1 INTRODUCTION

1.1 Background

Nauru Ocean Resources Inc. (NORI), a wholly owned subsidiary of The Metals Company Inc. (TMC), plans to carry out testing of a polymetallic nodule collector system in the NORI-D contract area (NORI-D) of the eastern Clarion Clipperton Zone (CCZ), north Pacific Ocean. The CCZ is a region of commercial interest due to the presence of polymetallic nodules, covering an area over 4.5-million-km^2 with a typical nodule concentration of 15 kg/m^2 (MIDAS, 2016).

At the time of writing an Environmental and Social Impact Assessment (ESIA) is in process for the commercial mining of polymetallic nodules within NORI-D. The information gathered will inform a commercial Environmental Impact Statement (EIS) that will accompany NORI's application for a licence to operate commercially. The commercial EIS will include the information required by the International Seabed Authority (ISA) to make an informed decision on the feasibility of the application in terms of its social benefits and environmental impacts. Testing of the prototype collector vehicle (PCV), nodule processing system, the nodule riser system, and surface processing onboard the surface support vessel (SSV) (collectively referred to as The Collector Test) is considered an essential component of the commercial ESIA.

The International Seabed Authority (ISA) requires that an Environmental Impact Assessment (EIA) also be conducted for the Collector Test and an EIS submitted by the contractor to the Secretary-General no later than one year in advance of the activity taking place (ISBA/25/LTC/6/Rev.1/6B/B/34). The Collector Test EIS was submitted to the ISA on 29th July 2021 soon after which the document was released for a 45-day public comment period. A revised version of the Collector Test EIS was submitted to the ISA on 1st March 2023 which addressed relevant, valid and unique comments received from stakeholders.

This Environmental Management and Monitoring Plan (EMMP) has been compiled in response to the findings of the Collector Test EIS and incorporating inputs provided by various scientific groups during the Collector Test Monitoring planning workshop conducted at the Royal Geographic Society headquarters in London UK from 5-7th April 2023. The scientific groups in attendance have been contracted by NORI to conduct both additional baseline studies and monitor the environmental performance of the Collector Test.

1.2 No Significant Impacts

The information provided in the Collector Test EIS supports the finding that the proposed mitigation measures, additional project specific controls and small scale of the test program sufficiently minimise all physicochemical, biological, and cumulative impacts to non-significant levels. In the absence of significant residual impacts, the risk of the Collector Test resulting in 'serious harm' to the marine environment at a regional scale, is 'Low'.

Non-significant residual environmental effects will be monitored in accordance with Best Environmental Practices described in this EMMP.

1.3 The Collector Test

It is necessary to demonstrate the technical, economic, and environmental feasibility of operations proposed for the commercial collection of polymetallic nodules. The Collector Test is NORI's opportunity to demonstrate to the regulator that nodules can be successfully collected from the seabed and transported to a surface vessel. It will also allow assumptions about the design of the PCV and riser system to be tested under field conditions. The results of the test will be used to inform and improve the design and environmental performance of the commercial system.

The Collector Test will be conducted in parallel with studies of the physicochemical and biological baseline of NORI-D; the combined results will provide critical data for the commercial ESIA.

The Collector Test will take place in international waters and will adhere to the latest ISA recommendations (ISBA/25/LTC/6/Rev.1; 30 March 2020).

This EMMP is informed by data collected from the eastern CCZ and NORI-D and summarised in the Collector Test EIS (NORI, 2022), which outlines the potential environmental impacts associated with the Collector Test and serves to provide the basis for assessment of the proposed activities by the ISA.

1.4 Scope

"Environmental Effects" are defined as any consequences in the Marine Environment arising from the conduct of activities, whether positive, negative, direct, indirect, temporary or permanent, or cumulative effect arising over time or in combination with other mining impacts. The environmental effects of the Collector Test are described in Chapters 7 and 8 of the *NORI-D Collector Test Study Environmental Impact Statement* (NORI, 2022). This EMMP has been developed:

- Based on the environmental impact assessment and the Environmental Impact Statement;
- In accordance with the relevant regional environmental management plan; and
- Prepared in accordance with the applicable guidelines, Good Industry Practice, Best Available Scientific Evidence and Best Available Techniques.

This EMMP outlines commitments and procedures on how monitoring, management and mitigation measures will be implemented, how the effectiveness of such measures will be monitored, what the management responses will be to the monitoring results and what reporting systems will be adopted and followed.

1.5 Objectives

The key objectives of the Collector Test, as stated in the EIS, are to:

- Test the PCV and riser system components to inform the design and operation of the integrated system.
- Develop sound procedures to assess environmental risks associated with polymetallic nodule collection.
- Study the environmental impacts of polymetallic nodule collection to inform monitoring and mitigation measures and the development of management plans for full-scale operations.

To achieve these objectives the following three types of monitoring will be applied:

- **Validation Monitoring**: This monitoring takes place at the commencement of the project or activity and involves intensive, real time, and comprehensive monitoring to validate assumptions made in the baseline, EIA and EIS phase of the project. Upon the completion of the validation monitoring period, it is expected that uncertainty will be reduced, and the operation may enter a ‘steady state’ compliance monitoring period, which may be less intense.
- **Compliance Monitoring**: This monitoring is implemented throughout the project’s operations to ensure that the prescribed mitigation measures are effective in reducing the residual impacts

to acceptable levels. This monitoring should be conducted periodically, the timing of which will vary from project to project (but which will be agreed with the Authority and set out in the EMMP). It must be used to check that the levels of specific environmental parameters are compliant with applicable regulations, Standards or guidelines, and contractual obligations.

- **Long-term Monitoring**: Monitoring of Environmental Effects continue after completion of operations. This monitoring will be a continuation of some aspects of the compliance monitoring components, but likely with adjusted frequency and timescale. The details of long-term monitoring will be developed in accordance with the Closure Plan.

In the context of the objectives of the Collector Test most of the monitoring conducted will be Validation Monitoring, which is the focus of this EMMP. There will be a low level of Compliance Monitoring to ensure that mitigation commitments made in the EIS are adhered to; and the foundation will be set for Long-Term Monitoring as the Collector Test will represent the first temporal data point in the long-term monitoring program for the Impact Reference Zone (IRZ) and Preservation Reference Zone (PRZ).

1.6 Project Proponent

The Project proponent is Nauru Ocean Resources Inc. (NORI), a wholly owned subsidiary of The Metals Company which holds interests in commercially exploring the seafloor for polymetallic nodule deposits that are rich in base and strategic metals. The Government of Nauru is the sponsor of NORI's exploration rights within the NORI exploration areas.

The Metals Company (TMC) is a publicly listed Canadian company focused on producing clean base metals from polymetallic nodules. TMC has exploration rights issued by the ISA to three designated areas in the CCZ, sponsored by Nauru (NORI exploration areas), Tonga (TOML exploration area), and Kiribati (Marawa exploration area).

In July 2011, NORI formally signed the agreement with the ISA for exploration areas in the Pacific Ocean and became the first private sector organization to be granted an exploration contract. The contract gives NORI exclusive rights to conduct polymetallic nodule exploration activities within the four NORI exploration areas in the CCZ. NORI has been granted 74,380 km2 of exploration territory with their initial contract period maintained for 15 years.

2 PROJECT OVERVIEW

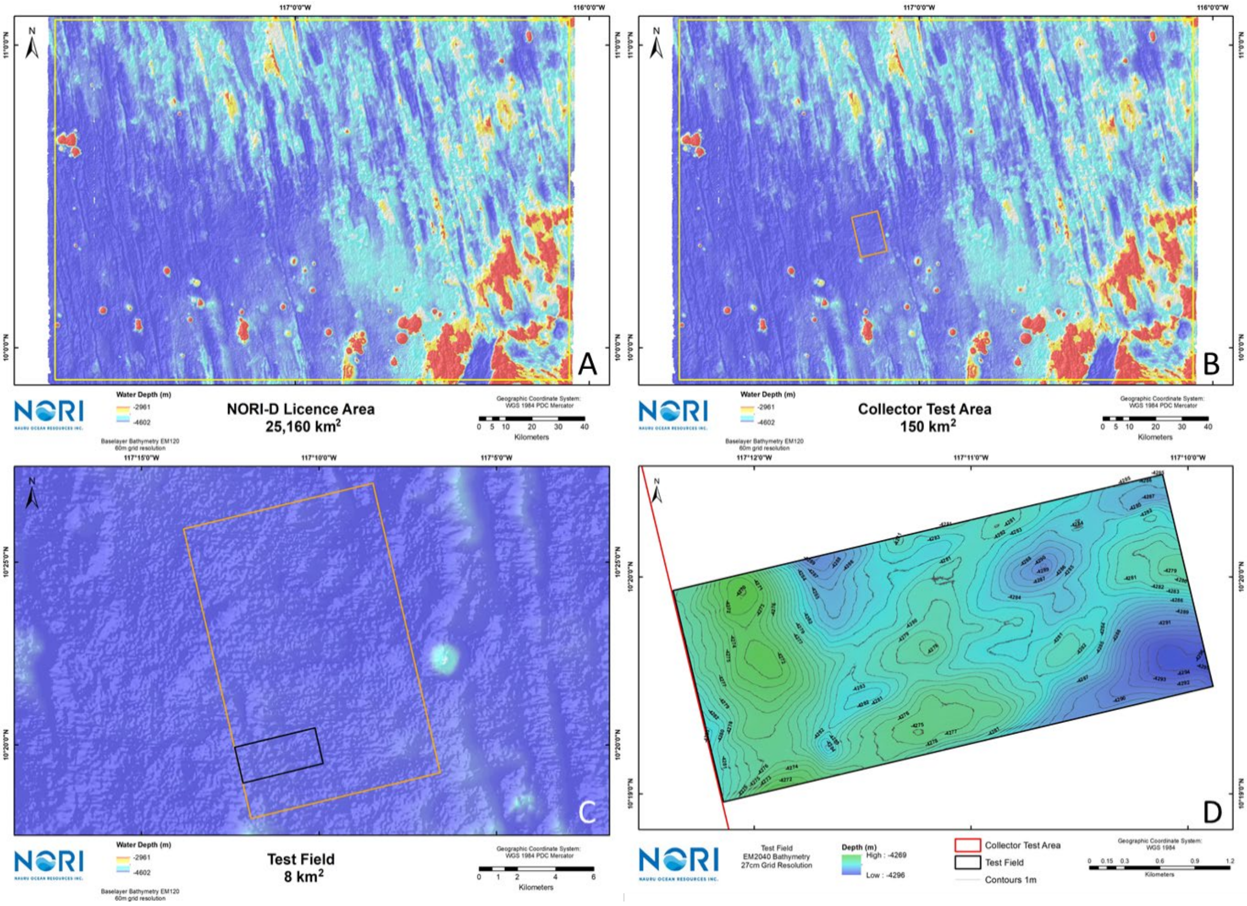
A full project description is provided in Chapter 3 of the EIS, an overview of salient features is provided below.

2.1 Collector Test Area

The collector test will be conducted in the NORI-D contract area (Figure 2-1A) in a designated 150 km^2 Collector Test Area (CTA; Figure 2-1B) within an 8 km^2 Test Field (TF; Figure 2-1C). The CTA and TF have been selected to be representative of the target nodule collection areas represented within NORI-D, based on bathymetry (Figure 2-1D), slope, water depth, nodule type, nodule distribution, and geoform classification.

The 8 km^2 TF represents 0.09% of the geoform/habitat represented on NORI-D and does not include any potentially sensitive geoforms or habitat types, such as seamounts. Of the 8 km^2 TF only 0.5 km^2 will be directly disturbed by the tracks of the PCV, although it is anticipated that the total area that will be subjected to increased levels (>0.5 mm) of sedimentation after the completion of the collector test will be approximately 6 km^2, and that the sediment footprint may extend beyond the boundaries of the TF into the CTA.

Figure 2-1. NORI-D contract area (A); Location of Collector Test Area (B); Location of Test Field (C); Bathymetry of Test Field (D).



2.2 System Components

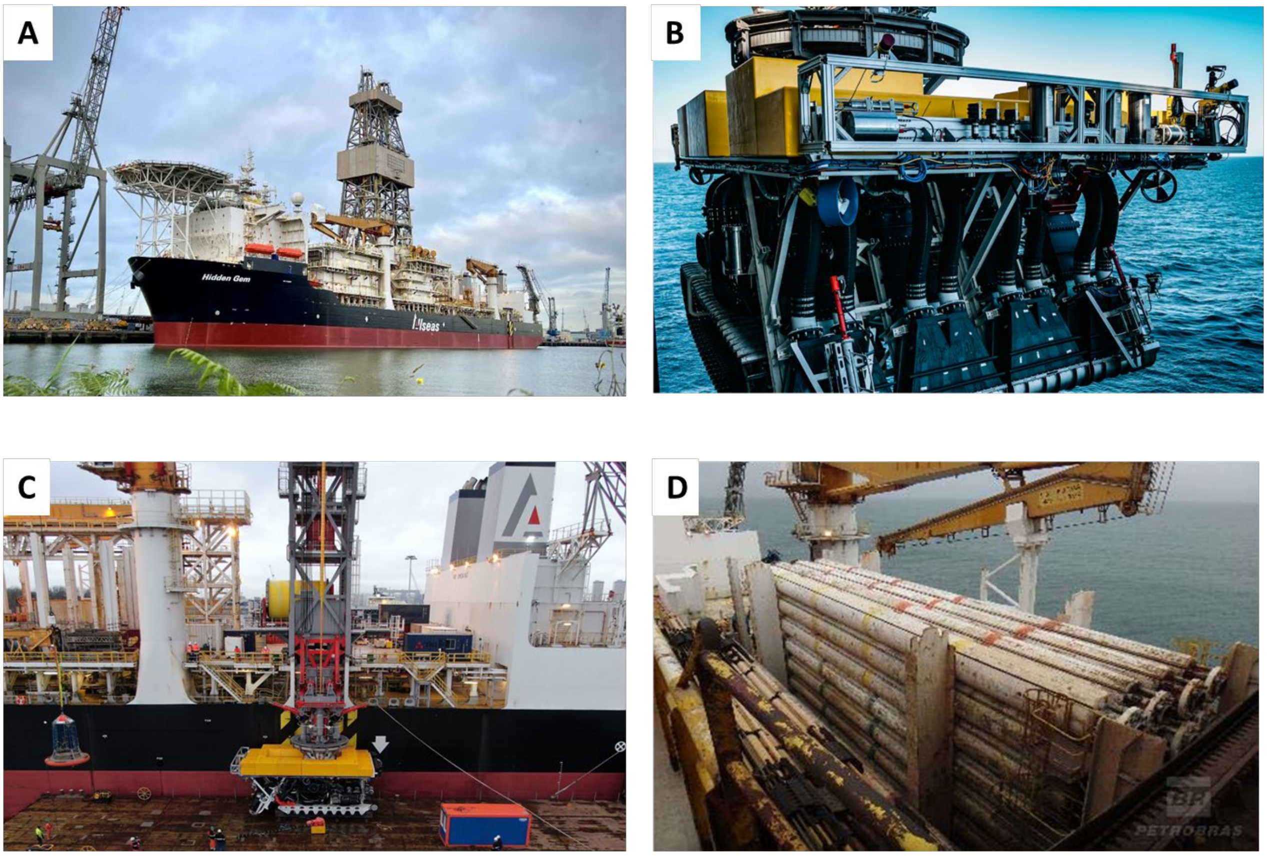
The main components to be tested include the Surface Support Vessel (SSV; Figure 2-2A), a dynamically positioned ship that will accommodate, launch, and recover the PCV and provide all other associated support equipment.

The PCV (Figure 2-2B) is one-half scale of the proposed commercial size, but otherwise, is a similar tracked vehicle that uses suction technology to collect nodules from the seafloor and will be controlled via an umbilical from the SSV. The PCV will be deployed from the SSV using a bespoke Launch and Recovery System (LARS) permanently installed to the side of the SSV (Figure 2-2).

A riser and return system (Figure 2-2D) will transport the collected nodules from the seabed to the surface and discharge water separated from nodules via a return pipe at a trial depth of 1,200m (the outlet to be positioned below the mesopelagic zone).

Assistance to the PCV for monitoring, attaching the riser system, visual and sonar surveys etc. will be provided by a Remotely Operated Vehicle (ROV) that will be available for environmental monitoring operations. Umbilicals on both the PCV and the ROV will provide the power and control of all the subsea equipment from the SSV to the seafloor.

Figure 2-2. Key system components. Surface Support Vessel (A); Prototype Collector Vehicle (B); Launch and Recovery System (C); Riser Pipe (D)



2.3 Vessels

Collector Test operations and associated monitoring will be conducted from two surface vessels. The Collector System will be deployed, operated, and recovered by Allseas from the *SSV Hidden Gem*. The science and monitoring studies will be coordinated by NORI from the *OSV Island Pride* operated by Ocean Infinity.

The *SSV Hidden Gem* is a former 228m drill ship that has been converted into a dedicated polymetallic nodule production vessel. Conversion works were completed in Rotterdam and included installation of a launch and recovery (LARS) system. The LARS has been specifically designed to safely deploy and recover the 12m, 80 tonnes, PCV from a stable midship position.

Operated by Ocean Infinity, the Island Pride is an advanced, multi-functional vessel used in geophysical survey, environmental sampling, and light construction. It has exceptional performance with regards to sea keeping/station keeping capacities and stability.

The Island Pride has the capacity to accommodate up to 102 persons and provides adequate meeting rooms to meet client specifications.

The vessel is equipped and certified according to IMO Class II for Dynamic Positioning, ensuring the vessel to obtain the best capabilities in DP manoeuvring. The vessel surpasses industry standards with regards to performance, and fully complies with requirements for energy efficiency and conservation.

Technical specifications for both vessels are provided in Table 2-1

Table 2-1. Technical specifications for the *SSV Hidden Gem* and *OSV Island Pride*

IMO:	9445150
Name:	HIDDEN GEM
Vessel Type - Generic:	Other
Vessel Type - Detailed:	Drill Ship
Status:	Active
MMSI:	215700000
Call Sign:	9HA5252
Flag:	Malta [MT]
Gross Tonnage:	60331
Summer DWT:	61042 t
Length Overall x Breadth:	228 x 42 m
Year Built:	2010
Home Port:	BASSETERRE

IMO:	9630547
Name:	ISLAND PRIDE
Vessel Type - Generic:	Other
Vessel Type - Detailed:	Offshore Supply Ship
Status:	Active
MMSI:	257406000
Call Sign:	LAGN8
Flag:	Norway [NO]
Gross Tonnage:	6983
Summer DWT:	4600 t
Length Overall x Breadth:	103.3 x 21 m
Year Built:	2014
Home Port:	AALESUND

2.4 Offshore Operations

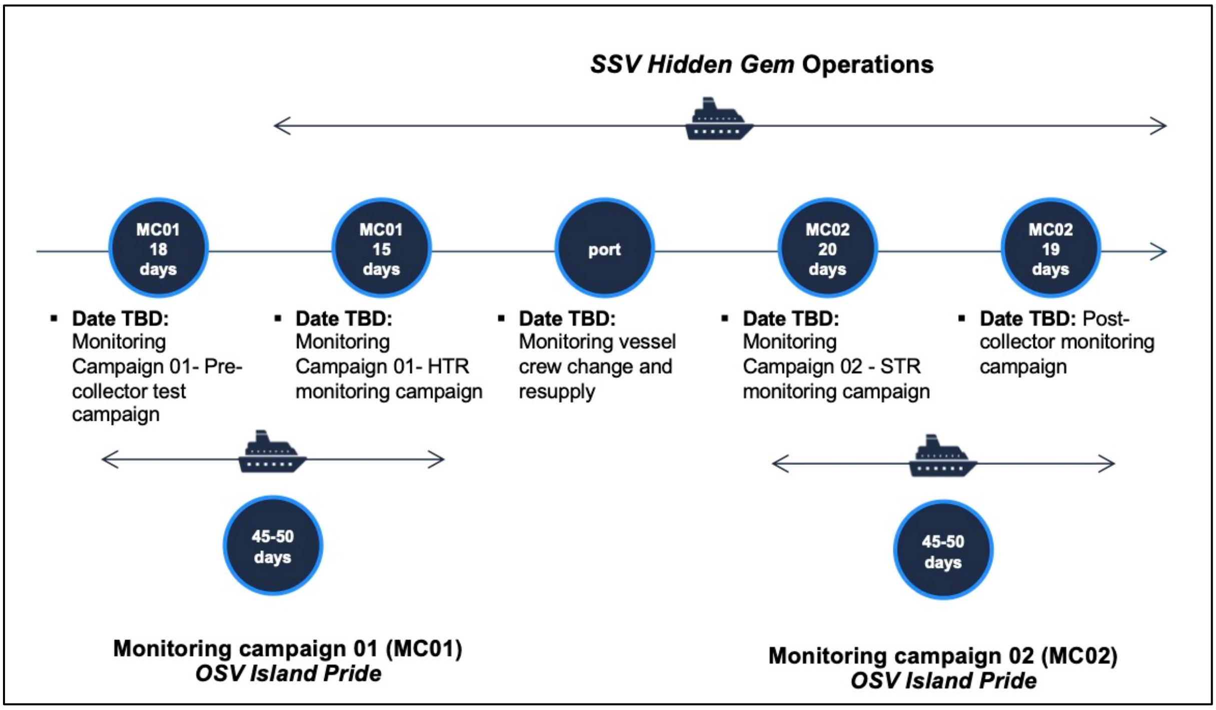
2.4.1 Campaign Schedules

Monitoring of the Collector Test will be conducted over two sequential campaigns each of 45-50 days in duration (Figure 2-3). The first campaign (MC01), scheduled to start in early Q3/2022 and will focus on testing the PCV on the seafloor; the second campaign (MC02), schedule for late Q3/2022, will focus on the performance of the full collection system.

Monitoring will comprise of pre-test, test, and post-test phases conducted over short temporal scales (hours, days, weeks), predominantly focusing on the technical performance of the collection system and immediate environmental impacts. The Collector Test also provides an opportunity to challenge assumptions made during collector system design and verify plume models.

Post-test studies will be conducted in the hours, days, weeks or months immediately following the completion of testing activities. The purpose of this monitoring program will be to quantify the immediate impacts of mining to the receiving environment, the findings will inform the commercial ESIA.

Figure 2-3. Collector Test Campaign Program



2.4.2 Roles and Responsibilities

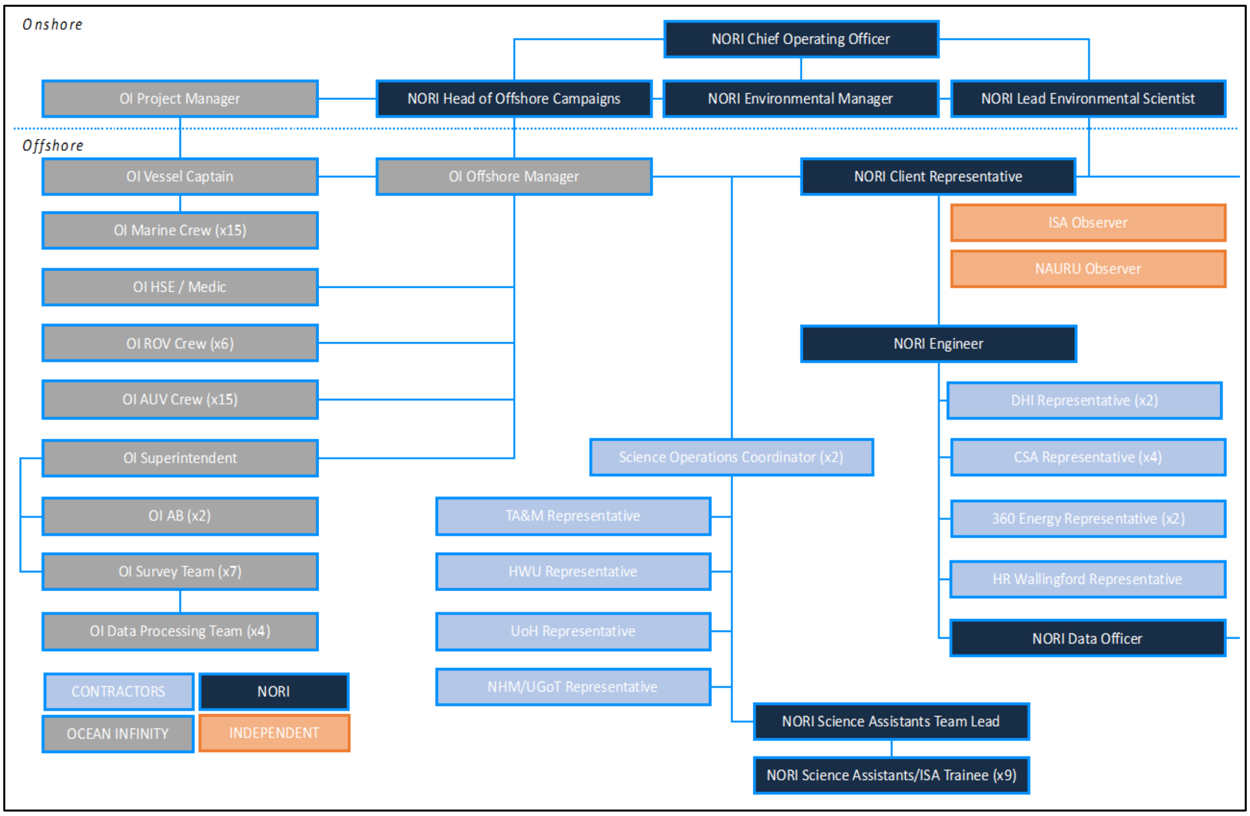
Offshore, there will be defined roles between vessels. The *SSV Hidden Gem* will be the platform from which the collector system operations will be coordinated, including deployment, operations and retrieval. It will also be the platform from which near field (i.e., ≤200 m from the collector system) and inline sample and data collection will be conducted. The *OSV Island Pride* will be the platform from which monitoring operations are coordinated. This will include coordinating with, and providing direction to, the scientific staff onboard the *SSV Hidden Gem* about to near-field monitoring requirements; and coordinating the extensive far-field monitoring program (i.e., ≥200 m from the collector system) monitoring activities.

Onboard the *OSV Island Pride* the tasks associated with the coordination and execution of the monitoring program will be distributed between the following parties:

- NORI Personnel – Development, planning and coordination of the monitoring program
- Ocean Infinity Personnel – Daily operations of the vessel and launch and recovery of equipment from the back deck.
- Contractors – Execution of specialized elements of the monitoring program related to specific areas of expertise
- Independent Observers – Will observe the monitoring activities and report back to their respective regulatory bodies.

An organization chart summarizing the lines of responsibility between these parties is provided in Figure 2-4. Details of the role and responsibilities of the personnel onboard the monitoring vessel are provided in Appendix 1.

Figure 2-4. Organisation chart for the implementation of monitoring activities onboard the *OSV Island Pride*



2.5 System Test Runs

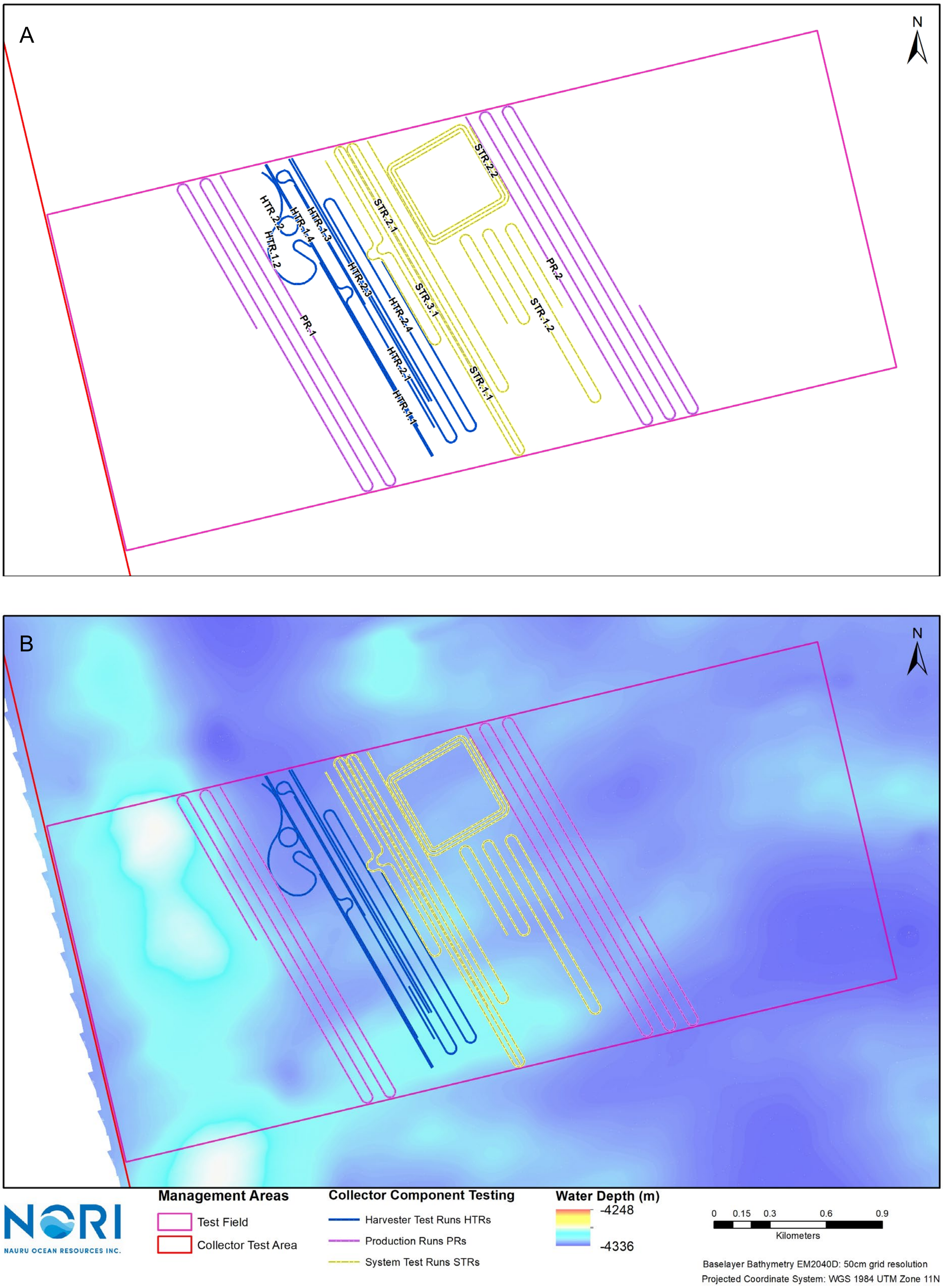
The PCV and riser pipe will be deployed and controlled by Allseas from the *SSV Hidden Gem*; the monitoring activities will be conducted from the *OSV Island Pride*. Harbour Acceptance Tests (HATs) completed and Sea Acceptance Tests (SATs - North Sea drive test) have been completed.

For the collector test operations, the *SSV Hidden Gem* will transit from port (provisionally San Diego) to NORI-D for an estimated 60 days on location. Once initial field inspection and preparation are complete, the PCV will be lowered to the seafloor and the testing sequence will commence with manoeuvrability and pick-up tests. These will involve straight line and turning tests, obstacle avoidance tests and line tracking tests, taking an estimated 97 hours to complete. This will be followed by pick-up efficiency tests, requiring an estimated 127 hours. During these trials the PCV will not be connected to the riser system and any nodules collected will be discharged to the seafloor behind the PCV.

The next stage involves the riser installation, commissioning and integration testing (210 hours), followed by system line and manoeuvring test runs, initially without nodule production at slow speeds (0.1 to 0.5 m/s), then with nodule production ramp-up to full capacity (319 hours). Testing will progress to performance test runs to determine nodule production rates and efficiencies under straight line, 180° turning, and contour mining; this will be followed by advanced capacity and slope ability test runs. The trials will end with an emergency shutdown test prior to de-commissioning and site closure.

The estimated overall total time requirement for system testing is 860 hours, during which the PCV will travel approximately 82 linear kilometres and collect approximately 3600 wet tonnes of nodules.

Figure 2-5. Test run plan (A) and approximate location and orientation of test runs within the Test Field (B).



The Allseas test plan, in simple terms, includes five different types of tests;

i. Harvester Test Runs (HTR 1) which involves the vehicle tracking on the seafloor with no collection and thus no collection plume),

ii. Harvester Test Runs (HTR 2) generates a benthic plume only, with no mid water column discharge),

iii. System Test Run (STR 1.1), which involves the vehicle tracking on the seafloor with no collection and thus no collection plume,

iv. System Test Runs (STR 1.2 – 3.1), which generate both benthic and mid-water plumes at ≤ production capacity) and;

v. Production Runs (PR, which generate both benthic and mid-water plumes at full production capacity).

The layout of the provisional collector test track plan is shown in Figure 2-5A. The alignment of test tracks shall be considered final as these are based on weather vanning of surface vessel. Location and characteristics of specific test runs are subject to change with the exception of PR tests being at the East and West limits.

Only the performance of the PCV will be tested during the initial test runs; this will involve putting the vehicle through several performance and functionality trials on the seabed (HTR; Figure 2-5A). HTR trials will be non-productive, meaning that nodules will not be collected, or they will be collected and exited from the rear of the PCV at the seabed. Non-productive trials generate a benthic plume only.

Following the HTR trials the full collector system will be connected and commissioned, consisting of the PCV, riser pipe, surface processing and return pipe system (STR; Figure 2-5A). During STR trials production will be ramped meaning that nodules plus entrained sediment and cold water, will be transferred to the surface vessel, eventually reaching full production capacity.

Productive runs (PR/; Figure 2-5A) will be conducted at, or close to, full capacity, generating both benthic and midwater plumes simultaneously.

The ultimate location of each of the HTR, STR and PR are to be confirmed however they will be located within the generalised track location box (Figure 2-5B) and will be in a NW-SE orientation.

A summary of the test run schedule is provided in Table 2-2.

Table 2-2. Summary of test run schedule

Code	Program Item	Vessel Time		Collected Nodules		Distance Travelled	
		Hrs	Cumulative	t, wet	cumulative t, wet	km	cumulative km
FIP	Field Inspection & Preparation	22.4	22.4	-	-	-	-
HTR	Harvester (collector) Test Runs						
HTR.1	Manoeuvrability Test Runs						
HTR1.1	Straight-line test	28.0	50.3	-	-	3.00	3.00
HTR1.2	Turning (radius) test	25.5	75.9	-	-	1.14	4.14
HTR1.3	Obstacle avoidance test	26.0	101.8	-	-	1.69	5.83
HTR1.4	Lane tracking test	26.0	127.8	-	-	1.69	7.51
HTR.2	Pick-up test runs						
HTR.2.1	First pick-up test	28.8	156.6	-	-	1.50	9.01
HTR.2.2	Pick-up test during turning	25.5	182.1	-	-	0,41	9.43
HTR.2.3	Pick-up efficiency test	35.9	218.0	-	-	3.00	12.43
HTR.2.4	Pick-up performance with turning	34.1	252.0	-	-	4.48	16.91

Code	Program Item	Vessel Time		Collected Nodules		Distance Travelled	
		Hrs	Cumulative	t, wet	cumulative t, wet	km	cumulative km
RIC	Riser Installation & Commissioning	186.0	438.0	-	-	-	-
SIT	System Integration Test	32.9	470.9	-	-	-	-
STR	System Test Runs						
STR.1	Commissioning Test Runs						
STR1.1	Manoeuvrability test	38.0	508.9	-	-	4.97	21.88
STR1.2	Production ramp-up test	39.5	548.5	403	403	4.28	26.17
STR.2	Nominal Performance Test Runs						
STR2.1	Straight-line performance test	37.9	586.3	491	894	4.69	30.85
STR2.2	Contour mining (field test)	38.8	625.1	680	1,575	5.20	36.05
STR.3	Advanced Test Runs						
STR3.1	150% capacity test runs	34.6	659.8	462	2,037	4.49	40.55
STR3.2	Slope ability test runs (>4°)	37.5	697.2	462	2,500	4.49	45.04
PR	Production Runs						
PR.1	12hrs@ 100% nominal production rate	45.4	742.6	870.6	3,370	8.46	53.68
PR.2	24hrs@ 60% nominal production rate	61.8	804.5	1,044.7	4,415	10.37	64.05
EST	Emergency shutdown test	32.9	837.4	-	-	-	-
DSC	Decommissioning and site closure	74.6	912.0	-	-	-	-
	Total	912.0	-	4,415	-	64.05	-
	Total days	38.0	-				

3 MONITORING

The ISA recommends a dedicated assessment of the technical and environmental performance of the collector system prototype system (ISBA/25/LTC/6/Rev.1; 30 March 2020). The inclusion of a Collector Test into the commercial EIA process provides the opportunity to assess the technical performance of the prototype collector system and its potential environmental impacts in the NORI-D contract area which is proposed at a scale and duration of activities that is sufficient to meet the study objectives but of insufficient magnitude to incur any serious harm to the marine environment. As such, the Collector Test is essentially an experiment dedicated to test and refine the technical performance of the equipment and provide empirical (*in-situ*) environmental monitoring data during and after the test, which is essential to inform impact predictions and to apply best mitigation practices to a commercial system.

In this context, validation monitoring (see Section 1.5) is key to the assessment of the technical and environmental performance of the collector prototype system. Validation monitoring methods are described below.

3.1 Environmental Effects

The Collector Test EIS identified at total of 103 environmental effects that have the potential to cause impact to the receiving environment. Although the EIS demonstrates that it is unlikely that there will be any significant residual impacts, and that the risk of the Collector Test resulting in ‘serious harm’ to the marine environment at a regional scale is ‘Low’, the environmental effects identified in the EIS form the basis for the validation and compliance monitoring programs.

The environmental effects identified in the EIS, together with the zone of influence, causal activity, and vulnerable VECs/Impact Pathways, are summarised in Table 3-1, Figure 3-1, Table 3-2 and Table 3-3.

Table 3-1. Environmental effects per zone

IMPACT ZONE	ZONE	NUMBER OF ENVIRONMENTAL EFFECTS
IMPACT ZONE 1	Atmospheric	8
	Euphotic (0-200 m)	23
IMPACT ZONE 2	Mesopelagic (200-1,000 m)	11
	Bathypelagic (1,000-4,000 m), and	17
IMPACT ZONE 3	Abyssal (4,000-6,000 m; inc. benthic boundary layer and seafloor)	44
TOTAL		**103**

Figure 3-1. Schematic representation of impact zones as defined in the collector test EIS (2022)

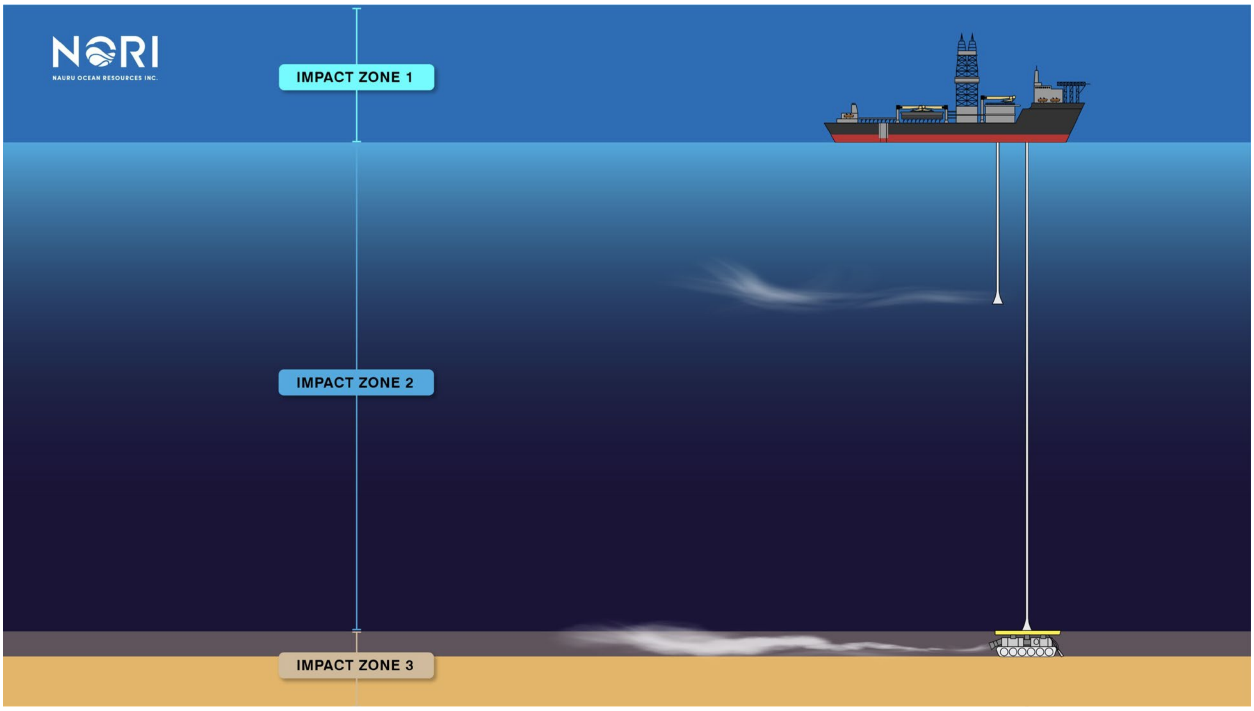


Table 3-2. Environmental effects per project related activity

ACTIVITY	NUMBER OF ENVIRONMENTAL EFFECTS
Transit to Collector Test Area	4
Offshore inspection and preparation	10
PCV Deployment	7
Jumper and riser deployment	8
Riser commissioning	6
Subsea connection of jumper on PCV	3
System Testing	43
Emergency shutdown testing	0
Riser and PCV recovery	15
Transit from test site	7
TOTAL	**103**

Table 3-3. Activities, valued ecosystem components, and impact pathways

ACTIVITY	VECS	IMPACT PATHWAYS
Transit of the vessel from San Diego to the CCZ	Air quality/GHG	Vessel's diesel engines will emit fumes into the atmosphere reducing local air quality and contributing to GHG emissions.
	Noise/vibration/light	Vessel's diesel engines will generate noise and vibrations which could disturb birds, cetaceans, and turtles. Vessel will emit light.
	Cetaceans/turtles	Vessel strike on cetaceans or turtles
	Water quality	Intentional or accidental release of pollutants from the vessels could negatively impact water quality
Offshore Inspection and Preparation	Water quality	Leakage of hydraulic fluids, oil, or other substances from the ROV could negatively impact water quality throughout the water column during its descent to the seabed.
	Noise/vibration/light	Deployment of ROV top the seabed has potential to generate noise, vibration, and light.
	Benthic Biota (sediment, nodule, free swimming)	Deployment of the ROV and other equipment (inc. LBL network) to the seabed has the potential to physically disturb sediment and nodule dwelling animals.
	Benthic Habitat Quality	Deployment of other equipment (inc. LBL network) to the seabed will physically disturb benthic habitat by creating contours in the sediment.
PCV Deployment	Cetaceans/Turtles	Lowering the PCV through the splash zone could disturb or physically strike cetaceans or turtles that are in close proximity to the vessel.

ACTIVITY	VECS	IMPACT PATHWAYS
	Water Quality	Leakage of hydraulic fluids, oil, or other substances from the PCV could negatively impact water quality throughout the water column during subsea lowering.
	Benthic Biota (sediment, nodule, free swimming)	Touchdown of the PCV on the seabed will physically disturb, displace or kill sediment and nodule dwelling animals.
	Benthic Habitat Quality	Touchdown of the PCV on the seabed will physically disturb the benthic habitat by creating contours in the sediment and/or moving or crushing nodules.
Jumper and Riser Deployment	Cetaceans/Turtles	Lowering the jumper and riser tubes through the splash zone has the potential to disturb or physically strike cetaceans or turtles that are in close proximity to the vessel.
	Water Quality	Leakage of hydraulic fluids, oil, or other substances from the ROV during manipulation of the jumper or riser could negatively impact water quality throughout the water column.
Riser Commissioning	Noise/Vibration	Surface and/or subsea noise or vibrations caused by pressure testing of the riser pipe could disturb birds, cetaceans, and turtles.
	Cetaceans/Turtles	Surface and/or subsea noise or vibrations caused by pressure testing of the riser pipe could disturb birds, cetaceans, and turtles
Subsea Connection of Jumper on PCV	Water Quality	Leakage of hydraulic fluids, oil, or other substances from the ROV during connection of the jumper on the PCV could negatively impact water quality throughout the water column.
System Testing	Cetaceans/Turtles	Riser installation and commissioning tests, system integration testing, and system test runs all have the potential to create noise and vibration disturbances at the surface and throughout the water column from use of the air lift and through pressure testing of the system which could disturb diving and foraging behaviour.
	Microbes	Manoeuvring the PCV on the seabed, pick-up test runs, and system test runs will physically disturb the sediments and nodules potentially disrupting the microbial community structure in the surface layers of the sediment, and seafloor metabolic activity
	Water Quality	Manoeuvring the PCV on the seabed, pick-up test runs, and system test runs will physically disturb the sediments

ACTIVITY	VECS	IMPACT PATHWAYS
		and nodules creating a sediment plume and potentially mobilizing particle-bound nutrients and trace metals.
	Noise/Vibration/Light	Manoeuvring the PCV on the seabed and pick-up test runs will create noise and vibration which could disturb or displace motile large macrofauna. Riser installation and commissioning tests, system integration testing, and system test runs all have the potential to create noise and vibration disturbances at the surface and throughout the water column from use of the air lift and through pressure testing of the system. PCV will emit light.
	Benthic Biota (sediment, nodule, free swimming)	Manoeuvring the PCV on the seabed and pick-up test runs will create noise and vibration which could disturb or displace motile large macrofauna. Riser installation and commissioning tests, system integration testing, and system test runs all have the potential to create noise and vibration disturbances at the surface and throughout the water column from use of the air lift and through pressure testing of the system. PCV will emit light. Manoeuvring the PCV on the seabed and pick-up test runs will physically disturb or remove sediment and nodule dwelling animals. System test runs will create a benthic plume, as entrained sediment is ejected from the rear of the PCV; this plume will be denser than that formed during the manoeuvrability and pick-up test runs and will blanket and smother surrounding sessile biota.
	Sediment Geochemistry	Manoeuvring the PCV on the seabed, pick-up test runs, and system test runs will mix the surface layers of the sediment, disrupting oxygen concentration gradients in the surface layers and potentially mobilizing particle-bound nutrients and trace metals.
	Benthic Habitat Quality	Manoeuvring the PCV on the seabed and pick-up test runs will physically disturb the benthic habitat by creating contours in the sediment, disrupting surface layers of sediment, and/or moving or crushing nodules. System test runs will create a benthic plume, as entrained sediment is ejected from the rear of the PCV; this plume will be denser than that formed during the manoeuvrability and pick-up test runs and will blanket and smother surrounding sessile biota.
	Nekton	Nekton in the mesopelagic and bathypelagic zones could be impacted by noise and vibration from the air lift system

ACTIVITY	VECS	IMPACT PATHWAYS
		and by suspended sediment and mobilized chemicals released from the return water pipe outlet at 1,200 m.
	Zooplankton	Zooplankton in the euphotic, pelagic and bathypelagic zones could be impacted by noise and vibration from the air lift system and by suspended sediment and mobilized chemicals released from the return water pipe outlet at 1,200 m.
	Water Quality	Water quality in the bathypelagic zone and below could be impacted by increased turbidity caused by suspended sediments and mobilized chemicals released from the return water pipe outlet at 1,200 m.
	Climate Regulation	Emissions of GHGs to the atmosphere through travel, operation of equipment or mobilization of sequestered C in benthic sediments.
Emergency Shutdown Testing	N/A	There are no environmental aspects anticipated to be associated with the emergency shutdown testing of the system.
Riser and PCV Recovery	Cetaceans / Turtles	Rising the jumper hose, riser pipe, and PCV through the splash zone could disturb or physically strike cetaceans or turtles that are in close proximity to the vessel.
	Water Quality	A ROV will be used for recovery, leakage of hydraulic fluids, oil, or other substances from the ROV could negatively impact water quality throughout the water column.
Transit of the vessel from the CCZ to San Diego	As for previous transit	As for previous transit
Cumulative Impacts	Ecosystem Function	Disruption of key ecosystem functions as a result of additive or synergistic impacts from project related activities.
	Ecosystem Services	Disruption of climate regulation capacity

3.2 Validation Monitoring Program

The validation monitoring program consists of seven study streams designed to investigate the key environmental effects of the Collector Test, including:

Seafloor Studies – to investigate of the impact of the collector system on seafloor structure, biota and habitats

- Biological – to investigate the impacts to megafauna, macrofauna, meiofauna, foraminifera, benthic scavengers and seabed respiration.

- Chemical - to investigate the impacts to the sediment geochemistry
- Geophysical – to investigate the impacts to the seafloor geomorphology including the removal nodules and physical alterations to the sediments.

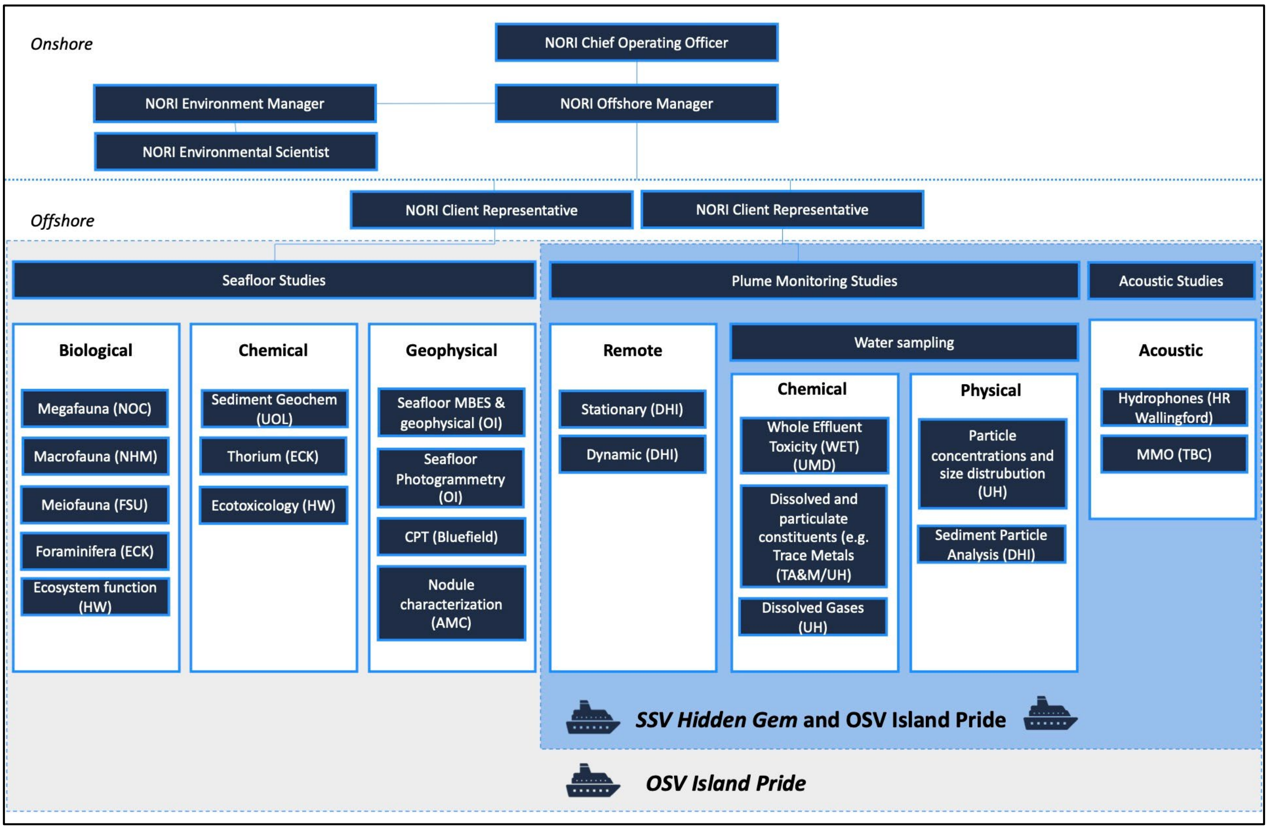
Plume Monitoring Studies - to investigate the impact of the benthic operational plume and mid-water discharge on water quality

- Remote – mapping of plume dynamics
- Chemical – to investigate impacts of the benthic operational and mid-water plume on water chemistry
- Physical - to investigate impacts of mid-water plume on physical properties of the water columns

Acoustic Studies – to investigate impacts of noise on aquatic receiving environment.

The organization of the workstreams is summarized in Figure 3-2.

Figure 3-2. Management and organisation of validation monitoring study streams.



3.2.1 Remote Sensing of Plumes

Lead Contractors: DHI and CSA – third party oversight by HR Wallingford and NOC

The plume modelling conducted by DHI for the Collector Test EIA (DHI, 2022) will be field verified during the collector test. These studies will be conducted in accordance with the ISA recommendations paragraph 38 sub clause (e) and (k) [bold italicised]. The requisite section recommends monitoring of:

> *C. Information and measurements to be provided by a contractor performing an activity requiring an environmental impact assessment during exploration*

38 (e) Methods for separation on the sea floor of the mineral resource and the sediment, including washing of the minerals, ***concentration and composition of sediment mixed with water in the seabed-disturbance plume, height above the sea floor of discharge plumes****, modelling of particle size dispersion and settlement, estimates of depth of sediment smothering with distance from the mining activity, and estimates (based on plume models) of the spread of the plumes in the water column horizontally and vertically, including particle concentrations as a function of distance from, and duration of, the proposed mining activity;*

38 (k) ***Volume and depth of discharge plume****, concentration and composition of particles in the discharged water, chemical and physical characteristics of the discharge and* ***behaviour of the discharged plume at the surface, in mid-water or at the seabed, as appropriate.***

3.2.1.1 Plume Monitoring Program Philosophy

The overall plume monitoring program consists of two key components:

- Near-field monitoring of the plume refers to data collected within 200m of the collector system. This 200m buffer zone is necessary to ensure that monitoring activities do not conflict with system operations. All near field data collection will be coordinated from the *SSV Hidden Gem*, primarily through instrumentation attached to the PCV, riser pipe, return pipe, or the SSV ROV which will be deployed from the *SSV Hidden Gem*, and will operate within the 200m buffer zone.
- Far-field monitoring of the plume refers to data collected outside the 200m collector system buffer zone. This data will be collected with a series of static sensors, moorings, and OSV ROV/AUV mounted sensors deployed from the *OSV Island Pride* and will operate outside the 200m buffer zone.

Near-field and far-field monitoring of the plume will be conducted in Impact Zones 2 and 3 as defined in the Collector Test EIS:

- Impact Zone 1 – Atmosphere, Surface Waters and Euphotic zone (0m -200m)
- Impact Zone 2 –Mesopelagic (200-1,000m) and Bathypelagic zone (1,000m -4,000m)
- Impact Zone 3 –Abyssal (4,000m -6,000m) and Benthic (seabed) zones

The overall philosophy behind the plume monitoring program is summarized in Figure 3-3. There are 6 key components:

1) **Fixed Monitoring Stations:** that will stay in place for the duration of the Plume Monitoring Program. This includes references stations and fixed current monitoring stations with real time data connectivity to feed into the Decision System. Fixed monitoring stations also include an array of sediment plates.
2) **Movable Monitoring Stations:** that will be re-located prior to each HTR, STR and PR test based upon information from the Decision System. These stations focus on measurement of TSS and temporal measurement of sedimentation.
3) **Dynamic ROV Monitoring**: that will fly transects through the plume to attain a 3-dimensional picture of the plume characteristics. ROV monitoring will be undertaken in both the near-field and far field and will utilize information from the Decision System and real time data feeds to determine transect locations.

4) **AUV Monitoring:** that will fly patters further way from the plume source to supplement the ROV measurements and confirm the limit extent of the suspended plume and will utilize information from the Decision System to flight paths.
5) **PCV Monitoring**: to measure plume characteristics as close to source as practical
6) **Return Water Discharge Monitoring:** to provide a robust determination of the mass flux of sediment discharged at the mid water discharge.

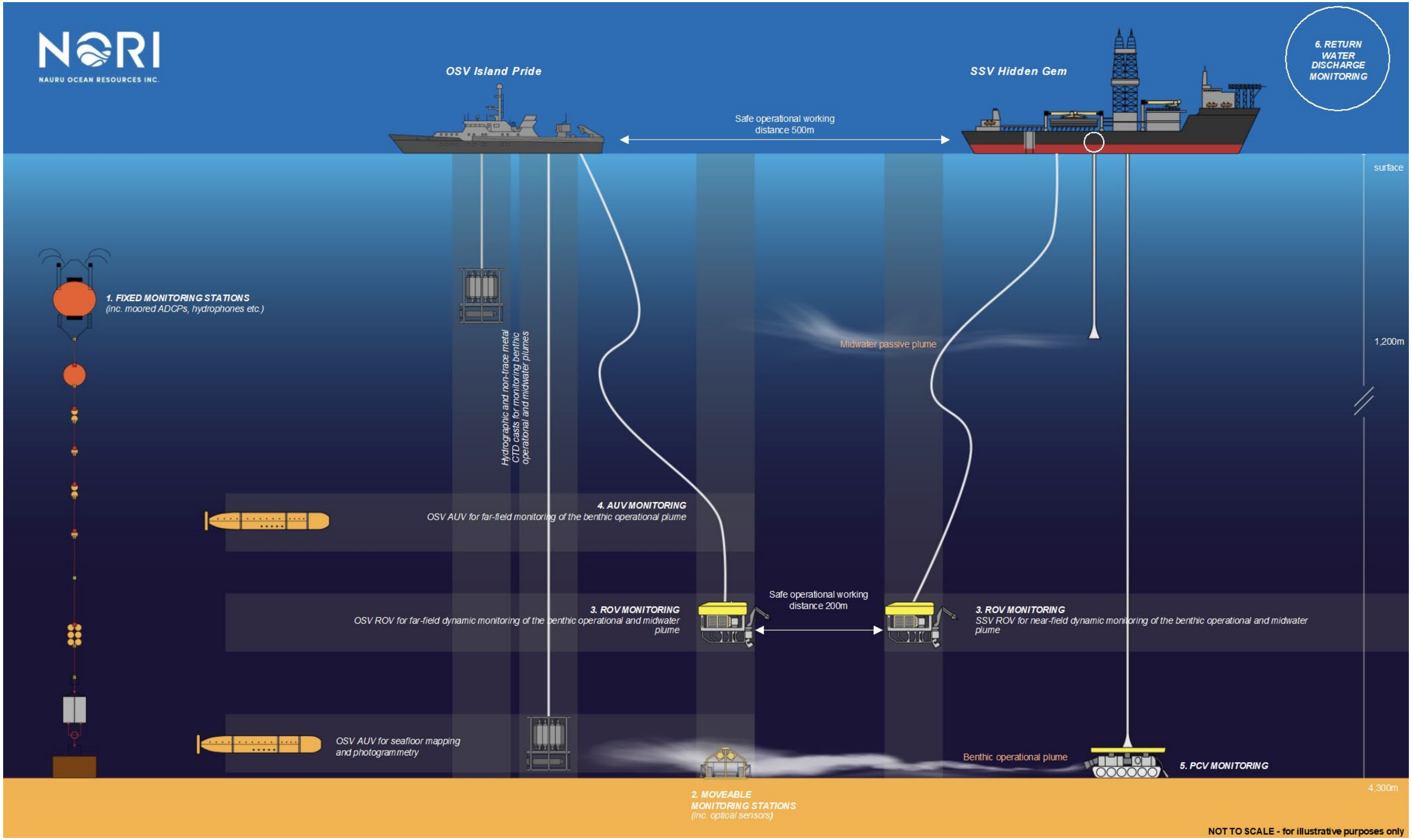
Figure 3-3. Overview of Plume Monitoring Program

A summary of this component array is provided in Figure 3-4.

Recognizing the difficulties associated with locating the sediment plumes, the key components of the monitoring program will be controlled by a Decision System (protocol) that relies on near real time current information and sediment plume forecasting to make decisions on moveable equipment locations, ROV transects and AUV flight paths for each HTR, STR and PR test runs.

The specific characteristics of the six components of the Plume Monitoring Program are described in the subsequent sections, differentiated between near-field and far-field components of the program followed by a description of the Decision System.

Figure 3-4. Plume monitoring component array



3.2.1.2 Near-Field Monitoring Components

The near-field monitoring components will be carried out from the *SSV Hidden Gem* and consist of three main components:

(i) Dynamic ROV Monitoring

Mobile near-field transect monitoring using equipment deployed on the SSV ROV will be used to supplement the monitoring equipment deployed on the PCV. The mobile monitoring is expected to provide the best source of information on the transport and dispersion of both the benthic and mid water plume, with the near-field ROV monitoring being particularly important as, due to the proximity to the plume source, the near-field monitoring is more likely to find the plume and once found more likely to experience concentrations well in the range of detection of the monitoring equipment. The SSV ROV will be equipped with a downward looking ADCP with plume backscatter capability, bottom track (benthic plume) and real-time connection through the ROV MUX, optical backscatter with real-time connection through the ROV MUX and Niskin water samplers plus backup optical turbidity instrumentation and CTD. At the time of writing there is also the possibility that the ROV may be equipped with a depth rated LISST for determination of particle size and TSS.

The flight plan will be guided by information provided by the Decision System. Once the plume is found real time data feeds from the ROV instrumentation will be used to adjust the transect plan on the fly. Information on the near-field plume location will be fed to the far-field monitoring team to aid with locating the plume in the far-field.

(ii) PCV Monitoring

The PCV will be instrumented with a variety of sensors including 2 rearwards facing ADCPs (600KHz and 300KHz to avoid interference and oriented to avoid bed interference) recoding TSS via backscatter plus optical turbidity instruments for redundancy. These instruments will provide TSS information close into the crawler discharge.

(iii) Return Water Discharge Monitoring

Allseas will monitor the return water discharge leaving the *SSV Hidden Gem*, this will include (as far as the Plume Monitoring program is concerned): discharge, TSS, temperature and turbidity measurements.

3.2.1.3 Far-Field Monitoring Components

The far-field monitoring components will be carried out from the *OSV Island Pride* and consist of four main components:

(i) Fixed Monitoring Stations

Stationary current monitoring using bottom founded upward looking ADCP monitoring equipment will be deployed just out-side the perimeter of the active PCV test field to provide real time near-bed current information to support the Decisions System. Two (2) stations will be used to provide redundancy. Fixed stations are considered to be better suited than moorings due to possibilities for more reliable communication. These stations will also be set-up to supplement the plume monitoring coverage provided by the Movable Stations and will also provide background CTD (not real time) data.

Stationary current monitoring using buoyed mooring mounted ADCPs out-side the perimeter of the test field (with sufficient clearance to avoid conflict with Allseas operations) will be deployed to provide real-time mid-water column current information to support the Decision System. Two (2) current measurement instruments (one upward and one downward looking instrument on the same mooring) will be used to provide redundancy. The location of this mooring (and location of the equipment in the string) will be chosen to allow this mooring to serve as the Reference Station required by the ISA guidelines. In addition to current measurements the mooring will provide temperature, salinity, TSS/Turbidity and sedimentation (automated sediment trap).

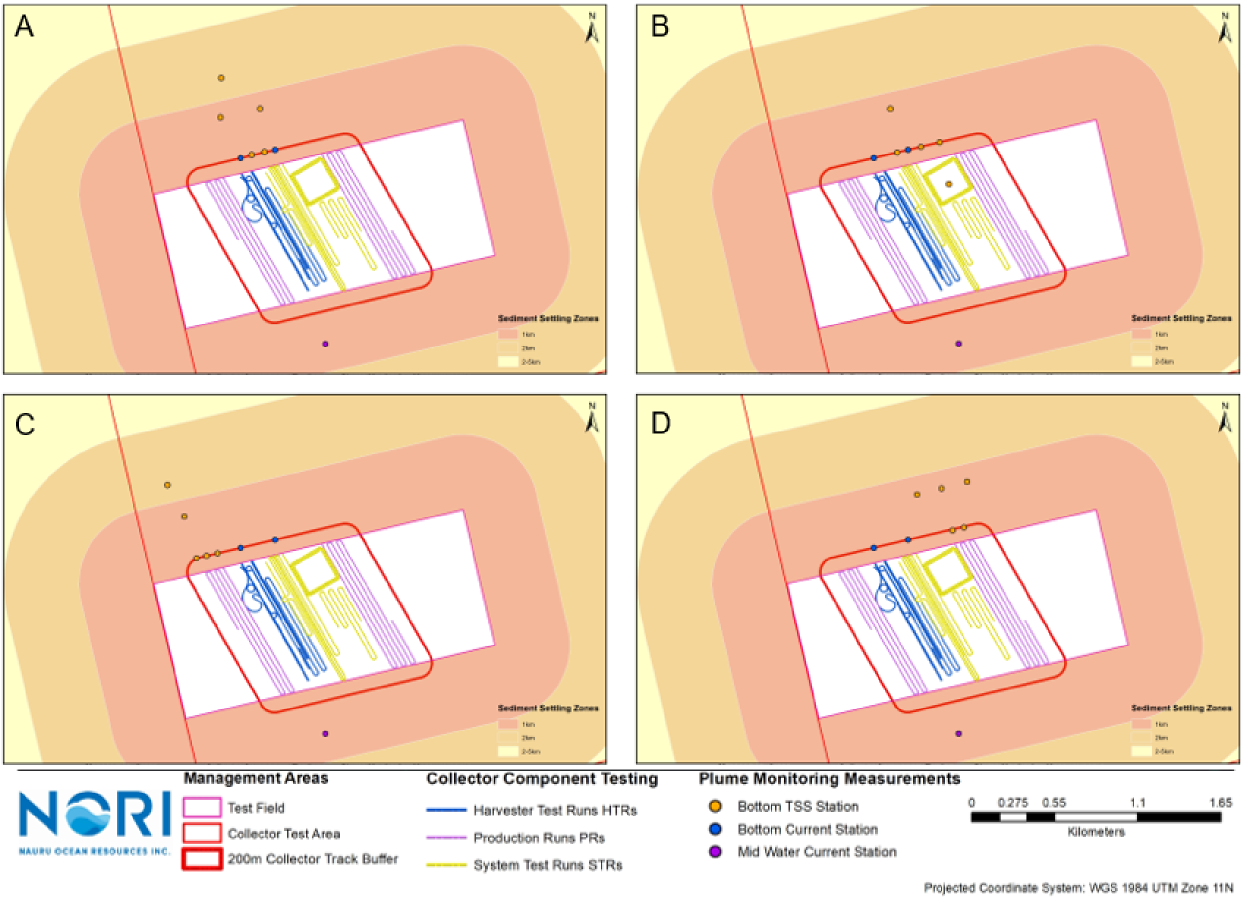
Finally, an array of sedimentation monitoring stations will be deployed with sedimentation plates (sedimentation to be documented by photographic observations during ROV recovery) will be deployed in the potential sediment plume area of affect as determined by the Decision System.

(ii) Moveable Monitoring Stations

Five (5) bottom mounted monitoring equipment stations will be deployed inside or adjacent to the Test Field. These stations are intended to measure temporal variability in the sediment plume conditions as the plume passes over the sensor location during the passage of the PCV. Each station will record TSS profiles via acoustic backscatter, NTU measurements via optical instrumentation (as redundancy) and DGT® or other passive water quality sampler. The best locations for each of these five movable stations will be determined prior to each HTR, STR and PR test based on information from the Decision System.

Three (3) movable sedimentation rate monitoring stations will also be deployed as part of the moveable monitoring stations with the best locations each of these three movable sedimentation stations also determined prior to each HTR, STR and PR test based on information from the Decision System.

Figure 3-5. Example locations of fixed and moveable monitoring stations for HTRs (A); STRs (B); PR1 (C) and PR2 (D) Three moveable sedimentation rate monitoring stations will also be added to each array.



(iii) ROV Monitoring

Mobile far-field transect monitoring using equipment deployed on the OSV ROV will be used to supplement the fixed and movable bottom mounted instrumentation described above. The mobile monitoring is expected to provide the best source of information on the transport and dispersion of both the benthic and mid water plume. The OSV ROV will be equipped with a downward looking ADCP with plume backscatter capability, bottom track (benthic plume) and real-time connection through the ROV MUX, optical backscatter with real-time connection through the ROV MUX and Niskin water samplers plus backup optical turbidity instrumentation and CTD.

The flight plan will be guided by information provided by the Decision System and communication with the near-field plume monitoring team (as the plume is expected to be easier to find in the near-field). Once the plume is found, real time data feeds from the ROV instrumentation will be used to adjust the transect plan on the fly.

(iv) AUV Monitoring

While the OSV ROV monitoring will focus close to the interface between near-filed and far-filed, AUV monitoring will be used to provide monitoring data further way from the source of plume generation to map the spatial extent of the plume (to detection limit). The OSV AUV(s) will be equipped with an optical backscatter sensor with flight plans determined by information provided by the Decision System.

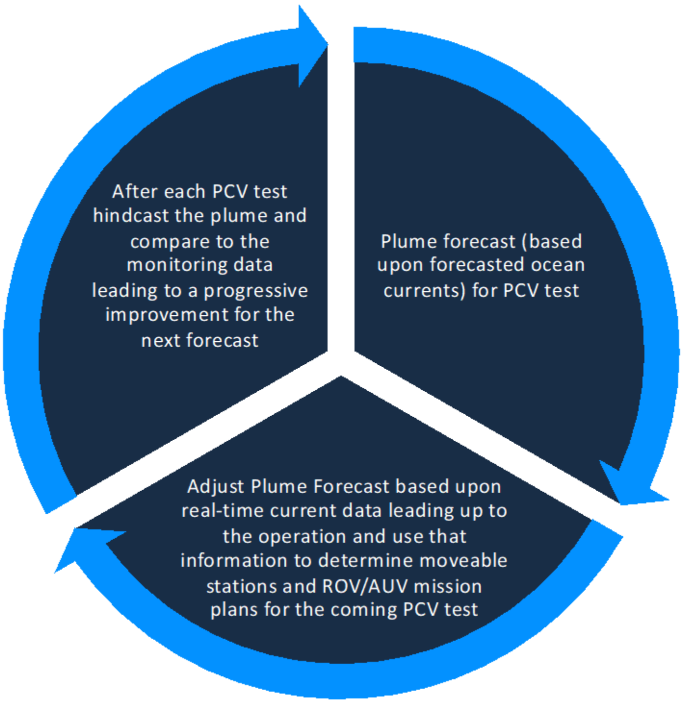
AUV monitoring also includes (with respect to the Plume Monitoring program) pre- and post- collector test multibeam, geophysical and photogrammetry surveys of the TF and the potential impact area as determined from the Decision System.

3.2.1.4 Decision System

The decision system (really a decision protocol as it is not an automated system) is at the heart of the plume monitoring program philosophy and is derived from tried and tested approaches to shallow water Plume Monitoring undertaken as part of EMMP carried out using the Feedback (proactive) management approach as described in Guidelines such as PIANC 108-2010 (Foster *et.al*., 2010)

The Decision System Consists of three main steps in a feedback loop as described in Figure 3-6.

Figure 3-6. Overview of Decision System Feedback Loop



The Decision System operates at a number of temporal scales:

- Before field mobilization the Plume Forecast will be run, without the feedback loop, based upon the updated Allseas test program (production plan, dates and durations). This is critical information for the preparation of the Plume Monitoring Plan.
- When the long moorings are recovered (approximately 2 weeks prior to the start of the PCV tests) the recovered current data will be used adjust the base Plume Forecast. This information will be used to determine the location of the Reference Mooring (a component of the Fixed Monitoring Stations) plus any reference stations required by the science teams.
- Approximately 1 week before the start of PCV operations current data from the Reference Mooring (which has near real time connectivity) will be used to further adjust (refine) the Plume Forecast. This will be used to locate the remaining Fixed Monitoring Stations (2 benthic TSS stations and sedimentation stations) plus any stations that the Science team require to be in the expected plume footprint.
- days prior to the PCV operations and throughout the PCV operations a daily sequence of plume forecast (based on Allseas planned operations) and hindcast (after operations start based on realized Allseas operations) will commence. The daily forecast will be adjusted by the real time current data in the hours from execution to deployment.

The daily forecasts will be used to:

- Plan and deploy the location of the movable monitoring stations
- Plan the flight plans for the ROV. The ROV will adjust its flight plan based upon the most recent near real time current data on decent to station
- Plan the AUV mission plan (multiple options). The option to execute will be selected based upon the most recent near real-time current data on arrival at holding station at depth

The daily hindcast will be used to progressively improve the daily forecast and thereby improve the performance of the monitoring program.

3.2.1.5 Temporal Coverage

Plumes will not be generated during the entire period of the HTR, STR and PR programs. All fixed and movable monitoring stations will be in place prior to the HTR program. The initial 50% of HTR program will be treated as a period of testing for the mobile monitoring system (e.g., using the Decision System to direct ROV and AUV operations, familiarization of OSV ROV operations crew to the procedures of tracking plumes, testing and confirming communication protocol with Allseas etc.). The latter 50% of the HTR program will be subject to the full monitoring program. This is critical as Allseas near-field monitoring program for the benthic plume will focus on the HTR program, such that concurrent near-field and far field data is critical.

The STR program consists of 5 separate test programs that will generate benthic and mid water plumes. During the STR program, simultaneous benthic and mid water column plumes will be generated. During the STR tests it is currently planned that approximately 80% the far-field ROV monitoring effort will be placed on the benthic plume and 20% effort on the mid-water plume. This is due to expected difficulties in detecting the far-field mid water plume, thereby maximizing the amount of positive (i.e., above background) data recovery. It is currently planned that AUV time will be allocated approximately 80% to the benthic plume and 20% to the mid water plume for similar reasons. Allseas will focus the majority of the STR nearfield program monitoring at the mid water column discharge where the near field monitoring is more likely to capture positive (i.e., above background) data.

The PR program consists of 2 separate tests. These shall be treated in the same manner as the STR program.

3.2.1.6 Expected Results

To support meeting the ISA recommendations, the plume modelling measurements will characterize the sediment plume, its transport, dispersion and settling characteristics as well as information regarding possible release of metals to the overlaying water as far as such may influence settling characteristics (third party Science Contractor will be responsible for more detailed water chemistry monitoring). The Plume Monitoring program is therefore expected to deliver:

- Size and size distribution of particulates in generated plumes and how such changes over time/distance
- Spatial distribution of suspended sediment plumes (TSS and NTU). Hereunder the horizontal and vertical extent of plumes as well as the particulate concentration in the plumes
- Total sediment flux at the near field boundary in the benthic plume
- Sedimentation pattern associated with the benthic plume
- Temperature and salinity in the mid-water plume
- Basic hydrographic data such as temperature, salinity, current speed and direction at the mid-water discharge elevation and near the seabed
- Concentration of metals released from the sediments in so far as these may influence sediment settling characteristics
- Water and sediment samples for reference and calibration

Data will be reported in a format suitable for submission to ISA including an interpretive report.

Data analytics will be carried out to post process the collected sediment plume monitoring data in a form suitable for sediment plume model calibration and validation.

3.2.2 Physicochemical Characterization of Plumes

Lead Contractors: University of Hawaii and Texas A&M

Overall, the philosophy for mid-water plume sampling for impact zone 2 will directly address parts of the following regulatory recommendations detailed in ISBA/25/LTC/6/Rev1 Paragraphs 38 (e) and (k) and 40 (c), (d), (f) and (g) reproduced below. Note that the parts in bold are particular focus areas. Any square brackets are NORI's additions to clarify the scope related to this section of the EMMP.

> ***C. Information and measurements to be provided by a contractor performing an activity requiring an environmental impact assessment during exploration***
>
> *38 (e) Methods for separation on the sea floor of the mineral resource and the sediment, including washing of the minerals, concentration and composition of sediment mixed with water in the seabed-disturbance plume, height above the sea floor of discharge plumes, modelling of particle size dispersion and settlement, estimates of depth of sediment smothering with distance from the mining activity, and estimates (based on plume models) of the spread of the plumes in the water column horizontally and vertically,* ***including particle concentrations as a function of distance from, and duration of, the proposed mining activity;***
>
> *38 (k) Volume and depth of discharge plume,* ***concentration and composition of particles in the discharged water, chemical and physical characteristics of the discharge*** *and behaviour of the discharged plume at the surface, in mid-water or at the seabed, as appropriate.*

D. Observations and measurements to be made after undertaking an activity that requires an environmental impact assessment during exploration

(c) Possible changes in communities, including microbes and protozoa, in adjacent areas not expected to be perturbed by the activity, including discharge and seabed-disturbance plumes and ***food web structure;***

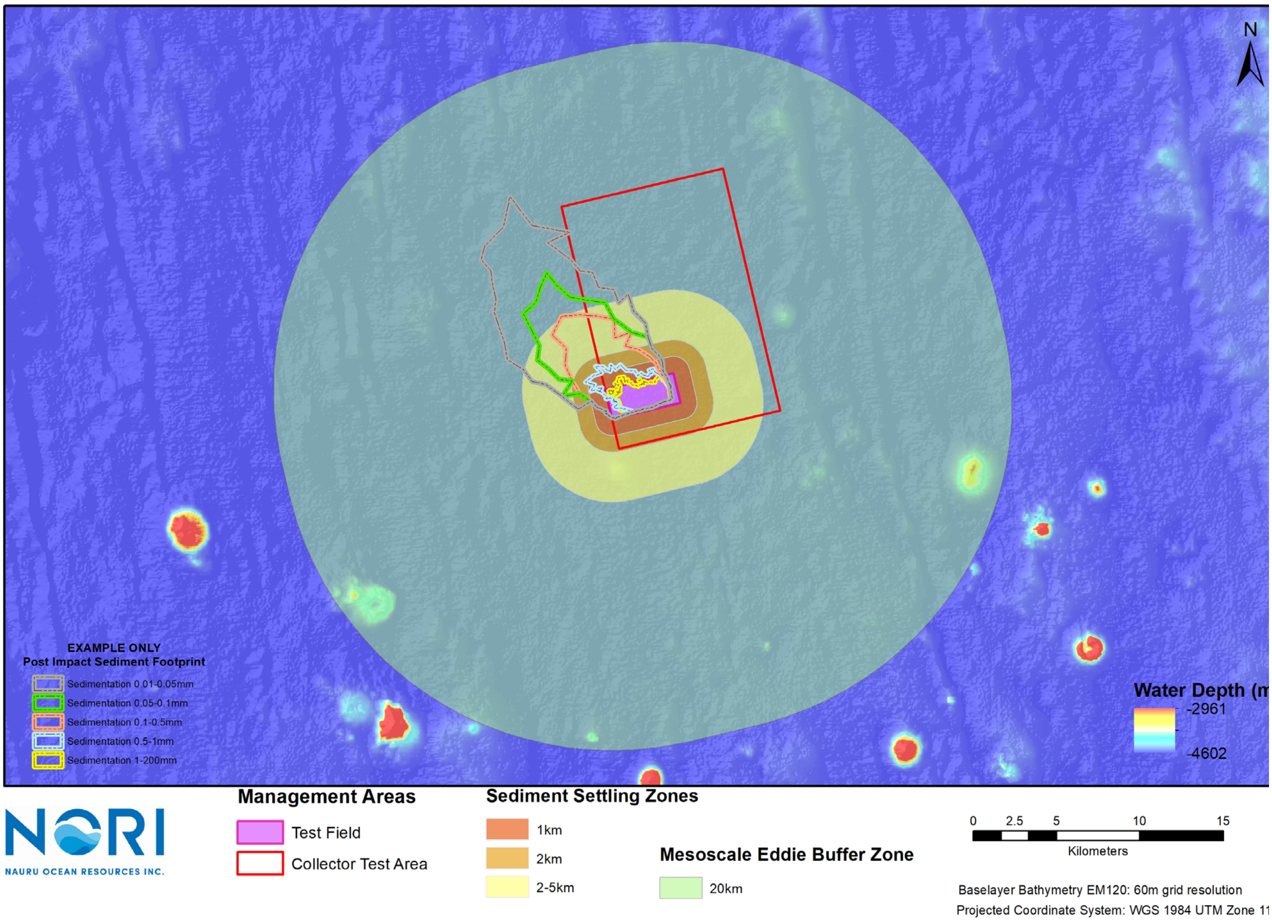
(d) Changes in the ***characteristics of the water at the level of the discharge plume*** *during the mining test, and changes in the behaviour of the biota at and below the discharge plume (see also annex I, para. 13);*

(f) ***Levels of metals*** *found in key and representative benthic biota subjected to sediment from the operational and* ***discharge plumes;***
(g) Resampling of local environmental ***[water chemistry]*** *baseline data and evaluation of environmental impacts;*

3.2.2.1 Survey Design and Sampling Philosophy

Sampling Strategy: Background end-member hydrographic CTD and trace metal clean CTD casts will be conducted outside the 20km buffer surrounding collector test operations (Figure 3-7). This is deemed sufficient distance as to not be impacted by the operations but close enough in proximity to ensure that the samples are within a spatial range of a mesoscale eddy, that have shown significant variability in oceanographic parameters in the upper ~1500m water column. These casts are also essential to calibrate sensors of both the primary and secondary ROV and hydrographic and trace metal clean CTD rosettes.

Figure 3-7. Collector Test Area, Test Field, modelled plume footprints, and mesoscale eddy buffer zone



Equipment: The following equipment and arrays will be used by contractors to collect samples and data to analyse the physicochemical characteristics of the baseline condition and the mid-water and benthic plumes.

- Hydrographic CTD equipped with Niskin bottles,
- LISST Deep
- Trace metal-free CTD
- Free-floating array (one 3-day deployment)
- McLane large volume *in situ* pumps

Near-Field Monitoring Array:

i) Remotely tripped Niskin bottles will be attached to the SSV ROV to collect water samples at specific depths and from specific points within the benthic operational and mid-water plumes.

ii) Inline sampling will be conducted on the *MV Hidden Gem*. Water samples will be collected at the top of the riser, where the subsea slurry enters the vessel and/or right before release into the return water pipe, where the excess water is released back into the water column at 1,200 m depth.

iii) Time-sensitive analytes will be assessed onboard the vessel, and water samples preserved for analysis of non-time sensitive analytes at an onshore lab.

Contractors will provide personnel aboard the *SSV Hidden Gem* to supervise the calibration, configuration and installation of the monitoring array equipment, mission planning and supervision of the SSV ROV crew to ensure adequate sample collection and provide QA/QC support.

Far-Field Monitoring Array:

i) Remotely tripped Niskin bottles will be attached to the OSV ROV to collect water samples at specific depths and from specific points within the benthic and mid-water plumes.

ii) Hydrographic CTD equipped with Niskin bottles and LISST Deep

iii) Trace metal-free CTD

iv) Free-floating array (one 3-day deployment)

This sampling strategy and equipment arrays will be employed to collect water samples for the following studies.

3.2.3 Characterization of particle concentration and size distribution of plumes.

Data Collection - Water column particle/sediment profiles within the mid-water and benthic plumes will be measured in two ways. First, a transmissometer on the CTD rosette will be used to measure light transmission. This measurement will allow characterization of particle concentrations which may include sediment as well as detrital and living particles. In addition, particle abundance and particle size distribution in the water column will be measured using a Laser In-Situ Scattering and Transmissometry (LISST) sensor (LISST-DEEP Type-B, 650 nm, Sequoia Scientific) for 32 logarithmically spaced classes centered between 1.36 and 230.14 µm, with bandwidths ranging from 0.22 to 38 µm. This sensor will be mounted onto the CTD but can only be deployed to 4000 m (the upper depth rating of the sensor). This sensor will allow characterization of the in-situ particle characteristics of the water column at and below the midwater discharge depth. For deeper depths, as for the characterization of the benthic plume, data will be used from the transmissometers mounted on the CTD and the ROVs together with discrete samples (collected also with the CTD and ROVs) analyzed onboard using the LISST.

Sediment samples collected via coring operations will also be analysed to allow discrete characterization of the particle size distribution of sediment material independent of the suspended sediment.

Finally, slurry samples will be collected in-line from the riser pipe tap. This will be analysed using a LISST capable of continuous (1 Hz) underway measurement of the concentration of particles in the 1.25 – 250 µm size range (32 bins).

Calibration of the CTD transmissometer and LISST will be done by collecting samples for total suspended solids and elemental analyses of particulate C (PC) and particulate N (PN) in the upper the water column, as well as in the sediment plumes. Seawater samples will be transferred from the Niskin or GoFlow bottles into 4-L clean bottles via Tygon tubing which incorporates an in-line 202 µm Nitex® screen pre-filter to remove zooplankton or any other rare particles. The samples will be vacuum filtered onto pre-combusted (450 ºC, 4 hours) and pre-weighted 25-mm diameter Whatman glass fiber filters, which are then stored frozen at -20 ºC until analysis. The samples will be dried and weighed, and then will be measured using an Exeter Analytical CE-440 CHN elemental analyzer.

Data Analysis - Sensor data and samples will be shipped to the University of Hawaii and processed onshore.

3.2.4 Characterization of dissolved oxygen concentration of mid-water and benthic plumes

Sample Collection - Full water column profiles of dissolved oxygen (DO) will be collected prior to the onset of Collector Testing operations using Winkler Titration on the hydrographic and trace metal rosettes. These results will provide accurate and precise baseline DO profile as well as providing a check on the factory calibration of all DO sensors on the CTD rosettes.

DO analysis will also be conducted on water samples collected from within the benthic and mid-water plumes generated during productive test runs (i.e., STR and PR) sampled with Niskin bottles mounted on ROVs. These results will provide accurate and precise DO measurements within and surrounding the plume and can be used to confirm the calibration of the oxygen sensors on the ROVs. To improve the sensor calibration, water collected from within the oxygen minimum zone (OMZ) will also be analysed to increase the dynamic range of DO concentration for sensor calibration.

These analyses will address revised ISA Guidelines (30 March 2020), which included characterization of DO concentrations within oxygen minimum zones.

DO concentrations of water samples collected from the riser head will also be conducted. The DO concentration of deep seawater brought to the surface during mining operations and that will be reinjected at 1200 m is uncertain. Air bubbles created by the airlift will likely equilibrate with seawater and when they reach the surface those bubbles will sparge gasses from seawater. Both processes will change the dissolved oxygen concentration of deep seawater at the surface. The aeration will probably promote equilibration with atmospheric O_2, however the resulting dissolved oxygen concentration is difficult to predict and must be measured. Measurements of dissolved oxygen on water samples from the riser head can also be used to calibrate any oxygen sensors on a flow-through in-line system installed to monitor DO.

Sample Analysis - Dissolved oxygen samples will be collected from Niskin/GoFlo bottles before other samples to avoid exchange of oxygen with the atmosphere and no samples will be taken from bottles that show signs of leakage. Seawater for dissolved oxygen analysis will be transferred from sample bottles to an iodine flask of known volume using gas tight plastic tubing and the temperature of the seawater measured as it was sampled and recorded. Iodine flasks will be quickly rinsed then allowed to overflow approximately three volumes. One millilitre of manganese chloride (3 M) will be added to the iodine flask followed by 1 mL of alkaline iodide, the flask capped and agitated for 30 seconds. After approximately 20 minutes, the floc formed by the addition of manganese chloride and alkaline iodide will be resuspended by agitation. To minimize oxygen exchange with the atmosphere, seawater will be added around the iodine flask cap. All samples will be kept in the dark until analysis.

All samples will be analyzed using a Brinkman Model 809 Titrando automated computer-controlled titration system. Prior to analysis, the water surrounding the iodine flask cap will be removed and 1 mL of sulfuric acid (10N) added. A Teflon stir bar will be carefully placed in the iodine flask and sample placed on the automated stirrer of the Titrando. Samples will be titrated using sodium thiosulfate solution (0.05 N, NIST Traceable) using Brinkman Tiamo (ver 2.3) software with factory-recommended settings.

Analytical blanks will be created by adding 1 mL sulfuric acid to seawater followed by 1mL of alkaline iodide and 1 mL of manganese chloride and analyzed as a sample using the same procedures as a sample. Standardization of the sodium thiosulfate solution will be achieved by adding 5.000 mL of potassium iodate solution (0.025 N, NIST Traceable) to an analytical blank solution using a Brinkmann Model 665 Dosimat and analyzed as a sample.

3.2.5 Characterization of pH of plumes

Revised ISA Guidelines (30 March 2020) significantly expanded expectations for the scope of oceanographic measurements. Baseline data requirements of these revised guidelines included characterization of inorganic carbon chemical speciation: “Measure pH and other components of the carbonate system where appropriate (e.g., carbon dioxide, alkalinity)” Section III, B, 15, b, iv.

Sample Collection - Full water column pH profiles will be collected prior to the onset of Collector Testing operations from the same bottle samples used for measurement of total dissolved inorganic carbon and alkalinity. These results will provide complete characterization of the carbonate system in seawater as needed to meet ISA Guidelines (Section III, B, 15, b, iv).

pH will also be measured for on water samples collected from within the benthic and mid-water plumes generated during productive test runs (i.e., STR and PR) sampled with Niskin bottles mounted on ROVs. These results will provide accurate and precise pH measurements within and surrounding the mid-water plume. Where possible, samples for pH measurement will be drawn from the same bottles as those for measurement of total dissolved inorganic carbon and alkalinity.

These results will allow us to determine how the carbonate system will be affected by plume water injection.

pH will also be measured for water samples from the riser head whenever samples for total dissolved inorganic carbon and alkalinity are taken. The pH of deep seawater brought to the surface during mining operations and that will be injected at 1200 m is uncertain.

Sample Analysis - The pH of seawater samples will be measured using the methods of (Dickson A.G., 2007). In this procedure, the introduction of the indicator dye m-cresol purple causes dissociation into the base (I2-) and acid (HI-) forms, each of which has different wavelengths for the absorbance maxima of m-cresol purple (578 nm and 434 nm, respectively). The pH of seawater samples determines the resulting ratio of dissociated concentrations, and therefore the absorbance ratio can be used to determine seawater pH highly accurately.

Water samples will be collected after oxygen samples and/or prior to any other samples directly into optical quality quartz-glass cuvettes with a 100 mm path length and stored in darkness in a Peltier temperature-controlled cooler and allowed to reach 25°C (~4 hours) prior to sample analysis. Water samples will be individually allowed to further equilibrate at 25°C in a Quantum Northwest TC 1 Temperature-Controlled cell holder in the spectrophotometer for an additional ~5 minutes prior to measurements. Background absorbance will be recorded at 3 wavelengths (730, 578, and 424 nm) before 100 µL of m-cresol purple dye (adjusted to pH 7.9) will be added to the cuvette and mixed thoroughly. The pH of the m-cresol purple dye will be measured using a cuvette with a 2 mm path length and adjusted to 7.9 by addition of a base just prior to sample analysis. Absorbance will be recorded again at 730, 578, and 424 nm after the addition of the m-cresol purple dye, using 730 nm as an analytical blank and requiring that measurements with and without dye be within ±0.001 before other wavelength measurements will be taken. The pH of the sample will be determined by the calculations outlined in (Dickson A.G., 2007). Analysis of replicate samples collected during DG5B and DG5C representing analytical and sample uncertainty was ±0.009.

3.2.6 Characterization of the productivity of phytoplankton communities in the epipelagic zone

The Collector Test campaign will serve as the third temporal baseline study for phytoplankton productivity studies that will help characterize the seasonal variability in this oceanic region, as indicated by the ISA guidelines (Annex I, 15). High frequency measurements of dissolved O_2 concentrations in the upper mixed layer (<50 m) will be used to quantify primary productivity and respiration from the daily-scale oxygen variations, as has been done on previous baseline campaigns.

Data Collection – A free-drifting sediment array will be used as a platform for the deployment of two optode O_2 sensors. The optodes will be calibrated with discrete samples collected using the hydrographic CTD rosette immediately before and after and deployment and recovery of the array and measured using Winkler Titration.

Data Analysis - The high-frequency O_2 time-series will be used to estimate daily rates of gross primary production and respiration using a least squares approach following Barone *et al*. (2019). The model assumes that respiration is constant throughout the day, photosynthesis is linearly proportional to light intensity, and light intensity varies as a simple function of solar elevation as in cloud free conditions. Rate uncertainties are calculated by bootstrapping the residuals between measured O_2 and the fitted model.

In accordance with ISA recommendations (Annex I, 11), a pair of global-scale primary production models will be utilized to estimate net primary production (NPP) in the NORI-D contract area; these models rely on various combinations of satellite-based ocean colour, phytoplankton absorption and sea-surface temperature. The two models used will be the VGPM, a chlorophyll-based model, and the CAFÉ model, an absorption-based model. Each model makes different assumptions about the relationship between proxies of phytoplankton biomass and the rate and primary production. These models will be compared with primary productivity observations made at the site to determine which model is more accurate in the NORI-D region and will be used to predict expected seasonality not captured in the sampling.

3.2.7 Characterization of food web linkages using stable isotope analysis

Diel vertically organisms connect mesopelagic and epipelagic food webs and thus could translocate the impacts of deep-sea mining plumes. Vertical migrations have a large influence on foraging ecology and sources of nutrition (Romero-Romero *et al*., 2019) and the basal sources of nutrition, surface phytoplankton, sinking marine snow, or much smaller particles change with depth (Choy *et al*., 2015; Gloeckler *et al*., 2018; Hannides *et al*., 2013; Romero-Romero *et al*., 2020). Knowledge of food web connections can also aid in understanding trace metal accumulation and transfer from the site of mining or the discharge plume to surface waters or other areas removed from mining itself.

This study is designed to answer the following questions: Does mining generated sediment and resuspended organic matter enter food webs? In other words, are the particles added to midwaters by mining generated sediment plumes the same size as those consumed by suspension feeders? Are these particles comprised of mainly organic-poor material and therefore dilute the nutrition of particles that are known to support mesopelagic food webs outside of the influence of the sediment plume?

To characterize food webs during baseline studies and subsequently answer these questions after mining tests, the organic carbon content and stable isotopic composition of water column particles will be measured, as this is the food source for mesopelagic zooplankton (Hannides *et al*., 2013; Hannides *et al*., 2020), many of which are suspension feeders or omnivores.

This portion of the overall study directly addresses ISA Guidelines on understanding food web structure and function (e.g., Annex 1, 39) and the use of stable isotope analyses to understand those processes (Annex 1, 27, 30).

Sample Collection – Suspended particles will be collected to establish a third baseline measurement at the CTA site at NORI-D. Size fractionated particles (0.7-6, 6-53 and >53 µm) will be collected at a similar depth resolution as on previous campaigns (8 depths) to be used as a third baseline measurement.

Sinking Particles: Passively sinking particulate matter will be collected using a surface tethered free-floating array with 24 VERTEX-style particle interceptor (PIT) traps positioned at a depth below the euphotic zone (~65-90 m) and above the oxygen minimum zone following the protocol of (Knauer *et al*., 1979). These traps will be deployed for approximately 70 to 80 hours and tracked using a surface buoy equipped with floats, a strobe, radio directional finder and Iridium satellite tracking device.

Size fractionated particles: Size fractionated particles will be collected using in situ Large Volume Water Transfer Systems (McLane WTS-LV) equipped with either an 8 L/min or 30L/min pump head. Main sampling depths for particles include the surface mixed layer (~25-50m), the transition to the OMZ (70-150 m), the beginning of the mesopelagic (250 m), several depths within the mesopelagic above the proposed discharge depth (~400 and 850 m), and two depths in the upper bathypelagic (1000-1500 m).

AA CSIA: Size fractionated filters and zooplankton will be prepared for compound specific amino acid (AA) δ13C and δ15N analysis (AA-CSIA). Nitrogen isotope analysis will be prioritized over carbon isotope analysis.

Sample Analysis – Suspended particles will be analysed for the content of PC, POC and PN as well as carbon (δ13C) and nitrogen (δ15N) isotopic values using a Costech elemental combustion system coupled to either a Thermo-Finnigan Delta Plus XP or a Delta-V Advantage Isotope Ratio Mass-Spectrometer.

Size fractionated particles collected by the McLane pumps transferred to the University of Hawaii and analysed for PC, POC, PN and triplicate isotope analysis of the carbon and nitrogen isotopic composition of amino acids (~0.5 mg of N).

AA CSIA will be analysed by preparing size fractionated filters and zooplankton for compound specific amino acid (AA) δ13C and δ15N analysis (AA-CSIA). δ13C values of individual amino acid trifluoroacetyl/isopropyl ester derivatives will be determined using an IRMS (MAT 253) interfaced with a Trace GC Ultra via a combustion furnace (1000°C) and ConFlo IV interface (Thermo Scientific). The δ15N values of AA trifluoroacetyl/isopropyl ester derivatives will be determined using gas chromatography combustion isotope ratio mass spectrometry (Hayes *et al*., 1990). Trophic position will be estimated using the difference in δ15N values between the trophic amino acid glutamic acid (Glx) and the source amino acid phenylalanine (Phe) or lysine (Lys).

3.2.8 Ecotoxicology and whole effluent testing (WET)

Lead Contractor: University of Maryland

Sample Collection: Using the following equipment, contractors will measure overall water toxicity of the mid-water discharge and benthic operational plume:

- Trace metal-free CTD
- Near-field ROV niskins
- Far-field ROV niskins
- Inline sampling on board the *SSV Hidden Gem*

Microtox FX will be used to conduct triplicate measures of overall water toxicity from the same sample depths and regions as the baseline cruise to ensure comparisons are consistent. Samples will also be obtained from the inline sampling that will be conducted on the *SSV Hidden Gem*. Water samples will be collected at the top of the riser, where the subsea slurry enters the vessel and/or right before release into the return water pipe, where the excess water is released back into the water column at 1,200 m depth to test whole effluent toxicity using Microtox FX. While this measure by itself may not represent actual toxicity to deep-sea animals we can relate Microtox results in a parcel of water to previous measure of overall water toxicity, changes in ecotoxicity measures from other ecosystems using the literature, water chemistry, and trace metals data collected by the trace metals team.

In addition to the collection of field samples, 240 L of subsea slurry produced during the 24 hr test-mining trial (10 L/hr). Water will be stored at 4°C immediately following collection in 24 metals-clean high density polyethylene carboys.

Sample Analysis: Post-campaign, water will be shipped where it will be used to conduct laboratory dose-response whole effluent toxicity (WET) tests using standard test organisms in regulatory risk assessments (e.g., sheepshead minnow, mysid shrimp). The dose-response WET tests will be conducted using other marine species for more specific comparisons to mid-water organisms (e.g., fish, crustaceans, and jellies). Dose-response WET tests will include a control and four or more experimental groups, each with four replicates containing a minimum of 10 individuals, which will be exposed to dewatering effluent at full concentrations, and in a dilution series reducing the concentration by 10x, 100x, and 1000x using a static-renewal approach (Munoz-Royo *et. al*. 2021). Both acute (48 – 96 hr) and short-term chronic (7-day) tests will be performed. Water quality parameters (i.e., turbidity, ammonia, temperature, dissolved oxygen, salinity, and pH) as well as organism responses will be monitored daily. Metals concentrations will also be measured from water samples taken from experimental tanks on days 0, 1, 3, and 7 of experiments to monitor test organism metals exposure. Biological responses that will be recorded during these tests will include survival, growth (dry weight), and fecundity (mysid only), as well as behavioral responses (e.g., lethargy, narcosis, impaired buoyancy/orientation, etc.). Based on results of WET tests, additional replicate exposures will be prepared using sub-lethal effluent concentrations to assess induction of biomarkers of metals exposure (using the same methods as described for baseline collections). Effects will be assessed in organisms following 1, 3, and 7-day exposures to investigate the time-course and amplitude of response induction.

Statistical differences in WET test and biomarker responses between experimental groups and controls will be determined using one-way ANOVA with appropriate transformation or application of nonparametric tests where needed. These analyses will determine no observable effect concentrations (NOAEC) and the lowest observable effect concentrations (LOAEC) to dewatering effluent where possible. Dose-response relationships between experimental concentrations of dewatering effluent and measured responses (e.g., respiration rate, metallothionein concentration) will also be calculated using generalized linear models with appropriate distributions. These models will help to characterize the toxicity of dewatering effluent to marine organisms.

3.2.9 Trace metal and water chemistry

Lead Contractors: University of Hawaii and Texas A&M

Sample Collection: Using the following equipment and sampling techniques trace metals and nutrient concentrations will be measured from both the mid-water plume and benthic plume during STR and PC operations.

Seawater samples will be collected using a trace metal clean rosette mounted with GO-Flo bottles that have been proven contamination-free for trace metal analysis. GO-Flo bottles will be carried individually into a sampling van supplied with HEPA-filtered air to prevent contamination from the ship’s deck or surroundings during sample processing. Seawater will be filtered through pre-cleaned 0.2 µm Supor filters into acid-washed bottles for concentration analysis. Volume passed through the filters will be recorded for particle concentrations taken from digestions of the filtered material.

During STR and PR trials seawater sampling and analysis will be conducted to characterize the following physical and chemical characteristics of the mid-water and benthic plumes:

- Benthic plume endmember: Use Niskin bottles on ROV(s) to collect dissolved and particulate samples. Do this ≥3 times for temporal variability.
- Benthic plume shape/intensity: Use trace metal CTD to sample the collector plume as soon as possible after collector has passed at high depth resolution (2, 5, 10, 15, 20, 30, 40, 50, 100, 150, 200 m above seafloor) to characterize plume shape/intensity (≥3 sites).
- Benthic plume dissipation rate: Use trace metal CTD to sample the plume at 2, 5, 10, and 20m above seafloor as soon as possible after collector has passed. Then wait and repeat at same depths after unit time has passed, and then again after another unit time passed (3 total times; ≥2 sites)
- Mid-water discharge material endmember: Collect multiple samples of the riser pipe and discharge pipe solutions from the *SSV Hidden Gem* for complete chemical characterization. Repeat ≥6x for temporal variability.
- Mid-water discharge plume shape/intensity: Use Niskin bottles on the ROV to characterize the "dynamic" discharge plume for its dissolved and particulate constituents. Do this ≥3 times for temporal variability.
- Mid-water discharge plume shape/intensity: Tow-yo trace metal clean CTD to search for the plume. Fire bottles over time/space (1000-1500m) to characterize the "ambient" discharge plume for its dissolved and particulate constituents (≥2 times for temporal variability).

Sample Analysis:

i) *Dissolved Fe, Mn, and Al* –Seawater filtrate (0.2 µm) will be collected into acid-washed 125 mL polymethylpentene bottles and immediately acidified to 0.006 M hydrochloric acid (HCl) using sub-boiling distilled HCl. The sample bottles will be stored in polyethylene bags in the dark at room temperature be-fore analyses, usually within 24 hours of collection. Prior to analysis, samples for dissolved aluminium (dAl), iron (dFe) and manganese (dMn) are microwaved in groups of 4 for three minutes at 900 W to 60 ± 10◦C in an effort to release dFe from complexation in the samples. Samples are allowed to cool for at least 1 hour prior to Flow Injection Analysis (FIA). Dissolved Al, Fe and Mn are determined from subsamples using standard methods. Samples will be analyzed in groups of 8, and the samples collected at each station will be generally analyzed together during the same day.

ii) *Dissolved Fe, Mn, Cu, Cd, Zn, Ni, Pb, and labile Co*–Seawater filtrate (0.2 µm) will be collected into acid-washed low-density polyethylene (LDPE) bottles and acidified to 0.024 M HCl (Optima grade, Fisher) shipboard. After 2 months, the samples will be analyzed for Fe, Mn, Zn, Cu, Cd, Ni, and Pb simultaneously using the automated, multi-element flow injection analysis (FIA) technique developed by Fitzsimmons using the commercially available SeaFAST pico system (Elemental Scientific). This method is the offline, multi-element alternative to the online-coupled FIA-ICP-MS method. Standardization is by isotope dilution, except for the mono-isotopic element Mn, where matrix-matched external standard curves are employed (with internal drift corrections using indium). Analysis will proceed using the Element XR HR-ICP-MS in the Williams Radiogenic Laboratory at Texas A&M University.

iii) *Particulate metals*–Particles will be collected onto 0.2 µm filters with the volume passed over the filter recorded to ±10 mL. Filters will be dried at sea and stored individually in PetriSlides and frozen at -20°C for storage until analysis. Frozen filters will be cut using a ceramic rotary blade on a light table. A filter portion will be digested in an acid-clean Teflon vial (Savillex) in 1.0 mL 8 M nitric acid and 2.9 M hydrofluoric acid refluxed at 135°C for at least 4 hours. After evaporating to dryness, 100 µL of nitric acid will be added and evaporated again to remove hydrofluoric acid residues. Finally, solutions will be brought up in 3.0 mL of 5% v/v nitric acid for archiving until analysis. Analysis will proceed using the Element XR HR-ICP-MSin at the R. Ken Williams Radiogenic Laboratory at Texas A&M University on 5-100x dilutions of the archived solutions. Quantification will be made using nine-point multi-element standard curves with an acid matrix identical to that of the samples and standard concentrations bracketing the samples.

iv) *Total Dissolved Hg*–Seawater filtrate (0.2 μm) will be collected into pre-cleaned glass bottles following cleaning with bromine monochloride. Total dissolved Hg analyses will use purge and trap methods and cold vapor atomic fluorescence.

v) *Dissolved macronutrients (nitrate+nitrite, phosphate, silicate)* -Seawater filtrate (0.2 μm) will be collected into acid-washed 50 mL bottles and immediately frozen at -20°C until analysis. Samples will be analyzed at the UH S-Lab using a Seal Analytical Nutrient Autoanalyzer and established methods.

vi) *Total alkalinity and dissolved inorganic carbon*–Unfiltered seawater samples will be collected directly into pre-combusted 500 ml borosilicate bottles. 200 μl of saturated mercuric chloride (HgCl2) will be added to each sample. The bottle will be sealed with a ground glass stopper and secured with polyethylene tape or a large rubber band. The samples will be stored in a cool, dark, location (preferably refrigerated but not frozen) and brought back to a shore-based facility for analysis. They will be analyzed using a Gran titration (alkalinity) and coulometric detection (DIC) using a VINDTA carbon dioxide extractor.

vii) *Dissolved organic carbon*–Filtered (dissolved) seawater samples will be collected directly bottle into a 24 mL vial. 200 uL of 50% Phosphoric acid (H3PO4) will be added per mL of sample and frozen immediately following acidification. Samples will be brought back to the University of Hawaii S-Lab for analysis using a Shimadzu TOC-L combustion analyzer.

3.2.10 Acoustic studies

Lead Contractors: HR Wallingford and Scottish Association for Marine Science (SAMS)

Data Collection: The survey and fieldwork programme are designed in accordance with the good practice recommendations for underwater noise measurements (Robinson *et al*. 2014), and takes into account previous studies undertaken by NORI to support the collector test EIA (EnviroGulf Consulting, 2022).

The survey will collect underwater sound recordings from activities related to the collector test by distributing sensors from the seabed through the water column, using a seabed lander and a mooring. The main aim will be to assess sound pressure levels from the activities at different depths within the water column and at different distanced from the trial activities.

Using a single mooring with a vertical riser, hydrophones will be placed near the seabed for assessment of the PCV and at strategic places through the water column to capture noise components along the length of the riser and return pipe. A total of three hydrophones will be installed on the mooring, with a separate hydrophone deployed on a seabed lander.

Preliminary underwater sound model: Sound propagation will be modelled in and around the CTA using HR Wallingford's underwater acoustic propagation model (UnaCorda) which is a sub-module of the HAMMER toolbox (Hydro Acoustic Modelling for Mitigation and Ecological Response). UnaCorda is a validated numerical model based on the Range-dependent Acoustic Model (RAM) parabolic equation method of determining underwater sound propagation. It has been benchmarked against known underwater acoustic models and has been fully validated against field data (Rossington *et al*, 2013).

Starting with an estimated sound level spectrum for each of the identified sources of noise (e.g., nodule collector, riser, vessels), UnaCorda will be used to predict the propagation and attenuation of the underwater sound pressure waves as they travel away from each source and refract vertically throughout the water column and interact with the bed sediment. The model will be repeated in numerous directions so that it covers 360º around each noise source to provide a spatial map of the sound levels.

The model takes into account interactions of the propagated noise with the bathymetry, seabed sediment type, variations in sound speed with water depth, water temperature (thermoclines), salinity (haloclines) and reflections from the sea surface. Underwater sound is assessed for discrete frequencies over the range of concern (usually between 10 Hz and 20 kHz). Total energy, or broadband sound, is then calculated from the modelled discrete frequencies by summing the energy across all considered frequency bands.

The model requires as input, details of the water depth and bathymetry (used to make the model mesh), bed sediment type (for deriving sound attenuation parameters) and a source level spectrum for the sound emitted from each sound source. In deep water, as is the case here, the vertical profile of salinity and temperature in the water column is necessary for accurately modelling the speed of sound profile which can lead to changes in the predicted impacts caused by the emitted noise over time (generally seasonally). In particular, the presence of the SOFAR channel 1 (at about 800 m depth) will influence the propagation of the sound and ultimately affect the extent of any potential impacts for species that may occupy different heights in the water column.

The source levels of the underwater sound emitted during the mining operations will not be confirmed prior to the collector tests. Hence, the source level and frequency spectrum of the underwater sound emitted during the collector test will initially be determined empirically using data derived from the literature and information provided by Allseas and build on the estimations made within the collector test EIA (EnviroGulf Consulting, 2022).

To account for the moving PCV, the model will be rerun for up to three scenarios with the collector located at different points within the planned test field.

Data Analysis: Underwater sound pressure level data will be collected during the collector tests, and this will be used to validate the preliminary noise model described above. Refinements to the initial estimates of source level spectra are likely to be required at this stage based on the new sound measurements. The validated underwater sound model for the 1/2 scale collector tests will subsequently be scaled up to simulate full scale mining activity. As well as a detailed description of the proposed full-scale equipment from NORI, this will involve further modification of the source level spectra using information from the literature.

Using the scaled-up source levels, potential impacts of the predicted sound on the marine fauna in the study area will be assessed, focussing primarily on marine mammals. The potential impacts will be assessed using the combined underwater sound fields from the multiple sources of sound that are likely to be radiating noise simultaneously during the mining activity.

Possible impacts can range from behaviour changes to temporary threshold shift (TTS) through to permanent threshold shift (PTS) in hearing functionality. These impacts will be assessed using a combination of RMS sound pressure level (SPL) and cumulative sound exposure (SELcum) metrics. For the latter, the sound energy dosage for each animal individual will be assessed over a 24-hour period. The proximity of the receptors to the sound sources at the start of the sound emission will be a key factor determining the potential effects, as will their hearing/sound detection abilities. The critical sound level thresholds for different mammal species groups will follow the guidelines of Southall *et al* (2019). These thresholds will be applied to determine the potential zones of impact from underwater sound propagation for the species of interest. The ability of the mammals to respond to the sound and swim away to reduce their sound exposure will be included in the assessment.

3.2.11 Seafloor Studies – physical and chemical

Overall, the philosophy for the seafloor sampling in impact zone 3 will directly address parts of the following regulatory recommendations detailed in ISBA/25/LTC/6/Rev1 Paragraph 38 (b), (d) and (p) and 40 (a), (b) and (g) reproduced below. Note that the parts in bold are particular focus areas. Square brackets are our additions to clarify the scope related to this section of the EMMP.

> *C. Information and measurements to be provided by a contractor performing an activity requiring an environmental impact assessment during exploration*
>
> *38 (b) **Depth of penetration in the sediment** or rock **and the lateral disturbance caused by the collector**;*
>
> *38 (d) Ratio of sediment separated from the mineral source by the collector, volume and size spectra of **material rejected by the collector**, size and geometry of seabed-disturbance plumes and the trajectory and spatial extent of the plumes relative to the particle sizes within;*
>
> *38 (p) **Baseline maps** (e.g., side-scan sonar, **high-resolution bathymetry, sea floor bottom type**) of the **deposits to be removed**;*
>
> *D. Observations and measurements to be made after undertaking an activity that requires an environmental impact assessment during exploration*
>
> *40 (a) **Thickness of redeposited sediment** and rock rubble over the area affected by the **operational plume caused by the mining activity** and by the discharge plume and changes in substrate heterogeneity*
>
> *40 (b) Changes in species composition, diversity and abundance of pelagic (where applicable) and benthic [mega/macro/meiofauna and foraminifera] communities, including microbes and protozoa, including recolonization, changes in foundation species, three-dimensional-habitat-forming species, ecosystem engineers, **bioturbation rates, chemical effects** and changes in behavior of key species (subjected to impacts such as smothering by sedimentation);*
>
> *40 (g) Resampling of local **[sediment geochemistry; physical properties]** environmental baseline data and evaluation of environmental impacts;*

3.2.11.1 Survey design and sampling philosophy

To understand the impacts of the collector test operations on the seafloor, the following monitoring operations will be conducted both pre- and post-collector test. It is anticipated that a nested survey and sampling approach will be required to meet the technical performance and environmental objectives of the collector test.

3.2.12 Seafloor mapping and photogrammetry (AUV Surveys)

Lead Contractors: Ocean Infinity

The objectives of the AUV surveys for both the pre-collector and post-collector campaigns are:

Multibeam Survey:

- Depth of penetration in the sediment and lateral disturbance caused by the collector.
- Width, length and pattern of the collector tracks on the seafloor.
- Determine the thickness of the sediment redeposition layer

Image Survey:

- Determine the extent and thickness of the sediment redeposition layer

Data Collection: Pre-planned AUV survey lines for each designated survey area will be developed prior to launch. Each AUV will have its own mission plan. For this project up to 3 AUVs can be deployed simultaneously. Each AUV will collect multibeam, CTD and turbidity data along survey lines. Individual AUVs may be tasked to perform unique missions, e.g., low altitude AUV camera runs.

Data coverage and survey line spacing depend on the required survey resolutions and local bathymetric terrain. All mission and line planning information will be detailed in the project execution plan (PEP) prior to mobilization. However, the objectives of the MBES missions are as follows:

- 100% Coverage of TF, including 220 m buffer
- Buffer to ensure virgin ground adjacent to test site is incorporated into bathymetric DTM as a cross-check of datums between bathymetric surveys.
- Extend MBES to ensure that it covers the test track plans and where subsea assets (e.g. plume monitoring sensors are to be deployed)
- “Nested” bathymetric surveys would follow selected PR collector track lines, utilising either ROV or AUV survey platform
- These surveys are to be run at a lower altitude (< 10 m) with a tightened swathe, to further try and improve resolution.

The objectives of the pre- and post- photogrammetry runs are as follows:

Pre-collector test photogrammetry is required to:

i. optically characterise any existing sedimentation where visible on the seafloor in the wider CTA and;

ii. to establish nodule density and abundance within the TF

Post-collector test photogrammetry is required to:

i. determine the extent of the sedimentation from collector test operations. This data will be used to verify the plume model and to determine the sampling array for post-collector test benthic operations (section 3.2.17.1) and;

ii. determine the efficiency (nodules collected) and selectivity (nodules remaining on seafloor) of the collector system,

For the precision required, AUVs will be positioned using seafloor LBL acoustic array. The AUV based photographic work will be accomplished by flying the AUV at the closest (safe) altitude above the seafloor to acquire high-definition images at a speed to maintain heading.