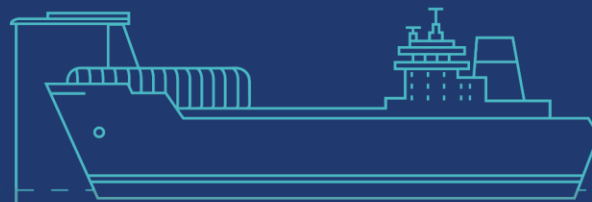


Guidance for geophysical surveying for UXO and boulders supporting cable installation

Offshore Wind Accelerator
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The Offshore Wind Accelerator (OWA) is the Carbon Trust's flagship collaborative research, development and deployment programme. The joint initiative was set up between the Carbon Trust and nine offshore wind developers in 2008, with the aim to reduce the cost of offshore wind to be competitive with conventional energy generation, as well as provide insights regarding industry standard (and best practice) health and safety requirements. The current phase involves participation from nine international energy companies: EnBW, Equinor, innogy, Ørsted, RWE, ScottishPower Renewables, Shell, SSE, and Vattenfall Wind Power, who collectively represent 75% of Europe's installed offshore wind capacity.

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Unexploded ordnance specialists Ordtek Limited provide UXO management to both land and marine developments.

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Abbreviations

Abbreviations	
2D	Two Dimensional
3D	Three Dimensional
ALARP	As Low As Reasonably Practicable
ALR	Acceptable Level of Risk
AUV	Autonomous Underwater Vessel
CDM	Construction Design and Management (regulations)
CR	Offshore Client Representative
DoB	Depth of Burial
DTM	Digital Terrain Model
DQO	Data Quality Objective
EIA	Environmental Impact Assessment
EM	ElectroMagnetic
E/N	Eastings/Northings
EVT	Equipment Verification Test
GIS	Geospatial Intelligence System
ID	Identification
IHO	International Hydrographic Office
ISO	International Organisation for Standardisation
kHz	kilohertz
KP	Kilometre Point
LMA/LMB	Luftmine type A/B, German non-ferrous WWII mine
M	Metres
MBES	Multibeam Echo Sounder
nT	nanotesla
NEQ	Net Explosive Quantity
PC	Personal Computer
PEP	Project Execution Plan
PLGR	Pre-Lay Grapnel Run
(p)UXO	(potential) Unexploded Ordnance
ROV	Remotely Operated Vehicle

ROTV	Remotely Operated Towed Vehicle
RPL	Route Position List
QA	Quality Assurance
QC	Quality Check
SBP	Sub-bottom Profiler
SIT	Surrogate Item Test
SLAM	Simultaneous Location and Mapping
SSS	Sidescan Sonar
WROV	Workclass Remotely Operated Vehicle
UAV	Unmanned Aerial Vehicle
USBL	Ultra Short Baseline
USV	Unmanned Surface Vehicle

1. Background and objective

The objective of this document is to provide content for a practical guidance document to the application of geophysical methods as part of the risk management strategy when undertaking the planning and design of submarine power cables. This document is specifically concerned with geophysical methods deployed in support of management of the risk presented by unexploded ordnance (UXO) in section 2 and boulders in section 3.

An aim of these guidelines is to assist developers and contractors in the creation of datasets with systematically designed specification, consistent structure, and with documented provenance. In this way, evaluation of the suitability of a specific dataset for a specific purpose should be facilitated, allowing maximum value to be realised from each dataset.

1.1 Introduction and bounds of this guidance

An understanding of the risks presented by obstructions to cable installation is required to inform the processes of planning and execution of cable installation projects. Risks presented by obstructions may be classified into multiple types, such as UXO, boulders, in-service and out-of-service cables, pipelines and other seabed infrastructure, wrecks and debris, habitats and environmental restrictions, and sites of archaeological significance, together with seabed and sub-seabed engineering considerations and geohazards. Obstructions may be classed as potentially interfering with the cable itself, or the operations and equipment required to install, maintain or decommission it. Projects may have multiple phases, and may require risks to be quantified variably at different points in the project lifecycle.

This document provides guidance in the specification and quality management of marine geophysical survey operations in support of the management of UXO and boulder risks. Investigations onshore and in the intertidal zone are not addressed. This guidance does not address either UXO risk definition or the interrogation of the data to generate a potential UXO (pUXO) listing.

Additional guidance may be required to support the implementation of geophysical methods in support of management of risk introduced by other classes of obstruction, and engineering considerations, listed above.

Geophysical data form part of the knowledgebase used in the evaluation of risk in installation of submarine cables. The array of risks presented has potential impact on stakeholders working on emplacement, operations and maintenance and decommissioning. Use of geophysical data as part of the risk mitigation strategy of a project organisation is an option that each project organisation should evaluate in regard to its own risk tolerance and applicable regulations. This guidance represents an indication of good practice, but no liability or warranty is accepted should data be generated using this guidance.

1.2 Existing guidance

A process for managing risk from UXO in the marine environment is described by the CIRIA 754 guidelines (CIRIA 754, 2015), with a high-level introduction to some of the geophysical methods that may be applied. CIRIA 754 is considered the de facto standard for the management of UXO risk.

No similar guidance exists for the management of the risk presented by other obstructions to the emplacement and operation of submarine power cables, though there are a number of useful

guidelines that have been developed for offshore survey operations that are suited to the purposes of obstruction identification including:

- SUT OSIG: Guidance Notes for the Planning and Execution of Geophysical and Geotechnical Ground Investigations for Offshore Renewable Energy Developments;
- OGP: Guidelines for the conduct of offshore drilling hazard site surveys;
- DNVGL-RP-0360: Subsea Power Cables in Shallow Water;
- Offshore Wind Programme Board: Overview of geophysical and geotechnical marine surveys for offshore wind transmission cables in the UK;
- Carbon Trust CTC835, Cable Burial Risk Assessment Methodology;
- ISO19901-8: 2014 Marine Soil Investigations.

It is anticipated that the International Organisation for Standardisation (ISO) will publish guidelines for Marine Geophysical Investigations in the context of offshore structures for petroleum and natural gas industries, to be named ISO 19901-10. At the time of writing of this report, the standard is under construction, the content may overlap with that provided in this guidance.

1.3 Stakeholders

Cable installation presents risk to developers, operators and to contractors; all have a stake in risk mitigation with limited possibility for comprehensive indemnification. These guidelines are designed to provide confidence that the provenance of data input to a risk mitigation strategy is recorded, such that risk-sharing between developers and contractors can be negotiated and designed in an informed way.

It is recognised that cable installation, operation and maintenance and decommissioning are tasks that span significant time. The systematic approach to survey specification presented in this guidance is encouraged to facilitate effective transmission of information between multiple contributors and stakeholders through the period of existence of the submarine cable.

1.4 Integration of multiple survey objectives

The survey methods that are likely to be employed in support of risk management of UXO and boulders to cable installation, operation and maintenance and decommissioning may also contribute to the understanding of other categories of risk. Sub-seabed investigations to support the geological understanding of the site for engineering design, and bathymetric investigation to support understanding of mobile seabed sediments in particular are likely to overlap in scope with the survey specifications established for the detection, location and measurement of UXO and boulders. This guidance should be used sympathetically with the equivalent processes in place supporting the management of other risks in order to optimise survey programmes and assure that the needs of each investigation are appropriately addressed.

1.5 Approach

This document is organised to enable the developer to implement recommendations within a generic risk management approach illustrated in Table 1. The information generated by the risk assessment of Phases 1-3 is used to inform the requirements of the geophysical survey. In relating the risk assessment to the survey specification for each class of risk to be mitigated it becomes straightforward to evaluate cost-benefit balance for each survey package in terms of the desired outcome.

Table 1: Risk management approach for UXO and obstructions to cable installation

Phase	Operation	Operational class
1	Identification of hazards and potential hazards	Plan
2	Evaluation of potential risk	
3	Initial definition of risk mitigation strategy	
4	Location and identification of hazards (survey)	Do
5	Update of risk mitigation strategy	
6	Implementation of risk mitigation measures	
7	Evaluation of residual risk	Check
8	Review, evaluation of requirement for further work.	Act

The approach outlined in Table 1 is equally applicable to UXO, boulders and other classes of risk. The goal of such an approach is usually the control of risk to an acceptable level. For example, UXO risk in the UK must be managed to a level ‘As Low As Reasonably Practicable’ (ALARP), other states and jurisdictions may have different terminology and definitions. Where the risk is a project risk (i.e. not one that is regulated by law) the definition and terminology of an acceptable level is set by the project.

1.6 Defining risk tolerance

Defining an Acceptable Level of Risk (ALR) requires an understanding of the vulnerabilities of the various elements of the project (personnel, equipment, quality, timeline, budget) to the array of hazards presented, and the tolerance of the project to the impacts should the potential hazards be realised. ALR may be defined by regulations or legislation – for instance the use of the acronym ALARP is widespread as it is the term used in UK law. Other acronyms are in use, and in this guidance ALR is the generic term.

For UXO, the development of the risk register is well covered by CIRIA 754, existing practice as illustrated in Figure 1, and similar equivalent protocols employed by risk management specialists. This document does not replicate aspects of the risk management process described elsewhere, but does highlight where information should be extracted from these operations. It is implicit that a framework for systematic risk management should be in place, and equivalent operations to those in Figure 1 should be used as sources of information.

For boulder risk management this guidance provides a minimal framework for a risk management-based approach to the specification of target characteristics for geophysical survey.

1.7 Geophysical survey design for risk management

Once an ALR has been established, the array of target items which the geophysical survey should resolve can be defined, together with the precision with which they should be located and measured.

A working definition of an ALR should be established for all hazards, all locations, and in all project phases where survey work may be required. This guidance makes the case to consider ALR definitions in Phase 1, for review in Phases 3, 5 and 7. If multiple phases of survey work are implemented, then definition of ALR may vary between them.

Early definition of ALR for each class of hazard, and review of objectives *prior to* deployment of resources to site, is likely to provide assurance that the work packages contributing to the risk management effort remain outcome focussed, and their cost is appropriate.

As a geophysical survey campaign may be required to contribute to the mitigation of multiple classes of risk, the survey design phase should integrate the requirements of each class and ensure that survey specification is appropriate for the ALR of each.

1.8 Survey implementation

The incorporation of the ALR into the survey design allows clear definition of the quality assurance (QA) metrics required to assure the geophysical survey is acquired to specification. These can be set as Data Quality Objectives (DQOs). While it is not appropriate to guarantee performance in terms of detection of hazards (there are too many variables outside the control of a survey contractor to provide a commercially viable guarantee of this), a clear set of DQOs can be a firm requirement for the aspects of the geophysical survey which can be controlled.

2. Geophysical survey for UXO risk mitigation

2.1 Introduction

There is well-established risk mitigation practice in place for UXO in the marine environment, Figure 1 illustrates a workflow used frequently by Ordtek. This workflow is compliant with the guidance contained within CIRIA 754 (a UK-specific document) but is globally applicable in principle and is straightforward to adapt where definitions and terminology for the ALR differ.

Key information for the specification and design of a geophysical survey for UXO is generated during Phases 1, 2, and 3 of this workflow, and sections 2.2-2.4 in this guidance briefly describe these key resources in the context of the risk management practice illustrated in Figure 1. This guidance is focused on Phase 4, after which information gained from the geophysical survey is developed and returned to the risk management workflow.

UXO Risk Management Framework

Applicable to all activities and projects in the marine environment in line with CIRIA C754

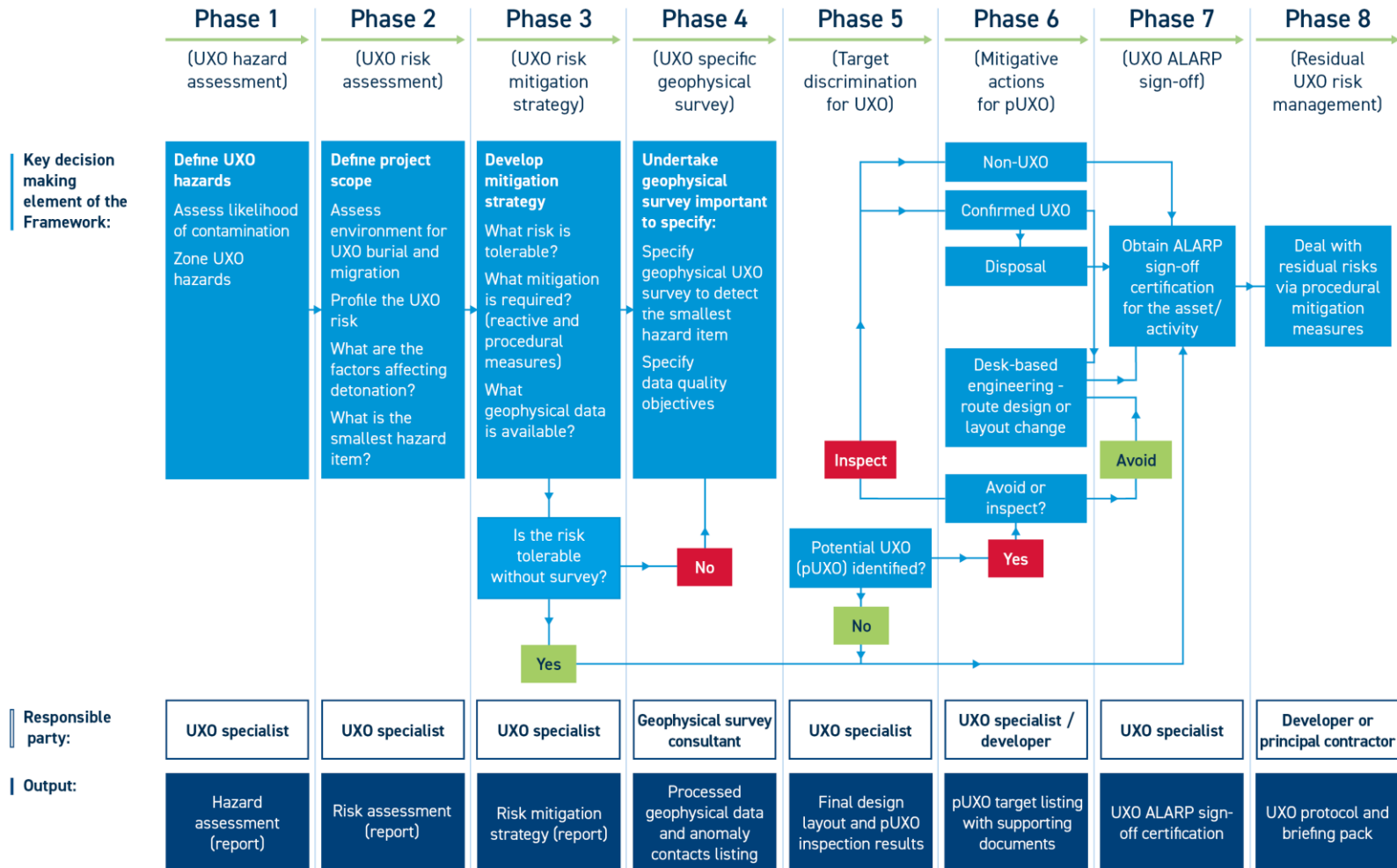


Figure 1: Example UXO Risk Management Framework (Source: Ordtek)

2.2 Phase 1 – Development of a UXO hazard register

2.2.1 Objective

To identify the array of potential hazards, and their potential impact on the project.

For the specification of geophysical survey work, the Hazard Register is a key document describing the set of objects that the survey may be designed to detect.

2.2.2 Outcome

A hazard register describing the types of UXO potentially present at the site and their physical characteristics relevant to detection. This register should be supplemented by a clear description of the boundaries of the site, information on the seabed and metocean conditions within it, and any zoning with respect to the potential presence of UXO.

2.2.3 Method

In order to create an initial register of potential hazards, the scope of interactions with the seabed and sub-seabed that the cable installation, operation, maintenance and decommissioning operations should be clearly identified. These should include:

- the proposed cable route for planning, installation, operation, repair and decommissioning operations;
- a prediction of the range of operations and equipment that could be active at the site.

With some operational information in place the Project UXO Hazard Register can be created using the process as described in Chapter 6 of CIRIA 754, or an equivalent. The corridor to be evaluated should be defined based on the UXO types anticipated.

Note that the description in Figure 1 includes an evaluation of the likelihood of presence of each UXO type in the operational area – this is only part of the evaluation of likelihood of the hazard being realised, which is properly evaluated during the risk assessment (section 2.3 – Phase 2). Zoning of the site with reference to the potential presence of UXO, or particular types of UXO, may be part of the hazard register.

If a Project UXO Hazard Register is already in place for the site, it is recommended to review it and confirm that it was made with an appropriate scope and is of sufficient quality to support the current work.

This evaluation does not consider the detectability of the objects concerned.

2.2.4 Output relevant to geophysical survey

Register of UXO possibly present with characteristic dimensions and properties, zonation of possible UXO presence, zonation of pertinent seabed conditions, and an indication of possible depths of burial.

2.2.5 Skillset required

- UXO risk management - evaluation of all current and historic use or disposal of ordnance at the site;
- Risk Assessment – incorporation of UXO risk management into project risk management plan;

- Engineering - knowledge of the cable installation, operation and maintenance and decommissioning activities could be useful to deliver insight into particular operational vulnerabilities of equipment and/or personnel.

2.3 Phase 2 - Evaluation of potential risk

2.3.1 Objective

To define an initial risk register for the UXO hazards to the project in order to inform an initial risk mitigation plan.

For the specification of geophysical survey work, the risk assessment and the information supporting it are key resources describing the set of objects that the survey will be designed to detect, and some details of the environment in which they may be found.

2.3.2 Outcome

A Project UXO Risk Register including all identified hazards, an estimated likelihood of their being encountered, the possible range of consequence of their encounter and an estimated risk prior to any mitigation.

2.3.3 Method

With the Project UXO Hazard Register in hand an evaluation of the risk presented by these hazards may be made. The risk assessment could follow immediately from development of the hazard register. However, it is useful to recognise that a risk assessment contains substantial context-specific consideration, so while a hazard register might be relevant through the lifetime of the project, the risk assessment component is more dynamic, may be more focussed on a particular activity or asset. Therefore, the two activities are separated in this guidance.

Typically, such a risk assessment would fall into two sections: a) the likelihood of encountering the hazard during the activities evaluated and; b) the impact of such an encounter. In the case of UXO, a) may include the likelihood of detonation (either in situ, or upon recovery of subsea equipment). Chapter 7 of CIRIA 754 provides a description of the Risk Assessment process in the context of UXO risk management.

Inputs to the Risk assessment include:

- UXO Hazard Assessment (Section 2.2, Phase 1);
- current cable route alignment;
- a prediction of foreseeable operations for design, installation, operation, maintenance and decommissioning for the planned cable;
- water depths within the corridor;
- anticipated maximum required cable burial depth;
- expected seabed conditions, including some anticipation of seabed mobility;
- geological information for the area;
- heritage, archaeological, ecological information for the area;
- environmental information for the area;
- metocean information for the area.

Many of these inputs are important information for the specification of the geophysical survey work.

With the input data in place, an evaluation of the likelihood of an encounter with UXO hazards, and the consequence of such an encounter can be made. Consequence should consider impact on personnel, public, environment and project assets. The planned cable route may be subdivided into zones, e.g. to allow variation of consequence with water depth, geological conditions, or variable environmental, heritage or ecological significance of the site, or to allow for variable likelihood of encountering a hazard in planning, installation, operation and maintenance or decommissioning.

The output is an initial risk assessment, including any zonation, which may be used to determine the requirement for further investigation and the objectives of such an investigation.

2.3.4 Output relevant to geophysical survey

Inputs listed in section 2.3.3, and zonation of risk prior to mitigation

For the purpose of specification of geophysical survey work, the physical characteristics of the UXO objects to which geophysical methods are sensitive are provided by the Project UXO Hazard Register, the risk assessment involves the anticipated context in which the UXO hazards should be mapped.

2.3.5 Skillset required

- UXO risk management - evaluation of all current and historic use or disposal of ordnance at the site;
- Risk Assessment – incorporation of UXO risk management into project risk management plan;
- Engineering - knowledge of the cable installation, operation and maintenance and decommissioning activities could be useful to deliver insight into particular operational vulnerabilities of equipment and/or personnel.

2.4 Phase 3 - Risk mitigation strategy

2.4.1 Objective

To make an initial plan for risk mitigation at the site, including definition of hazards to be targeted for reconnaissance.

For the purpose of specification of geophysical survey work, the Project UXO Risk Mitigation Strategy contains a definition of the Acceptable Level of Risk (ALR), and this in turn allows the definition of the smallest geophysical feature to be detected.

2.4.2 Outcome

An initial risk mitigation plan, including survey objectives, risk assessment, definitions of ALR(s) for each class of hazard identified, any zonation of the site for variation of ALR definition.

2.4.3 Method

It is recommended that a risk mitigation strategy should be explicitly considered as an evolving plan, with an initial strategy set before geophysical work is defined and scope for update as knowledge of the site evolves. The ALR is expected to be established during development of a risk mitigation strategy as a result of the evaluation of risk tolerance and specification of mitigation measures.

The geophysical survey work to detect, locate and identify UXO hazards is treated as part of the risk mitigation operations. Multiple survey operations with differing ALR may be required depending on

the outcome of survey, inspection or clearance activities. In all cases, it is recommended that the definition of the set of targets to be detected is made as an outcome of a cycle of development of a risk mitigation strategy.

A description of the principles used in the development of a risk mitigation strategy for UXO are provided in chapter 8 of CIRIA 754.

Inputs to the risk mitigation strategy should include:

- the initial Project UXO Risk Register and risk assessment;
- the array of possible mitigations for the risks in the initial Project UXO Risk Register;
- a database of existing information available for the site, including geoscientific data;
- a concept of budget for the operations under consideration;
- a policy for management of UXO risk from a legal (statute and common law) perspective;
- a policy of management of UXO risk from the project perspective.

The Project UXO Risk Mitigation Strategy may be represented as the addition of a mitigation plan for each risk documented in the Project UXO Risk Register together with a review and update loop. It is recommended that mitigation plans for each class of risk (i.e. each type of UXO) include requirements for detection and location of targets in order to provide clear objectives for survey and investigative work. In the context of geophysical survey work, these give clear criteria for DQOs and performance evaluation in the review of residual risk.

For the specification of geophysical survey operations as part of the risk mitigation plan, the following outputs from the risk mitigation strategy development process are required:

- the set of targets for the geophysical survey;
- the detectable characteristics (size, mass, conductivity, magnetic permeability) of the targets;
- the possible positions that potential hazards may be found – the corridor to be surveyed, any zonation with regard to UXO hazards, conditions or consequence, and the depth range to be targeted;
- the required precision with which hazards are to be located;
- an acceptable budget for risk mitigation and the geophysical survey component.

2.4.4 Output relevant to geophysical survey

The key deliverable from phase 3 is the set of risk tolerances associated with each hazard (UXO class) the physical characteristics of the items and the possible range of conditions in which they may represent a risk requiring mitigation. This set of information informs the specification and parameterisation of the survey work to follow, principally through the identification and description of the smallest signal to be detected. [Table 2](#) illustrates an example target table summarising the characteristics of the targets pertinent to geophysical survey specification.

Table 2: Example target characteristics table for geophysical survey

Index	Hazard	Zone	Mitigation required	Survey requirement	Detectable property	Maximum depth bsb	Location precision
1	UXO1	1	Avoid or remove	Detect and locate	Trace ferrous material 50kg non-ferrous material 0.5x0.5x2m	3m	< 2m
2		2	Remove	Detect and locate	Trace ferrous material 50kg non-ferrous material 0.5x0.5x2m	3m	< 2m
3	UXO2	All	Remove	Detect and locate	50kg ferrous 0.2x0.2x0.7m	3m	< 1m

Data and products from previous surveys or those acquired for regulatory, EIA, consent and feasibility studies may not be of sufficient resolution for the purposes of detailed UXO and obstruction identification. These data must be evaluated with the objectives described above in view, so that they may be incorporated into the mitigation plan in a systematic way. The targets listed in Table 2 can have representative anomaly characteristics calculated for an appropriate survey configuration to evaluate the possible use of products from previous survey work – Table 3 is an example of an anomaly calculation for magnetic field data.

Table 3: Example evaluation of legacy survey characteristics against anomaly patterns

Index	Hazard	Zone	Maximum depth bsb	Anomaly amplitude	Anomaly peak width	Survey noise floor	Survey pitch
1	UXO1	1	3m	3 nT	<6 m	1 nT	5 m
2		2	3m	3 nT	<4-10 m	1 nT	5 m
3	UXO2	All	3m	30 nT	<4-10 m	1 nT	5 m

In this case the survey pitch does not give sufficient coverage to confidently predict that anomalies will be identified, and in the case of items with indices 1&2 the survey noise floor is only just small enough to confidently identify an anomaly above noise.

2.4.5 Skillset required

The development of a risk mitigation strategy requires personnel skilled in UXO risk management, cable installation, project management and geophysics in order to populate the tables with scores that can be used to make sensible decisions.

There is a risk that if this step is done without appropriate diligence, the documentation may be used to poorly inform a decision with significant cost implication, and potentially significant consequence.

2.5 Phase 4 - Geophysical survey for detection and location of potential UXO

2.5.1 Objective

To define and execute survey work to detect and locate the array of potential UXO hazards at the site.

2.5.2 Outcome

A register of contacts as defined in Phases 1 and 2, with locations provided to the precision defined in Phase 3.

2.5.3 Method

Phase 4 has four clear components – scoping, procurement and execution and reporting. After the scoping phase and with estimated timings and costs in hand a review, with potential costs in view, of the definitions of ALR for risks identified at the site is advised.

- Scoping: Specification of target geophysical signal characteristics, initial alignment and survey corridor, shortlisted survey methods and anticipated parameters, specification of deliverables.
- Procurement: Commissioning of survey work and associated offshore and onshore support.
- Execution: Acquisition, processing and initial interpretation of data.
- Reporting: Assembly of products for incorporation into the risk management knowledgebase.

Description of these elements follows in sections 2.5.5.3 to 2.5.5.7.

Quality Assurance of Phase 4 is critical. The collateral developed in operations 1-3 should be used to define appropriate metrics to assure that survey work is fit-for-purpose.

It is recommended at this stage that significant emphasis be placed on the specification of appropriately accurate positioning of the sensors and diligent logging and processing of navigation data; this will lead to greater confidence in the contact locations during the survey interpretation and analysis phase. High quality location information is a requirement for accurate location of targets with reduced buffer zones for UXO, greater flexibility for micro-routing and reduced time in field inspection and clearance of targets.

2.5.4 Skillset required

The detection and location of hazards primarily requires personnel with skills in geophysical survey, data processing and interpretation together with UXO specialists and those with hydrographic and positioning, logistics and project management skills. Engineering input is limited to definition of the activities anticipated during development, operation and decommissioning and therefore specification of the vectors by which UXO may come into contact with project assets, and this input should already be in place if the workflow of Figure 1 has been followed. The requirement to interface the various skill sets needed is set out within both the OGP 2017 and OSIG 2014 guidelines, that during the planning, execution, interpretation, analysis and planning of the acquired datasets and engineering phases, competence in each of the disciplines contributing to the survey is required and that management of the key investigations should be undertaken by a competent person. Investigations for UXO are regulated in the UK by Health and Safety regulations, CDM 2015 and Corporate Manslaughter legislation so careful interpretation of the terminology ‘competent person’ is prudent, as discussed in CIRIA 754.

2.5.5 Scoping

Table 4 illustrates the set of data products that are typically used to develop the contact register, with the measurement methods that contribute to each. This table is constructed according to the data product, rather than survey type, to emphasise that multiple measurements may contribute to the same output. This raises a significant consideration for the users of these data, in that data may be delivered according to their measurement type, with a risk that data positioning error, measurement configuration and interpretational uncertainty contribute to multiple registration of single targets. It is recommended that an explicit strategy for the integration of multiple measurements is implemented to establish understanding and control of positional uncertainty for UXO hazards.

2.5.5.1 Detection of non-ferrous UXO

Typically, most items of UXO contain ferrous materials. As such magnetometry is suitable to detect them when they are on the survey, partially buried or fully buried. However, there are a range of UXO items that are constructed from non-ferrous materials, and when buried there is currently no survey method that can reliably, accurately and provably detect them when buried without prior knowledge of their location. While experience has shown the 3D SBP methods are technically capable of detecting such items, particularly LMB mines, it has not been proven with an actual buried low-ferrous mine find. The majority of previous LMB mine finds have been seen in acoustic datasets with the mine only partially buried. However, LMB mines have been found using a magnetometer array setup combined with a 2D seismic array. However, this only gave one dimension (length only rather than a length and width). It is important to consider the cost of performing a high-resolution 3D SBP in the ALARP assessment, as it is significantly higher than conventional survey (magnetometer, side scan sonar and multibeam echosounder), at approximately twice the cost for regular UXO specified surveys.

2.5.5.2 Geophysical method overview

- Magnetometry measures variation in the magnetic field and is often used for detecting ferrous items including pUXO. However, it cannot be used for detecting non-ferrous items.
- Multi-Beam Echo Sounder (MBES) and Side Scan Sonar (SSS) data are used in combination for mapping and understanding the distribution of objects on the seabed.
- Sub Bottom Profiler (SBP) can be used to understand the sub-seabed structure and may inform analysis of the explosive potential of UXO. 3D seismic methods of various resolutions may be implemented, which may provide an accurate location of a sub-seabed object.
- Electromagnetic (EM) methods may be used to detect anomalously conductive material beneath the sea bed, within a few metres of the sea bed.

Deployment of geophysical methods may be from a surface vessel, either directly attached or towed, from an airborne platform (manned or unmanned) or from sub-surface platforms either towed (Remotely Operated Towed Vehicle, ROTV), free flying (Remotely Operated Vehicle, ROV), or untethered (Autonomous Underwater Vessel, AUV). Figure 2 illustrates some of the options. Some are semi-permanent installations on dedicated survey vessels, while others can be installed on multi-purpose craft. It is important that the position of instrumentation relative to its navigation reference point is properly established and validated.

Geophysical surveys, particularly those involving towed gear, are generally acquired in line plans composed of nominally straight-line segments, though ROV, AUV and vessel-fixed instruments are not limited to this requirement. The spacing between acquisition lines, frequency of measurement along lines, requirement for intersecting 'tie' lines, vertical position of the instruments, power and frequency settings for active measurements are some of the many parameters that contribute to the survey design. The risk mitigation plan should inform the survey designer of the characteristics of the set of targets that is required to be resolved by the geophysical survey. The characteristics must be

translated into anticipated geophysical responses in order to define a survey specification – critical characteristics might be signal amplitude, spatial extent, pattern or gradient and these will inform the requirements of the of the instrumentation, logging systems and the line plan. Sections 2.5.5.3 to 2.5.5.7 describe the principles of the key geophysical methods with the controlling parameters that have critical influence on the survey performance.

To ensure that specifications and objectives that have been set out in the initial operations described above are met during the data acquisition phase then an experienced offshore client representative who is familiar with the requirements of the project and offshore survey operations of a similar nature should be appointed. The output of Phases 1-3 will help the offshore client representative to understand the motivation for the scope, but this is no substitute for at least a thorough briefing and ideally their involvement in the development of the scope of work itself.

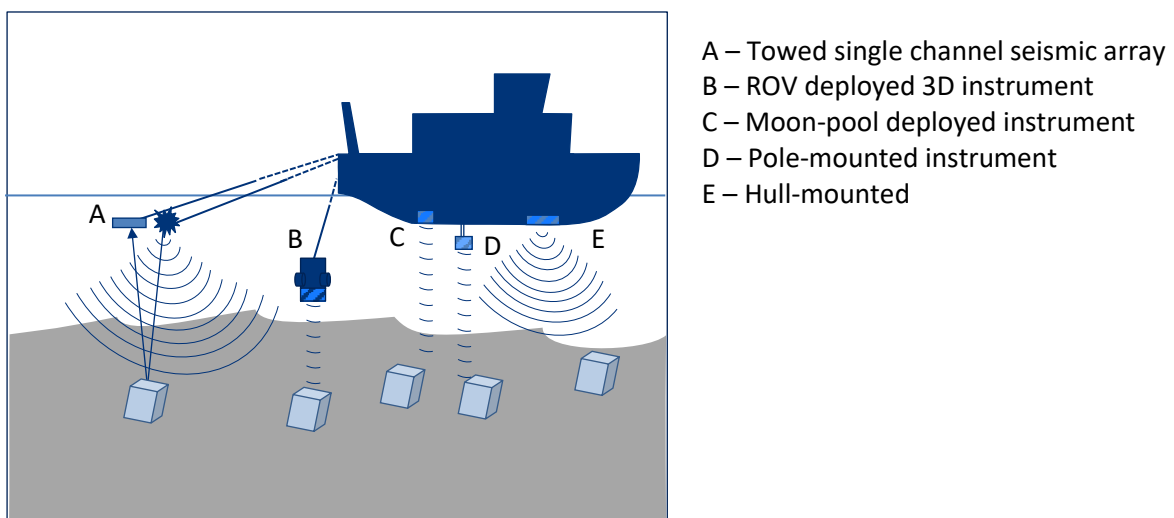


Figure 2: Schematic illustration of the different modes of deployment for sub-bottom profiler instruments.

Table 4: Deliverables from the geophysical survey required for UXO risk mitigation

Data Product	Primary Use	Measurements	Component Products	Derived Products	Drivers for Precision
Digital Seabed Model	Detection and location of obstructions at seabed and other installation considerations	MBES	Bathymetry DTM grid	Contact list Contact zonation map	Instrument configuration Survey altitude Line spacing Grid pitch
			Bathymetry Point cloud	Seabed slope map Bedform map	Instrument configuration Survey altitude Line spacing
			backscatter	Seabed sediment classification	Instrument configuration Survey altitude Line spacing Grid pitch
		SSS	Raw sonar files	Contact list Contact zonation map	Instrument configuration Survey altitude Line spacing
			Sonar Mosaic		Instrument Configuration Grid Pitch
		Magnetic Anomaly map	Detection and location of ferrous material at or below seabed	Magnetometry Magnetic gradiometry	Magnetic anomaly profiles
Magnetic anomaly grids	Contact zonation map Analytic Signal grids				Instrument configuration Survey altitude Line spacing Grid pitch
Magnetic gradient anomaly grids	Magnetic anomaly depth models				Instrument configuration Survey altitude Line spacing Grid pitch
Magnetic anomaly ribbon plots					Instrument configuration Survey altitude Grid pitch

Electromagnetic anomaly map	Detection and location of conductive material at or below seabed	Electromagnetic (EM) survey	EM anomaly profiles	Contact list	Instrument configuration Survey altitude Line spacing
			EM anomaly grid	EM anomaly depth model	Instrument configuration Survey altitude Line spacing Grid Pitch
2D Sub Bottom profiles	Image 2D geology sub-seabed	Sub Bottom Profiler (SBP)	Seismic sections	Geological interpretation	Water depth Trace spacing Source type
	Detect Obstructions sub-seabed			Contact list	Water depth Trace spacing Source type
3D sub-Bottom volumes	Image 3D geology sub-seabed	3D seismic survey	Contact list		Water depth Line spacing Trace spacing Source type
	Detection and location of sub-seabed objects		3D reflection amplitude volume	3D reflectivity volume	Water depth Line spacing Trace spacing Source type
Operational Report			Operational Report Data Processing Reports		
Interpretation Report			Individual Measurement interpretation	Individual contact list	
			Integrated interpretation	Integrated contact list	
Metadata					

Scoping of survey work should follow the requirements identified in Phase 3 in the Target Specification Summary, with a significant caveat that some contingency must be allowed for the discovery of unexpected objects at the sea bed.

It is crucial to recognise during scoping that objects smaller than the minimum size (or signal amplitude) resolvable by the survey will not be mapped, but may be present in unknown number.

Subsections 2.5.5.4 to 2.5.5.8 provide an overview of the quality and resolution controlling parameters of each measurement type contributing the data products in Table 4.

2.5.5.3 Validity over time of geophysical data used for UXO risk management

The time elapsed between collection of any data contributing to risk mitigation and the date of seabed operations may be significant. While the lateral migration of objects may or may not occur, migration

of bedforms certainly does (at various rates, directions and degrees of consistency), and a significant elapsed time may lead to migration of a bedform such that a previously undetected hazard becomes apparent, or comes into the depth range of interest for an installation or maintenance operation.

It is important to consider possible movement of target and environment, and any other mechanism of change, when evaluating the potential viability of existing geophysical data for risk mitigation. Existing data may accurately represent a previous state and be useful to illustrate change even if current survey work is commissioned.

Geophysical data itself does not have a ‘shelf life’ as such. It is recommended that a review of the provenance of any existing geophysical data considered for use in UXO risk mitigation is performed, with survey objectives and DQOs set up as they would be for a new survey. The precautionary principle should then hold, only using existing data when it is positively evaluated as having satisfactory quality for the purpose to which it is being put.

It is recommended to pay close attention to the quality of positioning of all data and to the vertical reference systems used, these are frequent sources of uncertainty and mistakes. Where depths are referenced from sea floor or an instrument altitude, ensure that the reference surface is available (as seabed mobility may cause change).

A ground data ‘shelf life policy’ such as that illustrated in Table 5 may be useful to concisely summarise the maximum age of data with site specific limits set according to anticipated rates of change. A UXO consultant should be engaged to make this site-specific assessment and where necessary implement a series of UXO risk management actions to address excess time lapse between acquisition and seabed interaction.

Table 5: Suggested format of a shelf-life policy (modified From OGP 2017)

Activity level	Seabed Data	Sub Seabed data
None	5yrs	Up to 10yrs
Planned Marine or engineering activity	1 yr	Up to 10yrs
Construction	Pre-installation	Up to 10yrs

Other reasons for new survey may include:

- significant amount of time elapsed since the last survey;
- occurrence of an anomalous significant storm, tide, or high current event;
- anomalous changes in the level and/or morphology of the seabed;
- a significant event (e.g. UXO detonation);
- trawling, construction, dredging or other sea bed activity within the area;
- a technical or operational development that changes the definition of ALR.

On balance, given that most UXO is likely to be partially or completely buried, it is considered that fishing trawl is the most likely vector for movement of UXO during the period of existence of a cable.

While it is widely acknowledged that the example shelf-life policy of Table 5 is a moderately conservative estimate and the actual validity is likely to be considerably longer, it would not be prudent to issue an open-ended statement though, declaring that survey results will remain valid indefinitely.

It is important to recognise that within this period the residual risk could rise; despite burial, it is still possible for UXO to be dragged into the area. It may be considered that any marginal elevation of risk

between survey and installation is tolerable and can safely be reduced to below the ALARP threshold through procedural and reactive mitigation measures.

2.5.5.4 Magnetometry

Magnetometry is used in UXO detection campaigns to detect items with significant content of ferrous material – many classes of UXO have significant ferrous content with some notable exceptions. The detectable magnetic anomaly associated with objects containing ferrous material is spatially limited. The amplitude of the anomaly is a function of the mass of ferrous material and an inverse function of the cube of its distance from the sensor. The spatial extent of the anomaly is a function of the vertical distance between the target and the sensor paths. Figure 3 illustrates schematically the pattern of Total Field magnetic anomaly expected from a ferrous object.

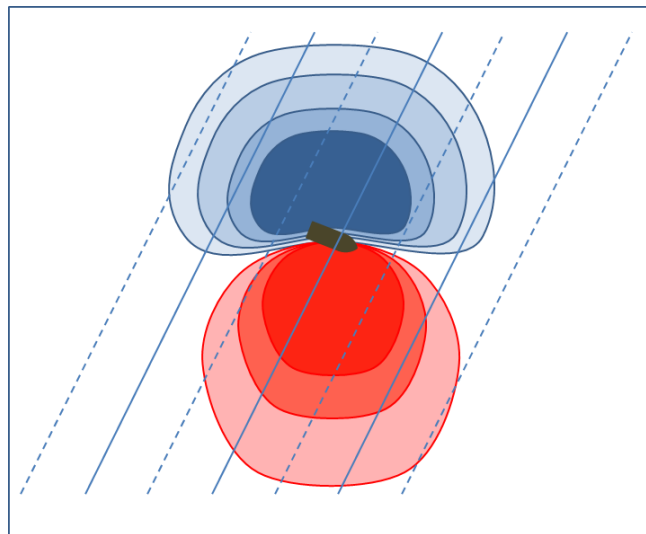


Figure 3: Magnetic anomaly (total magnetic intensity) above a ferrous object

Figure 3 shows that only part of the magnetic anomaly would be sampled by each profile. It is clear that the anomaly recorded on a single profile could take many forms, from a clear positive-to-negative response through the axis of the anomaly to much lower amplitude, single polarity responses if the anomaly is intersected off-axis.

Confident identification and location of targets requires that the spatial pattern of an anomaly can be interpolated from the collection of profiles. Derived data products such as analytic signal, while apparently simplifying the map, demand adequate sampling and processing of the Total Magnetic Field anomaly in order to be accurate (analytic signal requires a calculation of the spatial gradient of the Total Magnetic Intensity). Thus, it is recommended that an objective design criterion for line spacing is used to assure the viability of the dataset for its intended purpose.

If the objective of the survey is limited to detection then a suggested line spacing allowing three lines to sample one anomaly half-width (measured above the noise floor) may suffice. Should a requirement to model burial depth and/or mass of ferrous material be anticipated, then at least five traverses per anomaly half-width may increase the chance of recording the detail of the magnetic anomaly for these processes.

As a rule of thumb, the anomaly half width will be of the order of the distance between the ferrous material and the instrument flight path.

In Figure 4 the profile view N-S through the axis of an anomaly is provided as a schematic. Some critical observations are:

- deeper objects give a smaller amplitude and wider anomaly than those closer to the sensor;
- anomalies from objects close to the sensor have smaller spatial wavelength;

- noisy magnetic data (indicated by the halo on the schematic response patterns of Figure 4) can result in distorted or undetectable magnetic anomalies;
- inferences of depth are made relative to the altitude of the sensor path.

The calculation of line spacing required to give 'full coverage' is therefore a function of the altitude of the sensor above the maximum depth of investigation required, the size of the signal anticipated from the hazard with the smallest magnetic signal, and the noise floor of the sensor.

In practice, the sensors deployed are generally very similar in performance, allowing relatively simple tables or nomograms to be used to establish an altitude and line spacing tolerance for a given target anomaly size and amplitude.

Typical altitudes above sea bed are of the order of 3-5 m, and instrument line spacing <5 m.

As an example calculation of line spacing; targets at a maximum burial depth of 2 m, and a minimum instrument altitude of 3 m above sea bed, are expected to have a Total Field anomaly half width of the order of 5 m. A line spacing of 1 m would be recommended if it is anticipated that modelling may be applied, while a 2m line spacing may be sufficient for detection of the anomaly. Items of UXO of total mass between 50 and 250 kg may have anomaly amplitudes of the order of 10-50 nT at 3 m altitude, well above a survey noise floor at 1-2 nT. However, at 10 m instrument altitude similar items may only produce an anomaly just above the noise floor. Confident identification of an anomaly can only be made at signal amplitudes of the order of three times the noise floor. Note therefore that the line spacing should be set considering the minimum survey altitude and the noise requirements should be set considering the maximum anticipated instrument altitude.

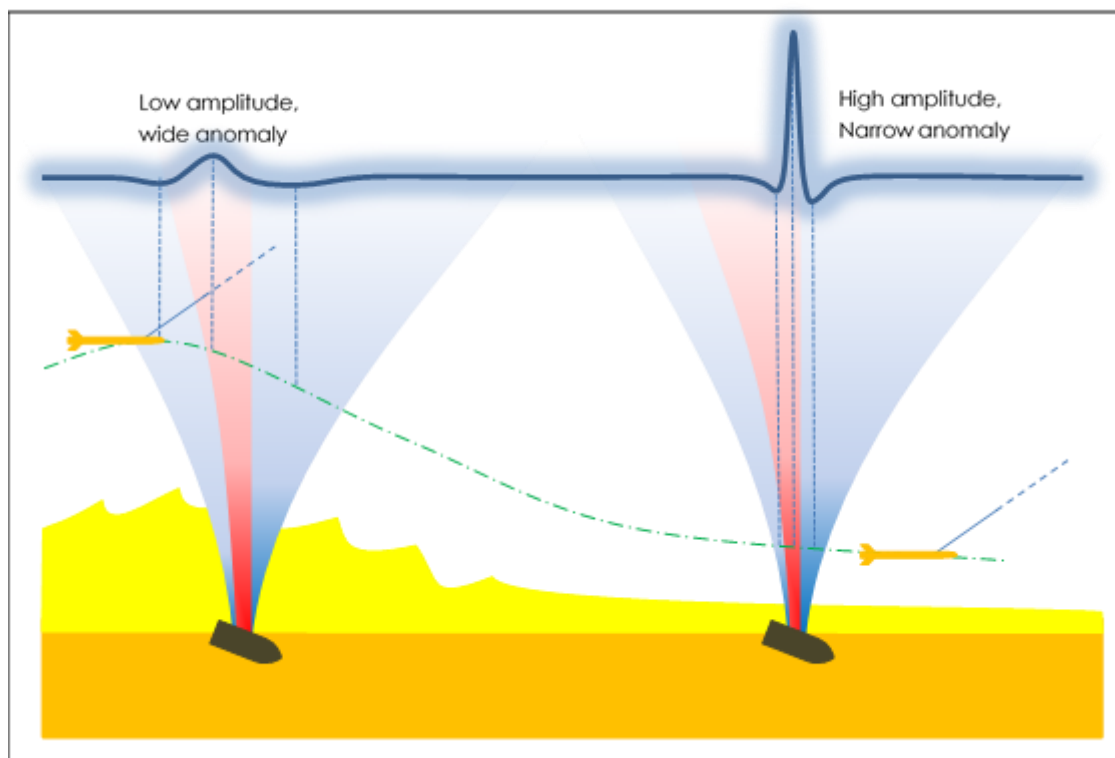


Figure 4: Schematic image of magnetic anomaly patterns above a ferrous object lying at the base of mobile sediment.

Instruments are normally deployed in a towed 'fish', suitably distant from the magnetic field distortions induced by the towing vessel and any other equipment. The towing distance is typically 3-5 times the length of the vessel involved, and the sensor may be 'piggy-backed' on the same tow-line with other instruments. Altitude is controlled by the towing speed and a balanced arrangement of buoyancy and hydrodynamic surfaces on the towfish. The position of the magnetic sensor is typically

monitored using an Ultra-Short Base Line (USBL) system with a transponder positioned as close as possible to the sensor without inducing signal distortion, towfish may have an altimeter incorporated. As indicated in Figure 4, the instrument altitude may follow a smoothed version of the seabed topography, with significant variation.

Magnetic gradiometry may be recorded by an assembly of magnetometers fixed to a rigid frame, processed to optimise recovery of the difference in magnetic field across the known baselines of the structure. Magnetic gradiometry offers a few significant advantages; the time-variant field induced by solar activity is cancelled as a common mode between the magnetometers (removing a potentially significant source of noise), positions of anomalies may be interpreted with better confidence, calculation of derived data quantities (e.g. analytic signal) can be made with more robust direct (rather than calculated) gradient terms. However, gradient signals are more sensitive to instrument noise and variation of altitude, so care is required to assure the acquisition system is configured with an appropriate noise floor. Processing must be diligently applied. Interference between magnetometry instruments and other systems must be minimised.

If it is expected that an attempt to model the depth to a ferrous object will be required, it is important to ensure that a good representation in the horizontal plane of the anomaly is mapped. This may require data acquisition at line spacing of the order of 1-2 m.

As a result of this tight line spacing requirement, where modelling of targets may be required, magnetometers are generally operated within an array behind single or multiple ROTVs that are available in various configurations. These reduce the number of lines a vessel has to run to acquire the required number of magnetometer lines. These ROTV's have the advantage of offering a fixed towing point closer to the magnetometer itself, reducing uncertainties with positioning. However, they require skilled operators to pilot them; at the time of writing there are significant improvements in progress to the operating systems for these devices. The use of AUV platforms has similar performance benefits and positional requirements.

Proprietary software exists that can monitor whether line spacing and altitude specifications have been maintained or exceeded. Survey operators along with offshore client representative must be satisfied that acceptable coverage has been achieved over the survey area before the vessel leaves the site, in line with the ALR principles defined in the risk mitigation plan.

Due to the tight line spacing requirement and the use of towed equipment, magnetometry work can generate a significant amount of infill requirement. It is recommended that a robust set of DQOs be agreed such that the developer, their UXO specialist, offshore client representative and their cable installation contractor have a ready understanding of any compromise to the quality of the dataset. Suggestions are given in Table 6. Deviations from an agreed line spacing and altitude should be mapped, as while an upward deviation reduces the amplitude of an anomaly, a downward deviation moves the sensor to a position in which the anomaly is smaller in space possibly compromising resolution of steeper gradients in the magnetic field. Both may result in compromised detection or modelling of targets.

Table 6: Target and survey parameters for magnetometry

Scope Requirement	Measurement Parameter	Controlling Parameter	Suggested Guidance	QA metric
Minimum anomaly amplitude	Total Anomaly magnitude	- Noise floor	Minimum signal-to-noise ratio of 3	RMS noise
Minimum anomaly dimension	Line spacing	- Navigation - Instrument positioning	At least 3 profiles per anomaly half width	Linekeeping tolerance Altitude Tolerance Coverage tolerance
Modelling depth and target	Spatial anomaly shape	- Navigation - Instrument positioning	At least 5 profiles per anomaly half width	Linekeeping tolerance Altitude Tolerance Coverage tolerance

2.5.5.5 Multi Beam Echo-Sounder (MBES) data

Multi Beam Echo Sounder (MBES) instruments operate by emitting a radial acoustic pulse or chirp, measuring the returned echo using an array of receivers arranged to monitor a set of incoming ray paths through beamforming. They are highly parameterisable devices. Modern instrumentation can deliver over 1000 receive beams per ping with dual head instruments; this can result in apparently very high-resolution data with a broad swath width.

Each beam has a ‘footprint’, conceptually the area of the seabed that reflects the beam. This is related to the ‘beam width’, increases with range, and may be larger than the beam spacing. Figure 5 is a schematic illustration of MBES configuration showing key parameters.

The detection of seabed obstructions using MBES instruments is dependent on the density of soundings per square metre of ensonified seabed, and the precision with which these soundings are located. The location of targets has sources of uncertainty in the position and attitude of the MBES instrument itself, and uncertainty in the range and direction of the sounding recorded by the instrument. MBES instruments may be fixed to a surface vessel, in which case the instrument position can be determined with good precision using GNSS (in real time or with post-mission calculation) and inertial methods. If the MBES instrument is deployed on a sub-surface platform, a secondary positioning system such as USBL must be implemented.

The dependence on density of soundings per square metre is illustrated in Figure 5. A density of 9 soundings per square metre, which may satisfy IHO Special Order, may be insufficient to guarantee detection a small target, and would be unlikely to be sufficient to provide a confident measurement of the object. A sounding density of 40 per square metre, a value which is fairly typical of high performance, surface deployed instruments in moderate water depths, may be sufficient to detect such an object, but still may not be sufficient to provide good measurements of it. However, larger objects may be well resolved at this sounding density and the benefit of precise location in comparison to the output of Side Scan Sonar or Magnetometry may be significant.

The footprints illustrated in Figure 5 show that at higher values of soundings per square metre there may be significant overlap between soundings. Beamwidths typically lie between 0.5° and 2°, corresponding to footprints of 0.4-1.5 m at around 20 m depth. This also represents a component of the limit to the size of smallest detectable object.

MBES deployed on sub-surface platforms can yield very high-sounding density and small footprint, but in doing so add a requirement for significant positioning technology – a robust USBL geometry, inertial systems and Simultaneous Location and Mapping (SLAM) type processing operations are available to assist.

The calculation of bathymetry from MBES records requires the time difference between ping and return to be converted into a range. This is a function of the speed of the acoustic pulse in water, which may be variable. Measurement of the speed of sound in water close to the instrument is often made semi-continuously. Vertical profiles through the water column are required to be collected sufficiently frequently to capture temporal variation at the site, often associated with variable (*e.g.* tidal) flow patterns but other possible sources of variation of acoustic speed should be considered as well.

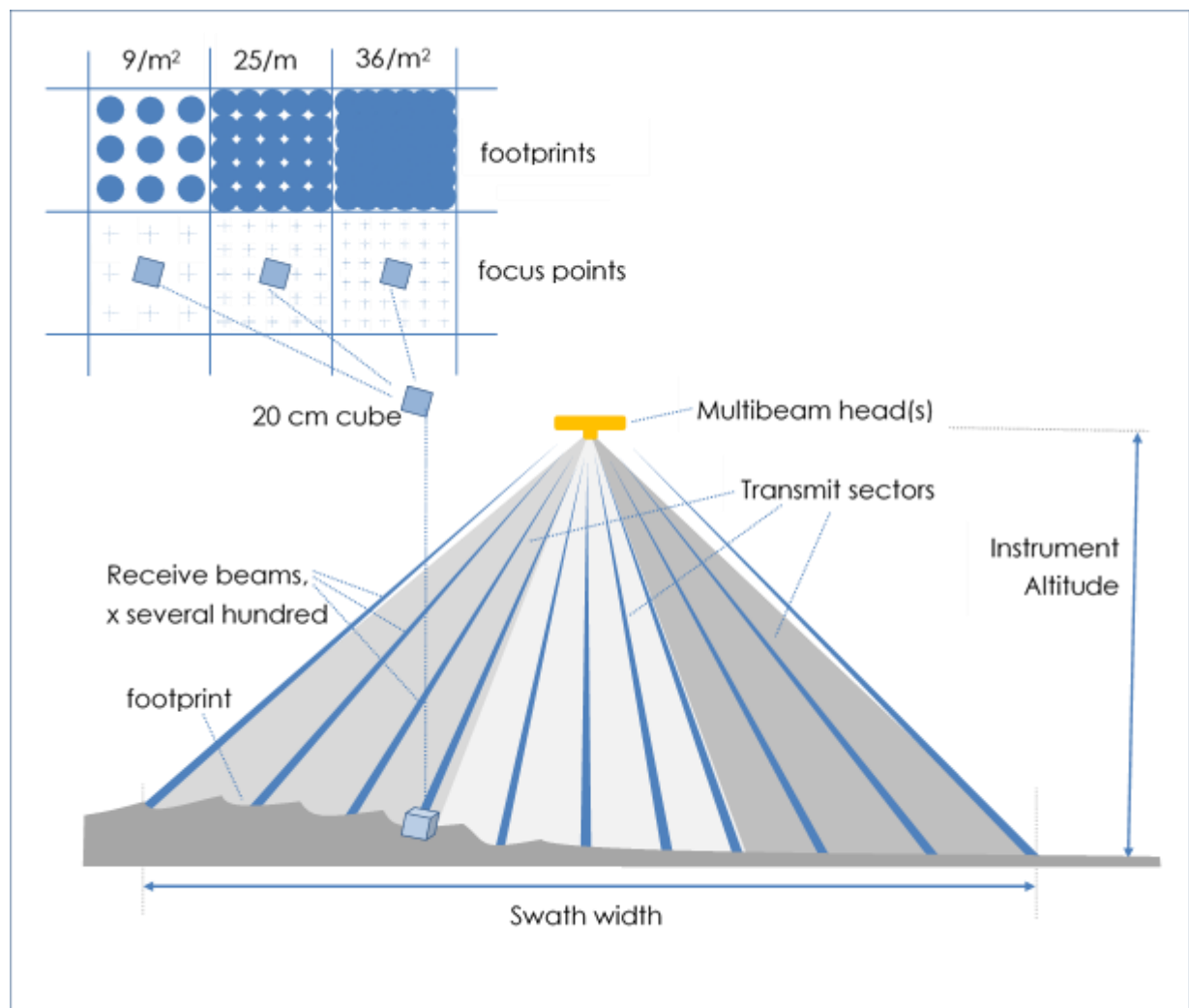


Figure 5: Schematic illustration of the configuration of Multi-Beam Echo-Sounder measurements.

Modern MBES systems with dual swath and dual receive head configurations can deliver high precision along and across track, and large swath width. However, depending on the height and configuration of the instrument above the seabed, at low sensor height swath width can still be the primary control on line spacing. Some indicative operating parameters are given in Table 7.

It is important to recognise that variation in the speed of sound in water may influence the swath width of MBES, and the presence of a thermocline or halocline may induce refraction of the beam of sufficient magnitude to influence coverage as well as influencing the depth calculation.

Table 7: Operating parameters of some common MBES systems

Instrument	Frequency	Min/Max range	Max Swath width
Kongsberg M3 Sonar	500kHz	0.2-50m	120 degrees
Kongsberg GeoSwath	125,250,500kHz	0.3-200m	195-780m
Kongsberg EM2040	200-400kHz	0.3-600m	130-200 degrees
R2 Sonic 2022	170-450kHz	Up to 400m+	10-160 degrees
R2 Sonic 2020	200-400kHz	Up to 200m+	10-130 degrees

Effective operation of these tools to get the required resolution is dependent on operating parameters and configuration. It is important that they are configured in order to achieve the required specifications of the survey with the following considerations:

- full coverage of the survey corridor;
- production of a single, correctly referenced surface for the project;
- acquisition and processing parameters driven by the minimum size of hazard to be detected;
- in line with any required hydrographic standards.

Key parameters and DQOs are presented in Table 8.

Key drivers for precise target location:

- accurate calibration of the instrument at mobilisation;
- accurate sound velocity profiles at an appropriate interval;
- configuration of instrument parameters to suit minimum size of hazard to be detected, water depth (or platform altitude), line spacing and survey speed;
- high quality vessel positioning and attitude data;
- accurate in-field quality and coverage monitoring;
- accurate data processing and gridding.

A focus at the mobilisation stage on checking and calibrating a vessel’s navigation and bathymetric systems and consequent reporting within a mobilisation and operations report is an important element of survey metadata. The survey contractor and the offshore client representative for the developer should satisfy themselves that the systems have been correctly calibrated before survey operations begin and acceptable coverage has been achieved before a vessel leaves the survey area.

It is recommended that interpretation from sonar and magnetometry datasets should be correlated to the bathymetric DTM before and if an expression of the target is visible on bathymetric data then this should be used as the primary position reference.

Table 8: Target and survey parameters for Multi-Beam Bathymetry

Scope Requirement	Measurement Parameter	Controlling Parameter	Suggested Guidance	QA metric
Spatial Resolution	Grid pitch	Minimum number of soundings per m ²	9 soundings per cell	Ping density map
Vertical resolution	Vertical resolution	Frequency Signal to noise ratio Speed of sound in water measurement	Vertical uncertainty < 1/3 of the smallest vertical target dimension	Speed of Sound in water measurements Mobilisation tests Total Vertical Uncertainty
Positioning	Navigation	Navigation Instrument Attitude	Positional uncertainty < 1/3 of the grid pitch	Mobilisation tests Total horizontal Uncertainty

2.5.5.6 Side Scan Sonar

Side scan sonar projects a radial acoustic pulse into the water column and records the arrival of reflections from the seabed as a time record relative to the time of emission. Figure 6 illustrates, schematically, the configuration of the technique. The time record may be interpreted directly (the so-called ‘waterfall’ plot, best for highest resolution) or converted to a range relative to the instrument position for location of targets on the sea floor (the ‘mosaic’ plot) usually with some loss of resolution due to gridding.

SSS instruments are generally towed at a lower altitude above the sea bed than the altitude of an MBES instrument. Their wavelength and beamwidth may also be smaller, and the incidence angle of the beam is favourable for the detection of relatively low-relief seabed features. SSS data are often acquired in conjunction with MBES data, the two datasets contributing to a seabed contact map in a complementary way.

Seabed objects reflect as anomalous amplitudes in the time record, and textures and seabed features can be determined by variation in patterns of the amplitude map. The horizontal dimensions of an object can be estimated from the size of the anomaly in the scan, and its height relative to the seabed may be estimated from the length of its shadow (annotated t_s in Figure 6). Side scan sonar is normally acquired from a towed ‘fish’ which projects pulses normal to the path of the fish. The track immediately below the fish path, where pulses from each side might interfere, is normally configured to have low amplitude; this zone is termed the ‘nadir’.

Figure 6 illustrates the principle of overlap, which provides coverage of the nadir by the long-range part of the adjacent scan. This construction is often the source of the primary consideration for line spacing for SSS surveys. It is important to note the effect of seafloor topography on this overlap condition; sea-floor slope always results in a reduction in line spacing required for full coverage.

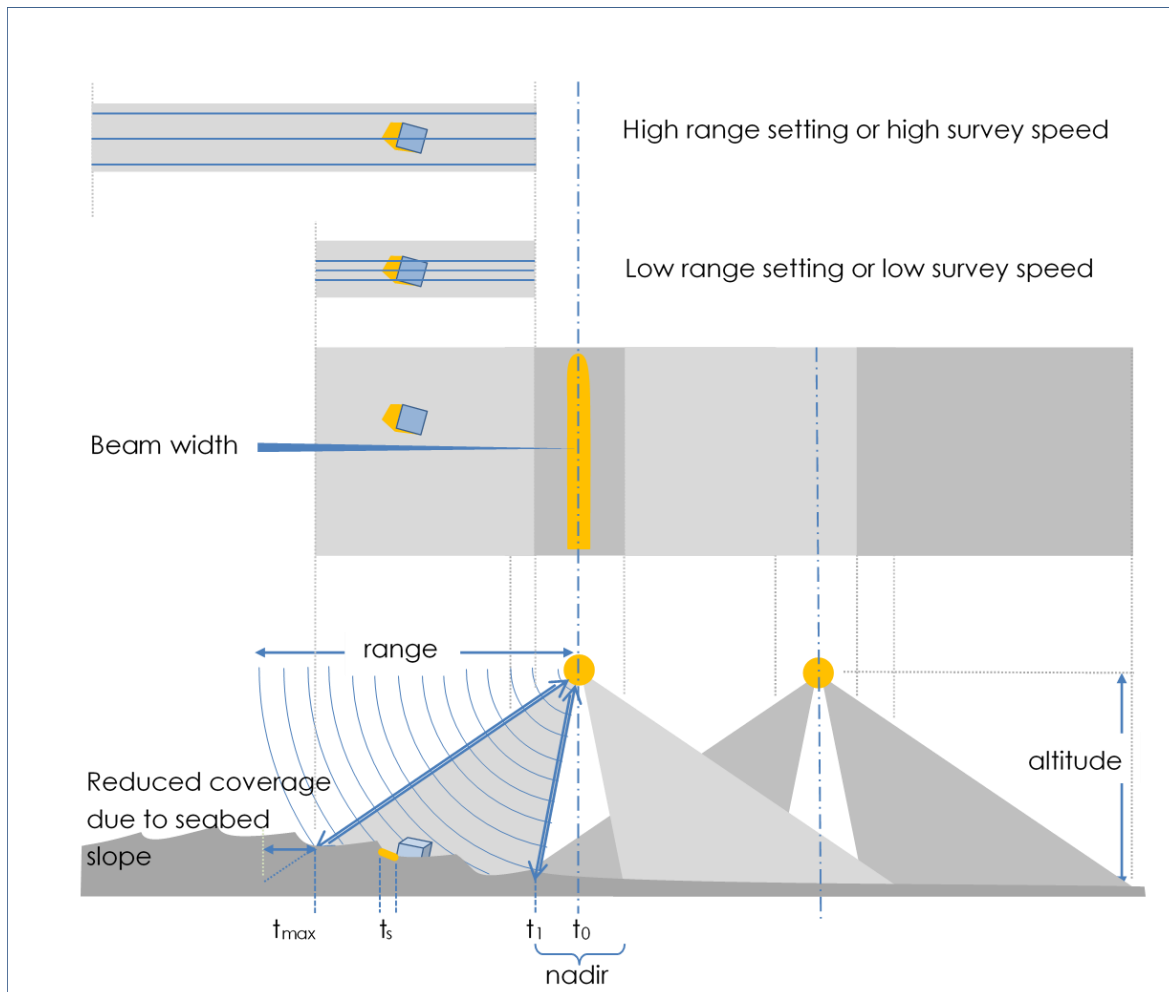


Figure 6: Schematic diagram illustrating factors influencing the configuration of a Side Scan Sonar survey

The range, altitude and frequency of the sonar pulse determine the across-track resolution of the data. Along track resolution is also influenced by the range setting, as this determines the 'record time' required to log returns from objects at the maximum range; as only one pulse should be active per record, the record time sets the pulse rate and therefore the number of pulses per metre at the towed speed of the fish. Figure 6 contains a simplified illustration of this situation, though instruments may implement multiple pulses with different ping signatures (small differences in pulse shape) to allow a greater along-track measurement rate. There is an influence on the lateral resolution by the beam width, a function of frequency, but this is likely to be secondary to the pulse rate in determining along track resolution.

Typical maximum effective range for various pulse frequencies are presented in [Table 9](#).

Table 9: Maximum effective ranges of various frequency side scan sonars (Taken from the product sheets accompanying products from Klein and Edgetech)

SSS dominant Frequency	Maximum effective range
75KHz	700-800m
100kHz	600m
120kHz	250-500m
270kHz	150-300m
410kHz	130-200m
455kHz	200m
500Khz	150m
540kHz	100-150m
850kHz	50-75m
900kHz	75m

It should be noted that these ranges are considered the maxima in ideal conditions. Edgetech state within a technical note that “Maximum range may be given to mean the ability of the operator to see the echo of a large target above the obscuring noise...The difference in the maximum range...for the same sonar may be as great as 30-50% of stated range” (Edgetech Application Note, Sidescan Sonar Range, 2007). Effective sonar range is limited by environmental and operational conditions including:

- water temperature and salinity;
- thermoclines;
- haloclines;
- water depth limiting geometry (shallow water);
- environmental conditions including, currents, tides and weather conditions.

Most of these conditions may also lead to potential uncertainty in the conversion of the SSS profile from a time to a range.

Due consideration needs to be given to all of these during the planning stage and operators will often employ some basic rules of thumb based on the configuration of the instruments such as:

- SSS should be flown at an altitude 10-15% of its range, above seabed for optimisation;
- the sweet spot for imaging objects on a single channel is between 1/3 and 2/3 of its range;
- full coverage of a site is required to ensure the nadir below an SSS track is covered from adjacent lines.

It is important to note that whilst theoretical coverage should be 100% of the survey corridor, the limiting factors outlined above can limit effective range. A good example is within the Baltic Sea where the thermocline is a known problem for effective sonar ranges. It is important that both the operator and clients’ representative are satisfied that full coverage has been achieved and to check that no infill is required before leaving the survey area.

Higher frequencies (>500khz) with the shorter ranges (<50m) give the best resolution when data is played back on PC monitors during the interpretation phase, which highlights the need for good quality widescreen monitors, linked to powerful hardware for interpretation. This interpretation relies

on accurate positioning of the SSS fish as this is generally towed at ranges of 3-5 times the water depth behind a survey vessel. Interpretation needs to be consistent with targets presented within complementary datasets, including the MBES and magnetometry data.

Key parameters and DQOs are presented in Table 10.

Table 10: Target and survey parameters for Side Scan Sonar

Scope Requirement	Measurement Parameter	Controlling Parameter	Suggested Guidance	QA metric
Smallest detectable object dimension	Across-Track Resolution	Frequency Speed of sound in water	3 samples per min. dimension	Continuous recording Sound velocity profile Sensor attitude
	Along-track resolution	Ping rate Vessel speed	3 pings per min. dimension	Continuous recording Vessel speed Sensor attitude
Vertical detectability	Acoustic shadow length	Sensor altitude Sampling rate	Vertical uncertainty < 1/3 of the smallest vertical target dimension	Sound velocity profile measurements Altimeter / USBL uncertainty
Coverage	Navigation	Instrument positioning Instrument Attitude Range Seabed Slope Sound velocity	200% coverage with no nadir gap	Navigation uncertainty Altimeter / USBL uncertainty Coverage plot

2.5.5.7 Sub-bottom profiler

A sub-bottom profiler emits an acoustic pulse into the water column, this pulse is partially transmitted into the sub-seabed and reflected from various boundaries within the geological column.

Reflections occur at boundaries in acoustic impedance, UXO items should reflect acoustic energy whether ferrous or non-ferrous as long as the spectrum of the acoustic pulse and the geometry of the SBP ray paths are suitable. Therefore, 3D SBP can represent an important resource in the location of sub-surface non-ferrous UXO.

Reflections may occur at surfaces, or at point or line discontinuities as diffractions. UXO may return only diffracted events, or a combination of surface reflection and diffraction for larger items. A 2D (linear) SBP survey delivers reflection data in a region immediately below the survey line, while a 3D SBP survey delivers a contiguous volume of data. Point diffractions may be returned from positions laterally displaced from a 2D SBP survey line; caution must be exercised in assigning precise locations to the source of such events.

The frequency of the acoustic pulse of an SBP is generally lower than that of an SSS or MBES instrument in order to penetrate the sub-seabed without excessive loss of energy to scattering and absorption, therefore ultimate resolution is generally lower than that of methods targeting only the sea floor. The highest frequency SBP acoustic sources are solid state devices found in parametric, pinger or chirp systems. These are usually classed as shallow penetration systems and are most often

deployed for surveys requiring information at high resolution to depths relevant to cable installation. These often the sources for 3D SBP systems proposed for non-ferrous UXO detection. Lower frequency sources may be used – electrostatic sparkers, boomer-type devices using electromagnetic repulsion of metal plates, and even small airgun sources. These are more often deployed where the survey is required to have greater penetration for an alternate purpose such as foundation design. Lower frequency sources tend to have lower vertical resolution, and may have lower horizontal resolution – incorporation of such data into the knowledgebase for management of UXO and boulder risk should be done with awareness of the limitations of lower resolution data.

Figure 7 illustrates the geometrical principle of a single channel, 2D SBP recording surface and diffraction events. 3D SBP systems are more complex but conceptually can be reduced to a 3D array of raypaths returning an ‘umbrella shaped’ diffraction signal. Identification of UXO is typically dependent on the ability to identify the hyperbolic pattern, so requires sufficiently small trace interval to populate the hyperbola with (say) > 10 data points.

The acoustic pulse is generated at intervals along the survey line $S_1 - S_5$, reflects at boundary at A and returns along a similar raypath to a receiver normally close to the source. Reflections from subhorizontal layers would have a sub-vertical raypath. Diffracted rays can be significantly non-vertical – the ray paths associated with shots $S_1 - S_5$ indicate the group of rays reflecting from a diffracting target. As the raypaths of the non-vertical rays are longer, their reflections return to the receiver at later times at greater offset from the target, resulting in the hyperbolic signature along-track illustrated in Figure 7. Note that a diffraction can be recorded from a target laterally offset from the seismic line, whereas a surface reflection can only appear from a reflecting point if the surface is dipping laterally.

Diffracted events are the primary indication of smaller boulder or UXO targets on SBP data. Differentiation between diffractions from UXO and boulders is unlikely to be made from smaller contacts as resolution is not generally sufficient, but for larger targets spanning several traces *some* indication of the dimensions of a target may be derived from reflection events in migrated 3D SBP data. As illustrated in Figure 7, location of these targets on 2D SBP sections is reasonably accurate in the along track direction, but uncertainty in the across-track direction is of the order of the width of the diffraction hyperbola observed on the section. Diffracting bodies further than the half-width of a hyperbola from the line are unlikely to return an interpretable image. A diffraction on a 3D SBP survey is a dome shape, so a key benefit of a well-parameterised 3D SBP survey is the ability to detect and locate sub-seabed point diffractors without the across-track uncertainty of the 2D method.

The line spacing that would be required to create ‘full coverage’ for detection of UXO or boulders using 2D SBP would be very small and is generally considered uneconomic. 3D SBP at a useful resolution for UXO detection is also relatively expensive and generally implemented as a very focussed survey.

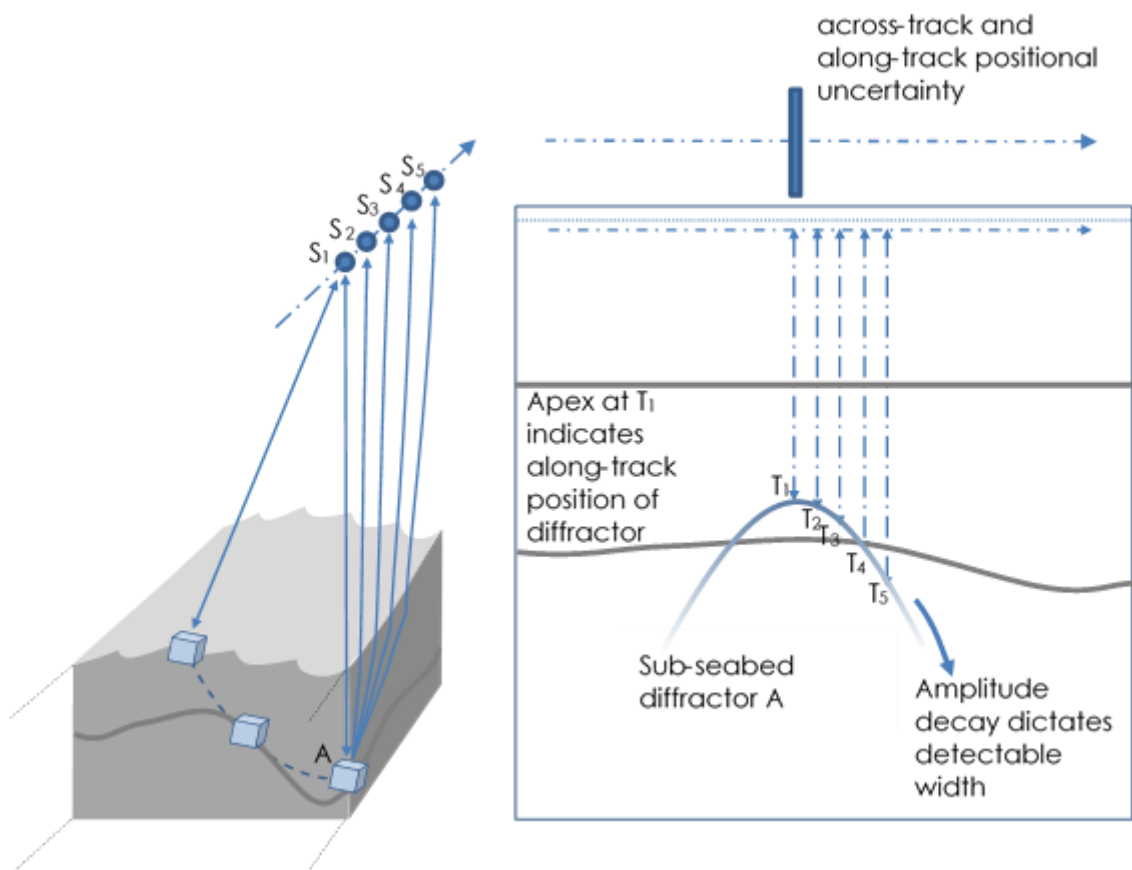


Figure 7: Schematic illustration of the configuration of diffracted events on Sub-Bottom Profiler measurements.

SBP is often the only means of imaging beneath the sea bed. Geological interpretation of the SBP data is also a useful tool to establish context within which UXO may be located – e.g. particular layers, or infilled channels, possibly contributing to the evaluation of the impact of a detonation. Thus, SBP is one of the measurements that is likely to contribute to risk management associated with boulders, UXO, engineering considerations and seabed mobility. Care is recommended to assure that the parameterisation of SBP investigation is suitable for the purpose for which it was commissioned, and any compromises are worked through and accepted before survey work starts.

Successful recording and interpretation of reflected energy from subsurface bodies is dependent on a number of factors. Source power and frequency, together with the material properties of the sub-seabed medium are the primary controls on the distance an acoustic pulse will travel. Source spacing determines the number of traces contributing to a diffraction hyperbola. The bandwidth of the acoustic source is significant – higher bandwidths allow the creation of a sharper pulse either at the source, or after processing in the case of a CHIRP type device. Weather conditions, particularly the degree of aeration of the water around the instrumentation can represent a limiting factor. Some representative source characteristics are provided in Table 11.

Table 11: Typical operating characteristics for common 2D sub-bottom profiling instruments

Sub-Bottom Profiler	Typical Frequency (Hz)	Resolution and Penetration	Comment
Parametric	4000-15,000	Resolve layers $\leq 10\text{cm}$ typical penetration 5-20m	Good for imaging soils, highly directed beam may not return extensive diffraction
Pinger	2000-7000	Resolve layers $\leq 20\text{cm}$, typical penetration of 5-10m	Ideal for imaging soils structure within DoB of a cable.
Chirp	1000-8000	Resolve layers $\leq 15\text{cm}$, typical penetration of 5-20m	Similar to pinger with greater range of resolution and penetration
Sparker	50-4000K	Resolve layers $\leq 0.5\text{m}$, single channel up to 50m+, multichannel 300m+	Extensive range of sparkers within the industry, ideal for foundation design studies, data can be used for inter array cable installation, not ideal for route surveys as resolution with top 1m below seabed is often compromised.
Boomer	300-3000	≤ 0.3 resolution up to 50m+	A good second tool to consider for Cable route surveys

Data processing of single-channel SBP data are fairly straight forward, as with all acoustic techniques the recording of the reflected pulse at a time after the transmission is the primary data. This has to be corrected for geometric factors and converted to a range (depth) using a representation of the speed of sound in the water and geological components of the raypath.

As co-location of identified targets on SBP, SSS, MBES and magnetometry data is critical to the avoidance of excessive inspection costs, instrument positioning and recording of navigation data are critical. SBP data should be corrected for vertical offset due to tide and platform heave.

SBP data may be acquired as a multi-channel survey which involves recording reflected signals from a source into multiple receivers. These may be towed in line, or nearly in line with the seismic source as a '2D' survey, or distributed as an array both in-line and across the track of the survey as a '3D' survey. The primary benefit of a 2D multi-channel SBP is the improvement in signal-to-noise ratio particularly at depth. However, it is also possible, with appropriate geometry, to configure a multi-channel survey to deliver closer trace spacing than the shot spacing, and therefore potentially improve the resolution of diffraction hyperbolae.

If the perceived risk from poorly located buried obstructions and pUXO remains above what can be considered acceptable by the project then the possibility of a separate, targeted 3D SBP campaign could be included. The logistical requirements, cost and time for this is likely to be significantly higher per square metre than 2D SBP survey.

3D SBP methods may be deployed by ROV or deployed at the surface, and use a variety of methods to create a volume map of the subsurface. Various combinations of physical sensor array, beamforming and synthetic aperture techniques may be implemented in an attempt to measure as large a volume per instrument pass as possible. All are characterised by a dependence on the sound velocity profile

in water and the sub-seafloor for successful data processing and location of objects. Precise location of the source and sensor components of the survey is also critical.

Both beamforming and synthetic aperture techniques are susceptible to the introduction of noise through positioning and velocity errors. The methods of processing are under continuous, relatively rapid development, so a cautious approach is advised with carefully specified DQOs. Careful processing and a focus on optimising signal to noise is appropriate, though it is important to recognise that these operations do not necessarily lend themselves well to rapid delivery of results. However, the potential value of a well-executed 3D SBP survey is significant in the precise location and delineation of subsurface objects, potentially covering the entire plausible range of depths of interest for cable installation.

Specialist contractors tend to provide the 3D SBP data of interest to UXO Risk mitigation. There are relatively few of them, and relatively few geophysical consultants and offshore client representatives that can support the survey from an experienced and informed position.

Most 3D SBP implementations require reasonably good understanding of the principles of operation of the equipment to define a robust survey plan and set of QA metrics. However, it is likely that instrument positioning, source spectra and seismic velocity will be common to all.

Key operating parameters and possible DQOs are provided in Table 12.

Table 12: Target and survey parameters for Sub Bottom Profiling

Scope Requirement	Measurement Parameter	Controlling Parameter	Suggested Guidance	QA metric
Smallest object to be detected	Measurable reflection	Seismic source bandwidth Seismic wavelet	Wavelength <~ 4 x smallest required depth resolution	EVT Source power monitor
	Trace spacing	Shot and receiver spacing	10 traces per diffraction width	Trace spacing profile Fold plot
Maximum depth of investigation	Maximum depth of coherent reflection	Seismic source power Seismic source bandwidth Signal to noise ratio Weather and sea conditions Subsurface conditions	Signal to noise ratio > 3	Seismic sections

2.5.5.8 Electromagnetic methods

So-called electromagnetic (EM) systems are designed to detect anomalous electrical conductivity relative to the 'background' properties of the water and seabed material. UXO containing metallic material, ferrous or non-ferrous, represents anomalous conductivity. Therefore, electromagnetic methods may represent a method of detection and location of non-ferrous UXO.

Electromagnetic systems generally operate in some variant of a method in which a coil mounted on an instrument platform is energised with electrical current setting up a magnetic field illustrated schematically in Figure 8. The electric current in the coil, and therefore the magnetic field, are time variant. A conductive body, such as a metallic target within the field of influence of the magnetic field, will be energised with eddy currents in response to the time variant magnetic field, and the variation of these eddy currents distorts the time variation of the magnetic field relative to its behaviour in the absence of an anomalous conductive body. This in turn influences the behaviour of the electric current in the sensing coil of instrument, which is measured as a difference between the undistorted and distorted current profile. These measurements may be made in a variety of ways (in the time or frequency domain), often refined using proprietary methods specific to instrument manufacturers and/or contractors.

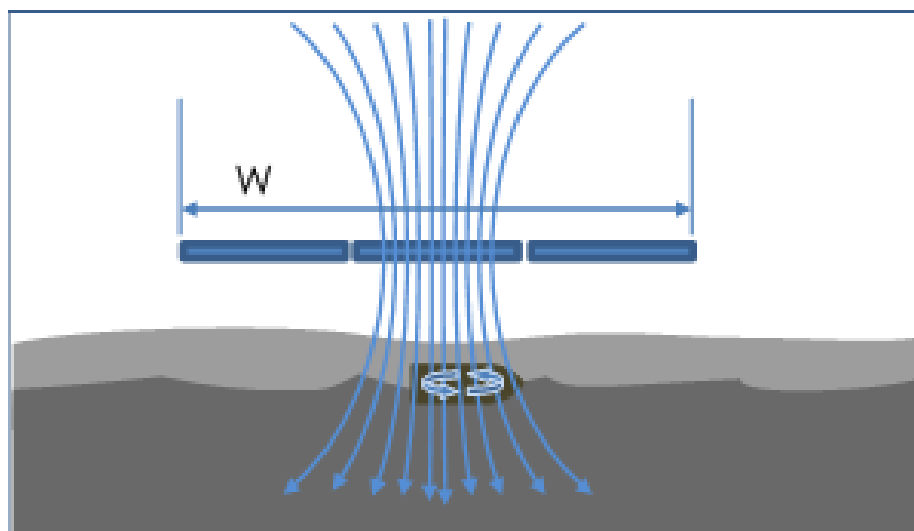


Figure 8: Schematic illustration of the pattern of magnetic field induced by current in the central coil of a 3 coil EM configuration. Eddy currents in a conductive target are shown.

The configuration of the coils varies between systems, they can be co-located or separated, overlapped, or oriented on varying axes to tune systems towards target configurations.

Electromagnetic (EM) systems may detect all types of conductive materials.

On land these systems are used for the detection of ferrous and non-ferrous ordnance. However, in seawater the presence of conductive seawater surrounding the transmitter and receiver coils can substantially reduce the effectiveness of the system.

By mounting the coils on an ROV and keeping them very close (maximum 1.0m) to the seabed, systems can detect pipes and large UXO to burial depths of ~ 2.0m. The width of the array of coils on a typical instrument is of the order of 3 m, this will be closely related to the line spacing required to deliver continuous coverage of the subsurface.

The time variant electric field is driven with a controllable cycle rate typically of the order of 1-4 Hz. This rate, coupled with the rate of progress of the instrument platform, determines the number of tests per metre made by the system. A number of 'positive' responses on a target to classify it as a

real anomaly should be established as a detection threshold, and this number used to establish the survey design. These values and typical UXO dimensions suggest that the pace of an ROV supported EM investigation for UXO is likely to be of the order of 1 m/s for a ~3 m swath.

EM equipment can be tuned to specific target properties and used for more accurate determination of the depth to target. Configuration may be established either from a database of target responses or by testing against a known object. It is recommended that in this case verification is sought and documented to confirm the parameterisation and performance of the search in the context of the seawater and ground properties, and the ROV configuration at the work site.

The effect of the conductive seawater and the conductive elements of the ROV must be compensated in the analysis stage of the data workflow. The compensation processes and the evidence of their performance should be part of the mobilisation test and a verification of performance at the work site should be made at appropriate intervals. Changes in conditions that may affect compensation e.g. changes in salinity, presence of conductive bodies, changes in configuration of the ROV or movement of manipulators should be identified and compensation performance either verified or re-parameterised performed should those conditions be experienced.

Some key survey parameters and possible DQOs are provided in Table 13.

Table 13: Target and survey parameters for electro-magnetic surveying

Scope Requirement	Measurement Parameter	Controlling Parameter	Suggested Guidance	QA metric
Smallest detectable conductive body	Instrument sensitivity	Seawater compensations Background compensations Signal to noise ratio	Instrument specific compensation parameterisation Min. SNR of 3	Compensation verifications EVT in representative conditions
	Spatial sample interval	Cycle rate Platform speed	At least 9 readings within the area of smallest conductive anomaly	EVT in representative conditions
Target positioning		Platform positioning Cycle rate Platform speed		Platform positional uncertainty Platform speed profile
Coverage		Platform positioning	>100% coverage	Platform track plot or swath plot

2.5.5.9 Survey design

The required target specification outputs are used with the controlling parameters in sections 2.5.5.4 to 2.5.5.8 to provide the survey design boundary conditions to be implemented.

Key parameters are the required instrument sensitivity, the required measurement density (e.g. line spacing) for each measurement type, vessel speed limits (normally a maximum but with towed equipment a minimum speed is also important to maintain control) and the survey boundary required. Note that the use of different survey platforms (surface vessel, ROTV, ROV, AUV) with different drafts and weather tolerances may have a strong influence on line plans and operational considerations.

The survey boundary may be restricted to the engineering corridor illustrated in Figure 9, to minimise cost. This highlights the need for diligent version control to ensure that all changes in the engineering corridor are applied to the geophysical survey design.

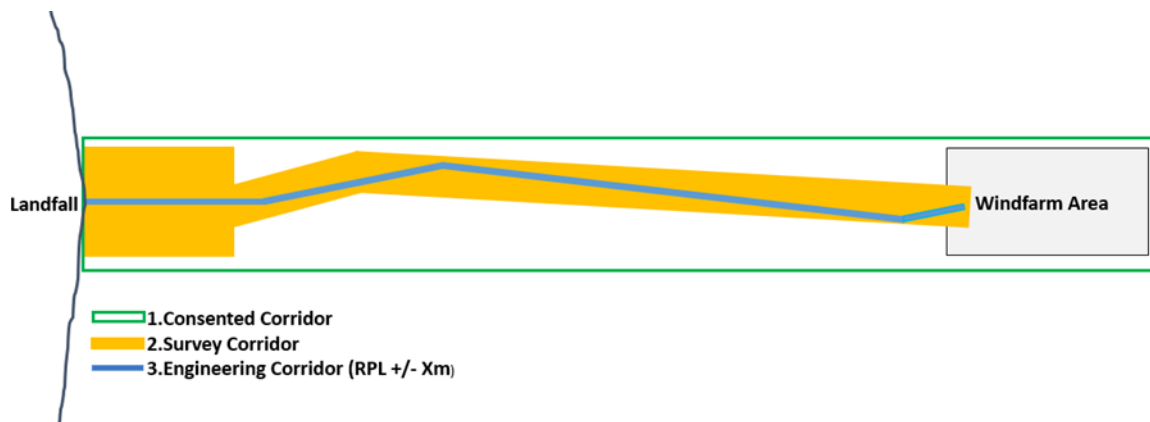


Figure 9: Survey boundaries

As UXO risk management is potentially regulated by statute and common law, it is anticipated that survey work to acquire data for systematic UXO risk mitigation will take priority in the design over that for additional objectives only influencing project risk. However, it is likely that multiple objectives will be included in survey design, and compromises to survey performance as a result should be evaluated objectively.

2.5.5.10 Notes on the selection of line spacing

Once a survey boundary has been defined it is important to ensure appropriate coverage of the corridor for all of the required data products. Different instruments and methods have different measurement spacing requirements; the instrument with the shortest effective range should be the primary control on planning line spacing. These can change, influenced by instrument altitude, water depth and other environmental conditions. Particular consideration for the range of each measurement type is presented in the subsections 2.5.5.4 - 2.5.5.8, summarised in Table 14.

For the purposes of cost-effective line running, normally line plans run parallel to the survey corridor, with orthogonal 'tie' lines to enable compensation and QA of time-variant shifts (e.g. tide, solar magnetic field). However, there are circumstances in which this may compromise survey quality or be extremely inefficient, in which case an evaluation of the impact of the compromise versus the cost of a less logistically efficient line plan must be made. If currents/tides, seabed morphology, magnetometry requirements or other operational requirements mean a different line orientation needs to be considered, this decision should be made between survey contractor, onshore client personnel and offshore client representative.

Table 14: Common line spacing specifications

Instrument	Line spacing	Comment
Magnetometer Gradiometer	<1/5 of the smallest expected anomaly half width	Defined by magnetometer performance, altitude above seabed and commonplace definition of smallest threat item.
EM	Dependent on the instrument coil configuration	Defined by the width of the set of EM coils or the effective swath width of the instrument. Specifying overlap requirements and/or multi-directional passes over a potential target may be required.
MBES	Dependent on the configuration of the instrument and its altitude above the seabed	Defined by the outcome of the findings from Phase 1
SSS	Defined by frequency and range required to achieve full coverage and sufficient resolution	Also defined by Phase 1, Need to ensure full coverage under nadir of adjacent lines
SBP	Either 3D, or if 2D defined by engineering requirements. Should be able to delineate boundaries of geological features within the corridor	Delivers indicative imagery along the navigation track If geological inference is used to predict structurally controlled hazard accumulations or variation in consequence, line spacing must sample the structure in question

At this point a review of the ALR for each potential hazard could be made, particularly where the measurements intended to support mitigation of the hazard are the drivers of survey cost.

Once a coherent set of design parameters and a survey configuration has been established, a scope of work can be created from which to manage the procurement and implementation of survey work. It is important that careful version control of the scope of work is maintained – any updates to the alignment or boundaries of the survey area must be clearly communicated to assure effective transmission to the survey team.

2.5.5.11 Skillset required

It is recommended that geophysical survey experts lead the development of the survey scope, involving UXO risk management experts, representatives of other stakeholders (e.g. archaeology, ecology, environment), and cable installation experts to discuss and agree the final survey parameters. The geophysical experts can inform the key stakeholders of the impact of changes and compromises, and the key stakeholders can most readily judge the appropriacy of the ALR definitions in use and any changes to them that are proposed.

2.5.6 Procurement

Survey fees are generally controlled by a day-rate or a per-kilometre rate, with modulation by the ratio of 'productive' km to unproductive km (e.g. line turns), the number of sensors logging data, risk of downtime due to weather, competing operations, tide or other limiting influences. Contractors and clients may elect to agree commercial terms on a remeasurable, fixed fee or hybrid basis.

The following components should be concluded in a proposal for geophysical work:

- scope of work:
 - survey design;
 - equipment;
 - personnel;
 - vessel and instrument platform;
 - deliverables list;
 - reporting requirements;
- required timing;
- quality management requirements:
 - navigation acceptance criteria;
 - positioning data acceptance criteria;
 - geophysical data acceptance criteria;
 - weather acceptance criteria;
- safety requirements;
- environmental requirements;
- communication and meeting requirements.

2.5.6.1 Skillset required

Commercially skilled personnel should manage the procurement process with the close assistance of geophysical and UXO risk management experts to ensure that modifications to the requirements do not unacceptably compromise the objectives of the work. It may be beneficial to recognise that data acquisition, processing and interpretation may be different specialisms requiring the involvement of additional personnel, particularly for innovative methods, demanding applications or otherwise unusual circumstances.

2.5.7 Start-up

2.5.7.1 Project documentation

It is considered best practice to create and work from a set of Project Documentation that should include a Project Implementation Plan, a Safety Plan, Quality Plan and Environment Plan. These documents are the translation of the survey objectives defined by the scope of work into the operational practice of the contractor selected to perform the work. They are the working guidance for contractor personnel and the CR, and as such are critically important to the operation of the survey.

The data objectives defined by Phases 1-3, together with the survey design parameters and the DQOs chosen should be presented together in the Project Documentation to provide a concise and coherent guide to the required parameters of the geophysical survey programme.

Preferred structure and content of the project documentation will vary between contractors and clients and it may be advantageous to construct bridging documents to map between critical elements of operational documentation (particularly emergency response plans and safety plans).

Production data acquisition should in every case be preceded by documented approval by the client of project documentation, mobilisation, and the equipment verification tests (EVT).

Any deviation from the agreed plans should be agreed by the client, by a specified process either directly or via the CR, and it is recommended that every deviation is evaluated specifically for its

potential impacts (neutral, positive and negative) on the project objectives and performance requirements.

Project documentation should include details of all progress reporting requirements and DQOs including templates and schedules as appropriate.

2.5.7.2 Mobilisation

As field operations start a systematic set of checks are required to enable validation of the survey outputs as suitable for inclusion in UXO risk management activity. Geophysical surveys generally include mobilization and calibration operations, confirming and documenting the vessel configuration, calibrations and operational state of its instrumentation. UXO work demands a higher standard of validation, normally including an Equipment Verification Test (EVT) designed to observe and document the performance of the detection equipment in its full survey configuration and to provide cross-validation of the sensing and positioning performance of multiple geophysical instruments in sensing a single target object. In some cases, an additional Surrogate Item Test (SIT) is appropriate, defined here to be operations using a known object to optimise the survey parameters for a target. While EVTs are expected for UXO surveys, SITs are not regarded as a requirement for all surveys and should be implemented with care where the characteristics of a survey make such a test beneficial. SITs are not described in this guidance as they are both survey and instrument dependent, the method, deliverables and QA of a SIT should therefore be agreed by the client, their UXO specialist, offshore client Representative (CR) and geophysical expert prior to the test. Conclusions based on EVT and SIT must be logically robust – both tests can only confirm performance in the test itself and cannot unequivocally guarantee detection of a different target elsewhere.

2.5.7.3 Testing and calibration

Prior to departure for production work, Equipment Verifications Tests (EVT) or Surrogate Item Tests (SIT) a survey vessel must be configured according to the commitments made in the scoping and procurement phases. This configuration must be tested and validated as acceptable by the client (usually a client representative) including validation of:

- navigation systems and co-ordinate reference system;
- instrument positioning equipment;
- geophysical equipment;
- survey systems;
- operating procedures;
- survey planning;
- communications and reporting procedures;
- safety management systems;
- Emergency Response Plan.

Mobilisation and calibrations are reported quickly and signed off by the CR. It is recommended that the CR should work to an agreed checklist to ensure that all required validations are included.

2.5.7.4 Equipment Verification Test (EVT)

Prior to performing the contracted UXO-specified geophysical survey an Equipment Verification Test (EVT) should be undertaken by the geophysical survey contractor. This task should be performed once the mobilisation and calibration of the survey equipment has been accepted by the Client. The necessary assessments and calibrations must be performed according to the manufacturer's specifications or generally accepted procedures.

The intention is to fulfil the following objectives:

1. Document the capabilities and limitations of each geophysical detection instrument selected for UXO risk mitigation including positioning.
2. Observe each geophysical detection instrument operating in the contractor's configuration, using the Survey Contractor's personnel and methodologies. This should include ensuring noise levels are within acceptable limits.
3. Evaluate the Survey Contractor's data acquisition, data transfer quality, and data QC method.
4. Evaluate the Survey Contractor's method of data analysis and evaluation.
5. Illustrate how predictive responses and how the equipment performs in accordance with a known discrete item on the seabed.

Ultimately the intention is to provide evidence that the configuration deployed meets the criteria needed for the UXO risk management strategy.

It may be suggested that an EVT may be extended to evaluate a linekeeping tolerance either laterally (survey line deviations) or vertically (altitude deviations). However, care must be taken to recognise that the test item may not properly represent the smallest target to be detected. Similarly, the use of EVT items to evaluate the performance of depth-detection processes should be treated carefully. The UXO specialist should be consulted to approve the use of such test data in this context.

2.5.7.5 Important considerations

Through the evolution of offshore geophysical UXO survey and data analysis, several key lessons have been learned that should be acknowledged:

1. There are rarely occasions when an EVT shall not be performed ahead of a UXO-geophysical survey. An EVT shall be performed if faulty equipment has been highlighted and new instruments introduced.
2. No interpretive parameters or discriminatory data shall be derived from the test, the sample set and positional control is insufficient to rely upon.
3. The guidance provided by CIRIA has now been superseded through the real-world experience. It is not recommended that this specific section within the CIRIA guidance is referred to.
4. It should be recognised that pursuit of an optimised data acquisition and data processing parameterisation for a test object, or tuning of a system to detect marginal responses, can lead to significant uncertainty in the timing of survey work. This is not within the current understanding of the ALARP principle.
5. Substitutions or alterations to the EVT plan may need to be considered if, for example, the Survey Contractor can demonstrate suitable tests that fulfil the verification objectives. Such changes or exceptions to this specification shall be clearly described and presented to the Client.

2.5.7.6 EVT planning

The EVT methodology should be included in the survey contractor's project documentation (e.g. the Project Implementation Plan). This should be approved by both the Client and their specialist Consultants.

As a minimum, the following aspects should be covered:

- description of the test item;
- launch and recovery of the test item;
- location reconnaissance to locate a magnetically “clean” and relatively featureless area of seabed for the EVT;
- deployment location of test;
- line planning;
- reporting and data outputs.

The selection of the test item makes up the first stage of the EVT process. The item should not necessarily aim to accurately replicate a specific item of UXO, but instead provide a repeatable and meaningful test for the survey array to ensure all sensors and positional systems are functioning as designed.

For this, typically a tubular section of rolled steel of a size and mass of ferrous material representative of the smallest target required, with appropriate lifting eyes, is sufficient, although alternative items would be considered subject to the approval of the UXO specialist responsible for sign-off. Should an existing item be available with suitable properties, it is acceptable to use such an item over the fabrication of a new item.

2.5.7.7 EVT data acquisition

The EVT should aim to replicate survey activity contracted by the Client, therefore all sensors which are to be run in the full survey should be utilised and recorded. The test should take place close to or on the location of the Project to ensure conditions during the test are as representative of the full survey as possible.

The EVT should be witnessed by the Client’s offshore representative.

Rarely there is the need for a UXO specialist to be offshore during the EVT, but this may speed up acceptance of the data. Typically, the geophysical survey contractor proceeds to live data acquisition once they are satisfied with the EVT data. However, this is at their risk pending formal acceptance onshore.

2.5.7.8 EVT deliverables - report

Following the undertaking of the EVT, a full report should be issued to the Client and then made available to their specialist consultants for review and acceptance. This report should include:

- EVT item description and images;
- brief methodology synopsis;
- imagery of MBES, annotated with EVT item highlighted;
- imagery of MBES with all targets from all datasets plotted;
- imagery of SSS, annotated with measured dimensions of targets;
- imagery of MAG and/ or EM (all runs) with MBES target plotted;
- target details from all datasets: MBES (easting, northing), SSS (easting, northing, length, width, height), MAG and /or EM (easting, nothing, altitude, residual peak to peak nT);
- positioning comparison table;
- positioning comparison table using MBES position as test item’s true location in relation to SSS and MAG and/or EM targets.

2.5.7.9 EVT deliverables - datasets

As a minimum a data package equivalent to the example in Table 15 shall be presented alongside the EVT report. This example is written for a survey conducted using magnetometry, using files associated with the software package Geosoft's application Oasis Montaj as a delivery medium. The content of the data package for EVT shall be agreed as part of the project documentation, prior to commencement of the test. Deliverables may be adjusted to suit the measurement technology and software package in use. These data are usually transferred via electronic file transfer.

Table 15: Example EVT deliverables

EVT Data Requirements	Description	Format/extension
Magnetometer	Oasis Montaj Project (containing the following presented in a data linked Map)	-
	Oasis Montaj Database (with processing and QC channels remaining)	.gdb
	Total field Residual Grid	.grd/.flt
	Analytical Signal Grid	.grd/.flt
	Altitude Grid	.grd/.flt
	Target List including; Unique Target ID, Easting, Northing, Residual Field (nT) Peak to Peak Value, Analytical Signal, Sensor Altitude (m), Wavelength (m)	.shp/.csv
Magnetometer	Sensor track plot	.shp
Side Scan Sonar	Georeferenced Mosaic	.tif
	Target List including; Unique Target ID, Easting, Northing, Length (m), Width (m), Height (m), Interpretation/description, Confidence Rating	.shp/.csv
Multibeam Echosounder (MBES)	Georeferenced MBES Grid (0.25m)	.tif

2.5.7.10 EVT validation and formal acceptance

On review of the necessary information a competent organisation should issue a document clearly stating that the EVT has been successful and the data can be relied upon for UXO risk management purposes. This shall be issued within 48hrs of the data and report being available.

2.5.7.11 Skillset required

EVT design, implementation and QA is an important part of the validation process of a survey to be used in UXO risk management and as such should be performed by personnel with demonstrable and documented skill in the use of the geophysical systems deployed and UXO risk management. As the EVT is required to be formally accepted, personnel making this acceptance are required to be formally

competent. Ideally the UXO specialist contracted to provide the final interpretation should be involved.

2.5.8 Production data acquisition

Data acquisition should progress with the involvement of an offshore client representative (CR) who is effectively briefed on the motivation for the survey work and the reasoning behind the scope of each element. The documentation generated in previous sections will allow the offshore CR to understand the survey well and make rapid operational decisions coherently with the survey objectives.

2.5.8.1 Data acquisition

Geophysical data acquisition requires the co-operation of marine personnel, engineering personnel and geophysical personnel to maintain a robust and safe survey performance. Operations may be undertaken from smaller day craft to large vessels capable of supporting 24hr working for long campaigns. Teams and equipment configuration may be well established, or assembled temporarily for the survey.

Use of effective Project Documentation as a working manual for the production data acquisition is key to a predictably run campaign particularly for an unfamiliar configuration.

2.5.8.2 Quality management

Data quality management during survey acquisition should be focussed on assuring that the data are acquired such that they satisfy the QA criteria (DQOs) set during the project scoping and setup phases. A high priority should be assigned to the assurance that data are recorded and secured at an early 'raw' stage, such that any mistakes in handling or processing data (offshore or onshore) can be recovered.

'Fitness-for-purpose' is not a useful phrase in this context as contractors are unlikely to assume the liability of promising this. CRs, though generally selected to be experienced and can be well briefed, may be too 'temporary' in the project to take responsibility for evaluating fitness-for-purpose as well. Therefore, a set of objective quality metrics (DQOs) is recommended as the basis for unequivocal data evaluation. The quality metrics should be established from the key parameters for each survey methods, agreed between client, CR and contractor, and tolerances and thresholds documented before production acquisition begins.

The CR should provide confirmation that the objective quality metrics are being adequately monitored and met, that operations are safe, that downtime is properly justified and recorded and that the client's objectives for the survey are being reasonably met.

2.5.8.3 Skillset required

Data acquisition required diverse skillsets:

- marine skills to operate and maintain the survey vessel;
- marine skills to sail the survey vessels within the linekeeping tolerance;
- logistics skills to ensure that equipment, supplies and personnel are organised;
- engineering skills to deploy and operate the geophysical equipment;
- geophysical skills to record, process, perform QA operations on geophysical data;
- QA skills including client representation to assure project quality;
- reporting skills to produce and deliver outputs.

2.5.9 Data processing

Data processing is defined here as operations performed on survey data to transform raw information into properly located geoscientific data with optimised signal to noise ratio. Data processing generally does not involve 'interpretive' decisions (e.g. processes designed to emphasise an interpreted characteristic of data) although there are unavoidable exceptions to this that should be carefully managed (e.g. the development and implementation of a velocity field for time-to-depth conversion).

Each of the geophysical methods has its own data processing requirements, with the common factor being the integration of the measurement with the positioning data. It is recommended that a record of navigation data from GNSS systems, and any data from inertial navigation systems used to interpolate GNSS point fixes is kept in addition to integrated geophysical and navigational data records.

Data processing operations and QA processes, including all required DQOs, are recommended to be included at an appropriate level of detail in the Project Documentation to maintain focus on the survey outcome.

2.5.9.1 Digital seabed model

Processing of MBES and SSS data contributing to the digital seabed model should follow well established hydrographic principles. In general, the bathymetry dataset is expected to represent the primary reference for positioning of objects, with the SSS data used for identification of objects. Hydrographic standards set by the IHO do not include quantitative specification of MBES or SSS data density for objects of characteristic dimensions of UXO; it is recommended that survey-specific thresholds and QA tolerances are established to augment the guidance and QA standards set by the IHO.

2.5.9.2 Magnetometry and EM

Processing of magnetic field and EM data can be described in phases:

- import of raw data and attachment of positioning information;
- data cleaning – removal of instrument noise, natural noise, vessel induced noise;
- levelling, gridding, calculation of gradients and derived products;
- separation of regional (long wavelength) and residual field (short wavelength);
- identification of anomalies potentially representing UXO.

These operations can be applied in various data processing packages, offshore or onshore, using parameterisation defined using objective criteria for optimisation. QA products for data processing operations could include:

- verification of positioning and coverage;
- inspection of noise removed for indication of removal of potential signal;
- difference plots between grid and levelled point values;
- gradients, 4th difference and other error indication maps from grids;
- inspection of regional field for possible remainder of residual signal;
- inspection of final data vs. raw profiles for verification of the preservation of signal wavelength and amplitudes.

It is recommended that a set of QA products is agreed between client, UXO specialist and contractor(s) prior to the commencement of data processing activity.

It is recommended that consideration is made for the necessity for real-time or near-real-time results from geophysical surveys. If real-time processed data is not required, it *may* reduce project risk and improve quality to allow a more measured approach to be adopted with some delay before delivery of data. However, it is important to ensure that resources are available for such activity for as long as is necessary post-mission to complete work with uniform quality, and that reporting deadlines are compatible with a processing delay.

2.5.9.3 Sub-bottom profiler

Data processing of sub-bottom profiler data can be described in phases:

- import of raw data and attachment of positioning information;
- data cleaning;
- amplitude compensation;
- datum reduction;
- signature processing;
- imaging (stack, migration).

Within these generic categories there may be wide variation in process content and order between instrument types, particularly between single- and multi-channel configurations, 2D and 3D configurations, and the different sources implemented pingers, chirps, parametric and sparker devices, boomers or airguns. Quality management should be survey specific, but may include:

- verification of positioning and coverage;
- inspection of noise reduction processes to verify the integrity of signal;
- confirmation of datum reduction quality including depth reference;
- confirmation of polarity, phase and stability of the wavelet;
- evaluation of consistency of spectra, signal-to-noise ratio and amplitude;
- confirm consistency of depth converted SBP data and bathymetry;
- confirm the integrity of the output files including key header information.

Multi-channel and 3D surveys involve more complex data processing sequences, with dependence on skilful parameterisation to optimize performance. There is greater emphasis on imaging processes that present features on the sub-surface data volume closer to their actual position, and these processes are often critically dependent on the use of an appropriate seismic velocity field.

Careful determination and QA of the velocity field should be a feature of all surveys based on multi-channel, 3D or imaging principles. In the context of cable installation, the limited range of depth often leads to the use of a simple velocity model. For some circumstances, this is reasonable. However, this should be confirmed explicitly, as there are situations in which rapid lateral and vertical velocity variation can introduce errors. Velocities for 3D SBP surveys are potentially significant particularly where beamforming and synthetic aperture techniques are applied. In these cases, the velocity profile in the water column is also important. It is recommended that sensitivity tests are made for 3D SBP surveys, and appropriate velocity QA metrics adopted and parameterized to suit the method and configuration in use.

2.5.9.4 Quality Management

It is recommended that a skilled geophysicist be assigned to oversee the various data processing operations and to specify, inspect and document an appropriate array of data processing QA operations and products. Data processing QA should include systematic documentation and verification of parameters that influence the output. The fundamental principle that processes designed to reduce noise should minimally impact the desired signal are valid and provide a basis for

systematic optimization of the data processing operations and provide simple, objective quality assurance measures.

Data processing can be performed offshore or onshore, with more complex, time consuming or technically demanding operations possibly taking place onshore. This must involve transmission of data to an onshore facility. It is important to establish a set of offshore processes that will provide assurance that data are of sufficient quality to be processed successfully onshore to avoid delays to demobilisation.

2.5.9.5 Skillset required

It is recommended that personnel with geophysical and hydrographic skillsets are assigned to perform data processing and to provide QA in this context. It is recommended that UXO risk management experts are involved as required to ensure that the QA of the data is sufficient to qualify the data for use in UXO risk management.

Many of the more commonplace geophysical systems have well established workflows and software in place to process data and these could be used successfully by relatively inexperienced personnel. While this is clearly an advantage, it is also important to ensure that personnel with less experience are supported by experts to mitigate the propagation of errors.

Geophysical methods that are less commonplace – 3D sub-bottom profilers, EM and magnetic gradient systems may have less developed workflows and support software and particular care should be provided here to ensure that sufficient personnel are available with the appropriate skills in both the application of data processing (contractors) and assurance of its quality (client).

2.5.10 Interpretation

It is likely that individual UXO specialists, cable installation specialists and developers may have a variety of preferences for interpreted data dependent upon experience, position of the survey in the project timeline and other factors.

Initial Interpretation for potential UXO outputs contacts lists with components including:

- unique index number;
- co-ordinates;
- seabed elevation at contact;
- anomaly characteristics – length, width, amplitude(s);
- comments;
- possible association with contact indices of other measurements.

Possible UXO contacts in magnetometry and EM mapping should be identified using objective criteria – thresholds for signal amplitude for a given spatial wavelength are commonly applied. These thresholds are established using the information extracted from the Risk Analysis where ALR and the smallest signal to be detected was defined. Where survey design and data acquisition has resulted in a complete coverage of the area of interest, objective criteria should return the comprehensive set of contacts with signals within the array of potential targets, with few, if any, potential contacts missed. Contacts lists from the magnetometry survey should be assembled with unique indices for each.

SSS interpretation is required as an independent activity, generating another contacts list. SSS contacts are likely to include non-ferrous objects on the seabed. However, at this stage it is not recommended that any filtering or classification of contacts according to a perceived likelihood of UXO status be performed at this stage.

MBES interpretation may be undertaken. However, resolution is unlikely to be sufficient to identify or discriminate UXO independently. The MBES data do represent a good source of positional information

if a magnetic and/or SSS contact can be confidently related to an MBES feature, and in this situation it is recommended that position from MBES is used as the primary position reference.

The set of measurements may contain noise that triggers the thresholds for the objective criterion, and therefore it is likely that an initial contact list should contain a subset of ‘false positives’.

High quality (low noise) data are expected to have fewer false positives. Lower quality data, whether due to higher noise or weaker coverage, are expected to require a greater degree of skill to eliminate false positives. False positives may result from noise in geophysical data, or geophysical signal caused by non-UXO objects.

Data with gaps in coverage of raw data may include ‘false negatives’ and also distorted anomalies caused by data processing operation acting on undersampled data.

It is helpful to include a comments column in a contacts list to describe the circumstances of the contact and potentially any observations made during the development of the geophysical dataset that may influence the classification of an anomaly.

This initial interpretation of contacts may be made initially by contractors associated with the data acquisition, by third party contractors, client personnel or others and these interpreters are not required to be qualified as specialists competent in the identification of UXO from pUXO contacts. The key deliverable is an objectively interpreted contacts list with advisory notes. Note that false positives must not be eliminated from a contacts list without the involvement of a UXO specialist, as signal from apparently non-UXO clutter may mask genuine UXO targets.

The initial ‘objective’ interpretation represents the point of handover from ‘Geophysical Specialist’ to ‘UXO Specialist’.

Although in practice personnel may have skill in both domains, it is important to register the point in the workflow at which it becomes imperative that activity is performed within a ‘competent organisation’. Classification of possible UXO (destined for further investigation) and non-UXO (assigned a low risk, possibly not for further inspection) is an operation with potentially high consequence. In Figure 1 this handover represents the transition from Phase 4 to Phase 5.

During Phase 5 the contacts lists delivered by Phase 4 will be classified by personnel within a competent organisation against likelihood of being UXO and possible type. It is recommended that attempts to model magnetic or conductivity anomalies to estimate depth or other parameters are made in Phase 5, by personnel demonstrably skilled in the application of the geophysical algorithms and software to be used.

2.5.10.1 Skillset required

The development of an initial contacts list requires personnel skilled in the inspection and interpretation of geophysical datasets and the ability to organise and maintain a potentially large database of contacts. Involvement of UXO risk management specialists is required as detection thresholds are established, and these personnel should be part of the QA process for the initial interpretation.

2.5.11 Reporting

The creation of a coherent record of the outcome of the survey and its analysis is the primary objective of the survey work. The data required to be returned to the risk management process are target locations and uncertainties (ideally in location, and uncertainty in classification). Depending on the point in the project development that survey work is implemented, a variety of representations of targets may be appropriate:

- explicit Target listings (required for UXO);

- target densities per unit area;
- target densities per unit volume.

As the explicit identification, location and measurement of individual targets remains a labour intensive and time-consuming task, careful consideration should be made of the requirements for reporting. If the design task at hand does not require explicit target definition, consider a spatial or volumetric classification, pending explicit re-interpretation of the dataset at a later date. Such considerations can deliver appropriately detailed data.

Target listings should include target index numbers. A clear strategy should be established to handle the correlation of targets between measurements. It is important to recognise that where different measurement methods deliver different responses from the same anomaly it is considered best practice to index apparent targets from each measurement separately, later constructing a bridging table linking the anomalies. In this way the risk of misidentifying clusters of anomalies as a single target is minimised.

A tiered data package is recommended, allowing different groups of users clear access to the data types useful to each without risk of important data elements being missed:

1. Target data
 - a. Contact databases – Magnetometry, EM, SSS, MBES, SBP
2. Supporting data
 - a. Bathymetry
 - b. Side scan sonar mosaics
 - c. Magnetic field charts and profiles
 - d. Electromagnetic anomaly charts and profiles
 - e. Sub-bottom profiler sections or volumes
 - f. Sub-bottom profiler interpretations
 - g. GIS
3. Working data – software-specific project databases
 - a. Magnetometry interpretation project files
 - b. EM interpretation project files
 - c. SSS and MBES target picking project files
 - d. Seismic interpretation project files
 - e. GIS files
4. Raw data
 - a. Magnetometry raw data
 - b. SSS raw data
 - c. MBES raw data
 - d. EM raw data
 - e. SBP raw data
 - f. Navigation data
5. Reports
 - a. Mobilisation, calibrations and EVT reports
 - b. Operational reports
 - c. Data processing reports
 - d. Interpretation reports
 - o Integrated survey results report.

Geospatial Intelligence Systems (GIS) may be a useful medium for curation, analysis and delivery of a subset of the datasets. It is recommended that GIS files should not be the only medium by which data are delivered unless the format is such that individual data elements within the GIS are independently readable (including their required metadata) by generic tools.

The Integrated Survey Results Report should contain a description of the location, format and metadata format for each of the delivered data elements. An example tiered data deliverables set is provided in Table 16.

Table 16: Example tiered data delivery

Deliverable	Format	Comments
Target data		
Contact lists	ASCII/PDF	Include target identification thresholds
Classification metadata		
Supporting data		
Bathymetry DTM	ASCII (xyz)	Resolution as required
Bathymetry Shaded Relief and Slope	Geotiff	Derived product of Bathymetry DTM
SSS Mosaics	GeoTiff	Resolution as required
Magnetometer/Gradiometer field strength	GeoTiff/ASCII	Resolution as required
EM anomaly	GeoTIFF/ASCII	Resolution as required
SBP interfaces and interpretation	XYZ, GIS	Derived from Survey contractor's interpretation
SBP interpretation	PDF	Images of contractors' interpretation
Interpreted Alignment Charts	PDF/DWG	Centreline Geological Profile
Seabed Features Interpretation	PDF/GIS	
Centreline Geological Profile	DWG	
Instrument track plots	XY, GIS	
Working Data		
SSS Interpretation	Interpretation Project	Delivered using agreed proprietary software filesystem
MBES Interpretation	Interpretation Project	Delivered using agreed proprietary software filesystem
SBP Interpretation	Interpretation Project	Delivered using agreed proprietary software filesystem
Magnetometry Interpretation	Interpretation Project	Delivered using agreed proprietary software filesystem
EM Interpretation	Interpretation Project	Delivered using agreed proprietary software filesystem

Raw Data		
Magnetometer Data	ASCII	Correct navigation data attached
SSS data	XTF	“
MBES data	ASCII	“
MBES Backscatter data	ASCII/gsf/Geotiff	“
EM data	ASCII	“
SBP data	SEGY	“
Navigation data	P1/90	
Reports		
Mobilisation Report	PDF	<p>Include</p> <p>DGPS verification</p> <p>Gyro Cal</p> <p>MBES cal</p> <p>USBL cal</p> <p>SSS & SBP Trails</p> <p>Magnetometer/Gradiometer set up</p> <p>EVT</p> <p>Narrative of events</p> <p>Conclusions as to results of various calibrations and tests</p>
Integrated Survey Results Report	PDF	<p>Target listings</p> <p>Images of classified target distributions</p> <p>Target register describing minimum hazard objects</p> <p>Target picking criteria for all datasets</p> <p>Minimum target sizes identified</p> <p>Correlation between target lists</p> <p>Description of uncertainties</p> <p>Description of Target Results package</p> <p>Description of Metadata package</p>
Survey Operational/HSE Report	PDF	<p>Operational parameters</p> <p>Vessel and instrument configurations</p> <p>QA operations</p> <p>Survey Logs</p>
Environmental Report	PDF	
Environmental Video/photos	Mpeg/jpeg etc.	

To ensure that specifications and objectives that have been set out in the initial operations described above are met during the data acquisition phase then an experienced offshore client representative

who is familiar with the requirements of the project and offshore survey operations of a similar nature should be appointed.

The data collected as part of the survey should be loaded into a GIS project containing the knowledgebase to be used in cable route planning. This data environment will be used for the purposes of further analysis and to assess target locations that may require further intervention. The following is the recommended minimum for what should be considered as part of an effective review:

- current Engineering Corridor (RPL +/- Xm);
- existing infrastructure;
- contacts list;
- shaded relief;
- seabed slope;
- bathymetric values;
- SSS sonar mosaic;
- Magnetometer field image;
- Geological Unit Interfaces as generated from SBP data;
- geological maps generated from SBP data;
- other spatial data e.g. Google Earth images and Admiralty Charts.

With this in place, appropriately skilled GIS operators alongside specialists from UXO, engineering and geoscience should now be able to update the risk register with sufficiently accurate location of the potential hazards anticipated in the desk-top study of Phase 1.

2.5.11.1 Skillset required

Accurate and comprehensive reporting and delivery of the survey output represents the outcome of the geophysical survey campaign and the desired product. Reporting is not confined to the later stages of survey work but includes material generated at all stages.

The Risk management approach to Geophysical Survey Management advocated in this guidance requires some emphasis of the reporting task in collating and coordinating collateral originating from multiple sources without corrupting its integrity.

Skillsets required in the production of the output are:

- geophysical skills;
- UXO specialist skills;
- GIS skills;
- communication skills;
- logistical skills – preparing and delivering a comprehensive suite of products;
- project management skills.

2.6 Summary

A geophysical survey management approach that is fundamentally integrated with the risk management methods commonly used in the mitigation of UXO risk ensures that the design of the geophysical survey is tightly linked to its objectives.

It is inevitable that the involvement of UXO and geophysical specialists will be required as well as engineering specialists for design and installation considerations. The guidance advocates the creation of clear geophysical specifications and DQOs associated with the target characteristics, which should enable all stakeholders to understand the linkage between survey type, cost, time and performance.

This understanding is expected to facilitate the decision-making process, to make it clear when changes are required, and to enable accurate evaluation of the datasets for appropriacy of use through the period of existence of the cable.

3. Geophysical survey for detection and mapping of boulders

3.1 Introduction

Boulders at and below the seabed may present an impediment to the installation of cables, as well as other seabed and sub-seabed engineering such as foundations and pipelines. This guidance is specifically targeted at the installation, operation and maintenance and decommissioning of submarine cables.

Although boulders are generally regarded as a 'project risk' (a risk to the cost, timing or assets of a project), rather than a 'safety risk' (a risk to the wellbeing of personnel, assets or the environment), this guidance uses a risk management framework to assist in the design and management of geophysical survey work in a similar way to the approach taken in section 2 – Geophysical survey for UXO risk mitigation.

Detail is included in sections 3.2-3.4 devoted to developing the risk mitigation strategy because established guidance is not present. Some risk management collateral is illustrated as example tables, registers and risk assessments – these are for illustration of content only and any details within are not necessarily realistic. These sections should not be treated as an exhaustive guide but rather as examples primarily to illustrate the use of these tools to extract and collate the information required to design, parameterize and assure the quality of survey work.

3.2 Phase 1 – Development of a boulder hazard register

3.2.1 Objective

To identify the array of potential hazards and their impact on the project.

For the specification of geophysical survey work, the Hazard Register is a key document describing the set of objects that the survey may be designed to detect.

3.2.2 Outcome

A hazard register describing the types of boulder potentially present at the site and their physical characteristics relevant to the risk to operations and relevant to detection. This register should be supplemented by a clear description of the boundaries of the site, information on the seabed and metocean conditions within it, and any zoning with respect to the potential presence of boulders.

3.2.3 Method

In order to create an initial register of potential hazards, the scope of interactions with the seabed and sub-seabed that the cable installation, operation, maintenance and decommissioning operations should be clearly identified. These should include:

- water depth;
- required cable burial depth;
- corridor required for installation, operation, repair and decommissioning operations;
- review databases for existing in-service and out-of-service infrastructure;
- expected ground conditions, including some anticipation of seabed mobility.

The type of hazard that may present a risk should be identified and classified with criteria relevant to the activity concerned (not necessarily the same as the engineering definitions of cobbles and boulders).

While size is clearly the primary characteristic influencing both the potential interaction between a boulder and cable installation operations and the detectability of boulders, it may be relevant to include other characteristics for example hardness (e.g. granite vs clay) or density might be relevant to classification of consequence later in the process.

The planned cable alignment may be subdivided into zones at any point in the sequence of operations, e.g. to allow variation of consequence with water depth, seabed or geological conditions, or to allow for variable likelihood of encountering a hazard.

The term 'boulder' has a definition – objects with a dimension > 256 mm (although some references use the limit >200 mm). 'Cobbles' range between 64 mm and 256 mm. It is suggested that objects of smaller size than the formal lower limit for a 'boulder' may be relevant in some cases, and here caution is advised in terminology when preparing a hazard register and survey scope.

It is useful to include an evaluation of the potential consequence of hazards to the cable installation, operation and maintenance and decommissioning activity. Scoring potential consequence could be specific to zones and/or activity (e.g. installation method).

An example hazard register, is presented in Table 17, and example consequence table included in Table 18.

3.2.4 Output relevant to geophysical survey

Register of boulder types possibly present with characteristic dimensions and properties, zonation of possible boulder presence, zonation of pertinent seabed conditions and an indication of possible depths of burial.

3.2.5 Skillset required

Here it is likely to be of benefit to involve geologists and specialists with expertise in the tools and approaches available to the developer for survey, route planning, cable installation, operation and maintenance and decommissioning.

This stage is identifying the array of hazards that may be significant. At this stage care should be taken not to eliminate hazards because of a perception that they may not be present – that is for the next operation.

Table 17: Example hazard register

Index	Hazard	Potential Consequence			
		Zone	Installation Approach	Installation Approach	Installation Approach
			A	B	C
1	Cobble 64-256 mm	All	1	2	3
2	Boulder1 256-1500 mm	All	2	2	4
3	Boulder2 >1500 mm	All	3	3	3

Table 18: Example consequence table

Hazard	Potential Consequence	Score (range)
Cobble 64-256 mm	Reduced progress rates for cable trenching.	1-3
	Extra wear on cutting chain/wheel if using mechanical trencher.	1-3
	Reduced burial, especially for jet trenching if the cobbles are too large/heavy to fluidise.	3-7
Boulder 1 256-1500 mm	Boulders at seabed may impede burial progress (lower progress rates if you are able to get through/past) and pose a risk of damage or instability to the tool.	2-5
	They pose a risk to trenching and can lead to localised areas of reduced burial. Jet trenching may be particularly susceptible to boulders forcing the retraction of jetting swords, whereas ploughing may potentially have more success in forcing obstructions aside.	2-5
	Large boulders may cause damage to the jetting swords or wear/damage of cutting chains.	3-7
Boulder 2 >1500 mm	As above but less likely to be forced aside.	3-7

3.3 Phase 2 - Evaluation of potential boulder risk

3.3.1 Objective

To define an initial risk profile for the hazards to the project in order to inform an initial risk mitigation plan.

The risk assessment introduces the consideration of the operations anticipated to the potential hazards logged in the hazard register. For the specification of geophysical survey work, the risk assessment and the information supporting it are key resources describing the context of the set of objects that the survey will be designed to detect. Of these, the smallest target to be detected (in terms of its geophysical signature) is the most influential to the design of the geophysical survey.

3.3.2 Outcome

A Project Boulder Risk Register including all identified hazards, an estimated likelihood of their being encountered, and an estimated risk prior to any mitigation.

3.3.3 Method

With the hazard register in hand an evaluation of the risk presented by these hazards may be performed. Typically, such a risk assessment would fall into two sections: a) the likelihood of encountering the hazard and; b) the impact of such an encounter. Inputs to the risk assessment include:

- geological understanding of the area;
- understanding of current and historic activity that may have introduced boulders to the area;
- any previous experience of the area;
- reporting and data from the reconnaissance surveys performed as part of feasibility studies, regulatory, EIA and consent obligations.

It is recommended that where possible the range of anticipated installation methods and equipment is considered as the definition of smallest hazard is made, in order to properly inform the definition of ALR. A consequence table (an example is provided in Table 19) may be useful to record the potential impact of boulders upon different operations and types of equipment.

Table 19: Example risk register

Index	Hazard	Zone	Consequence	Likelihood	Risk
4	Cobble 64-256 mm	All	2	3	6
5	Boulder1 256-1500 mm	All	4	2	8
6	Boulder2 >1500 mm	All	3	1	3

Revised definition of smallest target may be made following the definition of an initial risk mitigation strategy should the cost of the required geophysical survey be excessive.

If the selection of installation approach is to be influenced by the output of the geophysical survey then a clear understanding of the smallest detected object threshold output from the geophysical survey must be part of the decision base; i.e. if the installation approach is sensitive to material smaller than the smallest detected object, then it should be recognised that potentially significant objects, unmapped by geophysics, may be present.

With the smallest hazard defined, a desk study may be performed to evaluate the likelihood of such objects being present at surface or within the subsurface to a depth defined by the installation boundary conditions.

Principally, the desk study should evaluate an array of plausible mechanisms of emplacement of obstructions, including but not limited to:

- deposition as part of sedimentary processes;
- transport by glacial processes;
- emplacement by extrusive or intrusive volcanic or hydrothermal processes;
- development by geochemical processes (e.g. concretions);
- anthropogenic deposition (e.g. ships ballast).

Care should be taken not to conclude early that boulders are not present because a mechanism of emplacement has not been suggested.

3.3.4 Skillset required

The desk study evaluating potential occurrence of geological observations requires the input of a geologist familiar with the geology of the site. If the site is located in an area subject to anthropogenic disturbance additional skills in evaluation of the likelihood of other sources of obstructions should be included.

It is useful to involve personnel with experience of risk analysis and risk management to enable the risk analysis to be tailored to suit the project.

3.3.5 Output

The outcome of the Phase 2 is a Project Boulder Risk Register for the site under investigation. The Project Boulder Risk Register should be used to inform the scope of an initial risk mitigation strategy including the scoping of further investigation and survey work as required.

In Table 20 the maximum consequence for the array of hazards in combination with all installation methods evaluated is chosen. In some cases, it may be more appropriate to retain each installation method in view, in which case a risk register for each method should be constructed (this is likely to be useful where it becomes evident that the choice of installation method has a significant influence on the cost of achieving ALR).

Table 20: Example risk tolerance table

Consequence	1	2	3
Likelihood			
1	1	2	3
2	2	4	6
3	3	6	9

Setting up a risk tolerance table, which involves a definition of Acceptable Level of Risk (ALR) given as an example in Table 20, requires some care and may be subject to iterative review as costs and risks are balanced, and decisions are made (e.g. refinements to installation methods and equipment). In Table 20 risks with a score of 3 or less are deemed to have met the criterion for ALR and only require monitoring, those with a score between 4 and 7 may be mitigated and monitored, those with a score of 9 must be mitigated or avoided.

It is important to be consistent across project phases, in order to be able to monitor and assure the reduction of residual risk.

Actions in response to the identification of potential hazards are specified in the Risk Mitigation Strategy of Phase 3, and it is here that adaptability may be introduced to vary the response spatially or at different phases of the cable installation project.

3.4 Phase 3 - Boulder risk mitigation strategy

3.4.1 Objective

To make an initial plan for risk mitigation at the site, including definition of hazards to be targeted for reconnaissance.

For the purpose of specification of geophysical survey work, the Project Boulder Risk Mitigation Strategy contains a definition of the Acceptable Level of Risk (ALR), and this in turn allows the definition of the smallest geophysical feature to be detected and mapped.

3.4.2 Outcome

An initial risk mitigation plan, definitions of ALR for each class of hazard identified, description and definition of zonation of the site for variation of ALR definition.

3.4.3 Method

It is recommended that an initial risk mitigation strategy should be constructed *before* geophysical work is defined. Here, the survey work to detect, identify and locate hazards is treated as part of the risk mitigation operations.

Mitigation, may of course be to avoid or accept the risk as is. However, outwith these extremes it is likely that the initial mitigation strategy will include some attempt to develop more detailed understanding of the type, distribution and position of hazards.

This is the primary objective of the geophysical surveys.

The guidelines set out in DNVGL-RP-0360 illustrate the requirements from an engineering perspective (recognising boulders as a potential risk to engineering operations):

“Detailed data shall be obtained for the total length of the planned cable route, covering a corridor of sufficient width to provide adequate information for design of the cable route as well as installation and operation related activities, considering possible route adjustments due to subsequent findings”.

However, DNVGL-RP-0360 does not define ‘detailed data’ in the context of boulders. The Initial Risk Mitigation Strategy contains the array of potential hazards and the requirements for their detection, identification and location in order to mitigate to achieve a risk level as low as reasonably practicable. In this way a working definition for ‘detailed data’ is provided.

The initial risk mitigation strategy should include:

- the initial risk register;
- the array of mitigations for the initial risk register;
- the set of targets to be detected and located by geophysical survey;
- the detectable characteristics (scale, conductivity, magnetic permeability, geological material) of the targets;
- the possible vertical positions that targets may be found (seabed, sub-seabed);
- the required precision with which targets are to be located;
- definition of the survey corridor;
- zonation of the site to accommodate variable risk or risk tolerance.

This set of information informs the specification and parameterisation, of the investigative survey work to follow. Table 21 illustrates an example risk mitigation table.

Table 21: Example risk mitigation strategy

Index	Hazard	Zone	Risk	Mitigation required	Survey requirement	Survey requirement
					Phase 1	Phase 2
1	Cobble 64-256 mm	All	9	avoid	Detect and zone	Detect, locate
2	Boulder 1 256-1500 mm	All	8	remove	Detect and zone	Detect, locate and measure
3	Boulder 2 >1500 mm	All	3	avoid	Detect and locate	Detect, locate and measure

Data and products from the Reconnaissance Survey required for regulatory, EIA, consent and feasibility studies may not be of sufficient resolution for the purposes of detailed boulder identification and mapping. These data must be evaluated with the specifications described above in view so that they may be incorporated into the mitigation plan in a systematic way.

It should be noted at this stage that focus should be on specifying appropriately accurate positioning of the sensors and associated navigation data as this will translate to achieving greater confidence of the target locations during the survey interpretation and analysis phase. This will, in turn, lead to more accurate location of targets with reduced buffer zones for UXO, greater flexibility for micro-routing and consequently, reduced time in field of inspection assets looking for, and clearing targets on the seabed.

At different phases of a project, it may be optimal to specify survey work to return information at different levels of precision:

Detect: discover the presence of an anomaly of a particular class

Locate: Accurately deliver the location of the centroid of the object

Zone: Deliver a perimeter within which some number density (objects per square metre, objects per metre cubed) of objects are indicated

Measure: deliver the dimensions of an object with some quantified confidence

These classes of survey requirement are included in the Risk Mitigation Strategy of Table 21 as different requirements at phases 1 and 2 of the project programme. Here for example Phase 1 might be route planning for costing in which only ‘immovable’ boulders and UXO are required to be located and measured precisely. Here a second phase of survey work is anticipated, with a smaller area and more precise requirements, and an opportunity is taken to defer the precise measurement of UXO and obstructions to this phase to improve efficiency. It may be that two surveys are planned, or survey performance for the Phase 2 requirements incorporated into Phase 1 data acquisition specification with only re-interpretation anticipated in support of Phase 2. The relative costs and benefits of either approach will be dependent on the survey areas proposed, the requirements of each, and the array of concurrent data acquisition programmes that influence the survey design(s) and costs.

3.4.4 Output relevant to geophysical survey

The key deliverable from Phase 3 is the set of risk tolerances associated with each hazard (boulder class), the physical characteristics of the items and the possible range of conditions in which they may represent a risk requiring mitigation. This set of information informs the specification and parameterisation of the survey work to follow, principally through the identification and description

of the smallest signal to be detected. Table 22 illustrates an example target table summarising the characteristics of the targets pertinent to geophysical survey specification.

An example risk assessment with mitigation plan is provided in Table 21. The survey requirements are used to populate the target specification summary (Table 22) which is used to establish the resolution requirements of the geophysical survey.

3.4.5 Skillset required

In order to populate the tables with scores that can be used to make sensible decisions, the development of a risk mitigation plan requires personnel skilled in:

- geology;
- geophysics;
- risk management;
- cable installation engineering;
- project management.

Table 22: Example target specification summary

Target Class	Zone	Property	Dimension	Anomaly Characteristics	Location Precision	Max. depth (m BSB)	Corridor width
Cobble	All	size	<256 mm	texture on SSS Diffraction 1 m	Per unit area / volume	2	
Boulder 1	All	size	256-1500 mm	Object on SSS, MBES Diffraction 5 m	<1.0 m	3	
Boulder 2	1, 5	size	>1500 mm	Object on SSS, MBES Diffraction 10 m	<2.0 m	5	

3.5 Phase 4 - Geophysical survey for detection and location of boulders

3.5.1 Objective

To define and execute survey work to detect and locate the array of potential hazards at the site.

3.5.2 Outcome

A register of contacts as defined in Phases 1 and 2, with locations provided to the precision defined in Phase 3.

3.5.3 Method

Phase 4 has four clear components – scoping, procurement and execution and reporting. After the scoping phase and with estimated timings and costs in hand a review, with potential costs in view, of the definitions of ALR for risks identified at the site is advised.

- Scoping: Specification of target geophysical signal characteristics, initial alignment and survey corridor, shortlisted survey methods and anticipated parameters, specification of deliverables.
- Procurement: Commissioning of survey work and associated offshore and onshore support
- Execution: Acquisition, processing and initial interpretation of data
- Reporting: Assembly of products for incorporation into the risk management knowledgebase.

Description of these elements follows in sections 3.5.4 to 3.5.11.

Quality Assurance of Phase 4 is critical. The collateral developed in Phases 1-3 should be used to define appropriate metrics to assure that survey work is fit-for-purpose.

It is recommended at this stage that significant emphasis be placed on the specification of appropriately accurate positioning of the sensors and diligent logging and processing of navigation data; this will lead to greater confidence in the contact locations during the survey interpretation and analysis phase. High quality location information is a requirement for accurate location of targets with reduced buffer zones, greater flexibility for micro-routing and reduced time in clearance of targets.

3.5.4 Skillset required

The detection and location of hazards primarily requires personnel with skills in geophysical survey, data processing and interpretation together with those with hydrographic and positioning, logistics and project management skills. Engineering input is limited to definition of the activities anticipated during development, operation and decommissioning and therefore specification of the vectors by which boulders may come into contact with project assets, and this input should already be in place if the workflow of Table 1 has been followed. The requirement to interface the various skill sets needed is set out within both the OGP 2017 and OSIG 2014 guidelines, that during the planning, execution, interpretation, analysis and planning of the acquired datasets and engineering phases, competence in each of the disciplines contributing to the survey is required and that management of the key investigations should be undertaken by a competent person.

3.5.5 Scoping

Table 23 illustrates the set of data products that are typically used to develop the Boulder contact register, with the measurement methods that contribute to each. This table is constructed according to the data product, rather than survey type, to emphasise that multiple measurements may contribute to the same output. This raises a significant consideration for the users of these data: Data may be delivered according to their measurement type, with a risk that data positioning error (horizontal and vertical), measurement configuration and interpretational uncertainty contribute to multiple registration of single targets. It is recommended that an explicit strategy for the integration of multiple measurements is implemented to establish understanding and control of positional uncertainty for Boulder hazards.

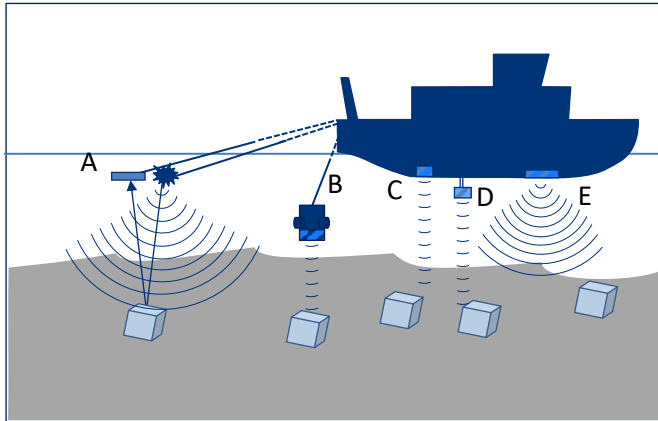
3.5.5.1 Geophysical method overview

- Magnetometry measures variation in the magnetic field and is often used for detecting ferrous items including pUXO. However, it cannot be used for detecting non-ferrous items. Therefore, magnetometry is of limited use in boulder detection and location unless there is reason to identify items with significant magnetic mineral content.
- MBES and SSS data are used in combination for mapping and understanding the distribution of objects on the seabed.
- SBP (including all applicable variants of single and multi-channel seismic / acoustic methods) can be used to understand the sub-seabed structure. 3D seismic methods of various resolutions may be implemented, which may provide an accurate location of a sub-seabed object. Variants of 3D SBP remain the only method for location and measurement of sub-seabed boulders.
- Electromagnetic (EM) methods may be used to detect anomalously conductive material beneath the sea bed, within a few metres of the sea bed – their use for detection of boulders is generally very limited and they are not discussed in this section.

Deployment of geophysical methods may be from a surface vessel, either directly attached or towed, from an airborne platform (manned or unmanned) or from sub-surface platforms either towed (Remotely Operated Towed Vehicle, ROTV), free flying (Remotely Operated Vehicle, ROV), or untethered (Autonomous Underwater Vessel, AUV). Figure 10 illustrates some of the options. Some are semi-permanent installations on dedicated survey vessels, while others can be installed on multi-purpose craft. It is important that the position of instrumentation relative to its navigation reference point is properly established and validated.

Geophysical surveys, particularly those involving towed gear, are generally acquired in line plans composed of nominally straight line segments, though ROV, AUV and vessel-fixed instruments are not limited to this requirement. The spacing between acquisition lines, frequency of measurement along lines, requirement for intersecting 'tie' lines, vertical position of the instruments, power and frequency settings for active measurements are some of the many parameters that contribute to the survey design. The risk mitigation plan should inform the survey designer of the characteristics of the set of targets that is required to be resolved by the geophysical survey. The characteristics must be translated into anticipated geophysical responses in order to define a survey specification – critical characteristics might be signal amplitude, spatial extent, pattern or gradient and these will inform the requirements of the of the instrumentation, logging systems and the line plan. Sections 3.5.5.3 to 3.5.5.6 describe the principles of the key geophysical methods with the controlling parameters that have critical influence on the survey performance.

To ensure that specifications and objectives that have been set out in the initial operations described above are met during the data acquisition phase an experienced offshore client representative who is familiar with the requirements of the project and offshore survey operations of a similar nature should be appointed. The output of Phases 1-3 will help the offshore client representative to understand the motivation for the work scope and should be included in a briefing package.



- A – Towed single channel seismic array
- B – ROV deployed 3D instrument
- C – Moon-pool deployed instrument
- D – Pole-mounted instrument
- E – Hull-mounted

Figure 10: Schematic illustration of the different modes of deployment for sub-bottom profiler instruments.

Table 23: Deliverables from the geophysical survey required for boulder risk mitigation

Data Product	Primary Use	Measurements	Component Products	Derived Products	Drivers for Precision
Digital Seabed Model	Detection and location of obstructions at seabed and other installation considerations	MBES	Bathymetry DTM grid	Contact list	Instrument configuration Survey altitude
				Contact zonation map	Line spacing Grid pitch
			Bathymetry Point cloud	Seabed slope map	Instrument configuration Survey altitude Line spacing
			Bedform map		
		Backscatter	Seabed Sediment classification	Instrument configuration Survey altitude Line spacing Grid pitch	
		SSS	Raw sonar files	Contact list	Instrument configuration Survey altitude Line spacing
Sonar Mosaic	Contact zonation map		Instrument Configuration Grid Pitch		
Magnetic Anomaly map	Detection and location of ferrous material at or below seabed	Magnetometry Magnetic gradiometry	Magnetic anomaly profiles	Contact list	Instrument configuration Survey altitude
			Magnetic anomaly grids	Contact zonation map	Instrument configuration Survey altitude Line spacing Grid pitch
			Magnetic gradient anomaly grids	Analytic Signal grids	Instrument configuration Survey altitude Line spacing Grid pitch
			Magnetic anomaly ribbon plots	Magnetic Anomaly depth models	Instrument configuration Survey altitude Grid pitch

2D Sub Bottom profiles	Image 2D geology sub-seabed	Sub Bottom Profiler (SBP)	Seismic sections	Geological interpretation	Water depth Trace spacing Source type
	Detect obstructions sub-seabed			Contact list	Water depth Trace spacing Source type
3D sub-Bottom volumes	Image 3D geology sub-seabed	3D seismic survey	Contact list		Water depth Line spacing Trace spacing Source type
	Detection and location of sub-seabed objects		3D reflection amplitude volume	3D reflectivity volume	Water depth Line spacing Trace spacing Source type
Operational Report			Operational Report Data Processing Reports		
Interpretation Report			Individual Measurement interpretation	Individual contact list	
			Integrated interpretation	Integrated contact list	
Metadata					

Scoping of survey work should follow the requirements identified in Phase 3 in the Target Specification Summary, with a significant caveat that some contingency must be allowed for the discovery of unexpected objects.

It is crucial to recognise during scoping that objects smaller than the minimum size (or signal amplitude) resolvable by the survey will not be mapped, but may be present in unknown number.

Subsections 3.5.5.3 to 3.5.5.6 provide an overview of the quality and resolution controlling parameters of each measurement type contributing the data products in Table 23.

3.5.5.2 Notes on the age of data

The time elapsed between collection of any data contributing to risk mitigation and the date of seabed operations may be significant. While the lateral migration of objects may or may not occur, migration of bedforms certainly does (at various rates, directions and degrees of consistency), and a significant elapsed time may lead to migration of a bedform such that a previously undetected hazard becomes apparent, or comes into the depth range of interest for an installation or maintenance operation.

It is important to consider possible movement of target and environment, and any other mechanism of change, when evaluating the potential viability of existing geophysical data for risk mitigation. Existing data may accurately represent a previous state and be useful to illustrate change even if current survey work is commissioned.

Geophysical data themselves do not have a ‘shelf life’ as such. It is recommended that a review of the provenance of any existing geophysical data considered for use in boulder risk mitigation is performed, with survey objectives and DQOs set up as they would be for a new survey. The precautionary principle should then hold, only using existing data when they are positively evaluated as having satisfactory quality for the purpose to which they are being put.

It is recommended to pay close attention to the quality of positioning of all data and to the vertical reference systems used, these are frequent sources of uncertainty and mistakes. Where depths are referenced from sea floor or an instrument altitude, ensure that the reference surface is available (as seabed mobility may cause change).

A data ‘shelf life policy’ such as that illustrated in Table 24 may be useful to concisely summarise the maximum age of data with site specific limits set according to anticipated rates of change (i.e. maximum age of data may be large where seabed changes are small or slow, and may be smaller where mechanisms of change may cause more rapid or larger variation).

Other reasons for new survey, can include:

- significant amount of time elapsed since the last survey;
- occurrence of an anomalous significant storm, tide, or high current event;
- anomalous changes in the level and/or morphology of the seabed;
- a significant event (e.g. UXO detonation);
- trawling, construction, dredging or other sea bed activity within the area;
- a technical or operational development that changes the definition of ALR.

Table 24: Suggested format of a shelf-life policy (modified From OGP 2017)

Activity level	Seabed Data	Sub Seabed data
None	5yrs	Up to 10yrs
Planned Marine or engineering activity	1 yr	Up to 10yrs
Construction	Pre-installation	Up to 10yrs

3.5.5.3 Magnetometry

Magnetometry is used in UXO detection campaigns to detect items with significant content of ferrous material – many classes of UXO have significant ferrous content with some notable and important exceptions. Boulders containing sufficient magnetic mineralisation are not the norm and magnetometry is not regarded as a primary tool for their detection (however, it is possible for anomalies caused by boulders to have amplitudes similar to UXO). Description is included here for completeness. The detectable magnetic anomaly associated with objects containing ferrous material is spatially limited. The amplitude of the anomaly is a function of the mass of ferrous material and an inverse function of the cube of its distance from the sensor. The spatial extent of the anomaly is a function of the vertical distance between the target and the sensor paths. Figure 11 illustrates schematically the pattern of Total Field magnetic anomaly expected from a ferrous object.

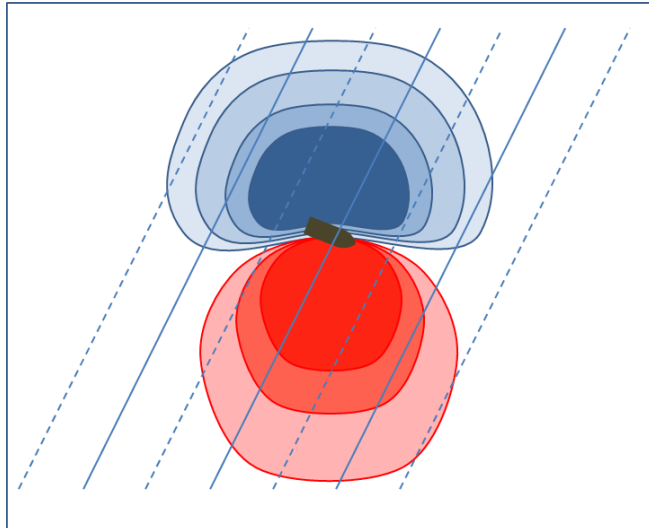


Figure 11: Magnetic anomaly (total magnetic intensity) above a ferrous object.

Figure 11 shows that only part of the magnetic anomaly would be sampled by each profile. It is clear that the anomaly recorded on a single profile could take many forms, from a clear positive-to-negative response through the axis of the anomaly to much lower amplitude, single polarity responses if the anomaly is intersected off-axis.

Confident identification and location of targets requires that the spatial pattern of an anomaly can be interpolated from the collection of profiles. Derived data products such as analytic signal, while apparently simplifying the map, demand adequate sampling and processing of the Total Magnetic Field anomaly in order to be accurate (analytic signal requires a calculation of the spatial gradient of the Total Magnetic Intensity). Thus, it is recommended that an objective design criterion for line spacing is used to assure the viability of the dataset for its intended purpose.

If the objective of the survey is limited to detection then a suggested line spacing allowing three lines to sample one anomaly half-width (measured above the noise floor) may suffice. Should a requirement to model burial depth and/or mass of ferrous material be anticipated then at least five traverses per anomaly half-width may increase the chance of recording the detail of the magnetic anomaly for these processes.

As a rule of thumb, the anomaly half width will be of the order of the distance between the ferrous material and the instrument flight path.

In Figure 12 the profile view N-S through the axis of an anomaly is provided as a schematic. Some critical observations are:

- deeper objects give a smaller amplitude and wider anomaly than those closer to the sensor;
- anomalies from objects close to the sensor are spatially restricted;
- noisy magnetic data (indicated by the halo on the schematic response patterns of Figure 12) can result in distorted or undetectable magnetic anomalies;
- inferences of depth are made relative to the altitude of the sensor path.

The calculation of line spacing required to give 'full coverage' is therefore a function of the altitude of the sensor above the maximum depth of investigation required, the size of the signal anticipated from the hazard with the smallest magnetic signal, and the noise floor of the sensor.

In practice, the sensors deployed are generally very similar in performance, allowing relatively simple tables or nomograms to be used to establish an altitude and line spacing tolerance for a given target anomaly size and amplitude.

Typical altitudes above sea bed are of the order of 3-5 m, and instrument line spacing <5 m.

Instruments are normally deployed in a towed 'fish', suitably distant from the magnetic field distortions induced by the towing vessel and any other equipment. The towing distance is typically 3-5 times the length of the vessel involved, and the sensor may be 'piggy-backed' on the same tow-line with other instruments. Altitude is controlled by the towing speed and a balanced arrangement of buoyancy and hydrodynamic surfaces on the towfish. The position of the magnetic sensor is typically monitored using an Ultra-Short Base Line (USBL) system with a transponder positioned as close as possible to the sensor without inducing signal distortion, towfish should have an altimeter incorporated.

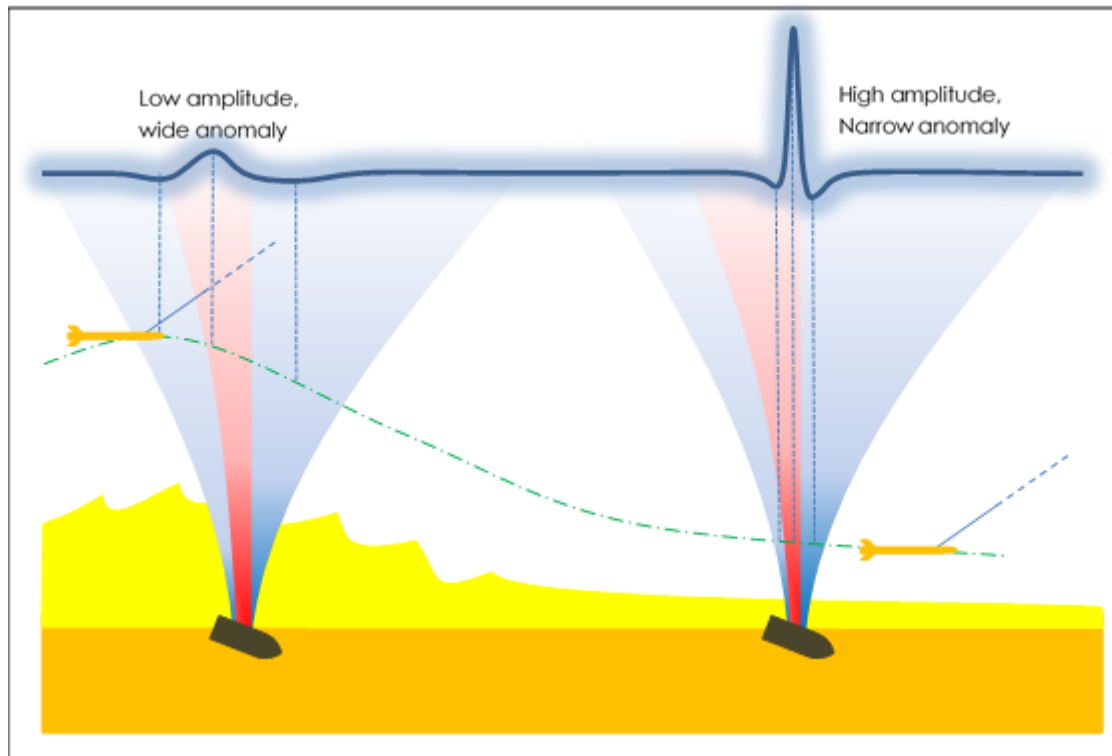


Figure 12: Schematic image of magnetic anomaly patterns above a ferrous object lying at the base of mobile sediment.

Magnetic gradiometry may be recorded by an assembly of magnetometers fixed to a rigid frame, processed to optimise recovery of the difference in magnetic field across the known baselines of the structure. Magnetic gradiometry offers a few significant advantages; the time-variant field induced by solar activity is cancelled as a common mode between the magnetometers (removing a potentially significant source of noise), positions of anomalies may be interpreted with better confidence, calculation of derived data quantities (*e.g.* analytic signal) can be made with more robust direct (rather than calculated) gradient terms. However, gradient signals are more sensitive to instrument noise and variation of altitude, so care is required to assure the acquisition system is configured with sufficiently accurate positioning systems and an appropriate noise floor. Processing must be diligently applied. Interference between magnetometry instruments and other systems must be minimised.

If it is expected that an attempt to model the depth to a ferrous object will be required, it is important to ensure that a good representation in the horizontal plane of the anomaly is mapped. This may require data acquisition at line spacing of the order of 1-2 m.

As a result of this tight line spacing requirement, where modelling of targets may be required magnetometers are generally operated within an array behind single or multiple ROTVs that are available in various configurations. These reduce the number of lines a vessel has to run to acquire the required number of magnetometer lines. These ROTV's have the advantage of offering a fixed towing point closer to the magnetometer itself, reducing uncertainties with positioning. However, they require skilled operators to pilot them; at the time of writing there are significant improvements

in progress to the operating systems for these devices. The use of AUV platforms has similar performance benefits and positional requirements.

Proprietary software exists that can monitor whether line spacing and altitude specifications have been maintained or exceeded. Survey operators along with offshore client representative must be satisfied that acceptable coverage has been achieved over the survey area before the vessel leaves the site, in line with the ALR principles defined in the risk mitigation plan.

Due to the tight line spacing requirement and the use of towed equipment, magnetometry work can generate a significant amount of infill requirement. It is recommended that a robust set of DQOs be agreed such that the developer, their UXO specialist, offshore client representative and their cable installation contractor have a ready understanding of any compromise to the quality of the dataset. Suggestions are given in Table 25. Deviations from an agreed line spacing and altitude should be mapped, as while an upward deviation reduces the amplitude of an anomaly, a downward deviation moves the sensor to a position in which the anomaly is smaller in space possibly compromising resolution of steeper gradients in the magnetic field. Both may result in compromised detection or modelling of targets.

Table 25: Target and survey parameters for magnetometry

Scope Requirement	Measurement Parameter	Controlling Parameter	Suggested Guidance	QA metric
Minimum anomaly amplitude	Total Anomaly magnitude	Noise floor	Minimum signal-to-noise ratio of 3	RMS noise value (from EVT)
Minimum anomaly dimension	Line spacing	Navigation Instrument positioning	At least 3 profiles per anomaly half width	Linekeeping tolerance Altitude Tolerance Coverage tolerance
Modelling depth and target	Spatial anomaly shape	Navigation Instrument positioning	At least 5 profiles per anomaly half width	Linekeeping tolerance Altitude Tolerance Coverage tolerance

3.5.5.4 Multi Beam Echo-Sounder (MBES) data

Multi Beam Echo Sounder (MBES) instruments operate by projecting a radial acoustic pulse or chirp, measuring the returned echo using an array of receivers arranged to monitor a set of incoming ray paths through beamforming. They are highly parameterisable devices. Modern instrumentation can deliver over 1000 receive beams per ping with dual head instruments; this can result in apparently very high-resolution data with a broad swath width.

Each beam has a 'footprint', conceptually the area of the seabed that reflects the beam. This is related to the 'beam width', increases with range, and may be larger than the beam spacing. Figure 13 is a schematic illustration of MBES configuration showing key parameters.

The detection of seabed obstructions using MBES instruments is dependent on the density of soundings per square metre of ensonified seabed, and the precision with which these soundings are located. The location of targets has sources of uncertainty in the position and attitude of the MBES instrument itself, and uncertainty in the range and direction of the sounding recorded by the instrument. MBES instruments may be fixed to a surface vessel, in which case the instrument position can be determined with good precision using GNSS (in real time or with post-mission calculation) and inertial methods. If the MBES instrument is deployed on a sub-surface platform, a secondary positioning system such as USBL must be implemented.

The dependence on density of soundings per square metre is illustrated in Figure 13. A density of 9 soundings per square metre, which may satisfy the requirements of IHO Special Order, is likely to be insufficient to guarantee detection a small target, and would be unlikely to be sufficient to provide a confident measurement of the object. A sounding density of 40 per square metre, a value which is fairly typical of high performance, surface deployed instruments in moderate water depths, may be sufficient to detect such an object, but still may not be sufficient to provide good measurements of it. However, larger objects may be well resolved at this sounding density and the benefit of precise location in comparison to the output of Side Scan Sonar or Magnetometry may be significant.

The footprints illustrated in Figure 13 show that at higher values of soundings per square metre there may be significant overlap between soundings. Beamwidths typically lie between 0.5° and 2° , corresponding to footprints of 0.4-1.5 m at around 20 m depth. This also represents a component of the limit to the size of smallest detectable object.

MBES deployed on sub-surface platforms (ROV, AUV) can yield very high-sounding density, but in doing so add a requirement for significant positioning technology – a robust USBL geometry, inertial systems and Simultaneous Location and Mapping (SLAM) type processing operations are available to assist.

The calculation of bathymetry from MBES records requires the time difference between ping and return to be converted into a range. This is a function of the speed of the acoustic pulse in water, which may be variable. Measurement of the speed of sound in water close to the instrument is often made semi-continuously. Vertical profiles through the water column are required to be collected sufficiently frequently to capture temporal variation at the site, often associated with variable (*e.g.* tidal) flow patterns but other possible sources of variation of acoustic speed should be considered as well.

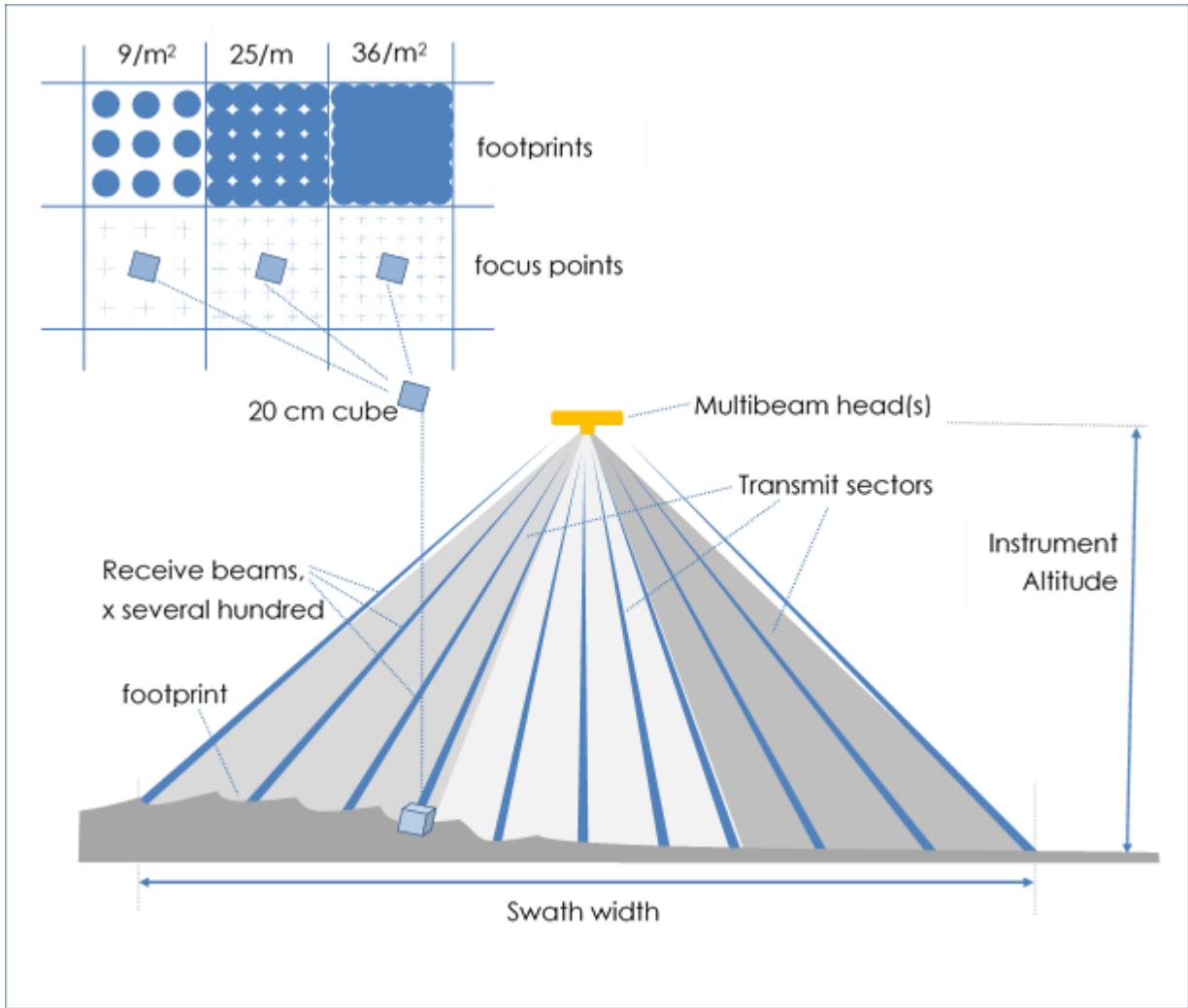


Figure 13: Schematic illustration of the configuration of Multi-Beam Echo-Sounder measurements.

Modern MBES systems with dual swath and dual receive head configurations can deliver high precision along and across track, and large swath width. However, depending on the height and configuration of the instrument above the seabed, at low sensor height swath width can still be the primary control on line spacing. Some indicative operating parameters are given in Table 26.

It is important to recognise that variation in the speed of sound in water may influence the swath width of MBES, and the presence of thermocline or halocline may induce refraction of the beam if sufficient magnitude to influence coverage as well as influencing the depth calculation.

Table 26: Operating parameters of some common MBES systems available

Instrument	Frequency	Min/Max range	Max Swath width
Kongsberg M3 Sonar	500kHz	0.2-50m	120 degrees
Kongsberg GeoSwath	125,250,500kHz	0.3-200m	195-780m
Kongsberg EM2040	200-400kHz	0.3-600m	130-200 degrees
R2 Sonic 2022	170-450kHz	Up to 400m+	10-160 degrees
R2 Sonic 2020	200-400kHz	Up to 200m+	10-130 degrees

Effective operation of these tools to get the required resolution is dependent on operating parameters and configuration. It is important that they are configured in order to achieve the required specifications of the survey with the following considerations:

- full coverage of the survey corridor;
- production of a single, correctly referenced surface for the project;
- acquisition and processing parameters driven by the minimum size of hazard to be detected;
- in line with any required hydrographic standards.

Key parameters and DQOs are presented in Table 27.

Key drivers for precise target location:

- accurate calibration of the instrument at mobilisation;
- accurate sound velocity profiles at an appropriate interval;
- configuration of instrument parameters to suit minimum size of hazard to be detected, water depth (or platform altitude), line spacing and survey speed;
- high quality vessel positioning and attitude data;
- accurate in-field quality and coverage monitoring;
- accurate data processing and gridding.

A focus at the mobilisation stage on checking and calibrating a vessels' navigation and bathymetric systems and consequent reporting within a mobilisation and operations report is an important element of survey metadata. The survey contractor and the offshore client representative for the developer should satisfy themselves that the systems have been correctly calibrated before survey operations begin and acceptable coverage has been achieved before a vessel leaves the survey area.

It is recommended that interpretation from sonar and magnetometry datasets should be correlated to the bathymetric DTM and if an expression of the target is visible on bathymetric data then this should be used as the primary position reference.

Table 27: Target and survey parameters for Multi-Beam bathymetry

Scope Requirement	Measurement Parameter	Controlling Parameter	Suggested Guidance	QA metric
Spatial Resolution	Grid pitch	Minimum number of soundings per m ²	9 soundings per cell	Ping density map
Vertical resolution	Vertical resolution	Frequency Signal to noise ratio Speed of sound in water measurement	Vertical uncertainty < 1/3 of the smallest vertical target dimension	Speed of Sound in water measurements Mobilisation tests Total Vertical Uncertainty
Positioning	Navigation	Navigation Instrument Attitude	Positional uncertainty < 1/3 of the grid pitch	Mobilisation tests Total horizontal Uncertainty

Note that vertical and horizontal uncertainties are compound quantities dependent on the quality of the instrument positioning, the MBES data acquisition and processing and the chosen resolution of the output. The scope requirements for vessel-fixed MBES may need to be refined to recognise that its advantage – reasonably accurate feature positioning – is offset by a minimum detectable object scale that is relatively large (of the order of a metre) relative to common boulder survey requirements. Therefore, scope requirement of the MBES component may not be the smallest object to be detected. If MBES is deployed from a subsurface platform, smaller objects may be detected, but greater emphasis is placed on instrument positioning as a limit to performance, and the cost of the survey work may change.

3.5.5.5 Side Scan Sonar

Side Scan Sonar projects a radial acoustic pulse into the water column and records the arrival of reflections from the seabed as a time record relative to the time of emission. Figure 14 illustrates, schematically, the configuration of the technique. The time record may be interpreted directly (the so-called ‘waterfall’ plot, best for highest resolution) or converted to a range relative to the instrument position for location of targets on the sea floor (the ‘mosaic’ plot) usually with some loss of resolution due to gridding.

SSS instruments are generally towed at a lower altitude above the sea bed than the altitude of an MBES instrument. Their wavelength and beamwidth may also be smaller, and the incidence angle of the beam is favourable for the detection of relatively low-relief seabed features. SSS data are often acquired in conjunction with MBES data, the two datasets contributing to a seabed contact map in a complementary way.

Seabed objects reflect as anomalous amplitudes in the time record, and textures and seabed features can be determined by variation in patterns of the amplitude map. The horizontal dimensions of an object can be estimated from the size of the anomaly in the scan, and its height relative to the seabed may be estimated from the length of its shadow (annotated as t_s in Figure 14). Side scan sonar is normally acquired from a towed ‘fish’ which projects pulses normal to the path of the fish. The track immediately below the fish path, where pulses from each side might interfere, is normally configured to have low amplitude; this zone is termed the ‘nadir’.

Figure 14 illustrates the principle of overlap, which provides coverage of the nadir by the long-range part of the adjacent scan. This construction is often the source of the primary consideration for line spacing for SSS surveys. It is important to note the effect of seafloor topography on this overlap condition; sea-floor slope always results in a reduction in line spacing required for full coverage.

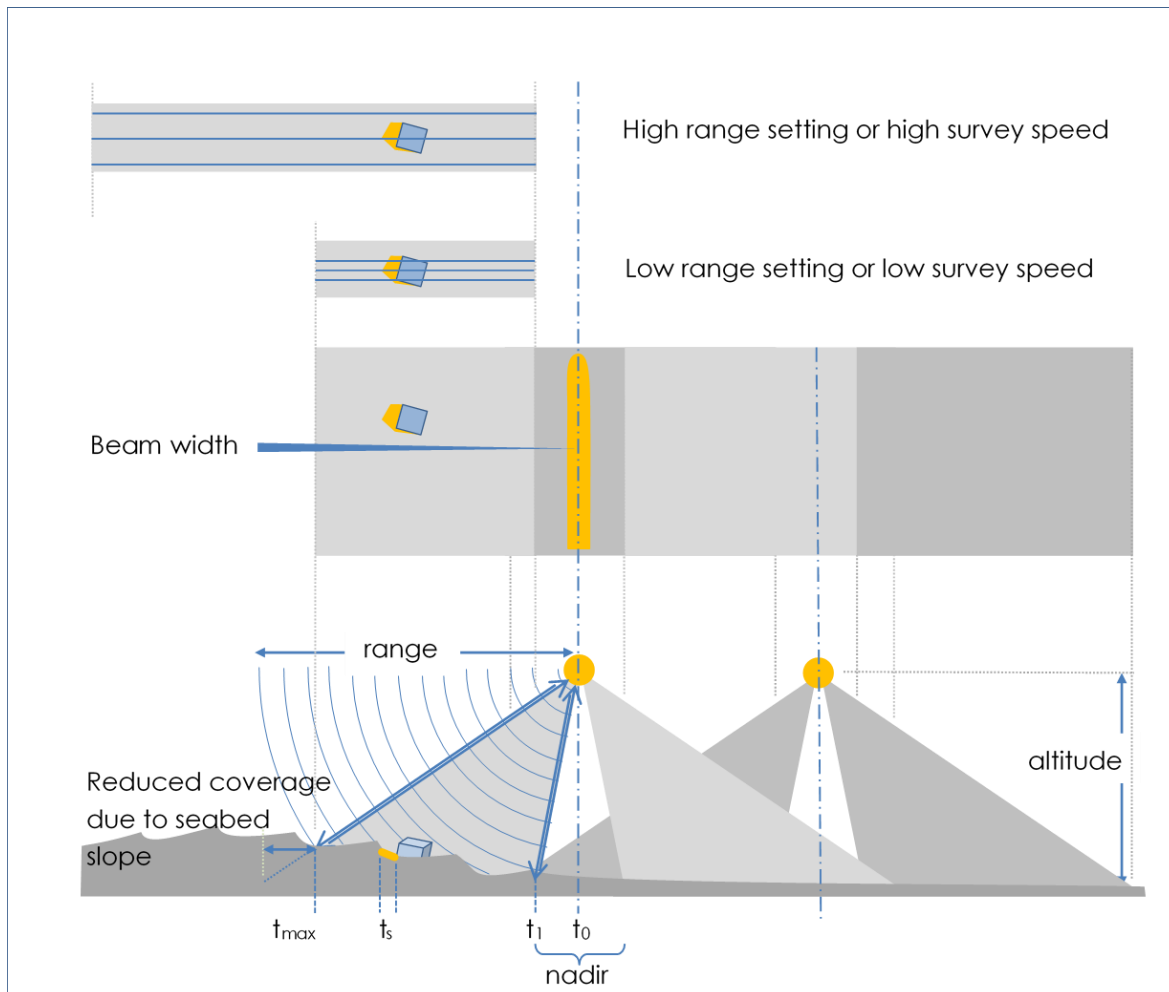


Figure 14: Schematic diagram illustrating factors influencing the configuration of a Side Scan Sonar survey.

The range, altitude and frequency of the sonar pulse determine the across-track resolution of the data. Along track resolution is also influenced by the range setting, as this determines the 'record time' required to log returns from objects at the maximum range; as only one pulse should be active per record, the record time sets the pulse rate and therefore the number of pulses per metre at the towed speed of the fish. Figure 14 contains a simplified illustration of this situation, though instruments may implement multiple pulses with different ping signatures (small differences in pulse shape) to allow a greater along-track measurement rate. There is an influence on the lateral resolution by the beam width, a function of frequency, but this is likely to be secondary to the pulse rate in determining along track resolution.

Typical maximum effective range for various pulse frequencies are presented in Table 28.

Table 28: Maximum effective ranges of various frequency side scan sonars (Taken from the product sheets accompanying products from Klein and Edgetech)

SSS dominant Frequency	Maximum effective range
75KHz	700-800m
100kHz	600m
120kHz	250-500m
270kHz	150-300m
410kHz	130-200m
455kHz	200m
500Khz	150m
540kHz	100-150m
850kHz	50-75m
900kHz	75m

It should be noted that these ranges are considered the maxima in ideal conditions. Edgetech state within a technical note that:

“Maximum range may be given to mean the ability of the operator to see the echo of a large target above the obscuring noise. The difference in the maximum range...for the same sonar may be as great as 30-50% of stated range” (Edgetech Application Note, Sidescan Sonar Range, 2007).

Effective sonar range is limited by environmental and operational conditions including:

- water temperature and salinity;
- thermoclines;
- haloclines;
- water depth limiting geometry (shallow water);
- environmental conditions including, currents, tides and weather conditions.

Most of these conditions may also lead to potential uncertainty in the conversion of the SSS profile from a time to a range.

Due consideration needs to be given to all of these during the planning stage and operators will often employ some basic rules of thumb based on the configuration of the instruments such as:

- SSS should be flown at an altitude 10-15% of its range, above seabed for optimisation;
- the sweet spot for imaging objects on a single channel is between a 1/3 and 2/3rds of its range;
- full coverage of a site is required to ensure the nadir below an SSS track is covered from adjacent lines.

It is important to note that whilst theoretical coverage should be 100% of the survey corridor, the limiting factors outlined above can limit effective range. A good example is within the Baltic Sea where the thermocline is a known problem for effective sonar ranges. It is important that both the operator and clients’ representative are satisfied that full coverage has been achieved and to check that no infill is required before leaving the survey area.

Higher frequencies (>500kHz) with the shorter ranges (<50m) give the best resolution when data is played back on PC monitors during the interpretation phase, which highlights the need for good quality widescreen monitors, linked to powerful hardware for interpretation. This interpretation relies on accurate positioning of the SSS fish as this is generally towed at ranges of 3-5 times the water depth behind a survey vessel. Interpretation needs to be consistent with targets presented within complimentary datasets, including the MBES and magnetometry data.

Key parameters and DQOs are presented in Table 29.

Table 29: Target and survey parameters for Side Scan Sonar

Scope Requirement	Measurement Parameter	Controlling Parameter	Suggested Guidance	QA metric
Smallest detectable object dimension	Across-Track Resolution	Frequency Speed of sound in water	3 samples per min. dimension	Continuous recording Sound velocity profile Sensor attitude
	Along-track resolution	Ping rate Vessel speed	3 pings per min. dimension	Continuous recording Vessel speed Sensor attitude
Vertical detectability	Acoustic shadow length	Sensor altitude Sampling rate	Vertical uncertainty < 1/3 of the smallest vertical target dimension	Sound velocity profile measurements Altimeter / USBL uncertainty
Coverage	Navigation	Instrument positioning Instrument Attitude Range Seabed Slope Sound velocity	200% coverage with no nadir gap	Navigation uncertainty Altimeter / USBL uncertainty Coverage plot

Note that while SSS tend to have a smaller beamwidth than MBES devices, and are flown closer to the sea bed, their ability to detect and measure seabed objects is limited by the instrument characteristics, survey design and setup parameters described above. The precision at which seabed objects may be located by SSS alone is limited by the precision of the positioning (typically by USBL) and attitude of the fish (by internal attitude sensors). It is important to recognise the contribution of all these factors in the scope requirement, survey design and QA metrics to ensure that a coherent and achievable scope is set.

3.5.5.6 Sub-bottom profiler

A sub-bottom profiler emits an acoustic pulse into the water column, this pulse is partially transmitted into the sub-seabed and reflected from various boundaries within the geological column.

Reflections occur at boundaries in acoustic impedance, boulders should reflect acoustic energy as long as the spectrum of the acoustic pulse and the geometry of the SBP ray paths are suitable. 2D SBP does not (economically) provide full coverage of the sub-seabed, but 3D SBP can represent an important resource in the location of sub-surface boulders.

Reflections may occur at surfaces, or at point or line discontinuities as diffractions. Boulders may return only diffracted events, or a combination of surface reflection and diffraction for larger items. A

2D (linear) SBP survey delivers reflection data in a region immediately below the survey line, while a 3D SBP survey delivers a contiguous volume of data within a certain resolution. Point diffractions may be returned from positions laterally displaced from a 2D SBP survey line; caution must be exercised in assigning precise locations to the source of such events.

The frequency of the acoustic pulse of an SBP is generally lower than that of an SSS or MBES instrument in order to penetrate the sub-seabed without excessive loss of energy to scattering and absorption, therefore ultimate resolution is generally lower than that of methods targeting only the sea floor. Vertical resolution, and horizontal footprint (a Fresnel zone, conceptually similar to the beamwidth of SSS and MBES devices) are larger as acoustic wavelengths are greater. These are generally of the order of decimetres to metres, and approximately correlate to the scale of the smallest detectable object. The highest frequency SBP acoustic sources are solid state devices found in parametric, pinger or chirp systems. These are usually classed as shallow penetration systems and are most often deployed for surveys requiring information at high resolution to depths relevant to cable installation. These often the sources for 3D SBP systems proposed for sub-seabed boulder detection. Lower frequency sources may be used – electrostatic sparkers, boomer-type devices using electromagnetic repulsion of metal plates, and even small airgun sources. These are more often deployed where the survey is required to have greater penetration for an alternate purpose such as foundation design. Lower frequency sources tend to have lower vertical resolution, and may have lower horizontal resolution – incorporation of such data into the knowledgebase for management of boulder risk should be done with awareness of the limitations of lower resolution data.

Figure 15 illustrates the geometrical principle of a single channel, 2D SBP recording surface and diffraction events. 3D SBP systems are more complex but conceptually can be reduced to a 3D array of raypaths returning an ‘umbrella shaped’ diffraction signal. Identification of boulders is typically dependent on the ability to identify the hyperbolic pattern, so requires sufficiently small trace interval to populate the hyperbola with (say) > 10 data points.

The acoustic pulse is generated at intervals along the survey line $S_1 - S_5$, reflects at boundary at A and returns along a similar raypath to a receiver normally close to the source. Reflections from subhorizontal layers would have a sub-vertical raypath. Diffracted rays can be significantly non-vertical – the ray paths associated with shots $S_1 - S_5$ indicate the group of rays reflecting from a diffracting target. As the raypaths of the non-vertical rays are longer, their reflections return to the receiver at later times at greater offset from the target, resulting in the hyperbolic signature along-track illustrated in Figure 15. Note that a diffraction can be recorded from a target laterally offset from the 2D seismic line, whereas a surface reflection can only appear from an off-line reflecting point if the surface is dipping laterally.

Diffracted events are the primary indication of smaller boulder targets on SBP data. Differentiation between diffractions from UXO and boulders is unlikely to be made from smaller contacts as resolution is not generally sufficient (diffractions do not yield the dimensions of their source), but for larger targets (occupying > 5 seismic traces) *some* indication of the dimensions of a target may be derived from specular reflection events in migrated 3D SBP data. As illustrated in Figure 15, location of these targets on 2D SBP sections is reasonably accurate in the along track direction, but uncertainty in the across-track direction is of the order of the width of the diffraction hyperbola observed on the section. Diffracting bodies further than the half-width of a hyperbola from a 2D line are unlikely to return an interpretable image. A diffraction on a 3D SBP survey is a dome shape, so a key benefit of a well-parameterised 3D SBP survey is the ability to detect and locate sub-seabed point diffractors without the across-track uncertainty of the 2D method.

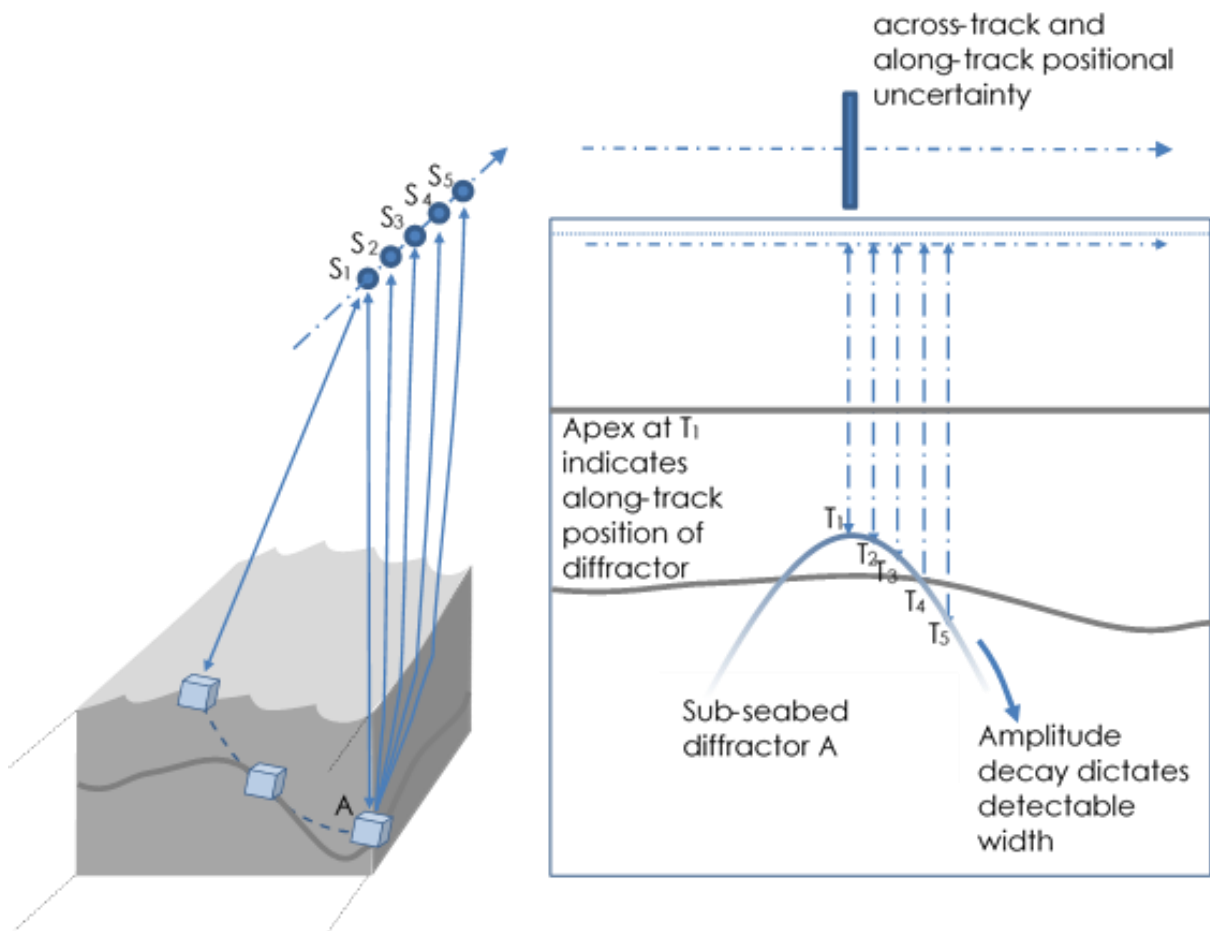


Figure 15: Schematic illustration of the configuration of diffracted events on Sub-Bottom Profiler measurements.

The line spacing that would be required to create ‘full coverage’ for detection of UXO or boulders using 2D SBP would be very small and is generally considered uneconomic. 3D SBP at a useful resolution for UXO detection is also relatively expensive and generally implemented as a very focussed survey. Resolution of 3D SBP solutions is very dependent on the method implemented, but is fundamentally controlled by the wavelength of the source.

SBP is often the only means of imaging beneath the sea bed. As such its output can be used to qualify assumptions on the relationship between the number of targets (generally boulders) observed at the sea bed and the number present sub-seabed. Geological interpretation of the SBP data is also a useful tool to establish context within which boulders are located – e.g. particular layers, or infilled channels. Thus, SBP is one of the measurements that is likely to contribute to risk management associated with boulders, UXO, engineering considerations and seabed mobility. Care is recommended to assure that the parameterisation of SBP investigation is suitable for the purpose for which it was commissioned, and any compromises are worked through and accepted before survey work starts.

Successful recording and interpretation of reflected energy from subsurface bodies is dependent on a number of factors. Source power and frequency, together with the material properties of the sub-seabed medium are the primary controls on the distance an acoustic pulse will travel. Source spacing determines the number of traces contributing to a diffraction hyperbola. The bandwidth of the acoustic source is significant – higher bandwidths allow the creation of a sharper pulse either at the source, or after processing in the case of a chirp type device. Weather conditions, particularly the degree of aeration of the water around the instrumentation can represent a limiting factor. Some representative source characteristics are provided in Table 30.

Table 30: Typical operating characteristics for common 2D sub-bottom profiling instruments

Sub-Bottom Profiler	Typical Frequency (Hz)	Resolution and Penetration	Comment
Parametric	4000-15,000	Resolve layers $\leq 10\text{cm}$ typical penetration 5-20m	Good for imaging soils, highly directed beam may not return extensive diffraction
Pinger	2000-7000	Resolve layers $\leq 20\text{cm}$, typical penetration of 5-10m	Ideal for imaging soils structure within DoB of a cable.
Chirp	1000-8000	Resolve layers $\leq 15\text{cm}$, typical penetration of 5-20m	Similar to pinger with greater range of resolution and penetration
Sparker	50-4000K	Resolve layers $\leq 0.5\text{m}$, single channel up to 50m+, multichannel 300m+	Extensive range of sparkers within the industry, ideal for foundation design studies, data can be used for inter array cable installation, not ideal for route surveys as resolution with top 1m below seabed is often compromised.
Boomer	300-3000	≤ 0.3 resolution up to 50m+	A good second tool to consider for Cable route surveys

Data processing of single-channel SBP data are fairly straightforward, as with all acoustic techniques the recording of the reflected pulse at a time after the transmission is the primary data. This has to be corrected for geometric factors and converted to a range (depth) using a representation of the speed of sound in the water and geological components of the raypath.

As co-location of identified targets on SBP, SSS, MBES and magnetometry data is critical to the avoidance of excessive inspection costs, instrument positioning and recording of navigation data are critical. SBP data should be corrected for vertical offset due to tide and platform heave.

SBP data may be acquired as a multi-channel survey which involves recording reflected signals from a source into multiple receivers. These may be towed in line, or nearly in line with the seismic source as a '2D' survey, or distributed as an array both in-line and across the track of the survey as a '3D' survey. The primary benefit of a 2D multi-channel SBP is the improvement in signal-to-noise ratio particularly at depth. However, it is also possible, with appropriate geometry, to configure a multi-channel survey to deliver closer trace spacing than the shot spacing, and therefore potentially improve the resolution of diffraction hyperbolae.

If the perceived risk from poorly located buried boulders remains above what can be considered acceptable by the project then the possibility of a separate, targeted 3D SBP campaign could be included. The logistical requirements, cost and time for this is likely to be significantly higher per square metre than 2D SBP survey.

3D SBP methods may be deployed by ROV or deployed at the surface, and use a variety of methods to create a volume map of the subsurface. Various combinations of beamforming and synthetic aperture techniques may be implemented in an attempt to measure as large a volume per instrument pass as possible. All are characterised by a dependence on the sound velocity profile in water and the sub-

seafloor for successful data processing and location of objects. Precise location of the components of the survey is also critical.

Both beamforming and synthetic aperture techniques are susceptible to the introduction of noise through positioning and velocity errors. The methods of processing are under continuous, relatively rapid development, so a cautious approach is advised with carefully specified DQOs. Careful processing and a focus on optimising signal to noise is appropriate though it is important to recognise that these operations do not necessarily lend themselves well to rapid delivery of results. However, the potential value of a well-executed 3D SBP survey is significant in the precise location and delineation of subsurface objects, potentially covering the entire plausible range of depths of interest for cable installation.

Specialist contractors tend to provide the 3D SBP data of interest to boulder risk mitigation. There are relatively few of them, and relatively few geophysical consultants and offshore client representatives that can support the survey from an experienced and informed position.

Most 3D SBP implementations require reasonably good understanding of the principles of operation of the equipment to define a robust survey plan and set of QA metrics. However, it is likely that instrument positioning, source spectra and seismic velocity will be common to all.

Key operating parameters and possible DQOs are provided in Table 31.

Table 31: Target and survey parameters for 2D Sub bottom profiling

Scope Requirement	Measurement Parameter	Controlling Parameter	Suggested Guidance	QA metric
Smallest object to be detected	Measurable reflection	Seismic source bandwidth Seismic wavelet	Wavelength <~ 4 x smallest required depth resolution Wavelength <~ smallest target object dimensions	EVT Source power monitor
	Trace spacing	Shot and receiver spacing	10 traces per diffraction width	Trace spacing profile Fold plot
Maximum depth of investigation	Maximum depth of coherent reflection	Seismic source power Seismic source bandwidth Signal to noise ratio Weather and sea conditions Subsurface conditions	Signal to noise ratio > 3	Seismic sections

For 3D SBP the configurations of systems and the post-processing methods implemented by different contractors are generally proprietary and pivotal to the resolution of the acquired data. It is important to ensure that a clear scope requirement is set, and the survey parameters and (critically) QA metrics

agreed with the provider as properly indicative of performance. At this time, there is little precedent and reliable generic rules of thumb do not exist.

3.5.5.7 Survey design

The required target specifications output are used with the controlling parameters in sections 3.5.5.3 to 3.5.5.6 to provide the survey design boundary conditions to be implemented.

Key parameters are the required instrument sensitivity, the required measurement density (e.g. line spacing) for each measurement type, vessel speed limits (normally a maximum but with towed equipment a minimum speed is also important to maintain control) and the survey boundary required. Note that the use of different survey platforms (surface vessel, ROTV, ROV, AUV) with different drafts and weather tolerances may have a strong influence on line plans and operational considerations.

The survey boundary may be restricted to the survey corridor or the engineering corridor illustrated in Figure 16, to minimise cost. This highlights the need for diligent version control to ensure that all changes in the engineering corridor are applied to the geophysical survey design.

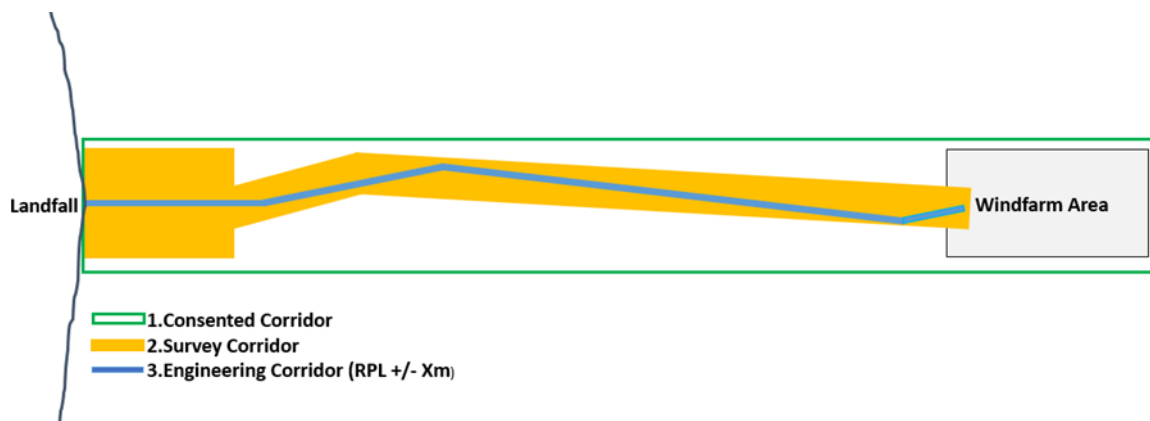


Figure 16: Survey boundaries

It is likely that multiple objectives will be included in survey design, and compromises to survey performance as a result should be evaluated objectively.

3.5.5.8 Notes on the selection of line spacing

Once a survey boundary has been defined it is important to ensure appropriate coverage of the corridor for all of the required data products. Different instruments and methods have different measurement spacing requirements; the instrument with the shortest effective range should be the primary control on planning line spacing. These can change, influenced by instrument altitude, water depth and other environmental conditions. Particular consideration for the range of each measurement type is presented in the subsections 3.5.5.3-3.5.5.6, summarised in Table 32.

For the purposes of cost-effective line running, normally line plans run parallel to the survey corridor, with orthogonal 'tie' lines to enable compensation and QA of time-variant shifts (e.g. tide, solar magnetic field). However, there are circumstances in which this may compromise survey quality or be extremely inefficient, in which case an evaluation of the impact of the compromise versus the cost of a less logistically efficient line plan must be made. If currents/tides, seabed morphology, magnetometry requirements or other operational requirements mean a different line orientation needs to be considered, this decision should be made between survey contractor, onshore client personnel and offshore client representative.

Table 32: Common line spacing specifications

Instrument	Effective line spacing	Comment
Magnetometer/Gradiometer	<1/5 of the smallest expected anomaly half width	Defined by magnetometer performance, altitude above seabed and commonplace definition of smallest threat item.
EM	Dependent on the instrument coil configuration	Defined by the width of the set of EM coils or the effective swath width of the instrument. Specifying overlap requirements and/or multi-directional passes over a potential target may be required.
MBES	Dependent on the configuration of the instrument and its altitude above the seabed	Defined by the outcome of the findings from Operation 1
Sidescan Sonar	Defined by frequency and range required to achieve full coverage and sufficient resolution	Also defined by Operation 1, Need to ensure full coverage under nadir of adjacent lines
SBP	5-50m, should be able to delineate boundaries of geological features within the corridor	Delivers indicative imagery along the navigation track If geological inference is used to predict structurally controlled hazard accumulations or variation in consequence, line spacing must sample the structure in question

At this point a review of the ALR for each potential hazard could be made, particularly where the measurements intended to support mitigation of the hazard are the drivers of survey cost.

Once a coherent set of design parameters and a survey configuration has been established, a scope of work can be created from which to manage the procurement and implementation of survey work. It is important that careful version control of the scope of work is maintained – any updates to the alignment or boundaries of the survey area must be clearly communicated to assure effective transmission to the survey team.

3.5.5.9 Skillset required

It is recommended that geophysical survey experts lead the development of the survey scope, involving UXO risk management experts, representatives of other stakeholders (e.g. archaeology, ecology, environment), and cable installation experts to discuss and agree the final survey parameters. The geophysical experts can inform the key stakeholders of the impact of changes and compromises, and the key stakeholders can most readily judge the appropriacy of the ALR definitions in use and any changes to them that are proposed.

3.5.6 Procurement

Survey fees are generally controlled by a day-rate or a per-kilometre rate, with modulation by the ratio of 'productive' km to unproductive km (e.g. line turns), the number of sensors logging data, risk of downtime due to weather, competing operations, tide or other limiting influences. Contractors and clients may elect to agree commercial terms on a remeasurable, fixed fee or hybrid basis.

The following components should be concluded in a proposal for geophysical work:

- scope of work:
 - survey design;
 - equipment;
 - personnel;
 - vessel and instrument platform;
 - Deliverables list;
 - Reporting requirements;
- required timing;
- quality management requirements:
 - navigation acceptance criteria;
 - positioning data acceptance criteria;
 - geophysical Data acceptance criteria;
 - weather acceptance criteria;
- safety requirements;
- environmental requirements;
- communication and meeting requirements.

3.5.6.1 Skillset required

Commercially skilled personnel should manage the procurement process with the close assistance of geophysical and UXO risk management experts to ensure that modifications to the requirements do not unacceptably compromise the objectives of the work. It may be beneficial to recognise that data acquisition, processing and interpretation may be different specialisms requiring the involvement of additional personnel, particularly for innovative methods, demanding applications or otherwise unusual circumstances.

3.5.7 Start-up

3.5.7.1 Project documentation

It is considered best practice to create and work from a set of Project Documentation that should include a Project Implementation Plan, a Safety Plan, Quality Plan and Environment Plan. These documents are the translation of the survey objectives defined by the scope of work into the operational practice of the contractor selected to perform the work. They are the working guidance for contractor personnel and the CR, and as such are critically important to the operation of the survey.

The data objectives defined by Phases 1-3, together with the survey design parameters and the DQOs chosen should be presented together in the Project Documentation to provide a concise and coherent guide to the required parameters of the geophysical survey programme.

Preferred structure and content of the project documentation will vary between contractors and clients and it may be advantageous to construct bridging documents to map between critical elements of operational documentation (particularly emergency response plans and safety plans).

Production data acquisition should in every case be preceded by documented approval by the client of project documentation, mobilisation, and the equipment verification tests (EVT).

Any deviation from the agreed plans should be agreed by the client, by a specified process either directly or via the CR, and it is recommended that every deviation is evaluated specifically for its potential impacts (positive and negative) on the project objectives and performance requirements.

Project documentation should include details of all progress reporting requirements and DQOs including templates and schedules as appropriate.

3.5.7.2 Mobilisation

As field operations start a systematic set of checks are required to enable validation of the survey outputs as suitable for inclusion in boulder risk management activity. Geophysical surveys generally include mobilization and calibration operations, confirming and documenting the vessel configuration, calibrations and operational state of its instrumentation. UXO work demands a higher standard of validation, normally including an Equipment Verification Test (EVT) designed to observe and validate the performance of the detection equipment in its full survey configuration and to provide cross-validation of the sensing and positioning performance of multiple geophysical instruments in sensing a single target object. In some cases, an additional Surrogate Item Test (SIT) is appropriate, defined here to be operations using a known object to optimise the survey parameters for a target. While EVTs are expected for UXO surveys and are recommended for boulder surveys, SITs are not regarded as a requirement for all surveys and should be implemented with care where the characteristics of a survey make such a test beneficial. SITs are not described in this guidance as they are both survey and instrument dependent, the method, deliverables and QA of a SIT should therefore be agreed by the client, their UXO specialist, CR and geophysical expert prior to the test. Conclusions based on EVT and SIT must be logically robust – both tests can only confirm performance in the test itself and cannot unequivocally guarantee detection of a different target elsewhere.

3.5.7.3 Testing and calibration

Prior to departure for production work, Equipment Verifications Tests (EVT) or Surrogate Item Tests (SIT) a survey vessel must be configured according to the commitments made in the scoping and procurement phases. This configuration must be tested and validated as acceptable by the client (usually a client representative) including validation of:

- navigation systems and co-ordinate reference system;
- instrument positioning equipment;
- geophysical equipment;
- survey systems;
- operating procedures;
- survey planning;
- comms and reporting procedures;
- safety management systems;
- emergency response plan.

Mobilisation and Calibrations are reported quickly and signed off by the CR. It is recommended that the CR should work to an agreed checklist to ensure that all required validations are included.

3.5.7.4 Equipment Verification Test (EVT)

Prior to performing the contracted Boulder-specified geophysical survey an Equipment Verification Test (EVT) should be undertaken by the geophysical survey contractor. This task should be performed once the mobilisation and calibration of the survey equipment has been accepted by the Client. The necessary assessments and calibrations must be performed according to the manufacturer's specifications or generally accepted procedures.

The intention is to fulfil the following objectives:

1. Document the capabilities and limitations of each geophysical detection instrument selected for boulder risk mitigation including positioning.
2. Observe each geophysical detection instrument operating in the contractor's configuration, using the Survey Contractor's personnel and methodologies. This should include ensuring noise levels are within acceptable limits.
3. Evaluate the Survey Contractor's data acquisition, data transfer quality, and data QC method.
4. Evaluate the Survey Contractor's method of data analysis and evaluation.
5. Illustrate how predictive responses and how the equipment performs in accordance with a known discrete item on the seabed.

Ultimately the intention is to provide evidence that the configuration deployed meets the criteria needed for the boulder risk management strategy.

It may be suggested that an EVT may be extended to evaluate a linekeeping tolerance either laterally (survey line deviations) or vertically (altitude deviations). However, care must be taken to recognise that the test item may not properly represent the smallest target to be detected.

3.5.7.5 Important considerations

Through the evolution of offshore geophysical boulder survey and data analysis, several key lessons have been learned that should be acknowledged:

1. There are rarely occasions when an EVT shall not be performed ahead of a UXO-geophysical survey. Boulder surveys do not have such a strict recommendation, but EVT is likely to be of benefit. An EVT shall be performed if faulty equipment has been highlighted and new instruments introduced.
2. It should be recognised that pursuit of an optimised data acquisition and data processing parameterisation for a test object, or tuning of a system to detect marginal responses, can lead to significant uncertainty in the timing of survey work. Such tuning should be made with caution if contractor and client are confident the genuinely representative targets *and* the conditions of the surrounding material are available.
3. Substitutions or alterations to the EVT plan may need to be considered if, for example, the Survey Contractor can demonstrate suitable tests that fulfil the verification objectives. Such changes or exceptions to this specification shall be clearly described and presented to the Client.

3.5.7.6 EVT planning

The EVT methodology should be included in the Survey Contractor's Project Documentation (e.g. the Project Implementation Plan). This should be approved by both the Client and their specialist Consultants.

As a minimum, the following aspects should be covered:

- description of the test item;
- launch and recovery of the test item;
- location recognisance to locate a magnetically “clean” and relatively featureless area of seabed for the EVT;
- deployment location of test;
- line planning;
- reporting and data outputs.

The selection of the test item makes up the first stage of the EVT process. The item should not necessarily aim to replicate a specific item but provide a repeatable and meaningful test for the survey array to ensure all sensors and positional systems are functioning as designed.

For this, typically a tubular section of rolled steel with appropriate lifting eyes is sufficient, although alternative items would be considered. Should an existing item be available with similar suitable dimensions, it is acceptable to use such an item over the fabrication of a new item.

3.5.7.7 EVT data acquisition

The EVT should aim to replicate survey activity contracted by the Client, therefore all sensors which are to be run in the full survey should be utilised and recorded. The test should take place close to or on the location of the Project to ensure conditions during the test are as representative of the full survey as possible.

The EVT should be witnessed by the client’s offshore representative.

Typically, the geophysical survey contractor proceeds to live data acquisition once they are satisfied with the EVT data. However, this is at their risk pending formal acceptance onshore.

3.5.7.8 EVT deliverables - report

Following the undertaking of the EVT, a full report should be issued to the Client and then made available to their specialist consultants for review and acceptance. This report should include:

- EVT item description and images;
- brief methodology synopsis;
- imagery of MBES, annotated with EVT item highlighted;
- imagery of MBES with all targets from all datasets plotted;
- imagery of SSS, annotated with measured dimensions of targets;
- imagery of MAG and/ or EM (all runs) with MBES target plotted;
- target details from all datasets: MBES (easting, northing), SSS (easting, northing, length, width, height), MAG and /or EM (easting, nothing, altitude, residual peak to peak nT);
- positioning comparison table;
- positioning comparison table using MBES position as test item’s true location in relation to SSS and MAG and/or EM targets.

3.5.7.9 EVT deliverables - datasets

As a minimum a data package equivalent to the example in Table 33 shall be presented alongside the EVT report. This example is written for a survey conducted using magnetometry, using files associated with the software package Oasis Montaj from Geosoft as a delivery medium. The content of the data package for EVT shall be agreed as part of the project documentation, prior to commencement of the test. Deliverables may be adjusted to suit the measurement technology and software package in use. These data are usually transferred via electronic file transfer.

Table 33: Example EVT deliverables

EVT Data Requirements	Description	Format/ extension
Magnetometer	Oasis Montaj Project (containing the following presented in a data linked Map)	-
	Oasis Montaj Database (with processing and QC channels remaining)	.gdb
	Total field Residual Grid	.grd/.flt
	Analytical Signal Grid	.grd/.flt
	Altitude Grid	.grd/.flt
	Target List including; Unique Target ID, Easting, Northing, Residual Field (nT) Peak to Peak Value, Analytical Signal, Sensor Altitude (m), Wavelength (m)	.shp/.csv
Magnetometer	Sensor track plot	.shp
Side Scan Sonar	Georeferenced Mosaic	.tif
	Target List including; Unique Target ID, Easting, Northing, Length (m), Width (m), Height (m), Interpretation/description, Confidence Rating	.shp/.csv
Multibeam Echosounder (MBES)	Georeferenced MBES Grid (0.25m)	.tif

3.5.7.10 EVT validation and formal acceptance

On review of the necessary information a competent organisation should issue a document clearly stating that the EVT has been successful and the data can be relied upon for boulder risk management purposes. This shall be issued within 48hrs of the data and report being available.

3.5.7.11 Skillset required

EVT design, implementation and QA is an important part of the validation process of a survey to be used in boulder risk management and as such should be performed by personnel with demonstrable and documented skill in the use of the geophysical systems deployed and UXO risk management. As the EVT is required to be formally accepted, personnel making this acceptance are required to be formally competent. Ideally the UXO specialist contracted to provide the final interpretation should be involved.

3.5.8 Production data acquisition

Data acquisition should progress with the involvement of an offshore Client Representative (CR) who is effectively briefed on the motivation for the survey work and the reasoning behind the scope of each element. The documentation generated in previous sections will allow the offshore CR to

understand the survey well and make rapid operational decisions coherently with the survey objectives.

3.5.8.1 Data acquisition

Geophysical data acquisition requires the co-operation of marine personnel, engineering personnel and geophysical personnel to maintain a robust and safe survey performance. Operations may be undertaken from smaller day craft to large vessels capable of supporting 24hr working for long campaigns. Teams and equipment configuration may be well established, or assembled temporarily for the survey.

Use of effective Project Documentation as a working manual for the production data acquisition is key to a predictably run campaign particularly for an unfamiliar configuration.

3.5.8.2 Quality management

Data quality management during survey acquisition should be focussed on assuring that the data are acquired such that they satisfy the QA criteria (DQOs) set during the project scoping and setup phases. A high priority should be assigned to the assurance that data are recorded and secured at an early 'raw' stage, such that any mistakes in handling or processing data (offshore or onshore) can be recovered.

'Fitness-for-purpose' is not a useful phrase in this context as contractors are unlikely to assume the liability of promising this. CRs, though generally selected to be experienced and can be well briefed, may be too 'temporary' in the project to take responsibility for evaluating fitness-for-purpose as well. Therefore, a set of objective quality metrics (DQOs) is recommended as the basis for unequivocal data evaluation. The quality metrics should be established from the key parameters for each survey methods, agreed between client, CR and contractor, and tolerances and thresholds documented before production acquisition begins.

The CR should provide confirmation that the objective quality metrics are being adequately monitored and met, that operations are safe, that downtime is properly justified and recorded and that the client's objectives for the survey are being reasonably met.

3.5.8.3 Skillset required

Data acquisition requires diverse skillsets:

- marine skills to operate and maintain the survey vessel;
- marine skills to sail the survey vessels within the linekeeping tolerance;
- logistics skills to ensure that equipment, supplies and personnel are organised;
- engineering skills to deploy and operate the geophysical equipment;
- geophysical skills to record, process, perform QA operations on geophysical data;
- QA skills including client representation to assure project quality;
- reporting skills to produce and deliver outputs.

3.5.9 Data processing

Data processing is defined here as operations performed on survey data to transform raw information into properly located geoscientific data with optimised signal to noise ratio. Data processing generally does not involve 'interpretive' decisions (e.g. processes designed to emphasise an interpreted characteristic of data) although there are unavoidable exceptions to this that should be carefully managed (e.g. the development and implementation of a velocity field for time-to-depth conversion).

Each of the geophysical methods has its own data processing requirements, with the common factor being the integration of the measurement with the positioning data. It is recommended that a record of navigation data from GNSS systems, and any data from inertial navigation systems used to interpolate GNSS point fixes is kept in addition to integrated geophysical and navigational data records.

Data processing operations and QA processes, including all required DQOs, are recommended to be included at an appropriate level of detail in the Project Documentation to maintain focus on the survey outcome.

3.5.9.1 Digital seabed model

Processing of MBES and SSS data contributing to the digital seabed model should follow well established hydrographic principles. In general, the bathymetry dataset is expected to represent the primary reference for positioning of objects, with the SSS data used for identification of objects. Hydrographic standards set by the IHO do not include quantitative specification of MBES or SSS data density for objects of characteristic dimensions of UXO; it is recommended that survey-specific thresholds and QA tolerances are established to augment the guidance and QA standards set by the IHO.

3.5.9.2 Magnetometry and EM

Processing of magnetic field and EM data can be described in phases:

- import of raw data and attachment of positioning information;
- data cleaning – removal of instrument noise, natural noise, vessel induced noise;
- levelling, gridding, calculation of gradients and derived products;
- separation of regional (long wavelength) and residual field (short wavelength);
- identification of anomalies potentially representing targets.

These operations can be applied in various data processing packages, offshore or onshore, using parameterisation defined using objective criteria for optimisation. QA products for data processing operations could include:

- verification of positioning and coverage;
- inspection of noise removed for indication of removal of potential signal;
- difference plots between grid and levelled point values;
- gradients, 4th difference and other error indication maps from grids;
- inspection of regional field for possible remainder of residual signal;
- inspection of final data vs. raw profiles for verification of the preservation of signal wavelength and amplitudes.

It is recommended that a set of QA products is agreed between client, geophysical specialist and contractor(s) prior to the commencement of data processing activity.

It is recommended that consideration is made for the necessity for real-time or near-real-time results from geophysical surveys. If real-time processed data is not required, it *may* reduce project risk and improve quality to allow a more measured approach to be adopted with some delay before delivery of data. However, it is important to ensure that resources are available for such activity for as long as is necessary post-mission to complete work with uniform quality, and that reporting deadlines are compatible with a processing delay.

3.5.9.3 Sub-bottom profiler

Data processing of sub-bottom profiler data can be described in phases:

- import of raw data and attachment of positioning information;
- data cleaning;
- amplitude compensation;
- datum reduction;
- signature processing;
- imaging (stack, migration).

Within these generic categories there may be wide variation in process content and order between instrument types, particularly between single and multi-channel configurations, 2D and 3D configurations, and the different sources implemented pingers, chirps, parametric and sparker or boomer devices. Quality management should be survey specific, but may include:

- verification of positioning and coverage;
- inspection of noise reduction processes to verify the integrity of signal;
- confirmation of datum reduction quality including depth reference;
- confirmation of polarity, phase and stability of the wavelet;
- evaluation of consistency of spectra, signal-to-noise ratio and amplitude;
- confirm consistency of depth converted SBP data with bathymetry;
- confirm the integrity of the output files including key header information.

Multi-channel and 3D surveys involve more complex data processing sequences, with dependence on skilful parameterisation to optimize performance. There is greater emphasis on imaging processes that present features on the sub-surface data volume closer to their actual position, and these processes are often critically dependent on the use of an appropriate seismic velocity field.

Careful determination and QA of the velocity field should be a feature of all surveys based on multi-channel, 3D or imaging principles. In the context of cable installation, the limited range of depth often leads to the use of a simple velocity model. For some circumstances, this is reasonable. However, this should be confirmed explicitly, as there are situations in which rapid lateral and vertical velocity variation can introduce errors. Velocities for 3D SBP surveys are potentially significant particularly where beamforming and synthetic aperture techniques are applied. In these cases, the velocity profile in the water column is also important. It is recommended that sensitivity tests are made for 3D SBP surveys, and appropriate QA metrics adopted and parameterized to suit the method and configuration in use.

3.5.9.4 Quality management

It is recommended that a skilled geophysicist be assigned to oversee the various data processing operations and to specify, inspect and document an appropriate array of data processing QA operations and products. Data Processing QA should include systematic documentation and verification of parameters that influence the output. The fundamental principle that processes designed to reduce noise should minimally impact the desired signal are valid and provide a basis for systematic optimization of the data processing operations and provide simple, objective quality assurance measures.

Data processing can be performed offshore or onshore, with more complex or time consuming or technically demanding operations possibly taking place onshore. This must involve transmission of data to an onshore facility. It is important to establish a set of offshore processes that will provide assurance that data are of sufficient quality to be processed successfully onshore to avoid delays to demobilisation.

3.5.9.5 Skillset required

It is recommended that personnel with geophysical and hydrographic skillsets are assigned to perform data processing and to provide QA in this context. It is recommended geophysical experts are involved as required to ensure that the QA of the data is sufficient to qualify the data for use in boulder risk management.

Many of the more commonplace geophysical systems have well established workflows and software in place to process data and these could be used successfully by relatively inexperienced personnel. While this is clearly an advantage, it is also important to ensure that personnel with less experience are supported by experts to mitigate the propagation of errors.

Geophysical methods that are less commonplace – 3D sub-bottom profilers, EM and magnetic gradient systems may have less developed workflows and support software and particular care should be provided here to ensure that sufficient personnel are available with the appropriate skills in both the application of data processing (contractors) and assurance of its quality (client).

3.5.10 Interpretation

It is likely that individual geophysical specialists, cable installation specialists and developers may have a variety of preferences for interpreted data dependent upon experience, position of the survey in the project timeline, and other factors.

Initial Interpretation for boulders outputs contacts lists with components including:

- unique index number;
- co-ordinates;
- seabed elevation at contact (estimated elevation from bathymetry adjacent to the boulder, or boulder peak minus height from SSS);
- anomaly characteristics – length, width, height;
- comments;
- possible association with contact indices of other measurements.

SSS interpretation is required as an independent activity, generating a primary seabed contacts list (as SSS is generally the highest resolution method applied).

MBES interpretation may be undertaken. However, resolution is unlikely to be sufficient to identify or describe boulders independently. The MBES data do represent a good source of positional information if a magnetic and/or SSS contact can be confidently related to an MBES feature, and in this situation, it is recommended that position from MBES is used as the primary position reference.

High quality (low noise) data are expected to have fewer false positives. Lower quality data, whether due to higher noise or weaker coverage, are expected to require a greater degree of skill to eliminate false positives. False positives may result from noise or distortion in geophysical data.

Data with gaps in coverage of raw data may include ‘false negatives’ and also distorted anomalies caused by data processing operation acting on undersampled data.

It is helpful to include a comments column in a contacts list to describe the circumstances of the contact and potentially any observations made during the development of the geophysical dataset that may influence the classification of an anomaly.

The interpretation of boulder contacts may be made by contractors associated with the data acquisition, by third party contractors, client personnel or others. Various automated and semi-automated boulder picking tools are under development at the time of writing, with the potential to vastly improve the turnaround time of boulder mapping exercises. Automated and manual processes require diligent QA metrics and processes to assure the accuracy of their product.

The key deliverable is an objectively interpreted contacts list with advisory notes. Where boulders are numerous, it may be acceptable to define a region as a boulder field possibly with a number of boulders per unit area. If this approach is taken, it is recommended to approach each class of boulder in the hazard register separately to ensure that each are mapped appropriately – for example isolated large boulders within a field of cobbles should still be explicitly identified.

3.5.10.1 Skillset required

The development of an initial contacts list requires personnel skilled in the inspection and interpretation of geophysical datasets and the ability to organise and maintain a potentially large database of contacts. Involvement of engineering specialists is recommended as detection thresholds are established, and these personnel should be part of the QA process for the initial interpretation.

3.5.11 Reporting

The creation of a coherent record of the outcome of the survey and its analysis is the primary objective of the survey work. The data required to be returned to the risk management process are target locations and uncertainties (ideally in location, and uncertainty in classification). Depending on the point in the project development that survey work is implemented, a variety of representations of targets may be appropriate:

- explicit target listings;
- target densities per unit area;
- target densities per unit volume.

As the explicit identification, location and measurement of individual targets remains a labour intensive and time-consuming task, careful consideration should be made of the requirements for reporting. If the design task at hand does not require explicit target definition, consider a spatial or volumetric classification, pending explicit re-interpretation of the dataset at a later date. Such considerations can deliver appropriately detailed data.

Target listings should include target index numbers. A clear strategy should be established to handle the correlation of targets between measurements. It is important to recognise that where different measurement methods deliver different responses from the same anomaly it is considered best practice to index apparent targets from each measurement separately, later constructing a bridging table linking the anomalies. In this way the risk of misidentifying clusters of anomalies as a single target is minimised.

A tiered data package is recommended, allowing different groups of users clear access to the data types useful to each without risk of important data elements being missed:

1. Target data
 - a. Contact databases – Magnetometry, EM, SSS, MBES, SBP
2. Supporting data
 - a. Bathymetry
 - b. Side scan sonar mosaics
 - c. Magnetic field charts and profiles
 - d. Electromagnetic anomaly charts and profiles
 - e. Sub-bottom profiler sections or volumes
 - f. Sub-bottom profiler interpretations
 - g. GIS
3. Working data – software-specific project databases
 - a. Magnetometry interpretation project files

- b. EM interpretation project files
 - c. SSS and MBES target picking project files
 - d. Seismic interpretation project files
 - e. GIS files
4. Raw data
- a. Magnetometry raw data
 - b. SSS raw data
 - c. MBES raw data
 - d. EM raw data
 - e. SBP raw data
 - f. Navigation data
5. Reports
- a. Mobilisation, calibrations and EVT reports
 - b. Operational reports
 - c. Data processing reports
 - d. Interpretation reports
 - e. Integrated survey results report.

Geospatial Intelligence Systems (GIS) may be a useful medium for curation, analysis and delivery of a subset of the datasets. It is recommended that GIS files should not be the only medium by which data are delivered unless the format is such that individual data elements within the GIS are independently readable (including their required metadata) by generic tools.

The Integrated Survey Results Report should contain a description of the location, format and metadata format for each of the delivered data elements.

An example tiered data deliverables set is provided in Table 34.

Table 34: Example tiered data delivery

Deliverable	Format	Comments
Target data		
Contact lists	ASCII/PDF	Include target identification thresholds
Boulder density maps	GIS (.shp), Geotiff	Shapefiles and charts at agreed classification intervals
Classification metadata	ASCII	
Supporting data		
Bathymetry DTM	ASCII (xyz)	Resolution as required
Bathymetry Shaded Relief and Slope	Geotiff	Derived product of Bathymetry DTM
SSS Mosaics	GeoTiff	Resolution as required
Magnetometer/Gradiometer field strength	GeoTiff/ASCII	Resolution as required
EM anomaly	GeoTIFF/ASCII	Resolution as required
SBP geological interpretation	XYZ, GIS	Derived from Survey contractors interpretation
SBP interpretation	PDF	Images of contractors' interpretation
Interpreted Alignment Charts	PDF/DWG	Centreline Geological Profile
Seabed Features Interpretation	PDF/GIS	
Centreline Geological Profile	DWG	
Instrument track plots	XY, GIS	
Working Data		
SSS Interpretation	Interpretation Project	Delivered using agreed proprietary software filesystem
MBES Interpretation	Interpretation Project	Delivered using agreed proprietary software filesystem
SBP Interpretation	Interpretation Project	Delivered using agreed proprietary software filesystem
Magnetometry Interpretation	Interpretation Project	Delivered using agreed proprietary software filesystem
EM Interpretation	Interpretation Project	Delivered using agreed proprietary software filesystem
Raw Data		
Magnetometer Data	ASCII	Correct navigation data attached
SSS data	XTF	“
MBES data	ASCII	“
MBES Backscatter data	ASCII/gsf/Geotiff	“

EM data	ASCII	“
SBP data	SEGY	“
Navigation data	P1/90	
Reports		
Mobilisation Report	PDF	Include DGPS verification Gyro Cal MBES cal USBL cal SSS & SBP Trails Magnetometer/Gradiometer set up EVT Narrative of events Conclusions as to results of various calibrations and tests
Integrated Survey Results Report	PDF	Target listings Images of classified target distributions Target register describing minimum hazard objects Target picking criteria for all datasets Minimum target sizes identified Correlation between target lists Description of uncertainties Description of Target Results package Description of Metadata package
Survey Operational/HSE Report	PDF	Operational parameters Vessel and instrument configurations QA operations Survey Logs
Environmental Report	PDF	
Environmental Video/photos	Mpeg/jpeg etc.	

The data collected as part of the survey should be loaded into a GIS project containing the knowledgebase to be used in cable route planning. This data environment will be used for the purposes of further analysis and to assess target locations that may require further intervention. The following is the recommended minimum for what should be considered as part of an effective review:

- current Engineering Corridor (RPL +/- Xm);
- existing infrastructure;
- contacts list;
- shaded relief;
- seabed slope;

- bathymetric values;
- SSS sonar mosaic;
- magnetometer field image;
- interface elevations / isochores as generated from SBP data;
- geological maps generated from SBP data;
- other spatial data e.g. Google Earth images and Admiralty Charts.

With this in place, appropriately skilled GIS operators alongside specialists from UXO, engineering and geoscience should now be able to update the risk register with sufficiently accurate location of the potential hazards anticipated in the desk-top study of Phase 1.

3.5.11.1 Skillset required

Accurate and comprehensive reporting and delivery of the survey output represents the outcome of the geophysical survey campaign and the desired product. Reporting is not confined to the later stages of survey work but includes material generated at all stages.

The Risk management approach to Geophysical Survey Management advocated in this guidance requires some emphasis of the reporting task in collating and coordinating collateral originating from multiple sources without corrupting its integrity.

Skillsets required in the production of the output are:

- geophysics;
- geology;
- GIS and data management;
- communication;
- logistics– preparing and delivering a comprehensive suite of products; and
- project management.

3.6 Summary

A geophysical survey management approach that is fundamentally integrated with the risk management methods commonly used in the mitigation of boulder risk ensures that the design of the geophysical survey is tightly linked to its objectives.

It is inevitable that the involvement of engineering and geophysical specialists will be required. The guidance advocates the creation of clear geophysical data quality objectives associated with the target characteristics, which should enable all stakeholders to understand the linkage between survey type, cost, time and performance. This understanding is expected to facilitate the decision-making process, to make it clear when changes are required and what key information should be included in documentation. Key specifications and Data Quality Objectives are provided for each geophysical method described to facilitate the construction of a comprehensive survey data package with well documented provenance.

4. References

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