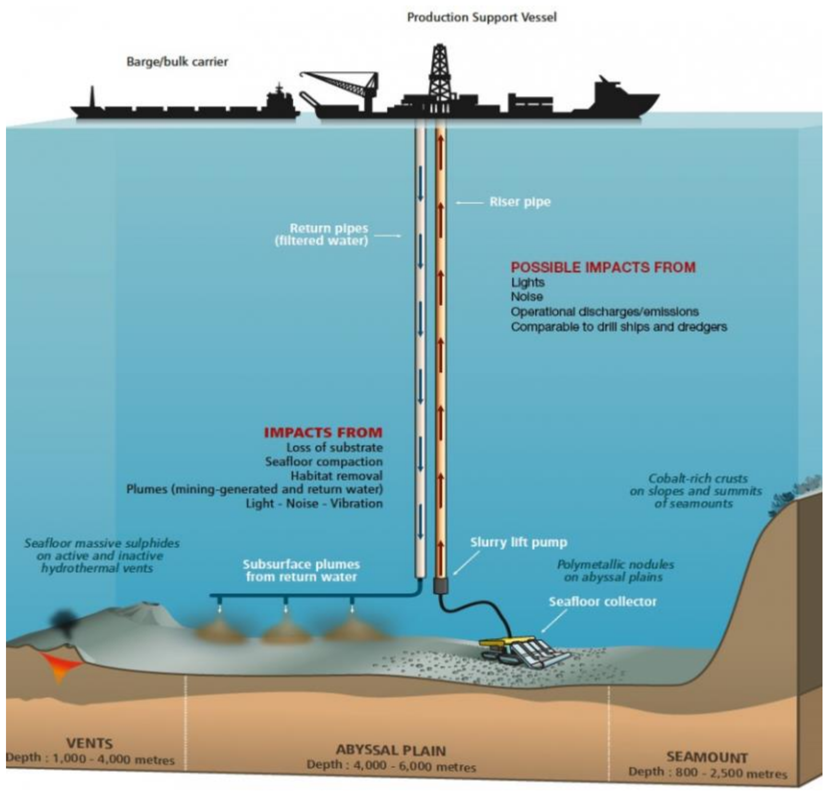
Deep Seabed Mining: Environmental Assessment and Management Guidelines

Step by Step Process to Evaluate Applications for Deep Seabed Mining



12 May 2022

Photo on Cover: Credit: IUCN. https://www.iucn.org/resources/issues-briefs/deep-sea-mining

Prepared by:

Craig Vogt
Craig Vogt Inc
Ocean & Coastal Environmental Consulting
Hacks Neck, Virginia – Eastern Office
Pagosa Springs, Colorado – Western Office
USA
Craig@CraigVogt.com
www.CraigVogt.com

Authors Note: This document is an attempt to develop a step-by-step and iterative process for use in evaluation of applications for deep seabed mining (DSM). These guidelines are based upon the Waste Assessment Guidelines of the IMO's London Convention & Protocol for evaluation of wastes proposed for disposal in ocean waters. These guidelines do not replace the efforts by ISA in environmental assessment and management of DSM but could assist in organizing how the ISA's key elements are considered in evaluation of applications for deep seabed mining.

These guidelines were generated as a follow-up action to the Deep-Sea Mining: Resolving Risk Workshop held in November 2018 at MIT in Cambridge, Massachusetts, USA.

Abstract

Deep-seabed mining that is proposed to occur at depths around from 1,000 meters up to 4,000-6,000+ meters, like all mining activities, has the potential to cause unacceptable environmental harm if not managed appropriately. The mined materials will commonly contain copper, nickel, and cobalt in addition to manganese. The deep-seabed mining industry is in its infancy, with mining and environmental protection techniques in development. During mining, the two primary sources of impact are the removal of ore from the seabed and the discharge of return water after dewatering operations on the support vessel.

Disturbance of the seabed will instigate mixing of sediments with seawater immediately overlying the seabed. The formation of sediment plumes will likely occur. Effects will be site-specific and will depend strongly on the seabed composition (e.g., silt vs sand), the type of technology used, the nature of the biota, and the oceanographic conditions in the area. Equipment that digs into or removes the upper layers of sediment can have an effect through direct impact of buried infauna and by compacting the substrate through the weight of the mining tools. Ore will be separated from the sediment at the seabed and then the ore will be pumped to a ship where they will be separated from the seawater. The dewatering process will discharge the separated seawater and associated sediments back into the sea (below the light zone and possibly back to the seafloor). The amount of fine materials in the return water, which could cause a turbid plume, will depend on the amount and physical characteristics of the materials present after the ore separation process at the seabed and dewatering process on board the surface vessel.

The key steps in the environmental management framework are the environmental prevention audit, characterization of potential risks, identification of action levels, identification of mitigation for those risks, monitoring of project conditions, and adaptive management. The environmental management framework in this document is modeled after the International Maritime Organization's London Convention & Protocol's Waste Assessment Guidelines (IMO, n.d.); those Guidelines have been used successfully around the world to control waste disposal into ocean waters. The objective of the environmental management framework in this document is to assist in the organized consideration of ISA's key elements to environmental assessment for decision-making, and overall, to support the consideration of seabed ore mining in a manner that enables economic, social, and environmental objectives to be achieved.

Nodules on the Seabed at 4,000-6,000 meters deep
Credit: ISA

Table of Contents

Section 1. Introduction
Deep Seabed Mining: Environmental Assessment and Management Guidelines

Introduction

These Guidelines for Environmental Assessment and Management for deep seabed mining are intended for use by states issuing contracts for deep seabed mining or by the International Seabed Authority (ISA), the United Nations entity responsible for regulating deep seabed mining**.** The guidelines are specifically targeted to the seabed mining operations and the associated waste that is generated. They do not apply to the normal operations of the surface vessels associated with deep seabed mining. They can assist the contract issuing authorities in evaluating applications for deep seabed mining in a manner consistent with the provisions of the United Nations Convention on the Law of the Sea.

The United Nations Convention on the Law of the Sea (UNCLOS) is an international agreement that came into force in 1984. It lays down a comprehensive regime of law and order for the world's oceans and seas, establishing rules governing all uses of the oceans and their resources. It enshrines the notion that all ocean-space problems are closely interrelated and need to be addressed as a whole.

The Convention governs all aspects of ocean space, such as delimitation of boundaries, environmental protection, marine scientific research, economic and commercial activities, the transfer of technology, and the settlement of disputes relating to ocean matters. The Convention has a number of provisions, the most significant of which cover navigation, archipelagic status and transit regimes, exclusive economic zones (EEZs), continental shelf jurisdiction, deep seabed mining, exploitation regime, protection of the marine environment, scientific research, and the settlement of disputes.

Part XI of the Convention provides for a regime relating to the minerals on the seabed outside any state's territorial waters or EEZ, called "the Area', which, according to article 136 of the Convention, are the "common heritage of mankind." This means that the ISA is not only responsible to authorize and control seabed exploration and mining, but also for protecting the marine environment in the Area and for ensuring a fair and equitable allocation of the proceeds from seabed mining royalties.

ISA operates by contracting private and public corporations and other entities to explore, and eventually exploit, specified areas on the deep seabed for mineral resources essential for building most technological products.

Overarching Considerations

Three overarching considerations should guide planning and contracting activities related to deep seabed mining.

1. Because of the uncertainties associated with mining in the deep sea, the precautionary principle should be applied to evaluate and manage the potential for unacceptable adverse impacts from deep seabed mining.

2. Use of best available technology and best management practices are essential in the viability of deep seabed mining proposals.
3. Environmental impacts should be minimized to the extent practicable, without creating unacceptable adverse impacts. Acceptance of a deep seabed mining application does not remove the obligation to make further attempts to reduce adverse impacts to the marine environment.

Overview of Deep Seabed Mining

Seabed mining is the mining of minerals on the seabed generally at depths of 4,000 meters and deeper. In the deep seabed, deposits can be divided into three categories: (1) polymetallic sulphides, (2) cobalt-rich ferromanganese crusts and (3) polymetallic nodules. These differ in composition, shape, and location.

- Polymetallic sulphides (also called seafloor massive sulphides (SMS)) are metal sulphides formed on the seafloor from minerals dissolved in superheated waters near subsea volcanic areas. In contrast to crusts and nodules, they often have a conical shape. They commonly contain copper, lead, zinc, and other minerals.
- Cobalt-rich ferromanganese crusts form as pavements on the seafloor on the flanks of seamounts, ridges, and plateaus. In addition to cobalt, they may also contain lesser amounts of other metals such as copper and nickel.
- Polymetallic nodules (also called manganese nodules) are similar in composition to ferromanganese crusts but occur in the form of small potato-like nodules scattered randomly on the surface of the seafloor. They commonly contain copper, nickel, and cobalt in addition to manganese.

During the exploitation phase (i.e., mining of the seabed) which will follow the exploration phase, remotely operated vehicles (ROVs) and underwater mining machines collect or cut pieces of the mineral deposits in the seabed. Risers or some other form of hauling system are then used to carry the ore from the seabed up to the vessel on the surface. The ore is then separated from the water and any associated seabed materials (e.g., sand and silt) on the vessel. The separated water and seabed materials are returned to the water column below the vessel at a depth to be determined. The ore is then transported from the mining site to processing plants on land.

Due to the large quantities of ore, extraction of the minerals from the ore will normally take place onshore but processing directly on the support vessel at the site is possible. Disposal of mine tailings would then become a management issue.

Seabed mining operations will be conducted at locations which may differ significantly with respect to their natural environment, local communities, and geological characteristics. In addition, technological developments will change the seabed mining industry over time.

Overview of Potential Environmental Impacts and Sources of those Impacts

The two primary potential areas of impacts are the ore extraction on the seabed and the discharge of water and sediment after dewatering the ore on the support vessel. A seabed mining operation will generally destroy and/or eliminate the existing habitats within the mining zone (i.e., where the ore is being extracted). This is an inherent consequence of the removal of the ore resource from the seabed and is largely independent of the specific mining technique. During the extraction phase, disaggregating the ore on the seafloor will involve the direct physical impact by crushing or removal of habitat and animals. Mobile swimming or crawling animals may be able to move aside, but sessile (immobile) fauna in the path of the mining operation will be affected.

Disturbance of the seabed will increase mixing of sediments with overlying seawater. The formation of sediment plumes is likely. Depending upon the amount of suspended sediments and currents, plumes can smother animals and affect the feeding efficiency of animals such as filter-feeders (e.g. anemones and sponges) and affect surface-deposit feeders. Plumes may also cause possible toxicological effects depending on the content of the dispersed particles (e.g., if heavy metals are present). Effects are site-specific and will depend strongly on the seabed composition, the type of technology used, the nature of the fauna, and the oceanographic conditions in the area.

In seabeds with soft sediment, equipment that digs or sinks into the sediment can have an effect through direct crushing of buried infauna (animals that live in sediment) and by compacting the substrate through the weight of the harvesting machinery. Loss due to crushing or removal of benthic animals on a large-scale could result in a reduction of habitat complexity and associated invertebrate biodiversity.

Other effects from the actual ore extraction include noise, vibration, and light from vessel and underwater vehicle operations, all of which may attract, cause avoidance, and change behavior by animals.

Transporting the ore from the seafloor to the surface support vessel will be conducted by a lifting system, which is envisaged, in most cases, to be a fully-enclosed riser pipe, developed by the oil and gas industry.

Onboard the support vessel, the ore will be separated from the seawater that is pumped up with it. This process is called dewatering and is likely to occur immediately above or near to the extraction site. While the ore will be transported to an onshore processing facility (concentrator), the water and associated sediment that has been separated from the ore will be discharged back to the sea (return water). The discharge of return water is most likely to occur somewhere in the midwater column, or near the seabed. The depth of the discharge will depend on factors such as the water depth of the mining operations, cost, and environmental parameters including among other things, local currents which will influence the extent of the return water plume. The return water will contain fine materials. In addition to potential changes in turbidity, return water could have different physical properties (e.g., temperature, salinity) than the receiving environment. Physical, chemical, and toxicity testing will be needed to assess potential impacts of the fine materials. Hydrodynamic modelling will be used to estimate the fate of the discharge and to inform discharge equipment design (e.g., diffusers, appropriate depth, and direction of discharge).

For most of the existing seabed mining technical concepts, a subsea discharge pipe is suggested for the discharge of return water at a relatively deep level in the water column, the preference in some cases may be close to the seabed; discharging return water at depths well above the seabed may provide for sufficient dilution to result in inconsequential impacts. The difference between the return water discharge plume and plume from ore extraction on the seabed is that the return water plume has the potential to spread over much larger areas due to it being discharged at water layers with potentially stronger currents. The return water plume can also reach surface layers if upwelling currents are present or if there are differences in density (due to different salinity and temperature) compared to the ambient water. Increased turbidity in the upper water column could reduce sunlight penetration and, as the content of the return water would contain residues from the ore extraction, it could have heavy metals with the potential for varying toxicological effects.

Overview of ISA's Environmental Management Approach

The ISA is currently developing regulations for protection of the marine environment (ISA, n.d.). The process to move to commercial size deep seabed mining first includes a contract for exploration and that is to be followed by a contract for full size mining operation (termed exploitation in UCLOS). Key elements in the consideration of environment impacts for each mining site include:

- Environmental Scoping and Management Systems
- Regional Environmental Management Plan
- Baseline Environment Survey
- Environmental Impact Assessment
- Environmental Impact Statement
- Hazard Identification and Risk Management Plan
- Environmental Management and Monitoring Plan
- Emergency Response and Contingency Plans
- Adaptive Management
- Site Closure Plan

The intention of the guidelines in this document is to provide an organizational framework for how each of ISA's key elements above could be considered in reaching a decision for a proposed project. It is noted that the guidelines in this document are based upon the London Convention's and Protocol's Waste Assessment Guidelines (IMO n.d.), which have been successfully applied world-wide by member states in protecting the oceans from unacceptable adverse impacts of wastes disposed into ocean waters.

On the left: Example of a model for a nodules collector developed by Aker Wirth GmbH
On the right: Example of surface support vessels. Source: Royal IHC

Organization of these Guidelines

The step-by-step process shown in the text box is not designed as a conventional “decision tree.” In general, the process should be considered in an iterative manner ensuring that all steps receive consideration before a decision is made to issue a contract.

The Step-by-Step Process for Evaluation of Applications for Deep Seabed Mining	
STEP 1	Environmental Impact Prevention Audit and Waste Management Options
STEP 2	Waste Characterization: Physical, Chemical, and Biological Effects
STEP 3	Action List and Action Levels
STEP 4	The Baseline Survey for Environmental Assessment of the Extraction and Dewatering Discharge Sites
STEP 5	Assessment of Potential Environmental Effects
STEP 6	Issue Contract with Contract Conditions
STEP 7	Monitoring and Adaptive Management

Section 2 Step 1----Environmental Impact Prevention Audit and Waste Management Options

The initial stages in assessing whether to issue a contract should include an evaluation of:

- The details of the mining operation, including the sources or actions that could potentially cause environmental harm within those processes.
- The types, amounts, and relative hazards of those actions/activities.
- The technology used to minimize generation of sediment plumes or other sources of wastes. Details on the engineering design and operating parameters are essential to ensure that the risk of non-compliance with these guidelines is minimized and acceptable.
- Potential for emergencies and associated impacts to the marine environment.

In general terms, if the required audit reveals that feasible opportunities exist for waste prevention or reduction of sediment plumes or prevention of other wastes, an applicant is expected to formulate and implement a prevention/reduction strategy in collaboration with ISA. In this step, two of the ISA elements are initially addressed, identification of hazards and the potential for emergencies. The Hazard Identification and Risk Management Plan would be completed during Step 5, as would the Emergency Response and Contingency Plan. Contract issuance or renewal decisions should assure compliance with any resulting waste reduction and prevention requirements.

Section 3 Step 2----Waste Characterization: Physical, Chemical, and Biological Effects

Characterization is conducted in order to collect the information that will be needed to inform management decisions including determining whether and under what conditions the mining operation can be contracted. Characterization is performed by collecting information about the physical, chemical, and biological attributes of the seabed to be dredged and the discharge from the dewatering operation from the support vessel.

An evaluation is needed of the physical characteristics of the seafloor sediments to be mined. The basic physical characteristics required are the amount of material, particle size distribution and other geotechnical attributes of the sediment (e.g., specific gravity of solids). This data can provide useful information for predicting the generation of plumes and their behaviour, fate, and transport of the sediment (in combination with information about currents).

Contaminants of concern are heavy metals and their potential for acute and chronic toxicity and their bioavailability. Characterization should assess the presence and bioavailability of heavy metals in the seabed to be mined as well as in the discharge from the dewatering operation from the support vessel. Bioavailability is defined as "being capable of being absorbed and available to interact with the metabolic processes of an organism (USEPA 1992)." A number of chemical processes can limit the bioavailability of contaminants, such as binding between the contaminant and different forms of organic carbon.

Bioavailability considerations could be included in the comparative assessment of management options to obtain an accurate understanding of the potential for exposure and effect, and to identify management actions that can be taken to reduce risks to human health and the environment (ITRC 2011).

The physicochemical factors that can influence bioavailability vary depending on the chemical attributes of the contaminant but include oxidizing and reducing conditions in the water column and sediment, the amount of organic carbon present in the sediment, the form of organic carbon present, as well as factors affecting the geochemical state of the sediment over time (e.g., bioturbation, physical disturbance of the sediment matrix (NRC 2003; Wenning et al. 2005).

The potential for biological effects can be assessed directly using toxicity tests and, indirectly, through the use of inferences developed from physical and chemical lines of evidence. Sediment is a chemically and physically complex matrix. This complexity places limitations on the use of physical and chemical data alone to estimate the bioavailability and toxicity of contaminants present in the sediment.

Biological tests provide a means to measure contaminant bioavailability, bioaccumulation of contaminants into tissues, and toxicological effects (e.g., mortality, reduced growth). Toxicity tests serve an integrative function given that adverse effects in organisms are caused by the cumulative influence of each bioavailable contaminant including those that are not quantified by chemical analysis.

In order for biological characterization to provide an adequate scientific basis for determining the potential for adverse effects on marine life, human health and the environment, the evaluation should be responsive to the conceptual model developed for the project, e.g., in regard to the species known to occur in proximity to mining operations and the dewatering operation discharge, and the processes and pathways that could result in adverse effects.

Biological tests should incorporate species that are considered appropriately sensitive and ecologically relevant (in view of the seabed sites under consideration). The effects and processes of interest in a biological characterization include direct toxicity and indirect effects resulting from contaminant bioaccumulation and movement within the food chain. Specific processes and effects of interest at and in the vicinity of the site include the potential for:

- Acute toxicity,
- Chronic toxicity, such as long term sublethal effects,
- Bioaccumulation.

Exemptions from Detailed Chemical and Biological Characterization

Material may be exempted from full chemical and biological characterization, if it is predominantly sand, gravel, or rock, on the basis that heavy metals are not bioavailable.

Photo credit: ISA

Section 4 Step 3----Action List and Action Levels

The Action List and Action Levels provide a mechanism for determining whether the potential adverse impacts from the mining operation are acceptable. It constitutes a crucial part of these guidelines, and the intention is that the action list will be updated as more information becomes available.

Deep seabed mining includes three potential pathways for unacceptable adverse impacts to result from the operations. A conceptual model for these pathways and potential impacts is shown in Figure 1. These pathways include:

1. Crushing or removal of habitat and organisms in the extraction of the ore from the seabed. Deep seabed mining operations will result in loss of habitat and loss of marine life in the footprint of the mining machines and from extracting the ore. This is unavoidable.
    - Similar to dredging of navigation channels, these impacts are deemed an inevitable result of deep seabed mining and are accepted, if the mining application is approved.
    - Depending upon the extent of impacts, mitigation actions may be appropriate. This is case-by-case.
2. Creation of plumes from the ore extraction process.
3. Creation of plumes from the discharge from the dewatering operation from the support vessel.

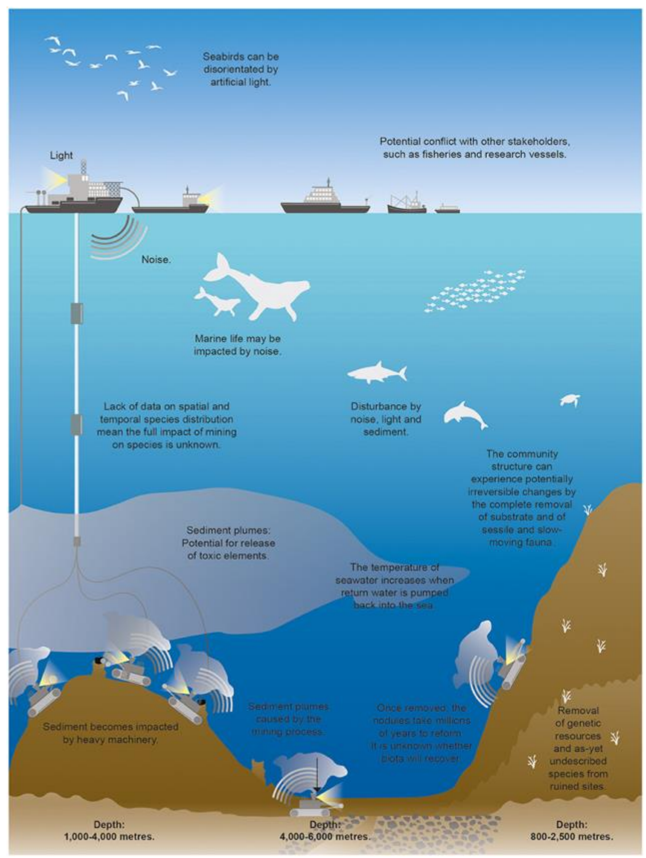


Figure 1. Conceptual model of the pathways and receptors of deep-sea mining releases of sediments. Credit: Miller et al. 2018.

An assessment of the marine life and habitat should be conducted (see Step Four in the next section) prior to approval of the application, to facilitate understanding and how to manage the overall impacts to flora and fauna in the footprint and in the areas potentially impacted by the sediment plumes.

The Action List and Action Levels

The Action List would contain chemical or physical parameters (e.g., heavy metals and turbidity) for which specific action levels would be set. The Action List could also contain biological entities for which toxicity limits are established (i.e., action levels). These action levels are used to identify where environmental concern may be low or high for a particular parameter. Mixing zones[1] are generally used and defined on a case-by-case basis. Action levels, to be met at the edge of the mixing zone, are often developed using a reference-based approach or an effects-based approach, which are noted below. Another approach could be a technology-based approach, also noted on point 3 below.

1. In a reference-based approach, action levels for physical, chemical, or biological characteristics can be set based on knowledge of background or ambient conditions at or near the extraction site. Reference-based levels are commonly used for setting lower benchmarks and lower action levels as it is reasonable to expect that levels that are similar to background levels would be unlikely to cause unacceptable effects.
2. In effects-based approaches, action levels for physical, chemical, or biological characteristics are based on knowledge of effects that can be produced following exposure to turbidity or heavy metals in the plumes. Such limits can be based on information concerning the likelihood or magnitude for an effect, such as through the use of toxicity tests or chemical-based sediment standards.
3. In a technology-based approach, applicants are required to use mining equipment that is the best technology available (BAT) which is explicitly designed to control and minimize the creation of sediment plumes. Applicants are expected to demonstrate what is considered BAT in pilot and prototype testing of the mining equipment. The action levels for turbidity and heavy metals and the mixing zone will be based upon that those test results and modeling using actual data on the physical and chemical/toxicity testing of the seabed sediments to be disturbed by the mining operations, as well as currents at the mining site[2]. It is understood that outside the mixing zones, and levels of turbidity and heavy metals will be established for each site based upon the capabilities of the mining equipment; if those levels are deemed to cause serious harm to habitat and biota, more stringent requirements can be set.

The action list becomes a functional decision-making tool by integrating the relevant characteristics (the list) and benchmarks (the levels) to form a decision rule. The decision rule can be as simple as a pass/fail criterion for single benchmarks, or it can be a more complex rule that combines multiple lines of evidence in a weight-of-evidence approach (IMO 2009).

An Action List should specify an upper level and may also specify a lower level. The upper level should be set to avoid acute or chronic effects on sensitive marine organisms, representative of the marine ecosystem. Specifying upper and lower action levels will result in three possible categories:

---

[1] Mixing zones can be defined as how far increased levels of turbidity spread in a certain time, such as four hours, or can be defined as a distance from the mining operation, such as 100 meters in all directions.

[2] In the USA, the technology-based approach was used under the Clean Water Act to regulate industrial waste discharges to rivers, lakes, estuaries, and coastal waters (USEPA n.d.). It was assumed that BAT will achieve an acceptable level of environmental protection, but if not, more stringent standards could be set.

- *Exceeding* the relevant upper level would cause unacceptable biological responses, unless made acceptable through the use of management techniques or processes;
- *Below* the relevant lower levels for specified substances which cause biological responses considered to be of little environmental concern; and
- Specified substances which cause biological responses *below* the upper level but *above* the lower level that require more detailed assessment before acceptability can be determined.

Potential Physical Impacts from Turbidity

Increased turbidity in the plumes generated from the extraction operations on the seabed need to be controlled, given the potential for adverse impacts to marine life. Concerns relate to extent of the mixing zone, the levels of turbidity in the mixing zone, and the levels of turbidity outside the mixing zone. Variables in determination of acceptability of effects to biota include the physical characteristics (i.e., grain size) of the seabed particles, the amount of suspended sediments released to the water column, and whether there are effects beyond physical effects (i.e., toxicity due to bioavailable heavy metals associated with the suspended solids in the plume).

The discharge from the dewatering operation onboard the support vessel will also create a plume that needs to be controlled. There will be similarities between this plume and the plume created during the extraction mining process given that physical characteristics of both plumes' particles are from the same source; however, the discharge point will likely be different and thereby the potential for spreading of the plume and its mixing zone characteristics will be different.

The action level for turbidity levels should be set such that turbidity does not exceed XXX NTU outside the mixing zone for the extraction site and the mixing zone for the dewatering discharge. The specific level will depend upon local site characteristics. The size of the mixing zones will depend upon the discharge depth and currents, including up-welling, that exist at those sites, to be determined by in-situ current measurements, background turbidity, and modeling. It is understood that outside the defined mixing zone, turbidity levels will not be significantly increased over background.

Potential Toxic Impacts from Chemical Constituents

For mining operations that result in bioavailable heavy metals in the plumes from the extraction phase or in the dewatering operation discharge, an action list and action levels should be established. In selecting substances for consideration in an Action List, priority should be given to toxic, persistent and bioaccumulative substances. Similar to action levels for turbidity, the action levels should be met at the edge of the mixing zone.

Notes regarding action levels for deep seabed mining: the approach in Step 3 is from the London Convention & Protocol's experience with wastes proposed to be disposed in ocean waters. Developed from the understanding of impacts upon habitats and marine organisms in coastal waters and not the deep sea, action levels for specific chemical substances have been developed for contaminants in dredged material. The IMO will publish those action levels in 2022.

Section 5 Step 4----The Baseline Survey for Environmental Assessment of the Extraction and Dewatering Discharge Sites

The environmental characteristics of the extraction site and the site of the dewatering discharge site are of paramount importance in determining the potential for unacceptable adverse impacts resulting from the mining operation.

It is essential that data be available on the oceanographic, chemical, and biological characteristics of the general area in which the extraction site and the discharge site are located. Relevant information may include:

1. The nature of the seabed, including benthos in the sub-seabed, including its topography, geochemical and geological characteristics, its biological composition, and biological activity;

2. The physical nature of the water column, including temperature, depth, possible existence of a thermocline/pycnocline and how it varies in depth with season and weather conditions, tidal period and orientation of the tidal ellipse, mean direction and velocity of the surface and bottom drifts, velocities of bottom currents and currents at the depth of the dewatering discharge, up-welling, turbidity and suspended matter; and

3. The chemical and biological nature of the seabed and water column, including pH, salinity, dissolved oxygen at surface and bottom, chemical and biochemical oxygen demand, nutrients and their various forms and primary productivity.

Important amenities including biological features and uses of the sea should be considered include proximity and relation to the following.

1. Migration routes
2. Seasonal and critical habitats
3. Areas of special scientific or biological importance, such as sanctuaries and marine protected areas
4. Fishing areas
5. Spawning, nursery, and recruitment areas
6. Shipping lanes
7. Military exclusion zones
8. Engineering uses of the seafloor including undersea cables and pipelines

The potential physical impacts to be considered include the following.

1. Habitat destruction or alteration due to changes in bottom topography or crushing by mining equipment

2. Transportation of suspended sediment plumes from the extraction and dewatering sites to sensitive areas

3. Burial of benthic organisms

Temporal characteristics should be considered to identify potentially critical times of the year (e.g., for marine life) when normal mining operations should be managed or should not take place. Managing the exposure and risks associated with mining during critical times can also be addressed through the use of engineering and operational controls as described in Section 7. Biological considerations relative to the timing of mining operations include the following.

1. Periods when marine organisms are migrating
2. Breeding periods
3. Periods when marine organisms are hibernating on or buried in the sediments
4. Periods when particularly sensitive and possibly endangered species are exposed

The baseline study should document the natural characteristics of the surrounding environment in the areas to be directly and indirectly impacted by the extraction operations and the dewatering discharges. The baseline study provides the basis from which to judge environmental impacts. Text Box 1 includes examples of what should be considered in a baseline study.

Box 1 The Baseline Survey (DNV GL AS 2016)

1. Physical oceanography
    - Oceanographic conditions, including the current, temperature and turbidity regimes, along the entire water column and, in particular, near the seafloor.
    - Measurement programme adapted to the geomorphology of the seabed and the regional hydrodynamic activity at the sea surface, in the upper water column and at the seabed.
    - Physical parameters at the depths likely to be impacted by the discharge plumes during the testing of collecting systems and equipment.
    - Particle concentrations and composition to record distribution along the water column.
2. Geology:
    - Geographic information system regional maps with high- resolution bathymetry showing major geological and geomorphological features to reflect the heterogeneity of the environment. These maps should be produced at a scale appropriate to the resource and habitat variability.
    - Information on heavy metals and trace elements that may be released during test mining and their concentrations.
3. Chemical oceanography
    - Information on background water column chemistry, including water overlying the resource, in particular on metals and other elements that may be released during the mining process.
    - Information on heavy metals and trace elements that may be released during test mining and their concentrations.
    - Additional chemicals may be released in the discharge plume following processing of the resource during test mining.
4. Sediment properties
    - The basic properties of the sediment, including measurement of soil mechanics and composition, to adequately characterize the surficial sediment deposits which are the potential source of deep-water plume.

- Sample the sediment taking into account the variability of the seabed.

5. Biological communities, (using high-resolution bathymetric maps to plan the biological sampling strategy, taking into account variability in the environment)
    - Data on biological communities, samples of fauna representative of variability of habitats, bottom topography, depth, seabed and sediment characteristics, abundance and mineral resource being targeted.
    - Data on the seafloor communities specifically relating to megafauna, macrofauna, meiofauna, microfauna, demersal scavengers and fauna associated directly with the resource, both in the exploration area and in areas that may be impacted by operations (e.g. the operational and discharge plumes).
    - Assess pelagic communities in the water column and in the benthic boundary layer that may be impacted by operations (e.g. the operational and discharge plumes).
    - Record in dominant species baseline levels of metals that may be released during mining.
    - Record sightings of marine mammals, other near-surface large animals (such as turtles and fish schools) and bird aggregations, identifying the relevant species where possible. Details should be recorded in transit to and from areas of exploration and on passage between stations. Temporal variability should be assessed.
    - Establish at least one station within each habitat type or region, as appropriate, to evaluate temporal variations in water column and seabed communities.
    - Assess regional distribution of species and genetic connectivity of key species.
    - Collections should be photo-documented (and indexed to video imaging) in situ to provide an archive of context/setting information for each sample.
6. Bioturbation (where appropriate): gather data on the mixing of sediments by organisms
7. Sedimentation: gather time series data on the flux and composition of materials from the upper water column into the deep sea

Section 6 Step 5----Assessment of Potential Environmental Effects

The assessment of potential environmental effects provides a basis for deciding whether to approve, modify, or reject the proposed mining operation, and for defining environmental monitoring requirements.

Assessment of Potential Effects

The assessment of potential effects involves five distinct actions:

1. Prepare a comprehensive environmental impact assessment, including seabed extraction operations, the dewatering discharge, and other potential actions or activities that may cause environmental harm, including those associated with the support vessels. The environmental impacts assessment should summarize the characteristics of the seabed sediment, the sediment plume from the extraction site, and the sediment plume from the dewatering discharge site.

2. Conduct an environmental risk assessment. The risk assessment should consider the primary sources of potential harm to the marine environment and evaluate that risk of harm to the marine environment. A risk management plan should be developed including an emergency preparedness plan and procedures. There may be a need for mitigation during or after the mining operations.

3. Determination of the acceptability of the effects and potential risks. The characteristics of the extraction site and the dewatering discharge site (refer to Sections 3 and 5), and the characteristics of the sediment plumes should be considered relative to the action levels (refer to Section 4); this analysis, along with the risk evaluation, provide a basis for determining if unacceptable adverse impacts are predicted or whether adverse impacts are predicted but are considered acceptable. This would form the basis for the environmental impact statement.

4. If the environmental impacts are considered acceptable (with or without management measures), and a contract is likely to be issued, impact hypotheses should be prepared that outline the expected impacts of the mining project. The impact hypotheses provide the basis for any needed management measures and targeted monitoring requirements to be specified in the contract. Impact hypotheses should be specified for:

    - Crushing or removal of habitat and organisms in the extraction of the ore from the seabed.
    - Creation of plumes from the ore extraction process.
    - Creation of plumes from the discharge from the dewatering operation from the support vessel.

- Other potential sources and impacts to the marine environment from such sources as the support vessels.

5. Assessing the actual impacts by evaluating the impact hypotheses using the data collected during post contract monitoring programs required in the contract (refer to Section 8).

Risk Assessment and Risk Management[3]

Risk assessment is the overall process of risk identification, risk analysis, and risk evaluation, which form the basis for a risk management plan, as well as an emergency response and contingency plan.

The purpose of risk identification is to find, recognize, and describe potential hazards, uncertainties, and risks that are associated with the mining operation and the support vessel in terms of potential harm to the marine environment. Sources of risks should have been identified in Step 1 (refer to Section 2), and the objective is to determine the uncertainties of whether those sources are under control. Examples would include the extent of the plume caused by the harvesting equipment, potential for breakage of the riser pipe, and the amount of sediments (total suspended solids) contained in the dewatering discharge.

The purpose of risk analysis is to comprehend the nature of the risks and their characteristics including, where appropriate, the level of risk. Risk analysis involves a detailed consideration of uncertainties, risk sources, consequences, likelihood, events, scenarios, and controls and their effectiveness. Risk analysis should consider factors such as:

- The likelihood of events and consequences;
- The nature and magnitude of consequences;
- Complexity and connectivity;
- Time-related factors and volatility;
- The effectiveness of existing controls; and
- Sensitivity and confidence levels.

Risk analysis provides an input to risk evaluation, to decisions on whether risk needs to be managed and how, and on the most appropriate risk treatment strategy and methods.

The purpose of risk evaluation is to support decisions. Risk evaluation involves comparing the results of the risk analysis with established risk criteria (refer to Section 4) to determine where additional action is required. This can lead to a decision to:

- Reject the application;
- Consider risk management options;
- Undertake further analysis to better understand the risk; and
- Determine that the project is acceptable with existing controls or added risk treatment control.

The purpose of risk treatment is to select and implement options for addressing risk. Risk treatment involves an iterative process of:

- Formulating and selecting risk treatment options;
- Planning and implementing risk treatment;
- Assessing the effectiveness of that treatment;
- Deciding whether the remaining risk is acceptable; and
- if not acceptable, taking further steps.

[3] This subsection on Risk Assessment and Risk Management is directly extracted with modifications from ISO 31000 (ISO 2018)

Selecting the most appropriate risk treatment option(s) involves balancing the potential benefits derived in relation to the achievement of the acceptable environmental impacts against costs, effort, or disadvantages of not going forward with the mining project.

Preparation of Impact Hypotheses

The assessment of the potential for impacts to the marine environment should lead to a concise statement of the expected consequences of the mining project, i.e., the impact hypothesis. Impact assessment proceeds by establishing a hypothesis, or prediction, about the potential impact, and then testing it scientifically.

> It is important to understand that if the expected consequences of the mining project are judged to cause unacceptable adverse impacts to ecological resources based upon characteristics of the sediment and sediment plumes and the characteristics of the surrounding environment including oceanographic conditions, then two choices exist, a contract cannot be issued (i.e., impact hypotheses are not needed) or the project should be modified such that impacts are considered acceptable.

For those projects for which impacts are likely to occur but are considered acceptable (i.e., meeting the Action Levels (see Section 4), impact hypotheses should be prepared. An impact hypothesis is a prediction of the likely environmental impact of the mining project. The assessment of potential effects should integrate information on the characteristics of the sediment, the mining technique, and the characteristics of the expected sediment plumes. The assessment should include potential pathways of exposure. It should comprise a summary of the potential effects on ecological receptors and human health, amenities and other legitimate uses of the sea, and should define the nature, and temporal and spatial scales of expected impacts based on reasonably conservative assumptions. In some cases, formal risk assessment procedures can facilitate the evaluation of potential effects including problem identification, exposure assessment, effects assessment, and risk characterization.

The conceptual model developed for the project under evaluation will assist in capturing the range of potential effects and formulating questions and hypotheses to be tested. Example questions that could be derived from the conceptual model include:

1. How will sediment and any associated bioavailable heavy metals be transported and dispersed in the marine environment?
2. How will the concentrations change as they disperse and settle?
3. What marine organisms are present (or likely to be present, based on past monitoring or life history information) in the zone of exposure?
4. What are the expected exposure pathways?
5. How would acute or sublethal toxicity be expressed in terms of consequences for populations of organisms in the vicinity of the mining project?

These questions can be rephrased as hypotheses that can be tested statistically with empirical data during the mining operation.

In constructing an impact hypothesis, particular attention should be given to, but not limited to, potential impacts on amenities, sensitive areas (e.g., spawning, nursery or feeding areas), habitat (e.g., biological, chemical, and physical modification), migratory patterns, and marketability of ecological resources. Consideration should also be given to potential impacts on other uses of the sea including fishing, navigation, engineering uses, areas of special concern and value, and traditional uses of the sea.

The expected consequences of the mining project should be described in terms of the habitats, processes, species, communities and uses that are expected to be affected. The precise nature of the predicted effect (e.g., change, response, or interference) should be described. The effect should be quantified in sufficient detail so that there would be no doubt as to the variables to be measured during field monitoring. In the latter context, it would be essential to determine *where* and *when* the impacts can be expected.

Emphasis should be placed on biological effects and habitat modification as well as physical and chemical change. However, if the potential effect is due to bioavailable heavy metals, the following factors should be addressed:

1. Estimates of statistically significant increases in seawater, sediments or biota in relation to existing conditions and associated effects; and
2. Estimates of the contribution made to local and regional fluxes and the degree to which existing fluxes pose threats leading to adverse effects on the marine environment or human health.

Impact hypotheses should consider the cumulative effects of the mining project, taking into account spatial and temporal factors.

An analysis of project design and management alternatives should be considered in the light of a comparative assessment of the following concerns: ecological and human health risks, environmental costs, potential hazards (including accidents), economics, and exclusion of future uses. If this assessment reveals that adequate information is not available to determine, with confidence, the likely effects of the proposed mining project, including potential long-term harmful consequences, then the project should not be considered further, until adequate information is available.

Once the potential environmental effects have been formulated into impact hypotheses, the specific provisions of the field monitoring programme can be designed. Impact hypotheses should be developed to address the effect of the mining project and, if needed, applying management measures (i.e., engineering and operational controls). Modifications via engineering and operational controls of mining and dewatering discharge operations may be an effective means of controlling the potential for both physical and biological effects.

An evaluation of the mining project could include a long list of exposure scenarios and possible effects. Impact hypotheses cannot attempt to reflect them all. It must be recognized that even the most comprehensive impact hypotheses will not address all possible scenarios and unanticipated impacts. It is therefore imperative that the monitoring programme be linked directly to the hypotheses and serve as a feedback mechanism to verify the predictions and the adequacy of management measures applied to the mining project. As a part of this process, it is important to identify the sources and implications of consequential uncertainties.

Photo credit: ISA

Section 7 Step 6----Issue Contract with Contract Conditions

A decision to issue a contract should only be made if all impact evaluations are completed, the monitoring requirements are determined (refer to section 8), and the results of the assessment determine the acceptability of impacts of the proposed mining project. The provisions of the contract shall ensure, as far as practicable, that environmental disturbance and detriment are minimized and any benefits maximized.

Requirements for each of the ISA key elements should be met. These include:

- Baseline Environment Survey
- Environmental Impact Assessment
- Environmental Impact Statement
- Hazard Identification and Risk Management Plan
- Environmental Management and Monitoring Plan
- Emergency Response and Contingency Plans
- Site Closure Plan
- Adaptive Management (see Section 8)

Contract conditions should be drafted in plain and unambiguous language, containing at a minimum, the following data and information specifying:

1. The location of the mining site and area to be mined;
2. The depth and location of the dewatering discharge;
3. The method of mining and techniques employed to minimize spreading of the sediment plumes;
4. Any engineering and operational conditions;
5. Any mitigation that is required;
6. An emergency preparedness and procedures plan;
7. Monitoring and reporting requirements; and
8. Decommissioning and site closure requirements.

As a part of project planning and decision-making, the consultation process should include relevant stakeholders, ensuring opportunities for public review and participation beginning from the earliest stages of the project through to completion, including the contracting process. Such coordination activities stimulate joint fact finding, often identifying opportunities to improve the overall project.

The contract is an important tool for managing the mining project and it will contain the terms and conditions under which the project may take place as well as provide a framework for assessing and ensuring compliance. In granting a contract, the hypothesized impact occurring at the mining site and in surrounding areas, such as alterations to the physical, chemical, and biological compartments of the local environment is accepted by the contract issuing authority. If the monitoring specified in the contract determines results significantly different than that predicted and result in unacceptable adverse impacts, the contract conditions for engineering and operational controls should be revisited.

Contracts will be based upon use of the best available technologies and best management practices to minimize environmental changes as far as practicable, given technological and economic constraints.

Any required mitigation for adverse impacts will be included in the contract. This is one area that can be revisited after the contract is issued; the results of monitoring may indicate that the predicted impacts are exceeded and thus, mitigation could be an appropriate alternative.

Considerations and requirements for site closure when the mining project is completed should be included in the contract.

Contracts should be reviewed at regular intervals, taking into account the results of monitoring and the objectives of monitoring programmes. Review of monitoring results will indicate whether field programmes need to be continued, revised, or terminated, and will contribute to informed decisions regarding the continuance, modification or revocation of contracts. This provides an important feedback mechanism for the protection of human health and the marine environment.

Section 8 Step 7----Monitoring and Adaptive Management

Monitoring plays an important role in managing effects upon the marine environment from deep seabed mining operations. Monitoring provides further critical feedback on the effectiveness of individual contract conditions, the evaluation process used in the contract evaluation process, and the management of specific mining sites. It can also increase knowledge about environmental conditions and the effects of an activity which can then serve as a basis for better assessment of environmental effects during other mining projects.

Monitoring is used to verify that contract conditions are met (compliance monitoring). Monitoring is also to assess that the assumptions made during the review of the proposed mining project and the estimate of potential environmental impacts were correct and sufficient to protect the environment and human health (field monitoring). It is essential that such monitoring programmes have clearly defined objectives.

Compliance monitoring involves providing assurances that:

1. The mining equipment and procedures are what is specified in the contract;
2. The mined material is handled and transported in accordance with the contract;
3. The area mined and volume is consistent with the contract; and
4. The dewatering discharge disposal depth and location are the same as specified by the contract.

Field monitoring involves sample collections at or near (and surrounding areas) the mining site and the dewatering discharge site. Measurements should be made over different spatial or temporal scales. What is monitored will depend directly on the impact hypotheses that were constructed during the assessment of potential effects (refer to section 7). Monitoring should be conducted with a clear purpose and the information should be used to assess and modify management actions (e.g., future project evaluations, ongoing project operations, or mining site management policies) and future contracting decisions, as appropriate.

The impact hypothesis forms the basis for defining field monitoring. The measurement programme should be designed to ascertain that changes in the receiving environment are consistent with predictions. The following questions should be answered:

1. What testable hypotheses can be derived from the impact hypothesis?
2. What measurements (e.g., type, location, frequency, performance requirements) are required to test these hypotheses?
3. How should the data be managed and interpreted?

Measurements should be designed to determine whether the zone of impact and the extent of change outside the zone of impact differ from those predicted. This can be accomplished by designing a sequence of measurements in space and time that gauges both the spatial scale and magnitude of any observable changes. Frequently, these measurements will be based on a null hypothesis, i.e., that no significant change due to mining activity can be detected.

Basing monitoring programmes on null hypotheses is a prospective (and not retrospective) approach in that acceptable and unacceptable adverse impacts are clearly defined before sampling begins, predicting what environmental resources are at risk, and the magnitude and extent of that risk from the mining activity and the dewatering discharge. The thresholds at which impacts will be adverse should be clearly defined prior to monitoring. Considerations in this regard include:

1. The monitoring programme should involve sampling before, during (where and when feasible) and after mining operations at the site and at appropriate reference sites.
2. Sampling design needs to consider the number of samples necessary to statistically test the hypotheses. The amount and type of testing necessary to support the decision will vary from project to project. It is important that the scale of the monitoring relates to the extent of the perceived problem and that the physical, chemical, or biological components of the monitoring programme relate to the cause of interest or concern.
3. The design of the monitoring programme should include identification of the physical fate of the sediment in any plumes that are created by the mining operation or the dewatering discharge as the first step, in order to determine if the sediment plumes are confined to the predicted mixing zone. This information will influence the design of sampling to test null hypotheses that address both physical and biological effects of the sediment plumes.
4. The monitoring programme should be designed to help ensure an appropriate balance between the data collection and analysis effort. It should also ensure the confidence needed to make judgments on whether contract conditions are being met and if management actions are needed. The programme should be progressive in that sampling results, as well as advances in technology and scientific understanding, can be used to adapt and modify the monitoring programme or modify the questions being addressed by the null hypotheses.

Different levels of monitoring intensity should be designed into the programme. Each level incorporates its own testable hypotheses, environmental thresholds, sampling design, and management options should the environmental thresholds be exceeded. Each level should be designed such that there would be no need to implement the next more intensive level unless the null hypotheses are exceeded. Information from each monitoring level should have direct application for the decision-making process. Monitoring results may lead to decisions to conduct additional confirmatory monitoring, initiate monitoring at the next level, make specific operational changes in the mining operations or possibly modify the dewatering process aboard the support vessel before discharge back to the sea. For example, if monitoring finds significant turbidity due to the sediment plume outside of what was predicted, that finding could trigger the need to conduct sampling to assess the extent of transport outside of the mixing zone and biological effects that may have resulted.

It may usually be assumed that suitable specifications of existing conditions in the receiving area are already contained in the contract application. If specification of such conditions is inadequate to permit the formulation of an impact hypothesis, the contracting authority will require additional information before any final decision on the contract application is made.

Research information should be taken into account that is produced over time by academic institutions, government agencies, mining companies, NGSs, and other organizations that have performed studies relevant to deep seabed mining to apply to the design of monitoring programmes.

The results of monitoring (or other related research) should be reviewed at regular intervals in order to determine the need for:

1. Modifying or terminating the field-monitoring program;

2. Modifying or revoking the contract;
3. Redefining the mining site; and
4. Modifying the basis on which applications for contracts are made and assessed.

The monitoring activities described above require significant interaction between programme designers, project managers and the contract issuing authority. Timely communication among these parties regarding monitoring progress and results is critical to understanding whether sampling within a particular level is sufficient, whether additional monitoring and assessment are needed, whether additional management actions should be undertaken, and to ensure the timely application of management actions when such actions are needed.

The above provides the basis for monitoring and based upon the results of monitoring, making changes as needed to the contract provisions. Some would call this a form of adaptive management. With a more formalized approach to adaptive management, levels of uncertainty about impacts on the environment should decrease over the course of the project as more accurate information is collected – project effects are continuously evaluated through various means and especially through monitoring to determine the need for modification.

8.14 The uniqueness of a more formal approach to adaptive management is that the overall process is thought through, designed prior to implementation of the project, and included in the contract. What this means is a series of “what if” questions, followed by a series of “what will be done” statements. Budgeting for the monitoring and the potential modifications to the project is essential. The classic adaptive management process (IADC 2016):

- <u>Plan</u>: The first step during which goals and objectives of the project and its parameters are defined, alternative actions are evaluated, and a preferred strategy is selected.
- <u>Design</u>: The phase when a flexible management action is identified or designed to address project challenges.
- <u>Implement</u>: The selected action is implemented according to the design.
- <u>Monitor</u>: The results or outcomes of the operational management action are monitored.
- <u>Evaluate</u>: The system response is then evaluated in relation to specified goals and objectives.
- <u>Adapt</u>: The contractor can adapt various integrated actions combining operational-technical-environmental-economic issues in proper monitoring and management to achieve goals and objectives.

Section 9 Summary

The environmental management framework in this document is modeled after the International Maritime Organization's London Convention & Protocol's Waste Assessment Guidelines (IMO, n.d.); those Guidelines have been used successfully around the world to control waste disposal into ocean waters.

The intention of the guidelines in this document is to provide an organizational framework for how each of ISA's key elements could be considered in reaching a decision for a proposed project.

The key steps in the environmental management framework include:

Step 1 Environmental Impact Prevention Audit and Waste Management Options

Step 2 Waste Characterization: Physical, Chemical, and Biological Effects

Step 3 Action List: Guidelines and Standards

Step 4 The Baseline Study for Environmental Assessment of the Extraction and Dewatering Discharge Sites

Step 5 Assessment of Potential Environmental Effects

Step 6 Issue Contract and Contract Conditions

Step 7 Monitoring and Adaptive Management

The challenges to be addressed are not simple. Data and information gaps include:

- Biological resources: Deep sea habitats are rich in biodiversity, inhabited by a wide range of species, and many are new to the scientific world.
- Mining equipment technology is being developed and the capabilities for minimizing potential plume generation are not well known:
    - Levels of suspended solids in the plume and turbidity from extraction actions.
    - Extent/dispersal of plumes horizontally and vertically; sedimentation rates.
    - The presence of heavy metals and potential for toxicity and bioaccumulation.
- The keys to decision-making that meet the objectives of the ISA include:
    - What are impacts to habitats and species?
    - What is an acceptable level of impact?
    - How is that acceptable level of impact achieved, measured, and reported?

References

DNV GL AS. (2016, September). Recommended Practice Managing environmental aspects and impacts of seabed mining DNVGL-RP-O601. https://standards.globalspec.com/std/14476183/DNV-RP-O601

IMO. London Convention & Protocol (2009). *Guidance for the development of action lists and action levels for dredged material*. https://www.gc.noaa.gov/documents/gcil_imo_dmaction.pdf

IMO. London Convention & Protocol. (n.d.). Waste Assessment Guidance. https://www.imo.org/en/OurWork/Environment/Pages/wag-default.aspx

International Association of Dredging Companies (IADC). (2016). *Facts about Adaptive Management*. https://www.iadc-dredging.com/ul/cms/fck-uploaded/documents/PDF%20Facts%20About/facts-about-adaptive-management.pdf.

ISA. (n.d.). The Mining Code: Standards and Guidelines. https://isa.org.jm/mining-code/standards-and-guidelines

ISO 31000. (2018). *Risk Management---Guidelines*; Second Edition 2018-02.

ITRC. (2011). Incorporating Bioavailability Considerations into the Evaluation of Contaminated Sediment Sites. https://projects.itrcweb.org/contseds-bioavailability/

Miller, Kathryn; Thompson, Kirsten F.; Johnston, Paul; and Santillo, David. (2018, January 10). An Overview of Seabed Mining Including the Current State of Development, Environmental Impacts, and Knowledge Gaps. https://www.frontiersin.org/articles/10.3389/fmars.2017.00418/full

National Research Council. (2003). *Bioavailability of Contaminants in Soils and Sediments: Processes, Tools, and Applications*. Washington, DC: The National Academies Press. https://doi.org/10.17226/10523.

USEPA. (1992). *Framework for ecological risk assessment.* EPA/630/R-92/001. Risk Assessment Forum. US Environmental Protection Agency, Washington DC. http:// www.epa.gov/raf/publications/pdfs/FRMWRK_ERA.PDF.

USEPA. (1992). *Dermal Exposure Assessment: Principles and Applications*. EPA/600/8-91/011B. Interim Report. Office of Health and Environmental Assessment, Washington, D.C.

USEPA. (n.d.). Summary of the Clean Water Act. 33 U.S.C. §1251 et seq. (1972). https://www.epa.gov/laws-regulations/summary-clean-water-act

Wenning, Richard J., Batley, Graeme E., Ingersoll, CG., and Moore, David. (2005, January). *Use of Sediment Quality Guidelines & Related Tools for the Assessment of Contaminated Sediments*. SETAC Press. https://www.researchgate.net/publication/264552155_Use_of_Sediment_Quality_Guidelines_Related_Tools_for_the_Assessment_of_Contaminated_Sediments