


ISA TECHNICAL STUDY NO. 29

Remote monitoring systems in support of inspection and compliance in the Area

INTERNATIONAL SEABED AUTHORITY

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ACRONYMS

1994 Agreement	Agreement relating to the Implementation of Part XI of the United Nations Convention on the Law of the Sea
AIS	automatic identification system
AUV	autonomous underwater vehicle
Draft Regulations	Draft Regulations on Exploitation of Mineral Resources in the Area
GPS	global positioning system
IMO	International Maritime Organization
ISA	International Seabed Authority
LRIT	long range identification and tracking
LTC	Legal and Technical Commission
ROV	remotely operated vehicle
SAR	synthetic-aperture radar
UNCLOS	United Nations Convention on the Law of the Sea
VMS	vessel monitoring systems

FOREWORD

Designing a robust and transparent inspection and monitoring regime will be critical to ensure the ongoing compliance of contractors under the regulatory framework for deep-seabed mining. Part XI of the Draft Regulations on Exploitation of Mineral Resources in the Area (Draft Regulations) contains provisions concerning the powers and functions of the International Seabed Authority (ISA) to carry out inspection for the purposes of ensuring compliance with the United Nations Convention on the Law of the Sea (UNCLOS), the 1994 Agreement Relating to the Implementation of Part XI of UNCLOS (1994 Agreement), and ISA rules, regulations and procedures.

A key feature of this inspection regime, in addition to physical inspections by inspectors, is the remote monitoring of all mining activities. Section 102 of the Draft Regulations recognises the importance of establishing a system of electronic monitoring of exploitation activities in the Area to record information, including the date, time and position of all mining activities, to ensure that mining operations are restricted to the mining area and to prevent unapproved activities by a Contractor.

In this connection, a study was comissioned to DNV to: (i) identify remote monitoring technologies, including emerging technologies that could be applied in the context of deep-sea mining for the purpose of remote monitoring (ii) identify minimum resource and capacity requirements for the effective use of remote monitoring technology and (iii) identify the best combination of remote monitoring and other tools to ensure that ISA can carry out its inspection and enforcement activities effectively. I wish to acknowledge the work of DNV in the preparation of this study.

It is with this background that I have the pleasure to present this technical study on remote monitoring systems in support of inspection and compliance in the Area. This study will provide a useful basis for further work to be undertaken by ISA and others, including the development of remote monitoring technologies and the preparation of standards and/or guidelines to assist contractors in complying with their obligations under the Draft Regulations.

Michael W. Lodge
Secretary-General
International Seabed Authority

EXECUTIVE SUMMARY

1. The Draft Regulations on the exploitation of mineral resources in the Area of the seabed beyond national jurisdiction (the Area) are currently developed by ISA.[1] Part XI of the Draft Regulations on inspection, compliance and enforcement contains provisions relating to the powers and functions of ISA to carry out inspection for the purposes of ensuring compliance with the United Nations Convention on the Law of the Sea (UNCLOS), the 1994 Agreement, ISA rules, regulations and procedures, and the terms and conditions of an exploitation contract.

2. The Draft Regulations recognize the importance of establishing a system of remote monitoring for exploitation activities in the Area, in addition to the use of physical inspections, to record information concerning mining activities (the 1994 Agreement, Section 2).

3. Against this backdrop, ISA contracted DNV to undertake a study (this report) on remote monitoring systems in support of inspection and compliance in the Area.

4. Deep-sea mineral resources are mainly located in water depths of 1,000 m or more, with some resources being found as deep as 6,000 m. So far, no exploitation of mineral resources in the Area has taken place. Exploration is, however, currently being undertaken and regulated by sets of exploration regulations adopted by ISA in 2010 (for polymetallic sulphides), 2012 (for cobalt-rich ferromanganese crusts) and 2013 (for polymetallic nodules). In this context, deep-sea mining technology is being developed. The specific mining equipment and technologies that will be used will likely vary depending on the mined minerals (i.e. polymetallic nodules, polymetallic sulphides or ferromanganese crusts).

5. Travel to sites for mineral-resource exploitation in the Area can take several days by ship from the nearest harbour. This makes physical inspections challenging in terms of time and cost. Remote monitoring would allow ISA to supplement and support physical inspections from land-based locations and enable spot checks in case of suspicion of irregularities.

6. A basic and very important question is which data is needed by ISA, and how such data can be collected, processed and transmitted to ISA, to allow for effective remote monitoring of exploitation of mineral resources in the Area. This report provides suggestions on the type of data to be collected and where such data should be collected (i.e. the sea surface, water column or seabed).

7. Remote monitoring technologies already exist in other sectors such as offshore petroleum installations, submarine pipelines, submarine cables and fisheries.

[1] International Seabed Authority (2019). Draft Regulations on Exploitation of Mineral Resources in the Area (ISBA/25/C/WP.1).

8. Monitoring offshore installations has shown some technologies are reliable. Still, there are challenges in implementing real-time monitoring offshore (signal loss, data lag or insufficient power). Offshore petroleum activities seldom take place deeper than 1,000 m, while exploitation of mineral resources in the Area could take place in much deeper waters. This would be very demanding for the monitoring equipment and the communication of data to the sea surface.

9. Several existing and proven (as well as some emerging) remote monitoring technologies are suitable to monitor seabed mineral-resource exploitation.

10. To obtain the **position of surface vessels**, there are, for example, the Automatic Identification System (AIS) and Long Range Identification and Tracking (LRIT). LRIT is assumed to have higher integrity than data received through AIS. Further, satellite service providers offer commercially-available vessel detection with global coverage. Several providers also offer onboard tracking devices, which typically include a built-in global positioning system (GPS) receiver and a satellite transmitter to share position information to a shore-based web solution. The underwater positioning and navigation can be done using underwater acoustics. The support vessel communicates via a transducer to transponders on the objects at the seabed so that the depth and offset from the support vessel's GPS position can be calculated. Relaying subsea positioning data to land can be done by a satellite link from the support vessel, or via radio signals for shorter distances.

11. Vessel Monitoring Systems (VMS) are used in commercial fishing to allow tracking and monitoring of the activities of fishing vessels. A VMS is a satellite-based monitoring system which, at regular intervals, provides data to the relevant fisheries authorities on the location, course and speed of vessels. The setup of VMS systems has many similarities with what is needed to obtain basic data for remote monitoring of exploitation of mineral resources in the Area. Using experience from an already existing system such as VMS will help obtain a faster implementation of remote monitoring of exploitation of mineral resources in the Area.

12. To obtain the **production rate and total amount of produced ore**, the mining vessels' loading computer software can be used. All mining support vessels would likely have an installed loading computer kept up-to-date about the amount of ore in cargo holds for the calculation and monitoring of vessel stability. An emerging technology would be to use a flow meter mounted on the pipe that is not in contact with the ore.

13. To obtain **environmental data from the sea surface**, real-time sensors for parameters such as wind speed, wind direction, air temperature, sea temperature and air pressure (barometers) commonly installed on all vessels can be used. Such data can also be collected by remote sensing via satellites and airplanes. Satellite-based observations of the oceans can detect and monitor the evolution of oil spills, plumes, total suspended matter concentration, dissolved organic matter, sea surface temperature, wave height etc. Data is available from both open and commercial platforms and service providers. Drones have not been assessed as suitable for such monitoring yet. A regular drone can only fly to about 50 km from its base station (typically on land) and can be difficult to control even at shorter distances. Environmental data from the water column and seabed can be collected by mobile sensor platforms (such as remotely operated vehicles (ROVs), autonomous underwater vehicles (AUVs), mining equipment, surface- controlled instrument carousels etc.) or fixed sensor platforms (as landers or moored with buoys).

14. Based on the assessment of the remote monitoring systems studied in this report, an optimal option for the remote monitoring system which ISA could use in the context of inspections, from a cost and capacity requirement perspective, is outlined, without prejudice to the future shape of the inspection mechanism to be established, including the respective roles of the ISA Secretariat, the Legal and Technical Commission (LTC), sponsoring States and flag States. That option is summarised as follows:

- *Data collection:* Data would be collected by the Contractor under the obligations of the Environmental Management and Monitoring Plan. Data to be monitored are presented in this report. ISA would not need its own monitoring equipment on site. The Contractor would operate the various sensors, collect the required data and transmit it to ISA.

- For spot checks over long intervals or upon suspicion of irregularities, satellite data could be used to monitor the position of all vessels at the mining site. Further, satellite imagery would provide information on oil spills and may also provide information on plumes on the sea surface. Satellite data would enable ISA to obtain satellite imagery of the sea surface.

- *Data processing:* The raw data collected by the Contractor would be processed at the mining site before being transmitted to the ISA Secretariat, e.g. in the form of a monitoring report. This would reduce the amount of data transmitted to the ISA Secretariat. Further, the Contractor should be required to store key raw data in agreement with ISA, to allow for an assessment of the data by the inspectors, without prejudice to the role of the LTC concerning inspections.

- *Data security:* The data collection, processing, transmission and storage would be protected/encrypted to avoid tampering. The mining support vessel should have a "black box" to ensure that the data has not been tampered with before or during transfer.

- *Data storage:* To reduce risks of system failure and loss of data, both the data that the Contractor generates and that the ISA Secretariat receives should be continuously backed up and stored. If data does not get through to the ISA Secretariat, the Contractor should have a system to be able to resend the data from its backup system.

- If ISA Secretariat does not receive the monitoring report within a certain period, consideration could be given to ISA taking measures to rectify the issue.

15. The yearly cost for ISA per mining project of the optimal option described above is estimated to be USD99,000 (including ISA staff).

16. In addition, "minimum" and "maximum" options are presented to show the differences in cost, resources and capacities if more or fewer parameters are monitored. The yearly cost for ISA for the "minimum" option is estimated to be USD54,000, and the cost for the "maximum" option is estimated to be USD390,600.

1. INTRODUCTION

17. Designing a robust and transparent inspection programme will be key to successfully implementing regulatory framework of ISA, particularly the exploitation regulations, and to ensuring compliance. At the same time, the development and implementation of a fit-for-purpose regulatory and enforcement framework and of an inspection mechanism need to factor in the remoteness of future mining operations. Physical inspections of the mining area may present practical challenges. In the context of oil and gas operations, the move towards greater depths, higher pressures, increased uncertainty and rising production costs has resulted in the rapid advancement of remote real-time monitoring technology in connection with health, safety and environmental matters. Similarly, remote monitoring technologies have been increasingly relied upon in the context of land-based mining as a complement to physical inspections, in particular for mining concessions located in difficult-to-access areas.

18. In the context of the development of regulations (Draft Regulations, ISBA/25/C/WP.1) on the exploitation of mineral resources in the Area of the seabed beyond national jurisdiction (the Area) by ISA, submissions from stakeholders on the Draft Regulations have stressed the importance of a robust inspection mechanism for ISA, noting the need to bear in mind that a mechanism should not impose major administrative costs, and suggested relying on remote monitoring. Suggestions were made to draw on the experience of other international organizations and regulatory bodies with remote monitoring. The ISA LTC has also acknowledged the value and significance of remote monitoring technology (ISBA/25/C/18).

19. Part XI of the Draft Regulations on Inspection, compliance and enforcement, contains provisions relating to the powers and functions of ISA to carry out inspection for the purposes of ensuring compliance with the UNCLOS, the 1994 Agreement, ISA rules, regulations and procedures, and the terms and conditions of an exploitation contract.

20. The Draft Regulations recognize the importance of establishing a system of remote monitoring for exploitation activities in the Area, in addition to the use of mandatory physical inspections (1994 Agreement, Section 2).

21. Draft regulation 96(5)(f) provides that the Contractor has to accept the deployment of remote real- time monitoring and surveillance equipment, where required by the Secretary-General, and facilitate the activities of inspectors in deploying such equipment and having access thereto.

22. Draft regulation 102 recognizes the importance of establishing a system of electronic monitoring of exploitation activities in the Area to record information on all mining activities to ensure that mining operations are restricted to the

mining area and prevent unapproved activities by a Contractor.

Regulation 102

Electronic monitoring system

1. A Contractor shall restrict its mining operations to the Mining Area.

2. All mining vessels and mining collectors shall be fitted with an electronic monitoring system. Such system shall record, inter alia, the date, time and position of all mining activities. The detail and frequency of reporting shall be in accordance with the Guidelines.

3. The Secretary-General shall issue a compliance notice under regulation 103, where he or she determines from the data transmitted to [ISA] that unapproved mining activities have occurred or are occurring.

4. All data transmitted to [ISA] under this regulation shall be transmitted to the sponsoring State or States.

23. In addition, the Draft Regulations place obligations on the Contractor to undertake environmental monitoring with a view to ensuring the protection of the marine environment from harmful effects of activities in the Area. Such monitoring is also intrinsically linked to monitoring for inspection and compliance purposes, as the techniques and tools used in the context of environmental monitoring are likely to be the same. The data collected as part of an environmental monitoring programme may provide valuable information on the extent of the mining operations and compliance with the relevant environmental standards.

24. It should also be mentioned that the relevant ISA regulations concerning remote monitoring would complement the mandatory International Maritime Organization (IMO) regulations applicable to surface mining vessels and to support vessels. These IMO regulations, stemming from the International Convention for the Safety of Life at Sea and the International Convention for the Prevention of Pollution from Ships, address safety and environmental aspects.

25. Against this backdrop, the ISA Secretariat contracted a consultant, DNV, to undertake a study to:

a) Identify remote monitoring technologies, including emerging technologies that could be applied in the context of deep-sea mining for the purpose of remote monitoring in the context of inspection, including in light of existing practices in industries such as oil and gas and by regional fisheries management organizations

b) Identify minimum resource and capacity requirements for the effective use of remote monitoring technology

c) Identify the best combination of remote monitoring and other tools to ensure that ISA can carry out its inspection and enforcement activities effectively

26. The report is organized as follows:

Chapter 3 provides some background on the systems for a seabed mineral-resources exploitation project and the purpose of remote monitoring.

Chapter 4 provides suggestions concerning the parameters that should be monitored.

Chapter 5 identifies remote monitoring technologies of relevance for the exploitation of mineral resources in the Area, with a focus on:

- Existing and proven remote monitoring technologies from other sectors that can be adapted for remotely monitoring exploitation of seabed mineral resources
- Existing and proven as well as emerging technologies suitable for remotely monitoring exploitation of seabed mineral resources

Chapter 6 identifies the minimum necessary resource and capacity requirements to operate a remote monitoring system effectively. This includes cost for data collection, processing, security, transfer and storage.

Chapter 7 identifies the best combination of remote monitoring and other tools to ensure that ISA can carry out its inspection activities effectively.

27. Based on the identified information in Chapters 4 to 6, an optimal option is presented. In addition, "minimum" and "maximum" options are presented to show the differences in cost and required resources (human and equipment) and capacities.

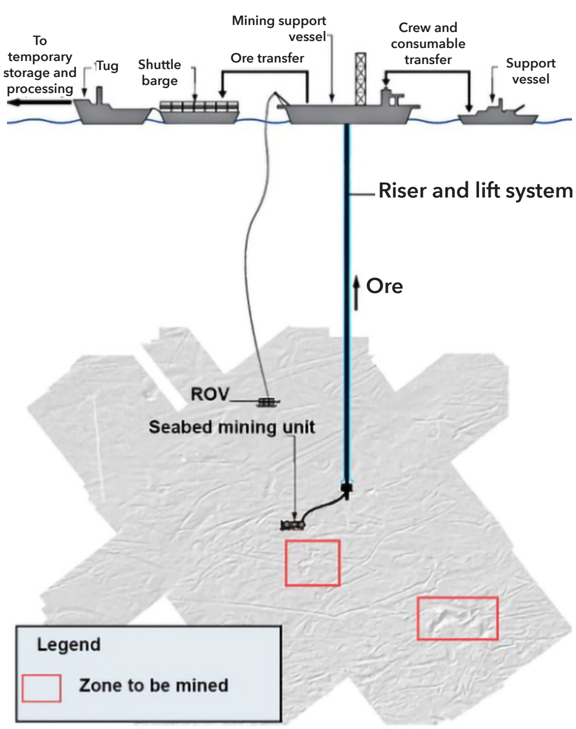
2. BACKGROUND

2.1 The mining site

28. Deep-sea mineral resources are mainly located in water depths of 1,000 m or more. Some resources are found as deep as 6,000 m.

Figure 1 shows a potential deep-sea mining site.

Figure 1. General illustration of a potential deep-sea mining site



29. The specific mining technologies that will be used will vary depending on the minerals that are being mined (i.e. nodules, sulphides or crusts). However, remote monitoring technologies will not differ based on the specific mining technology used. Therefore, the remote monitoring technologies described in this report are not specific to the various mining technologies, unless stated otherwise.

30. When discussing mineral resources exploitation technologies, it has to be pointed out that no commercial deep-sea mining has taken place so far. There are, however, several projects under development and some equipment tests have been performed.

31. The setup at the mining site can be divided into three parts:

The sea surface: The sea surface is where the mining support vessel is located and where the ore arrives from the seabed. Different approaches are under evaluation for ore dewatering. Ore dewatering on the mining support vessel may have harmful environmental effects. Other approaches include dewatering on the seafloor and lifting the ore in a closed circuit with a medium with much better transport capacities than seawater (something similar to drilling fluids). The mining support vessel may then transfer the ore to a barge or a ship that brings the ore to an ore processing plant on land. In addition, support vessels will help with crew changes and bring in necessary consumables. This part of the mining operation, given its location at the surface, is theoretically the easiest to monitor as the data is more easily collected and the collected data can be sent directly from the mining support vessel.

The water column: From the sea surface down to the seabed is a lift system which brings the ore up to the mining support vessel. The lift system could be, for example, a riser through which the ore is pumped or a container that is lifted through the water column. There could be, in some cases, a pipe bringing the return water from the dewatering of the ore on the mining support vessel back down close to the seabed. More likely, the transporting fluid would be constantly used in closed circuits, and seawater from deep sources would not be released at higher oceanographic levels. An umbilical going from the mining support vessel down to the mining unit on the seabed supplies necessary (remote) control, energy (electric, hydraulic) and data transfer. In addition, functionality needs to be monitored by the production process, and the mining support vessel usually would have one or several remotely operated vehicles (ROVs) or autonomous underwater vehicle (AUV) fitted with cameras for visual inspections and different tools to carry out operational functions on underwater equipment. While ROVs transmit data in real-time, AUV systems are more difficult to monitor. The information first has to be collected underwater and then sent to the mining support vessel for further transmission.

The seabed: The mining unit operates on the seabed. The design of the mining unit will vary depending on the resources that are being mined (polymetallic nodules, seafloor massive sulphides or cobalt-rich crusts). In many technical concepts, the mining unit would be equipped with a subsea pump connected to the riser bringing the ore up to the mining support vessel. Taking into account the long pumping distance, additional pumps along the riser may also be necessary. Transport of the ore from the seabed to the vessel in batches using some type of container is considered time-consuming and costly. The presence of umbilicals on the seabed from ROVs, collectors or drilling technologies would allow for real-time data transmission to the mining support vessel and facilitate seabed monitoring. Seabed information, however, first has to be collected for further transmission.

2.2 Use of remote monitoring by ISA

32. Locations for mineral resources exploitation in the Area can be several days by ship from the nearest harbour. This makes physical inspections more difficult in terms of time and cost. Remote monitoring would make it possible for ISA to supplement and support physical inspections from land-based locations and enable spot checks in case of suspicion of irregularities.

33. Remote monitoring would also allow ISA to follow and inspect mineral-resource exploitation activity from its main office in Kingston, Jamaica, or from elsewhere in the world. The main technical challenges with remote monitoring are:

- collection of data
- transfer of data
- ensuring that data cannot be manipulated
- interpretation of data
- storage of data.

34. Specific challenges related to these issues are addressed in Chapter 6.

3. PARAMETERS TO BE MONITORED

35. A basic and very important question is which data is needed by ISA to allow for effective remote monitoring of exploitation of mineral resources in the Area.

36. A wide range of data will be collected by the Contractor and could also be used by ISA for inspection and compliance purposes.

37. Table 1 lists the parameters considered relevant for remote monitoring of exploitation in the Area. However, it is noted that scientific discussions towards defining the necessary environmental parameters to be monitored are ongoing.

38. Table 1 also sets out the suggested type of data to be collected and where such data should be collected (sea surface, water column or seabed).

39. Table 1 is divided into three main groups of parameters for monitoring activities:

- *Parameters related to position:* These parameters provide information on the position of the mining support vessel, mining unit etc.
- *Parameters related to production:* These parameters provide information on how much ore is actually mined at the site.
- *Parameters related to the environment:* These parameters provide information about the environmental conditions at the site such as the weather, oceanography, plumes, seabed conditions, noise, light, marine biodiversity and habitats.

Table 1. Parameters for remote monitoring of exploitation activities

Parameter	Type of data	Collection location
Parameters related to the position		
Position of the mining support vessel	Coordinates (x, y) + IMO identification number	Sea surface
Position of the mining unit including water depth	Coordinates (x, y, z)	Seabed
Parameters related to production		
Amount of ore on board the mining support vessel	Volume and weight of ore, calculated based on displacement of the vessel	Sea surface

Parameter	Type of data	Collection location
Amount of ore being transported through the water column to the mining support vessel	Flow of ore (mixed with transport medium) measured with a flowmeter if a riser is used, or weight of the ore if transported in batches	Water column (riser)
Area of seabed covered	Distance travelled (collector), metres drilled (drill) or area covered (drill, grab, ablation tool)	Seabed
Parameters related to the environment		
Meteorological conditions	Data from weather stations on temperature, wind speed and direction, air pressure and precipitation	Sea surface (above)
Oceanographic conditions	Data from sensors that measure wave height, wave period, wave direction, current direction, current velocity and directions, temperature, salinity, surface productivity and turbidity (including x, y, z coordinates for all measurements)	Sea surface (all data) Water column (current direction, current velocity and direction, temperature, salinity and turbidity) Seabed (same as for water column)
Pollution generated by the mining support vessel (oil spills, spills of ore material etc.)	Satellite data and/or turbidity sensors	Sea surface
Plumes generated in the water column (for example from collector, riser or return water discharge)	Observations from ROV/AUV camera/laser beam/radar technology and/or data from turbidity sensors at different water depths	Water column

40. The parameters described in Table 1 aim to monitor the activities of a Contractor while mining at a site to ensure that no unapproved activity takes place. Studying the long-term effects of mining activities would require measuring additional parameters.

41. The focus of the remote monitoring done by ISA is compliance with the ISA rules and the contract that the Contractor has for the mining operation.

42. Based on experience, it is suggested that ISA should define which data sets need to be received to allow continuing operations.

43. The parameters listed in Table 1 are all of interest, but some are considered more important to monitor than others. Chapter 7 lists the required parameters under the optimal option, the minimum option (the minimum of parameters needed) and the maximum option (all parameters needed).

44. Considerations related to some of the parameters listed in Table 1 are as follows:

- The parameter measuring the amount of ore being transported through the water column to the mining support vessel is assumed to be technically challenging and costly to establish if a riser is used. There will be a need to install a flow meter in the riser, similar to what is commonly used in on-land mining and in waste management to measure the total flow of both ore and transport medium. If the ore is transported in batches, such as in containers through the water column, it will be easier to control it on board the mining support vessel. Therefore , it is suggested that the amount of ore should be controlled by the weight of ore, calculated based on flow rates and densities as well as the volume displacement of the vessel, and/or by weighing the transport containers if batchwise transport is used.

- The environmental parameters linked to noise and light emissions are assumed to give less important information concerning unapproved activities. Sedimentation during mining activities is largely a function of the mining process, and the collector and drilling technologies. Measures have to be in place to keep plumes below a critical level.

- The noise parameter could preferably be controlled as a part of the certification of the equipment that the Contractor will use at the mining site. Noise emission should not exceed a level to be determined.

- The light source parameter could be identified during the application process and measures could be taken already at the planning stage of the project. Light emissions should not exceed a level to be determined.

- However, if noise and light are already monitored by the Contractor at the mining site, and the parameters are readily available, ISA could use them for inspection purposes.

4. RELEVANT REMOTE MONITORING TECHNOLOGIES FOR EXPLOITATION OF MINERAL RESOURCES

45. Remote monitoring and inspection technologies already exist in other sectors, such as offshore petroleum installations, submarine pipelines, submarine cables and fisheries. The first part of this Chapter describes such existing technologies.

46. The second part of this Chapter describes how existing and proven as well as emerging remote monitoring technologies can be used in the context of seabed mineral-resources exploitation, with or without modifications. "Existing and proven remote monitoring technologies" means technologies that can be applied for monitoring and inspection processes in seabed mineral-resources exploitation today. "Emerging remote monitoring technologies" means technologies that could be further developed and applied for monitoring and inspection processes in seabed mineral-resources exploitation when exploitation becomes fully operational.

4.1 Examples of existing and proven technologies from other sectors

47. Several examples of existing and proven remote monitoring technologies from other sectors could be adapted for remote monitoring exploitation in the Area. Examples of such sectors include:

- offshore petroleum installations
- submarine pipelines and submarine cables
- fisheries.

Offshore petroleum installations

In the context of offshore petroleum installations, parameters that are also relevant for monitoring exploitation of mineral resources in the Area are also monitored.

Seabed currents are monitored by current meters installed directly on platforms and with current meters placed on the seabed, with the data sent by cable to the platform.

Many platforms also have sensors for sound and light, with the data sent by cable to the platform.

Different methods are used to detect plumes around platforms:

- Echo sounders for tracing the extent of a plume
- Turbidity measurements to detect where in the water column most of the particles are
- Sedimentation monitors, which send an alarm if excess sedimentation is accumulated in sediment traps
- Video and imaging are increasingly used, mainly ROVs and AUVs equipped with cameras

Equipment for detecting pollution in the water body, for example methane gas and oil, is also used. This is done by installing methane sniffers and oil detectors on AUVs and ROVs. It is also possible to use biosensors, with mussels that respond to contaminants in the water, and monitor clams' heart rate and frequency of opening and closing, which, if irregular, indicates contamination.

It is important to have solid detection systems that can respond quickly to oil spills from offshore petroleum installations. A wide range of systems are used for this purpose:

- Synthetic-aperture radar (SAR) detects small-scale two-dimensional-data from aircraft or satellites and derive 3D data from shadows
- Optical sensors detect changes in colour, permeability etc. from the air or mounted on vessels
- Side looking airborne radar or SLAR is used to map the sea surface from the air
- Laser fluorescence or LFS sensors are mounted on either vessels or aircraft to detect oil spills
- Microwave radiometry or MWR is mounted on vessels or aircraft to detect and assess oil slick thickness
- Infrared or ultraviolet line scanner is used for airborne monitoring of oil spills and relative oil spill thickness
- Forward looking infrared or FLIR is an optical instrument identifying oil slicks and thermal properties of the sea surface
- Light detection and ranging or LIDAR is 3D laser scanning with several applications, used from vessels, aircraft or subsea, to map, e.g., particle plumes and spills
- Cameras or video are used on ROVs, AUVs, vessel, aircraft or satellite.

In recent years, there has been substantial development in monitoring technology at offshore petroleum installations, driven by the digital revolution. An example is multisensory monitoring systems, where several sensors are placed on a lander that can perform oceanographical measurements, particle measurements and visual observations and send real-time data to a server solution. It is also possible to make such data open to the public.

Experiences from monitoring offshore installations have proven the reliability of some of the technologies but have also shown that there are challenges related to implementing real-time monitoring offshore (i.e. loss of signal, data lag and insufficient power).

The main challenge for monitoring exploitation of mineral resources in the Area compared to offshore petroleum activities is that petroleum activities seldom take place deeper than 1,000 m, while exploitation of mineral resources in the Area could take place in deeper water, locally up to 6,000 m. This is demanding for the monitoring equipment and also for the communication of data to the sea surface, but common technology and real-time transmission via umbilicals with glass fibre optics are frequently used with ROV surveys.

Figure 2. Schematic illustration of environmental monitoring of offshore petroleum activities showing a lander with camera systems and sensors, with separate units for additional sensors, fibre-optic and power connections

Source: LoVe Ocean Observatory

Submarine pipelines and submarine cables

Submarine pipelines

Submarine pipelines are found worldwide on the seabed and are used for transporting mainly oil and gas. The pipeline is laid directly on the seabed or below the seabed inside a trench.

Submarine gas pipelines produce bubbles when gas leaks. Detection of the bubbles allows tracing of the gas leak. The detection can be done by active sonar systems that emit sound pulses for detection of bubbles or with passive sonar systems that have hydrophones listening for bubbles (see Figure 3).

Leaks from submarine oil pipelines can be detected by fluorescence meters or optical cameras mounted on an ROV.

Leaks can also be detected by using a capacitive sensor monitoring change in the dielectric constant of the medium surrounding the sensor.

Another possibility is to use internal leak detection systems based on the continuous calculation of the mass balance. The mass balance is calculated based on pressure and fluid flow measured at the inlet and outlet of the pipeline. A deviation in the mass balance indicates a leakage.

A method to monitor the entire length of an oil pipeline is to place a fibre-optic cable along the whole pipeline length. Leaks are indicated by changes in temperature along the pipeline. By scanning the total length of the fibre, the temperature profile along the pipeline is determined and the point of the leak can be detected.

The detection systems for leaks based on detecting gas bubbles from submarine pipelines are not directly transferable to the monitoring of exploitation of mineral resources in the Area. A leak from a riser or transport container for minerals will mainly emit particles, not gas bubbles. On the other hand, leak detection technologies based on mass balance or optical cameras could also be used in exploitation of mineral resources in the Area.

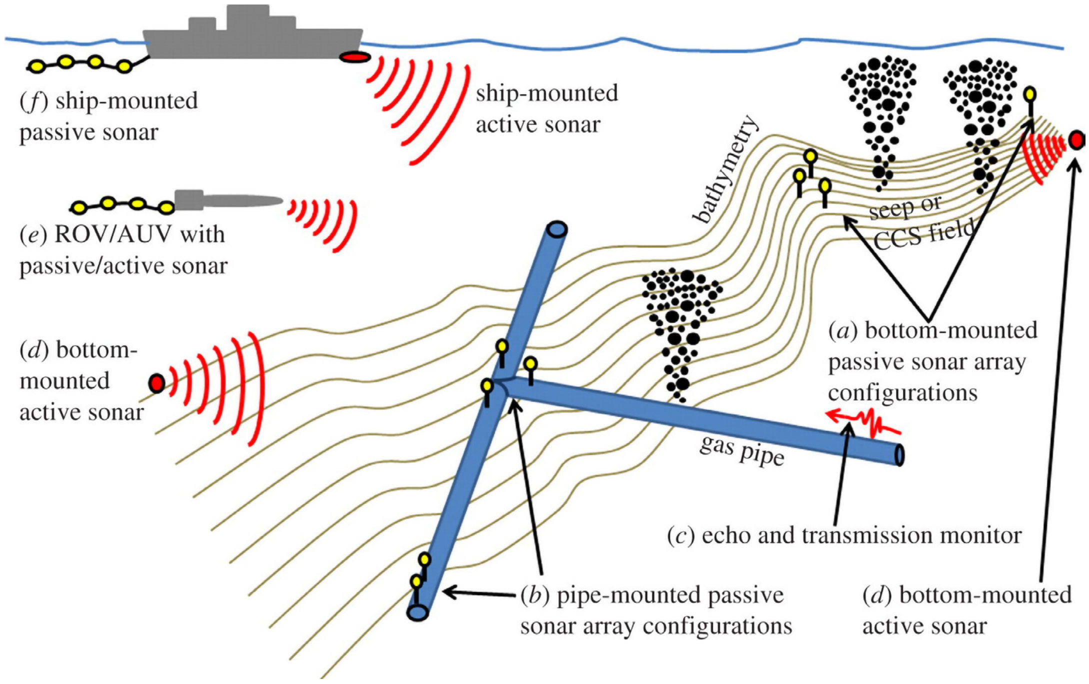
Submarine cables

There is a wide range of submarine cables on the seabed, mainly used to carry telecommunication signals across stretches of the oceans and seas. The most modern cables use optical fibre technology to carry digital data, including telephone, Internet and private data traffic.

Submarine cables can break due to fishing trawling activity, anchors, earthquakes or turbidity currents. It is important to detect and quickly repair a broken cable. The location where the cable is broken is identified by sending signal pulses through the cable. The damaged area of the cable will bounce back the pulse to the signaling site which sent the data. Calculating the time delay from the reflected signal, it is possible to locate the exact point and area of the problem.

The use of submarine cables for data communication will be helpful to monitor the exploitation of mineral resources in the Area. They can, for example, connect different monitoring devices (e.g. lander systems) on the seabed.

Figure 3. Detection of gas bubbles from pipeline with active or passive sonar systems



Source: Royal Society Publishing

Fisheries

The VMS are systems that are used in commercial fishing to allow tracking and monitoring of the activities of fishing vessels.

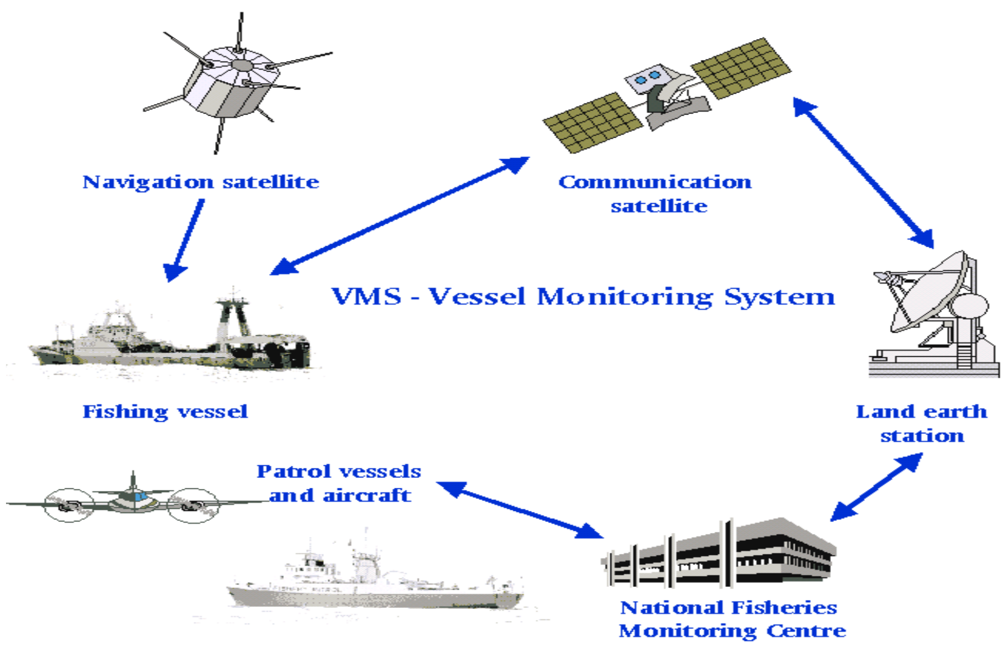
A VMS is a satellite-based monitoring system which, at regular intervals, provides data to the relevant fisheries authorities on the location, course and speed of vessels. VMS is a standard tool of fisheries monitoring and control that is used worldwide. Catch reports are not themselves part of VMS, but they are often correlated with VMS data as part of an overall fisheries monitoring control and surveillance programme. It is also possible to register fishing gear that is used in the VMS system. This can be used to detect abnormal fishing vessel behaviours with respect to the registered fishing gear.

VMS components on the fishing vessel minimally include a GPS antenna and receiver, a computer (which may be embedded or user-supplied), and a transmitter and antenna appropriate for the communications that links the vessel to the Fishing Monitoring Center, an information security center where the VMS data are protected from intentional or accidental damage or disclosure and only authorized personnel can access the data.

The type of VMS system that is used depends on the vendors and models approved by the fishing vessel's State of registry and the functionality requirements. Normally a national or intergovernmental body will specify approved equipment to ensure end-to-end system integrity and service level, meeting specific requirements applicable to the vessel type. For example, some systems require a user interface on the vessel, whilst others have a simple black box transceiver with no user interface.

The setup of VMS systems has many similarities with what is needed to obtain basic data for remote monitoring of exploitation of mineral resources in the Area. Using the experience from an already-existing system such as the VMS will help to enable faster implementation of remote monitoring of exploitation of mineral resources in the Area.

Figure 4. The main components of an VMS



Source: European Commission

4.2 Existing and proven (and emerging) technologies suitable to monitor the exploitation of seabed mineral resources

48. Several existing and proven (and some emerging) remote monitoring technologies are suitable to monitor seabed mineral resources exploitation.

49. Monitoring of mineral resources exploitation in the Area presents a number of challenges. These include:

- The mining site is often far out in the ocean with long distances to land, complicating data transfer.
- The data collected from the seabed and water column has to be transmitted through the water column as far as several thousand m up to the mining vessel. With existing technology, this would preferably have to be done through a cable or umbilicals with fibre optics due to substantial challenges with sending signals along such distances through the water.

- Transferring data from the seabed via cables is generally expected to be more challenging in abyssal depths (>4,000 m) than transferring data from bathyal depths (1,000–4,000 m). The use of fibre-optic cables will significantly reduce transfer times.

50. The remote monitoring technologies suitable for seabed mineral resources exploitation can be divided into technologies for positioning, production and environment.

4.2.1 Positioning

51. There are several existing and proven technologies for obtaining the position of surface vessels.

52. **AIS**: The position of the mining support vessel and other supporting vessels can be checked through an AIS, an automatic tracking system using transponders on the vessel which can send information about its position to ISA.[2]

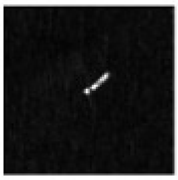
53. **LRIT**: In 2009, IMO implemented mandatory requirements for cargo ships above 300 gross tonnage to transmit information including vessel ID, position and time of position through a certified onboard solution to a system called LRIT where information is received by the shore-based LRIT data centres and used by national and regional authorities in relation to traffic surveillance, monitoring and intervention when vessels may represent a risk to safety at sea or towards the coastal State, for search and rescue purposes and to detect illegal activities.[3]

54. LRIT information from every vessel will be available at 6 hour intervals. Still, the reporting interval exercised by the vessel is configurable from the onshore LRIT data centre on request by LRIT data users or authorities.

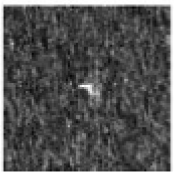
55. Whether ISA will be able to get access to LRIT data for contractors' vessels could be further investigated, as information received through this system is assumed to have higher integrity than data received through the AIS system.

56. **Satellite-based vessel detection:** Satellite service providers offer commercially-available vessel detection with global coverage, with an estimated positional accuracy of 100 m. Depending on the latitude, the number of vessel detection observations per day from commercial providers will typically be two near the equator, between two and three at latitude 30 degrees, and between three and five at latitudes above 60 degrees (Ayasse and Bishop, 2020). Such vessel detection does not require a signal from the vessel and is therefore assumed to have high integrity. In addition to monitoring of identified vessels, satellite-based vessel detection enables monitoring and snapshots of all surface assets, down to typically 10 m length, in the area of interest (Chapter 5.2.3).

Figure 5. Examples of satellite pictures of a 139 metre-long ship (top) and 10 metre-long ship (bottom)



Position 28.92696N 94.78471W
Heading (SAR) 047
Length (SAR) 139 m
Width (SAR) 13



Position 29.12639N 94.82178W
Heading (SAR) 214
Length (SAR) 10 m
Width (SAR) 4

Source: KSAT

57. **Drone-based vessel detection:** The use of drones for all types of monitoring is

[2] http://www.imo.org/en/OurWork/Safety/Navigation/Pages/AIS.aspx
[3] http://www.imo.org/en/OurWork/Safety/Navigation/Pages/LRIT.aspx

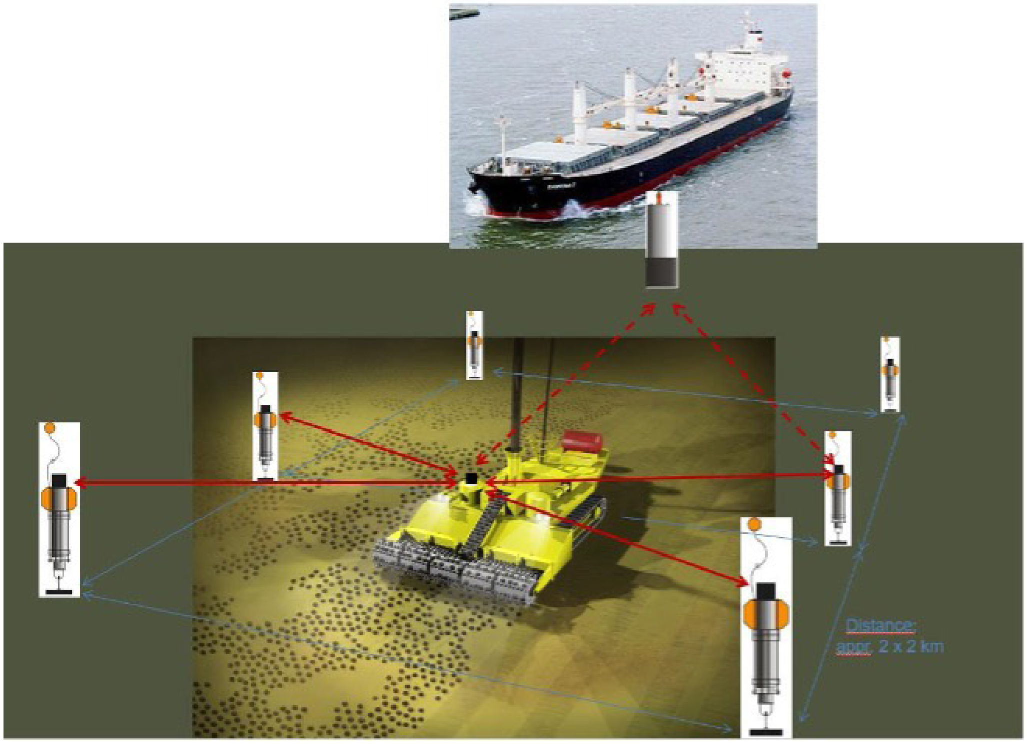
emerging. However, they are not suitable for vessel detection yet. The main reason is because a regular drone can fly about 50 km from its base station (typically on land) and can be difficult to control even at shorter distances. This is a significant limitation, as most seabed mining activities are expected to occur far from land. As these technologies are developing rapidly, there is a good possibility of more suitable drone technology in the future.

58. **Autonomous vessel tracking devices:** Several providers offer onboard tracking devices, typically including a built-in GPS receiver and a satellite transmitter (e.g. Inmarsat) to transmit position information to a shore-based web solution. As this is an autonomous transmitter only connected to the vessel power supply, the information integrity is considered high.

59. **Underwater acoustic positioning/navigation systems:** Positioning of the mining unit, including water depth can be done by underwater acoustics. The support vessel communicates via a transducer to transponders on the objects at the seabed, so that the depth and offset from the support vessel's GPS position can be calculated.

60. **Ultra-short-baseline:** This system is most commonly used and is expected to work at distances up to 8,000 m. The positioning accuracy can be further improved by placing navigation beacons or transponders on the seabed (long-baseline). When using these systems at large depths, a lag in the positioning of the subsea units must be expected. The accuracy of positioning at 2,000–5,000 m water depth with these systems is generally within 10 m.

Figure 6. Nodes sending monitoring data (including position) from transponders on the seabed to the surface vessel, which has a receiving transponder



Source: EvoLogics

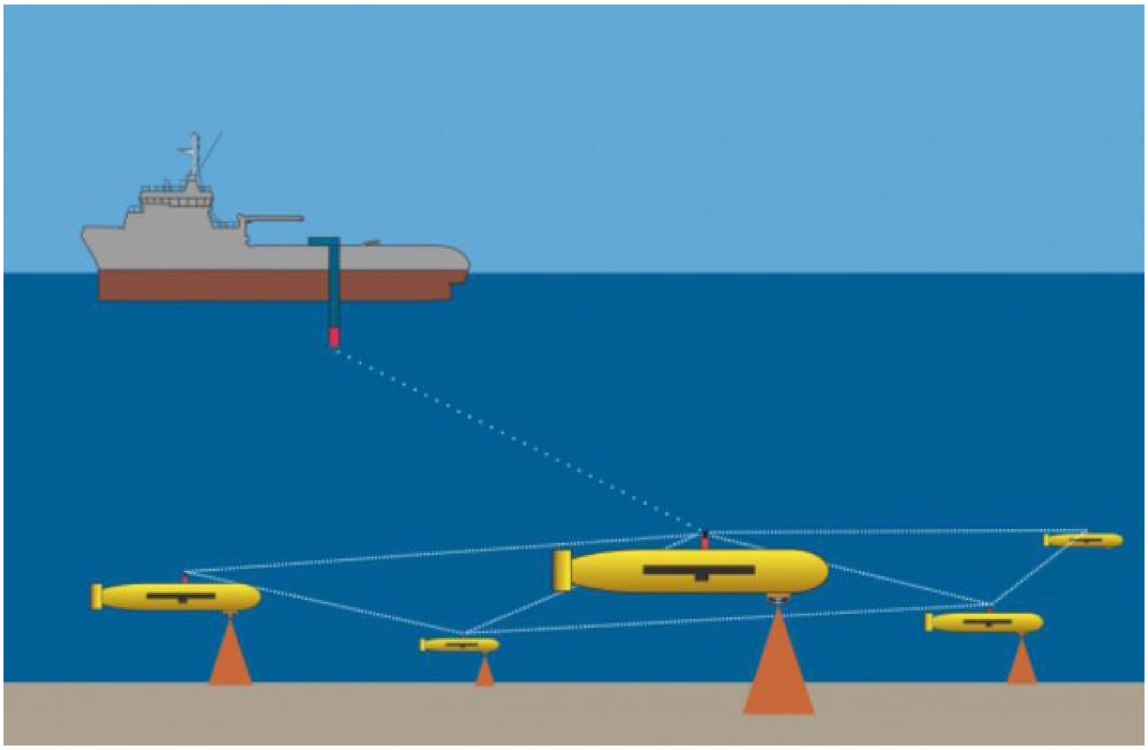
[4] Ayasse, R. and C. Bishop (2020), KSAT, Norway (personal communication).

61. Relaying subsea positioning data, for example to ISA in Kingston, can be done by a satellite link from the support vessel or via radio signals for shorter distances. Navigational strings can be sent as digital telegrams to be interpreted by the receiver, or the receiver can have a mirror screen of the navigation system on their location. This is commonly done when one vessel is undertaking the subsea operation, while other vessels can watch the navigation screen remotely.

62. **Swarm technology and underwater positioning (emerging technology):** An emerging technology that can be used for getting the position of the mining unit, including water depth, is to utilize several AUVs communicating with each other and with a surface vessel, ensuring that positioning of the subsea components is up to date (see Figure 7).

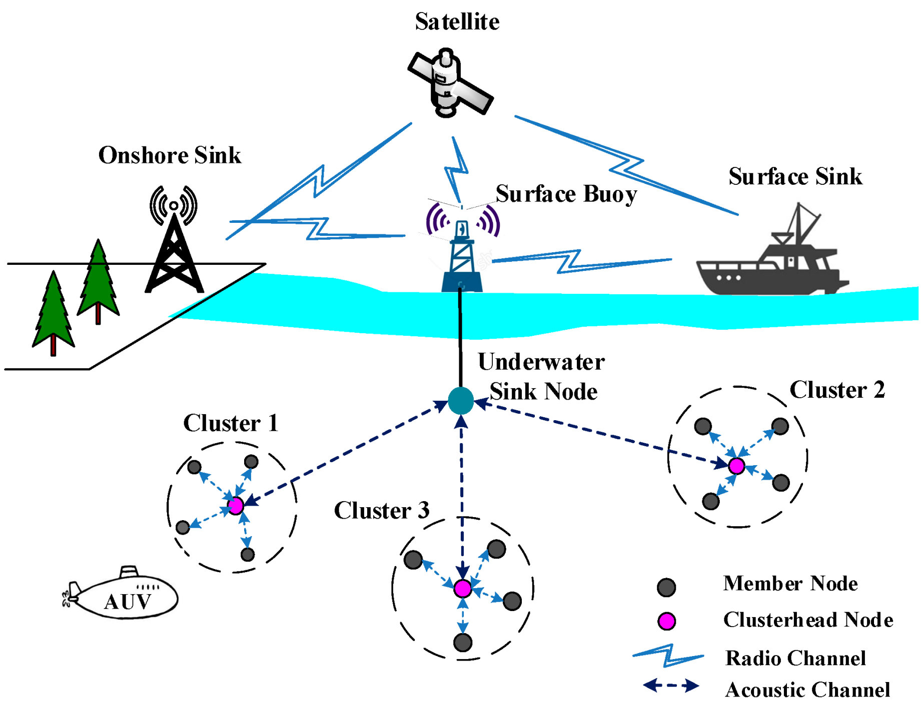
63. The AUVs can further communicate with subsea nodes, collecting data and relaying data to sink nodes for further transfer. The overall system is often defined as a wireless underwater sensor network consisting of several components: onshore sink, surface buoy, underwater sink node, and underwater sensor nodes (Figure 8). Moreover, satellites, vessels and AUVs can be used to expand the sense and communication range. Underwater sensor nodes monitor physical or environmental conditions, such as pressure, sound, temperature etc. and cooperatively transmit data to the underwater sink node. The data are transmitted to a surface buoy via a wired link, and finally received at an onshore sink or surface sink via radio communication (Morozs et al. 2018).

Figure 7. AUVs working as a swarm and as interconnected subsea networks



Source: Sonardyne

Figure 8. Underwater wireless sensor network



Source: Yang, 2018.

4.2.2 Production

64. Loading condition as a measure of production: With respect to monitoring production rate and the total amount of produced ore, the mining vessel's loading computer software can be used. Installation, functionality and use of loading computers are addressed in various IMO and classification guidelines and requirements. All mining support vessels would likely have an installed loading computer kept up to date with the amount of ore in cargo holds for the calculation and monitoring of the vessel's stability. The entry of the amount of cargo in cargo holds can be automated and/or manual. The cargo load can be compared with production numbers from collector/ drill and flow measurements in the riser system. Provided the loading computer is provided with an appropriate digital output interface, the amount of ore can be automatically sent to the data processing computer or "black box" for entry into a weekly monitoring report as cargo produced since the last report and the total cargo onboard. If such a digital output interface is not provided, such entries can be done manually to the data processing computer or "black box".

65. **Flow of ore through the riser (emerging technology):** With respect to the amount of ore pumped through the riser up to the vessel, technologies from other sectors, such as magnetic flow meters or sonar flow meters, can be used.

66. Magnetic flow meters generate a magnetic field in the pipe. When a conductive medium (the ore) passes through the magnetic field, a voltage is generated which is proportional to the velocity of the medium. By knowing the medium's velocity and the cross-section of the pipe, the flow can be calculated.

67. With sonar flow meters, the sonars "listen" to and interpret pressure fields generated by turbulent pipe flows.

Figure 9. Magnetic flow meter (right) and sonar flow meter (left)

Source: Metron Technology and Cidra.

68. Both technologies are non-intrusive meaning they are not in contact with the ore. To our knowledge, flow meters have not been tried out for seabed mining applications. It is noted that even if the flow can be calculated, it will be difficult to know how much ore and how much transport medium is going through the riser.

4.2.3 Environment

69. Environmental data from the sea surface: Environmental data from the sea surface, including meteorological and oceanographic data, can be collected directly on the vessel.

70. Systems using raw data from shipboard navigation radars have been installed on vessels and offshore installations for monitoring of multiple environmental and oceanographic parameters, wave/swell height, such as period and direction of wave and swell, as well as surface current speed and direction. Such systems also offer the possibility to detect oil spills on the surface.

71. Real-time sensors for parameters such as wind speed, wind direction, air temperature, sea temperature and air pressure (barometers) are commonly installed on all vessels. Real-time environmental sensors have also been installed on the hull of vessels to measure parameters such as salinity and phytoplankton.

72. **Remote environmental monitoring/ satellites:** Data can also be collected by remote sensing via satellites, drones and airplanes.

73. There are about 5,000 satellites orbiting the planet and observing the whole earth. However, coverage and accessibility can differ largely and be quite limited.

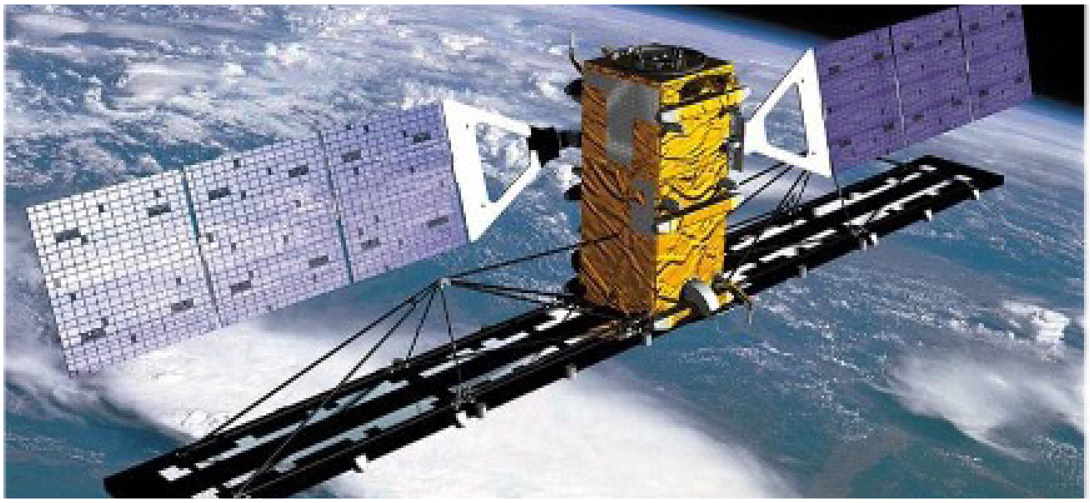
74. Satellite-based observations of the oceans can detect and monitor the evolution of oil spills, plumes, total suspended matter concentration, dissolved organic matter, sea surface temperature, wave height etc. Data is available from both open and commercial platforms and service providers.

75. Satellites can also be used for detecting vessels and their position (Chapter 5.2.1).

76. Satellites mainly use optical or radar data sensors to detect oil spills or plumes on the sea surface.

Optical data: Satellites that use optical technology can be considered passive looking sensors. They examine the surface of the Earth across a varied spectrum of electromagnetic radiation, from the visible to the thermal range. Passive sensors measure reflected sunlight emitted from

Figure 10. Satellite using SAR radar technology



Source: European Space Agency

the sun. When the sun shines, passive sensors measure this energy.

Radar data: Satellites that use radar technology can be considered active looking sensors. They emit a beam of microwave radiation towards the Earth, and the sensor that is sensing the radiation collects radiation reflected back to the receiver. The radar echo is received by the satellite antenna and recorded. The distance between the satellite and the reflection points on Earth is then measured and processed, so that imagery is obtained and understandable for humans and artificial intelligence.

77. A cloudy sky is not a problem for a satellite using radar technology, offering monitoring capability on the ground in all weather and all light conditions. Such a capability is not possible for sensors using passive technology, as the ground view is obstructed by clouds.

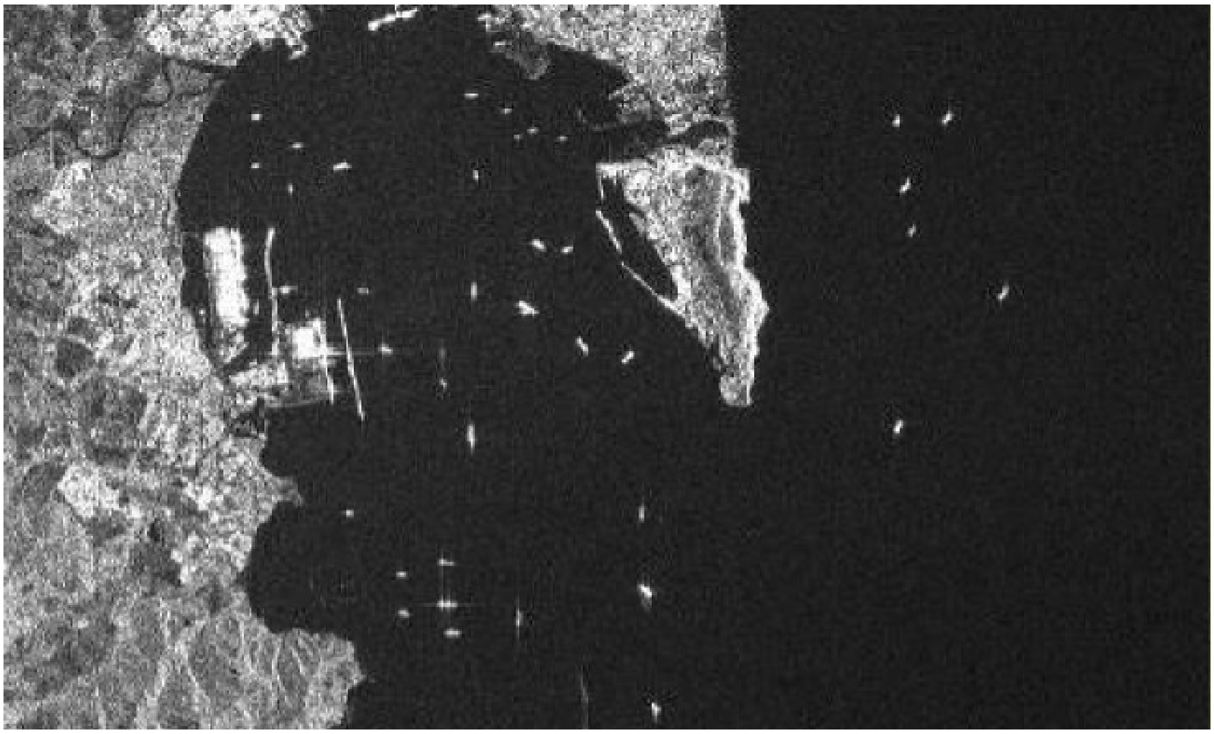
78. The dampening effect of oil on the sea surface enables the detection of oil spills using radar technology. Plumes are not assumed to provide the same dampening effect and are therefore assumed to be more difficult to detect with radar sensors due to gravity and settlement through the water column.

79. However, procedures may be developed utilizing optical sensors to detect visually distinct plumes on the surface. The availability of satellites with sufficient optical capacities has not been investigated in detail, but the geographical and time coverage of such capacity will likely increase in the near future. Satellite-based monitoring also makes it possible to detect temperature shifts on the sea surface which may indicate discharges to the sea from the mining support vessel, or other vessels supporting the operation.

80. National and international space agencies have satellites offering free open data. The finest spatial pixel resolution for such open-source data is about 7 m x 7 m. This should be sufficient to identify vessels, oil spills and plumes. Typically, satellites from a space agency (free data) will pass over a mining area around the equator approximately every sixth day (about once a week). If the mining area is located at high latitudes, satellites will pass every day. If an image of the mining area every sixth day is infrequent, it may be possible to combine free data from different space agencies to get images more frequently.

81. The images taken by the satellites need to be pre- and post-processed, and detection/classification algorithms need

Figure 11. Vessels observed between Gibraltar and Algeciras in September 2017 (SAR data)



Source: Sentinel

to be deployed to retrieve vessels, oil spills and plumes.

82. There are also many commercial satellites worldwide that offer imagery services. If a better image resolution is needed in cases of suspected unapproved activities or incidents, it is possible to buy commercial satellite images, as these can have a pixel resolution of 1 m x 1 m or even better. Such images must be ordered ahead as they are taken especially for the task. Given the fine spatial resolution of such images, they are quite large in size (roughly around 20 GB for an image). A commercial company will roughly charge around USD400 for such an image and around USD1,500 for both image and a report identifying the processed identified items in the image. The higher cost for the processing results from expert processing and interpretation of the images, including, for example, identifying the type of vessels and calculating the size of plumes.

83. Satellites with sensor technology and the appurtenant sensor data processing methods are already a very important monitoring technology. However, they can also be regarded as an emerging technology because they are continuously refined and expected to provide even more reliable and precise information for monitoring purposes in the future.

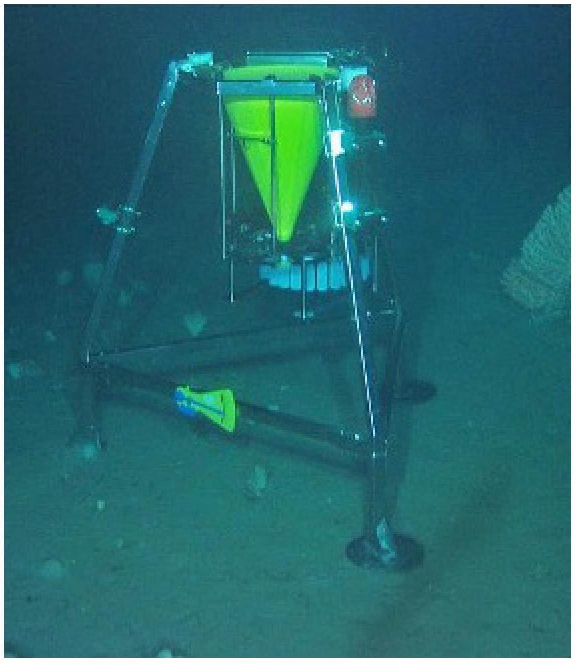
84. **Environmental monitoring with drones:** The use of drones is emerging technology for all types of monitoring, including environmental. The advantage of using drones compared to satellite monitoring is that the drone can fly much closer to the object and register more details than what is possible from a satellite. However, drones have not yet been found to be suitable for environmental monitoring. The main reason is that a regular drone can fly about 50 km from its base station (typically on land) and it can be difficult to control even at shorter distances. This is a significant limitation as most seabed mi-

ning activities are expected to take place far from land. As these technologies are developing rapidly, there is a good possibility that there will be more suitable drone technology in the future.

Figure 12. Drone used for collection of aerial (weather) data

Source: Science Direct

Figure 13. A lander (tripod) equipped with sediment trap, current meter and turbidity meter



Source: DNV

85. Environmental data from the water column and seabed: A multitude of data types can be collected in the water body or on the seabed. The data can range from oceanographical data (temperature, salinity currents) to more environmental data concerning particle or plume distribution, discharges of pollutants, noise and vibration.

86. Two main types of platforms for collecting data exist:

- mobile sensor platforms (ROVs, AUVs, mining equipment, surface-controlled instrument carousels etc.)
- fixed sensor platforms (as landers or moored with buoys).

87. Mobile sensor platforms can move around in the environment collecting data that is then either stored or sent directly to the surface vessel in real-time. The fixed installations need to be cabled to docking stations or signal buoys that mobile platforms can visit and must be able to download the data via acoustic or optical modems, or radio signals.

88. After retrieval of the data, the surface vessel can send raw data or prepare data packages to be sent to ISA.

89. Recent emerging technologies are data buoys and glider systems that drift around in the oceans along well-defined ocean currents, being submerged for longer periods and collecting data on temperature, pressure, salinity, oxygen concentration, nutrients, pH and chlorophyll in the sea. When reaching the surface, the systems send their data via satellite connection to shore. However, one point to note is that the drifts measure every 2–5 seconds or less, providing one measurement at a certain time at a certain position and only along the currents, thereby potentially limiting the exposure time and therefore environmental survey capacities.

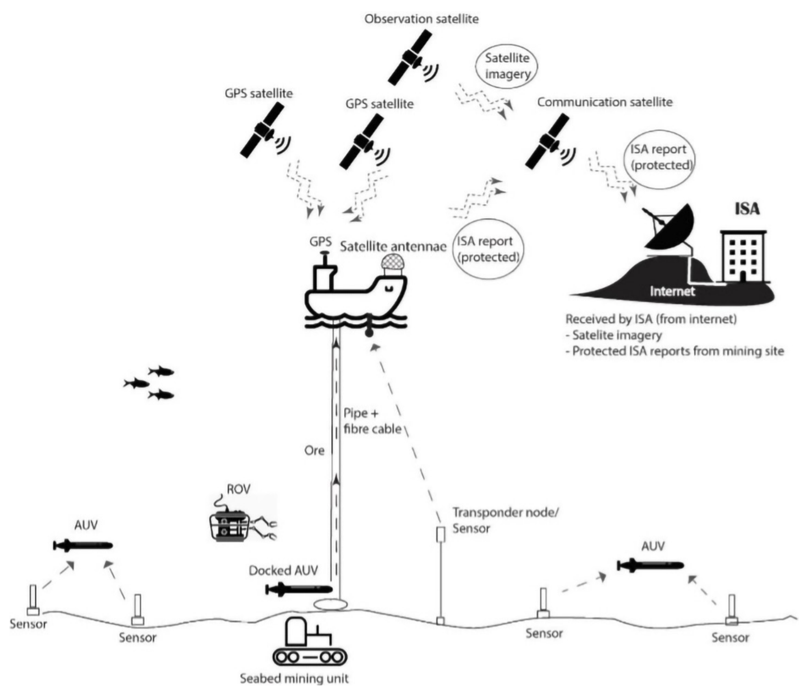
5. MINIMUM RESOURCE, CAPACITY AND COST REQUIREMENTS

90. This Chapter presents the minimum necessary resource and capacity requirements related to the different parts of remote monitoring. Further, unit costs are given (as far as possible) for the different items included in data collection, processing, security and transfer to shore. However, there are significant uncertainties associated with the indicated costs, as similar operations and equipment have not yet been commercially used at water depths relevant to this study.

91. In Chapter 7, the total costs for the "optimal", "minimum" and "maximum" options are presented, which are combined costs of the unit costs in this Chapter.

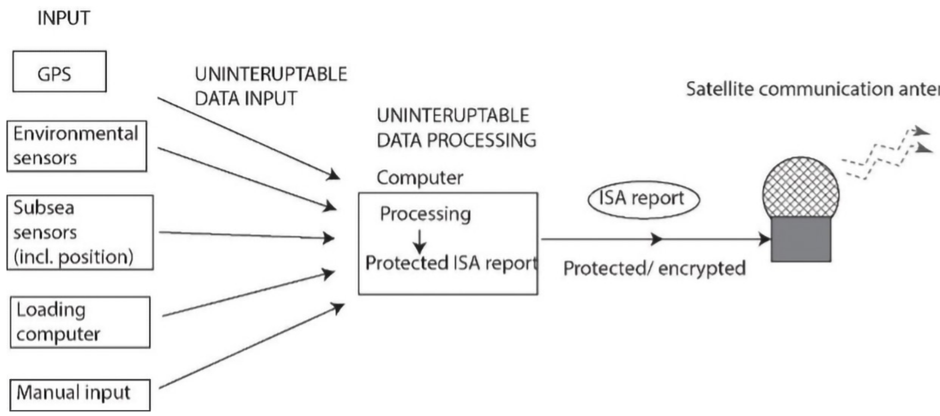
92. Such information will assist in assessing the extent to which ISA can carry out such tasks with its own personnel, or if further external assistance would be needed.

Figure 14. Main infrastructure of a remote monitoring system for exploitation of seabed mineral resources



Source: DNV

Figure 15. Infrastructure for data collection and processing of protected ISA monitoring reports



Source: DNV

5.1 Data collection

Monitoring from vessel(s)

93. The mining vessel (i.e. the Contractor) collects all data (positions, production data, environmental data etc.) that is necessary and required by ISA.

94. Data collected on the seabed or in the water column can be locally stored on the stationary sensor platforms, unless direct communication is possible. ROVs or AUVs can be used to collect the data from the sensor platforms, which transfer the data via acoustic or optical technology to the ROV/AUV. The ROVs or AUVs would then go to the docking station at the seabed mining site and the environmental monitoring unit. The data would then be sent via the umbilical (fibre-optic cable) up to the mining vessel.

95. Alternatively, all sensors can be concentrated in lander systems which may be connected via data cables, e.g. in a cable ring configuration, connected by umbilical (fibre-optic cable) up to the mining vessel.

96. *Necessary equipment including capabilities:* The Contractor would need lander-based sensor systems and ROVs/AUVs. The number of necessary sensors depends on the size of the mining project and the number of parameters to monitor. In general, at least four to six sets of the lander-based sensors are required. Depending on the mining area, a minimum of two AUVs or one ROV are needed for polymetallic nodule mining, as the battery pack is a limiting factor and keeps missions limited in range and duration, often as little as ten hours before recharging (recharging may take up to four hours). More than two AUVs would further increase the system redundancy. Polymetallic sulphides and cobalt-rich ferromanganese crust mining will cover smaller areas. In those cases, an ROV system could also acquire the data and use technical survey checks by the contractor. The umbilical of an ROV allows for real-time data transmission and unlimited diving.

97. *Necessary data transmission capacity:* Hydroacoustic modems can send data at rates up to 20 kbps (Kebkal et al. 2015) for distances up to 8 km.[5] A single-mode fibre-optic cable can send data rates of up to 10 gigabits per second at distances of over 80 km with commercially-available transceivers.[6] This means that

[5] Bannasch, R. (2020), EvoLogics, Germany (personal communication).
[6] https://en.wikipedia.org/wiki/Single-mode_optical_fiber

data transmission capacity is limited by the hydroacoustic modems, which have 500,000 times less data transmission capacity than a fibre-optic cable. The amount of data required by the Contractor and ISA may be quite different based on the different uses it is collected for. Higher data rates and better data capacities are easily obtained by ROVs. As an estimate, 20 kbps is considered sufficient for the daily data transmission from an acoustic sensor.

98. *Necessary amount of personnel and special expertise:* The Contractor should have a minimum of two monitoring experts on board the mining vessel at any time. The Contractor should also have the technical knowledge to repair or exchange any non-functioning monitoring or data transfer equipment.

99. *Purchase cost:* Costs for the Contractor will vary depending on the number of sensors and AUVs used. Sensors including batteries and transmitters cost around USD30,000 each. A set of sensors for different environmental parameters are more costly but are multipurpose and reusable. An AUV can cost on the order of USD500,000 to 1,000,000 (including necessary equipment). Deep-water AUVs often cost more than USD1,000,000.

100. *Installation cost:* Costs for installing the data collection system are mainly related to buying the necessary equipment (see above). In addition, there will be some cost for training the personnel operating the equipment. Additional costs will be related to cable connections between lander systems.

101. *Operating cost:* An ROV/AUV can cost on the order of USD2,000 to 8,000 per day to operate. Other costs include the personnel operating the equipment, spare sensors and other spare parts.

Satellite monitoring

102. Satellite monitoring can be based on free open data. If there are any unusual findings or questions, high-resolution images can be ordered from a commercial satellite image provider.

103. *Necessary equipment including capabilities:* ISA would need computers with sufficiently-sized displays to visually review the satellite imagery (free open data) or reports (commercial satellite image provider).

104. *Necessary data transmission capacity:* Ordinary Internet access is needed.

105. *Necessary personnel and special expertise:* A minimum of two (in-house) dedicated personnel would be required. The need for expertise would be higher if based on free open data only.

106. *Purchase cost:* Two computers with displays, around USD5,000.

107. *Installation cost:* Training of dedicated personnel would be required for free open data only, with a cost of about USD20,000.

108. *Operating cost:* Salary for two (in-house) dedicated personnel, although more may be required depending on the number of ongoing mining projects.

5.2 Data processing

109. "Data processing" means how the raw data from sensors and other monitoring equipment is transformed into information that can easily be understood and interpreted by offshore and onshore monitoring personnel.

110. For simpler sensors, most of the data processing may already have taken place subsea. However, for more specialized data, it is a relatively large task to select parameters to be processed further and to perform quality assessments. AUV and lander data, for example, constitute

relatively complex data for large parts of the water masses, and data selected for further processing must be checked. Other data are directly used in models or for displaying trends and graphics.

111. The result of the data processing should be a standard monitoring report (separate from the yearly report) submitted to ISA and sponsoring State(s) at intervals decided by ISA, e.g. on a daily or weekly basis. In line with draft regulation 102, ISA should develop guidelines to address the detail and frequency of reporting. It is suggested that this should include data handling (averaging time, resolution, data collection frequency, reporting frequency etc.). Such guidelines should preferably be adjustable to suit different mining sites and types of operations. The software for processing the data into a monitoring report must be traceable, i.e. detailed specification and software version control must be maintained.

112. To make the data easier to interpret, a "traffic light" system could be used, where data that can be automatically analysed is divided into "good" (green light), "medium" (yellow light) and "bad" (red light).

113. Data processing has to be safe from any potential manipulation. Raw data will be required in a format that suits the regulator's needs (i.e. ISA).

114. Necessary equipment including capabilities: The Contractor would need computer capacity to handle the incoming monitoring data onboard the mining vessel. A minimum of two large, dedicated, high-capacity computers should be on board the vessel to process monitoring data.

115. Necessary data transmission capacity: Described under "Data collection" above.

116. Necessary amount of personnel and special expertise: As mentioned under "Data collection" above, the Contractor should have a minimum of two monitoring experts with the necessary skills for handling the data processing.

117. Purchase cost: The cost for the Contractor to buy computers and necessary backup and storage systems is estimated at USD20,000.

118. Installation cost: The cost for the Contractor is mainly related to developing software for the processing of data. ISA will have costs for developing guidelines for the data processing, data protection and specifications of the monitoring report.

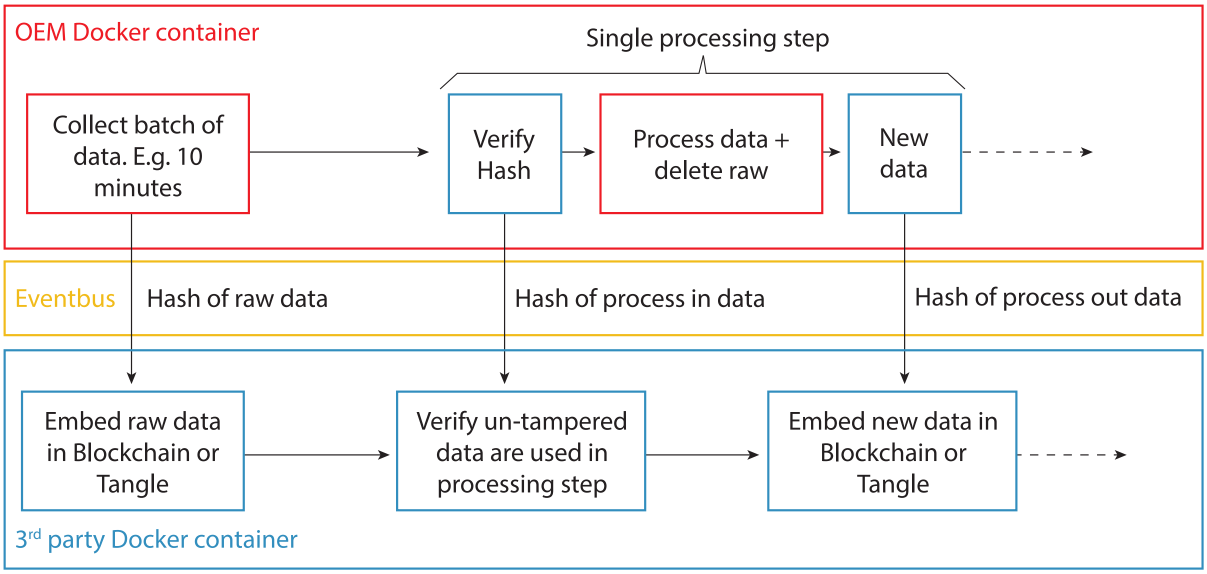
119. Operating cost: The cost for the Contractor will mainly be salary for the personnel operating and maintaining the data processing software.

5.3 Data security

120. Correct and untampered data is a key element of effective monitoring and verification of mining operations. The data collected by the Contractor will be shared with ISA (and the sponsoring State or States and inspectors). This means that sharing needs to be easy, yet secure. The sharing needs to be easy and secure. The data received from the Contractor cannot be tampered with.

121. Equipment intended for collecting data (numerical data, audio files and images) in a tamper-free infrastructure is already on board vessels. The most relevant example is the "voyage data recorder" equipment, similar to a "black box" on airplanes, where data is collected from multiple sources and stored on internal protected memory on board, ensuring that data received and stored cannot be manipulated. A similar approach is suggested for collection of subsea mining monitoring parameters, but where the data, instead of (or in addition to) being stored, are transmitted to shore data centre(s) accessed by ISA. It is suggested

Figure 16. To ensure that data is not tampered with, batches of collected data are hashed and embedded in the blockchain to make it possible to verify that the exact same data are still available. The same can be done for each batch of processed data by "hash-wrapping" it



Source: DNV.

that the transfer of data from the onboard data collection unit to shore should be secured, e.g. by encryption, to ensure integrity and authenticity. Numerous methods and standards describing secure data transfer can be found, for example the ISO 27000 series. Sufficient data communication capacity would be required to enable the efficient and timely transfer of required data. Sufficient backup and storage capacity in case of failure of data transmission would also be required.

122. The method described above is based on restricting or removing the possibility of interrupting data collection and processing. It is unknown whether solutions (standards, etc.) exist to fully ensure data and data process security in an open software environment. However, emerging techniques to check that data and processed data (called "new data" in Figure 16) are untampered may be developed in the near future. Figure 16 shows one example where installed software performs parallel checks to verify that data are untampered.

123. *Necessary equipment including capabilities:* The mining vessel should have a dedicated "black box" capable of ensuring that the data has not been tampered with when sent to ISA. The black box should have the necessary capacity to process the data and protect/encrypt the monitoring report.

124. *Necessary data transmission capacity:* See Chapter 6.4 below.

125. *Necessary personnel and special expertise:* The "black box" should be installed on the vessel before the mining operation starts. Such a unit should not require operational intervention.

126. *Buying cost:* The "black box" is a Contractor cost. Such boxes can be produced and sold for less than USD20,000. Costs for backup and storage are included in Chapter 6.2 above.

127. *Installation cost:* Installation of the "black box" is an initial cost for the Contractor.

128. *Operating cost:* There should not be any operating costs.

5.4 Data transfer to shore

129. The data collected by the Contractor can be transferred as monitoring reports via satellite communication to ISA. The data is sent protected/encrypted and has to be decrypted before it can be used.

130. The processed data or monitoring reports from the vessel is sent via communication satellite to land stations that can be accessed or transmitted via the Internet.

131. If position data for vessels is required, this can be obtained by AIS or from observation satellites as described in Chapter 5.2.1.

132. If satellite imagery is required for monitoring oil spills, plumes etc., these can be obtained from observation satellites as described in Chapter 5.2.3.

133. *Necessary equipment including capabilities:* The Contractor would require a satellite communication provider to get the data to shore. This is a commercial service that the Contractor would pay for. A "black box" would need to have the necessary capacity to send (and protect/encrypt) the data.

134. *Necessary data transmission capacity:* The data transmission capacity required would probably be quite low if the data were sent encrypted and packaged (as a monitoring report), for example every 24 hours.

135. *Necessary personnel and special expertise:* A "black box" should automatically transmit monitoring reports at fixed intervals, so the need for personnel with special expertise is limited.

136. *Buying cost:* The cost for the data transfer service is based on the amount of data transferred (Contractor cost).

137. *Installation cost:* Connection of the "black box" and satellite communication equipment is an initial commissioning activity, the cost of which is borne by the Contractor.

138. *Operating cost:* ISA would need personnel to review data monitoring and monitoring reports, and take appropriate action. The operating cost is covered by the salary of ISA personnel. Appropriate actions may imply having recourse to inspectors (see Chapter 7.4).

6. THE BEST COMBINATION OF REMOTE MONITORING AND OTHER TOOLS

139. This Chapter provides information on an optimal option of remote monitoring and other tools to ensure that ISA can carry out its inspection activities effectively from a cost and capacity-requirement perspective, and without prejudice to the future shape of the inspection mechanism to be established, including the respective roles of the ISA Secretariat, the LTC, sponsoring States and flag States.

140. In addition, "minimum" and "maximum" options are presented to show the differences in cost, resources and capacities. The estimated costs presented in this Chapter for the different proposals are costs to ISA.

141. For the assessment of the optimal option, the following factors were evaluated:

- Which data should be monitored?
    - o With respect to importance, the parameters were divided into three groups: the optimal option, the minimum option (the minimum of parameters needed) and the maximum option (including all parameters that could be of interest).
- How much monitoring equipment will be needed?
- How should the data be collected and transmitted and who should operate the various sensors and data transmission?
- How will the data be transformed into information that can be used and reviewed continuously by ISA (i.e. how do we implement deep-seabed big-data processing and analytics)?
- How do remote monitoring and other tools complement each other in assessing and determining risks and compliance?
- How can ISA secure data authenticity and integrity?
- What data maintenance and storage/backup aspects need to be taken into account to reduce the system failure risks?

6.1 Optimal option

142. An optimal option to remotely monitor the exploitation of mineral resources in the Area would consist of the following:

- *Data collection:* Data would be collected by the Contractor under the obligations of the Environmental Management and Monitoring Plan. Suggestions for the data to be monitored are presented below. ISA would not need its own monitoring equipment on site. The Contractor would operate the various sensors, collect the required data and transmit it to ISA.
- For spot checks over long intervals or upon suspicion of irregularities, ISA could also use satellite data to monitor the position of all vessels at the mining site. Further, satellite imagery would

provide information on oil spills and may also provide information on particle spills on the sea surface. Satellite data would enable ISA to obtain satellite imagery of the sea surface.

- *Data processing:* The raw data collected by the Contractor would be processed at the mining site before it is transmitted to ISA, e.g. in the form of a monitoring report. This would reduce the amount of data transmitted to ISA. Further, the Contractor should be required to store key raw data to allow for assessment of the data by the inspectors, without prejudice to the role of the LTC concerning inspections.
- *Data security:* The data collection, processing, transmission and storage would be protected/encrypted to avoid tampering. The mining support vessel would have a "black box" capable of ensuring that the data has not been tampered with before or during transfer.
- *Data storage:* To reduce the risks of system failure and loss of data, both the data that the Contractor generates and the data that ISA receives should be continuously backed up and stored. If data does not get through to ISA, the Contractor should have a system to be able to resend the data from its backup system.
- If critical parameters from the mining site, as defined by ISA, are not received, consideration could be given to ISA taking measures to rectify the issue.

6.1.1 Data to be monitored

143. Data that should be monitored under the optimal option are:

- Parameters related to the position:
  - position of the mining support vessel
  - position of the mining unit, including water depth
  - progress of mining tools, including distance and depth.
- Parameter related to production:
  - amount of ore in the riser system and on board the mining support vessel.
- Parameters related to the environment:
  - meteorological conditions
  - physical and chemical oceanographic conditions
  - plumes on the sea surface generated by the mining support vessel
  - plumes generated in the water column
  - plumes generated on the seabed by the mining activities
  - visual monitoring on and near the seabed during mining.

144. A detailed overview of the data that should be monitored is included in Appendix 1 also showing the suggested type of data, where they are registered (sea surface, water column or seabed) and by whom (the Contractor or ISA).

6.1.2 Costs

145. The costs for each mining project with the optimal option are presented in Table 2.

Table 2. Estimated costs for each mining project with the optimal solution

Item	Comments	Yearly cost per project
Monitoring the position of the mining vessel	AIS and cost-free satellite data	USD0
Satellite images to monitor activity on the sea surface (free services) Upon suspicion, a detailed position and high-resolution imagery report, including surface spill and plume indication, can be ordered	Detailed position and high-resolution imagery report considered needed ten times per year for each project	USD15,000
Monitoring of the mining site, including environmental and production aspects	Staff will be required to review the monitoring reports from the mining site, and other relevant reports (two full-time staff required at ISA based on an initial estimate of five projects per year = USD320,000/5) Inspections may also have a cost (one inspection per year for each project USD20,000 including transport to mining site = USD20,000)	USD84,000
Total		**USD99,000**

146. The cost in Table 2 is the estimated yearly cost for ISA per mining project, including ISA staff, under the optimal option.

147. ISA will also have an initial cost for establishing guidelines for data processing, data protection and specifications of the monitoring reports.

6.2 Minimum option

148. The minimum option differs from the optimal option in the following aspects:

- The amount of data to be transmitted is less (data from monitoring of plumes in the water column and on the seabed are not transmitted to ISA under this option, only data on pollution on the sea surface). This would lead to reduced remote environmental monitoring by ISA, and a reduced cost of processing and transmitting information from the mining site to ISA.
- No secure transmission system to send data from the support mining vessel to ISA is foreseen under this option. This would make it easier to manipulate data, which would not be desirable.
- Use of satellite data will be reduced to free open satellite services, i.e. no paid services will be used. This will still give

the position of the mining vessel, but with lesser-quality satellite images. The advantage is lower costs for ISA.

6.2.1 Data to be monitored

149. Data monitored under the minimum option are:

- Parameters related to the position:
    - o position of the mining support vessel
    - o position of the mining unit, including water depth.
- Parameter related to production:
    - o amount of ore on board the mining support vessel.
- Parameters related to the environment:
    - o meteorological conditions
    - o oceanographic conditions
    - o plumes on the sea surface generated by the mining support vessel.

150. A detailed overview of the minimum amount of data to be monitored is included in Appendix 1 showing the type of data, where they are registered (sea surface, water column or seabed) and by whom (the Contractor or ISA).

6.2.2 Costs

151. The costs for each mining project under the minimum option are presented in Table 3.

Table 3. Estimated costs for each mining project under the minimum option

Item	Comments	Yearly cost per project
Monitoring the position of the mining vessel	AIS and cost-free satellite data	USD0
Satellite images to monitor activity on the sea surface	Only use of free, open satellite services	USD0
Monitoring of the mining site, including environmental and production aspects	Staff will be required to review monitoring reports from the mining site, and other relevant reports (one full-time staff or two half- time staff required at ISA, based on an estimate of five projects per year initially = USD170,000/5) Inspections may also have a cost (one inspection per year for each project USD20,000 including transport to mining site = USD20,000) There is less information to review compared with the optimal option.	USD54,000
Total		**USD54,000**

152. The cost in Table 3 is the estimated yearly cost for ISA per mining project, including ISA staff, under the minimum option.

153. ISA will have a smaller initial cost for establishing guidelines for data processing, data protection and specifications of the monitoring report compared with the optimal option.

6.3 Maximum option

154. The maximum option differs from the optimal option in the following aspects:

- Under the maximum option ISA would have its own monitoring equipment (sensors) at the mining site. It would also have its own data communications infrastructure on board the mining vessel, transmitting it to ISA. ISA would be able to monitor independently:
    - position of the mining support vessel and the mining unit
    - plumes at the sea surface, in the water column and close to the seabed
    - the seabed with visual observations by having their own camera(s), laser or radar systems on the Contractors ROVs/AUVs and/or on the mining unit.
- ISA would frequently monitor the position of the mining support vessel and other surface vessels for ore transport, etc. Commercially-available services will provide high resolution satellite imagery and position/plumes/oil spills reports.
- ISA would operate their own sensors by remote control and collect the data and transmit the data when needed. The data to be monitored under this option are presented below.

6.3.1 Data to be monitored

155. Data monitored by ISA under the maximum option are:

- Parameters related to the position:
    - position of the mining support vessel
    - position of the mining unit, including water depth.
- Parameters related to production:
    - amount of ore on board the mining support vessel
    - amount of ore being transported through the water column to the mining support vessel.
- Parameters related to the environment:
    - meteorological conditions
    - oceanographic conditions
    - plumes on the sea surface generated by the mining support vessel
    - plumes generated in the water column
    - plumes generated on the seabed by the mining activities
    - visual monitoring on and near the seabed during mining
    - noise
    - light
    - sedimentation.

156. A detailed overview of the data to be monitored is included in Appendix 1 also including the type of data, where they are registered (sea surface, water column or seabed) and by whom (the Contractor or ISA).

6.3.2 Costs

157. The costs for each mining project with the maximum option are presented in Table 4.

Table 4. Estimated costs for each mining project under the maximum option

Item	Comments	Yearly cost per project
Nodes with sensors	Initial cost for eight nodes with sensors x USD30,000/3 (Assumed lifetime three years)	USD80,000
Satellite reports/imagery to monitor activity on the sea surface including positions	Weekly satellite reports 52 x USD1,500	USD78,000
ISA installs its own flowmeter on the riser	USD20,000/2 (this is a highly uncertain estimate) (Assumed lifetime two years)	USD10,000
ISA installs its own camera(s) on the Contractor's ROVs/AUVs and/or on the mining unit	One camera and communication software USD50,000/3	USD17,000
	(Assumed lifetime three years)	
ISA installs its own sediment traps on the seabed	Six sediment traps x USD20,000. Optical reading done by ROV/AUV USD120,000/3 (Assumed lifetime three years)	USD40,000
ISA establishes its own data collection, processing and communication infrastructure on board the mining vessel	USD100,000/3 (this is a highly uncertain estimate) (Assumed lifetime three years)	USD33,000
Monitoring of the mining site including environmental and production aspects	Staff will be required to review the monitoring reports from the mining site and other relevant reports (three full-time staff required based on an estimate of five projects per year initially = USD463,000/5) Inspections may also have a cost (two inspections per year assumed for each project at USD20,000 x 2 including transport to the mining site = USD20,000 x 2)	USD132,600
Total (rounded)		**USD390,600**

158. The cost in Table 4 is the estimated yearly cost for ISA per mining project, including ISA staff, under the maximum option.

159. ISA will have a similar initial cost for establishing guidelines for the data processing, data protection and specification of the monitoring report compared with the optimal option.

6.4 Need for physical inspections

160. The Draft Regulations contain provisions relating to the powers and functions of ISA to carry out inspections (Part XI), including sending ISA's inspectors on board vessels and installations.

161. In certain situations, ISA may consider sending inspectors to the site based on the input received through remote monitoring. Examples of such situations could include:

- New mining installations (production vessels, supply vessels, barges, mining units and riser systems), environmental monitoring installations (cable installations, lander positioning, data readout and supply units) and changes in the general technical setup
- Indications that unapproved mining activities are taking place
- Data received showing that environmental thresholds have been repeatedly exceeded
- Data not being transferred to ISA as required
- Data from the Contractor not corresponding to observations by ISA (satellite, etc.)
- Suspected issues concerning safety, labour and health conditions.

162. As shown in Chapters 7.1 to 7.3, physical inspections can be costly but should not be omitted if they are needed.

7. CONCLUSIONS

163. This report has provided an overview of the remote monitoring technologies used in monitoring, control and surveillance mechanisms in other extractive sectors, particularly offshore oil and gas and fisheries. A comprehensive remote monitoring mechanism as would be required in the context of the Draft Regulations for exploitation of mineral resources in the Area is not known to be implemented in comparable commercial industries. In this light, based on an assessment of the minimum requirements and parameters that would need to be monitored in the context of seabed mining, the report provides an overview of the various remote monitoring options available, including information on estimated costs, staffing requirements and necessary infrastructure, with a view to assisting ISA in developing its inspection, compliance and enforcement mechanisms, including the necessary regulatory and institutional framework for the use of remote monitoring in that context.

164. Without prejudice to the roles of sponsoring States, flag States and the Secretariat in the context of an inspection mechanism, the Secretariat has assessed that, with regard to data infrastructure and capacity, neither the optimal nor the minimal option would require an immediate increase in data infrastructure or capacity on the Secretariat side. No significant increase in the processing or networking infrastructure may be required in light of what is available in the DeepData database, based on the estimated amount of raw data and data volumes set out in this report. For the maximum approach, ISA would need additional infrastructure on the ship, which would feed into an expanded in-house infrastructure. With regard to staffing, additional staff would be required within the Secretariat under all options, with the required expertise to handle data from satellite monitoring and to review other monitoring data.

165. It is suggested that, in developing a remote monitoring system, ISA should put emphasis on critical components of the system, such as the "black box" and the satellite communication that transmit monitoring data/reports from the vessel to ISA. Backup functions are also essential to ensure that data do not get lost.

166. Further, in order for the remote monitoring system to be transparent and predictable, it is suggested that ISA should develop standards or guidelines concerning:

- The parameters to be monitored should be based on a cost-benefit assessment.
- Monitoring reports: The results of the data processing should be made available in a standard report, including data handling (averaging time, resolution, data collection

frequency, reporting frequency etc.). The guidelines should also specify the reporting frequency and be generic and adjustable to suit different mining sites and types of operations.

167. Standardization through standards or guidelines would enable commercial companies to develop and supply components, systems and services for this market.

TABLES AND FIGURES

Figure 12. Drone used for collection of aerial (weather) data.

Figure 13. A lander (tripod) equipped with sediment trap, current meter and turbidity meter.

Figure 14. Main infrastructure of a remote monitoring system for exploitation of seabed mineral resources.

Figure 15. Infrastructure for data collection and processing of protected ISA monitoring reports.

Figure 16. To ensure that data is not tampered with, batches of collected data are hashed and embedded in the blockchain to make it possible to verify that the exact same data are still available. The same can be done for each batch of processed data by "hash-wrapping" it.

REFERENCES AND BIBLIOGRAPHY

Ayasse, R. and C. Bishop (2020). KSAT, Norway (personal communication).

Bannasch, R. (2020). EvoLogics, Germany (personal communication).

European Commission (undated). Oceans and fisheries.

International Seabed Authority (2019). Draft Regulations on Exploitation of Mineral Resources in the Area (ISBA/25/C/WP.1).

Kebkal, K. G., A. K. Kebkal, O. G. Kebkal and R. Bannasch, (2015). Modelling and validation of basic characteristics in underwater acoustic sweep-spread-carrier communications. 2015 IEEE Underwater Technology (UT) Conference, 23-25 Feb. 2015, Chennai, India.

Morozs N., P. D. Mitchell, Y. Zakharov, R. Mourya, Y. R. Petillot, T. Gibney, M. Dragone, B. Sherlock, J. A. Neasham, C. C. Tsimenidis, M. E. Sayed, A. C. McConnell, S. Aracri and A. A. Stokes, (2018). Robust TDA-MAC for Practical Underwater Sensor Network Deployment: Lessons from USMART Sea Trials. In The 13th ACM *International Conference on Underwater Networks & Systems (WUWNet'18)*, December 3ś5, 2018, Shenzhen, China. New York: ACM. 8 pages.

ScienceDirect, (series of articles). Single-mode fibers.

Yang G., L. Dai and Z. Wei, (2018). Challenges, Threats, Security Issues and New Trends of Underwater Wireless Sensor Networks. Sensors 18: 3907.

APPENDIX

OPTIMAL OPTION

The Table A.1. below presents the optimal option, concerning the parameters to be remotely monitored.

"Monitored by" means who is doing the monitoring. In most cases it is the Contractor. Where "Contractor/ISA" is indicated, this means the Contractor would carry out the monitoring but ISA could carry out an additional check by, for example, using satellite data.

If the Contractor carries out the monitoring, the data should be sent to ISA in a protected manner.

Table A.1. The optimal option

Parameter	Type of data	Registered where	Monitored by
Parameters related to the position			
Position of the mining support vessel	Coordinates (x, y) + IMO identification number	Sea surface	Contractor/ISA ISA can get position data from satellite data
Position of the mining unit including water depth	Coordinates (x, y, z)	Seabed	Contractor
Parameters related to production			
Amount of ore on board the mining support vessel	Weight of ore calculated based on the displacement of the vessel	Sea surface	Contractor
Area on the seafloor covered	Distance travelled (collector), metres drilled (drill), the area covered (drill, grab, ablation tool)	Seabed	Contractor/ISA

Parameter	Type of data	Registered where	Monitored by
Parameters related to the environment			
Meteorological conditions	Data from weather stations on temperature, wind speed and direction, air pressure, precipitation	Sea surface (above)	Contractor/ISA ISA can get data from satellites and nearby weather stations
Oceanographic conditions	Data from sensors that measure the parameters: wave height, wave period, wave direction, current direction, current velocity, temperature, salinity, surface productivity and turbidity (including x, y, z coordinates for all the measurements)	Sea surface (all data) Water column (current direction, current velocity, temperature, salinity and turbidity) Seabed (same data as for the water column)	Contractor/ISA ISA can check sea surface with satellite data
Pollution generated by the mining support vessel (oil spill, spill of ore material etc.)	Satellite data and/or turbidity sensors	Sea surface	Contractor/ISA ISA can use satellite data
Plumes generated in the water column (for example from riser or return water discharge)	Observations from ROV/AUV camera and/or data from turbidity sensors at different water depths	Water column	Contractor
Plumes generated on the seabed by the mining activities (spill of ore material, return water discharge)	Observations from ROV/AUV camera and/or data from turbidity sensors	Seabed	Contractor
Visual monitoring on and near the seabed during mining	Observations from ROV/AUV camera on biological communities, substrate and bottom topography (video transects).	Water column Seabed	Contractor

MINIMUM OPTION

The Table A.2. below presents the minimum option, concerning parameters to be remotely monitored.

"Monitored by" means who is doing the monitoring. In most cases it is the Contractor. Where "Contractor/ISA" is indicated, this means the Contractor would carry out the monitoring but ISA could carry out an additional check by, for example, using satellite data.

If the Contractor carries out the monitoring, the data should be sent to ISA in a protected manner.

Table A.2. The minimum option

Parameter	Type of data	Registered where	Monitored by
Parameters related to the position			
Position of the mining support vessel	Coordinates (x, y) + IMO identification number	Sea surface	Contractor/ISA ISA can get position data from satellite data
Position of the mining unit including water depth	Coordinates (x, y, z)	Seabed	Contractor
Parameters related to production			
Amount of ore on board the mining support vessel	Weight of ore calculated based on the displacement of the vessel	Sea surface	Contractor
Parameters related to the environment			
Meteorological conditions	Data from weather stations on temperature, wind speed and direction, air pressure, precipitation	Sea surface (above)	Contractor/ISA ISA can get data from satellites and nearby weather stations
Oceanographic conditions	Data from sensors that measure the parameters: wave height, wave period, wave direction, current direction, current velocity, temperature, salinity, surface productivity and turbidity (including x, y, z coordinates for all the measurements)	Sea surface (all data) Water column (current direction, current velocity, temperature, salinity and turbidity) Seabed (same data as for the water column)	Contractor/ISA ISA can check sea surface with satellite data

Parameter	Type of data	Registered where	Monitored by
Pollution generated by the mining support vessel (oil spill, spill of ore material etc.)	Satellite data and/or turbidity sensors	Sea surface	Contractor/ISA ISA can use satellite data

MAXIMUM OPTION

The Table A.3. below presents the maximum option, concerning parameters to be remotely monitored.

"Monitored by" means who is doing the monitoring. In most cases it is the Contractor. Where "Contractor/ISA" is indicated, this means the Contractor would carry out the monitoring but ISA could carry out an additional check by, for example, using satellite data.

If the Contractor carries out the monitoring, the data should be sent to ISA in a protected manner.

Table A.3. The maximum option

Parameter	Type of data	Registered where	Monitored by
Parameters related to the position			
Position of the mining support vessel	Coordinates (x, y) + IMO identification number	Sea surface	Contractor/ISA
Position of the mining unit including water depth	Coordinates (x, y, z)	Seabed	Contractor/ISA ISA can estimate position by using its own sensors
Parameters related to production			
Amount of ore on board the mining support vessel	Weight of ore calculated based on the displacement of the vessel	Sea surface	Contractor
Amount of ore being transported through the water column to the mining support vessel	The flow of ore (mixed with water) measured with a flowmeter if a riser is used or the weight of the ore if it is transported in batches	Water column (riser)	(Contractor)/ISA ISA can install flow meter on the riser
Area on the seafloor covered	Distance travelled (collector), meters drilled (drill), the area covered (drill, grab, ablation tool)	Seafloor	Contractor/ISA

Parameter	Type of data	Registered where	Monitored by
Parameters related to the environment			
Meteorological conditions	Data from weather stations on temperature, wind speed and direction, air pressure, precipitation	Sea surface (above)	Contractor/ISA ISA can get data from satellites and nearby weather stations
Oceanographic conditions	Data from sensors that measure the parameters: wave height, wave period, wave direction, current direction, current velocity, temperature, salinity, surface productivity and turbidity (including x, y, z coordinates for all the measurements)	Sea surface (all data) Water column (current direction, current velocity, temperature, salinity and turbidity) Seabed (same data as for the water column)	Contractor/ISA ISA can check sea surface with satellite data
Pollution generated by the mining support vessel (oil spill, spill of ore material etc.)	Satellite data and/or turbidity sensors	Sea surface	Contractor/ISA ISA can use satellite data
Plumes generated in the water column (for example from riser or return water discharge)	Observations from ROV/AUV camera and/or data from turbidity sensors at different water depths	Water column	Contractor ISA can use own sensors
Plumes generated on the seabed by the mining activities (spill of ore material, return water discharge)	Observations from ROV/AUV camera and/or data from turbidity sensors	Seabed	(Contractor)/ISA ISA can use own sensors
Visual monitoring on and near the seabed during mining	Observations from ROV/AUV camera on biological communities, substrate and bottom topography (video transects)	Water column Seabed	(Contractor)/ISA ISA can have own camera(s) on the Contractor's ROVs/AUVs and/or on the mining unit
Noise	Sensors that measure the noise level from the mining activity	Water column Seabed	(Contractor)/ISA ISA can use own sensors

Parameter	Type of data	Registered where	Monitored by
Light	Sensors that measure the noise level from the mining activity	Water column Seabed	(Contractor)/ISA ISA can use own sensors
Sedimentation	Sediment traps in the vicinity of the mining area that measure the sedimentation rate	Water column Seabed	(Contractor)/ISA ISA can install own sediment traps on the seabed

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