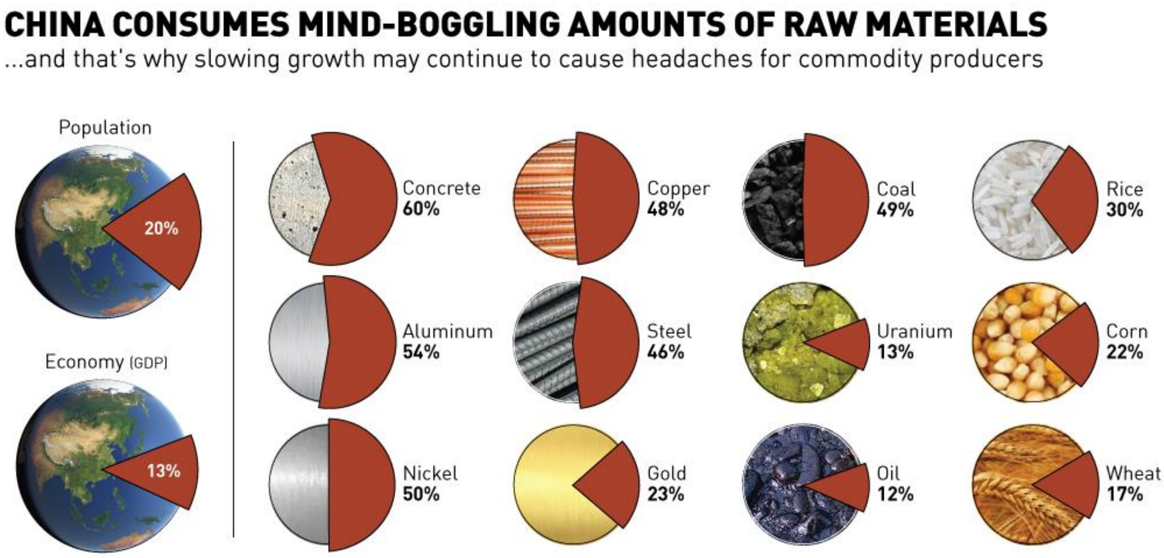


Figure 5 – Raw material consumed by China (source – visual capitalist.com).

4.3 Raw material extraction within Europe.

Countries and trading blocs (such as Europe) are becoming more aware of their raw material needs and the security of supply. Having security of supply is critical to the sustainability and growth of any country or trading block. The most effective way to ensure security of supply is to source materials indigenously.

Despite having significant mineral resources and a strong demand within the jurisdiction, the amount of mining within Europe has decreased significantly in recent years and Europe is becoming more and more dependent on imports for its raw materials needs.

Figure 6 illustrates which parts of the globe have seen the most growth in mineral abstraction in the past 20 years and this is particularly relevant with respect to the information provided on Europe.

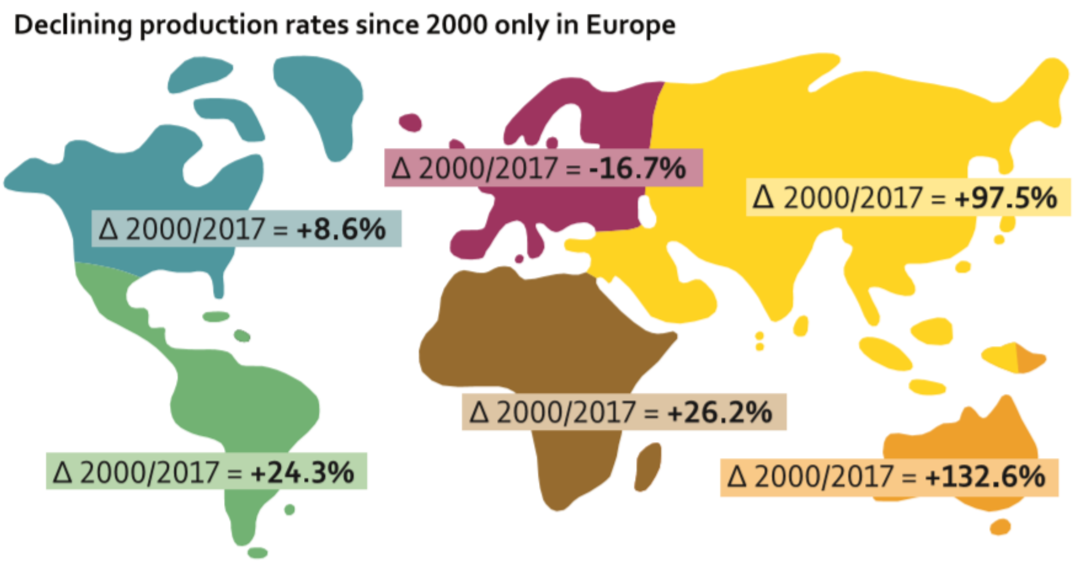


Figure 6 – Change in raw material abstraction by country.

While the amount of mining is Europe is falling with respect to other regions, Europe will need to compete with the rest of the world for its supply of raw materials in a market that predicts increasing demand pressure.

The lack of indigenous raw material supply for Europe is a threat to economic growth and achieving a zero-carbon footprint. The figure below, from EuroStat, gives an indication in the imbalance between import and export of key raw materials.

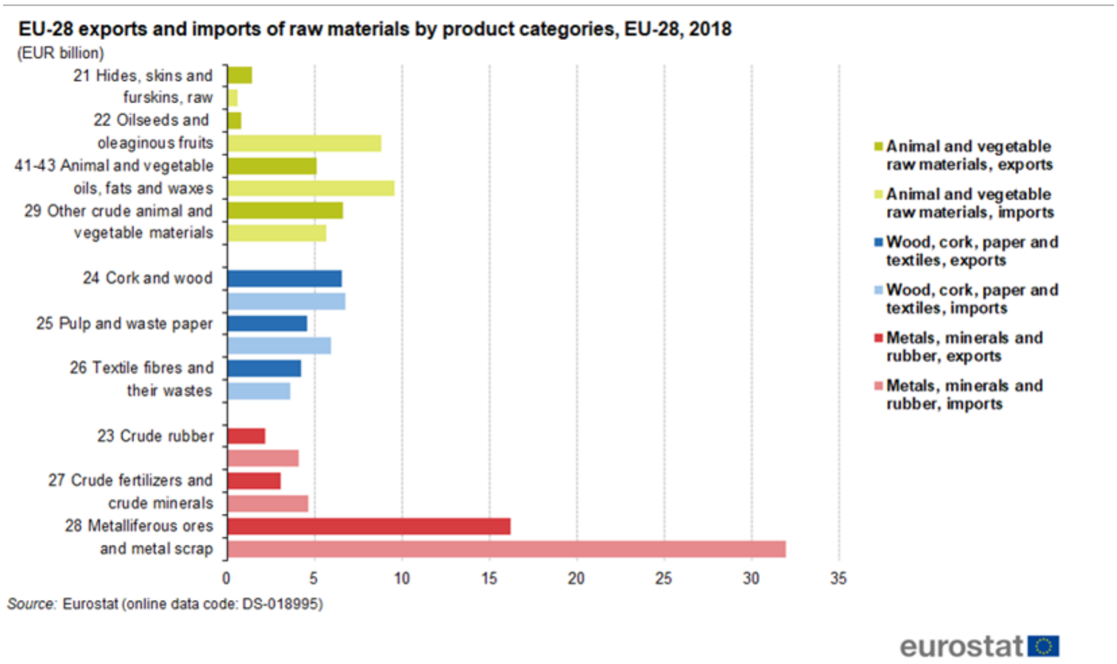


Figure 7 – On-line data for import and export of raw materials

Action is needed within Europe to address the abovementioned imbalance. In 2008, the European Commission adopted the raw materials initiative which set out a strategy for tackling the issue of access to raw materials in the EU. This strategy has 3 pillars which aim to ensure:

- Fair and sustainable supply of raw materials from global markets
- Sustainable supply of raw materials within the EU
- Resource efficiency and supply of 'secondary raw materials' through recycling

The strategy covers all raw materials used by European industry except materials from agricultural production and materials used as fuel. Ensuring sustainable access to these raw materials is crucial to the competitiveness and growth of the EU economy and to the objectives of the Europe 2020 strategy.

A list of critical raw materials has been prepared by the Commission and this is regularly updated. The most recent list can be found at the following location on the ec.europa.eu website. https://ec.europa.eu/transparency/regdoc/rep/1/2017/EN/COM-2017-490-F1-EN-MAIN-PART-1.PDF

Although mines have closed in Europe and the overall picture shows a decline in production it is the case that significant volumes of raw materials remain unmined within Europe. The Horizon 2020 program VAMOS (Viable Alternative Mine Operating System) states that over many centuries the easy-to-access mineral deposits have been mined and are mostly now almost depleted, while deeper lying ones have not been fully explored. The major opportunities to access raw materials within the EU are in greater depths, in remote, but also in populated areas, in former mine sites, in low grade deposits, and in small deposits where larger mining operations may not be feasible. Estimates indicate that the value of unexploited European mineral resources at a depth of 500-1,000 metres is approximately €100 billion.

4.4 Future metal / mineral demands

It is difficult to predict what specific metals and minerals may be required in future, as technical developments may drastically change in the decades ahead. However, it is possible to look at recent trends and short-term projections to highlight the areas of growth for the mining and raw materials sector. A major area of growth, previously mentioned in this report, is technologies associated with decarbonisation. There technologies, such as battery storage, require specific raw materials. The following figure shows the projected growth in raw materials associated with EV lithium ion batteries.

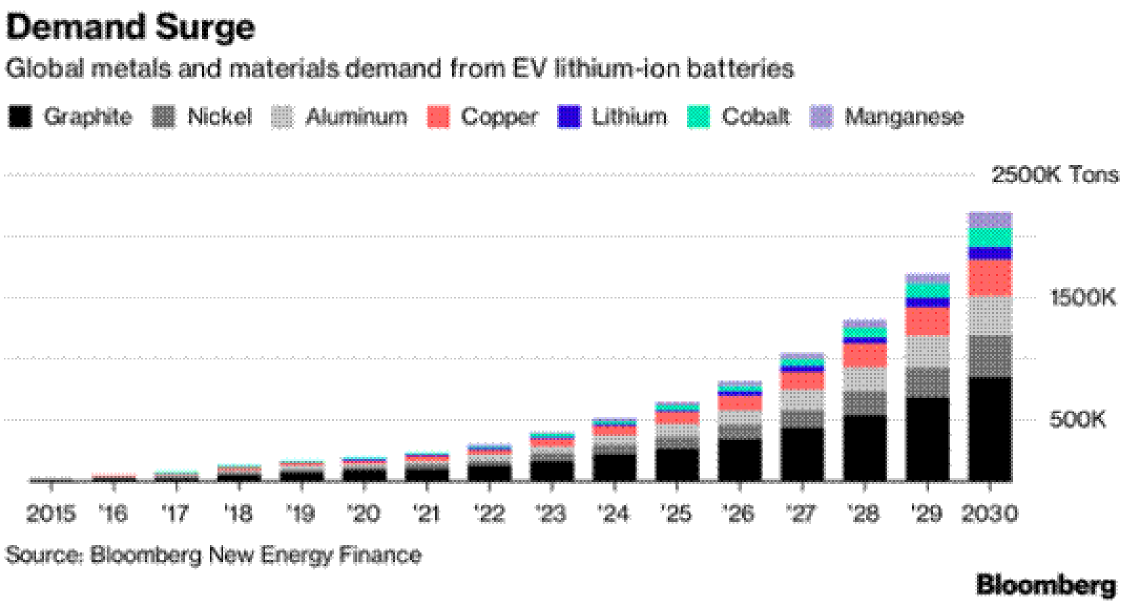


Figure 8 – Projected growth in raw materials associated with EV lithium ion batteries – Bloomberg.

The growth in the demand for Rare Earth Elements (REE) that are required for hi-tech application has been, and is expected to continue, to be a major area of growth. For example, colour cathode-ray tubes and liquid-crystal displays used in computer monitors and televisions employ europium as the red phosphor and no substitute is currently known.

REE are a group of 17 chemically similar elements crucial to the manufacture of many hi-tech products. The commonly accepted 17 REE are: cerium (Ce), dysprosium (Dy), erbium (Er), europium (Eu), gadolinium (Gd), holmium (Ho), lanthanum (La), lutetium (Lu), neodymium (Nd), praseodymium (Pr), promethium (Pm), samarium (Sm), scandium (Sc), terbium (Tb), thulium (Tm), ytterbium (Yb), and yttrium (Y).

The term 'Rare Earth Element' is somewhat of a misnomer as REE themselves are relatively abundant in nature but what makes them 'rare' is that they are difficult to extract, not least because they are quite dispersed and not often found in economically exploitable ore deposits. The figure below from the United States Geological Survey (USGS) gives a graphical representation of the abundance of REE.

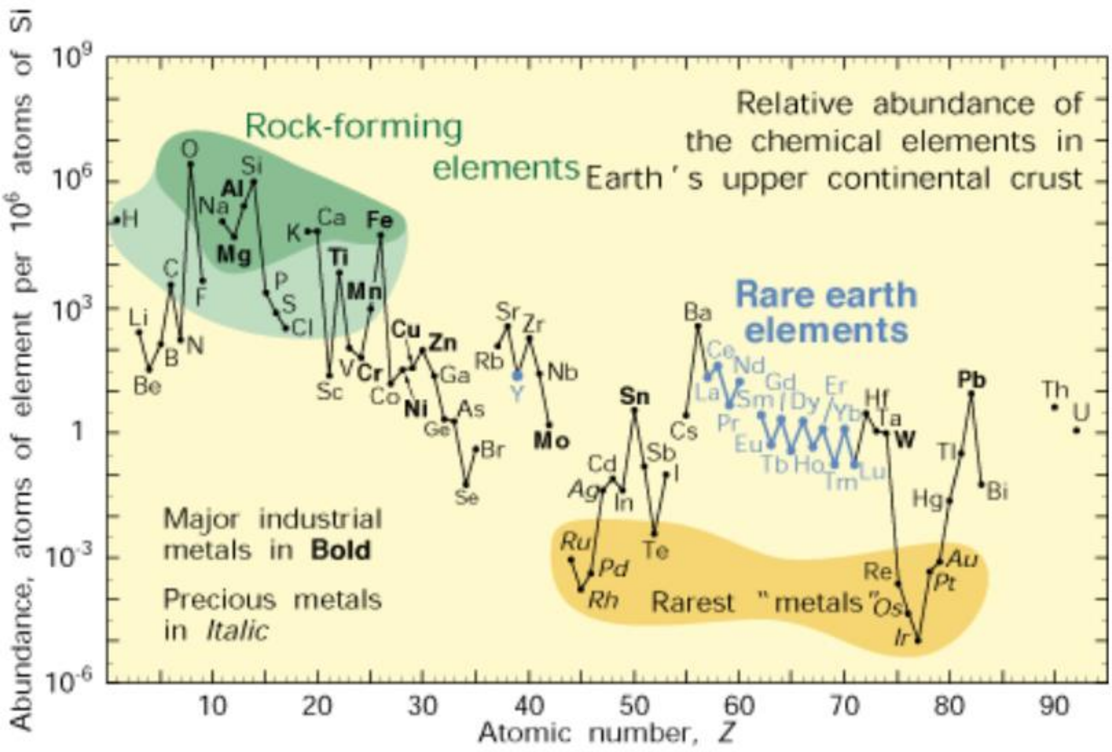


Figure 9 – USGS graph of rare earth elements

China currently leads the world with respect to abstraction of REE and this has been a source of recent global trade tensions.

4.5 Constraints facing the mining industry

The obvious cliché about the 'low hanging fruit' remains valid. Many of the best, most easily mined, resources have been mined in recent decades and future mining is forcing exploration companies and mining companies to look in more remote areas for resources. This is taking mining companies deeper underground, to more remote geographies and even potentially under the oceans. Research is taking place into mining minerals in near-earth asteroids and other celestial objects, albeit this has significant challenges, not least returning the mined material to Earth.
Mining is an energy intensive industry and in today's world of climate change risk and restriction on CO_2 emissions, this puts even greater pressure on mining companies to remove the resource in a sustainable manner.

EY (previously known as Ernst & Young) conducted a survey of over 250 sector participants from around the world and produced a list of top 10 risks for mining in 2019/20 and they were as follows:

1. License to operate
2. Digital effectiveness
3. Maximising Portfolio Returns
4. Cyber
5. Rising costs
6. Energy mix
7. Future of work force

8. Disruption
9. Fraud
10. New Word Commodities.

The top two risks for mining identified by EY could be considerably reduced with better geoinformation and in particular if advanced techniques, such as EO, was used more frequently to address the geoinformation requirements.

'License to operate' is the number 1 risk, and licence to operate is something that features extensively in this report in relation to geoinformation requirements. EY states that 'the stakeholder landscape is changing and miners need to adapt'. It is further stated that 'the sector is working to redefine its image as a sustainable and responsible source of the world's minerals. But while many in the industry are saying all the right things, their actions do not follow their words, and the many stakeholders are not fooled. License to operate has evolved beyond the narrow focus on social and environmental issues. There are now increasing expectations of true shared value outcomes from mining projects. Any misstep can impact the ability to access capital or even result in a total loss of license'.

The second biggest risk is also very relevant with respect to geoinformation as it relates to digital effectiveness. The sourcing of geoinformation is moving more and more to digital and mining companies need to recognise this and embrace this. The EY report acknowledges that there is a significant knowledge gap with respect to digital and it is reasonable to surmise that this is resulting in loss of opportunity and inefficiencies. The report states that '37% of management have little or no knowledge of the digital landscape. The stark reality is that digital is the key to achieving productivity and margin improvements. It is no time to stand still in an age of business transformation that is largely driven by digital'.

4.6 What are the implications and opportunities for technology advancement (including EO), and what does this mean specifically for Europe.

Mineral demand is ever increasing, the raw materials that were easy to mine have been, and are being, mined so it is now necessary to abstract raw materials that are harder to reach. There is also demand for new minerals, which is bringing new pressures. The following figure summaries which raw materials are of most importance and, of these, which have the greatest supply side risk.

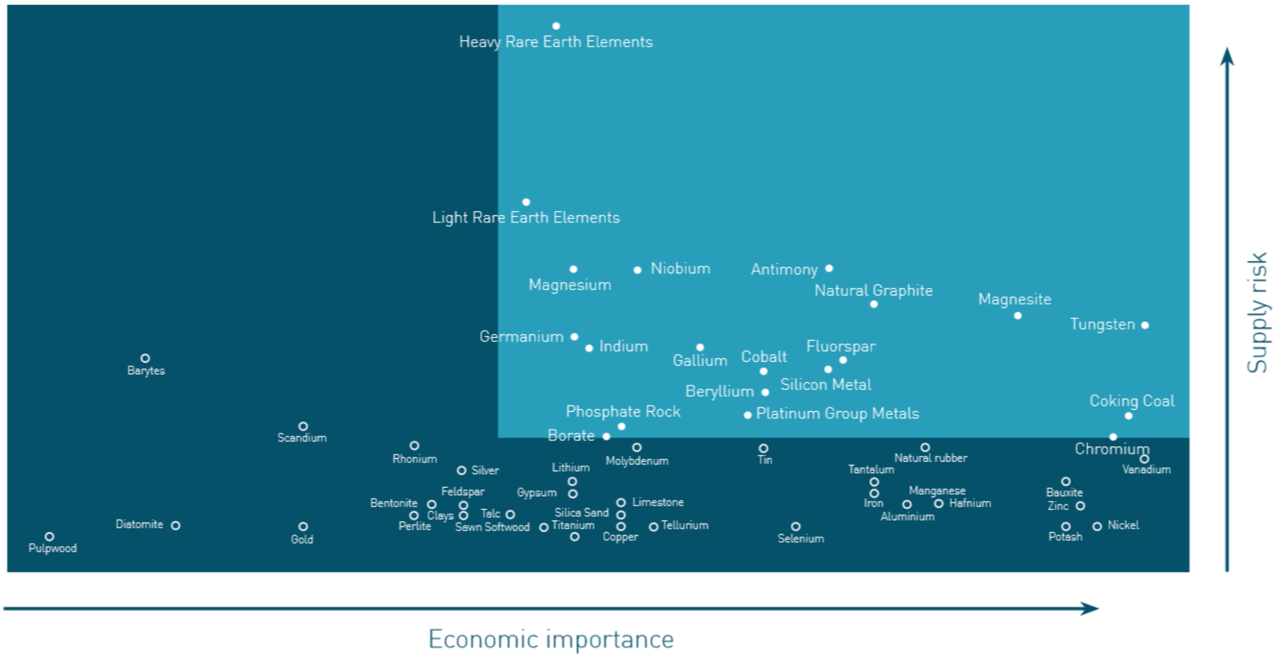


Figure 10 – critical raw materials, supply risk (source EU Commission 2014)

In order to meet the demand for raw materials companies and countries are going to have to invest in new mines, and where possible expand existing mines. Technology can, and will, play an important role in this investment. As will be explained further in this report, all mining starts with exploration (both green field and brown field) and exploration is intrinsically linked to technology. New exploration technologies can allow exploration to take place deeper and in more remote areas than before. Data processing is more effective as technology advances allowing exploration companies better interpret the data collected. As will be described in this document, advancements in EO technology is allowing mining and exploration companies to carry out very efficient screening of land masses to identify anomalies that may be indicative of mineral deposition. These technology improvements mean that it is now possible to see anomalies that previously may have been missed in earlier screening. An efficient identification of these anomalies assists the industry to get on the ground and do detailed assessments that are needed to identify an economic raw material resource. It is not just in exploration that technological advancements are being made, it is right across the mining cycle including the techniques used to develop and operate mines. Improving technologies will improve the economics of mining and this is needed in an environment where deeper more challenging ore bodies are going to be mined.

Because the demand is rising, and the supply is tightening this will inevitably result in price increases and particularly for those raw materials to the right and the top right of figure 10. This increase in price will justify the additional cost that will be required in developing and using the new technologies that are required.

From the earlier figures it can be seen that Europe has fallen behind in relation to mining. The European Union consumes about 25-30% of the world's metal production, whereas the extraction of metals in the EU accounts only for about 3% of the world's ore production. Despite the efforts to develop recycling technologies and material science, dependency on metal imports is growing every year. The EU's industry needs in metals are met by importing about 200 million tons of minerals each year. The rate of import dependency on metallic minerals ranges from 74% for copper ore, 80% for zinc and bauxite, and 86% for nickel, to about 100% for high-tech minerals such as rare earths, PGM, antimony, germanium, gallium, niobium, indium, beryllium, cobalt, tantalum and tungsten.

Although the amount of mining in Europe has drastically declined, Europe is still at the forefront of developing technology that is used within the mining industry, some of the largest mining equipment companies are based in Europe. For example, the Swedish giant Sandvik is selling equipment in more than 160 countries and is leading the way in remotely operated mining equipment. Academic and consultancy services based in Europe also generate large amounts of intellectual property used by the mining industry. The intellectual and technical ability is within Europe to continue to advance mining practices. This intellectual and technical ability needs to be applied to unlock the value that is in the mineral resources within Europe and ensure a secure supply of key raw materials into the future. EO is just one of the areas of advancement that can make this happen.

5 The Mining Cycle and (use/potential benefits of) EO

Mining is the extraction of valuable minerals or other geological materials from the Earth. Mining is required to obtain any material that cannot be grown through agricultural processes, or feasibly created artificially in a laboratory or factory. Mining is different from farming or factory production in that it must occur in the location of the orebody and this is often in remote or difficult locations.

Figure 11 – Mine Shaft in South Africa

Figure 12 – Open Pit Mine in Africa

There are several phases of the mining life cycle, which in their own right stand alone. These phases require and use very specialised services and techniques. EO is being used currently in the mining industry but its use varies from basic to very sophisticated use, depending on the phase of the mining cycle, the cost, type of company involved, jurisdiction and the level of detail required for the specific phase of the project.

There is a legacy of poor mining practices in many parts of the world and there is significant pressure on governments and their agencies to ensure that this is not allowed to continue into the future. As an example, in Ireland, there are a number of old mining operations that have left behind polluted and scarred landscapes. In recent years, there has been a major improvement in mine closures and the Lisheen Mine in Ireland is being hailed as one of the best examples of an environmentally and socially responsible closure in the world.

The trend for mining companies, governments and agencies is now to prevent the mistakes of the past from happening again and this is being achieved by early and ongoing intervention by Regulators, so that they have oversite and controls over the full mining cycle.

This chapter of the report will explain the mining cycle, providing individual detail on each phase of the cycle. It will also provide an overview of where EO technology is already being used and where there are opportunities for further usage.

There are five very specific phases of the mining life that are important in this discussion:

1. Exploration
2. Environmental Assessment, Planning and Approval
3. Design and construction
4. Operation
5. Closure and Aftercare

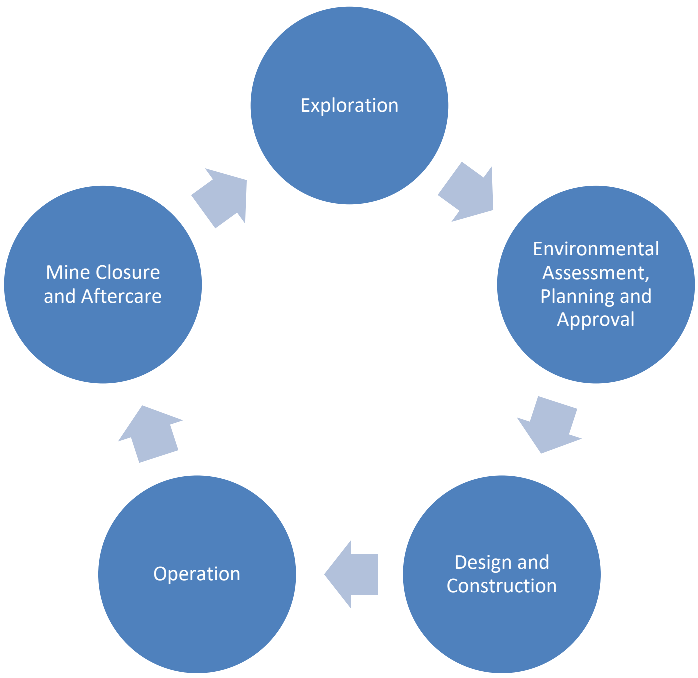


Figure 13 – Mining cycle

5.1 Exploration

The exploration of minerals in the extractive industry sector has many facets and most mineral exploration projects do not progress to the next phase of the mine life cycle. This is due to insufficient data, inability to discover sufficient mineral resource to make an economic ore reserve and other reasons such as environmental or regulatory issues. Therefore, it is likely that there are several thousand active exploration projects across the globe at any time.

The process of exploration typically includes a range of methods including, remote sensing, geophysics, geochemistry, trenching and core drilling.

Remote Sensing uses sensors for collecting data about an object or area without being in direct contact with it. The sensors can be located on satellites or on aircraft. Some examples are geological mapping, aerial photography, satellite imagery and airborne geophysical data.

Geophysics utilises measurements associated with physical properties made on or above the ground surface and in boreholes. Information is analysed to develop an understanding of structural and mineral geology. There are several geophysical methods which can be classified as passive (which uses naturally existing fields) or active (which utilises the generation of a stimulus).

Geophysical exploration can be based on:

- resistivity (measuring potential differences between two or more electrodes generated by a current introduced into the ground)
- gravity (measuring differences in specific gravity of rock masses)
- spontaneous polarization (measuring differences in spontaneous electrical potential caused by electrochemical reactions)
- induced polarization (measuring changes in double-layer charge within a mineral interface)
- magnetic susceptibility (measuring changes in structure or magnetic susceptibility in certain near-surface rocks)

Geochemistry involves the sampling of soils, vegetation, riverbeds, etc. which can be analysed for identification of geochemical anomalies. Regional geochemical exploration is traditionally based on topsoil or water stream sampling, where there may be an association between the presence of some chemical elements and the occurrence of certain mineral resources.

Trenching involves the use of shallow excavations for sampling of rock and other materials. Trenching also provides a level of continuous exposure to the materials of interest.

Figure 14 – Exploration Geologist at work

Core Drilling is normally used to access deeper areas of interest by using material extracted from a small diameter holes, where a core of rock is normally extracted. There are several methods of drilling available and used for different requirements. These include auger drilling, percussion drilling and rotary drilling.

The use of specific exploration methods is normally based on the variables associated with level of detail required, the phase of exploration, characteristics of the mineral deposit (type, size, location, etc.), time-frame available and the cost.

Figure 15 – Exploration core drilling

The exploration process normally starts with people or companies obtaining licences for exploration and then providing a commitment to carry out some exploration processes.

Typically, junior exploration companies follow scientific leads, narrow down target zones and then carry out specific techniques to identify minerals and other factors, which can potentially lead to an economic ore body. Finance is often a major problem for junior exploration companies for acquisition of available data or provision of exploration services in the field.

If quality targets have been identified, and a resource has been developed, junior companies will then turn to senior companies for funding or as a sale target. Senior mining and exploration companies often have significant budgets for exploration and for acquisition of junior companies. Many of the major mining companies will have strict criteria for acquisition or investment, with examples as below:

- Example 1; some majors will only consider acquiring brown field sites (sites with previous mining activity), as opposed to green field sites (where exploration is based more on conceptual ideas and the risks are greater).

- Example 2; some companies will only consider gold projects with resource estimates of 500,000 ounces of gold. A geological resource is a concentration of a minerals that has a reasonable prospect of economic extraction. There are varying levels of resource confidence including inferred, indicated and measured. A Resource is a concentration of a minerals that has a reasonable prospect of economic extraction.

From the perspective of EO, there are many areas of the exploration process which currently utilises EO techniques, such as:

- Satellites for mapping of relief, sampling targets, access, survey target identification and prior mining/exploration activity, 3-D maps and databases
- Airborne geophysics
- Drones

Small exploration companies cannot always afford the technology, the data or the specialist people to manage the data. The need for low cost, high resolution data is therefore imperative for the development and use of EO technologies in mining.

5.2 Environmental Assessment and Permitting

To achieve a permit to operate a mine, it is essential that a mine developer can demonstrate a full understanding of the natural environment in which it is proposed to develop the mine. The operator needs to ensure knowledge of the potential environmental impact of the operation. To understand the potential for environmental impact there are many aspects that need to be considered including visual impact, land use, habitat, waste management, air emissions and potential impact on water (abstraction and discharge). Data is required to assess and manage all these aspects.

Figure 16 – New Mining Operation in Africa

There are many techniques used by mine developers to acquire the information needed and EO is one of those techniques.

EO data can be used to assess the setting of a potential mine and how its development might impact visually on the environment. This data can also be used to gain a better understanding of other environmental factors such as habitat – e.g. extent of afforestation etc. Mining, if not properly managed, can impact on habitat and this impact will have a direct impact on the viability of wild animals. EO can be a very useful tool for firstly establishing the baseline number for animals in the area of mining and then tracking the numbers over the life of the mining operations. While EO is used for this application it is not used as widely as it could be.

It is inevitable that mining will impact on the topography around the mine. Open cast or surface strip mining requires the removal of large volumes of overburden which is stockpiled in waste rock dumps

(WRDs). EO can be used to establish baseline conditions and establish how these baseline conditions have changed during operations and as part of mine rehabilitation. This baseline data is a requirement of the permitting process. Underground mining will have a less pronounced impact on topography that open cast mining. However, underground mining does impact on topography and despite tight backfilling there will inevitably be some level subsidence on the ground about the mine; both directly above the mine and in the general environs of the mine. This can be either significant or miniscule, depending on many factors, such as depth, mining method, use of backfill, rock and soil types. In a well designed and managed mining operation, subsidence can be predicted to a high level of accuracy. Subsidence is traditionally assessed by survey techniques; establishing a network of benchmarks around the mine and measuring their elevation against a known datum. Measurements of the elevation can be taken throughout the life of the operation and during the closure and aftercare period. This is a very good example of where EO technology can be used to assess baseline ground levels in a pre-mining environment and then determine any subsidence levels in the post mining environment without any site work taking place and again while there are examples of EO being used for this purpose, the use is not widespread.

A typical assessment of subsidence around a mine can be seen in the chart below:

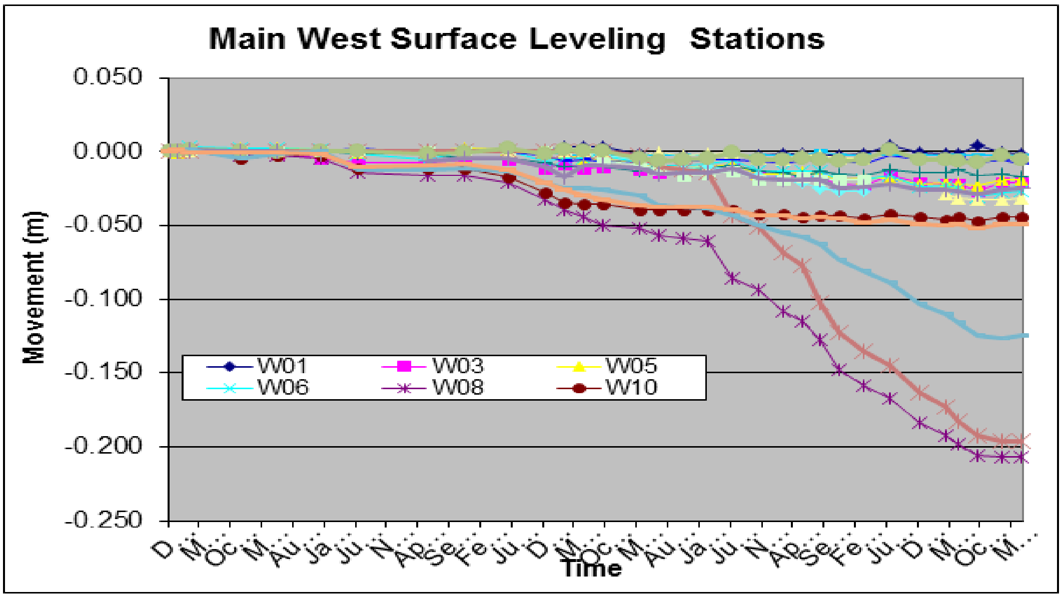


Figure 17 – Subsidence Graph

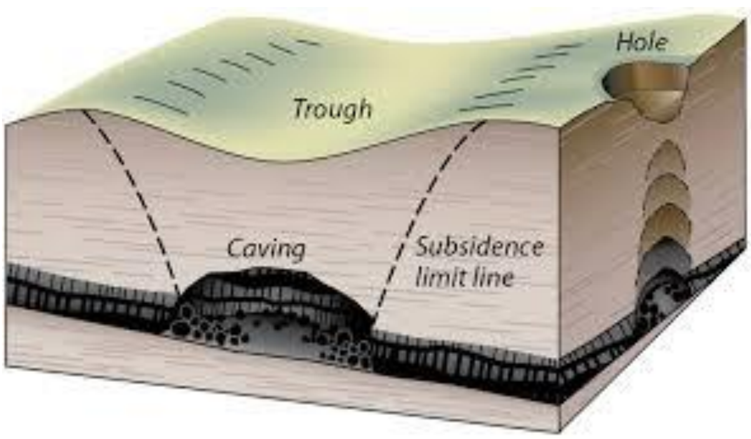


Figure 18 – Depiction of a subsidence event

From the graph, it can be seen that there is variation in elevation between the different benchmark locations at this site. Information such as this can be invaluable both during and following closure of the mine. Using current survey techniques, it may not always be possible to place benchmarks at all locations above the mine and as there is such variation in the between the different measurement locations it is possible that some areas of significant subsidence will not be measured. Therefore, a full understanding of the subsidence process may not always be possible. EO offers a practical way to establish ground elevation and variation over time over an extremely wide area. In a recent High Court case in Ireland, EO data was critical in the judgement issued by the judge. The court's view was that this data provided empirical evidence that the mining company did not adversely impact the landowner by mining under his property.

An aspect similar to subsidence but something that is potentially far more serious is the occurrence of sink holes related to mining. Although sink holes are natural phenomena and will occur in areas that have not been mined – it is the case that mining (particularly underground mining) can promote the occurrence of sinkholes particularly in karstic environments. Epikarst or 'fossil karst' is karst that has been filled with sand and gravels over time. Epikarst is typically stable and will not be the cause of sink holes. However, dewatering of underground mines can remobilise those sands and gravels that choked up the karst feature, removal of this material can result in the karst becoming unstable which can result in sink hole development. EO offers an effective means of identifying karstic features in a mining area and also tracking the potential development of karst.

Water is a key aspect and an understanding of the hydrological catchment in which the mine is located is vital to assess what impact may take place. Many developed countries will have hydrological data available. For example, the Irish Environmental Protection Agency 'catchments.ie' resource is a GIS enabled system with layers of information available to help the mine developer assess the receiving environment and assess their possible impacts. However, mining by its nature will very often take place in remote areas of the world that do not necessarily have such resources. The use of EO technology can allow a mine developer gather important information in relation to catchments that are otherwise not available.

5.3 Design and Construction

During the design and construction phase of a mining project the data gathering process is required to gain a full understanding of the site, hydrogeology, hydrology, catchment area, access routes, ground conditions such as underlying geology, soils and ecology. A complete understanding of the site and access is required, and, in some cases, this can be considerable. In recent times an increasing amount of this information is gathered using EO techniques and products.

Figure 19 – Concept design for new mine in Ireland

Baseline information is critical to ensure that impacts can be monitored, measured and rehabilitated, where required. Baselines for buildings, subsidence movement, water courses, aquifers, etc. all need to be established at the very earliest stage. Many mining operations have lawsuits taken against them by local people, communities, businesses or regulators, based on changes that have allegedly happened to their property or some factor associated with their lives. Structural deterioration of buildings, water course changes and subsidence are commonly cited to be the result of mining operations and this is where baseline data is critical. Much of this data can now be accessed by EO methods and EO has the advantage that there is historic data available because satellites have been and are constantly scanning and recording data. To refer back again to the Irish High Court case, in this instance the mine operator had not been using satellite techniques to measure subsidence during the period of the mines operations but a consultant was able to access the archives of a satellite provider to attain historic surface elevations for the area. So even where a mining company has not actually taken the decision to actively use EO or satellite it is important that they should be aware that they can retrospectively attain data (albeit they have no control over temporal or spatial resolution in this scenario).

Significant road construction to mining sites is sometimes required in very remote areas and high quality EO data can make planning of this process considerably easier and less costly. An example of this is the cluster of diamond mines in the Northwest Territories of Canada, with the mine located approximately 300 km from the nearest town of Yellowknife. Winter roads are in place and used to transport major supplies during a small window of winter when the lakes are frozen. Satellite data is a major benefit in this case, both in the original planning of road routes and for monitoring of annual data. Satellite weather data is also crucial to the safety of the transportation of materials to such remote locations.

Figure 20 – Diamond mining operations in Northern Canada.

High quality EO data, available at reasonable cost will reduce the time required, the cost of mining and potentially improve environmental impact (if used properly) of mining operations. Improvements in EO capability in areas such as ground penetration techniques, will further enhance the mining process.

5.4 Operation

Some mines have a short life of mine cycle, while others operate for many decades. These differing scenarios can offer different problems for data acquisition and management.

Short term mines operate in a timeframe where data requirements do not change significantly and when a monitoring system is in place, it may be fit for purpose for the life of mine. For long-term operations, there are continuous changes to the use of data gathering technologies and mining companies benefit from adapting to these changes.

Figure 21 – Open Pit Mine

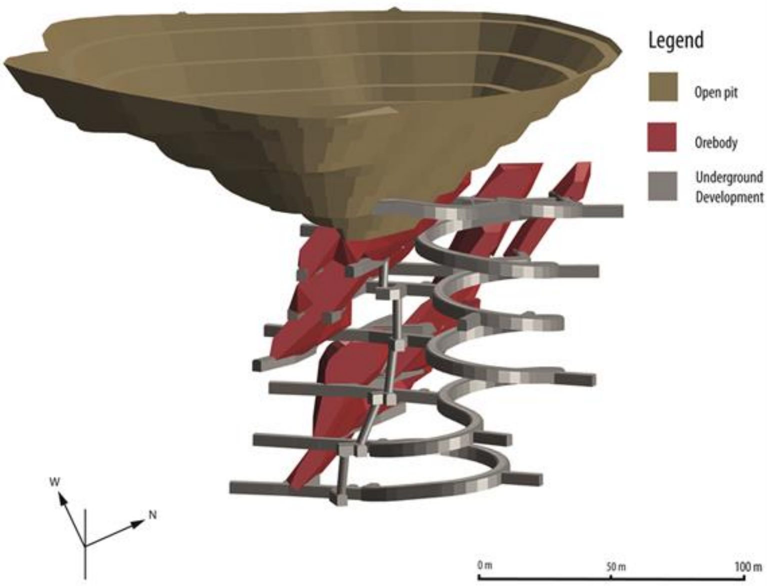


Figure 22 – Underground mine design – Open pit transition to underground

The key requirements for mine operators and regulators for acquisition of data during a mining cycle are:

- Surface mapping for subsidence monitoring
- Structural geology and geotechnical information
- Open pit surveys
- Ore and waste dump monitoring
- Water management – flows, changes to water courses, etc.
- Air quality
- Soil quality

- Pollution control
- Land use changes
- Illegal mining operations

EO information is replacing traditional methods, such as aerial photography and ground- based data surveys. Good management of mining activities can allow for fast resolution of problems observed at an early stage, avoid high remediation costs and satisfy all stakeholders.

Figure 23 – An open pit mining operation in Russia

Figure 24 - Underground load and haul operation

5.5 Mine Closure and Aftercare

Responsible mine closure is of critical importance to the mining industry. There have been many examples all over the world (in both developed and developing countries) of poor mine closure having an impact on the environment and on the health of people and communities living close to the mine. The reality is that in many cases the operator will be long gone before the impact is felt and as such will not be held accountable to put in place corrective actions. It will generally fall to the state to put in place the corrective actions and in many poorer communities there may be insufficient state funds to carry out the remediation and in these instances the environment and local communities will continue to suffer. It is for this reason that comprehensive closure planning has become a critical part of the mine permitting process. There is now a trend that governments will not issue permits to mine developers who cannot demonstrate that they have responsible closure programmes that are funded in advance.

Closing and rehabilitating a mine is a very complex task. Planning for the closure of a mine must take place before construction of the mine starts. A mine developer must know how they are going to close the mine and how they will demonstrate to regulatory authorities that they have managed all the risk.

Closure can be considered to take place over a number of phases. The phases can be taken to be:

- Progressive rehabilitation
- Active Closure
- Passive Closure

This is followed by a more lengthy and reduced intensity Aftercare phase.

In best practice mining operations, the following activities are now the norm.

Progressive rehabilitation.

Many mines currently do not wait for production to cease before commencing the implementation of a closure plan. A process that is referred to as 'progressive rehabilitation' - whereby parts of the site are rehabilitated while the mine was still in operation is now widely adopted by the mining industry. Mine rehabilitation is always a concern for stakeholders and in particular the community and adopting a progressive approach to closure can provide reassurance to these stakeholders.

Active mine closure

Active mine closure is the physical act of closing the mine and rehabilitating the area after production has ceased. Active mine closure involves demolition of infrastructure, capping of the tailings dam, plugging of all openings to the mine and other ancillary activities.

Passive mine closure

During passive mine closure all physical works are completed, and the mine operator is required to carry out monitoring and document all evidence that is required by the authorities to demonstrate that the mine has been successfully rehabilitated. The mine operator must be able to demonstrate that all environmental indicators (ground water chemistry, surface water chemistry, ground stability and soil chemistry are of good status and in steady state (or stable)). When the authorities are satisfied that the site is in steady state, a mine closure completion certificate will be issue to the mine operator and the site then goes into an aftercare period.

Aftercare

Aftercare is a period of less intensive monitoring. It will run for as many years as authorities require in some jurisdictions there is no provision for mine operators to finish the closure process i.e. aftercare can be seen as perpetual in some jurisdictions.

Various techniques are used to complete the monitoring that is required though all of the phases of mine closure. EO has multiple potential beneficial uses in the preparation and assessment of mine closure plans and this can be as simple as satellite imagery being used to confirm the removal of mining infrastructure.

A critical aspect of mine closure and aftercare is the need to rehabilitate the ground disturbed by mining. An operator will be required to reinstate a cover that is typical of the area prior to the commencement of mining (i.e. in some cases this may be grass cover). Survey techniques are used by environmental scientists to measure this rehabilitation and EO is becoming a useful tool for this purpose. For example, satellite datasets have enabled new methods of monitoring to be developed, such as mapping vegetation health using the Normalised Difference Vegetation Index (NDVI) as an indicator to identify subtle changes in vegetation composition and health over time. Whereas in the past resolution was often lacking, access is now available to much higher spatial and spectral resolution data through the WorldView-2 satellite launched in 2009 and Worldview-3 (WV3) launched in 2015.

EO offers a convenient mechanism to establish the extent of ground cover prior to the commencement of mining and to assess the performances of that cover after rehabilitation is complete. Traditionally mines have relied on field surveys or aerial photography for this data and the following three figures (25, 26 and 27) show how the rehabilitation of a mine can be documented by a series of aerial photos, showing the site in operation, in progressive closure and at the end of the closure process, respectively.

Figure 25 – Lisheen Mine Site 2014

Figure 26 – Lisheen Mine – Tailings Management Facility 2014 – Progressive rehabilitation started

Figure 27 – Lisheen Mine – Tailings Management Facility 2018 – Rehabilitation almost complete

While traditional aerial photography is useful to document the status of cover, EO offers better quality – see below an earlier image obtained from an on-line resource that shows the same tailings dam as the one shown in the photos above. This image is more useful in that it covers the entire area of the facility and is also taken at an angle that is perpendicular to the area in question and it is therefore accurate and not open to misinterpretation. Standard commercial aerial photography is taken at a low altitude and this result in foreshortening of the image.

Figure 28 – satellite image of the Lisheen Tailings Management Facility

From the photos above, it can be seen that the tailings dam in the image is capped but only partially vegetated. Vegetation is critical to any rehabilitation, whether that is a tailings dam, or an area disturbed by strip mining as the roots of the vegetation bind the cover in place. The long-term success and stability of the vegetation on the cap will need to be assessed by the operators for many years after rehabilitation. The time period varies across the world. While 30 years is often accepted as an appropriate aftercare period, some countries require a minimum of 100 years and some countries have no defined end to the aftercare period. As such, a low cost, high quality and effective method to assess the stability of the cover is very important for mine operators and regulators for future development.

The example above is for a small footprint (70 hectares) and while there are limitations to accuracy of aerial photography it can be reasonably effective for such small areas. When it comes to large areas of disturbance such as from strip mining or open cast coal mining, EO provides a very practical way of assessing the impact and rehabilitation of such large areas of disturbance (e.g. Figure 29). The image in Figure 29 is taken from groundup.org.za and is labelled as 'SPOT5 satellite imagery (2013) of open cast coal operations in Mpumalanga and encroachment on surrounding farmland'. An image such as this provides a very convenient way to qualitatively assess the impact of mining on a local environment.

Figure 29 – open cast coal operations in Mpumalanga (groundup.org.za)

6 Catalogue of current Geoinformation requirement and used by mining industry

As described at the outset; geoinformation is a very broad subject. It is essentially the information that characterises the planet. It includes, at minimum, all physical, structural, developmental / social and chemical properties of the Earth.

The objective of this report is to catalogue all of the geoinformation that is required by the mining industry. Mining is fundamentally associated the Earth and as such much of the 'information' that is required to develop and operate a mine will be 'geoinformation'.

Over the decades many different methodologies have been developed to acquire geoinformation data required for mining. As mining is a very traditional industry, many of the practices carried out today have been carried out the same way for decades. However, the mining industry has been developing and embracing new technologies to make the process more efficient from exploration to operation and finally to closure and rehabilitation.

The following sections describe the different geoinformation that is required in each of the mining phases. It summarises what different entities will require what with respect to geoinformation and it also seeks to highlight how other factors, such as mining type and geography, can influence the geoinformation requirement.

The information in this section is derived from the desktop review that was completed by LTMS, the expert knowledge of LTMS, Deltares and other members of the EO4RM project team, the workshop and many other sources. The expertise within the EO4RM team covers all aspects of mining, exploration, environmental and technology. The team also has experts who have expertise in data acquisition. The workshop included experts from industry, academics, government agencies and regulators. The workshop used breakout sessions with discipline experts within each of the groups to document what techniques are currently being used to acquire geoinformation within the mining industry. All of this information has been used to generate the tables and the text presented in this chapter as well as the additional detail on current techniques provided in Appendix 1 (see chapter 3 for more detail on sourcing of information).

The approach was to document the geoinformation requirements for each phase of the mine life cycle, as geoinformation requirements may be similar within the different phases but used for a different purpose. For example, topographical mapping is an example of geoinformation that is relevant to most of the mining phases but its application or use within each of the phases will be different. The topographical detail needed for exploration will be different to that detail that is need for operation and closure, as will the frequency and resolution of the measurement.

- Each of the four mining phases is detailed sequentially in this chapter.
- A reintroduction to the mining phase and description of the geoinformation need is provided.
- Each geoinformation requirement is given a unique identifier (e.g. E-1. Is the first geoinformation requirement for exploration and covers 'geological mapping of surface expressions' and P-1 is the first geoinformation requirement for permitting and covers 'water catchment (rivers, lakes etc.)'). There is no specific hierarchy or sequence to the order in which the geoinformation elements are catalogued.
- A textual description of each geoinformation requirement for each of the mining phases is precedes each of the geoinformation tables.

- A geoinformation table has been inserted for each of the mining phases and these tables catalogue the geoinformation requirement. The tables describe, how the data is currently achieved and what resolutions are required.
- Section 6.4 takes the geoinformation requirements and condenses them into challenges and needs, which are presented in a series of tables.

6.1 Geoinformation needs depending on geographic locations

The geoinformation needs will vary based on geography and in particular the techniques of gathering geoinformation will vary significantly depending on location and how developed the area of interest is.

The acquisition of geoinformation in the developing world or in more remote parts of the globe can be more difficult where there may not be existing infrastructure and datasets associated with the area in question. It will be necessary for the exploration or mining company to carry out this primary data acquisition. For example, in developed parts of the word there will generally be survey maps issued by some agency which may provide data down to 1 in 10,000 resolution, which will provide detail such as infrastructure that is required by a mine developer / exploration company. Many parts of the world will have government issued geological maps that indicate the mineral provenance for a specific geographic location, which will be of great benefit for an exploration company to begin their assessment.

When it comes to the initial planning required by the mining company to assess how it will acquire its geoinformation, the geographic location of the area in question will be an important consideration. Some geographic locations are more difficult to access than others and this impacts on how easy it is to attain the required geoinformation. In these locations mining companies may wish to fly over the area of interest rather than carrying out the initial assessment on the ground.

Some geographic areas will lend themselves more to certain techniques of data acquisition than others will. For example, the best geophysics results will be achieved in remote areas of the world where there has not been much anthropogenic interference, in these areas a very clean signal will be achieved (regardless of the specific geophysical technique). In more build up areas it is likely that there will be interference from buried pipe, overhead powerlines etc.

This section describes the current common geographies accessed by mining companies. However, as referred to in chapter 4, the defining of a mining geography may change in the decades ahead as mining companies go into more exotic areas such as potentially under the oceans or even near-earth asteroids and other celestial objects.

6.2 Geoinformation requirement and use by mining type

This report will refer to just three main types of mining. There are many more variations but for the purposes of this report the focus will be on the three primary types which are; underground, open-pit and strip mining. Other less common techniques, not to be included in this description, include dredging, block caving and in-situ leaching from underground.

The geoinformation required to find the ore (the exploration phase) will not vary between the different mining types and there will be a lot of commonality for example all mining requires buildings and tailings dams and these will have geoinformation needs to construct and monitor. However, there will be slight variations in the types of geoinformation required for the other phases. The geoinformation required for the different mining methods will be quite similar, any variation is highlighted in the following sections.

It appears likely that in the future, more mining may be using automatic (or remote) mining technology which will require more geoinformation and therefore increase the need for geoinformation.

6.2.1 Underground

Underground mining is carried out when minerals are extracted from underground by a series of underground excavations, referred to as 'workings'. Where possible the mining company will attempt to excavate within the rock that has mineral to avoid the generation of waste rock that has no value. Various techniques such as open hole stoping, room and pillar, and drift and fill are variations of how underground mineral is abstracted.

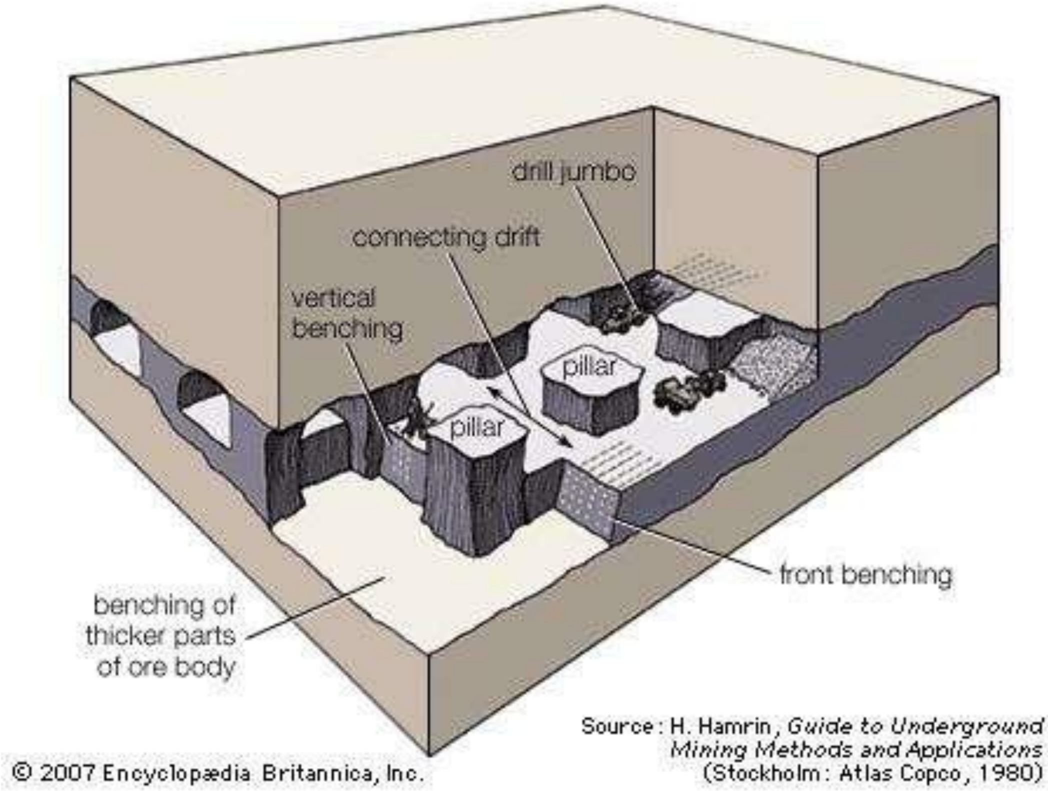


Figure 30 – Example of room and pillar underground workings

Some underground operations will be continuous, for example 'long wall' coal mining; where a continuous mining process is used to cut the coal deposits from the walls. Alternatively, it is necessary to drill and blast to liberate the ore. Ore is conveyed out of the underground workings by conveyor belts, trucks or buckets.

Surface subsidence and ground stability are key safety, environmental and social risks for underground mining and the geoinformation associated with these aspects are vitally important. Geoinformation will be required for parameters associated with, and in the control of, the mine (e.g. pillar deflection or subsidence), but geoinformation will also be required for parameters outside the control of the mine – (e.g. seismic information).

As an underground mine is covered with overburden and as such there are limitation to the use of earth observation techniques as it is not possible to observe workings directly. The workings must be surveyed using traditional techniques including modern digital scanners. Open-pit and strip mining lend themselves to aerial observation and assessment.

6.2.2 Open-Pit

As the name suggests; open-pit mining involves digging out rock or minerals from the earth from an open pit. The main feature that distinguishes this from underground mining is the need to remove all the overburden to get to the ore, whereas underground mining mines under the overburden and attempts to stay within the orebody as much as possible.

While both open-pit and underground mines produce tailings (the waste from mineral processing) and both also produce waste rock, open pit will produce far more waste rock than underground as all the overburden needs to be removed and stored (stored in WRD's) and will require ongoing geoinformation to assess the stability of these waste dumps.

Open-pit mines are dug using 'benches'. These benches can be at heights of 3 to 25m with widths dependent on the size of the mine operation and size of the plant being used. Side walls will be at an angle of less than vertical to minimise the risk of rock fall. A haul road is located at the side of the pit, forming a ramp up which trucks may drive, taking ore and waste rock. In addition to managing the slope of the pit walls, additional support such as cabling may be used to assist with structural stability. However, the management of pit stability is a key risk for open-pit mining.

The stability of the open pit and the WRD's is the key geoinformation requirement that is critical for open-pit mining. Surveys will be completed to monitor for movement of the pit wall face, ideally this monitoring will be continuous. Boreholes around the pit will be in place to monitor and reduce pore water pressure on the pit wall.

6.2.3 Strip mining

Strip mines are similar to open-pit mines, except in this instance the mineral is located close to surface and only requires shallow stripping of overburden and in some instances (e.g. mineral sands, oil sands) the material of interest is often located directly within the overburden itself.

In contrast to underground and open-pit mining; strip mining does not have significant requirements in relation to stability of the ground that is being mined as it is relatively shallow mining and is relatively stable (depending on the depth of mineral extraction).

Strip mining will often take place over larger surface areas and result in more disturbance of the surface. The rehabilitation of disturbed ground is a key metric for strip mining and progressive rehabilitation will often take place. Monitoring of progress of progressive rehabilitation is an important element of geoinformation for strip mining to demonstrate progress to the authorities.

6.3 Geoinformation requirement and use within the different mining phases

6.3.1 Exploration

The fundamental information required to develop any mining operation is identification and quantification of a mineral resource. A mineral resource can be mineral occurrence of economic interest that can be extracted from the earth. Mineral resources are in their nature variable and can include a broad range of target commodities, including base metals such as copper and zinc, to precious metal such as gold and platinum or bulk commodities such as coal, to name just a few. While the nature of these resources is usually very different, many of the exploration techniques and the data required can be similar in nature.

Mineral exploration can generally be described as the pursuit of an economic mineral resource, whether the aim is to extend an existing resource or the identification of a new ore body.

The initial phase of exploration will typically aim to establish the presence of a mineral resource in an area but will usually not be sufficient to identify the precise extent or quantities of the resource. The second phase is a targeted exploration programme that will quantify the mineral resource. Once a resource is identified, further work is required to establish what portion of this resource is economically extractable (this is known as the ore reserve). If the mine is developed, exploration is likely to continue at the mine for much of the operation in order to identify additional mineable ore, known as 'ore outside of reserve'.

Mineral deposits are formed by many different geological processes. Many minerals were deposited by hot fluids that flowed in faults around geological structures millions of years ago. While the fluids will no longer be flowing at this present time, the structures and indicative mineral alteration will often still be discernible. Having an understanding of such geological features is a key element of mineral prospecting and exploring.

Most developed countries issue geological maps that allow exploration companies to begin their preliminary assessments. Companies may choose to carry out additional assessments using geophysics and other techniques, to get a better understanding in the area of interest. Surface mapping is often conducted in order to search for outcropping mineralisation, important structural features or alteration that may be indicative to locating ore at depth. This can be carried out along with other assessment methods, such as soil or fluvial sediment sampling or groundwater analysis. If the results are positive, this phase will often be followed by targeted drilling of exploration holes that provide subsurface geological information within the prospective area. Depending on the results of drilling and the depth and concentration of mineral recovered, a company may continue to drill on a systematic grid to attempt to quantify the resource. This grid can be then tightened to give better resolution and allow geologists to interpolate the data between boreholes in order to estimate the overall quantity of mineral that is present within the resource.

A possible mining project will typically start as a concept with a rough indication of the resource and an approximated cost to develop the project. If the project passes this initial hurdle it will move to a prefeasibility study (PFS). If this is successful, and attracts investment, it will progress to a full feasibility study. During all these stages there will be greater understanding and increasing confidence in the nature and scale of the potential mineral resource, what the environmental setting is, and any peculiar challenges that may be faced during construction and operation of the mine, as well as what the project cost will be to develop key infrastructure. The gathering of information (and geoinformation) is fundamental to this process.

Earth Observation techniques have been and are currently being used for mineral exploration, and opportunity exists for increased use of these techniques as the technology develops. As mineral exploration, mining companies, and stakeholders become more familiar with the technology, the demand for Earth Observation data and techniques will likely increase.

The different types of geoinformation required for the exploration phase of mining and how these are attained are described below and detailed in table 6.1.

6.3.1.1 E-1. Geological mapping of surface expressions

Surface geology and topography is often very important with respect to mineral exploration.

Ore deposition will usually be associated with either specific rock types, geological structures, mineralogy or topography at the surface level. Features of the landscape evolution, post–ore deposition may also affect the interpretation of some exploration survey results in specific ways, and as such, the ability to recognise such surficial features can be critically important to an exploration program.

Particular rock types, topography and structure are known to exhibit specific signatures at surface that represent an expression of the deeper geology. Some of these surface features can be indicative when pursuing certain minerals. As such, the topography of an area, when combined with other remote sensing data such as spectral imagery, can be used to produce more detailed and informative geological maps. These are particularly useful in mineral exploration.

For example, mapping can establish the surface expression of fault structures, lithological contacts or variations which may be critical to the deposition of a particular mineral. Likewise, the mapping of sedimentary features such as palaeo-river channels, sedimentological transitions or palaeo-shorelines can be useful exploration tools, as sedimentation styles can often be used to constrain or predict deposition of minerals.

6.3.1.2 E-2. Geological mapping of subsurface expressions

Understanding of the geological setting and structure of prospective areas is of particular importance since many mineral deposits are controlled by larger features that can be discerned on a district or regional scale.

Geological mapping is often completed using remote sensing and field survey techniques, as well as various geophysical and geochemical methods. Magnetic and gravitational fields emanating from the Earth's interior highlight essential information concerning the nature of the underlying geology. Detection and analysis of natural or induced, seismic, electric and magnetic fields, are regularly used to construct images or models of what geological features are likely present in a region. This data can give insight into what the physical properties of the local area are, and as such, surveys can be used to establish the prospective potential of the area of interest or offer focussed targets to the exploration team.

6.3.1.3 E-3. Geochemical Mapping (Geochemical signatures / anomalies)

Exploration companies need to know the composition and distribution of minerals in the area they are exploring, either the actual concentration of the metal or chemical signature in the host rock. The concentration of interest can be the mineral of interest or it can be an 'indicator' mineral or minerals that can be indicative of the presence of the mineral of interest.

The concentration of a mineral (or minerals) of interest within a mineralised zone is typically referred to as the 'grade' of the mineralisation. If the mineralisation is considered economic then it is referred to as 'ore'. Ore grade is typically cited as a percentage on a dry weight for weight basis (w/w)[1].

Various measurement resolutions are required depending on the metal / mineral of interest. For example, for bulk commodities such as iron or manganese ore, grades typically exceed 45%. In base metals such as zinc, ore concentrations may be in the region of 4% to 30%, while copper ore concentrations will be typically less than 2%. For precious metals such as gold, silver or platinum, the grade is typically much lower and is usually quoted in grams-per-tonne (parts per million), where single integer values are mostly sufficient to make an ore economically viable. Therefore, resolution is often not as important for bulk commodities as it is for some of the rarer minerals that typically occur at lower concentrations and as such can be harder to detect.

The area to be mapped geochemically will change depending on the outcomes. Initial mapping will be on a regional basis and will cover vast areas of 1,000 km^2 and beyond. If this regional work shows anomalies or indicates the presence of a mineral or lithology of interest, the exploration work will move to a local level and will use the various exploration techniques as outlined in Appendix 1. As confidence builds in the presence of a significant and potentially economical resource, it will be necessary to get better definition of the orebody to firstly establish the mining reserve, and secondly develop a mining schedule to extract the reserve. In order to get this level of detail close-spaced drilling may be undertaken. In some cases where geological uncertainty is significant, this can be as close as a 15 m grid.

6.3.1.4 E-4. Infrastructural mapping including information on terrain and access / roadways

Exploration companies need to know how they will access and operate in any given area of interest. A particular exploration project might be located in any of a wide number of physical landscapes, ranging from urban or rural sites or to sites of cultural or natural interest. The

[1] All ore grades in this document are quoted as % and refer to a weight for weight percentage.

specific physical landscapes can vary greatly based on the climate and local socio-economic conditions, or other criteria such as biodiversity or modern-day land use. Detailed and up-to-date spatial information on the area of interest can be key to the success of any exploration program. For example, what tracks or roads are available to geologists or drill rigs to access the area of interest? Is there active farm-land that may have disturbed the soil or inhabitants that may be affected by nearby exploration activities?

Infrastructure mapping is also crucial to planning and execution of geochemical surveys and data interpretation. For example, installations such as electrical power supply lines, steel cased boreholes or underground water pipelines can severely affect geophysical survey results through interference in the signals being detected. The presence of a nearby refuse dump with discarded batteries or other electronics, even an industrial complex, several tens of kilometres away, can render geochemical surveys ineffective. This is especially the case if these features are not identified beforehand and acknowledged. Where possible mitigation measures must be put in place during the survey or interpretation. The greater the ability to detect, quantify, and determine the nature of the local landscape and historic or present man-made features, the greater the chances of exploration success will be. In this sense, up to date and thematically relevant geospatial data acquisition and availability is important.

Significant volumes of water are usually required for diamond drilling, one of the most widely used mineral exploration techniques, and therefore identifying a nearby water source and the logistics of water supply to the drill rigs is often important. While exploration camps can operate with generators, the availability of power is beneficial, and this information can be sourced from infrastructural mapping. There is also a need to identify any natural hazards in the area that may impact on Health and Safety of the project, and Earth Observation datasets can be useful in this regard.

6.3.1.5 E-5 Land ownership

Exploration companies will need to get the permission of landowners before they can carry out exploration activities. The company will need to get permission to work in the area where they will be carrying out their activities (drilling / trenching etc). The company may also need to get access rights from other third parties to get to the land on which they will to complete exploration works. Therefore, it is important that the company has a knowledge of all landowners in the region of the area on which exploration is to take place.

6.3.1.6 E-6 Environmental Monitoring

While many exploration techniques could be described as non-invasive with minimum risk of environmental impact (for example certain geophysics techniques). Other exploration techniques have the potential to cause environmental impact. An example of a technique that has the potential to cause impact on the environment would be core drilling. Core drilling can have a number of potential impacts on the environment if not properly managed. An example of one potential impact associated with core drilling, is the discharge of water, which will contain sediment and this sediment may contain minerals that can be harmful to the environment (the sediment itself can be harmful, as even if it is inert it can smother habitat).

Exploration companies need to risk assess for environmental impact associated with their proposed activities and carry out appropriate assessments to understand what impact they may have. This assessment may include environmental monitoring to establish baseline conditions. The company will then need to put in controls to manage the risk and importantly monitoring must take place to demonstrate that controls are working, and no impact is occurring (this monitoring may include measuring the physiochemical properties of water leaving the exploration site).

6.3.1.7 E-7 Affected stakeholders

Exploration activities have the potential to have an impact on others. In particular the more invasive exploration operations, such as trenching and core drilling, have a greater chance of impacting or causing disruption to others.

Exploration companies must carry out an assessment of the area on which they wish to carry out exploration works and ensure they understand the baseline conditions. Controls may be necessary to minimise impact and or compensation may need to be arranged with land owners if there is any loss to be incurred (for example a farmer may need to take animals away from the exploration site and would need to be compensated for the lack of access to grazing grounds). Further to 6.3.1.6, the exploration company must be able to provide assurance to affected parties that the lands have not been impacted by the exploration activities and are safe to be used again for their previous purpose (in particular in relation to agriculture, assurance will need to be provided to demonstrate that the area has been fully remediated and all mineralised material that may have been deposited on the ground has been removed).

6.3.1.8 E-8. Weather

Exploration sites are often in remote parts of the world and may need to be accessed by foot on ephemeral tracks or indeed by helicopter. Understanding and predicting the weather is critical to allow safe access to exploration sites.

Ref.	Type of geoinformation	Current Techniques[2]	Area to be assessed / monitored	Minimum Measurement Resolution Required	Minimum Measurement Refresh Rate Required
E-1	Topographic mapping of **surface** expressions	Digital Terrain Model (DTM) Satellite imagery (various) Drones / LiDAR Field mapping surveys	Regional to local scale >1,000 km^2 to <1km^2	Varying from regional to detailed (+/-1 m).	Annual Parameter is stable from a mineral exploration perspective.
E-2	Geological mapping of **sub-surface** expressions	Review of published information including Geological Survey issued maps Results of previous exploration Geophysics including; gravity, seismics, radiometrics, IR spectroscopy, magnetotelluric and electromagnetic techniques	Regional and local mapping required 10 km^2 to 1,000 km^2	Surface penetration is required to depths in excess of 1,000 m. Higher resolution is beneficial (minimum 30 m).	Annual Parameter is stable from a mineral exploration perspective.
E-3	Geochemical Mapping (Geochemical signatures / anomalies)	Geological Survey issued maps Walk-over (visual assessment / portable XRF, spectroscopy) Airborne / satellite imagery (various) and hyperspectral surveys Sampling & assaying of soils and rocks (surface and core) – Core Drilling / Trenching.	Regional and local mapping required. 1 km^2 to 1,000 km^2 Resolution down to 15 m X 15 m grid for orebody definition	Various measurement resolutions are required. Iron ore can be as high as 45%, economic gold ore may only be at 5ppm (g/tonne).	Annual Parameter is stable from a mineral exploration perspective.

[2] See Appendix 1

Ref.	Type of geoinformation	Current Techniques[2]	Area to be assessed / monitored	Minimum Measurement Resolution Required	Minimum Measurement Refresh Rate Required
		Plants (flora) can be used to detect minerals in the ground, as specific plants will grow in soils with high content of specific minerals – these plants are good indicators of possible mineral and provide targets for further exploration.			
E-4	Infrastructural mapping including information on terrain and access / roadways	Ordinance Survey Maps (OS Maps) Topographic Survey Maps GPS systems Satellite imagery (various)	Regional and local mapping required 10 km^2 to 1,000 km^2	A spatial resolution of at least: OS 1 in 50,000 for basic infrastructure such as roads (1 cm on the map represents 500 metres). OS 1 in 2500 for buildings / utilities (1 cm on the map represents 25 metres).	Annual Infrastructural projects take time, annual update sufficient.
E-5	Land ownership	Drones Surveys Land registry (Government)	10 km^2 to 1,000 km^2	Resolution of 1m^2 is required	Annual Transfer of land ownership is a slow process and does not change frequently.

Ref.	Type of geoinformation	Current Techniques[2]	Area to be assessed / monitored	Minimum Measurement Resolution Required	Minimum Measurement Refresh Rate Required
E-6	Environmental Monitoring	Flow meters Walk-over / Sampling Wet chemistry analytical techniques + spectrophotometer / AA / ICP Drone photography	1 km^2 to 100 km^2	1 m^2	Daily
E-7	Affected stakeholders (Possible impact on nearby industries including agriculture)	State Agencies - Farming advisories services Meetings with farmers and Vets Campaign of monitoring	1 km^2 to 100 km^2	1 m^2	Daily
E-8	Weather	State weather services Internet weather providers	Local and regional 10 km^2 to 1,000 km^2	Regional - 100 km^2 Local – 20/50 km^2	Weather updates may be required on an hourly basis. Forecast for 3 to 5 days may be required to plan expeditions.

Table 6.1 – Geoinformation requirements for exploration

6.3.2 Environmental Assessment and Permitting

A number of permits will be required to develop and operate a mine. A licence to abstract the mineral will be required, as well as permission to construct the infrastructure needed to abstract and process the mineral. Lastly, an environmental permit will be required to ensure that the operation does not cause any negative impact on the environment during the operational phase or after the mine closes in the aftercare phase. Initial data gathering for permitting purposes will commence during the pre-feasibility stage (PSF) and at the feasibility stage (FS) as the developer will need to understand the costs that are involved in building the appropriate infrastructure and ensuring adequate environmental controls are in place. The initial characterisation of the potential environmental and social impact will also take place during the PFS.

Large amounts geoinformation are required during the permitting process to fully understand what the impact of the mining project might be and what controls are required to control and monitor operations. This geoinformation is then submitted to the permitting authorities in order to demonstrate that the project is viable and will not have any negative impact.
The different types of geoinformation required for the environmental assessment and permitting are described below are detailed in table 6.2.

6.3.2.1 P-1. Water catchment (rivers, lakes etc)

Water is a key aspect of mining. Mining will typically take place over a very large footprint and will have a large area of influence. Mining companies need to identify the water catchment in which the orebody is located and they need to understand what impact they may have on that catchment in terms of discharging into it and, for example, where this might cause an impact in terms of risk of flooding etc. The company will also need to understand how abstracting water from the mine might impact on the water balance within the catchment and potentially deprive sensitive areas of water.

6.3.2.2 P-2. Groundwater

Although linked to the water catchment as part of the overall water cycle, groundwater can be considered as a separate geoinformation requirement.

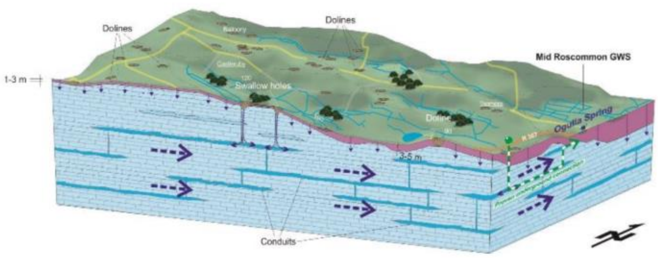


Figure 31 – water cycle – source Geological Survey of Ireland.

It is important for mining companies to understand the groundwater environment for a number of reasons.

1. It will be necessary to dewater the mining area and the company will need to understand what quantities of groundwater will need to be pumped, and possibly treated before discharge.

2. The company needs to understand who may be impacted by dewatering activities (i.e. what wells may be impacted, and will the company need to install a replacement supply scheme).
3. There is a risk that mining, and processing activities, may impact on groundwater quality – the mining company needs to understand the groundwater gradient and be able to assess what is the potential impact on sensitive receptors. The operator also needs to understand the baseline conditions from a quality perspective (i.e. what is the concentrating of various minerals already in the water pre-operation). This is important to quantify any impact and will also be important when agreeing closure success criteria.
4. Water is also required to operate a mine from welfare requirements (drinking and washing etc) to processing of ore washing etc. The groundwater resource is likely to be the source of this water, particularly for the welfare water.

Groundwater varies over the course of a year and therefore the assessment and characterisation of groundwater needs to take place on a seasonal basis to assess the potential impact. The area to be assessed and characterised will be established by modelling the catchment.

6.3.2.3 P-3. Population centres / social impact

Mining companies need to understand what impact they may have on people that live near the mine. A mine needs to understand where it can source workers and raw materials. For its employees it needs to know what resources are available from a recreational and accommodation perspective. Due to the nature of the industry there may be disturbance due to noise or blast vibration and this needs to be assessed and understood with respect to local population centres.

Mining also brings a lot of significant social benefits and it is important for the mining company to be able to demonstrate what positive benefit it can bring to an area in terms of infrastructure and jobs.

Population changes do not take place very quickly and therefore an annual update would be sufficient to detect changes in population.

6.3.2.4 P-4. Topographical Mapping

Many countries have government issued maps that detail the topography of an area. For example, in the UK and Ireland there is the Ordinance Survey (OS) in the US maps are issued by the USGS. Maps will be issued at different resolutions (e.g. 1 in 50,000 means 1 centimetre on the map equals 50,000 centimetres or 500 metres).

A topographical map (typically 1 in 50,000 OS map) will be typically required to be submitted as part of a planning permit application. The area of the proposed operation highlighted on a topographical map will describe the regional setting of the proposed operation. More detailed topographical assessment will also need to take place within a tighter area to better understand how the operation will sit in the environment and what visual impact there will be from the various infrastructural elements.

6.3.2.5 P-5. Receiving waters characterisation & assimilative capacity

P-1 describes the need to assess the catchment from a hydraulic perspective. The catchment also needs to be adequately characterised from a chemical and physiochemical perspective to understand sensitive receptors and assimilative capacity for any water discharges from the mine. It is necessary to assess the assimilative capacity for various chemical and physiochemical parameters. This assessment forms the baseline assessment for the area and may be used to assess the impact of the operation and to set appropriate emission limit values. It may also be used to set closure and rehabilitation success criteria.

The list of parameters to be measured will be established as part of the initial screening exercise. Measurement and assessment may not only be for the concentration of chemical and physiochemical parameters but may also include parameters such as colour, turbidity or algal blooms.

The concentration of various chemical parameters in the receiving environment will vary with some being more abundant than others. Common elements such as calcium can be over 50 mg/L, whereas elements such as lead can be < 1 mg/L. To give an indication of what levels of detection may be required, reference is made to the European Directive on environmental quality standards - Directive 2008/105/EC, which describes the desired concentration for various environmental parameters in water bodies. For example, the concentration limit for lead in fresh water is given as 0.007 mg/L and therefore a mine developer needs to be able to detect to this concentration at a minimum to ensure adequate information is provided during the permitting process (lead is one of many parameters that may need to be assessed), selecting which are the parameters of interest will be site specific.

Note that EC 2008/105/EC allows for background concentrations to be taken into account by Member States when assessing the monitoring results against the EQS. In particular they may take into account the natural background concentrations for metals and their compounds, if they prevent compliance with the EQS value (this is particularly relevant for mining where the mineral being mined will often be elevated in the surrounding environment; i.e. in water, sediment and soil).

To understand the receiving environment, it is necessary to sample over extended periods of time to allow for seasonal variation. Water quality data is typically gathered over at least one full year to take into account the variation that can be seen over different seasons. At certain geographic latitudes there may not be much seasonal variation but there may be other more local effects. Regulators my want multiyear studies to gather data and account for effects such as El Nino which are cyclical and occur every 2 years. Data can be gathered on a daily / weekly or monthly basis depending on the parameter.

6.3.2.6 P-6. Ambient Air Quality / Particulate Fallout

Mining companies need to understand what impact they may have on the air quality around the operation and what impact this air quality might have on people and the environment.

As part of the permitting process it is necessarily to establish what the baseline is, and to demonstrate that this will not be materially affected when mining operations are underway and when the mine is closed and rehabilitated. Sampling will be required over a wide area and the extend of monitoring required will typically be governed by dispersion modelling. A 10 km^2 area may be taken as typical for monitoring of ambient air for a mid-size mining operation. Within this 10 km^2 area in the order of 10 to 20 sampling points may be established.

There are very many different parameters of interest in relation to atmospheric emissions and ambient air quality. From an impact perspective; the typical parameters will be particulate and oxides of carbon, nitrogen and sulphur (COx, NOx and SOx). Individual metal parameters within the air column can also be determined. The amount of particulate that falls out on to the ground can be measured on a per m^2 basis (typically 'X' $mg/m^2/day$). Minimum levels of detection can be taken from 'Technische Anleitung zur Reinhaltung der Luft', which is a comprehensive document issued by the German government, which describes air quality standards. This document, commonly referred to as the 'TA Luft', is used by many countries and organisations as a reference for air quality. Dust deposition rates are typically reported on a per day basis. However, accumulations can be detected over a longer period of time and divided by the days that have elapsed to calculate a 'per day' rate of deposition. For both ambient and deposition monitoring; the greater the mass that is accumulated the more accurately it can be measured and therefore long sample times can be desirable. Therefore, monthly sampling will generally be acceptable.

6.3.2.7 P-7. Soil / Sediment Chemistry

Mining companies need to understand what impact they may have on the soil and sediment quality around the operation and what impact this might have on people and the environment. As part of the permitting process it is necessary to establish what the baseline is and to demonstrate that this will not be materially affected. An assessment will need to be completed on all lands that are susceptible to impact from the mining operation. When factors such as air emissions and water emissions are taken into account - this means that the footprint to be assessed can be hundreds of km^2. The area to be sampled will be dependent on the type and scale of the mining operation and may range from one sample per hectare (10,000m^2) to one sample for every 10 m^2. The sampling intensity may need to increase where there is significant variation in concentration.

There are many different chemical and physical properties of soils and sediments that need to be characterised before mining can be permitted in order to assess what potential there is for mining to have an impact. The so called 'Dutch intervention values' had been used for many years by industries to assess potential impact from soil contamination (http://esdat.net/Environmental%20Standards/Dutch/annexS_I2000Dutch%20Environmental%20Standards.pdf). This has been superseded by new Dutch legislation, the only reference that can be sourced at this time is in the Dutch language (https://wetten.overheid.nl/BWBR0033592/2013-07-01#Bijlage1).

Other guidance documents and assessment tools are also available, for example the LQM/CIEH Generic Assessment Criteria for Human Health Risk Assessment 2nd Ed.

(http://www.lqm.co.uk/pages/gac.html). And CL:AIRE (2010) Soil Generic Assessment Criteria for Human Health Risk Assessment (http://www.claire.co.uk).

6.3.2.8 P-8. Land Cover Usage

It is necessary to evaluate land usage (e.g. livestock, arable crops, forestry etc.) to understand the baseline condition of the land where mining is planned and to assess what the impact of mining might be and what the rehabilitation criteria might be. The area to be assessed for usage will depend on the area of land that may be impacted by the mining operation and will be in the order of 10 km^2 to 100 km^2. Land usage will not change greatly over short time periods. Therefore, from a permitting perspective, it is necessary to carry out this assessment on only one occasion prior to commencement of the mining project. Any follow up assessment may be completed at a frequency of c. every 6 months to allow for changes due to crop rotation.

6.3.2.9 P-9. Characterisation of Flora and Fauna

Flora and fauna are the sensitive receptors that may be impacted by mining activities. It is necessary to understand the baseline conditions (what is the species diversity, what is the species population, are there any endangered species). These data will be used to impose conditions on the mining operation during its operation and may also be used to establish what the rehabilitation criteria might be.

Published data can be a source of information, but it is likely that surveys will need to be completed by the developer. Surveys include logging numbers and species diversity (e.g. fish surveys & benthic population for water bodies / population counts for animals / flora counts). Surveys will typically adopt a sampling approach by establishing a sample size (area) and sample number to be representative of the area within the zone of influence of the mine. Fauna will populate large areas of land depending on the species and as such a large area needs to be assessed to understand population numbers and diversity. For assessing flora, a broad approach may be used for the initial characterisation. However, for both flora and fauna (including insects and macroinvertebrates) it will be necessary to complete detailed assessment at very high resolution to assess small plant and animal species. The typical quadrant size for assessing this biodiversity is 1 m^2.

A once off assessment will be required for flora and fauna as part of the permitting process. However, it will be necessary to carry out multiple assessments over a 12-month period to properly assess this geoinformation parameter. Populations of flora and fauna are subject to change over the year (with certain fauna species migrating and therefore will not be present all year around). Certain flora species will be more prominent, and more suitable for counting, at certain times of year when they are in bloom. An experienced biologist will understand what species of plant and animal are present in an area and be able to establish an appropriate temporal resolution for assessment. There is no specific refresh rate of sampling that is suitable for all site. Monthly is an indicator of the frequency of measurement that may be required.

6.3.2.10 P-10. Protected areas (Natura 2000 sites)

In addition to the characterisation of flora and fauna within the zone of influence of mining activities, within Europe mining companies are required to specifically identify and assess how their operations might impact on specific SAC's (Special Areas of Conservation) as prescribed by Natura 2000. The area to be characterised will be dependent on the scale of the operation. Land blocks of 10 km^2 and more than 100 km^2 will needed to be classified. In addition, SAC's within 15 km of the boundary of the site need to be specifically assessed.

6.3.2.11 P-11. National Monuments

National monuments and areas of cultural and/or heritage value may be sensitive to damage by mining activities. These may need to be identified / assessed / avoided / removed / protected, depending on the nature and importance of the monument. Resolution will vary depending on the monument but may be as small as 1 m^2, for example for standing stones or may be hundreds of m^2 for protected buildings and gardens. Millimetre accuracy will be required to establish baseline data for the monuments and demonstrate that no movement, that could result in damage, was caused by the mining activity.

6.3.2.12 P-12. Farming activities - Baseline crop health / animal health

Land use has already been identified as a specific geoinformation that is required. However, when the land use is agriculture it is important for the mining company to assess animal health/productivity and crop productivity in order to demonstrate that there is no impact once mining commences. Alternatively, as part of the project plan an appropriate compensation may be agreed with individual farmers if there is an impact (for example the mining operation may provide an alternative water supply if the farm water supply is impacted by mine dewatering or to enter into temporary land-swaps where the mine will swap un-affected land, owned by the mine, with farmers land that is likely to be impacted for periods of time during mining operations).

In order to understand farming productivity, it is necessary to engage in sampling. Various sampling methodologies are used by agronomists and farm advisory services. For crops, most sampling methodologies are based on taking representative samples within a grid pattern - a resolution of 10 m^2 should be sufficient to determine growth rates for crops. Animal health involves screening by vets - the parameters are too broad to capture in this report, they will include specific protein indicators of metabolic function, trace element concentrations, toxic element concentrations and weight gain per day to name a few.

Farming is a dynamic process and it is necessary to carry out ongoing assessment to understand productivity. Crop growth is seasonal and monthly intervals would be reasonable to assess performance of crops to assess growth rates and final yield. Animals are farmed for various reasons, with meat and dairy being the two most common. The frequency of assessment will vary depending on the animal type and the farming type. However, for indicative purposes monthly assessment over a six to twelve-month period would be sufficient to establish a good understanding of animal productivity.

6.3.2.13 P-13. Weather / Climate

During the environmental assessment and permitting phase, meteorological data will be required. Seasonal weather predictions (dry season/wet season), temperature, humidity and rainfall are of particular importance as these are risk factors with respect to overtopping water level within proposed structures and associated structural stability, water emissions and receiving environments.

Weather is also a factor when assessing the living conditions for employees and residents in the event of a proposed mining camp. For example; will precautions need to be taken for extreme heat, cold, rainfall or any other extreme weather event.

From a permitting perspective it is not just weather that needs to be considered but it is also climate and in particular the possible changes in climate. A mine developer needs to understand how these changes in climate might have an impact over the operational life of the mine particularly for large deposit, long life mines. Although this is probably of more relevance during the aftercare period of the mine. The developer will need to be able to demonstrate that the life of the mine and the proposed closure plan both take climate change into consideration.

6.3.2.14 P-14. Land Ownership

In order to develop a mining operation, it will be necessary to acquire land and the mining company must first know who are the owners of the lands in question to commence engagement.

In some instances, and depending on planning law, a mine may choose to apply for the various permits required to develop a mine without outright ownership of all the lands required. However, in this instance the mine will need permission from the landowner and will need to include a copy of that written permission in the permitting submissions (therefore the need still arises to know who the landowners are and have the relevant engagement).

6.3.2.15 P-15. Site design and layout of infrastructure

To prepare a submission for permitting the developer will need to have decided on the detail of the site layout, where all building will be etc. and what the size of all those buildings will be.

Depending on the submissions received during the permitting process, it may be necessary to revise the design and any future expansion of the mining operation will require the site design and layout to be revised.

Ref.	Type of geoinformation	Current Techniques[3]	Area to be assessed / monitored	Minimum Measurement Resolution Required	Minimum Measurement Refresh Rate Required
P-1	Water catchment (rivers, lakes etc.)	National published information (e.g. for Ireland; catchments.ie) Desktop study and field work	The size of a catchment will depend on the topography of the area in question. Catchments > 100 km^2	Typically, a 1 in 50,000 OS Map will be sufficient resolution to establish the catchment (1 cm on the map represents 500 metres).	Assessment is required over an annual basis. Will be subject to seasonal variation. Monitoring should be completed at least four times per year at equal intervals.
P-2	Groundwater	National published information (e.g. for Ireland; catchments.ie) Desktop study and field work Pump tests	The size of a catchment will depend on the topography of the area in question. Catchments > 100 km^2	1 in 50,000 (1 cm on the map represents 500 metres).	Assessment is required over an annual basis. Will be subject to seasonal variation. Monitoring should be completed at least four times per year at equal intervals.
P-3	Population centres / social impact	National Databases - Census figures. Site assessment / fly over / drive through	Regional - 50 km^2 Local – 1 km^2	1 in 10,000 OS map can be used to identify buildings. (i.e. 1 cm on the map represents 100 metres).	Annual

[3] See Appendix 1

Ref.	Type of geoinformation	Current Techniques[3]	Area to be assessed / monitored	Minimum Measurement Resolution Required	Minimum Measurement Refresh Rate Required
P-4	Topographical mapping	State issued maps (Ordinance Survey Maps) Digital Terrain Model (DTM) Drones / LiDAR Surveys	> 100 km^2	1 in 50,000 (1 cm on the map represents 500 metres). For vertical (height) contour lines, typically 10m is sufficient resolution.	Annual Very stable parameter
P-5	Receiving waters characterisation & assimilative capacity	National Databases Field work - including chemistry and flow monitoring.	> 100 km^2	Various chemical and physiochemical parameters.	Data may be required to be measured daily.
P-6	Ambient air quality / particulate fallout	National Databases Field work - including monitoring for existing air quality conditions.	c. 10 km^2	There are very many different parameters of interest in the atmosphere. Minimum levels of detection / resolution can be taken from 'TA Luft'.	Monthly

Ref.	Type of geoinformation	Current Techniques[3]	Area to be assessed / monitored	Minimum Measurement Resolution Required	Minimum Measurement Refresh Rate Required
P-7	Soil / sediment chemistry	National Databases Field work - including core / surface sampling for chemistry.	10 km^2 to 100 km^2 Depending on dispersion model.	There are many different chemical and physical properties of soils and sediments that need to be characterised. To understand the measurement resolution the 'Dutch Intervention values' can be taken as a minimum level of detection.	A single comprehensive assessment should be sufficient from a permitting perspective.
P-8	Land cover usage	National Databases. National and regional development plans. OS maps Field work	10 km^2 to 100 km^2	Land will need to be classified to a resolution of at a minimum 10 m^2.	Land usage will not change greatly over short time periods. From a permitting perspective it is necessary to carry out the assessment on a once off basis. Follow up may be completed at a frequency of c. every 6 months to allow for crop rotation.
P-9	Characterisation of flora and fauna	Published data Biological Surveys	1 km^2 to 10 km^2	1 to 10 m^2	Monthly

Ref.	Type of geoinformation	Current Techniques[3]	Area to be assessed / monitored	Minimum Measurement Resolution Required	Minimum Measurement Refresh Rate Required
P-10	Protected areas (Natura 2000 sites)	Prescriptive list and locations are published by government (with map details).	10 km^2 to 100 km^2	Resolution typically 10 m^2. However, detailed assessment within that 10m^2 may be required to locate small animals.	Once off assessment against Natura 2000 as part of the permitting process. Refreshing data is not a material issue unless the permitting process extends for multiple years and new areas are classified as SAC's.
P-11	National Monuments	National registers Site assessment / Survey Fly over Engage with indigenous people	1 km^2 to 10 km^2	1 to 10 m^2 <0.5 m vertical resolution	Once off assessment required as part of the permitting process.
P-12	Farming activities - Baseline crop health / animal health	State Agencies - Farming advisories services Meetings with farmers and Vets Campaign of monitoring	1 km^2 to 10 km^2	Resolution of 10 m^2 Parameters are too broad to capture – particularly for animal health.	Monthly

Ref.	Type of geoinformation	Current Techniques[3]	Area to be assessed / monitored	Minimum Measurement Resolution Required	Minimum Measurement Refresh Rate Required
P-13	Weather / Climate	Onsite weather stations Government weather sites Internet based weather providers	10 km^2 to 100 km^2	Various parameters	Hourly forecast 5 day long-range
P-14	Land ownership	Drones Surveys Land registry (Government)	1 km^2 to 1,00 km^2	Resolution of 1m^2 is required	Annual Transfer of land ownership is a slow process and does not turn over frequently.
P-15	Site design and layout of infrastructure	Drones / LiDAR Surveys AutoCAD	c. 10 km^2	1:1000 maps showing detail at <0.5 m. (1 cm on the map represents 10 metres)	From a permitting perspective this will be a once off exercise and will only be revisited as a result of queries during the permitting phase or future development of the mine and associated permitting.

Table 6.2 – Geoinformation requirements for permitting

6.3.3 Design and Construction & Operation

The core objective of mining is to extract the mineral resources in an efficient manner without having any negative impact on the environment or the community.
Many aspects associated with the design and construction of a mining facility are similar to traditional construction for other industries and typical information such as geotechnical assessment will be required. In addition to the design of the mine there may be a processing plant and there will be many other items of infrastructure required to support the operation; such as administration and welfare buildings as well as laboratories and workshops.

The developers also need to consider the logistical requirements of the project. For example; how will people, equipment and raw inputs (such as fuel) access the site. Large scale infrastructure work may need to be undertaken by the developer to just access the site and ensure a reliable supply of raw materials, for example many remote mine sites will construct an airport runway and helipads as part of the development.

For the purposes of the EO4RM project, the design and construction phase are being assessed with the mine operation phase, and geoinformation requirements can be found in the combined table 6.3.

When a mining project becomes operational the mine operator will continue to have geoinformation needs. These needs will relate to the various aspects of the operational mine including the assessment of production performance, managing and measuring all emissions and waste streams, and demonstrating there is no negative social or environmental impact. Both the operators and their regulators will require geoinformation data during this phase to recognise and monitor any changes to the environment. Mine operators will typically send information to regulators. However, in many instances, regulators will source their own independent information on the mining operation.

Monitoring of structures to warn of the risk of containment failure is of vital importance to ensure that there is no impact on society.

6.3.3.1 DO-1. Access to site - national roads / rail etc.

In order to develop a mine, it is necessary to access the mine site location with construction equipment, building materials and both mobile and fixed plant components. Assessment of infrastructure that is required to access the site is a critical aspect of planning and executing a mine development plan. Additional roads as well as modification to existing structures (low bridges etc.) may all need to be completed to allow a mine to be developed.

Infrastructural projects take time to develop and any changes to infrastructure that impact on the development or operation of the mine will therefore take time to be realised. As such, an annual update would be sufficient to detect change and mobilisation works associated with upcoming changes.

6.3.3.2 DO-2. Site design and layout of infrastructure

A mine developer needs to set out the infrastructure to ensure an efficient operation. It is important to minimise distances over which product and waste needs to be transported. This includes the distance between the mine and the ore stockpiles, between the stockpiles and the processing plant and lastly the processing plant should also be optimised with respect to distance from the TSF.

The site can also be optimised to shield the operation from neighbours to minimise disturbance. Very importantly - from an emergency planning perspective it is vital to assess an appropriate location for waste storage facilities to ensure that in the event of a failure the waste material will not flow towards an occupied area causing risk to life.

Once the mine site layout is agreed and construction has commenced it is now important for the mining company and contractors to track development progress. Routine progress meetings will be held with all key consultants and contractors and data is required for these meetings. Many progress meetings will take place on a daily basis. However, it is typical that there is a main progress meeting on a weekly basis and therefore weekly updates of infrastructure construction status is required.

6.3.3.3 DO-3. Land owned by operation

Mining operations will purchase large tracts of land that are required to develop infrastructure for the mining operation. Often the developer will purchase additional large tracts of land to maximise the distance between the mine and sensitive receptors and thus minimise or avoid nuisance. From a statutory perspective as well as from a corporate perspective it is necessary for the mining company to record all lands owned by the company.

In addition to annual reports that are required for mining companies, most companies will issue quarterly reports and will typically record data on a monthly basis for all of their corporate reporting requirements. Therefore, a monthly updated of land ownership would be required. Once the required footprint is acquired by the mining company there will be limited additional acquisition of land. In the event that additional lands are purchased a monthly reconciliation is sufficient.

6.3.3.4 DO-4. Land disturbed by mining activities

A key sustainability metric for corporate reporting and state reporting is land disturbed by mining. To tie in with corporate reporting, monthly assessment and reporting would be required.

6.3.3.5 DO-5. Land progressively rehabilitated

The modern approach to managing sustainability is to adopt a strategy of progressive rehabilitation - where the mine operator rehabilitates lands on an ongoing basis. This parameter will be part of the sustainability reporting for corporate reporting and state reporting. To tie in with corporate reporting requirement, monthly assessment and reporting would be required.

6.3.3.6 DO-6. Geotechnical assessment - karst mapping

In order for any construction to take place, a developer must ensure the ground on which the development is to take place is structurally competent and will not be susceptible to subsidence or collapse. It will therefore be necessary to carry out a geotechnical assessment before any construction is carried out. Once the assessment is complete, remedial action may be taken and further assessment may be required thereafter. Following the completion of all construction the buildings will then be monitored for structural stability (discussed at DO7 below).

6.3.3.7 DO-7. Infrastructure stability - buildings.

It is good practice to monitor all buildings on site to ensure they are structurally sound. This is particularly important for mining operations where buildings may be near to, or over, underground workings where subsidence is a risk. Trigger values will be established which will prescribe a movement that is tolerable, any readings above this will trigger a corrective action response.

The frequency for assessing stability will depend on site specific conditions and the associated risk of structural issues. Typically, buildings might only be surveyed on an annual basis. However, the more frequent this can be completed the better.

6.3.3.8 DO-8. Infrastructure stability - railways & roads

Reliable access and egress from the mine site are critical to a mining business. Robust access is required to allow people, raw materials and equipment enter the site and conversely this access also allows the mining company to export its final product to market.

Geoinformation element DO-08 is linked to DO-1 and DO-2. DO-1 and & 2 DO-2 refer to the initial infrastructure that is required to develop the mine. DO-8 is with respect to the on-going monitoring that is required to ensure this infrastructure is in good working order.

While much of the road & railway infrastructure will be state owned, in certain jurisdictions the access infrastructure may be owned and managed by the mining company, but in any case, it is important for the company to proactively manage this aspect to ensure there are no unforeseen interruptions to production.

The frequency for assessing stability will depend on site specific conditions and the associated risk of structural issues. The more frequent this can be completed the better. D0-8 covers all types of roads from dirt roads to tarred roads to ice roads and all will have their own specific monitoring requirements.

6.3.3.9 DO-9. Infrastructure stability - port facilities

In many instances a port is vital item of infrastructure to allow mining companies export their product. It is important to proactively assess and manage this facility to ensure no unforeseen interruptions to production. As is the case in DO-8, this aspect may be state owned and managed, or it may be owned by the mining company.

The frequency for assessing stability will depend on site specific conditions and the associated risk of structural issues. The more frequent this can be completed the better. Weekly / daily would be advantageous.

6.3.3.10 DO-10. Raw material stockpiles

Monitoring the quantity of raw material stockpiles is a key metric for management of production at a mine. Daily assessment will be required to manage most operations, with a minimum assessment frequency of month for reporting.

Depending on the size of the stockpile it may be necessary to monitor for stability. In this instance monitoring would be required daily.

6.3.3.11 DO-11. Ore stockpiles

Monitoring the quantity ore stockpiles is a key metric for management of production at a mine. Daily assessment will be required to manage most operations, with a minimum assessment frequency of month for reporting.

Depending on the size of the stockpile it may be necessary to monitor for stability. In this instance monitoring would be required daily.

6.3.3.12 DO-12. Final product stockpiles

Monitoring the quantity final product is a key metric for management of production at a mine. Daily assessment will be required to manage most operations, with a minimum assessment frequency of month for reporting.

Depending on the size of the stockpile it may be necessary to monitor for stability. In this instance monitoring would be required daily.

6.3.3.13 DO-13. Pit slopes stability

Monitoring of pit slope stability is vital for production as well as for health and safety. Partial or total failure of a pit will cover working areas with overburden and interrupt production it is also a major health and safety issue. Catastrophic unforeseen failure is likely to result in casualties or loss of life if employees are in the vicinity of a failure.

The frequency for assessing pit slope stability will depend on site specific conditions. However, the more frequent this can be completed the better. Daily visual assessments will be completed by mine officials during the operational phase of the mine and work will not be allowed to commence on each shift until a competent person certifies the area as safe. However, a pit is a dynamic workplace and ongoing assessment is required. Ground based radar systems provide continuous data which is ideal for early warning. Other techniques for assessing stability are listed in table 6.3 and discussed in Appendix 1.

In additional to the daily monitoring data it is also important to track cumulative movement over a longer time period to understand how the ground is behaving. It would be preferred to have continuous monitoring in place for this parameter. Minimum frequency would be daily.

6.3.3.14 DO-14. Tailings Storage Facilities stability

Monitoring of the tailings storage facility (TSF) stability is vital for health and safety of employees and neighbours - many fatalities and much environmental damage have been caused throughout the years from tailings dam failures. Failure of a TSF is also likely to close a mine permanently.

Daily visual assessments will be completed by mine officials during the operational phase of the mine. In additional to daily assessment there are many monitoring techniques that are used to assess TSF stability are listed in table 6.3 and discussed in Appendix 1. As is the case for pit slope stability, it is important to track cumulative movement over a longer time period to understand any trends that may be apparent. It is estimated that there are more than 3,500 TSFs currently in place around the globe.

It is preferred to have daily or continuous monitoring in place.

6.3.3.15 DO-15. Waste Rock Dumps stability

Monitoring of WRD slope stability is important for production and vital for health and safety. The frequency for assessing WRD stability will depend on site specific conditions. WRDs are often present at various locations throughout a mine site, both ex-pit and in-pit. Routine inspections and monitoring are needed. It is preferred to have daily or continuous monitoring in place.

Oxidation of a WRD can impact on stability but is generally more of a concern from an environmental perspective monitoring for signs of oxidation and acid rock drainage (ARD) is an important environmental measurement for many mines during the operational phase to demonstrate no impact on the environment. This is also a significant long-term (post closure) aspect and will be discussed in that section.

6.3.3.16 DO-16. Monitoring of cover performance (WRD / stockpile / tailings)

In many environments it will be necessary to introduce a cover (or protection layer) to prevent environmental impact associated with mining raw materials and by-products. In many instances this may be a water cover (reference Irish mines with pyritic tailings are required to maintain a water cover of 1 m during winter months and 1.3 m during summer months) and this water cover needs to be monitored to ensure it is of sufficient depth.

Water sprays may also be used and in this instance and they need to be checked to ensure they are operation, ensure they are covering the required area, and ensure that the material is been wetted sufficiently.

A vegetative cover will also be introduced to improve stability; however, this is typically only completed as part of closure / rehabilitation works.

6.3.3.17 DO-17. Monitoring in-pit water levels and moisture content of pit walls

Dewatering of a mine is needed during operation. If something goes wrong with the dewatering process e.g. failure of groundwater pumps it will lead to downtime and economic losses for the mining company. In addition, during heavy rainfall the pit will fill up with water

It is important that controls are in place to manage water within mines. Apart from monitoring groundwater pump performance/operation it is also possible to monitor water levels & moisture content at the pit floor and surrounding pit walls

6.3.3.18 DO-18. Location of occupied dwellings / sensitive receptors – including informal settlements (emergency planning & complaints management).

It is important to know the location of occupied dwellings that are close to the mine for emergency planning and in relation to the management of possible disturbance.

For emergency planning it is necessary for notifying property owners of any serious incidents and in particular any incidents that require evacuation.

In relation to disturbance, knowing the location of all occupied dwellings will assist a mining company understand the sensitive receptors in relation to disturbance. Blast designs may be modified to allow for the location of sensitive receptors. Also, additional noise and dust abatement can be installed close to sensitive receptors.

Formal housing typically has a long lead in time (of many months) and as such changes will be detectable over a long time period. However, informal settlements can establish in a very short period of time (days and weeks). Therefore, a refresh rate of no less than 7 days would be suitable for identification of people living within the zone of influence of a mine.

6.3.3.19 DO-19. Underground operations - surface subsidence

Backfill and ground support are a key part of underground mining, to maximise the abstraction of the resource and to minimise ground subsidence. Even with a comprehensive backfilling and support program, the risk of surface subsidence is significant. In many operations, based on the mining method and geological setting, some surface subsidence will be unavoidable. Monitoring ground subsidence allows a mine operator to ensure that the amount of subsidence is at all times within an agreed and tolerable range. Any exceedance of this range will allow the mine to notify the relevant parties and take additional corrective actions.

The frequency for assessing ground stability and surface subsidence will depend on site specific conditions. An underground mine may survey for settlement on a monthly, quarterly or annual basis. The ground control management plan will define the required monitoring frequency. The sooner a mine becomes aware of any settlement outside of the predicted range the better, to allow the mine inform the relevant stakeholders and take additional corrective action.

For an active mine, quarterly would be the minimum frequency of subsidence assessment with more frequent assessment being desirable.

6.3.3.20 DO-20. Monitoring routine water emissions

Discharging water into the environment is an activity that many mines around the world must undertake (as mining activities will in many cases end up below the water table). Mines are required to assess the impact that their water discharge may have on the receiving environment by measuring the volume of water and mass emission of various chemical parameters discharged. They must also assess the assimilative capacity of the receiving environment for the volume of water and the chemical parameters, this is achieved by measuring the receiving water conditions. Mapping the key locations with respect to water discharge and receipt into the environment is important to allow this information to be presented geographically.

Water volume discharged will vary depending on the operation and as a result of this the area that is susceptible to potential impact will also vary. The area that may be impacted by water discharges can be tens or even hundreds of km^2. Resolution for water discharged would expect to be known to an accuracy of at least 100 m^3/day.

It is necessary for the mine operator to measure the concentration of various chemical parameters to establish their mass emission. The accuracy required for the various chemical parameters is too varied to document in this report. A mine can measure hundreds of different chemical parameters, each with its own limit of detection which will vary by many orders of magnitude. Minimum levels of detection / resolution can be taken as the concentrations given in the European Directive on Environmental quality standards - Directive 2008/105/EC (see P5).

The frequency required for monitoring of water discharge into the environment will be site specific and will depend on sensitivities specific to each site. It would be expected that a mine will have monitoring data that is on a daily basis for most parameters, with flow discharge being reported on an hourly basis for many operations.

6.3.3.21 DO-21. Monitoring of any pollution plumes / algal blooms / sediment accumulation etc.

This geoinformation parameter relates to discrete loss of containment and seepages - for example seepage from a TSF. This geoinformation parameter will also measure the potential cumulative effects that prolonged discharges can have on the environment (e.g. suspended solids may be in compliance with emission limit values, but over time may result in accumulation of sediment within the receiving environment). Mapping the location and progress of any plumes and presenting these data geographically is an important aspect with respect to this parameter.

There are many factors that influence how plumes materialise. Production disruption and containment failures are key factors. Weather will also play a vital role as high temperatures can promote algal blooms, low rainfall will reduce river flow and may result in sediment accumulation, while increased rainfall may also be a factor as it may cause the mobilisation of material from the mine site.

The more frequent data is available to assess for plumes and track their progress the better. Weekly resolution would be the minimum requirement.

6.3.3.22 DO-22. Groundwater monitoring

Monitoring of ground water levels and chemistry is a key metric to establish what impact a mine may be having on the environment. This impact ranges from dewatering of the water table (and removal of groundwater that is required for abstraction by other stakeholders) to polluting of aquifers (which renders the aquifer of no use to other stakeholders and causes harm to the environment and as groundwater quality is an important environmental parameter). All groundwater eventually emerges to surface at some point and if there is contamination within the groundwater this will cause an impact on any plant or animal species that are exposed to this water when it emerges to surface. Groundwater plumes may undergo some attenuation as the flow within an aquifer and this is one of the reasons why it is important to tract and monitor groundwater plumes so this attenuation may be recorded. Mapping the location of the monitoring locations and presenting these data geographically is an important aspect with respect to groundwater, so a profile for quality and flow can be established and the potential impact may be understood.

As is the case with surface water, it will also be necessary to abstract groundwater samples and analyse for chemical parameters (various wet chemistry analytical techniques + spectrophotometer / AA / ICP) to understand the quality of the groundwater. The frequency will depend on site specific conditions but monthly or quarterly would be a typical interval for this type of monitoring as this will allow seasonal variation to be measured.

6.3.3.23 DO-23. Monitoring seepage from mine structures (e.g. TSF, WRD)

Tailings that are placed into a TSF are generally a mix of solids and water. In most cases the tailings will settle and the water will evaporate, but this is highly dependent on local weather conditions and chemical composition of the tailings. In wetter environments where the tailings will settle, the remaining 'tailings water' will decant or be pumped from the TSF before it is discharged to the environment. Tailings water will typically have elevated dissolved metal concentrations and other parameters such as sulphate and ammonia can be elevated, therefore it is usual for some treatment to take place before this water is discharged. In some cases, where the tailings will not settle readily, a slurry or mixture of solids and water remains with elevated concentrations of metals and other compounds, in comparison to background concentrations and higher in concentration that tailings water. In any case; whether it is a slurry of tailings and water or 'tailings water' this material needs to be managed. Many tailings dam walls and floors are lined with synthetic liner which, with adequate care on installation should have very low permeability, low permeability clay material can also be used to minimise seepage. However, some seepage is likely to occur in most dams and therefore this is a parameter that needs to be monitored, especially during heavy rainfall events.

In many instances this monitoring will be part of the groundwater monitoring programme as described in DO-22 with wells in specific locations around the TSF acting as sentinels for signs of seepage (elevated concentration of a specific chemical or element). In other instances, the seepage may be evident as a surface emission from the facility. The seepage will often be coloured due to the mineral content (an orange colour from the oxidised pyritic iron is a classic indication of seepage and this can be detected visually without any need for chemical analysis). However, rather than just gauging the colour chemical analyses will be of benefit to determine concentrations and establish the nature and the extent of the seepage. Seepage from a WRD which may occur as a result of heavy/continuous rainfall also needs to be monitored.

Mine waste is often characterised into groups which estimate the environmental risk of the material (e.g. with regards to acid forming potential, non-acid forming (NAF), potential acid forming (PAF) and acid forming (AF) waste, see the MEND Manual[4] or the INAP GARD guide[5]. Monitoring of the moisture content of (the dams of a) TSF and (the outer layers of a) WRD can be used as early warning for seepage.

6.3.3.24 DO-24. Monitoring of emissions to atmosphere - point source

Mining operations will have point source emissions to atmosphere from ventilations shafts, processing plants, labs, power plants etc. Measuring the quantity of different parameters emitted into the atmosphere (gaseous and solid) is an important aspect for mining companies to manage their potential environmental impact. Typical parameters are NOx, SOx, COx, particulates and H_2S.

The area required to be assessed will be dependent on the footprint of the mining operation and could be 1 km^2 to 10 km^2.

Emissions to the atmosphere can result in transboundary impacts on air quality beyond the site boundary. The extent of transboundary impact depends on the nature of the emission and also prevailing weather conditions and geographic features. Given the mobility of gaseous emissions, an area of hundreds of km^2 may need to be monitored.

Air emissions will take place on a continuous basis. Many air emissions will be stable and infrequent measurement of monthly to quarterly will be sufficient. Other emissions will be more variable, and these should ideally be measured on a continuous basis.

6.3.3.25 DO-25. Monitoring air emissions – fugitive

In addition to point source air emissions, mines will have significant fugitive air emissions. These emissions can be plumes from pit blasts, dust form vehicular movement, dust blow off TSF / WRD, and fires. Monitoring for fugitive emissions is an important aspect for mining companies to manage their potential environmental impact. This fugitive monitoring can also be used to identify sources of emission and implement corrective actions (including identifying spontaneous combustion fires so they can be extinguished).

The frequency required for monitoring this parameter is site specific. In many instances monthly would be sufficient but in particular for the identification of spontaneous combustion continuous monitoring would be of benefit.

6.3.3.26 DO-26. Waste management – audit of accumulations

In addition to the production of mine tailings, mining operations also produce more conventional waste streams. Accounting for these waste streams, quantifying the volume and demonstrating the responsible management of these wastes is a key environmental / sustainability metric.

[4] http://mend-nedem.org/wp-content/uploads/2013/01/5.4.2c.pdf
[5] http://www.gardguide.com/index.php?title=Main_Page

Waste generation will be most focused around the main areas of operation. While the size of mines will vary – the size of the area to be monitored with respect to waste generation / management could be c. 1 km^2 to 10 km^2.

Reporting frequencies will vary depending on operation. Typically for waste reporting a monthly consolidation will be sufficient.

6.3.3.27 DO-27. Mapping of any illegal mining operations

Mining companies must, in most instances, go through a rigorous permitting process to get permission to abstract minerals. However, it is the case that in many jurisdictions, individuals are prepared to ignore the law and attempt to mine without permission from the government. In some instances, this might be a small operation of one or two individuals, but in other instances it can be more significant with small mining companies engaged in illegal mining.

It is in the interest of mine operators and government agencies to ensure that no illegal mining takes places as this will result in a loss of profit and royalties, it will also introduce environmental and safety concerns as illegal miners will generally not operate to appropriate standards.

The monitoring intensity for illegal mining monitoring is dependent on the jurisdiction and the problem with this issue. It is expected that a refresh rate of monthly or quarterly would be sufficient for this parameter.

6.3.3.28 DO-28. Mapping of any informal settlements

DO18 refers to the identification of dwelling houses and this information parameter does refer to informal settlements. However, DO18 records dwelling houses with respect to a mine operators' requirement to understand where its sensitive receptors are. There is also a requirement for other entities such as government agencies to identify and manage informal settlements and as such this is recorded as an individual geoinformation requirement associated with mining.

A mine site operation will vary in size. Sites can range from a footprint of around 1 km^2 to 10 km^2. Measurement accuracy is required to at least 10 m^2 to identify individual structures that may form part of an informal settlement. Informal settlements can establish in a very short period of time (days and weeks), therefore a refresh rate of no less than 7 days would be suitable for monitoring this parameter.

6.3.3.29 DO-29. Weather

Weather is important to mining industries as severe weather can interrupt production and operators may need to implement emergency plans for certain weather events such as rainstorms / hurricanes / extreme cold.

The water balance is a key metric for all mine sites. Often there is only finite storage capacity in holding ponds and tailings storage facilities. Contingency plans will need to be developed if existing storage capacity is set to be exceeded. The volume of water to be pumped out of a pit or an underground mine will have a direct correlation with precipitation rates (underground workings will typically lag depending on their depth) - tracking the cumulative totals for precipitation within a given time period allows a mine operator ensure that sufficient water pumping and treatment capacity is in place to dewater the mine and ensure no impact on the environment. Mine operators need access to good reliable long-range forecasting. Although this varies depending on geography, in most instances based on current technology c. 5 days is as far as can be forecast with any accuracy. Records of individual parameters such as precipitation need to be recorded with a minimum refresh rate of daily. Other parameters such as wind speed may be required more frequently as for example wind speed is a critical parameter when planning lifting operations. In this instance hourly forecasts would be required.

6.3.3.30 DO-30. Impact on nearby industries (in particular agriculture).

During the baseline assessment, farming activities, if any, will have been identified and an assessment will have been completed. It is necessary for the mine operator to demonstrate that its operations have no impact on any farming businesses within its area of influence or if it does compensation will need to be agreed.

The area to be assessed will depend on the characterisation that took place during the permitting phase. Industries within 1,000 km^2 of the operation could be impacted, depending on the scale of the mine. Agricultural is the most sensitive to impact. Various sampling methodologies are used by farm advisory services, most are based on taking representative sample within a grid pattern - a resolution of 10 m^2 should be sufficient to determine growth rates for crops. Animal health involves screening by vets. The parameters to assess animal health are too broad to capture in this report, they include protein indicators of metabolic function, trace element concentrations, toxic element concentrations and weight gain per day to name but a few. Crop growth is seasonal. Monthly intervals would be reasonable to assess performance and a similar frequency can be adopted for animal health.

6.3.3.31 DO-31. Noise and vibration monitoring

Noise and vibration are significant aspects with respect to environmental control from mining operations. Noise and vibration will typically be the main source of complaints received from neighbours of the mine, particularly if the mine is close to an urbanised area.

Without providing an exhaustive list - the typical sources of noise are motors (pumps and fans - particularly ventilation exhausts), crushers, mills, mobile equipment, drill rigs and most significantly blasting. Blasting will create vibration and air over pressure which is the sound of the blast. Vibration from a blast will also cause secondary soundwaves by vibrating walls and windows in houses.

Noise is typically just a nuisance issue that needs to be managed to maintain good community relationships. Whereas vibration can cause damage to structures if blasts are not managed correctly.

Some noise emissions will be continuous (e.g. ventilation fans), whereas other will be intermittent (e.g. blasting). To assess the impact of the noise it is not just the loudness of the noise (typically expressed in decibel (dB)), it is also the tone of the noise (i.e. is it very low frequency or very high frequency) very high and very low frequencies are likely to me more disturbing. Impulsive noise will contain intermittent increases and decreases in loudness and example of an impulsive noise might be a jack hammer. The impulsive nature of the noise also needs to be considered, the more impulsive the noise is the more disturbing it will be.

Blasting has an additional disturbance factor in that it can cause a 'startle effect', as it can occur without any warning. Often blasting will take place at different locations around the same time and a neighbour will first hear distant rumbles of blasts before any large blasting notices from nearby blasts and as such they are prepared for the noise this is less likely to startle. Mines can also use a blasting horn, which can be first sounded to alert neighbours to an impending blast and minimises the likelihood of startle.

Ref.	Type of geoinformation	Current Techniques[6]	Area to be assessed / monitored	Minimum Measurement Resolution Required	Minimum Measurement Refresh Rate Required
DO-1	Access to site - national roads / rail etc.	Digital Terrain Model (DTM) Drones / LiDAR Surveys	> 100 km^2	1 in 50,000 OS map (1 cm on the map represents 500 metres). A 1 in 2500 OS map (1 cm on the map represents 25 metres) will provide additional resolution for areas where it is anticipated there may be issues (bridge details etc.). Detail to <0.5 m	Annual
DO-2	Site design and layout of infrastructure	Drones / LiDAR Surveys AutoCAD	c. 10 km^2	1:1000 maps showing detail at <0.5 m. (1 cm on the map represents 10 metres)	Weekly
DO-3	Land owned by operation	Drones Surveys Land registry (Government)	10 km^2 - 100 km^2	Resolution of 1m^2 is required	Monthly

[6] See Appendix 1

Ref.	Type of geoinformation	Current Techniques[6]	Area to be assessed / monitored	Minimum Measurement Resolution Required	Minimum Measurement Refresh Rate Required
DO-4	Land disturbed by mining activities	Drones Surveys	10 km^2 - 100 km^2	Resolution of 1m^2 is required	Monthly
DO-5	Land progressively rehabilitated	Drones Surveys	10 km^2 - 100 km^2	Resolution of 1 m^2 is required	Monthly
DO-6	Geotechnical assessment - karst mapping	Geological Survey issued maps Walk-over (visual assessment) Geophysics	10 km^2 - 100 km^2	Resolution of 1 m^2 is required	As required – per development plan
DO-7	Infrastructure stability - buildings.	Drones / LiDAR / InSAR Surveys tell-tales	c. 10 km^2	1:1000 maps showing detail at <0.5 m (1 cm on the map represents 10 metres)	Minimum annual

Ref.	Type of geoinformation	Current Techniques[6]	Area to be assessed / monitored	Minimum Measurement Resolution Required	Minimum Measurement Refresh Rate Required
DO-8	Infrastructure stability - railways & roads	Drones / LiDAR / InSAR Surveys	> 100 km^2	1:1000 maps showing detail at <0.5 m (1 cm on the map represents 10 metres)	Minimum annual
DO-9	Infrastructure stability - port facilities	Drones / LiDAR / InSAR Surveys tell-tales	c. 10 km^2	1:1000 maps showing detail at <0.5 m (1 cm on the map represents 10 metres)	Minimum annual
DO-10	Raw material stockpiles	Drones Surveys	c. 10 km^2	1:1000 maps showing detail at 0.005 - 0.5m (1 cm on the map represents 10 metres)	Preferred daily Minimum monthly
DO-11	Ore stockpiles	Drones Surveys	c. 10 km^2	1:1000 maps showing detail at 0.005 - 0.5m (1 cm on the map represents 10 metres)	Preferred daily Minimum monthly

Ref.	Type of geoinformation	Current Techniques[6]	Area to be assessed / monitored	Minimum Measurement Resolution Required	Minimum Measurement Refresh Rate Required
DO-12	Final product stockpiles	Drones Surveys	c. 10 km^2	1:1000 maps showing detail at 0.005 - 0.5m (1 cm on the map represents 10 metres)	Preferred daily Minimum monthly
DO-13	Pit slopes stability	Drones / LiDAR / InSAR Surveys Tension crack mapping Extensometers Time-domain reflectometer (TDR) Surface base radar	c. 10 km^2	5-10 mm accuracy	Preferred Continuous Minimum – Daily
DO-14	Tailings Storage Facilities stability	Drones / LiDAR / InSAR Surveys Piezometers / Boreholes Inclinometers Extensometers	c. 10 km^2	5-10 mm accuracy	Preferred Continuous Minimum – Daily

Ref.	Type of geoinformation	Current Techniques[6]	Area to be assessed / monitored	Minimum Measurement Resolution Required	Minimum Measurement Refresh Rate Required
DO-15	Waste Rock Dumps stability	Drones / LiDAR / InSAR Surveys Surface Base radar	c. 10 km^2	5-10 mm accuracy	Preferred Continuous Minimum – Daily
DO-16	Monitoring of cover performance (waste rock dump / stockpile / tailings)	Visual inspection Ultrasonic depth measurement units. Bathymetric surveys	c. 10 km^2	5-10 mm accuracy	Daily
DO-17	Monitoring in-pit water levels and moisture content of pit walls	Visual inspection Well dipping	c. 10 km^2	5-10 mm accuracy	Weekly
DO-18	Location of occupied dwellings / sensitive receptors (emergency planning & complaints management). Including informal settlements.	Ordinance Survey Maps Government statistics - census results Walk-overs	c. 100 km^2	1:1000 maps showing detail at <0.5m (1 cm on the map represents 10 metres)	Weekly

Ref.	Type of geoinformation	Current Techniques[6]	Area to be assessed / monitored	Minimum Measurement Resolution Required	Minimum Measurement Refresh Rate Required
DO-19	Underground operations - surface subsidence	Surveys InSAR	10km^2 - 100 km^2	1-5 mm accuracy, depending on land use (residential - unused)	Minimum quarterly. Preferred daily / continuous
DO-20	Monitoring routine water emissions	Flow meters Samplers Wet chemistry analytical techniques + spectrophotometer / AA / ICP	10 km^2 - 100 km^2	Various chemical parameters. Minimum levels of detection / resolution can be taken as given in Directive 2008/105/EC.	Minimum daily
DO-21	Monitoring of any pollution plumes / algal blooms / sediment accumulation etc.	Walk-over / Sampling Drone photography	10 km^2 to 100 km^2	The resolution should be to 1 m^2	Weekly
DO-22	Groundwater monitoring	GPS well location / site map Wet chemistry analytical techniques + spectrophotometer / AA / ICP	10 km^2 to 100 km^2	The resolution should be to 1 m^2	Monthly

Ref.	Type of geoinformation	Current Techniques[6]	Area to be assessed / monitored	Minimum Measurement Resolution Required	Minimum Measurement Refresh Rate Required
DO-23	Monitoring seepage from mine structures (e.g. TSF, WRD)	Borehole sampling Visually assessment Aerial photography Geophysics	c. 10 km^2	Required resolution will vary (measurement and the specific site). Monitoring is seeking to find variation or contrast to indicate an anomaly which may correspond to a seepage.	6 monthly
DO-24	Monitoring air emissions - point source	Flow meters Real time & Isokinetic Sampling Gravimetric / Colorimetric analyses	10 km^2 to 100 km^2	The resolution should be to 1 m^2	Continuous to quarterly
DO-25	Monitoring air emissions - fugitive	Ambient air quality monitoring Dust Deposition / pumped based systems / optical systems Analyses for chemicals by traditional means	10 km^2 to 100 km^2	The resolution should be to 1 m^2	Continuous for spontaneous combustion risk Monthly for other parameters

Ref.	Type of geoinformation	Current Techniques[6]	Area to be assessed / monitored	Minimum Measurement Resolution Required	Minimum Measurement Refresh Rate Required
DO-26	Waste management - audit of accumulations	Walk-over / audits	1 km^2 to 10 km^2	The resolution should be to 1 m^2	Monthly
DO-27	Mapping of any illegal mining operations	Aerial photography / drones Driving around site boundary	1 km^2 to 10 km^2	The resolution should be to 1m^2	Monthly
DO-28	Mapping of any informal settlements	Walk-over Aerial photography / drones Government agencies information	1 km^2 to 10 km^2	Area – 1 km^2 to 10 km^2 Resolution c. 10 m^2	Weekly
DO-29	Weather	Onsite weather stations Government Weather sites Internet based weather providers	10 km^2 to 100 km^2	Various parameters	Hourly forecast 5 day long-range

Ref.	Type of geoinformation	Current Techniques[6]	Area to be assessed / monitored	Minimum Measurement Resolution Required	Minimum Measurement Refresh Rate Required
DO-30	Impact on nearby industries (in particular agriculture)	State Agencies - Farming advisories services Meetings with farmers and Vets Campaign of monitoring	10 km^2 to 1,000 km^2	Various parameters.	Monthly
DO-31	Noise and vibration monitoring	Noise meters Vibrographs (accelerometers)	10 km^2 to 100 km^2	Resolution of: 1dB (noise) 0.1 mm/sec PPV (vibration)	Continuous

Table 6.3 – Geoinformation requirements for design, construction and operation.

6.3.4 Mine Closure and Aftercare

The responsibility of the mine operator does not stop when the mining has finished. Once mining is complete the operator is responsible for closing the mine and rehabilitating the site so that the area is safe and environmentally secure for the future.

In previous centuries and even in recent decades mine operators did not always do a good job rehabilitating their site after mining was completed. In many cases this was due to a ‘boom bust’ nature of the industry and often a mine closed during a downcycle when there were no funds were remaining to properly rehabilitate the site. Although there are still parts of the world where mines are not operated or closed well, it is the case that the developed countries now require mining companies to develop and implement robust closure plans. Governments often will not permit mine operators until there is an agreed closure plan in place, with secured funding put in place to implement this closure plan in the event of an unforeseen closure.

Significant amounts of data and geoinformation are required before and during the closure process as well as many years afterwards, during the aftercare period, to demonstrate that the site is safe and secure. Much of the geoinformation that was required during the operational phase will continue to be required during the closure and aftercare period and this data will be used to demonstrate to stakeholders that there is no negative impact arising and that the area is stable. Information will include an assessment of revegetation and stability of facilities such as WRD’s and TSF’s.

Although mine closure is a separate phase of the mining cycle and is captured separately in this document. It is worth noting that mine closure planning will be underway prior to the start of the mine and the mine closure phase will have significant overlap with the operation phase.

6.3.4.1 CA-1. Demonstration of rehabilitation / revegetation

Demonstration that the mine site has been rehabilitated and returned to an agreed endpoint is fundamental to achieving a successful mine closure and achievement of a mine closure certificate from regulatory authorities.

The endpoint will be based on the baseline data gathered during the permitting period and vegetation cover will be a key metric. Information on the extent (density) and variety of vegetation cover will be important to establish. Vegetation is often critical to provide structural integrity to ground cover and ensure that rehabilitation is not eroded by weather as the root system acts to bind the soil matrix.

The rate of growth for vegetation cover will vary depending on geography and climate but in any case, changes in vegetation density will be relatively slow and for comparative purposes a mine operator may only compare growth cover on a quarter by quarter or year by year basis. It is likely that monitoring will be required into the aftercare period to demonstrate that the revegetation is sustainable. Updates in aftercare may be quarterly or annual.

6.3.4.2 CA-2. Characterisation of Flora and Fauna

Demonstration that flora and fauna have returned to an agreed endpoint is an important measure of successful mine closure. The required endpoint will be based on the baseline data gathered during the permitting period. Large areas will need to be assessed to account for the area of influence that the mine and resolution detail should be assessed down to 1 m^2.

Fauna will populate large areas of land depending on the species and are subject to migrations so they need to be assessed over a longer time period to understand the population. Flora will also vary seasonally and monitoring needs to account for this seasonality. It is likely that follow up surveys will be required during the aftercare period.

6.3.4.3 CA-3. Soil Structure and Chemistry

Baseline characteristics for soil and sediment will be established during the permitting process. As part of the closure and rehabilitation process a mine must demonstrate that baseline soils and sediments are at baseline conditions, or at conditions agreed with the regulatory authorities based on guidance values as described in P-7.

The area to be assessed can be extensive; when factors such as air emissions and water emissions are taken into account it means that the footprint to be assessed can be hundreds of km^2. The resolution to be assessed will be dependent on the type and scale of the operation and may range from one sample per hectare to a tight sampling grid of 10 m^2 samples where there are 'hot spots' or expected variation in concentration due to the location of a specific mining activity that was a source of contamination.

Soil and sediment chemistry and physical composition will not vary in the short term. To demonstrate restoration of baseline conditions or other agreed endpoint, a once off assessment of the soil should be sufficient. Authorities may require follow up surveys during the aftercare period. Updates in aftercare would not be expected to be more frequent than annual.

6.3.4.4 CA-4. Demonstration of infrastructure removal

Mining companies must remove all buildings and infrastructure that will not be of value for the community or the state post closure (as will be agreed in permitting process). Buildings that are not removed will fall into disrepair, become eyesores and also be a potential location for unsocial behaviour. Demonstrating progress with respect to removal of infrastructure is an important closure metric for regulatory authorities and corporate offices and a monthly update would be desirable.

6.3.4.5 CA-5. Demonstration no impact on national heritage locations

National monuments and heritage sites will be identified as part of the permitting process, as part of the closure process it will be necessary to demonstrate that these sites have not been impacted by mining. Remedial works may need to be implemented and if required the mining company will need to demonstrate that these works were successfully completed. All sites identified in the baseline assessment will need to be reassessed - this will require a resolution of millimetre accuracy to demonstrate no movement to structures which could result in damage.

This will be most likely be a once-off assessment at the end of the rehabilitation process as the mine should be in steady state (no further subsidence etc.). If necessary additional infrequent surveying may be required during aftercare, this would be annual at the most frequent.

6.3.4.6 CA-6. Demonstrate no impact on SAC's (Natura 2000 sites)

All SAC sites will have been identified during the permitting process. The mine operator must demonstrate at closure that no impact has been caused to these sites by the mine's operations. The area will be dependent on the scale of the operation. The impact can extend beyond the mine's boundary. An area of more than 100 km^2 may need to be assessed, depending on the operation. In addition, SAC's within 15 km of the boundary of the site need to be specifically assessed with a resolution of 1 to 10 m^2 depending on the species.

This is a once-off exercise to be completed at the end of mine closure. Authorities may require follow up surveys during the aftercare period, this would be site specific and not expected to be more frequent than annual.

6.3.4.7 CA-7. Demonstration of return to baseline air quality - including deposition

Monitoring will be required during the closure and aftercare period to demonstrate that there are no ongoing air emissions from the site that could cause an impact. Point sources will no longer be operational. The focus will be on fugitive emissions from WRD's and TSF's. Assessment of this parameter will involve field work including measurement of air quality for various parameters and measurement of particulate fallout. Depending on climatic conditions air emissions can travel long distances. The area to assessed can be hundreds of km^2. Monthly data is sufficient, this can be used to calculate daily deposition rates.

6.3.4.8 CA-8. Farming activities - confirm return to baseline conditions for crops / animals

If there are farming activities within the area of influenced of the mine. The mine operator will need to provide on-going assurance for a period of time during the aftercare period that there is no impact on farming activities.

The area to be assessed will need to be consistent with the area that was assessed during the operational phase. As mining can have an impact well beyond the site boundary due to air and water emissions, the area to be assessed can be up to 1,000 km^2.

Various sampling methodologies are used by farm advisory services, most are based on taking representative samples. Animal health involves screening by Vets. The parameters to assess animal health are too broad to capture in this report, they include protein indicators of metabolic function, trace element concentrations, toxic element concentrations and weight gain per day to name but a few.

For crop growth the resolution of 10 m^2 should be sufficient to determine growth rates for crops. Crop growth is seasonal and assessment must take place over a full year, monthly intervals would be reasonable to assess performance. Monthly assessment is also appropriate for animal assessment.

6.3.4.9 CA-9. Demonstration of return to baseline water quality

The mine operator must demonstrate that water quality in the receiving environment has returned to baseline conditions or to other agreed endpoints. This includes surface and groundwater and will include all receiving environments that are within the area of influence of the mine (e.g. rivers, lakes etc.). National databases can be used as a source of data but field work, including chemistry and flow monitoring, will be required. Even in a closure and aftercare phase it is the case that many mines will continue to have a daily discharge, due to precipitation falling within the catchment of the site and flowing over WRD's and TSF's and therefore water will continue to remain a key aspect well after mining operations have ceased.

The size of a catchment will depend on the topography of the area in question. Catchments can be tens of km^2 to hundreds of km^2. The monitoring will tend to focus around the area of influence of the mine. Various chemical and physiochemical parameters will need to be assessed. Concentration will vary as will the limit of detection – the minimum levels of detection / resolution can be taken as the concentrations given in the European Directive on Environmental quality standards - Directive 2008/105/EC as described in P-5.

The frequency required for monitoring of water discharge into the environment will be site specific and depend on sensitivities specific to each site. Regulators may require monitoring on a daily basis for many parameters. Maintaining a daily assessment of water discharge on a daily basis into the aftercare period would be optimal.

6.3.4.10 CA-10. Plume tracing of leaks or seepage (surface water / groundwater / soil)

When a mine is in the closure or aftercare period it is the time when discrete plumes can be most problematic, particularly when operators have failed to implement a good closure programme. Mapping the location and progress of any plumes and presenting these data geographically is an important aspect with respect to this parameter.

Plumes will generally be most pronounced close to the source (the mining operation) however impact can extend well beyond the immediate environs of the mining operation. The area required to be assessed will be in the order of 10 km^2 to 100 km^2. The resolution should be to 1 m^2. The more frequent data is available to assess for plumes and track their progress the better, monthly resolution would be the minimum requirement.

6.3.4.11 CA-11. Demonstrate long term structural stability of key infrastructure - WRD's / TSF's / Pit

WRD's and TSF's will remain on the mine site long after mining has ceased. The structures will be stabilised as part of the closure plan, however there will remain a risk, albeit a reduced risk, of structural failure forever as long as the structure remains. The mining operator will be required to demonstrate the long-term structural stability of key infrastructure - WRD's / TSF's. The risk profile will be site specific.

The frequency for assessment will be dependent on the risk profile. In most instances the risk post closure will be reduced because the facility will be more stabilised and less dynamic (as material is no longer being placed). Once a facility is demonstrated to be stable the monitoring frequency may move to an annual basis. However, more frequent monitoring may be required and in particular an operator may be required to respond following specific events (rain events / seismic events). Continuous monitoring for structural stability would be ideal if a passive monitoring system was available.

When rehabilitating an open pit; in some cases the pit will be filled with waste/spoil, or it may even be operated as an inert landfill. In other instances, the pit will be transformed into a pit lake. Water will naturally accumulate in a mine pit once dewatering is stopped and adding water into the void will increase the stability of the pit walls (as opposed to leaving the void open).

Refilling a pit with fill material will result in a more stable structure but this is not always economically viable. Often the pit will be filled with inert material up to the water table level to protect groundwater.

6.3.4.12 CA-12. Weather

Weather continues to be an important factor post closure. The most important individual parameter will be precipitation as it will directly influence the water balance for the site.

Closure plans should be designed and implemented to cater for storm events (most jurisdictions will require 1 in 100-year storm surges to be catered for, while some authorities will require 1 in 10,000 year). Therefore, the need to analyse weather post closure is less important than it would have been when the site was in operation, as the site should be capable of dealing with all weather scenarios without the need for additional preparations. Weather data is also important in a post closure scenario to assess revegetation factors, particularly in more arid environments. While the focus of this geoinformation requirement is to collect real time data, this data will be used to assess the influence of climate change and how this impacts on the closure and aftercare plan.

In a post closure scenario the main area of interest will be relating to the TSF and WRD's and any other remaining infrastructure. Therefore, the area of interest will be in the order of 1 km^2 to 10 km^2.

There are too many individual weather parameters to detail. Post closure precipitation is the key parameter - mm/day is the desired resolution. In a post closure scenario, access to daily weather data is sufficient.

6.3.4.13 CA-13. Pit water quality

As described in CA-11 pits will in some cases be partially filled with solid material or in other cases will be transformed into a pit lake.

Long term monitoring is needed to evaluate the water levels, water quality (e.g. turbidity, pH, salinity, metal concentrations, stratification, biogeochemical processes) and potential flooding risks during heavy rainfall or storm events.

6.3.4.14 CA-14. Impact on nearby industries (in particular agriculture)

Although the potential impact on nearby stakeholders will be much reduced than the risk during operations (i.e. groundwater level recovery, plant and mine air emissions cease), the risk of a closed mine impacting on stakeholders is a significant risk.

In relation to the two aspects given in the example (ground water and air emissions), although groundwater levels may have recovered the chemistry of that water could be problematic. In relation to air emissions; although the processing plant will no longer have point source emissions, nor will there be ventilation emissions from the mine or dust blow from the active pit – there is a significant risk of fugitive dust emissions from a poorly rehabilitated site (e.g. dust blow of waste rock dumps and tailings dams).

Depending on the climate, there may or may not be surface water emissions from the closed mine site. Where there are surface water emissions, these must be monitored at the agreed frequency for the specific parameters of concern into the closure and aftercare period.

A detailed programme of monitoring needs to be agreed with Regulatory Authorities to define the appropriate level of monitoring to ensure there is no impact on stakeholders. Where there is measured impact the mining company will be required to carry out remedial actions and/or compensate the affected party.

Ref.	Type of geoinformation	Current Techniques[7]	Area to be assessed / monitored	Minimum Measurement Resolution Required	Minimum Measurement Refresh Rate Required
CA-1	Demonstration of rehabilitation / revegetation	Fly over / Aerial photography / walk-over / Satellite imagery	1 km^2 to 10 km^2	Resolution to 1 m^2	Quarterly
CA-2	Characterisation of Flora and Fauna	Published reports / surveys	10 km^2 to 100 km^2	1 m^2 resolution	Monthly assessment over a 12-month period
CA-3	Soil Structure and Chemistry	Field work - core / surface sampling for chemistry	>100 km^2	Detection level required, reference - 'Dutch values' 10 m^2 assessment	Annual
CA-4	Demonstration of infrastructure removal	Fly over / Aerial photography / walk-over / Satellite imagery	10km^2 to 100km^2	Resolution of 1m^2 is required	Monthly
CA-5	Demonstration no impact on national heritage locations	Site assessment / Survey Fly over Engage with indigenous people	1 km^2 to 10 km^2	1 to 10 m^2 <0.5 m vertical	Annual

[7] See Appendix 1

Ref.	Type of geoinformation	Current Techniques[7]	Area to be assessed / monitored	Minimum Measurement Resolution Required	Minimum Measurement Refresh Rate Required
CA-6	Demonstrate no impact on SAC's (Natura 2000 sites)	Walk-over / physiochemical assessment / biological assessment	> 100 km^2	1 to 10 m^2	Annual
CA-7	Demonstration of return to baseline air quality - including deposition	Published data Sampling	> 100 km^2	Resolution for dust deposition should be 1 m^2	Monthly
CA-8	Farming activities - confirm return to baseline conditions for crops / animals	State Agencies Meetings with farmers and vets Campaign of monitoring	100 km^2 - 1,000 km^2	Various methodologies	Monthly
CA-9	Demonstration of return to baseline water quality	National Databases Field work	10 km^2 to 100 km^2	Minimum levels of detection as per 2008/105/EC	Daily
CA-10	Plume tracing of leaks or seepage (surface water / groundwater / soil)	Walk-over / Sampling Drone photography	10 km^2 to 100 km^2	The resolution should be to 1 m^2.	Monthly

Ref.	Type of geoinformation	Current Techniques[7]	Area to be assessed / monitored	Minimum Measurement Resolution Required	Minimum Measurement Refresh Rate Required
CA-11	Demonstrate long term structural stability of key infrastructure - WRD's / TSF's / Pit	Surveys InSAR Water sampling (open water and boreholes)	10 km^2 to 100 km^2	5-10 mm accuracy Water chemistry accuracy	Minimum annual Continuous would be optimum
CA-12	Weather	Onsite weather stations Government Weather sites Internet based weather providers	1 km^2 to 10 km^2	Various	Daily
CA-13	Pit water chemistry	Water sampling Visual inspection / Aerial photography	c. 1 km^2	Water chemistry accuracy will be dependent on the parameter in question. Visual assessment can assess for changes in colour of water	Quarterly

Ref.	Type of geoinformation	Current Techniques[7]	Area to be assessed / monitored	Minimum Measurement Resolution Required	Minimum Measurement Refresh Rate Required
CA-14	Impact on nearby industries (in particular agriculture)	State Agencies - Farming advisories services Meetings with farmers and Vets Campaign of monitoring	10 km^2 to 1,000 km^2	Various parameters.	Monthly

Table 6.4 – Geoinformation requirements for design, construction and operation.

6.4 Needs and Challenges

The following section refines the detail of chapter 6 into specific 'challenges' and 'needs' that the mining industry has with respect to geoinformation. The tables 6.1 to 6.4 itemise all the individual geoinformation requirements required for each of the phases of mining. In this section these requirements are grouped into collective challenges and needs.

Because the geoinformation requirements are grouped in this next section; there are fewer challenges than specific geoinformation requirements. For example; DO-7, DO-8 and DO-9 detail the requirement for infrastructural monitoring of Buildings, Railways & roads, and Port facilities respectively. While in this next section these are condensed into one 'challenge' and that is structural and stability monitoring. Therefore, because of the grouping, there are less challenges than geoinformation requirements.

To continue with the example for structural and stability monitoring challenge. There are a number of specific needs identified for this challenge and they include; what specifically needs to be monitored for stability, what is the frequency at which this monitoring is required and what is the accuracy of the measurement that is required (i.e. to how many mm of accuracy).

The first table lists all the challenges associated with each of the mining phases and the following table details the specific needs for each of the mining phases.

EO4RM CHALLENGES			
EXPLORATION	PERMITTING PROCESS	DEVELOPMENT AND OPERATIONS	SITE CLOSURE AND AFTERCARE
TOPOGRAPHICAL MAPPING	WATER CATCHMENT	MAPPING OF INFRASTRUCTURE	GEOCHEMICAL MAPPING
GEOLOGICAL MAPPING	SOCIAL / DEMOGRAPHICS	SITE LAYOUT DESIGN	ENVIRONMENTAL MONITORING
GEOCHEMICAL MAPPING	TOPOGRAPHICAL MAPPING	LAND OWNERSHIP MAPPING	GROUND STABILITY / GEOTECHNICAL GEOCHEMICAL MAPPING
MAPPING INFRASTRUCTURE	AIR QUALITY	AFFECTED LANDS STATUS	AFFECTED STAKEHOLDERS
LAND OWNERSHIP MAPPING	GEOCHEMICAL MAPPING	GROUND STABILITY / GEOTECHNICAL	WEATHER / CLIMATE
AFFECTED STAKEHOLDERS	FLORA AND FAUNA	STRUCTURAL STABILITY MONITORING	MAPPING OF INFRASTRUCTURE
WEATHER	RESTRICTED LANDS	STOCKPILE MONITORING	STRUCTURAL STABILITY MONITORING
ENVIRONMENTAL MONITORING	MAPPING OF INFRASTRUCTURE	AFFECTED STAKEHOLDERS	
	LAND OWNERSHIP	ENVIRONMENTAL MONITORING	
	LAND USAGE	ILLEGAL MINING	
	GROUND STABILITY / GEOTECHNICAL	WEATHER	
	SITE LAYOUT		
	WEATHER / CLIMATE		

Table 6.5 – EO4RM Geoinformation Challenges

EXPLORATION - NEEDS

TOPOGRAPHICAL MAPPING	GEOLOGICAL MAPPING	GEOCHEMICAL MAPPING	MAPPING INFRASTRUCTURE	LANDOWNERSHIP MAPPING	AFFECTED STAKEHOLDERS	WEATHER	ENVIRONMENTAL MONITORING
+ / - 1m CONTOUR ELEVATIONS	MAPPING SUBSURFACE STRUCTURES	DETERMINE CONCENTRATION OF DIFFERENT CHEMICAL ELEMENTS	REQUIRED TO ESTABLISH SITE ACCESS - ROADS / TRACKS	PERMISSION TO EXPLORE ON LAND	IMPACT ON NEARBY INDUSTRIES (IN PARTICULAR AGRICULTURE - (CROP GROWTH RATES etc.)	WIND SPEEDS / RAINFALL	ENSURE NO IMPACT TO FLORA AND FAUNA
LANDFORMS / FEATURES	DETAIL REQUIRED UP TO A DEPTH IN EXCESS OF 1,000m3	REQUIRED DETECTION RESOLUTION VARIES. (E.G. Fe ~45%, Au 5 PPM or g/tonne)	REGIONAL AND LOCAL MAPPING REQUIRED	MAY NEED TO ACCESS THIRD PARTY LAND TO GET TO EXPLORATION AREA		HOURLY FORECASTS	ASSESS ALL RELEVANT ENVIRONMENTAL ASPECTS (AIR / WATER / WASTE).
	RESOLUTION TO 30m. AREAS UP TO 10,000M2	MAPPING REQUIRED OVER AREAS RANGING 1KM2 TO 1,000KM2				3 TO 5 DAY OUTLOOK FORECAST	

Table 6.6 – EO4RM Exploration needs

PERMITTING PROCESS - NEEDS (table 1)

WATER CATCHMENT		SOCIAL / DEMOGRAPHICS	TOPOGRAPHICAL MAPPING	AIR QUALITY	GEOCHEMICAL MAPPING	FLORA AND FAUNA	RESTRICTED LANDS
SURFACE WATER CHARACTERISATION	GROUNDWATER CHARACTERISATION	POPULATION DEMOGRAPHICS	+ / - 1m ELEVATION CONTOURS	AMBIENT AIR QUALITY FOR CHEMICALS OF INTEREST	SURFACE AND SUBSOIL GEOCHEMISTRY	PLANT POPULATION - NUMBER / DIVERSITY / SEASONAL VARIATION	AREAS PROTECTED FOR ENVIRONMENTAL REASONS (SPA'S etc.)
SURFACE WATER CHEMISTRY	GROUNDWATER CHEMISTRY	LOCATION OF HOUSING	LANDFORMS / FEATURES	AIR EMISSIONS	CONCENTRATION OF ELEMENTS OF INTEREST (MINERAL TO BE MINED)	ANIMAL POPULATION - NUMBER / DIVERSITY / SEASONAL VARIATION	AREAS PROTECTED FOR CULTURAL REASONS
SURFACE WATER SEASONAL FLOW	GROUNDWATER SEASONAL VARIATION			SEASONAL TRENDS	10 - 100KM2, DEPENDING ON DISPERSION MODEL.	TYPICALLY 1 TO 10KM2, BUT MAY EXTEND BEYOND THIS.	NATIONAL MONUMENTS - PROTECTED STRUCTURES
ASSIMILATIVE CAPACITY FOR CHEMICALS OF INTEREST	ASSIMILATIVE CAPACITY FOR CHEMICALS OF INTEREST			AREA MINIMUM OF 10KM2			AREA TO MATCH THE AREA BEING DEVELOPED
SURFACE WATER SUPPLY POTENTIAL	GROUNDWATER SUPPLY POTENTIAL						
AREA 100KM2. REFRESH QUARTERLY.	AREA 100KM2. REFRESH QUARTERLY.						

Table 6.7 – EO4RM Permitting needs (table 1)

PERMITTING PROCESS - NEEDS (table 2)

MAPPING OF INFRASTRUCTURE	LAND OWNERSHIP	LAND USAGE	GROUND STABILITY / GEOTECHNICAL	SITE LAYOUT	WEATHER / CLIMATE
TRANSPORT LINKS TO THE PROPOSED SITE - ROAD / RAIL / SEA / AIR	MAP OF OWNERSHIP OF PROJECT LAND AND ADJACENT LAND	CURRENT LAND USAGE AROUND PROPOSED MINING AREA	GROUND GEOTECHNICAL - GEOPHYSICS / PROBE DRILLING	DETAILS OF ALL INFRASTRUCTURE LOCATION FOR PROJECT	WIND SPEEDS / RAINFALL
WATER SUPPLY		PRODUCTIVITY OF LAND (I.E. IF IN FORESTRY OR AGRICULTURE)	EVIDENCE OF KARST OR SINKHOLES		HOURLY FORECASTS
POWER SUPPLY		STRATEGIC PLANNING - IS LAND ZONED BY GOVERNMENT FOR SPECIFIC USE / DEVELOPMENT	AREA TO MATCH AREA BEING DEVELOPED AND OUTER EDGE OF CONE OF GROUNDWATER DRAWDOWN.		3 TO 5 DAY OUTLOOK FORECAST
SOCIAL INFRASTRUCTURE - HOUSING / MEDICAL / WELFARE					ASSESS POTENTIAL IMPACT OR (AND TO) CLIMATE CHANGE

Table 6.8 – EO4RM Permitting needs (table 2)

DEVELOPMENT AND OPERATIONS - NEEDS (table 1)

EXISTING INFRASTRUCTURE	SITE LAYOUT DESIGN	LAND OWNERSHIP MAPPING	AFFECTED LANDS STATUS	GROUND STABILITY / GEOTECHNICAL
SITE ACCESS	OPTIMUM LOCATION OF KEY INFRASTRUCTURE	LANDS OWNED BY THE MINING COMPANY	LAND DISTURBED BY MINING	GROUND STABILITY ABOVE MINE WORKINGS
ROAD INFRASTRUCTURE	WELFARE BUILDINGS	RIGHTS OF WAY ON THIRD PARTY LAND	DISTURBED LANDS THAT HAVE BEEN REHABILITATED	REGIONAL GROUND STABILITY
RAIL INFRASTRUCTURE	AREA 10KM2 - WEEKLY REFRESH (DURING DEVELOPMENT)	STATE OWNED AND PRIVATELY OWNED LAND IN PROXIMITY TO THE MINE	AREA 100KM2 - MONTHLY REFRESH	GEOTECHNICAL PROPERTIES OF GROUND IDENTIFIED FOR BUILDING INFRASTRUCTURE
PORT INFRASTRUCTURE		AREA 100KM2		DATA WILL BE REQUIRED IN ACCORDANCE WITH THE DEVELOPMENT SCHEDULE. QUARTERLY MEASUREMENT FOR SUBSIDENCE IS ADVISABLE.
AREA 100KM2. INITIAL ASSESSMENT - ANNUAL REFRESH IF REQUIRED				

Table 6.9 – EO4RM Development and Operation needs (table 1)

DEVELOPMENT AND OPERATIONS - NEEDS (table 2)

STRUCTURAL STABILITY	STOCKPILE MONITORING	AFFECTED STAKEHOLDERS	ENVIRONMENTAL MONITORING	WEATHER	ILLEGAL MINING
BUILDINGS STABILITY	ORE STOCKPILES	IMPACT ON NEARBY INDUSTRIES (IN PARTICULAR AGRICULTURE - (CROP GROWTH RATES etc.)	WATER EMISSIONS	WIND / RAIN / TEMPERATURE	MONITOR FOR INFORMAL SETTLEMENTS
TAILINGS DAM STABILITY	WASTE STOCKPILES	LOCATION OF OCCUPIED DWELLINGS (DISTURBANCE AND EMERGENCY PLANNING)	AIR EMISSIONS	HOURLY FORECAST	MONITORING FOR SIGNS OF ILLEGAL MINING - PLANT / MATERIAL / PEOPLE
PIT SLOPE STABILITY	RAW MATERIALS STOCKPILES	AREA 100MK2, REFRESH RATE OF QUARTERLY (SEASONAL)	MONITORING PERFORMANCE OF COVER MATERIAL (e.g. WRD COVER)	3 - 5 DAY OUTLOOK	AREA TO BE MONITORED IN THE ORDER OF 10KM2
WASTE ROCK DUMP STABILITY	ANIMAL POPULATION - NUMBER / DIVERSITY / SEASONAL VARIATION		PIT WATER VOLUME AND CHEMISTRY		REFRESH RATE OF WEEKLY
INFRASTRUCTURE STABILITY (PORT / RAIL / ROADS)	AREA - 10KM2.		PLUME TRACKING (SPILLAGE / SEEPAGE / AIR EMISSION)		
AREA TO BE ASSESSED RANGES FROM 10K2 TO 100KM2	MEASUREMENT MINIMUM <0.5M		NOISE AND VIBRATION MONITORING		
ACCURACY MUST BE AT LEAST 0.5M (FOR DAM STABILITY ACCURACY MUST BE 5 TO 10MM)	MINIMUM MEASUREMENT FREQUENCY IS MONTHLY - OPTIMUM IS DAILY.		WASTE STORAGE		
MINIMUM MEASUREMENT FREQUENCY IS ANNUAL, OPTIMUM FROM DAM AND WRD IS DAILY.			AREA UP TO 100KM2. OPTIMUM IS DAILY REFRESH.		

Table 6.10 – EO4RM Development and Operation needs (table 2)

CLOSURE AND AFTERCARE- NEEDS

GEOCHEMICAL MAPPING	ENVIRONMENTAL MONITORING	GROUND STABILITY / GEOTECHNICAL	AFFECTED STAKEHOLDERS	WEATHER / CLIMATE	MAPPING OF INFRASTRUCTURE	STRUCTURAL STABILITY
SURFACE AND SUBSOIL GEOCHEMISTRY	AMBIENT AIR QUALITY - IN PARTICULAR FOR ELEMENTS THAT WERE MINED (DETERMINE IF THERE ARE FUGITIVE EMISSIONS). PLUME TRACKING	MONITOR AND TREND GROUND MOVEMENT (IN PARTICULAR AROUND AREAS THAT WERE MINED).	MONITORING PRODUCTIVITY OF STAKEHOLDERS - E.G. NEARBY FARMING OR FORESTRY -	WIND SPEEDS / RAINFALL	DEMONSTRATE ALL INFRASTRUCTURE ASSOCIATED WITH MINING IS REMOVED	DEMONSTRATE STABILITY OF ALL RETAINED INFRASTRUCTURE (E.G. TAILINGS DAMS / WASTE ROCK DUMPS)
MONITOR CONCENTRATION OF ELEMENTS OF INTEREST (MINERAL THAT WERE MINED MINED) IN SOIL AND SUBSOIL	SURFACE WATER QUALITY - IN PARTICULAR FOR ELEMENTS THAT WERE MINED (DETERMINE IF THERE ARE FUGITIVE EMISSIONS). PLUME TRACKING	5 - 10 MM ACCURACY REQUIRED	MONITOR AVAILABILITY OF RESOURCES THAT MAY BE REQUIRED BY STAKEHOLDERS - SURFACE & GROUND WATER SUPPLY.	HOURLY FORECASTS	MAP OF RETAINED INFRASTRUCTURE	5 - 10 MM ACCURACY REQUIRED
DEMONSTRATE THAT CONCENTRATION OF CHEMICAL ELEMENTS WILL NOTE CAUSE AN IMPACT (WILL VARY BY ELEMENT)	GROUND WATER QUALITY - IN PARTICULAR FOR ELEMENTS THAT WERE MINED (DETERMINE IF THERE ARE FUGITIVE EMISSIONS). PLUME TRACKING	MINIMUM QUARTERLY MEASUREMENT (IDEALLY DAILY / CONTINUOUS)	DEMONSTRATE NO IMPACT ON NATIONAL MONUMENTS OR PROTECTED AREAS	3 TO 5 DAY OUTLOOK FORECAST		CONTINUOUS MONITORING
ALLOW COMPARISON BETWEEN SOIL CHEMISTRY IN MINED AND NON-MINED AREAS	FLORA & FAUNA - MAPPING OF PLANT GROWTH / AREA OF VEGETATIVE COVER - MAPPING OF ANIMAL POPULATIONS			UNDERSTAND CLIMATE CHANGE RISK AND HOW THEY AFFECT CLOSURE PLAN (E.G. DROUGHT CAUSING DIEBACK OF VEGETATION OR FLOODING / STORM DAMAGE RISK)		

Table 6.11 – EO4RM Closure and Aftercare needs

Each of the phases of mining has its own individual challenges. However, there is quite a lot of overlap and in most instances the measurement technique used to acquire data for the challenge in one phase of mining will be an acceptable technique to acquire data for the challenges within the other phases of mining (where there are overlaps). The following matrix summaries the overlap of geoinformation challenges.

	TOPOGRAPHY	GEOLOGY	GEOCHEMISTRY	MAPPING INFRASTRUCTURE	WEATHER / CLIMATE	WATERCATCHMENT	AIR QUALITY	LAND USAGE	FLORA & FAUNA	RESTRICTED LANDS	SITE LAYOUT	LAND OWNERSHIP	AFFECTED LANDS STATUS	SOCIAL / DEMOGRAPHICS	GROUND STABILITY / GEOTECHNICAL	STOCKPILE MONITORING	AFFECTED STAKEHOLDERS	ENVIRONMENTAL MONITORING	ILLIGAL MINING	STRUCTURAL STABILITY MONITORING
RAW MATERIAL RESOURCE IDENTIFICATION AND QUANTIFICATION	■	■	■	■	■							■					■	■		
PERMITTING PROCESS	■		■	■	■	■	■	■	■	■	■	■		■	■					
DEVELOPMENT AND OPERATIONS				■	■						■	■	■		■	■	■	■	■	■
SITE CLSOURE AND AFTERCARE			■	■	■	■									■		■	■		■

Table 6.12 – EO4RM Matrix of geoinformation needs for different phases of mining

6.5 Geoinformation requirement and use by entity type

6.5.1 Exploration company

The Exploration phase of mining is essentially all about data (or geoinformation). The exploration company may be involved in a specific mineral type (or types) and will understand the places of the world where the mineral is most prominent. Commercial aspects may drive the minerals that the exploration company is most focused on as the outlook for different commodities will vary and the exploration company will want to focus its exploration into commodities (or minerals) that have a favourable price outlook.

The initial assessment will be in relation to what specific country the exploration company is interested in and the geoinformation that will be first assessed will typically be those data that are already available from the government or other entities (e.g. geological surveys). This initial assessment will be a desktop exercise and may form part of an application for a permitting licence.

The type and detail of geoinformation then required will depend on the area in question. For example if the area of interest has already been flown for geophysics and this data has been accessed and reviewed it is likely the exploration company may wish to engage in on the ground exploration activities (as per table 6.1).

Data / geoinformation quality is key for exploration companies as they must ensure their data will be compliant with various mineral classification codes (e.g. the Canadian CIM (Canadian Institute of Mining) or the Australian JORC (Joint Ore Reserves Committee Code).

Additional detail is available in section 6.3.1 and table 6.1.

6.5.2 Construction companies.

Construction companies will be engaged to develop mines and mining infrastructure. The typical geoinformation that is required for any construction job will be required by a construction company developing a mine. Details around site layout, access to site and in particular geotechnical information will all be required by construction companies. Some of this data will be available via government resources but much of the data will need to be gathered directly by the construction company, who will need to carry out survey and geotechnical assessments and complete detailed drawings for all aspects of the job.

In this report the construction element was linked to the operation element and additional detail is available in section 6.3.2 and table 6.2.

6.5.3 Mine operators

Mining is a very dynamic activity with a lot of change; changing weather, changing ground conditions, changing grade etc. and as such it is vital that up to date accurate measurements are available to allow the miner assess performance and plan production. The data that is required is for the most part the data that that is detailed as the geoinformation described in section 6.3.2 and listed in table 6.2.
In addition to operating the mine, the mine operator will also be involved in near mine exploration and will always have to have one eye to the planned closure of the operation. So mine operators will often be involved in 3 of the 4 phases of mining at any one time.

The exploration arm of the mine operator will require the associated geoinformation for green field operations. The likelihood of finding ore is always higher near to a location where there is already mineralised material hosted, so exploration will also take place by drilling additional exploration holes from within the mining workings, which requires less geoinformation than a green field exploration site.
As well as being involved in planning for closure and gathering the necessary information, the mine operator will also often be involved in implementing progressive closure works.
Aftercare will most likely be commenced by the mine operator, however this phase may pass on to a new entity on sale of the land post completion of the closure plan.

6.5.4 Government Authority / Agencies

Government authorities have a requirement to permit and oversee compliance of exploration and mining companies and must assess significant amounts of geoinformation when completing their role. As well as interacting with companies who have an interest in raw materials within their jurisdiction, government authorities and agencies, such as Geological Surveys, will have their own objectives and work programmes to complete and will carry out their own work to achieve these programmes, much of which will require geoinformation.

One area of work for most Geological Surveys is in relation to the publicising of information related to the geology and mineral resource of the country in question. In many instances the Geological Survey will gather their own data that evaluates and describes the country’s geology. A current example of such an activity is the ‘Tellus’ survey programme, which is an initiative by the Geological Survey of Ireland (GSI). The Tellus survey is a national programme that has an objective to gather geochemical and geophysical data across Ireland. Tellus involves two types of surveying, both airborne geophysical surveying using a low-flying aircraft, and ground-based geochemical surveying of soil, stream water and stream sediment. Product development is undertaken under five main themes, which are: mineral prospectivity, smart agriculture, environment and health, climate action and education. The GSI are gathering large amounts of geoinformation to develop these products.

When it comes to permitting and overseeing exploration and mining companies, in many instances the government authority will rely on the exploration and mining companies to supply the information. The government authority will have competent employees retained to review and assess this information. The government authorities may also engage external consultants with specific expertise to assist with the assessment of submitted information and these external consultants may also gather independent information.

6.5.5 Consultancies

Consultancies develop specific expertise and niche skills that are not always possible to develop within individual mining companies or government agencies.

Tables 6.1 to 6.4 describe types of geoinformation that is required for the various phases of the mining cycle. To acquire much of this geoinformation specialised knowledge and specialised equipment is required (for example geophysics for exploration construction). This equipment is often expensive and will need to be replaced frequently as technology advances. In many instances the mining or exploration company will only want this geoinformation on an ad-hoc basis and could not justify retaining the equipment and the people needed. Consultancies can justify the cost of purchasing, maintaining and replacing this equipment and retaining the expertise to operate the equipment. These consultancies will go from operation to operation as and when they are required. Larger mining and exploration companies may be large enough to have a central area of technical expertise and retain people and equipment to serve individual operational sites, but this is not very common and is becoming less common.

It may be of value for the mining company to have independent consultants gather some of the data as it may be sensitive and outside agencies may be more inclined to believe an independent consultant – this can relate to sensitive information about environmental impact or it may relate to calculations of ore reserve which would be very sensitive from a company valuation perspective.
Consultants essentially have a requirement for all of the geoinformation parameters detailed in tables 6.1 to 6.4, as consultancies are likely to provide their services to various parties involved in all phases and all aspects of mining. Mine operators will use consultants and the extent of their used will be based on a number of factors, namely:

1. Is the mine required by government or another regulator to used third party consultants?
2. Is it more cost effective to use consultants?
3. Is it the case that the mine does not have the expertise or equipment to gather the geoinformation and therefore must use the consultant?

As already described, consultancies will not just provide geoinformation to mining companies but will also work with and provide geoinformation for other entities such as government authorities. The extent to which they are used by other entities will be similar to the rationale that applies to mining companies – although a lack of expertise and specialist equipment are thought to be the main reason why other entities will retain consultants.

6.5.6 Academic / Research

Research is critical to advancing the extractive industry. While the large mining companies will have their own research sections, much of the fundamental research takes place at university level. Many research programmes in universities will be independent, while other programmes will be sponsored by companies working in the mining industry but will work independently and many will work on research. In many ways academic research serves a similar function to the consultancies described in 6.4.5 although they will be less driven by the financials.

Research takes place across all phases and aspects of the mining industry. From research into better ways of identifying and exploring for minerals to better processing technologies with increased mineral recovery, to study of the environmental consequences of mining both during operation and closure. The various branches of research are too vast to document in this report. An example of fundamental research taking place in the mining section is iCraig, the Irish Centre for Research in Applied Geosciences. iCraig is situated on the campus of University College Dublin and is Ireland's national geoscience research centre and has a mission is to transform Irish geoscience by driving research and discovery, delivering economic and societal benefit, and advancing public understanding. Comprising 150 researchers, seven research institutions and collaborating with more than sixty industry partners, our vision is to be a world leader in applied geoscience research, discovery, and public understanding of earth's critical resources and environment for a sustainable society. iCraig's multidisciplinary research transcends industry and academic boundaries to address key research challenges in the fields of energy security, raw materials supply, groundwater protection, safeguarding the geomarine environment and protection from the Earth's hazards.

Similar to consultancies academic research will be involved in essentially all of the geoinformation parameters detailed in tables 6.1 to 6.2 and they will have a required to gather information in all of these areas.

6.5.7 Legal / Regulatory requirements going forward and implications for geoinformation

The regulatory environment for the mining industry has become more and more onerous in recent decades due to poor practice and harm caused by the mining for raw materials.

In Europe specific legislation has been issued which places challenging requirements on mining companies and member state regulatory authorities who permit mining operations. An example of this is Directive 2006/21/EC, which provides a framework for the management of waste from mining industries. Commonly referred to as the 'Mine Waste Directive', this directive is very comprehensive and covers all aspects of management of mining related waste.

Environmental emissions legislation has become increasingly challenging and while this legislation is of great benefit to society, it does mean significant additional costs for mining companies to manage their operations, their risks and their emissions. In most instances, companies will need to complete more assessment of the receiving environment so there is a greater understanding and potential impact can be adequately assessed. In many instances this will result in a requirement for additional controls.

Health and safety, including occupational health standards, have continued to improve, particularly in more developed countries. European legislation has become more challenging in recent years, an example of this is the limits that were introduced for nitric oxide. While not a challenge for many workplaces it has proved very difficult for underground mines to manage their mobile plant that operated in confined space with restricted fresh airflow because of the restricted airflow, meeting the limit for nitric oxide in the workplace is difficult (note that the mining industry has secured a time extension for compliance with nitric oxide limits (to August 2023) – but this challenge is not going away and the industry in Europe will need to find a solution).

In some jurisdictions outside of Europe the legislative requirements are not as burdensome, but it is perhaps only a matter of time before these jurisdictions also become more draconian in their oversight of mining companies.

Mining companies themselves are also driving the improvement in standards. Particularly the major mining companies, many of which are public companies, are more aware of their responsibility to operate sustainably. In many developing countries where the major mining companies operate, the company will ensure it meets its own corporate guidelines on sustainability, even if these are more stringent than local laws. Recent high-profile failures within the mining industry (for example the recent failure at Brumadinho in Brazil) place more pressure on regulators and mining companies to ensure adequate controls are in place to manage risk.

These increasingly stringent operating standards will require additional geoinformation to be gathered by mining companies, both during the development phase to better understand the baseline conditions and set appropriate emission limits. Additional geoinformation will also be required during the operational phase to gain early warning of potential failures so preventative action can be taken. This additional geoinformation will also monitor emissions and ensure there is no impact on the environment or local stakeholders. As previously discussed; closure and aftercare have become more important phases of the mining cycle and mine operators will have ever more demanding requirements to meet in order to demonstrate that the operations have been successfully rehabilitated and are not causing any impact on the environment.

7 Geoinformation barriers and opportunities for improvement.

Recent years have seen major developments in gathering geoinformation for the mining industry. Sensors are becoming smaller and more powerful and, in many cases, more affordable. The means of deploying sensors into the field is becoming more flexible and attainable with advancements in drone technology and reductions in costs to get satellites into orbit. Software development means mining professionals can do more with the data when they get it. It is now possible to produce 3-D maps that can display an animation of the complete mining sequence. Modelling software is also becoming more powerful and provides benefits across all phases of the mining cycle from interpolating exploration data to optimise the mining resource, to stability modelling of dams and rock dumps, to modelling surface and ground water recoveries post closure of the mine.

While there have been advancements in the technologies and techniques used for collecting and analysing geoinformation, constraints remain. In many instances it is the introduction of the new technologies that also introduce constraints, for example the cost of the new technology. The following section details some of the key aspects of geoinformatics that can be a constraint or an opportunity for improvement.

7.1 Cost

Mining is a commercial endeavour, most mining and exploration companies have shareholders and must be able to minimise costs in order to deliver a financial return, while operating a safe and sustainable business.

There are two aspects to be discussed with respect to geoinformation cost and they are:

- The actual cost of attaining the geoinformation, and
- How comprehensive geoinformation can reduce operating costs.

7.1.1 Cost of attaining the geoinformation.

The significance of the cost of attaining geoinformation can depend on the phase of the mining cycle, as geoinformation will represent a different percentage of the total budget depending on the mining phase. During the exploration phase the majority of the costs for the operation will relate to geoinformation, as exploration focusses on acquiring and interpreting data to identify and quantify a potential orebody. Geoinformation is fundamental to completing this work. Whereas during the operational phase, the cost of geoinformation will be very low when compared to other operating costs such as power, labour etc. with respect to other mining costs. Therefore, it is more likely there will be greater focus on costs and reducing costs for those geoinformation techniques that are used during the exploration phase (similar applies to the aftercare phase, where gathering and assessing monitoring data is the key activity).

New technology will generally cost more given the cost incurred by the developers to bring the technology to market and as such the mining company will need to decide whether or not it wants to invest in the new technology. Equally the cost of new technology does also reduce as more competitors enter and compete for market share. Providers of geoinformation products to the mining industry must at all times assess the cost and margin of their product against the volume of sales, to decide the optimum pricing and marketing strategy.

So, while the cost of new geoinformation technology is an inevitable constraint to mining companies, in reality normal market forces will apply resulting in opportunity to invest at some point. The question for the mining company is when do the benefits to adopting the new technology outweigh the direct and indirect costs (e.g. training costs).

7.1.2 Reduce operating costs by using good quality geoinformation.

A large part of the rationale that a mining company will use when assessing new technologies is not just how will the new technology improve the process but how will it reduce operating costs.
New technologies offer significant opportunities for improvement on costs. For example; portable XRF technology has resulted in significant cost saving on laboratory costs. So not only will an exploration company get quicker results, it will get these results at a lower cost. However, it is not as simple as this either because although quick, low cost results are a positive factor, the quality and reliability of these results also needs to be considered. Portable XRF units will give a good indication but will not be as reliable or precise as fixed, calibrated lab equipment in a controlled environment. This will be discussed further in this section.

Earth Observation has also resulted in cost saving and offers significant opportunity for additional cost saving. It is now possible to complete the initial detailed screening of prospective exploration areas remotely by scanning and this saves significant costs associated with mobilising ground personnel and means that people and equipment are only mobilised into the field when there is some level of confidence that a mineral resource will be found. EO is still a relative new technology for exploration and opportunities for improvement will arise.

Savings can also be achieved by the prevention of loss associated with failures. For example, the cost of a tailings dam failure can run into billions and along with many fatalities, can bankrupt a mining company. Having an effective monitoring programme in place can provide early warning and critically allow a company to take action, which can prevent a potential failure from occurring or minimise the impact associated with a failure (if it can't be prevented). Traditional methods of monitoring for stability of tailings dams are limited and typically measurements are only possible at a limited number of monitoring points and the refresh rate for data is restricted due to the time it takes to complete monitoring. Continuous assessment of dams using InSAR can potentially provide an operator that critical early warning to prevent the loss and this is certainly an area of opportunity for geoinformation use.

Improving geoinformation by producing more data and organising / processing that data so that it can be interpreted quickly and effectively will result in savings and improvements. Information is fundamental to successful management – to quote an old business adage; 'If it can't be measured, it can't be managed'. Advancements in attaining geoinformation, provides the measurement information that allows the mining industry mange its operations more effectively.

7.1.3 Technical skills / knowledge needed to operate technology

Geoinformation for the mining industry is very specialised. Most of the techniques that are needed to gather and interpret mining geoinformation require specialist equipment and specialist training. The availability of trained people and equipment can be a constraint. This is inevitably a problem during periods of high metal prices when the industry is thriving, sourcing skilled people is often the main challenge for mining companies at that time.

Mining institutions and colleges stay up to date with developments in technology and include these new technologies and techniques in their syllabi and this continues to be the case. Specifically, in relation to geoinformation, mining colleges need to ensure that they include the developments in all areas, including remote earth observation to ensure that future mining professionals are aware of and proficient in, the various techniques that are available.

Developing tools to improve the ease with which geoinformation data can be used must advance at the same pace as the measurement techniques advance. For example; software is vital to process the vast amounts of data that is collected in order to produce concise reports that can be used to make decisions. Developing affordable software packages that are intuitive to use is vital to maximising the value from geoinformation.

A challenge and constraint for the mining industry is an adequate supply of skilled people. While, as already stated, new technologies will require skilled operators it is also the case that these new techniques for gathering and processing geoinformation can offer improvements from a skills basis. For example, the process of surveying an area of interest using traditional techniques such as a theodolite and a ranging pole can take a number of people a long period when a large area is required to be surveyed. However, one person can potentially take satellite data to produce a detailed topographical map for the same area – the larger the area the greater the potential value. Therefore, new technologies can meet the constraint of a lack of skilled people in the mining industry, even if it is just a reduction in the number of skilled people that are required.

Most errors are caused by people, and this is a primary reason why skilled people are required. However, even skilled people can make mistakes and cause an error, for example the person may not correctly set up or operate an instrument. Therefore, the less people that are involved in the process the less likelihood of error. Technology offers the possibility of reducing the number of people needed to collect and process information, as per the example provided earlier of traditional surveying versus using satellite data (notwithstanding the need for the layers of checking that will be required regardless of what techniques is used, i.e. even if you reduce the number required for a process to one person, it is still important that the work is checked).

7.1.4 Data Quality - Accuracy / Precision

Data quality is important in relation to geoinformation, as without good data quality the data is useless. Accuracy refers to the closeness of a measured value to a standard or known value. For example, if a concentration of a mineral is 0.5%, and you measure 10%; your result is inaccurate. Precision refers to the closeness of two or more measurements to each other. To continue with the example; even though 10% is an inaccurate result, if you measure 10% successively with multiple measurements then your measurement is very precise.

The object is to have results that are both accurate and precise.

Data quality is not a significant constraint as techniques have been developed and proven to be robust over the years. Provided the mining company is prepared to invest enough time and money in the work it is possible to produce good quality data. However, there is opportunity to develop techniques that can produce the same quality of data but at a lower cost and a shorter period of time. Earth observation techniques can help to fill this gap. Extensive cross checking with traditional and proven techniques will be needed to validate the new methods in order to develop confidence and acceptance by the regulators.

As described in section 7.2, skilled people and calibrated equipment are required to produce good data and, in most instances, it is the human factor that is the cause of error. Moving to more automated systems such as earth observation, may offer an opportunity to further improve data quality.

7.1.5 Sensitivity / Limit of detection

With all geoinformation measurements there is a certain level of detail that is required. This can also be thought of as the sensitivity of the measurement method. In some instances, it is not possible to measure with the required resolution and in this instance, there is no value in using this information or persisting with the measurements.

The limit of detection is the level below which the measurement cannot be made with any level of confidence. Below the limit of detection both accuracy and precision will suffer.

Although it depends on the application, for the most part, the better the sensitivity the more useful it is for mining and exploration companies. Measurement techniques must be able to measure to the level of detection required for the application or else there is no value in taking the measurement. For example, when carrying out surveys to assess structural stability of roads the surveyor might have a tolerance of 50 mm. Whereas when measuring the stability of a tailings dam or pit wall the tolerance may only be 5 to 10 mm. Therefore, the measurement technique needs to be able to measure a position to within 5-10 mm in each axis.

7.1.6 Temporal resolution

Temporal resolution is a measure of how frequently a measurement is refreshed. As per the tables 6.1 to 6.4, temporal resolution is more important for some geoinformation that it is for others. For example, in relation to exploration, many of the measurement parameters are quite stable and it is not necessary to repeat measurements. Whereas for other areas frequent monitoring is more critical.

An example where improvement is possible is monitoring of structures and in particular tailings management facilities, WRD's and ore stockpiles, where it would be advantageous to have monitoring daily or as close to continuous as possible.

As described in this report, it is still very expensive to put satellites into orbit but there are advancements in this regard as satellite technology is allowing smaller units to be produced. Additional satellites can mean improved temporal resolution as a number of satellites scan different parts of the globe at the same time and work together to produce more frequent updates.

7.1.7 Spatial resolution

Spatial resolution relates to the area over which a measurement is taken, or geoinformation is sourced. In many instances it is necessary to collect geoinformation over wide areas of land, for example when carrying out initial regional exploration work to source prospective areas it is necessary to carry out an assessment of thousands of hectares. Significant developments in Earth observation techniques is making the initial exploration of large areas more efficient and economical for mining and exploration companies. Improvements have been made in relation to hyperspectral imaging, making anomalies, that might be indicative of mineralisation, easier to locate.

7.1.8 Artificial intelligence

The use of artificial intelligence in the attainment and processing of geoinformation is a very recent area of development. The term geospatial artificial intelligence, or geoAI, has been coined to reflect the use of artificial intelligence (AI) in geoinformation.

There are both challenges and opportunities to the use of AI for geoinformation. Key areas of focus include urban and land use dynamics, where the explosion of data has led to a call for better techniques to address challenges in the field.

One challenge is to develop automated map readers using deep learning techniques that can separate textual information, such as names of places, from map features, including contours. The development of optical character recognition (OCR) allows map readers to understand variation between types of information, such as textual and graphic-based, so that they can be separated and interpreted together, such as naming of features.

Another area of focus and development is on enhancing low resolution imagery, so that these images can be used for additional interpretation. The use of convolutional neural networks (CNNs) has been extended to low resolution satellite imagery and it has been shown to improve feature identification as low resolution data could be enhanced with basic input in different spectral bands. This allows such approaches to possibly address the limitation of earlier satellite systems, such as the early Landsat systems, to be enhanced and better utilised for long-term land use change.

8 Conclusions and recommendations

All phases of the mining cycle are very dependent on information. The mining industry has established means of gathering the data that it requires to carry out its business. However, techniques for attaining geoinformation for the industry are continually improving and this is expected to continue. As opportunities for improvement or new needs arise it is expected that services providers will come up with solutions to meet these needs.

EO technology has been an area of development in recent decades and is likely to continue to advance. Exploration companies have used magnetic sensors for many decades, traditionally by aerial assessment (planes), which has been used to map large areas of land and identify anomalies.

At this time EO technology is mostly being used by specialised consultants who advise the mining industry and the major and mid-tier mining companies. EO is not being used as much as it could by the junior mining and exploration companies and improvements in education and costs are required to advance the usage within this cohort.

While EO ultimately offers cost savings to mining companies it is still a young industry and can be expensive. Major mining companies can afford to try new technologies in the knowledge that they will have the back up of existing technologies in the event there is any difficulty with the new technology. A junior company will need to choose its technology carefully as it may not have the flexibility to change and is unlikely to be to afford to run dual programmes. Stakeholders and in particular regulators will need to be provided with evidence that the technology is robust and reliable.

Drone technology has been an area of major development in recent years and looks likely to continue evolving. Drone technology offers an introduction to EO to source geoinformation for exploration and mining companies. Drones are now more stable and powerful and able to carry large payloads, which facilitates sensor development, with multiple functionality.

Although sensors are in fact being reduced in size, they are also becoming more powerful. Optical image resolutions have been, and are continually being, improved with high definition and then ultra-high definition and this is expected to continue. Hyperspectral images are now being captured and these images allow more information to be gathered within a tighter wavelength. Depending on how this raw data is processed it can reveal details and anomalies in the Earth that is extremely useful to mining companies.

The software that is being used to process the raw data is becoming more and more sophisticated and artificial intelligence is an area that is set to bring further advancements. AI may provide a solution to allow efficient interpretation of the large amounts of data that are associated with geoinformation. AI may also maximise the amount of usable data that can be gleaned from geoinformation and in particular the reprocessing of historical data.

As with all new technologies there will be early adopters. The challenge for service providers is to develop their product such that it offers, at the right price, the improvements that the industry wants. It is important that the service providers engage closely with the mining industry to ensure that their needs are correctly identified and addressed.

Although satellite data is being used by the mining industry to attain EO data it is concluded that it is being underutilised. The primary reason for this underutilisation is concluded to be a lack of awareness of the technology and its capabilities, a fear the possible costs that may be involved (without appreciating the cost savings that may be realised) and finally the usual 'fear of change' that is not just specific to EO satellite data but is a general reluctance to change which is part of the psyche of most people.

There is a poor legacy associated with mining across the world and while there have been improvements in recent decades, major failures continue to occur. Good geoinformation is fundamental to managing risk and preventing failures. Regulatory authorities are requiring the acquisition of high-quality data at all phases of a mining operation in order to identify and manage risk. EO data potentially has a major role to play in this, but the regulators will need to be assured of the reliability of the technology.

EO can provide a continuous flow of information for the management of subsidence, mapping, geology, biology, ecology, socio-economic development and can also provide data from very remote areas, to a higher quality and lower cost than ever before. However, as with any technology, there is scope for significant improvement in the quality and coverage of the data to assist in the discovery, operation and closure of mining operations.

The current problem is access to high quality data, cost of data and need for specialist people for data management, both with mining companies and with regulators. EO providers must engage closely with both mining companies and regulators to ensure that technologies advance in line with the requirements of the industry. Furthermore, EO providers must work with industry to educate them on new technologies and to ensure that employees have the requisite skills to effect the change.

This report does not make specific recommendations as this report is only the first phase of the EO4RM project, which provides the base for rest of the work to be completed. This report and, in particular the information included in chapter 6, will be used by the EO4RM team to identify gaps in relation to the use of EO and especially the use of satellite technology to gather geoinformation for the mining industry. This work will be presented as part of the ongoing EO4RM project.

9 EARSC portal

9.1 Introduction

The European Association of Remote Sensing Companies (EARSC) is a member based European non-profit organization that promotes the use of EO technology and especially the companies in Europe which offer EO-related products and services. The objective is to increase awareness, reinforce members´ products and services, support identification of new business opportunities and facilitate networking with other players in the sector. EARSC strives to provide a rich source of information about the sector and the products on offer; and provide facilities to enhance information exchange between service/product suppliers and potential customers through dedicated EO Forums in EARSC EO Portals.

9.2 Objective of the working space

One such dedicated EARSC Portal was set up within the framework of the best practise ESA project EO4OG, which serves as a template project to this project, to provide the project context as well as an exhaustive list of identified challenges specific to the Oil & Gas sector and link those to identified, mature EO Services and Products. This portal was designed to inform interested parties about the identified EO services out there and provide all necessary detail required to evaluate the applicability to the data & information needs of those parties. It further serves to allow interested parties to review and validate the identified user requirements (geoinformation needs).

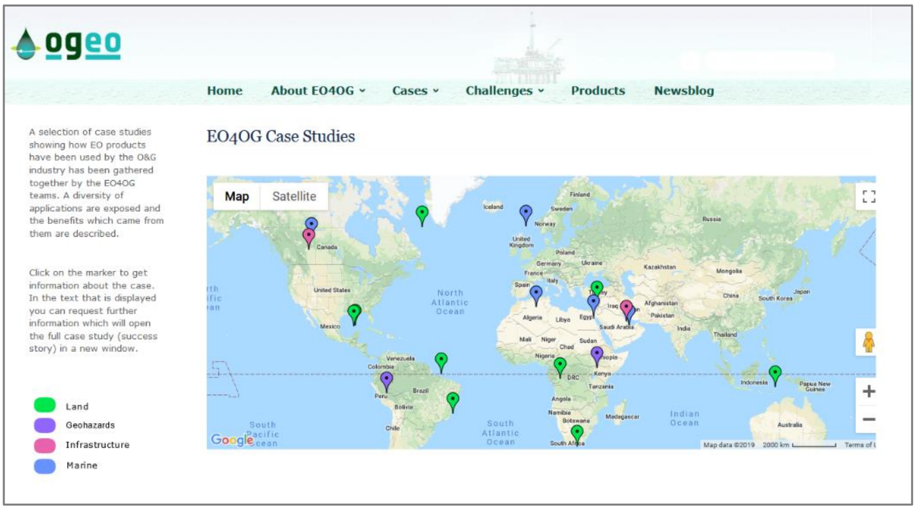


Figure 32 – Screenshot taken from EO4OG portal.

A similar, though somewhat more dynamic, portal will be set up for the EO4RM project to list and link the identified geoinformation needs along with their associated EO Services and Products. At the time of writing, the consortium is close coordination with EARSC to establish the EO4RM portal and design it in a way most suitable for navigation by Mining specialists and regulators rather than EO experts. The design will focus on easy and logical navigation for the intended users to support quick access to the desired information. The portal shall also facilitate the exchange of information between potential customers from the mining industry and the service providers of the EO solutions. Emphasis is put on a modern look and feel for comfortable navigation.

Appendix 1 – Current methods used to gather geoinformation in mining

This appendix provides detail on the current techniques used by the mining industry to gather geoinformation, as listed in the tables in section 6.3.

- Aerial Photography

Aerial photography is essentially taking photos from the air. The technique has been available for many decades. The area of development has been in the vehicle used to transport the camera into the air and also in the increased resolution of the photos that are now available.

In addition to an increase in the resolution (or dots per inch) there have also been advancements in the technology used to analyse the data collected. Analysis of hyperspectral images and stereo-images has resulted in much greater interpretation and value. Hyperspectral imagining requires the collection and processing of information from across the electromagnetic spectrum, not just the visible range. Spectral imaging divides the spectrum into many more bands other than visible allowing much more detail to be attained and interpreted.

With respect to the vehicles used to transport the camera into the air. Traditionally airplanes and helicopters were used but this is being enhanced and replaced by the use of drones and satellites. Drones offer great flexibility and the ability for 'non-pilots' to take photos. Anyone who has access to a drone, with a small amount of training, can immediately produce high quality digital aerial images. Satellites offer very wide field of view. Satellites also offer the advantage of having a bank of historic data that can be accessed.

- Agricultural assessment

Mining can impact on agriculture. For example, dewatering activities can impact on water supply for farmers, and air emissions of potentially harmful chemicals could impact on the growth / health of crops or animals.

Various metrics are available to measure performance of crops and animals. For animals it can be as simple as weight gain per day or can include specific detail of the health of an animal, metal concentration in blood and the function of various organs (measured indirectly by measuring specific proteins in blood).

Crop performance can be established by measuring dry matter yield after harvest. For a real-time assessment of crop performance, aerial photography can be used to establish the density of growth. Normalized Difference Vegetation Index (NDVI) uses multispectral satellite data to measure plant growth. It is based on the principle that plants reflect near-infrared light but absorb visible light during photosynthesis, calibrated results can be used to establish vegetation growth and overall biomass. To assess if a mine is having an impact it is possible to track pre mining agricultural performance (completed as part of baseline studies) to the performance recorded while the mine is in operation. Or in the event that there is no baseline it may be possible to compare the area within the zone of influence against government issued data or the mine can carry out an assessment of similar land that is outside the zone of influence of the mine and this land can be a control that is used to assess the performance of near mine lands.

- Air quality monitoring techniques

Air quality monitoring looks at the quality of the air and what contaminants are in suspension within the air column. Air quality monitoring also looks at the impact of fallout of particulates on the ground. The quality of the air column is generally referred to as 'ambient air quality', while the measurement of the material that falls out of the air column is referred to as dust deposition (note that dust deposition directly affects soil quality).

Techniques for measuring ambient air can be optical or gravitational Optical techniques transmit beams across the area of interest and a detector at the opposite side will collect the transmitted light and interpret the data to establish levels of contamination based on absorption at certain frequencies – a drop in intensity would be due to scatter from particulates. Light scatter can also be used as part of detection systems and can be used to determine size particle distribution of suspended particulates.

For gravitational techniques filters or dust bowls are measured to assess the accumulation of material. Dust bowls are passive in that the dust fallout passively into the bowl. Ambient monitors are active in that they abstract a sample of air using a pump at a specific flow rate and this air sample is either passed through a filter or passes through a detection chamber. In all cases the collection material (bowl or filter) must be precondition and post condition to ensure moisture is accounted for. When material is collected, either on a filter or in a bowl, the collected material can also be digested (dissolved in acid) and analysed by the techniques described for water analysis to determine the concentration of specific parameters such as metal.

There are other more exotic techniques; for example - the TEOM (tapered element oscillating microbalance) methodology, which vibrates a mounted filer and measures the variation in frequency, which will equate to the loading of the filter and can be used to calculate suspended particulate). There are techniques that use radioisotopes and other techniques that will not be discussed in this report.

- Analytical techniques – solids

There many analytical techniques used by the mining industry for the determination of concentration (or content) for solids in various media. The solids in question may be ore, soils, sediment, air filters to name but a few.

For most measurement techniques it will be necessary to prepare the sample for analysis, this may involve dissolving the sample in water, acid or some other solute, or it may involve the production of a sample pellet. This is often referred to as sample preparation or sample prep.

As often only a portion of the sample is actually analysed it is very important to ensure that a 'representative sample' is prepared, which will be representative of the concentration of the material as a whole. The techniques required to prepare a representative sample are themselves a science and specific equipment such as sample splitters are required.

A robust Quality Control System is required by the team taking the samples and analysing the samples to ensure results are representative.

Wet chemistry methods can be used for mineral assay (e.g. silver is commonly determined by titration). However, the most widely used analytical techniques for solid composition determination are ICP / AA / XRF.

The basic principles between the three techniques are similar. The sample material is energised or excited by an energy source which atomise / ionise the sample.

ICP and XRF work on the principle of emission - in that during the excitation one or more electrons from the atom are moved into a higher energy state (or orbital within the atom). The removal of an electron makes the atom unstable, and electrons in higher orbitals "fall" into the lower orbital to fill the hole left behind and re-stabilise the atom. In falling, energy is released in the form of a photon, the energy of which is equal to the energy difference of the two orbitals involved. Thus, the material emits radiation, which has energy characteristic of the atoms present.

AA is absorption based and relies on the Beer–Lambert law, which states that the attenuation of light to the properties of the material through which the light is travelling, the concentration is determined from the quantity of absorption of light by individual metallic ions.

ICP stands for - Inductively Coupled Plasma. It is an analytical technique that uses the high temperature of a plasma (6000 to 10,000 K) to ionize the sample, which produces excited atoms that emit electromagnetic radiation at wavelengths characteristic of a particular element. The quantity of each element can be determined by comparing to a set of known standards, which are measured during the sample run. The method of detection for ICP can vary from optical based systems to the more expensive mass spectrometer.

AA stands for - Atomic Absorption. AA is slower, less accurate and less precise than ICP. The sample is atomised using a nebuliser and a flame or a graphite furnace. A monochromator is used to select the specific wavelength of the light which is to be absorbed by the sample. The light remaining is detected by a photomultiplier. Early AA units could only determine elements one at a time, but advancements allowed for multiple elements to be determined in one pass.

XRF stands for - X-ray fluorescence (XRF). Similar to the two techniques above the material being analysed is excited by being bombarded with high-energy X-rays or gamma rays which excites the sample and fluorescence is the re-emission of radiation that is detected and is representative of the concentration of the element in question, when compared to a standard. XRF offers a significant advantage to the mining industry in that it is possible to have portable handheld XRF units that can be used in the field. A portable XRF unit will only determine the concentration of elements on the very surface of a sample – but it is possible to break and crush samples to allow an XRF provide a very reliable indication of overall concentration or grade of an ore.

- Analytical techniques – aqueous

There are various analytical techniques for measuring water quality. There are classical wet chemistry techniques which will often involve titration of chemicals, using a chemical of known concentration to establish the concentration of an unknown. Many of the wet chemistry methods also used colorimetric techniques to determine an endpoint concentration which is read off a spectrophotometry. The intensity of the colour will be representative of the sample concentration and is determined by comparison to standards of known concentration.

Chromatography is a technique to slow the passage of molecules allowing their separation to enable an individual measurement of concentration for each molecule to be determined and this is compared with a known standard. There are many variations of chromatography from ion chromatography to gas chromatography to high performance liquid chromatography. The technique of separation is the same although different separation columns will be used for different applications. Different detectors can be used to quantify the individual molecules once separated, detectors can be by mass spectrometry or simple conductivity.

Standard methods of analysis for water are issued and approved by various organisations (e.g. 'Standard methods for the examination of water and wastewater' - by E.W. Rice | 30 August 2017).

- Assay

Assay is a specific term that refers the testing of a metal or ore to determine its ingredients and quality. Most people will be familiar with the term an 'Assay Mark', which is a mark placed on precious metal by an official assay office to vouch for the purity of the metal.

There are different analytic techniques that are used to assay ore – some of which are explained in the 'analytic techniques – solids' section of this appendix.

- AutoCAD

CAD stands for Computer-Aided Design, it is specialised software that is used by architects, engineers, and construction professionals to produce 2D and 3D drawings and maps.

- Bathometric surveys

Bathymetric surveys allow the depth of a water body to be measured and recorded. It also allows underwater topography to be mapped. The technique is essentially a sonar system and there are variations with single beam, multibeam and doppler. But the principle is essentially the same; the echo sounder is attached to a boat and sends out an array of beams across an area of the waterbody floor. As the beams are bounced back from the waterbody floor, the data is collected and processed. The processed data can be viewed in real time on the boat during the survey and recorded to produce a map at the end of the survey.

This technique can be used for reservoirs, ponds and tailings dams.

- Biological assessment

While it is important to understand the concentration of various chemical parameters in air, water and soil, the ultimate measure is what impact mining or exploration might have on living organisms and their habitat (plants / insects / animals). Various ecotoxicity tests have been established for measuring the potential impact of various chemicals on plants and animals of different taxonomic rank. Various assessment methodologies have also been established that look at species number and species diversity to establish a score for the medium in question (for example the Trent Biotic Index is for macroinvertebrates in water). If a key indicator has large numbers of individual species and good diversity between species, this is a good indicator that the ecology of an area is healthy and not being impacted by mining activities.

- Core Drilling

Core drilling is a technique used in exploration and also for geotechnical reasons.

Core drilling is normally used to access deep areas of interest by using material extracted from a small diameter holes, where a core of rock is normally extracted. There are several methods of drilling available and used for different requirements. These include auger drilling, percussion drilling and rotary drilling.

From a geotechnical perspective it is the structure of the core that is of interest. E.g. are there many voids in the core that would be indicative of caves and voids underground. Is the core soft and friable or is it in one piece, solid and indicative of competent rock that will be structurally sound and suitable for construction.

The physical structure of core is also of interest from an exploration perspective as it can be used to better understand the geological structures that will be indicative of orebodies. However, from an exploration perspective it is the chemical composition of the core that is of particular interest to determine what is the quantity or the grade of the mineral in question. The core will generally be split with half being sent for assay and half being retained for additional checks and audit as may be required. Portable XRF units as well as visual inspections will give an initial estimate or ore grade.

All core will be logged and will typically be photographed to keep as a record.

- DTM

DTM stands for Digital Terrain Model and is essentially a map showing the elevation of the ground that is being survey, commonly referred to as the vertical datum. Data is processed to filter out non-ground points such as bridges and roads, and vegetation to get a smooth digital elevation model.

DTM's are typically created through stereo photogrammetry. The DTM points are regularly spaced and characterize the shape of the bare-earth terrain. DTM is not a measurement technique but rather it is the output from a measurement processing technology.

- Extensometers

An extensometer is essentially a device that is used to measure changes in the length of an object. It is useful for stress-strain measurements and tensile tests. To measure slope stability; an extensometer consisting of tensioned rods is anchored at different points in a borehole. Any movement will pull on the rod which moves a weight along a graduated track. The rate of movement can then be measured manually from the graduation markings.

- Geochemistry

Geochemistry is a general term for the sampling of soils and sediments (riverbeds, etc.), which can be analysed for identification of geochemical anomalies. Regional geochemical exploration is traditionally based on topsoil or water stream sampling, where there may be an association between the presence of some chemical elements and the occurrence of certain mineral resources.

- Geophysics

Geophysics is a very broad topic that involves various techniques that can be used to provide detail or indications about the geological structure of the earth / ground.

From a mining, or mineral exploration perspective, the geological structure is critical as it can be indicative of mineral deposition. Geological structure is also of vital importance for geotechnical applications as it can identify voids or weakness in rock that would pose a risk for construction activities or excavation of the ground.

Ground penetrating radar is a non-invasive geophysical technique that can be used to map overburden for geotechnical characterization.

Exploration geophysics is essentially an applied branch of geophysics, which uses physical methods, such as seismic, gravitational, magnetic, electrical and electromagnetic at the surface of the earth to measure the physical properties of the subsurface, along with the anomalies in those properties. Any anomaly may be indicative of mineral deposition and be used to justify additional exploration.

- Resistivity (measuring potential differences between two or more electrodes generated by a current introduced into the ground).
- Gravity (measuring differences in specific gravity of rock masses).
- Microgravity is a geophysical method that measures miniscule changes in the force of the earth's gravity. Changes in gravity measured at the earth's surface reflect the underlying geological structure, hence the accurate determination of gravity leads to an understanding of the ground beneath and can be used to detect sub-surface cavities or changes in sub-surface density.
- Spontaneous polarization (measuring differences in spontaneous electrical potential caused by electrochemical reactions).
- Induced polarization (measuring changes in double-layer charge within a mineral interface)
- Magnetic susceptibility (measuring changes in structure or magnetic susceptibility in certain near-surface rocks).

- GPS systems

GPS stands for Global Positioning System. It is a system that uses data from satellites that orbit the earth, which make it possible for people with ground receivers to pinpoint their geographic location with great accuracy. GPS is also widely used in systems being used to attain geoinformation.

- Ground / Land Surveying

Land surveying is the traditional technique used for determining the terrestrial or three-dimensional position(s) of points on the earth and the distances and angles between them and can be used to establish topographical maps.

Various equipment such as theodolites, GNSS receivers and retroreflectors are used as well as specialised surveying software.

- Inclinometers

An inclinometer can be used to measure lateral movement within a slope. It is made up of a borehole that is installed and cased within the area that is to be monitored. The end of the hole (or the casing) is assumed to be fixed so that the lateral profile of displacement can be calculated. The casing has grooves cut on the sides that serve as tracks for the sensing unit. The deflection of the casing, and hence the surrounding rock mass, are measured by determining the inclination of the sensing unit at various points along the length of the installations. The information collected from the inclinometers is important to slope stability

- InSAR

InSAR stands for Interferometric Synthetic Aperture Radar. This is a radar-based technique that is used for remote sensing. The InSAR unit emits radar waves and uses the differences in the phase of the returning waves to generate maps of surface deformation or digital elevation. The technique can measure millimetre changes in deformation over spans of days to years.

As with LiDAR the instrument needs to be mounted at an elevation and typically on an aircraft or a drone. InSAR units can also operate from space by being mounted on satellites.

InSAR is used predominantly to measure subsidence and structural stability.

- LiDAR

LiDAR stands Light Detection and Ranging. It is a remote sensing method that uses light in the form of a pulsed laser to measure ranges or variable distances to the earth. The light is reflected to the senor which allows a distance to be calculated. Data is processed producing three-dimensional information about ground that is being surveyed.

A LiDAR instrument principally consists of a laser, a scanner, and a specialized GPS receiver. The unit must be mounted above the ground and typically airplanes, helicopters and drones are used.

Topographic LiDAR uses a near-infrared laser to map the land, while bathymetric LiDAR uses water-penetrating green light to also measure seafloor and riverbed elevations.

- Noise meters

Noise meters or sound level meters are used to measure the loudness of sound that travels through air or the 'sound pressure level'. The meter consists of a processing unit and a microphone. The diaphragm of the microphone responds to changes in air pressure caused by sound waves. This movement of the diaphragm, i.e. the sound pressure deviation (pascal Pa), is converted into an electrical signal (volts V). The unit is calibrated using a calibrator (an instrument that emits a noise at a specific loudness). The calibrated unit will process a measured noise and process the data to display a reading. The most common measurement for noise is decibel (dB). The instrument can also report the sound pressure level for specific frequencies as humans can only hear sound within a specific frequency range (typically 20 Hz to 20 kHz). Sound readings are typically reported as 'A' weighted, which is focused on the frequency range of human haring, this is reported as dB(A).

When measuring air overpressure from blasting, the sound pressure level is reported unfiltered for frequency – i.e. as a linear sound pressure level in dB.

- Ordnance Survey mapping (OS Maps) / Survey Maps

Many countries have government issued maps that detail the natural and built environments of an area (e.g. OS maps in the UK, in the US maps are issued by the USGS).

These maps provide key geographical and infrastructural information such the location of roads and railways and urban centres. Survey maps will be issued at different resolutions (e.g. 1 in 50,000 means 1 centimetre on the map equals 50,000 centimetres or 500 metres). Survey maps are issued in different resolutions with both local and regional maps being issued for example a 1 in 10,000 map will provide more detail. Survey maps can also be very useful to developers as historic maps are often available and these can reveal certain baseline conditions, such as water springs, which may be of importance when developing a project.

- Piezometers / Borehole Piezometers

Piezometers are used to measure pore pressures or water level within containment structures, such as tailings dams. The principle is the same as the principle that results in different sounds produced by the string on a guitar or piano.

A steel wire that is stretched over a distance and will have a given frequency based on its tension. In a piezometer instrument, the wire is vibrated by an electromagnetic field (in the same way a guitar string may be plucked). The frequency of vibration will be sensed by the electromagnetic coil and is transmitted to the piezometer processing instrument. One end of the sensing wire is attached to a diaphragm that can be deformed by water pressure entering through a porous tip. An increase in water pressure from elevated piezometric levels reduces the tension in the wire by deforming the diaphragm inward and this can be detected by the instrument as a change in frequency.

Excessive pore pressure is an indicator of increasing instability and risk of failure. A factor of safety calculation will be completed to define the acceptable pore pressure within a given structure.

Water level within a wall can also be simply measured by dipping a borehole (these boreholes are also often referred to as piezometers). The higher the water level within a wall structure the lower the factor of safety for the wall.

- Population databases – census figures

Most developed countries issue census figures, generally at least once every 10 years to detail population and demographics for the country. Understanding population locations and density is key to developing mining operations and understanding what the social impact of the mine will be.

- Pump tests

Pump tests are tests where water is abstracted from a borehole well at a specific rate for a specific length of time. The purpose of the test is twofold. Firstly, pump tests are used to establish what the likely yield of a well will be (i.e. how many m^3 can it produce in a day or an hour). Secondly, by monitoring the water level in wells in the vicinity of the pump test it is possible to establish what is the zone of influence (or drawdown) of the pumping for different pumping rates.

The yield of the well is of value as it will describe how much water the well can produce. Mines need to know this as they will have a required amount of water needed for their employees, their process and possibly the local town. It may be necessary to install more than one well to meet the mines supply needs.

While it is important to understand the zone of influence of a well with respect to how it might impact on other wells. The zone of influence is of most use to mining companies to allow the company to estimate the likely zone of influence of the mine and also establish what volume of water will the mine need to abstract and treat. It will be necessary to carry out a number of pump tests over a large area to calculate the

- Soil quality monitoring techniques

Soil quality is measured by various analytical techniques. The purpose of soil testing is to look at the physical characteristics of the soil as well as the chemical characteristics. Physical assessment can be completed by passing the soil though sieves to establish particle size distribution. Other physical techniques are also available. Biological testing of soil will not be discussed in this report.

From a chemical characterisation perspective, there are certain chemical parameters (e.g. Nitrogen, Phosphorous, Potassium) that are required at a minimum concentration for the soil to be productive. From a mining perspective, exploration and environmental personnel will be interested in the concentration on certain minerals and elements that could be indicative of an orebody or could indicate contamination caused by mining, respectively.

In most instances the soil must be digested in acid and analysed by one of the techniques referred to above (e.g. AA / ICP). XRF can also measure the concentration of chemical elements directly (albeit just the surface layer) this can be completed in the laboratory or in the field using portable XRF units. All of these techniques are based on the same principle, which is by applying energy to a sample individual chemical elements will be elevated to a higher energy state and as they return to a lower energy state they will emit energy which will be specific to the element in question and the intensity of the emitted energy will be equivalent to the concentration of that element.

- Surface based radar

Surface or ground based radar can be used to measure slope stability. The technique is also based on SAR (Synthetic Aperture Radar) as described earlier. Differential interferometry compares interferometric measurements taken at different times to identify very small changes in structures and can be used to track movement of structures, which may be indicative of imminent failure (trigger values will be established for different structures).

- Tension Crack Mapping

This is a technique that can be used for measuring the significance of cracks on stockpiles and embankment walls. The formation of cracks at the top of a slope is a sign of instability. Measuring and monitoring changes in crack width and direction can be used to establish the extent of the instability. Measurements of tension cracks may be as simple as driving two stakes on either side of the crack and using a survey tape or rod to measure the separations or a portable wire-line extensometer can be used.

- Tell-tales

Tell tales are inexpensive devices used for monitoring ground or crack movement in structures. The device consists of two plates which are free to move independently. Each plate is fixed to either side of a crack. One plate is marked with a millimetre scale and the other with a hairline cursor cross. Any movement of the crack (widening or lengthening) will result in a movement of each of the plates relative to each other and the actual movement can be read off the scale.

- Time-domain reflectometer (TDR)

Time domain reflectometry can be used to monitor slope stability and movement. For stability monitoring applications using TDR, a coaxial cable is installed in a vertical borehole passing through the slope to be monitored. The electrical impedance at any point along a coaxial cable will change with any deformation of the insulator between the conductors. A brittle grout surrounds the cable to translate earth movement into an abrupt cable deformation that shows up as a detectable peak in the reflectance trace.

- Trenching

Trenching is widely used in exploration and involves the use of shallow excavations for sampling of rock and other materials. Trenching also provides a level of continuous exposure to the materials of interest.

- Ultrasonic depth measurement units.

Ultrasound is uses a transducer to generate sound waves in the ultrasonic range (above 18 kHz) by turning electrical energy into sound, then upon receiving the echo turn the sound waves into electrical energy which can be measured and displayed. The application is used widely in medicine to make cross-sectional images of various parts of the body so doctors can assess performance and identify potential issues. The technology has wide ranging applications in industry and can be used to measure wind speed and direction as well the movement of solid objects.

The application that has been described in this report is for measurement of water level. For this application, the soundwave is emitted from the sensor and bounced back from the water's surface. This information is then processed to determine the depth of the water.

- Vibrographs (accelerometers)

A vibrograph (or vibration monitor) measures vibration levels and is widely used in the mining industry to measure the vibration from blasting. At the heart of the instrument is an accelerometer that can measure rate of change of velocity of a body (or acceleration). The accelerometer is fitted into a 'geophone' that is secured to the body that is to be monitored for vibration (generally the ground or the foundations of a building).

Conventional accelerometers use a piezoelectric material (a material such as quartz that will release an electric charge when a force is applied to it). The electrical charge that is produced when the unit is exposed to a vibration is processed by the vibrograph to produce a vibration reading typically expressed as Peak Particle Velocity (PPV) in mm/sec or it can be expressed in units of acceleration such as 'g'.

Appendix 2 – Workshop Questionnaire & summary of responses

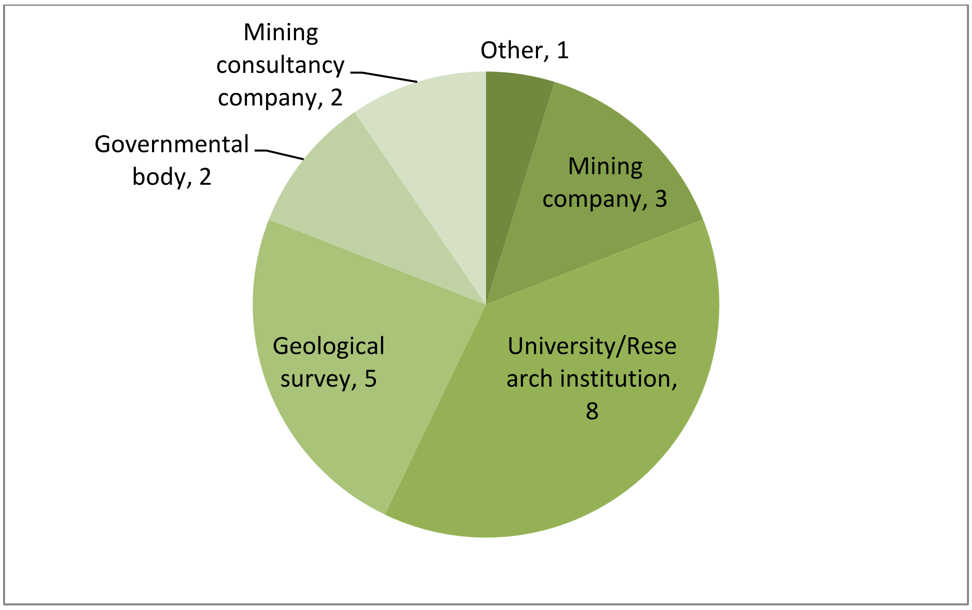
EO4RM - Earth Observation for the mining of Raw Materials

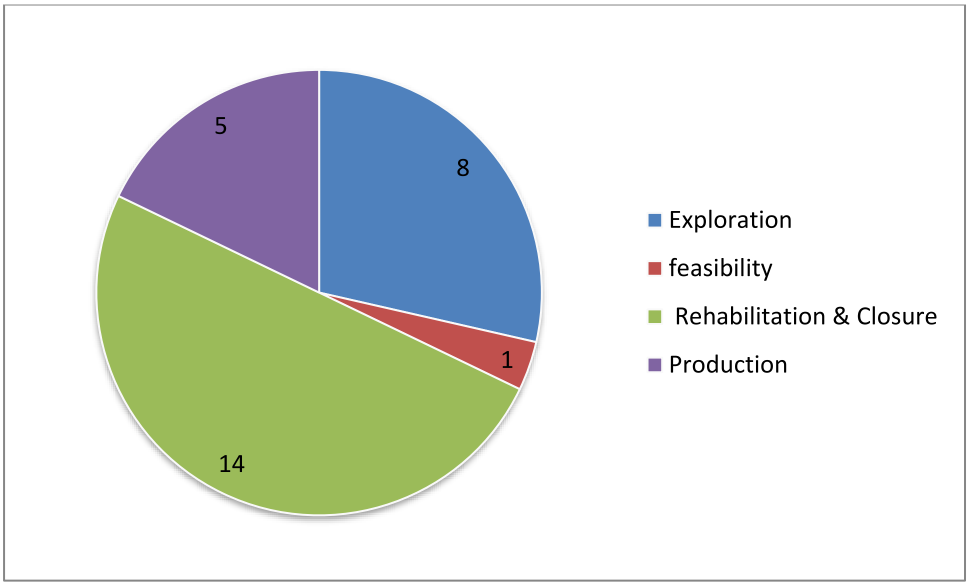
Questionnaire to prepare for the workshop on 6 June 2019

Name of your organisation	
Contact Person Name	
Contact Person job title	
Contact Person email address	
Country	
Do you agree to share the replies to the questionnaire, including your contact details, with the EO4RM team? highlight Y/N	*Yes / No*
Function of your organisation (highlight as appropriate).	*Mining Company - Operation*
	Mining Company - Corporate Office
	Consultant to mining industry
	Supplier of Equipment / Materials to mining industry
	Regulatory Authority / Government Official
	Supplier of exploration services to mining industry
If your organisation is involved directly in the mining industry – Please the relevant aspects of the mining cycle (more than one aspect may be selected).	*Exploration*
	Environmental Assessment / Planning Permitting
	Design / Construction
	Operation / Mining
	Mine Closure / Site Rehabilitation
Rate your organisation's familiarity with Earth Observation (EO) technologies (1 to 10). *1 being no familiarity and 10 being expert.*	
Does your organisation use EO technologies? highlight Y/N	*Yes / no*
Does your organisation have an EO specialist or GIS specialist employed? Please highlight Y/N.	*Yes / no*
If your organisation uses EO technology? Please circle the frequency that best quantifies the frequency of use. (Highlight as appropriate).	*Daily / Weekly / Monthly / Annually*
Annual budget for EO technologies / reports / consultants (highlight as appropriate).	*<€20kPA / €20k to €100kPA / >€100kPA*

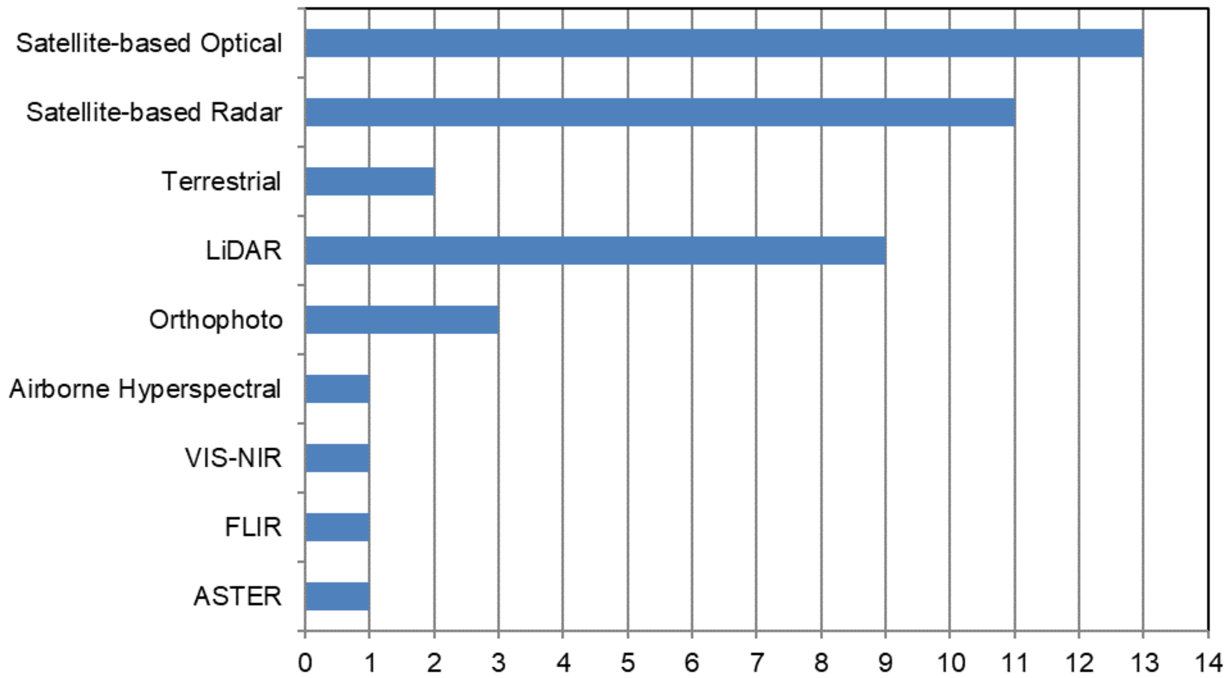
If your organisation uses, reports on or recommends EO technologies; please state the specific technologies used (e.g. Airborne LiDAR) more than one technology may be stated.	
If your organisation uses EO technology please state the specific use *(e.g. subsidence assessment).*	
Has your organisation considered the use of EO but chosen not to use the technology due to an obstacle? *If yes please briefly explain the nature of the obstacle (e.g. cost / availably / reliability etc.)*	
Are there any mining applications where you believe EO technologies may be of benefit but are currently not being used? *If you answered yes and provided an example - Is there any technology or service advancement required to facilitate this application?*	

Results 1 – Respondent type & Area of expertise with respect to mining

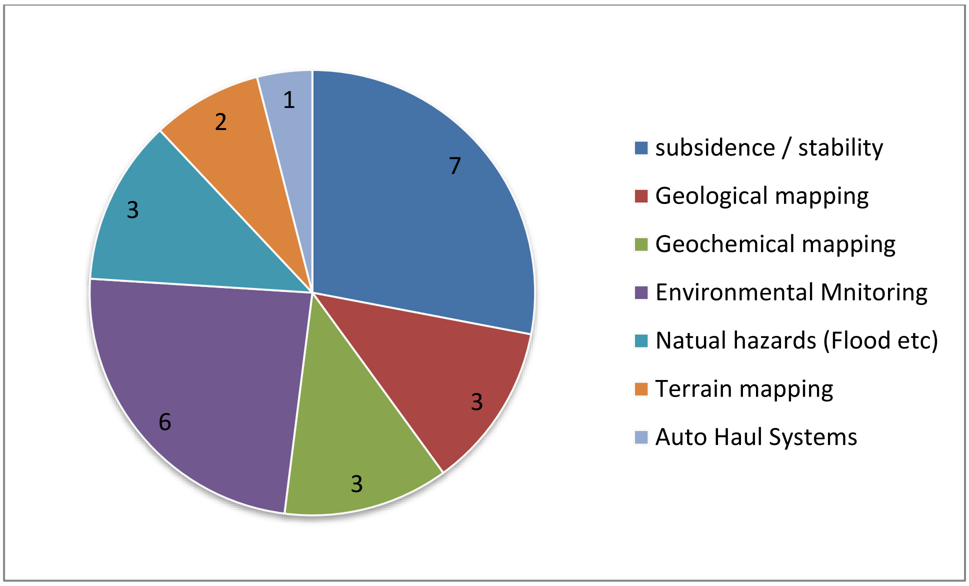




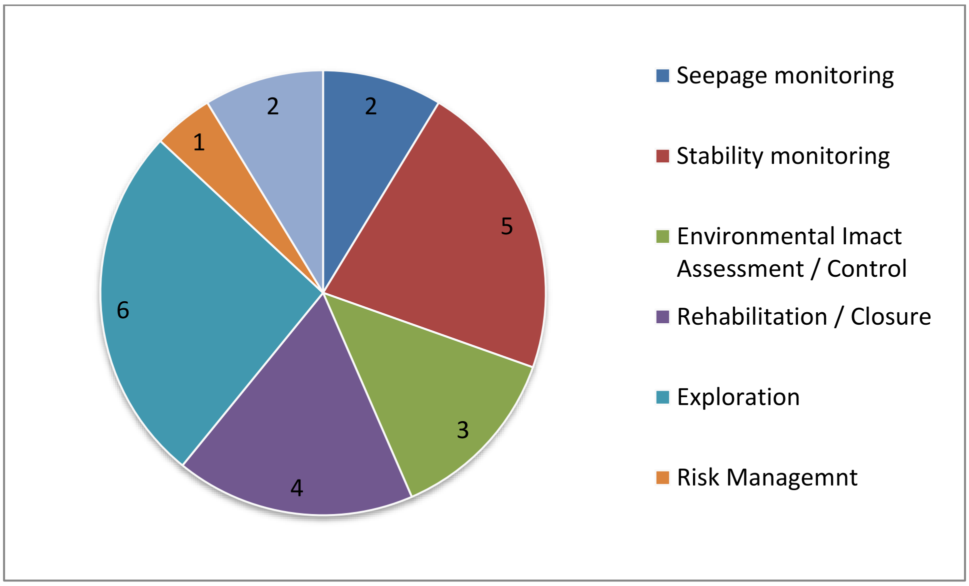
Results 2 – EO technologies used by respondents



Results 3 – Applications where EO technologies are routinely used by respondents



Results 3 – Potential areas of growth for EO technologies



Appendix 3 – IIB interviews

Interviewee: **Representative from Vedanta Zinc International**

Position: Senior Geologist at Black Mountain Mining South Africa

Interviewer: Gemma Spaak (Deltares) Norman Kiesslich (Geoville)

Date: 6th June 2019

1. **What is your current level of use for EO technologies?**

   Alan's knowledge currently limited to optical remote sensing (familiar with Landsat), perhaps a bit out of date with current satellites.
   South Africa: dry area so optical (hyperspectral and multispectral) technique works well
   Focus on band associations/band ratios to find areas with higher contrast versus lower contrast. Use EO to produce an image where every rock type is identified as a different colour.
   Alan currently does not use EO to map out minerals although he has used this capability in the past using ASTER data.

   Required resolution:
   - more is more
   - 1km by 1km way too coarse, even 30m has limitations when it comes to exploration and 2-5m would probably be ideal

2. **What are the most common EO technologies that you use or that you are associated with? Explain your level of use or engagement.**

   Optical (see above).
   Focus on band associations/band ratios to find areas with higher contrast versus lower contrast. Use EO to produce a map where every rock type is identified as a different colour.
   Alan does not use EO to map out minerals.

   Radar tomography data is used regularly but is not kept up to date, more of a once-off use.

3. **Which of the Mining Cycle areas are you most familiar with from an EO perspective?**

   Greenfields – exploration
   Environmental issues, biodiversity, vegetation, mapping plant health in very barren areas – permitting issues
   Risk of oil spills for the environment
   Dust monitoring for plant health
   Monitoring of traffic associated disturbance in the environment (destroying of vegetation, creating dust)

Map old dust versus new dust, plume of new dust coming from the mine

Improve the geological map and understand the region
Base metals often on fault structures which can sometimes be mapped using gravity. In areas where no ground or airborne gravity is available then satellite gravity (i.e. Grace) is very useful
Mapping fault structures, mapping sedimentology, mapping allochtonous/autochtonous sediments, mapping soil chemistry, mapping geological features (e.g. veins, paleochannels)

4. **Are there EO technologies currently available that you believe are not being utilised in the mining industry?**

   There are. Satellites can be used for various monitoring applications (e.g. for dust, vegetative change, mapping hydrocarbons/oil spills) but it is not being used to their full capacity (due to lack of capacity and lack of knowledge, and in some cases cost).

5. **Are there EO technologies currently available, that can be improved to make them more useful to the mining industry?**

   For optical: more spectra, narrower spectra at higher resolution, especially in SWIR, VNIR, TIR

   Improving satellite gravity data (GRACE, at the moment very coarse)

6. **Are there areas of the Mining Cycle where new technologies should be developed?**

   Subsidence, ground movement, change mapping

7. **What are the main reasons why EO technologies are not being fully utilised in the mining industry?**
   a. **Cost** – yes
   b. **Skill levels** –yes
   c. **Availability** – to a degree
   d. **Resolution of data** – in some cases
   e. **Refresh rate of data** – possibly, but likely relates back to cost
   f. **Accuracy / reliability** -
   g. **Lack of knowledge of EO products** – yes
   h. Other

   Lack of capacity and lack of knowledge are probably main barriers for not using EO in mining. Cost is also a barrier.

   What if EO technologies reveal the presence of more issues (e.g. mapping of more oil spills than previously recorded, mapping of environmental damage in m2) – this can increase the costs.

Process of obtaining a preferred supplier for the EO data is a nightmare (both within the mining company and the satellite data suppliers). Difficult as you do not get the data/product

8. In your opinion how should current and new EO technologies be briefed to the mining industry?
    a. Conferences/seminars/workshops
    b. Start briefings with the major mining companies first
    c. Offer services free of charge for a period of time
    d. Advertising campaign
    e. Other

Use students and academic institutions to get the knowledge out there (at reduce costs) – e.g. ArcGIS, Petrel

Alan attended a module at university that used TNTmips software for satellite imagery processing. The university was able to use a student license and this not only allowed students to understand the basics of imagery processing, but also to what satellite data was available and what it can be used for. This is probably one of the best approaches. Such modules are relatively common in the geosciences but are used less in environmental sciences, life sciences, oceanography etc and there is probably an opportunity for more EO technology promotion when studying these subjects.

9. Who should fund new EO developments for use in mining and other related industries?
ESA (or more importantly commercial satellite operators) need to come up with a sales pitch to drop prices for mining companies so they can buy the data at lower costs. If buying larger or more regular data can bring the price down then likely more companies will use it (particularly junior or mid-tier exploration / mining companies)
Mining companies should work together if possible to buy the data, but this is difficult. Government is another logical choice.

10. Where are the current knowledge gaps in your sector of the mining industry – what areas you are currently working on to gather data (reason for both these questions is that - it is possible that EO technology may have a quick cost effective solution).

Very easy for mining companies to fall behind when it comes to new technologies. Often one sticks to what one knows or is limited by capacity (i.e. processing software that is incompatible with newer/different formats)

Interviewee: **Representative from Barr Engineering**

Position: Vice-President Barr Engineering Co., USA and Barr Engineering and Environmental Consultants, Canada.

Interviewer: Brendan Morris (LTMS)

Date: 6th June 2019

1. What is your current level of use for EO technologies?
   Aware of EO technologies for use in Environmental and Tailings Dam applications, as well as, open pit mining and design of mining/mineral processing facilities.

2. **What are the most common EO technologies that you use or that you are associated with? Explain your level of use or engagement.**
   Lidar and InSar

3. **Which of the Mining Cycle areas are you most familiar with from an EO perspective?**
   Tailings (including the tailings disposal, basins and the dams) are my particular area of expertise, but I (as well as our company) have also worked with mining companies on (1) environmental permitting and planning-feasibility studies, (2) design through operations and (3) closure. Although I am familiar with exploration, it is not one of my core competencies, nor is it a core competency of our company.

4. Are there EO technologies currently available that you believe are not being utilised in the mining industry?
   Some juniors (exploration and mining) are using EO technology on a regular basis but others are not using it – Juniors often fail to achieve their targets more than any other group in the Mining Cycle and use EO technology the least.

5. **Are there EO technologies currently available, that can be improved to make them more useful to the mining industry?**
   See notes below

6. Are there areas of the Mining Cycle where new technologies should be developed?
   Technologies that benefit junior companies
   Any technologies that benefit junior companies are of benefit. New technologies that are able to penetrate the surface some distance would be a great benefit (see notes below). This may include ground penetrating radar, or a "signal" installed terrestrially at some depth below the surface that can be observed by EO technology.

7. What are the main reasons why EO technologies are not being fully utilised in the mining industry?
    a. Cost – Cost may be an issue with juniors but generally mining companies will pay for a good product
    b. Skill levels – Consultants may initially have the requisite skills and may be able to assist with on site development of mining companies
    c. Availability – Some concerns here regarding access to smaller companies
    d. Resolution of data – Not sure and depends on application
    e. Refresh rate of data – Not sure and depends on application
    f. Accuracy / reliability – There may be some understanding of this area, but it may not be fully understood
    g. Lack of knowledge of EO products – This is the key area for lack of use of EO technology. Needs to be addressed.
    h. Other – Drones and terrestrial technologies are better known

8. In your opinion how should current and new EO technologies be briefed to the mining industry?
    a. Conferences/seminars/workshops – This is the best way to advertise. Suggestions are SME, CIM, PDAC, Client mining companies (Consultants), workshops and seminars
    b. Start briefings with the major mining companies first – Second best way to advertise
    c. Offer services free of charge for a period of time – Not an option in my opinion, as mining companies typically will have enough resources to fund, but perhaps could offer a reduced charge initially.
    d. Advertising campaign – OK, but a good product will spread quickly, so advertisement will be a primary way to show users of the product as a viable technology.
    e. Other

9. Who should fund new EO developments for use in mining and other related industries?
   Mining companies through consultants and service providers

Notes in regard to tailings: Tailings Dams offer a unique challenge to mining operations as they increase in size over the life of the mine and are dynamic in that they contain materials that are solid, semi solid and liquid, sometimes in unknown locations and quantities within the dams. Therefore, the Observational Approach is used in the following way to: (a) first *test* and model to predict behaviour, (b) design with provisions for modification and (c) *monitor and observe* for performance. In a well-run mining operation, this cycle is repeated every few years, as the tailings basins are raised (in some cases, well over 100 m high). The *testing* and *monitoring of observations* part of this approach for these facilities seems to be ideally suited for EO. Further, although not desired, EO can also be used for identifying emergency conditions of tailings facilities and assisting with corrective actions.

Therefore, the strategy of mitigating risks is to use the "Observational Approach" using proper models and designs for the tailings facilities and rely on regular testing, monitoring and observations to verify performance (in accordance with the modelling and design predictions). Best practice is to implement the "Observational Approach" and utilize EO as part of the tailings management strategy, for the following specific areas:

1. Geologic features
2. Seismic activity
3. Dam stability
4. Groundwater and Seepage
5. Deformation
6. Water Balance
7. Tailings Mass Balance
8. Heat Balance
9. Delta Development
10. Pipeline and Discharge
11. Dust

In summary, the strategy for EO seems to be in the context of: Implementing Best Practices for predicting the performance using the "Observational Approach". If Best Practices are employed using the "Observational Approach", then appropriate EO measurements (along with other methods of measurements) will result in safe, robust and economical tailings facilities. Of course, EO can also be used as notifications for emergency conditions and subsequent remedial action.

Interviewee: Representative from GeoScience Ireland

Position: Director GeoScience Ireland

Interviewers: Esteban Aguilera (S&T), Margreet van Marle (Deltares)

Date: 6th June 2019

1. What is your current level of use for EO technologies?

My sense is that EO technologies are used by specialist design companies rather than general designers and contractors. More advanced ones use EO. Specialized companies are placed more directed towards the designers (geotechnical engineers). Designers tend to use both satellite observations as well as UAV based observations for observations of tailing dams, embankments, slopes.

Contractors tend to use UAV-based observations for surveying purposes, estimation of quantities (volumes) and stability. Geoinformation gap can be identified here: use EO to complement UAV measurement. Burden: If the user knows what the benefits are it probably is more inclined to use it.

Advantage of satellite-based EO: These observations might be used to validate field observations (piezometers/boreholes).-> useful in areas where monitoring is not frequent, or where people don't know how to interpret the ground-based observations.

Applications of EO technologies in the areas of pollution plumes and mine tailings.

Responsible companies would like to use all the available information (including remote sensing). It is up to the operators to use an advisor.

2. What are the most common EO technologies that you use or that you are associated with? Explain your level of use or engagement.

Satellite-based observations: Radar, multispectral,

Airborne observations (UAV, Helicopter, airplane): Lidar, gamma-ray, EM.

Terrestrial observations: EM and Ground penetrating radar

3. Which of the Mining Cycle areas are you most familiar with from an EO perspective?

Exploration; Satellite imagery gives broad information. Vegetation changes from more acidic to alkaline change -> visual inspection. Or lineaments (faults, cracks) -> also visible inspection.

Pictures are used to check structures (i.e. dams, faults), but also lithologies, to select better exploration targets -> optical imagery.

Gravity signature may change depending on the metal content -> **Geoinformation gap!**

Operations: Open pit mining, volume changes. As the mine deepens the pit becomes bigger. Measure of what happens and for regulators.

4. Are there EO technologies currently available that you believe are not being utilised in the mining industry?

Maybe GRACE – gravity; Karst topography/sinkholes (exploration, where to locate your tailings dam), Metal content (exploration phase).

Soil moisture – Passive Microwave remote sensing for liquefaction.

Weather: In Siberia when it is very cold, it is more expensive. Extreme weather may impact mining practices. Short-term (10-day) climate forecasting could be a possible way of predicting the effects.

In **Design**; multiyear precipitation could influence the location. Also, information about floodplains and changes of floodplains over time.

Reservoir availability during **Mining** phase.

5. Are there EO technologies currently available, that can be improved to make them more useful to the mining industry?

Spatial resolution of soil moisture

Lack of observations due to cloudy weather. Overcome by more/complementary measurements.

Integration of multi-sensor scales (terrestrial, airborne and satellite).

6. Are there areas of the Mining Cycle where new technologies should be developed?

Changed question to: what are the current problems encountered.

Exploration phase: New discoveries. Now and in the future we will need more and more cobalt, cupper, lithium, zinc, and other minerals for example for 'cloud working' and electrical vehicles. Finding these sources and developing them. Needs improving discovery rates. This topic is also related to socio-economic issues, peace and security.

Energy transition in the future.

7. What are the main reasons why EO technologies are not being fully utilised in the mining industry?
    a. **Cost** – HR imagery is more expensive. HR data processing is more time consuming.
    b. Skill levels
    c. Availability –
    d. **Resolution of data** - Spatial resolution differs per data product, but often is too course.

e. Refresh rate of data
f. Accuracy / reliability
g. Lack of knowledge of EO products – Is a problem. Also, part of how companies are structured. Often external expertise is needed.
h. Other - Often highly specialized people are needed to get the data and to process the data.
Barrier as well is that it EO not necessarily part of requirements/regulations.

8. In your opinion how should current and new EO technologies be briefed to the mining industry?
   a. Conferences/seminars/workshops

   EO trading companies.

   b. Start briefings with the major mining companies first
   c. Offer services free of charge for a period of time
   d. Advertising campaign
   e. Other

9. Who should fund new EO developments for use in mining and other related industries?

ESA, Copernicus, EC

10. Where are the current knowledge gaps in your sector of the mining industry – what areas you are currently working on to gather data – reason for both these questions is that - it possible that EO technology may have a quick cost effective solution.

Big knowledge gap on seismic information. Complementation of ground and airborne techniques.

Onshore: Seismic and EM observations (Both on-ground and below-ground).

Interviewee - Representative from Surveylab

Position - CEO of Surveylab -Sapienza, Italy

Interviewed by – Ton Peters (Deltares) & Stephen Wheston (LTMS)

Date – 6th June 2019.

Professional Experience in relation to EO and mining.

Surveylab provides consultancy to the mining industry. Their area of expertise is in relation to Environmental Assessment, Permitting and Planning. Earth Observation is fundamental to the business, the company uses EO data daily and are very familiar with the application, benefits and limitations of EO data.

The technologies used most often by Surveylab are INSAR and LIDAR for mapping, surface displacement, volume calculations and morphometric analysis. Surveylab provide assistance to the mining industry across all the mining phases. They provide assistance in relation to hydraulic modelling, deformation monitoring and in particular provides monitoring data that assess the stability of key infrastructure including ancillary infrastructure such as buildings and railways. Applications to assess pit slope stability and stability of waste management structures lend themselves readily to EO and the services provided by Surveylab.

EO techniques used by Surveylab.

While Surveylab use LiDAR, this is not satellite based and was not discussed in the interview.

The satellite based EO technology used by Surveylab are both optical and radar based. Surveylab mostly use optical systems followed by radar and lastly the technology they use least is hyperspectral. Radar interferometry covers a wide geographical area and is very accurate when measuring displacement.

Why is EO not being more widely used in mining.

Maria believes there is not enough done to promote the use of EO technologies in the mining industry. There is probably a lack of belief or trust in the technology and this is possibly informed by the fact that there is a lack of success stories relating to the use of EO in mining. Mining engineers are traditionally conservative and given the potential risks they are managing will tend to stick with the technologies that they have used before, that have been proven to work and that they trust. There are many examples of success of EO within mining and it is important that these are promoted by whatever means is most effective to explain the potential benefits to mining engineers.

Important to appreciate that there are limitations to what EO can do and explain this to the mining industry. It may well be the case that certain individuals are 'overselling' EO technology and what it can do, and this may be leading to mistrust from those who can see though this sales pitch.

<u>Opportunities for EO and its applicability for mining.</u>

The backscatter technique used to gather radar reflections is dependent on the physical characteristics of the material that is reflecting. Currently the technology only provides data on the physical properties of the surface. Miners are interested in deeper lithologies future developments may allow deeper penetration and data collection. The use of ground or near-earth data to 'calibrate' satellite systems is an area of possible opportunity.

The temporal refresh rates (every 15 days) are currently sufficient for most applications but an increase in resolution will provide benefits in relation to monitoring.

Stability and movement are most easily measure in the vertical axes. Many of the applications in mining are also interested in measuring movement of vertical faces. New technologies may allow better data to be gathered in relation to measuring stability of vertical faces.

Cube satellite and swarm technology offer opportunities for optical systems but not so much for radar.

Artificial Intelligence will be an important component to maximise the value to be gained from satellite data being gathered.

COSMO-SkyMed is an EO satellite-based radar system funded by the Italian Ministry of Research and Ministry of Defence and conducted by the Italian Space Agency, intended for both military and civilian use. Surveylab use data from this source and Maria points out the opportunity for more sharing of data from the various institutions that are collecting data from satellites. However, it is accepted that some governments may use these data for sensitive applications, not least national security and as such may be reluctant to share the data.

Appendix 4 – Selected Literature Reference

LR - 1	http://www.world-mining-data.info/wmd/downloads/PDF/WMD2018.pdf
LR - 2	https://earsc-portal.eu/display/EO4/EO4OG+Home.
LR - 3	https://ec.europa.eu/growth/sectors/raw-materials_it
LR - 4	https://earsc-portal.eu
LR - 5	https://pubs.usgs.gov/fs/2002/fs087-02/
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LR - 8	https://www.usgs.gov/centers/oki-water/science/bathymetric-surveys?qt-science_center_objects=0#qt-science_center_objects
LR - 9	https://pdfs.semanticscholar.org/6fae/683dff3c7d0029b717c25d358b9262b842b5.pdf
LR - 10	https://www.claire.co.uk/advanced-search?q=soil+values
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LR - 24	http://www.terrafirma.eu.com. Terrafirma: Pan-European Ground Motion Hazard Information System.
LR - 25	SYMIN: System for Monitoring Law Enforcement of Informal Mining. https://symin.gaf.de.
LR - 26	Waste Management (Mining): http://www.vae.esa.int/page_vaeproject342.php

LR - 27	Minerals4EU: Minerals Intelligence Network for Europe. http://www.minerals4eu.eu.
LR - 28	MINEO: Assessing and Monitoring the environmental impact of mining activities in Europe using advanced Earth Observation techniques. http://www.copernicus.eu/projects/mineo.
LR - 29	EO-MINERS: Earth Observation for Monitoring and Observing Environmental and Societal
LR - 30	GMES4Mining: http://www.gmes4mining.info.
LR - 31	Copernicus for Raw Materials Workshop, 5 September 2016, Brussels – Workshop Report: http://workshop.copernicus.eu/sites/default/files/content/attachments/ajax/raw_materials_ ws_report.pdf.
LR - 32	International Lead and Zinc Study Group (ILZSG). http://www.ilzsg.org.
LR - 33	International Copper Study Group (ICSG). http://www.icsg.org.
LR - 34	International Nickel Study Group (INSG). http://www.insg.org.
LR - 35	http://vamos-project.eu/