A review of the Irish Offshore Renewable Energy (ORE) Sector's data and information requirements in the context of the INFOMAR Seabed Mapping Programme

Review report

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Executive Summary

INFOMAR is a twenty-year project to map the physical, chemical, and biological features of Ireland's seabed, with the current phase concluding in 2026. INFOMAR is funded by the Department of the Environment Climate and Communications (DECC) and is jointly managed by Geological Survey Ireland and the Marine Institute. A review of data and information requirements of the Offshore Renewable Energy (ORE) Sector in Ireland has been undertaken in the context of the INFOMAR seabed mapping programme to examine its current outputs and capabilities, highlighting areas where the additional value may be added to programme activities to support the development of ORE in Ireland. The target audiences for this review are INFOMAR funding and delivery bodies and the ORE industry.

In the near-term, ORE developments are progressing in a developer-led environment. The dominant foundation technology is the monopile, alongside other fixed-bottom concepts (jackets and gravity-based foundations). The east coast is the focus for near-term developments, due to the favourable physical environment. In the long-term, indications are that moving towards a more centralised offshore renewable energy model is the preferred ORE delivery model post-2030, particularly in the context of harnessing the enormous potential for floating wind off the west coast of Ireland. INFOMAR deliverables have been assessed against the near-term and long-term geophysical, geotechnical, and hydrographic (G&G) ORE data needs. The value of INFOMAR G&G data at different stages of an individual ORE development has been assessed to understand the stage at which the most value from INFOMAR data is currently realised, and to identify potential adjustments to the INFOMAR programme that could deliver additional value to the ORE sector most effectively.

Currently, INFOMAR has by far the most value to the ORE sector in the pre-auction phases, being an invaluable resource for: assessing site viability and foundation optioneering for sites where bedrock is <25m below sea floor (bsf); understanding export cable route geology to the full depth of interest; and reducing the scope of pre-auction G&G surveys. However, types of geotechnical data that would typically be required for foundation assessments are not acquired by INFOMAR, and for fixed-bottom foundation sites the depth of interest can be up to 100mbsf, beyond the typical INFOMAR seismic penetration depth. For most sites, additional G&G data will therefore be needed prior to auction.

In the long term, the value in floating wind turbine installation areas is potentially greater due to the reduced depth of interest for foundations/anchors. This means that a higher proportion of floating wind projects may be able to complete their foundation optioneering studies based primarily on INFOMAR seismic data than for fixed-bottom developments. More broadly, long-term value for the INFOMAR project and its legacy may be derived by the current INFOMAR programme being built on or used as a template for a more centralised ORE data strategy post-2030. Although it is not anticipated that it will be feasible to implement all recommendations, a qualitative assessment of the additional value to the ORE sector of implementing these recommendations has been undertaken.

Recommendations have been made in three broad categories: changes to data handling, changes to data collection methodologies, and geographic area prioritisation. To maximise the value to the ORE sector, it is recommended that focus should be on obtaining additional seismic and geotechnical data to inform pre-auction stages of development, with targeting of specific geographic areas.

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1 Introduction

The Client has engaged GDG to undertake an independent and external review of data and information requirements of the Offshore Renewable Energy (ORE) Sector in Ireland in the context of the INFOMAR seabed mapping programme to examine its current outputs and capabilities highlighting areas where the additional value may be added to programme activities in order to support the development of ORE in Ireland (Specifically Offshore Wind but also addressing other relevant technologies and associated activities), in order to address the following needs:

A. Highlight ORE industry data requirements in context of INFOMAR programme outputs.
B. Highlight available knowledge and data resources in Ireland.
C. Examine potential benefits of increased programme engagement with industry.
D. Highlight present knowledge and data gaps which can be addressed.
E. Provide recommendations for enhancing INFOMAR support for ORE.

2 Scope

The target audiences for this review are:

- INFOMAR funding and delivery bodies (Geological Survey Ireland [GSI], the Marine Institute [MI], and the Department of the Environment Climate and Communications [DECC]).
- the ORE industry (developers, consultants, etc.).

The aim is to improve for both audiences the understanding of:

- how current INFOMAR programme deliverables can best be used by the Irish ORE sector.
- how they could be used in the near-term and long-term, based on:
    - improved industry awareness of the programme
    - changes in industry needs
    - ongoing programme developments
- sources of complementary information that can be used to supplement or enhance the results of INFOMAR data analysis.

In order to address the needs highlighted in Section 1, this report includes a number of sections which aim to address the various project needs. These sections are:

- Section 3: Summary of the INFOMAR programme.
- Section 4: Near-term ORE sector data needs (*Addresses need A).*
- Section 5: Long-term ORE sector data needs (*Addresses need A).*
- Section 6: G&G data gap analysis *(Addresses need D).*
- Section 7: Bridging the gap – INFOMAR (*Addresses Need E).*
- Section 8: Bridging the gap – Complementary information (*Addresses need B).*
- Section 9: Bridging the gap – industry responsibilities *(Addresses needs C and E).*
- Section 10: Case studies (*Addresses need D).*
- Section 11: INFOMAR data value to the ORE sector *(Addresses need C).*
- Section 12: Industry Engagement recommendations (*Addresses need C and E).*

When considering the data needs of the ORE sector in the context of INFOMAR programme outputs, this means consideration of geophysical, geotechnical, and hydrographic datasets. For the purposes of this review, these will be grouped together as Geotechnical and Geophysical (G&G) data.

This review focusses in particular on Offshore Wind, however the information is also relevant to other ORE sectors including tidal and wave projects.

3 INFOMAR Programme Overview

3.1 History

The task of mapping the seabed surrounding Ireland began in 1999 and the aim was to map Ireland's entire seabed – all 880,000km^2 – by 2026. The survey was originally known as the Irish National Seabed Survey (INSS) from 1999 to 2005. This early phase of the project started at the outer margins of Ireland's territorial seabed and worked its way towards the shore. In 2006 the project became known as the Integrated Mapping for the Sustainable Development of Ireland's Marine Resource (INFOMAR). INFOMAR is a twenty-year project to map the physical, chemical and biological features of Ireland's seabed. INFOMAR Phase 1 (2006 – 2016) focussed on 26 priority bays and three coastal areas (Figure 3-1).

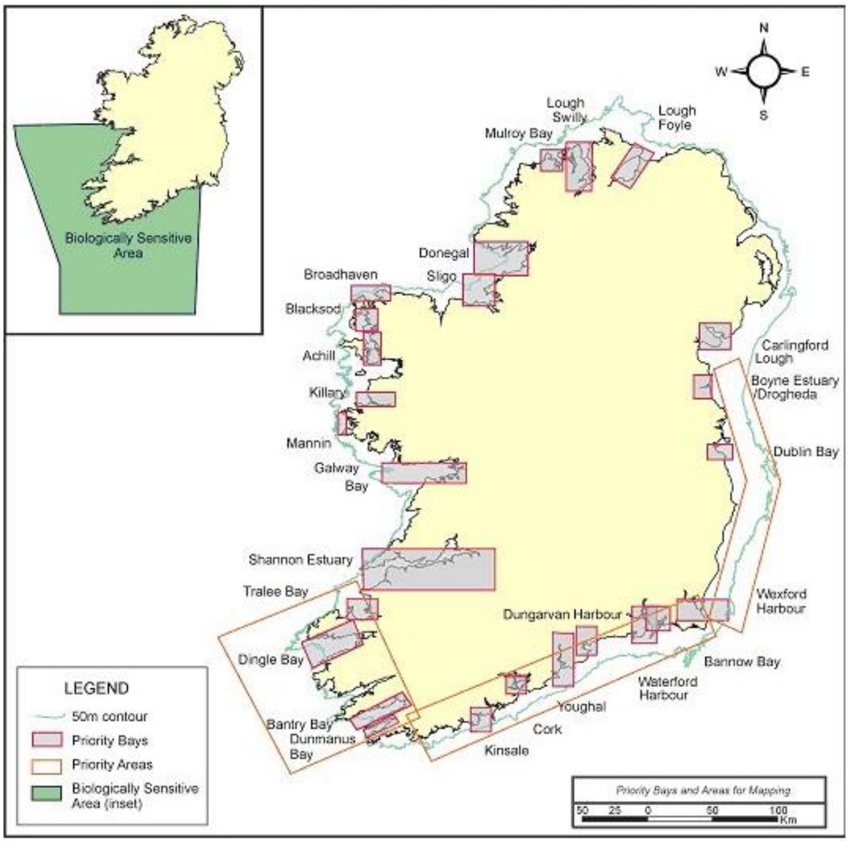

Figure 3-1 Initial focus of the INFOMAR Project in 2006 (http://www.gsiseabed.ie/).

Phase 2 of the project, which runs to 2026, aims to map the remainder of Ireland's Exclusive Economic Zone (EEZ). Understanding the geology and topography of the seabed, as well as information on seabed habitats in Irish waters, is crucial for all offshore projects including windfarms.

All of the INFOMAR datasets are open source and can be obtained in both raw and processed (where relevant) format. They provide an invaluable source of information allowing stakeholders from all corners of society the opportunity to research an area of Ireland's seabed without having to make a large initial investment.

3.2 Purpose

INFOMAR aims to provide comprehensive and accessible marine datasets for Irish waters that underpin and add value to Marine Research and Government Policy and allow Ireland to meet its obligations under The International Convention for the Safety of Life at Sea (SOLAS Convention). The INFOMAR programme delivers a wide range of benefits to many sectors allowing stakeholders to make informed decisions early in the project cycle using a freely available resource. INFOMAR is funded by the Department of the Environment Climate and Communications (DECC) and is jointly managed by Geological Survey Ireland and the Marine Institute.

The data can be used by those involved in:

- Offshore Renewable Energy.
- Oil and Gas exploration.
- Shipping and Navigation.
- Fisheries Management.
- Aquaculture.
- Marine Leisure and Tourism.
- Infrastructure Development.
- Environmental Monitoring.
- Coastal Behaviour.

The primary aim of the INFOMAR project is to map the Irish seabed and includes measuring water depth, identifying sediment types, and defining seabed features. This type of data enables the end users to describe physical features of the seabed.

The secondary aim of the INFOMAR project is to acquire other geophysical datasets using passive and sub-bottom profiler instruments, as well as geotechnical datasets.

3.3 Survey methods

To acquire the vast datasets involved in the INFOMAR project, a number of survey vessels are utilised. The Marine Institute co-ordinates the work of two large surveying vessels, the *RV Celtic Voyager* and *RV Celtic Explorer* (Figure 3-2) and the GSI manages five smaller research vessels for inshore and nearshore surveying (Figure 3-3). These are the platforms from which the geophysical and geotechnical information is acquired. Initially, a survey line plan is produced which the survey vessels follow. The line spacing should be narrow enough to allow adequate overlap of seabed imaging swaths. Line spacings are generally variable, narrowing in shallow water, wider in the deep. While all the following instruments may not be available on each survey vessel, this list shows the instruments that are utilised across the fleet to acquire the data.

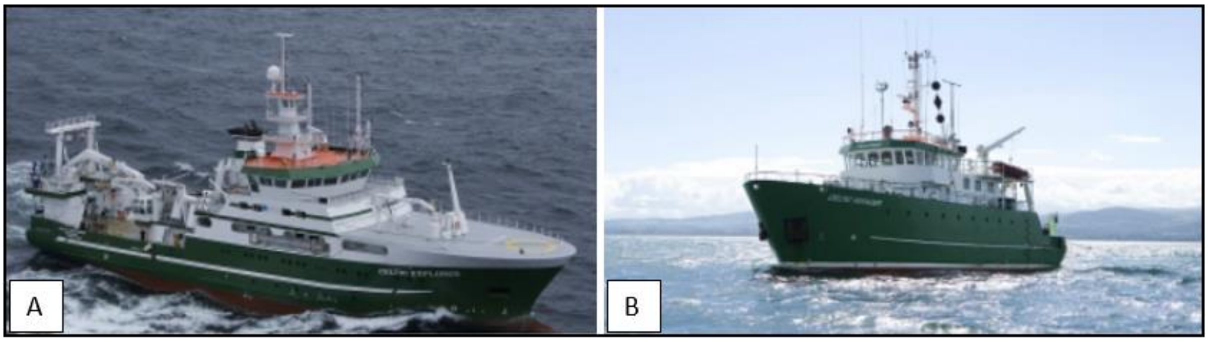

Figure 3-2 Vessels utilised during INFOMAR Phase 1 2006-2016: (A) *RV Celtic Explorer* and (B) *RV Celtic Voyager.*

Figure 3-3 GSI INFOMAR Inshore Fleet (courtesy of GSI) .

The acoustic devices utilised to achieve the primary goals of the INFOMAR survey, as outlined above, are:

- Multi-beam Echosounder (MBES).
- Single-beam Echosounder (SBES).

These allow for the bathymetric and topographic details of the seabed to be delineated. The MBES surveys acquire both water depth information and backscatter information. Backscatter is a measure of the intensity of the returning acoustic signal, from which seafloor sediment types can be inferred.

To achieve the secondary goals of the INFOMAR project the following geophysical and geotechnical equipment is used:

- Shallow Seismic Profiler (SBP: Pinger, Chirp and parametric [Innomar]).
- Seismic Sparker Profiler.
- Side-Scan Sonar (SSS).

- Magnetometer.
- Grab Sampler.
- Box corer.
- Vibrocorer.

The seismic sub-bottom profilers are generally deployed from the the *RV Celtic Voyager* and *RV Celtic Explorer* as well as the *RV Keary,* and *RV Geo*. These profilers enable the shallow geology beneath the seabed to be imaged on a seismic record.

The SSS, while seldom used for INFOMAR acquisition, is a sonar system that is used to create an image of large areas of the seafloor. It emits a conical pulse down towards the seabed across a wide angle perpendicular to the path of the towfish. The higher the frequency, the better the resolution but the lower the range covered either side of the vessel.

The magnetometer is regularly towed behind the survey vessels. It is used to measure magnetic field strength and is used to detect variations in the total magnetic field of the underlying seabed. It can help to identify infrastructure, debris and important archaeological sites like shipwrecks.

The data acquired using the Grab Sampler, the Box Corer and the Vibrocorer are used to ground truth the geophysical data and the interpretation. Recovered grab samples improve the accuracy of backscatter maps as well as Sediment Classification maps. Samples recovered during Vibrocore operations ground truth the geophysical data to depths of up to 6m, improving interpretation.

3.4 Delivery methods

The full suite of INFOMAR data including multibeam echosounder (MBES) bathymetry and backscatter, shallow seismic profiles, gravity, magnetics, sidescan sonar, oceanographic water column profiles, and ground-truthing sample data, is available to public and private bodies under the Irish Government's Open Data Initiative.

Access to INFOMAR data and supporting information are available through a revised programme website [1], which was launched in November 2018 and hosts a number of online portals [2]. These online portals allow easy access and visualisation of the data through user-friendly embedded data viewers and web map services (WMS). Users can display and interrogate multiple layers from the INFOMAR datasets in a Geographic Information Systems (GIS) style format. These data can then be downloaded using the programme's official data download portal: the Interactive Web Data Delivery System (IWDDS). The IWDDS delivers bathymetry, backscatter, gravity, magnetics and LiDAR data in a variety of formats, which are GIS compatible, including Raster, Vector and Grids. Google KMZ files and Fledermaus Scenes are also available for users less familiar with GIS, as are survey metadata, reports and charts. Other data, such as ground-truthing sample locations and shipwreck locations, are available as point files, whereas survey coverage and sediment classification are available as polygon files with survey tracklines as polyline files. Larger data files in formats less compatible with GIS, such as sub-bottom profiler data, are not available through IWDDS and need to be requested directly from the GSI. Gridded bathymetry data is available on a per-survey basis, as well as regionally merged grids, and is gridded at 5m resolution. Higher resolutions of the data can be requested through the Marine Institute Request for Digital Data [3] page.

EMODnet data curated by the GSI and INFOMAR is also available through the IWDDS. More information on EMODnet data can be found in Section 8.2. INFOMAR data is also available through a number of other international, open access data portals such as the National Oceanic and Atmospheric Administration (NOAA) archives, AORA (Atlantic Ocean Research Alliance), ASMIWG (Atlantic Seabed Mapping International Working Group) and CHERISH (Climate, Heritage and Environments of Reefs, Islands and Headlands). It is advised that, for ease of use and accessibility, the user access INFOMAR data directly through the revised programme website [1] and associated online portals [2].

4 Near-term ORE Sector data needs assessment – to 2030

4.1 Overview

The ORE sector in Ireland currently operates as a developer-led/decentralised model, in which developers are responsible for identifying and developing potential offshore wind farm sites, including construction of all assets, as described in the 'Consultation to Inform a Grid Development Policy for Offshore Wind in Ireland' [4]. At present developers may undertake early-stage site investigations by applying for and being granted a licence under the Foreshore Act 1933, as amended. They cannot, however, apply under the Foreshore Act to construct a windfarm at this time.

Ireland's Climate Action Plan (CAP) [5] published in June 2019, by the then Minister for Communications, Climate Action and Environment Richard Bruton, includes a goal of developing at least 3.5 GW of offshore wind capacity by 2030. The 3.5GW set out in the Climate Action Plan was increased to 5GW by the current Programme for Government, agreed in June 2020.

The achievement of this ambitious target of 5GW by 2030, requires a robust functioning consenting regime, a subsidy support scheme, and the facilitation of ORE connection into Ireland's electricity distribution system. Significant inroads have been made on all of these aspects over the past 18 months with a new support scheme RESS (Renewable Electricity Support Scheme) and a new Grid connection policy called Enduring Connection Policy (ECP) both now in operation. An offshore specific RESS is expected mid-2022.

In addition, the framework underpinning how Ireland aims to achieve this target is provided for in the Draft National Marine Planning Framework (NMPF) which was published in November 2019 and is expected to be finalised shortly. The National Marine Planning Framework includes a range of overarching objectives relating to the sustainable use of Ireland's vast marine territory (second largest in the European Union) and sets out the current state of play and future policy objectives for a range of marine sectors including offshore renewable energy. It also includes a number of actions including the provision of Statutory Development Management Guidelines for the Marine Area and a set of Offshore Wind Specific Guidelines.

In addition, the first major reform of marine consenting in the history of the State is being legislated for through the Maritime Area Planning Bill (MAP). The Bill underwent pre-legislative scrutiny by the Joint Oireachtas Committee on Housing, Local Government and Heritage in late 2020 and the report of the Joint Oireachtas Committee was published in February 2021. The recommendations of the report are currently being considered by DHLGH and the text of the Bill is expected to be finalised shortly. The Bill is of a high priority and efficient passage through the Houses is expected once the Bill is introduced in the Dáil in Q2 2021. As well as reforming marine consenting generally, it also provides for an ORE specific consenting regime bringing consenting for ORE under the terrestrial planning system in a process that is based on the Strategic Infrastructure Development Process.

The primary foundation technology being considered for projects currently in development is the monopile, with other fixed foundation types (jackets, gravity bases) also in contention. Fixed wind, mainly on the East Coast, is expected to be developed earlier than floating wind. However, interest in developing floating wind sites is increasing even for these early-stage projects, particularly as this opens up areas of deeper water to development not available for established fixed-bottom foundation options.

The types of Geophysical and Geotechnical (G&G) data required for any project, and their coverage, resolution, and timing, are dependent on multiple factors, with local regulatory requirements and choice of foundation technologies being particularly important. As the framework for development of offshore wind projects in Ireland is not yet complete, there is inevitably some uncertainty concerning the data needs at various project development stages. However, knowledge of typical development phases and data needs from more mature markets can provide guidance. In the near-term, the UK market in particular can be used to provide a reasonable idea of requirements at each development stage, as it operates under a developer-led model very similar to that which is currently in place in Ireland, where developers are responsible for identification and development of both sites and transmission cable corridors [4].

4.2 Considerations for near-term requirements

4.2.1 Consenting Needs and Stakeholder Requirements

The combination of RESS and the new consenting regime will require the gathering of detailed information of a consistently high standard to satisfy environmental legislation (EIA/AA) and to allow developers to bid into RESS auctions with a high degree of price certainty.

Multiple rounds of RESS auctions will be held. An Offshore specific RESS has been indicated for late 2021 with subsequent Offshore RESS auctions expected to be held every 18-21 months afterwards (maximum of three expected in current iteration). One project, Arklow Bank, intends to develop under a lease granted under the Foreshore Act 1933, as amended, and several projects called ‘relevant projects’, are progressing through development under a ‘transition protocol’ provided for under MPDM. There are also multiple projects known in the public domain in earlier stages of site identification and pre-development. Arklow and the relevant projects are likely to target Offshore RESS 1, while new projects will target RESS 2 or 3. Offshore RESS 2 will also include unsuccessful relevant projects from Offshore RESS 1.

There are currently multiple projects in the public domain, as shown in Figure 4-1. There may be other developers that have applied to the Department of Housing, Local Government and Heritage (DHLGH) for a licence under Section 3 of the Foreshore Act, 1933, as amended, to undertake site investigation activities within the Foreshore, the details of which are yet to be published in the public domain.

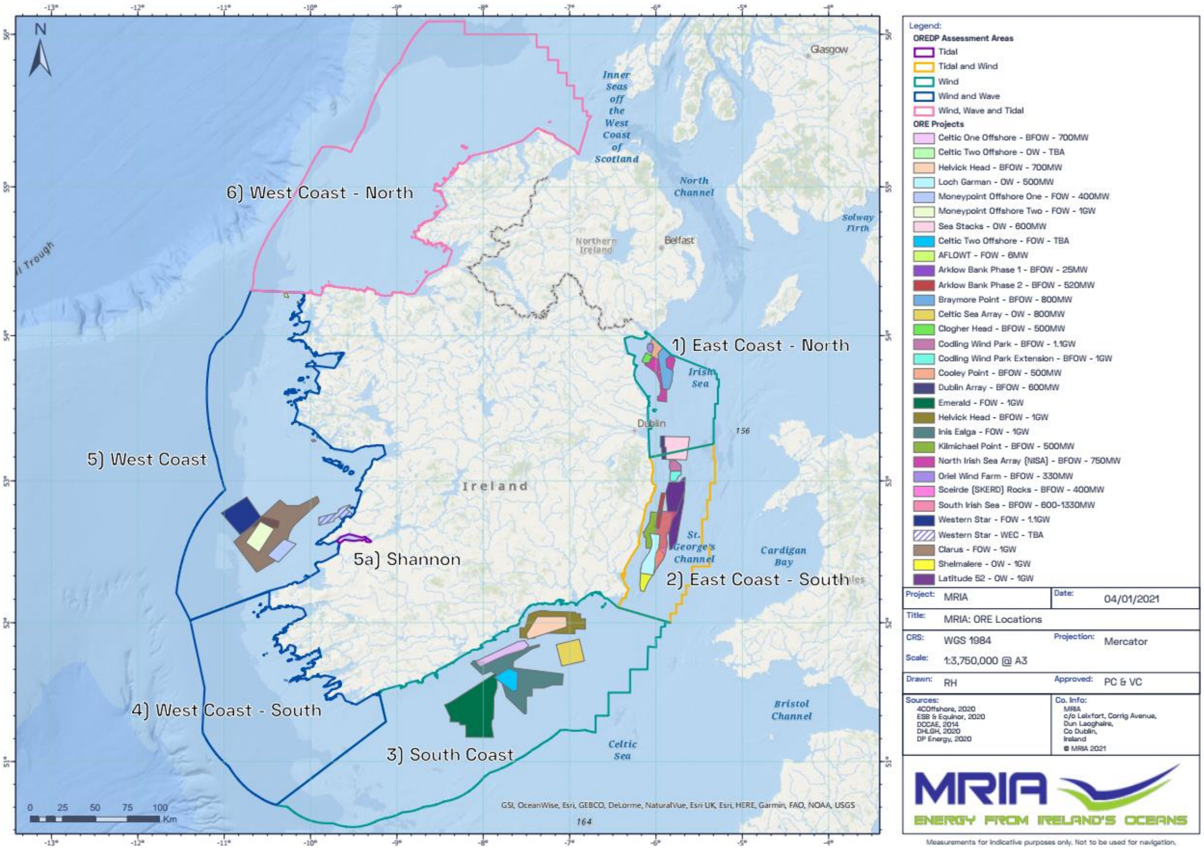

Figure 4-1 Irish offshore wind developments [6].

Likely timelines for projects, covering key milestones such as Environmental Impact Assessment (EIA) completion, RESS award and Final Investment decision (FID) are outlined in Table 4-1.

Table 4-1 Current market projections and project timelines.

PROJECT MILESTONES	RELEVANT PROJECT	NEW PROJECT
Planning Interest/cMAC Secured	H1 2022	H2 2022
EIA Completion	H1 2022	H1 2023
RESS Award	H2 2022	H1 2024 / H2 2025
Grid Offer Secured	H2 2022	H2 2025
FID	H1 2024	H2 2026
First Generation	2026	2029

The main stakeholder led demand for G&G data comes from the Underwater Archaeology Unit (UAU) of the National Monuments Service. UAU are concerned with the preservation of wrecks and other underwater archaeological features within Irish Territorial Seas and have general requirements for archaeological surveys which are set out in Table 4-2.

Table 4-2 UAU archaeological survey general requirements.

SURVEY TYPE	REQUIREMENTS FOR ARCHAEOLOGICAL PURPOSES
Side Scan Sonar	• Operational frequency of 410/500kHz. • 50m survey line spacing • 100% site coverage (overlap of areas may be required)
Magnetometer	• Should always be used in tandem with side scan sonar • Proton or caesium magnetometer • 50m side spacing • Should be used in conjunction with DGPS
Sub-bottom profiler (optional survey)	• Chirp system is preferred for resolution purposes • Should be used in conjunction with DGPS

Much of the early stages of site investigations are aimed at gaining a thorough understanding of the site conditions including identifying any constraining features. For that reason, initial site footprints tend to be much larger than the final development site. Full coverage of those initial sites would require months of continuous surveying to satisfy the conditions specified in Table 4-2. Detailed geophysical surveys of the refined site would form part of a project programme but would ideally come much later once the actual development site has been identified and developers are entering the detailed design phases of a project, when a greater level of detail is required.

GDG considers that availability of high-quality data at consistent levels of coverage combined with a detailed underwater archaeology risk assessment by an experienced underwater archaeologist could be an alternative to an early full coverage survey for early-stage archaeological impact assessment. The availability of the data for archaeological interpretation is key to engaging with stakeholders on this matter.

4.2.2 Current foundation technology

4.2.2.1 Overview of technologies

Understanding the data needs for designing the different foundation types that are likely to be used for near-term developments is necessary to provide a set of G&G survey baseline requirements to which INFOMAR programme deliverables can be compared. The selection of foundation type and the design for any site is a complex task, which strongly depends not only on the site characteristics, but also on the maturity and track record of different design concepts [7]. Disregarding other factors (such as supply chain and transmission considerations, stakeholders, and competition), key technical considerations for assessment of site viability and foundation optioneering include water depths, depth to bedrock, geological conditions, and seabed and sub-bed hazards and obstructions. Additional key technical factors required for more detailed design and cabling considerations include seabed stability, seabed mobility, and scour potential.

Driven Monopiles (MPs) are the most common substructure type, with driven piled jackets and Gravity-Based Foundations (GBS) also proven. These foundation types are illustrated in Figure 4-2. More recently alternative solutions such as drilled and grouted MPs and jackets, and caisson jackets, are currently under development in commercial scale offshore wind. This trend is considered likely to continue as industry experience increases and sites previously considered challenging for the traditional foundation types become more commercially viable. Other more novel foundation types (twisted jacket, OWLC, floating wind, etc.) are often proposed, but tend to be proprietary, which can limit contractual design and fabrication options, and have not been strongly demonstrated in commercial scale projects.

According to Wind Europe's key trends and statistics of offshore wind [8], monopiles represent 81.5% (4105 turbines) of all installed substructures in Europe, jackets 8% (403 turbines) and Gravity-Based Structures (GBS) 6 % (301 turbines) (Figure 4-3).

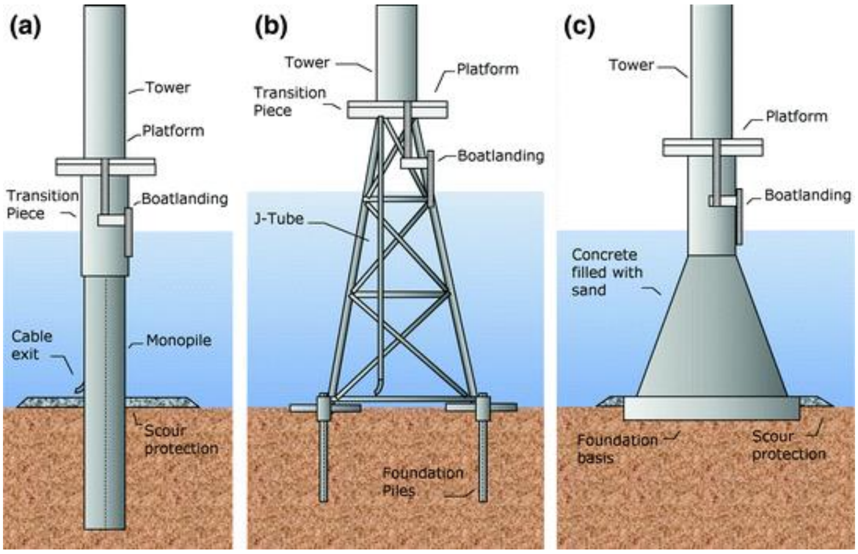

Figure 4-2 Foundation types [9]: (a) monopile, (b) jacket and (c) GBS.

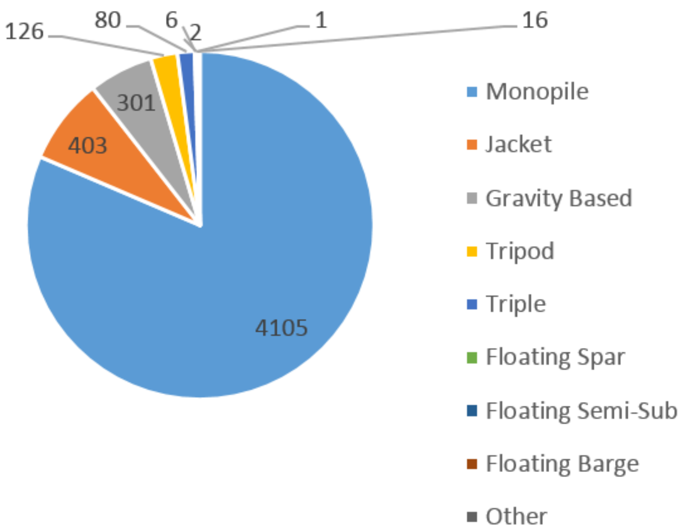

Figure 4-3 Total installed turbines in Europe up to the end of 2018 [8].

In 2018 alone, monopiles represented 74.5% of all installed offshore wind foundations, a decrease from 86% reported in 2017, with jackets the second most common substructure for offshore wind, with 119 jackets installed, representing 24.5% of foundations installed in the year (see Figure 4-4).

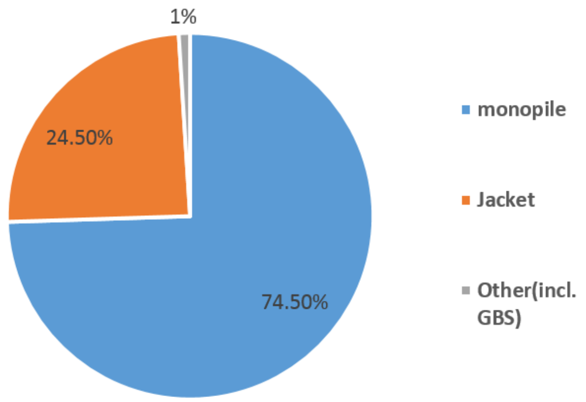

Figure 4-4: Percentage of turbine foundation type used in European offshore wind projects in 2018 alone [8].

This growth in use of jacket foundation can be explained by expansion into deeper waters (>30m), the development of more geologically complex areas, and the ever-increasing size of the Wind Turbine Generators (WTGs). Notable exceptions to this trend are in areas where the zones available for offshore wind developments are in concentrated areas, of similar water depth and ground conditions e.g. Dutch sector Offshore Wind Farms (OWFs).

Figure 4-5 shows the current worldwide mix of substructure types for projects operating at the end of 2018 along with the expected makeup of substructure types for the 37,203 MW of projects in the pipeline that have announced their intended substructure. In 2018, monopiles continued to dominate the operating fleet of global offshore wind turbines, representing 73.5% of the total market. Alternative substructure types, such as gravity-base (3.3%), jacket (6.5%) and tripod (4.7%) represent a much smaller share [10]. High rise pile caps are included in this figure, whereas they are absent in the European market. This is due to them being adopted in the Chinese and South East Asian markets. This is due to the local ground condition, combined with the local fabrication capacity. This is not anticipated to feature in future European projects. Additionally, semi-submersibles are included, as the graphs are not limited to fixed foundations.

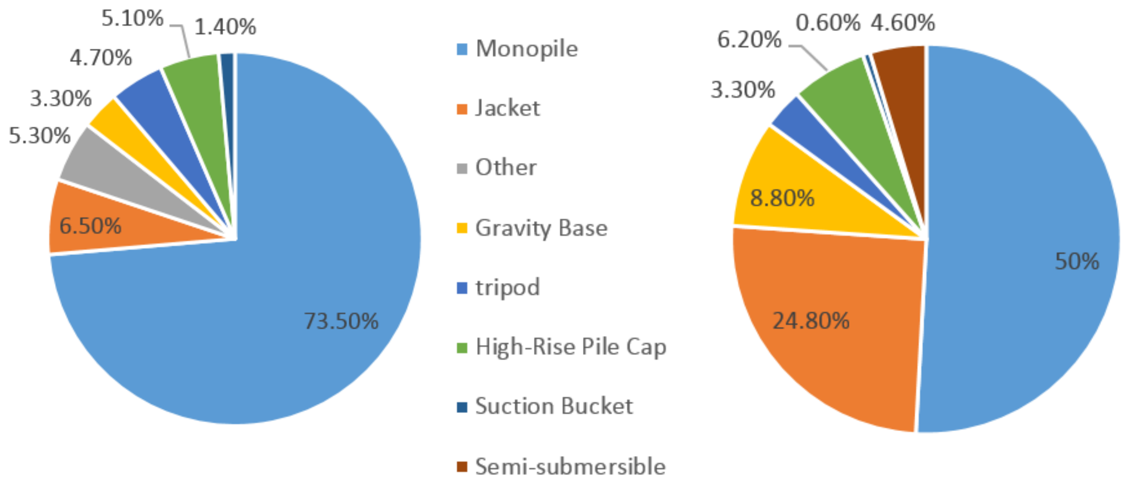

Figure 4-5: Worldwide trend in foundation type – comparison between commissioned installations up to the end of 2018 (left) and (right) future projects that have disclosed their foundation type [10].

Key facts concerning current foundation technologies in Europe are summarised in Table 4-3. A summary of feasible combinations of water depth and geological factors for the most commonly used foundation types (driven-pile, suction caisson, and GBS foundations) is provided inTable 4-4.

Table 4-3 Key facts for current foundation technologies.

FOUNDATION TYPE	KEY FACTS
Monopile	A monopile foundation is a single pile, with a large diameter. It is a bottom-supported steel structure designed to support an offshore wind turbine and is typically installed in waters <50m. Appropriate water depth feasibility limits for monopiles are also a function of WTG size and indicative ground strength. Monopiles are suited to most ground conditions with the exception of very soft ground near the surface; as this may result in excessively large embedment depths. Monopiles are preferentially driven: areas with shallow rock head level may cause early refusal or require drilling, which can significantly increase costs. An alternative is drive-drill-drive piles that combines both driving and drilling, and avoids grouting.
Jacket	Jackets are either three- or four-legged bottom supported foundations with a steel lattice framework. Jacket foundations are not particularly sensitive to water depths, and they have been used in water depths from 10 up to 60m for WTGs. Piled (driven or drilled) jackets have legs anchored to the seabed and can be either pre- or post-piled for driven piles, or pre-piled for drilled and grouted piles. Similarly to monopiles, the feasibility of driven jacket piles is very dependent on the ground conditions, and in the event of a site containing shallow bedrock, jacket piles may need to be drilled into place which represents a significant cost uplift on traditional driven piles. An alternative is drive-drill-drive piles that combines both driving and drilling, but avoids grouting. Jackets can also be mounted on suction caissons. A suction caisson foundation is a large steel cylinder, open at the bottom and sealed at the top. After an initial penetration under its own weight, the caisson is sucked into the seabed to target depth by creating a negative (suction) pressure inside the caisson. The need to create suction during installation limits the use of suction caissons to deeper waters for fixed offshore wind sites, and are unlikely to be feasible in sites below 35-40m water depths. Suction caissons may be installed in both sand and clay ground conditions: however, they are not suited to very hard ground, gravel deposits or rock at/near the surface. Historically there is significant experience in their use in the deep water oil and gas industry, however they are only currently being deployed in a few OWFs under construction/commissioning.
GBS	GBS foundations are shallow flat-based-bottom support structures utilising their self-weight to withstand overturning moment and sliding shear and held in place by gravity. They are normally constructed with reinforced concrete and vary in geometry, size and weight depending on specific design cases. GBS foundations have mostly been used in northern European offshore wind projects (301) installations up to 2018 [4] in shallow waters (<25m), and with smaller WTGs. Ground conditions conducive to GBS foundations include shallow bedrock, rock, course gravel, dense sand and highly over-consolidated clay, also, in challenging geology where it would be difficult to install piles.

Table 4-4 Summary of foundation types and site characteristics.

FOUNDATION TYPE	WATER DEPTHS*	DEPTH TO BEDROCK^
Driven MP	<50 m	Greater than foundation target depth (typically greater than 25 to 40mbsf)
Drilled and grouted or Drive-drill-drive MP	<50 m	Shallower than foundation target depth (typically shallower than 25mbsf)
Driven Jacket	10-60 m	Greater than foundation target depth (typically greater than 40 to 70mbsf)
Drilled and grouted or Drive-drill-drive Jacket	10-60 m	Shallower than foundation target depth (typically 0 – 40mbsf)
Jacket (suction caisson)	40-70 m	Typically greater than 8 to 10mbsf.
GBS	<25 m	Can be from near seabed.

**Individual sites may support foundations outside this range depending on local conditions.*

^Bedrock is defined as hard competent rock. It should be noted that many soft rocks such as Mercia Mudstone, weathered rock, chalk, and sedimentary soft rocks have been demonstrated to be 'drivable'.

4.2.2.2 Foundation development phases

Broadly speaking, there are four phases of pre-construction foundation development for an offshore wind farm site:

1. Initial site selection/site viability.
2. Foundation optioneering/conceptual foundation design.
3. Front-End Engineering Design (FEED): determination of development resource requirements via selection of most cost-effective solutions for turbine technology, foundations, grid connection points, layout optimisation, etc.
4. Detailed foundation design.

Initial site viability can usually be completed based on open data and desk studies (drawing on, for example, national water depth charts and publicly available geological mapping resources (including INFOMAR in Ireland), UK marine data exchange, published geological references or history experience from specialist consultants), given an understanding of high-level installation limits of current foundation technologies (water depths, bedrock depths). This phase also considers high-level technical and non-technical site constraints, such as existing infrastructure, archaeological sensitivity, conflicting site usage, availability of landfall points, local supply chain capacity, etc.

Site-specific reconnaissance geophysical and geotechnical data are often required for foundation optioneering studies; though this may be not necessary if there is sufficient information from similar/adjacent sites that is available. These foundation optioneering studies assess the site requirements for different foundation types against the specific site characteristics (bedrock depth, hazards, overburden strength), based on anticipated WTG sizes. A foundation optioneering report will identify one or more types of foundation suited for a site, WTG size, and rank them by suitability. Example high-level assessments for monopile and driven pile jacket foundations performed by GDG for an Irish Sea site are presented in Table 4-5 and Figure 4-6, based on medium-strength ground and WTG sizes in the 12 to 15MW range.

Table 4-5 Example drilled monopile feasibility study results for an Irish Sea site.

CRITERION	CATEGORY DESCRIPTION		
	LIKELY	POSSIBLE	UNLIKELY
Water depth	30-45m	45-60m	>60m
Seabed slope	N/A		
Depth to bedrock	<25mbsf	35-25mbsf	>35mbsf
Shallow gravel	N/A		
Shallow till layer	N/A		
Boulder field	No boulder field	Boulder field	

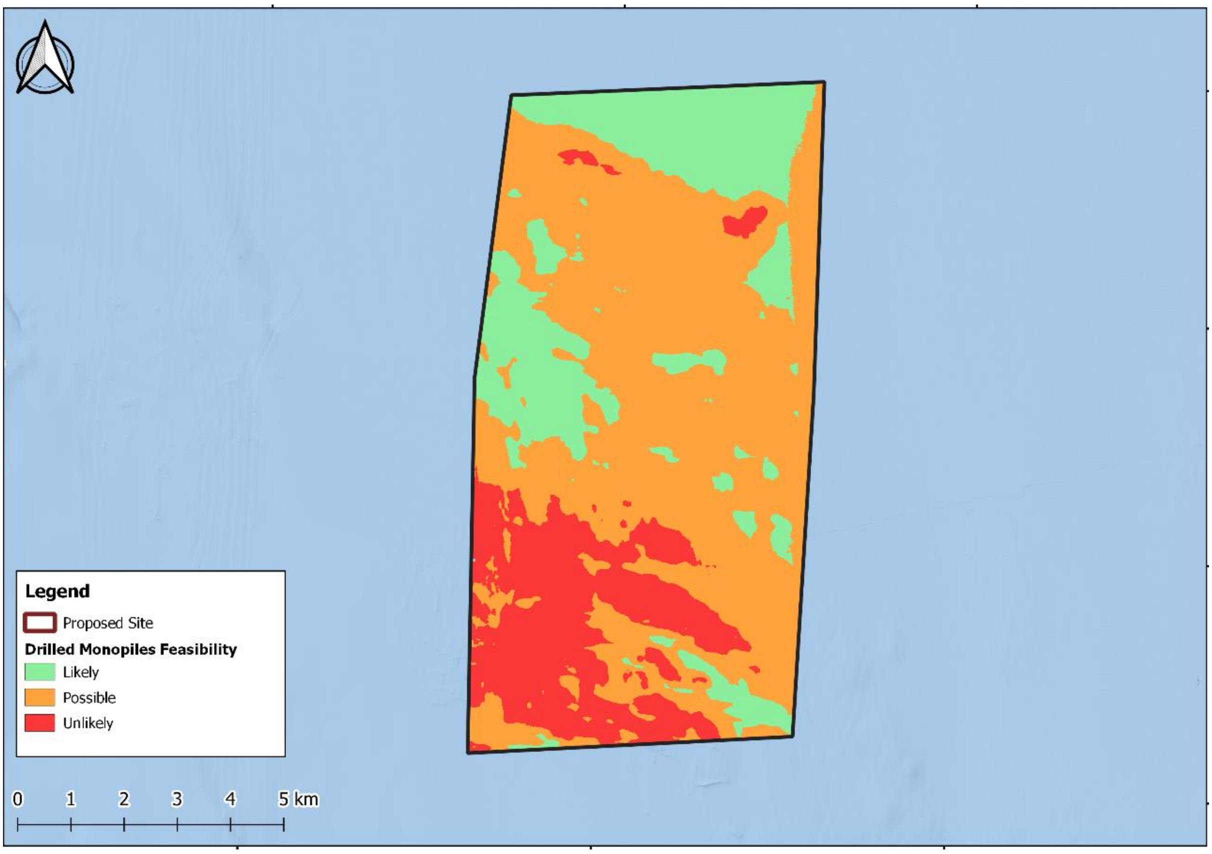

Figure 4-6 Example drilled monopile feasibility study results map for an Irish Sea site.

As a project develops, additional G&G information is required to rationally make informed decisions when refining the number of foundation options, and subsequently for the FEED process: to identify the final installation area, make final foundation type decisions, and optimise WTG array, Inter-Array Cable (IAC) and export cable layouts. This information includes a complete understanding of the soil units present (thickness, extent, representative geotechnical/engineering parameters) and both seabed and sub-bed hazards.

By the time the detailed design phase is reached, decisions should be made concerning specific foundation types at each location, and the anticipated foundation sizes (pile lengths, GBS size etc). Such information is necessary to inform the final geotechnical campaign. This final geotechnical campaign should include high quality sampling and laboratory testing to provide input to the detailed design. Having a good understanding of what is necessary for a particular design is important, as this may be the last opportunity to obtain such data.

4.2.2.3 Cabling considerations

Cable route selection, cable design, and design of cable installation methodology develop along a similar path as the foundation selection and optimisation process. At early stages, a large area may be identified within which the eventual cable route will lie. The main considerations for selection of this area include the extent of the landward boundary of the proposed windfarm area and the availability of landfall locations. Start and end points for the cable route will be refined based on landfall assessments and windfarm layout considerations, and the specific route then determined. Following route determination, detailed studies are undertaken to determine burial depths, installation methodologies and cable protection requirements.

For both export cable and inter-array cable routing and installation design phases, key technical considerations include:

- seabed hazards and obstructions (archaeology, UXO, seabed slopes, existing infrastructure, fishing traffic, rock outcrops, hard ground, etc.).
- geology (seabed substrates, geological units within 10mbsf).
- geotechnical and engineering properties (strength, thermal conductivity, corrosion potential, etc.).
- sub-bed hazards (shallow gas, peat, coarse sediments, etc.).
- seabed stability (mass movement potential, seabed deflation, lowest stable elevation) and seabed sediment mobility.

One key difference between the G&G data needs for cable and foundation design is that the depth of interest for cable-related surveys is usually no more than approximately 10mbsf: however, the depth of interest for sites with significant seabed mobility may exceed this.

Assessment of technical risks, and selection of surveying and data requirements to identify these risks, is commonly guided by the DNV GL recommended practice for subsea power cables in shallow water [11] and industry survey guidelines such at the SUT guidance notes [12]. Risks are considered as part of a Cable Burial Risk Assessment (CBRA) [13] that is used to determine the depth of lowering (vertical distance between top of cable and undisturbed [mean] seabed level) and requires the site conditions as an input.

4.2.3 Synthesis

As highlighted in Section 2, when assessing the data needs of the ORE sector in the context of INFOMAR programme outputs, this means consideration of geophysical, geotechnical, and hydrographic datasets (G&G data) within the context of development timelines (Section 4.2.1) and foundation requirements (Section 4.2.2).

G&G data for the ORE sector are typically obtained for the purposes of understanding seabed conditions and geology. A non-exhaustive list of information that is derived from G&G data includes:

- Seabed:
  - Water depth, slope, morphology.
  - Seabed sediments.
  - Bedforms, bed mobility, scour, bed stability.
  - Archaeology.
  - Ecology.
  - Obstructions and hazards – boulders, pockmarks, mounds, debris, infrastructure, etc.

- Sub-bed:
  - Stratigraphy, soil zonation, engineering parameters.
  - Archaeology – palaeolandscapes, buried sites/wrecks.
  - Geohazards – boulders, gas, Methane-Derived Authigenic Carbonate (MDAC) mounds, faults, channels, peat, fluid migration, etc.
  - Seismic risk.

Once acquired, G&G data should be collected into a ground model. Fundamentally, a ground model is a risk management tool. As defined by The Society for Underwater Technology (SUT) 'Guidance Notes for the Planning and Execution of Geophysical and Geotechnical Ground Investigations for Offshore Renewable Energy Developments' [12]:

> *"A ground model is a database of information that includes the structural geology, geomorphology, sedimentology, stratigraphy, geohazards and geotechnical properties of a site. […] The ground model is a key input to geotechnical design parameters for a site and to an understanding of how these may vary across a site."*

This definition relies primarily on G&G data: a broader definition of a ground model could include survey reports and information on other physical constraints, e.g. archaeological, benthic, and metocean data. However, the SUT definition provides sufficient context for this review.

If sufficient G&G surveys are not undertaken at an early stage, this risks the discovery of unforeseen ground conditions at a later stage of development. Unforeseen ground conditions can be hugely expensive, and, in the worst case, deadly, potentially resulting in:

- Expensive overengineering as mitigation of uncertainty.
- Costly late-stage layout changes and associated delays.
- Loss of capacity through curtailment of the buildable area.
- Inappropriate foundation selection requiring remedial engineering.
- Site Investigation and/or installation failures and associated legal claims.
- Accidents and fatalities.

G&G and related surveys are the biggest development expenditure that an offshore wind development will face pre-bid (e.g. [14]). For ORE developments progressing in the current regulatory environment, the challenge is, therefore, balancing the cost of early-stage surveys to determine the viability and value of a site against the requirement to minimise early-stage outlay in the case that the project is unsuccessful. It is therefore important to understand the minimum data requirements at each stage of a development.

One way to develop and formalise this understanding is to develop a G&G survey strategy, which establishes a survey schedule and projected costs early on with the goal of achieving the project objectives while mitigating risk and minimising early expenditure (i.e. pre-RESS award and pre-FID). Typical inputs to a survey strategy are summarised in Table 4-6, and Figure 4-7 illustrates how each type of input feeds into the survey strategy and initial ground model development.

Table 4-6 Survey strategy inputs.

TYPE OF INPUT	EXAMPLE INPUTS	
Opportunistic datasets	• Geological maps • Geological models • Geophysical data • Hydrographic data and charts	• Geotechnical data • Metocean data • Wreck databases • Infrastructure databases
Desk studies	• Geological • Morphodynamical • UXO	• Archaeological • Environmental • Ecological
Design milestones	• Buildability assessment and conceptual foundation design • Front-End Engineering Design (FEED)	• Cable Route selection • Layout optimisation • Detailed foundation design • Cable Burial Risk Assessment (CBRA)
Development milestones and inputs	• Government policy • Survey (Foreshore) licences • Survey standards • EIA • Planning interest (cMAC)	• Planning consent • Grid offer • Auction (RESS) • FID

From the information in the preceding sections, a guide to the probable data requirements at each stage can be developed, as outlined in Figure 4-8. As the ORE consenting framework is yet to be finalised the likely data requirements are based on GDG's knowledge of typical global development timelines and information needs for developer-led projects. The link to key Irish project milestones of RESS auction and FID for those projects with 'relevant' status is indicated. As the market progresses through rounds of RESS auctions, the stage of planning that projects must have achieved will increase, so by Offshore RESS 3, projects may require planning.

A typical ground model development data flow is illustrated in Figure 4-9. This demonstrates how data and survey needs are typically identified and addressed for an offshore wind project between the points of site selection and construction via the G&G survey strategy and ground model. The illustrated stages are based on a developer-led model that incorporates the key milestones of auction (e.g. Irish RESS or UK Contract for Difference [CfD]) and FID. A similar approach will also apply in the context of other ORE technologies, regardless of differences in depths of interest or data requirements.

Specific requirements for G&G and associated data in the context of the ground model development dataflow described above and current foundation technologies (Section 4.2.2) are described in Section 4.3.

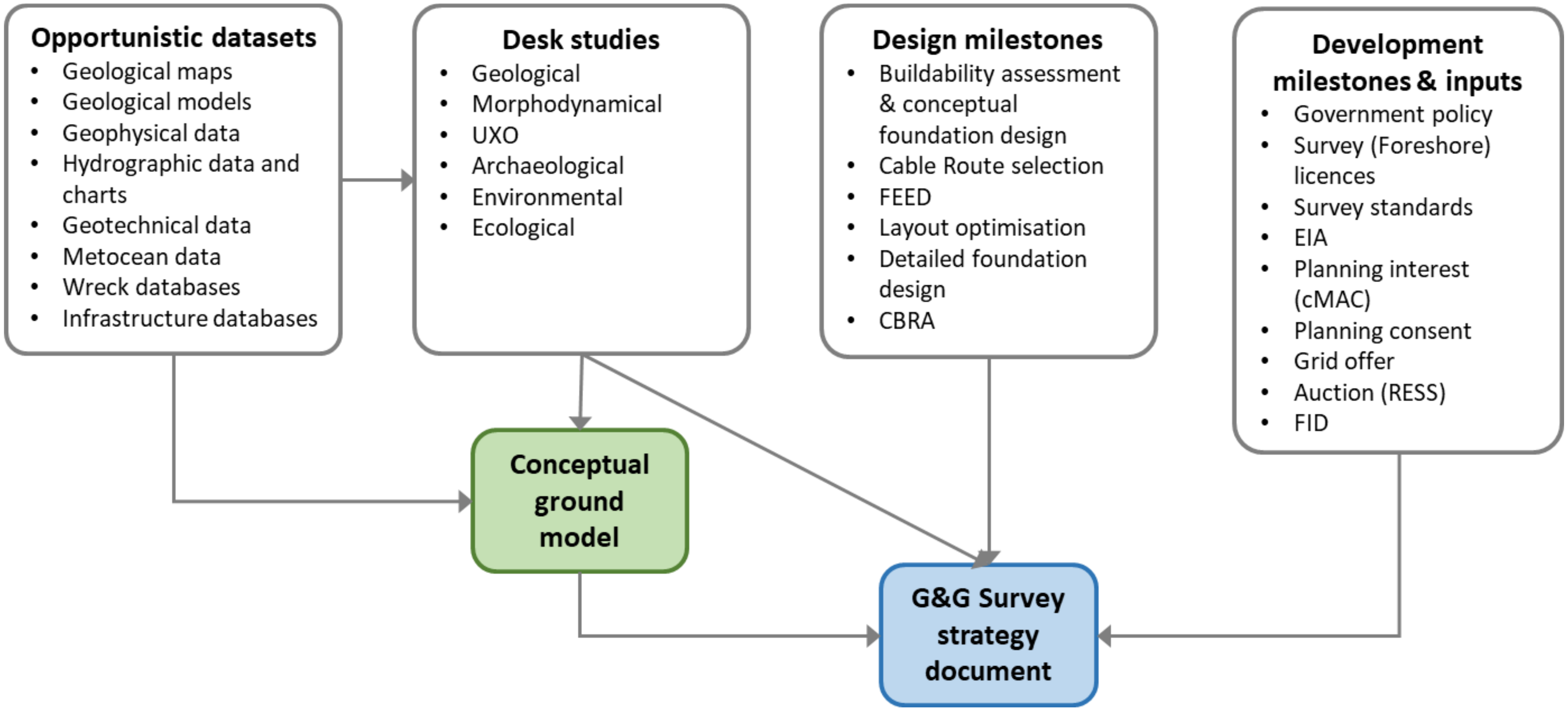

Figure 4-7 G&G survey strategy development.

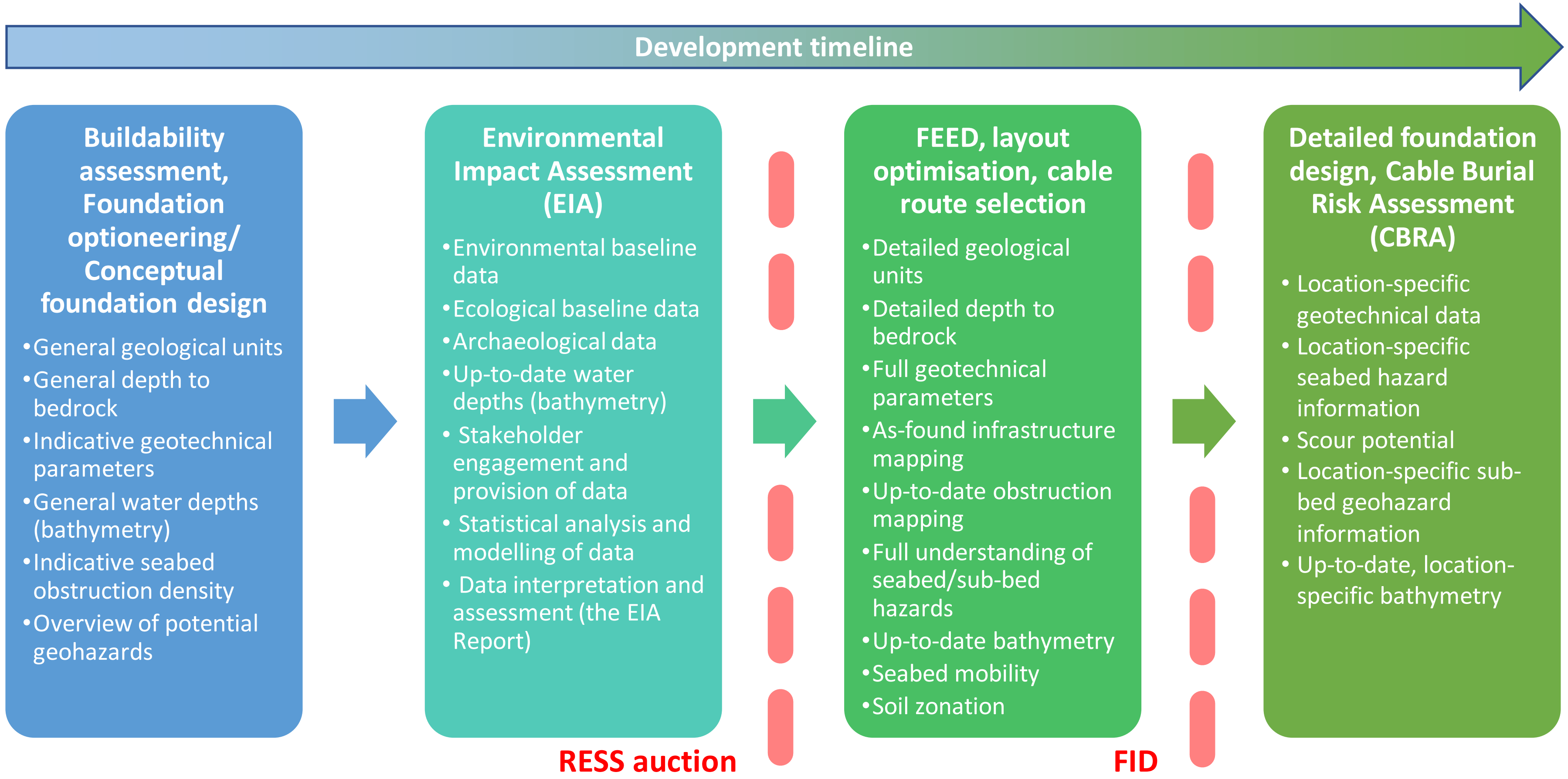

Figure 4-8 Guide to G&G data needs for development milestones for relevant projects.

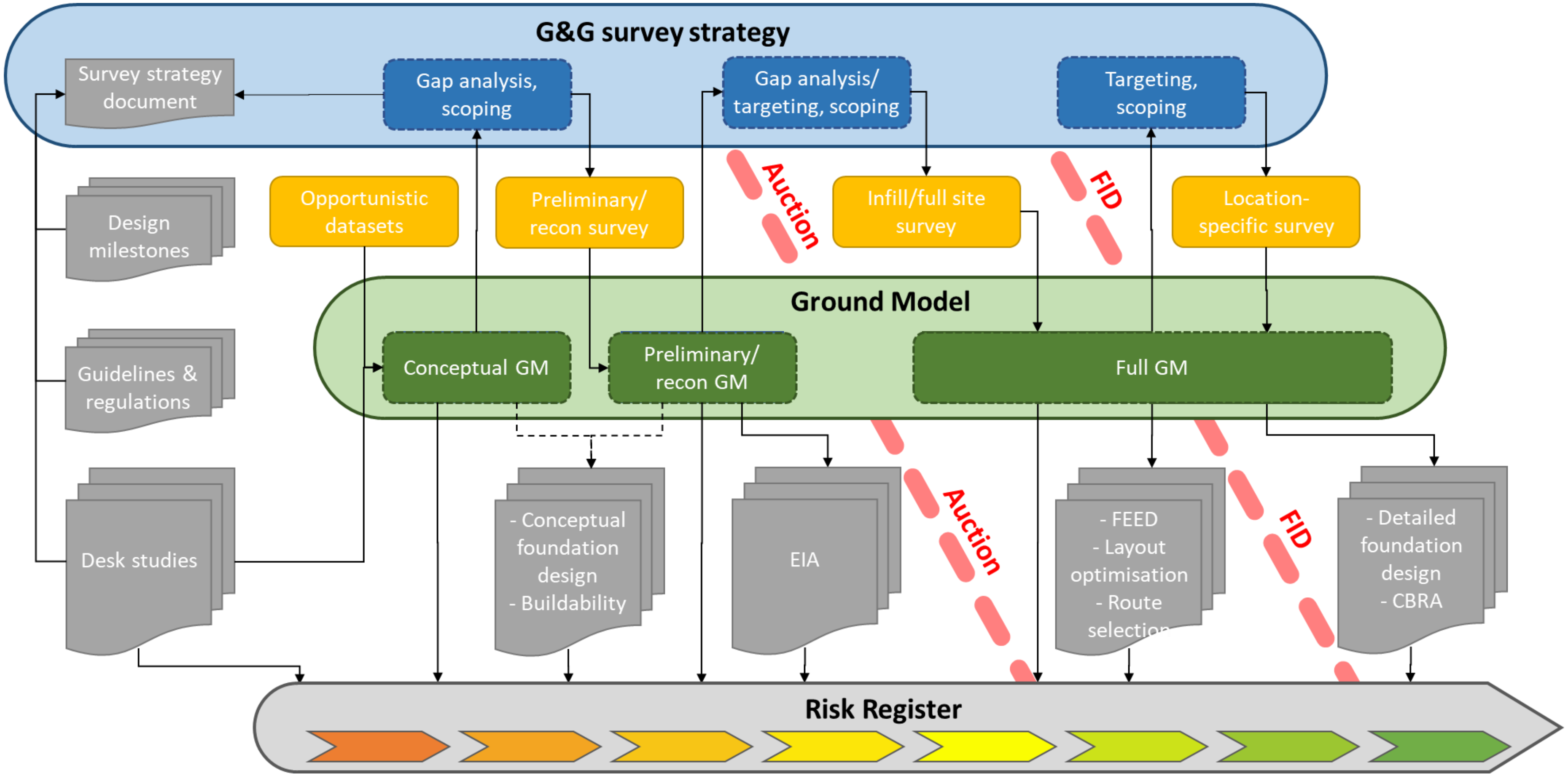

Figure 4-9 Generic ground model development G&G data flow for a developer-led model.

4.3 Near-term requirements

4.3.1 Geotechnical data

Geotechnical studies comprise geotechnical investigations and data interpretation. The geotechnical investigations may include the following:

- Seabed or downhole sampling followed by laboratory tests on the acquired samples.
- In-situ tests, for instance: piezo cone penetration tests (PCPT), seismic PCPT (SCPT), pressure meter tests (PMT), dilatometer tests (DMT/HPD).
- Associated data processing, data interpretation and parameter derivation.

The objective of the geotechnical investigation is to obtain for each geotechnical unit or formation the following data:

- Classification and description of the soils and rocks.
- Geotechnical parameters, for example, strength, stress history, and cyclic and dynamic parameters, relevant for the type of analysis/foundation type planned.

The interpretation of the geotechnical parameters provided shall allow a detailed and complete design of the foundations, and questions on the lateral extent and variation of geotechnical units and geotechnical parameters are issues that should be answered.

Soil and rock recovery equipment and methods must be selected to ensure high quality soil samples and rock cores are recovered for completion of onshore laboratory testing. Measured and derived geotechnical parameters shall be used for dimensioning and design of the proposed foundation solution. Generally, site investigations are completed in line with the recommendations in ISO 19901-8 Marine soil investigations [15].

Generally geotechnical is collected in two phases during an ORE development: a preliminary investigation which allows for the specification of a final, detailed investigation. At geologically complex sites, further or targeted investigations may be required.

A typical preliminary geotechnical investigation, summarised in Table 4-7, should allow selection of geotechnical parameters for each geological province highlighted during the interpretation of geophysical data:

- Stratigraphy.
- Nature of soils and identification.
- Basic geotechnical features: mechanical strength, deformability, stress history.

These objectives can be met by performing:

- Boreholes with the acquisition of intact samples followed by laboratory tests.
- In-situ tests.

Table 4-7 Preliminary geotechnical data requirements.

OBJECTIVE	METHOD	PENETRATION
• Stratigraphy • Nature of soils and identification • Basic geotechnical properties • Typical geotechnical profile for each geological province • Assessment of the geotechnical properties of materials and their spatial variability	• Seabed and downhole sampling • Downhole rock coring • Seabed or downhole in-situ tests, such as PCPT, PMT or DMT/HPD and/or with: • Well logging (natural radioactivity, PS Logging, HRAT imaging)	Sufficient to: • Encounter the main formations/units and understand their configuration at the macro scale of the site. • Establish profiles of geotechnical parameters over the height of the influence of foundations. • Depth of penetration for these needs are usually 50 to 60m below sea floor (bsf).

The final design of the foundations and installation studies assumes the definition of a profile of geotechnical parameters below each wind turbine. Detailed requirements are summarised in Table 4-8.

The number and type of seabed test, samples and borehole, and overall survey strategy shall be driven by the proposed foundation options. Generally, it is required during the detailed geotechnical investigation to undertake at least one borehole for each wind turbine location regardless of the considered type of foundation.

The number of site investigation points may be reduced if it can be demonstrated that the site, in whole or in part, is homogeneous enough to interpolate geotechnical data at some locations. This demonstration should be founded on a high-quality geological model, a detailed risk assessment, and a thorough integration process of the geotechnical and geophysical data.

In the event where gravity foundations are considered, it is usually necessary to undertake at least three peripheral boreholes in addition to a deep central borehole, to ensure that subsurface soil conditions are homogeneous over a depth of at least 10 m.

For piled foundations, the influence depth of the foundations is at least equal to the pile penetration (length of the shaft) plus the depth of the influence zone of the tip. The latter is usually estimated at 3 x diameter for piles of common diameters (< 2 m). For piles of very wide diameter, where capacity is essentially ensured by friction, the influence zone under the pile may be limited to half of the pile diameter.

Table 4-8 Detailed geotechnical data requirements.

OBJECTIVE	METHOD	FOUNDATION TYPE	LOCATION AND QUANTITY	PENETRATION
Final design of foundations Installation studies	Coring / sampling boreholes Boreholes with in-situ tests such as PCPT Boreholes with in-situ deformation tests (PMT, DMT) Mixed boreholes with alternating coring/sampling and in-situ testing	Slender Pile	1 borehole at the centre of each wind turbine location	Anticipated piles lengths + 3D minimum. Approximately 80mbsf.
		Monopile	1 borehole at the centre of each location + 3 boreholes on the periphery	Anticipated monopiles lengths + 0.5D minimum. Approximately 50mbsf.
		Gravity Base	1 borehole at the centre of each location	1.5 x foundation width or penetration of at least 2 m in the substratum. Approximately 30mbsf.
		Caisson	1 borehole at the centre of each location + 3 PCPT boreholes on the periphery	At least 10m penetration or until refusal (CPT). Approximately 20mbsf.
		Anchored	1 borehole at the centre of each location	1.5 x foundation width or penetration of at least 2 m in the substratum If Caisson, Skirts height + 2 m. Approximately 15mbsf.

Route-specific CBRA geotechnical data inputs as defined by the CBRA methodology guidance [13] (targeted at depth for required cable burial), are:

- Piezocone Penetrometer Testing (PCPT) to nominal 6mbsf at appropriate intervals along the proposed route and/or where sub-bottom profiling shows differences in soil condition and within the array area (subject to array geometry and cable routing).
- Direct sampling to nominal 6mbsf at appropriate intervals along the proposed route and within array area (subject to array geometry and cable routing), might be Vibrocore, Gravity Core, Piston Core, Borehole or similar.
- Geotechnical laboratory testing on selected samples to confirm engineering properties of sediments.

Table 4-9 summarises the various G&G survey types and their various applications.

Table 4-9 Summary of G&G and related survey types and their various applications.

SURVEY	TOPO-GRAPHIC		HYDROGRAPHIC AND ENVIRONMENTAL					GEOTECHNICAL										MARINE GEOPHYSICAL									METOCEAN				TERRESTRIAL GEOPHYSICAL			
APPLICATION	LIDAR/PHOTOGRAMMETRY	BATHYMETRIC LIDAR	SSS	SBES	MBES - BATHYMETRY	MBES - BACKSCATTER	DROP-DOWN CAMERA	GRAB SAMPLES	GRAVITY CORE[3]	PISTON CORE[3]	BOX CORE[3]	VIBROCORE[3]	SEABED PCPT	PCPT BOREHOLE[1]	SAMPLING BOREHOLE[1]	SEISMIC PCPT (SCPT)[1]	OTHER IN-SITU TESTING[4]	SCS (PINGER/CHIRP/PARAMETRIC)	SCS (SPARKER, BOOMER)	2D MCS (SPARKER, AIRGUN)	P-CABLE SEISMIC	3D MCS (HIGH RESOLUTION[5])	3D MCS [5]	SEISMIC REFRACTION	MAGNETOMETRY	MAGNETIC GRADIOMETRY	ADCP	WAVE BUOY	LIDAR	MET MAST	ELECTRICAL RESISTIVITY TOMOGRAPHY	SEISMIC REFRACTION	GPR	MASW
Water depths/bed levels	S	S		S	P																													
Seabed mobility					P*			S	S			S						S	S	S														
Scour			S		P			S	S			P																						
Seabed sediment			P		S	P		P	S			S																						
Seabed obstructions			P		S	S																			S	S								
Seabed infrastructure			P		S																				P									
Benthic habitat mapping			P		S	S	P	S																										
UXO			P		S																					P								
Archaeology (wrecks)			P		S																													
Offshore windfarm shallow geology and geohazards (for foundation design and inter array cables [IAC])			S		P			S	S	S	S	P	P	S	S	S		S	P	P	S	S		S										
Offshore windfarm deep geology and geohazards (for foundation design)													P	P	P	P	S	S	S	P	S		P											
Archaeology (palaeolandscape mapping)			S		P													P	P	P														
Export cable route shallow geology and geohazards (for Export Cable routes)				S	P			S	S	S	S	P	P	S	S			P	S	S	S	S		S										
Landfall topography	P	S																																
Landfall shallow geology and geohazards																															S	P	S	P
Metocean conditions																											P	P	P	P				

Primary/Secondary

**Repeat surveys required.*

[1]*Boreholes may be continuous PCPT or sample, or may be composite boreholes made up of alternating PCPT testing and sampling.*

[2]*SCPT may be conducted using seabed PCPT unit or downhole.*

[3]*Preference for seabed sampling equipment to be dictated by expected shallow soil conditions.*

[4]*May include PS Logging, DMT, HPD, Televiewer etc, requirement dependent on site conditions.*

[5]*'High' resolution is used here in the context of offshore wind surveys: in Oil and Gas terms both types of 3D MCS surveys would count as Ultra-High Resolution (UHR).*

4.3.2 Geophysical and hydrographic data

4.3.2.1 Hydrographic Datasets

Based on discussions in Section 4.3, it has been established that hydrographic datasets are required for developing a detailed and comprehensive understanding of seabed conditions to obtain accurate water depths, to calculate seabed slope and to map the morphology of the seabed. In addition, hydrographic data is commonly used to map seabed sediments and bedforms and in the monitoring of bed mobility, scour and bed stability. Hydrographic data are also essential in identifying obstructions and hazards on the seabed, such as boulders, pockmarks, mounds, debris and infrastructure. Finally, hydrographic data are used in archaeological and ecological studies. Hydrographic survey types and their various purposes are summarised in Table 4-9.

An outline of each data type required in the near-term is discussed below:

i. <u>Side scan sonar (SSS) data</u> are required for multiple purposes for which they are considered an important primary dataset. Namely for classification of seabed sediments, for the identification of seabed obstructions and infrastructure, benthic habitat mapping, UXO identification and in the identification of archaeology (for example shipwrecks) on the seabed. SSS data are also considered to be an important secondary dataset in the identification and mapping of scour on the seabed; in mapping shallow geology and geohazards for pile design and inter-array cables (IACs) and in identifying and mapping palaeolandscapes. One key consideration in the acquisition of SSS data, is the survey design itself. The final outcome and purpose of the dataset should be considered carefully to ensure that the correct equipment is deployed in terms of acquisition frequency, and also to ensure that the acquisition set up is designed appropriately in terms of line spacing and deployment methodology. For example, some SSS systems are towed behind the vessel as towfish, and some are mounted on a pole on the vessel hull. For offshore wind farm developments, SSS data are generally specified to be capable of achieving resolution seabed features and objects on the seabed with a minimum resolution of 0.3x0.3m to 0.5x0.5m across the whole site: this would usually be done with a line spacing of no greater than 50-75m. In the Irish sector, the UAU requirements are more stringent, calling for a SSS operational frequency of 410/500 kHz and 50m survey line spacing (Section 4.2.1). However, to identify the smaller objects down to 0.3x0.3m, an operational frequency of up to 600 kHz is often required, dependant on the line spacing. Some developers are more stringent and have been known to request that two SSS towfish are utilised in a single pass survey, with an operational frequency of 600-900 kHz, in which case the survey design and towing configuration needs to be carefully planned.

ii. <u>Single-beam echo sounder (SBES) data</u> are considered an important secondary dataset for verification of water depths/bed levels, but are seldom used as primary data except in very shallow waters (e.g. nearshore ends of cable routes).

iii. <u>High resolution multi-beam echo sounder (MBES) data</u> are an essential primary dataset. The fundamental purpose of acquiring MBES data is to obtain highly accurate measurement of the seabed and to provide a high-density full site coverage Digital Terrain Model (DTM). MBES acquisition results must comply with International Hydrographic Office (IHO) standards for hydrographic survey [16]. The final purpose of the dataset will determine the minimum standard, which for offshore wind developments is usually Special Order or Order 1a, the primary difference being the minimum resolvable seabed feature dimension. As well as providing accurate water depths, the MBES dataset is also essential for monitoring seabed mobility (repeat surveys required), and in determining the presence of scour on the seabed. In the case of scour around the base of the turbine, scour monitoring is required, in which case repeat surveys (normally annual) are also required. In addition, it is also an essential dataset in the interpretation of seabed and shallow geology geohazards for both the Offshore Wind Farm (OWF) and for the Export Cable Route (ECR). Finally, MBES datasets are also deemed primary in archaeological palaeolandscape mapping. For offshore wind developments, full site coverage data are usually required to be delivered at 0.5x0.5-1x1m.

iv. High resolution multi-beam echo sounder (MBES) backscatter data. These data are essential when it comes to seabed sediment classification and can also aid in benthic habitat mapping and in identifying seabed obstructions. Backscatter data for offshore wind sites is required to the same resolution as the bathymetry DTM.

4.3.2.2 Marine seismic datasets

Based on discussions in Section 4.3, it has been established that geophysical datasets are required for developing an understanding of sub-bed geology and geohazards. In particular, they provide information on the stratigraphy and aid in establishing soil zonation and engineering parameters. Geophysical datasets are also essential for identifying sub-bed geohazards such as boulders, gas, MDAC, mounds, faults, channels, peat and fluid migration. Finally, geophysical datasets are used to map sub-bed palaeolandscapes, buried sites and wrecks in archaeological investigations. Marine seismic survey types and their various purposes are summarised in Table 4-9.

Within the wind farm area, although foundation depths may be limited to ~70mbsf, geophysical data requirements will often extend to ~100mbsf in order to capture information on material up to the predicted depth of disturbance of both the piles and geotechnical investigations, and to provide context for the shallower geological interpretation.

Route-specific CBRA geophysical data inputs as defined by the CBRA methodology guidance [13] (targeted at depth for required cable burial) are:

- High-resolution MBES to establish the bathymetry and identify seabed morphology along and within the route corridor for the export cable and within the array area.
- Side Scan Sonar to locate and determine the nature and geometry of seabed features.
- Magnetometer survey to locate metallic obstructions.
- Sub-bottom profiling to detail on the structure of sediments and differentiate between sediment units within the top 5mbsf.

An outline of each data type required in the near-term is discussed below, including both seismic (Sub-Bottom Profiling, SBP) data and magnetometer data:

i. Single-Channel Seismic (SCS) - Pinger/Chirp/Parametric. High resolution SCS systems can generally achieve penetration depths of up to 50mbsf in soft soils, but more typically 5-

15mbsf. They are used as a primary dataset along the export cable route (ECR), in the mapping of the shallow geology and geohazards along the route. Additionally, they are an important dataset for the Inter-Array Cables (IACs). They are required for gaining information on the shallow geology in the top 5m of soil below seabed and are often used to interpret boulders below the seabed. In addition, they are essential for mapping palaeolandscapes.

ii. Single channel seismic (SCS) - Sparker/Boomer. The Sparker and Boomer systems provide slightly lower resolution data in comparison to the Pinger/Chirp/Parametric systems, but they provide deeper penetration into the soil as a result. SCS Boomer systems can penetrate in the region of 30 to 60mbsf, and SCS Sparker systems can penetrate up to 100mbsf. They are therefore particularly useful for understanding from 5m below seabed to the depth of the first seabed multiple or up to approximately 50mbsf, whichever is deeper. The depth of the seabed multiple in the record depends on water depth, for example, if the water depth is 20m, then the first seabed multiple will appear at ~23mbsf. Below the first seabed multiple, reflections from deeper interfaces are overprinted by echoes of reflections from shallow interfaces which makes then hard to interpret (although processing can be applied to partly compensate for this). However, despite this limitation these systems are invaluable for understanding the shallow geology and geohazards: they are essential for pile design, for inter-array cable installation, and for mapping palaeolandscapes. They also provide secondary datasets for investigating the export cable route.

iii. 2D Multi-channel seismic (MCS) – Sparker/mini-airgun. For understanding the geology at depths greater than ~50mbsf (the approximate limit of SCS systems) and also shallower geology in shallow waters where the presence of the seabed multiple limits the used of SCS systems, MCS data are essential. The nature of their acquisition is such that in processing, the seabed multiples can be removed from the record, and therefore geology and geohazard information below the multiple level can be interpreted. However, the vertical resolution is usually lower than that of an equivalent SCS survey. These datasets are particularly useful in establishing the depth to bedrock, if it falls within the depth of interest, which for monopiles and jackets can be up to approximately 100mbsf. They are a primary dataset for the investigation of shallow to deep geology for mapping of geology and geohazards for foundation design, and also palaeolandscape mapping. MCS surveys can also be useful in areas of complex geology, as they are more capable of imaging steeply dipping surfaces than SCS surveys, and acoustic blanking (signal loss caused by the presence of shallow gas), although significant volumes of gas will still cause 'blank' spots in MCS datasets.

iv. 3D Multi-channel seismic (MCS). These datasets are required only on the most complex of sites, for example a 3D MCS survey using a Sparker or mini-airgun source may be used in a complex glaciated landsystem where even 2D MCS surveys at a 100m line spacing may still fail to adequately capture complex, geotechnically-significant features such as palaeochannel networks. When this is the case, 3D MCS data are a primary dataset for investigating the deeper geology up to 100mbsf. 'High' resolution 3D MC surveys with higher-frequency sources may be used in offshore wind developments for imaging of shallow archaeological features or sub-surface boulders.

4.3.2.3 Marine magnetometry datasets

Marine magnetometer survey types and their various purposes are summarised in Table 4-9 and described below:

i. Marine magnetometer datasets. Single magnetometers are often towed behind the SSS towfish, at a height of 4-7m above seabed, as part of a standard survey setup for offshore wind. When acquired as a single line of data along each widely-spaced survey transect, the data are used to identify large seabed obstructions and infrastructure. The limitation for such surveys is that smaller objects which are far from the survey line will not be detected.

ii. Marine gradiometer datasets: Magnetometer data acquired as part of a marine gradiometer setup, in which multiple magnetometers are towed in an array, are essential for Unexploded Ordnance (UXO) detection. A tight line spacing and very careful survey design is required in this case, and the required survey geometry is dependent on factors such as water depth, expected size of UXO, and the survey vessel characteristics. If UXO are deemed to be a risk, a standalone survey for their detection is required using at minimum magnetic gradiometry.

4.3.3 Other data

Generally, benthic surveys are designed to ground proof geophysical data (MBES bathymetry and sidescan sonar) acquired for site characterisation of ground conditions, which has been interpreted to provide predictive habitat mapping.

All ORE projects will require targeted benthic ecology surveys for Environmental Impact Assessment (EIA) and Development Consent purposes. Standard survey methods should begin with the use of bathymetric mapping to measure the extent of the habitat area. This will normally be completed as part of the initial site suitability investigations. Drop down video should then be used to define habitat type and identify any Annex I habitats (e.g. Sabellaria reef or stony/cobble reef). This will be followed by grab sampling surveys to assess the species composition, macrofaunal communities and sediment particle size of grabs samples taken.

Data from geophysical and geotechnical surveys will inform the physical processes element of a project's EIA and specifically the baseline characterisation, numerical modelling and impact assessment elements. The baseline assessment of physical processes is developed through the analysis and interpretation of data and information from a variety of sources, including a programme of site surveys (geophysical, geotechnical, metocean), pre-existing datasets, mapping, available literature sources and output from numerical modelling. The impact assessment of a project's physical processes EIA chapter will draw upon site specific surveys, the conceptual understanding developed by numerical models as well data generated by programmes like INFOMAR which form part of the existing literature and mapping information.

4.3.4 Geographic areas

The Irish offshore regions can be broadly divided into three areas from an offshore wind development perspective [17]:

- West coast: water depths increase rapidly with distance from the shoreline along the West coast, and there are limited connection point opportunities.
- South coast: deep water combined with shallow rock.
- East coast: less severe wave climate, a large number of sandbanks and proximity to large domestic and export markets.

The most attractive environment for near-term developments is the east coast, where conditions are most suitable for proven fixed-bottom foundation technologies. Initially, developers have focussed on opportunities in water depths proven most economical for monopile foundations; however, as more and more developments saturate the east coast and fixed-bottom foundation technology continues to develop, developers are already considering potential sites in water depths of up to 70m for fixed-bottom foundations. Sites off the south coast are also being considered as can be seen in Figure 4-1: despite the near-term preference for fixed-bottom solutions, some south coast projects are already being investigated as potential floating wind sites. The potential for fixed-bottom foundations off the west coast faces water depth limitations, in addition to limited connection point opportunities.

4.4 Summary

Data requirements for site characterisation and ground model development for near-term ORE projects vary throughout the development process. Near-term developments are likely to be progressed using fixed-bottom foundation technologies: primarily monopiles, but also jackets and GBS, and will be primarily located off the east coast of Ireland in water depths of <70m.

The depth of interest for site characterisation spans the seabed to a depth of ~100mbsf, with the highest-resolution data required in the top 5-10m. The amount of data required increases through the pre-construction development process, with early-stage work able to proceed using a subset of data types that may be of relatively low resolution and not necessarily current, and later stages requiring more data types, and up-to-date, high-resolution datasets. Data types typically required throughout the process are:

- Site-wide high-resolution MBES data to establish the bathymetry and identify seabed morphology and seabed sediments.
- Site-wide, high-resolution SSS data to locate seabed obstructions and benthic habitats, and characterise seabed sediments.
- Site-wide magnetometer data at ~100m line spacing to locate seabed and shallow-buried infrastructure and wrecks.
- Targeted high-density magnetic gradiometer data to locate UXO.
- Site-wide shallow seismic/SBP data to identify geological units to up to 5-10mbsf at <10cm resolution.
- Site-wide medium-penetration single- and multi-channel seismic to identify geological units up to 100mbsf at <3m resolution.
- Site-wide and targeted geotechnical data and lab testing to determine typical and location-specific geotechnical and engineering parameters from seabed to up to 100mbsf.

5 Long-term ORE Sector data needs assessment – 2030 and beyond

5.1 Overview

Both the National Marine Planning Framework and the Marine Planning and Development Bill include provisions for a move to a more centralised offshore renewable energy model, and indications are that this is the preferred model post-2030, particularly in the context of harnessing the enormous potential for floating wind off the west coast of Ireland. A centralised model could take a number of forms with various levels of zoning provided for that would allow for varying levels of centralisation.

For long-term projects, focus is likely to shift to foundation concepts that can take advantage of areas not congested by fixed-foundation projects: this would mean a preference for areas of deeper water and/or shallower bedrock sub-optimal for fixed foundation technologies that are dominant in the near term. In practice, this will mean the south coast, west coast, and deeper-water areas of the east coast. Floating wind concepts are well-suited for these areas, although fixed-bottom designs will almost certainly continue to be pushed to increase their installation limits. Floating wind is a relatively new technology: however, the first commercial floating wind farm is already in operation.

5.2 Considerations for forecasting long-term requirements

5.2.1 Consenting Needs and Stakeholder Requirements

Compared to the current developer-led model, in plan-led or centralised model a State Body and/or the TSO/TAO is the responsible party for the complete process of wind farm site selection and pre-development and offshore grid connection development. Four options are currently under consultation for Ireland [4].

- Option 1: Developer led (as per current model). The developer is responsible for all pre-development, development, construction, operations, and maintenance.
- Option 2: Plan-defined, developer consents and builds. The State determines the zones open to development and identifies and manages onshore connection points. The developer remains responsible for site selection and pre-development, and the consenting and construction of the offshore wind farm transmission assets.
- Option 3: Plan-led, developer built. Offshore planning is the responsibility of the State, while developers are responsible for construction and operation.
- Option 4: As Option 3, but, alongside site pre-development, the construction, ownership, operation and maintenance of the offshore wind transmission assets are now centrally planned by the State.

The probable move to a more centralised delivery model focussed on the west coast of Ireland will have implications both for the consenting process and for stakeholder requirements, but the specific changes cannot be reliably predicted at this stage. Potential wind farms will still be progressed through an auction process with associated minimum data requirements for a development to progress.

5.2.2 Foundation technology developments

Looking at future projections on the right side of Figure 4-5, developers have indicated they plan to increase the use of jackets by roughly fourfold (increasing to 24%). This change corresponds to projects being developed in deeper water depths and with larger turbines. Gravity-base foundations are also slowly increasing their market penetration (increasing to 8.8%). This is anticipated to be because they do not require pile driving during installation, hence eliminating underwater noise and associated negative impacts to marine mammals or need for complex and expensive noise mitigation solutions or piling restrictions. Floating foundations are required for projects in water deeper than approximately 60m and will become more common, projected to be 4.6% of total for future projects that had disclosed their foundation types as of 2018 [10].

Within the Irish market, the foundation technology development with the largest impact is likely to be the development of floating wind. Floating wind, due to its ability to take advantage of deeper waters with relatively shallow anchor/foundations compared to piled jacket solutions.

Four main types of floating wind platform are currently defined, illustrated in Figure 5-1.

- Barge: A relatively flat platform floating at approximately sea surface.
- Semi-submersible: A relatively short, wide structure that extends from above the sea surface to below it; typically in the region of half to a third above.
- Spar: A long thin structure that extends significantly below the sea surface as a column.
- Tension Leg: A structure that is similar to the top bay of a jacket with tensioned lines anchoring it to the seabed (instead of the main lattice).

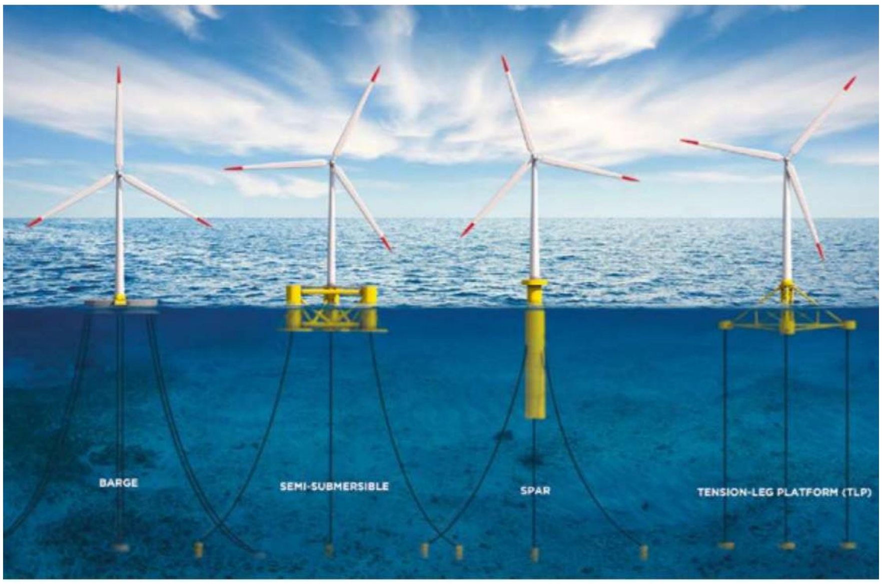

Figure 5-1 Typical floating offshore wind concepts [8].

Mooring systems used in floating offshore wind prototypes include [18]:

- Spread mooring systems with catenary or taut lines.
- Tension leg systems.

- Single-point moorings.

Various numbers of lines may be used depending on platform and degree of redundancy. Each line will need anchoring into the seabed. Various anchor types may be used, including [18]:

- Drag embedment anchors.
- Vertically loaded anchors (VLAs).
- Gravity-installed anchors, such as torpedo anchors of lumped mass.
- Driven piles.
- Suction piles.

The first commercial floating wind farm, Hywind Scotland, has been producing since 2017, with five spar-type turbines installed in 95-120m water depth, each turbine having three suction anchors [19]. Water depths of up to 200m off the Irish coast may be suitable for floating wind turbines. The exact foundation/anchor types that will be used for future developments will depend on water depths, platform types, geology, design code requirements, and preference of propriety floating foundation providers, as well as local market conditions. However, the foundation/anchor depths for floating platforms are anticipated to be shallower than for deep-water jackets (or monopiles), on the order of 30mbsf at maximum.

With respect to the foundation selection and development processes, a similar process may be followed as for fixed-bottom installations (Section 4.2.2.2), with the development following a de-risking and staged approach. The extent of the required G&G information varies significantly between the anchor types: for example a 'proof load' approach may require limited advanced geotechnical data, compared to a suction pile that may require a similar amount of advanced data to a fixed-bottom pile.

It is anticipated that cabling considerations will remain largely the same (Section 4.2.2.3).

5.2.3 Delivery models

In the context of G&G data collection and usage, whether the delivery model is developer-led or plan-led will influence:

- Who is responsible for collecting G&G data.
- Who is responsible for processing and interpreting data.
- Who is responsible for storing and distributing raw, processed and interpretative data, reports, and ground models.

In terms of delivery models, an idea of what a plan-led model could look like is provided by the Netherlands, where the Rijksdienst voor Ondernemend (RVO.nl, Netherlands Enterprise Agency), a government agency which operates under the auspices of the Ministry of Economic Affairs and Climate Policy, is responsible for identifying wind farm sites and organising all pre-development activities on those sites up to auction. This includes all desk studies, EIA, full-coverage G&G surveys, and ground model development necessary to inform FEED studies and make competitive tendering possible [20]. Desk Studies, preparation of specifications, surveys, client representation, data analysis, ground model development, and reporting are all performed by specialist contractors and consultants, through a combination of Owners' Engineer (expert support) contracts, G&G surveying contracts, and ground modelling contracts. Documents and data are stored and distributed by RVO.nl via a web portal. Offshore grid connections and cable route development are developed separately by TSO TenneT, the national electricity transmission system operator of the Netherlands.

The exact implications for Irish ORE developments will not be known until the future delivery model is decided. However, if a centralised/plan-led model is adopted then implications for the government or relevant state body, with specific reference to G&G data, can be projected based on the Dutch example. It is likely that G&G data-related impacts will include at minimum:

- Necessity for full time roles at the state body for organising and managing pre-development activities, including G&G data collection.
- State body will need capacity to store, catalogue, and distribute large volumes of G&G (and related) data between various consultants/contractors and developers.
- Requirements for clearly defined data standards for surveys conducted on or behalf of the State.

5.2.4 Increased local commercial survey capacity

Between 2020 and 2030 there is the opportunity for international contractors and indigenous Irish contractors to build up a decade of acquisition experience in ORE development areas of the Irish Sea, Celtic Sea and Atlantic Ocean. This should result in greater contractor availability in the long-term to undertake commercial G&G surveys. Contractors who have operated in the Irish ORE sector or expressed an intent to do so are summarised in Table 5-1, with their G&G survey capacity indicated. This is not intended as an exhaustive list, but to give an idea of potential survey capacity within the Irish ORE sector. This list also highlights the potential for novel survey technologies, with the presence of at least one company with a presence in Ireland (XOCEAN) commercially operating Unmanned Survey Vessels (USVs) for bathymetry and high-resolution SBP data collection.

Given the potential of the Irish Wind Sector and the current model in which multiple developers can carry out pre-development work on the same area (Figure 4-1), there is some potential in the Irish ORE sector for one or more contractors to engage in a multi-client survey strategy. Data from contract-based surveys are exclusive to the client: in the multi-client model, which is a common approach in the Oil and Gas sector, the geophysical contractor undertakes work using their own capital or pre-funding from interested companies. The data are then available to multiple clients.

The advantage of this approach for the wind sector is that multi-client surveys can potentially cover larger areas, and provide regional context for data, in a way that site-specific surveys cannot (in a similar way to the INFOMAR programme deliverables). This approach can also reduce the overall cost of wind developments, e.g. by removing the potential for multiple companies to commission duplicate surveys of the same type, and/or by covering more area per mobilisation (making the survey more cost effective than multiple mobilisations for individual site-specific surveys).

Table 5-1 Non-exhaustive list of G&G survey companies operating in the Irish ORE sector.

Contractor	G&G survey capability	Office in Ireland	Irish company
Green Rebel Marine	Geophysical, hydrographic, and geotechnical site investigation services	Y	Y
Alpha Marine + UltraBeam partnership	Geophysical and hydrographic site investigation services.	Y*	Y*
MMT	Geophysical, hydrographic, and geotechnical site investigation services	N	N
GEOxyz	Geophysical, hydrographic, and geotechnical site investigation services.	N	N
EGS (International) Ltd	Geophysical and hydrographic site investigation services.	N	N
Fugro	Geophysical, hydrographic, and geotechnical site investigation services.	N	N
Geoquip	Geotechnical site investigation services	N	N
G-tec	Geophysical and hydrographic site investigation services (geotechnical services were previously supplied but are no longer).	N	N
XOCEAN	Specialist geophysical contractor using USVs to collect high-resolution hydrographic and shallow seismic data.	Y	N

*Alpha Marine, based in Wicklow, are usually the leading partner with the AM – UB JV.

5.2.5 Synthesis

The G&G data requirements for long-term developments will remain largely the same as for near-term developments (Section 4.4), with the key differences being to do with the acquisition environment (deeper waters) and required investigation depths (shallower foundation target depths). The main changes relating to G&G data requirements in the long-term are likely to be more to do with when data are required relative to the project development stage, how data are collected and stored, and who has the responsibility for organising pre-development and development activities.

For long-term developments, the key factors influencing changing G&G data needs that have been highlighted in Sections 5.2.1 through 5.2.4 are:

- Changes in regulatory environment.
- Changes in the delivery model (probably transition from developer-led to plan-led).
- Changes in foundation technology (transition from fixed-bottom to floating technology).
- Increase in commercial G&G survey capacity and experience in Irish waters.

Specific requirements for G&G and associated data in the context of the long-term developments are described in Section 5.3.

5.3 Long-term requirements forecast

5.3.1 Geotechnical data

Long-term geotechnical data considerations will likely be very similar to those in the near-term (Section 4.3.1) as developments will still require foundation and cable route information. The key differences influencing data collection methods will be the water depths in which investigations will take place, and the investigation depths required. These differences will influence the choice of geotechnical investigation methods. In addition, different types of anchoring systems will have different footprints, which may influence the number of geotechnical tests required for a single turbine location.

5.3.2 Geophysical and hydrographic data

Long-term geophysical data considerations will be very similar to those in the near-term (Section 4.4.2), as developments will still require foundation and cable route information. The key differences influencing data collection methods will be the water depths in which investigations will take place, and the investigation depths required.

For fixed-bottom foundations, the depth of investigation below seafloor is often greater than the water depth, which usually necessitates multi-channel seismic surveying even where single-channel surveying/SBP would be theoretically capable of achieving the necessary investigation depth, due to the occurrence of seabed multiples (see Section 4.3.2.2). In contrast, for floating wind developments in deeper waters, the water depth may often be greater than the depth of investigation. In combination with the reduced depth of interest for floating wind anchors and foundations, compared to jacket foundations and deep monopiles, it may be that the likelihood of single-channel seismic/SBP being sufficient to obtain data to the full investigation depth for floating installations is greater than for fixed-bottom sites.

There may also be increased focus on both obtaining repeat, high-resolution bathymetry data and very-high resolution seismic data in the near surface, given the predicted use of catenary mooring lines and of anchoring systems that will likely include drag anchors, VLAs, and torpedo anchors in addition to piles and suction caissons.

5.3.3 Other data

The long-term data requirements for environmental and ecological data are very similar to those in the near-term: however, it is likely that over time survey techniques and data requirements will change and improve. This will very much be informed by analysis of the previous decade's data and a greater understanding of the marine environment and the potential impacts of ORE projects have been developed.

5.3.4 Geographic areas

As discussed in Section 4.3.4, the Irish offshore regions can be broadly divided into three areas from an offshore wind development perspective [17]:

- West coast: water depths increase rapidly with distance from the shoreline along the West coast, and there are limited connection point opportunities.
- South coast: deep water combined with shallow rock.
- East coast: less severe wave climate, a large number of sandbanks and proximity to large domestic and export markets.

With floating wind in consideration, this brings additional deep-water areas of the east and south coast into contention for offshore wind developments, but the expected target area is the west coast, where there is a lack of competition from fixed-bottom developments.

5.4 Summary

Data requirements for site characterisation and ground model development for long-term ORE projects will vary throughout the development process, as for near-term developments. However, the stages at which certain datasets are required are yet to be determined. Long-term developments are likely to be progressed primarily using floating wind technologies primarily located in deeper waters off the west coast of Ireland.

The depth of interest for floating wind site characterisation spans the seabed to a depth of ~30mbsf, with the highest-resolution data required in the top 5-10 m. Data types typically required throughout the process are:

- Site-wide high-resolution MBES data to establish the bathymetry and identify seabed morphology and seabed sediments.
- Site-wide, high-resolution SSS data to locate seabed obstructions and benthic habitats, and characterise seabed sediments.
- Site-wide magnetometer data at ~100m line spacing to locate seabed and shallow-buried infrastructure and wrecks.
- Targeted high-density magnetic gradiometer data to locate UXO.
- Site-wide shallow seismic/SBP data to identify geological units to up to 5-10mbsf at <10cm resolution
- Site-wide medium-penetration single-channel seismic to identify geological units to at least 30mbsf at <3m resolution.
- Site-wide and targeted geotechnical data and lab testing to determine typical and location-specific geotechnical and engineering parameters from seabed to up to at least 30mbsf.

The amount of data required increases through the pre-construction development process, with early-stage work able to proceed using a subset of data types that may be of relatively low resolution and not necessarily current, and later stages requiring more data types, and up-to-date, high-resolution datasets.

6 G&G data gap analysis

6.1 Overview

In this section, INFOMAR deliverables are assessed against the near-term and long-term G&G data requirements identified for each stage of an offshore wind development in Sections 4 and 5. Sections 7, 8, and 9 discuss how any identified gaps could be addressed by INFOMAR programme adjustments, the used of complementary datasets, and industry actions, respectively. Section 10 highlights some case studies of INFOMAR data use in offshore wind developments.

6.2 Previous reviews

6.2.1 INFOMAR/GDG

In 2012, GDG completed a report for INFOMAR to investigate the geotechnical uncertainties and risk to the foundations of future offshore wind farm developments around the Irish coast. This study proposed to review the existing INFOMAR data and to assess the potential usefulness of this data in de-risking the capital cost of offshore wind farm construction [17]. This work focussed on identifying bathymetry and geotechnical data gaps.

The conclusions of this report were that the INFOMAR coverage to date had provided widespread information around the Irish coast that would be useful in planning suitable sites for wind farm developments. However, two areas where additional information was needed were highlighted:

1. Bathymetric data in deep water sections of the Irish Sea.
2. Geotechnical data on soils in the region of 30-50mbsf.

This report concluded that to de-risk specific foundation concepts and capitalise on the abundant offshore wind resource, additional information would be required, including increased spatial coverage off the east coast, data from deeper soil strata, and more quantitative information regarding geotechnical properties.

The INFOMAR data gap analysis identified the following data gaps with respect to offshore wind developments:

1. There was limited soil information over the depth range that is relevant to wind farm foundations.
2. The available information did not contain quantitative parameters that can be used in design.
3. Where soil classification information was available, there was no clear framework defining the process to classify the seabed material.

The report concluded that the need for geotechnical information on deeper soils could be addressed in a relatively cost-effective manner by a programme of targeted seabed PCPT testing in Irish Coastal waters. It was concluded that completing PCPT or sample borehole (with high quality soils samples over the depth of interest for onshore laboratory testing) would be prohibitively expensive, and seabed PCPTs could be used as a simple and efficient means of obtaining strength profiles with depth of the underlying materials. The report developed a PCPT framework that could be implemented as a data gathering exercise within the INFOMAR programme, including recommended geotechnical sampling locations. In addition, it recommended that when soil samples are taken, a recognised classification system should be adopted to describe the engineering behaviour of the soil.

6.2.2 EirWind

The EirWind project, hosted by the Centre for Energy, Climate and Marine (MaREI), is aimed at supporting the development of offshore wind in Ireland through a number of targeted work packages. Work within the EirWind project identified three critical boundaries for assessing data coverage relative to offshore wind development: (1) the Irish EEZ; (2) the Irish continental shelf within the 200m isobath (i.e. <200m deep); and (3) the Irish continental shelf within the 70m isobath (i.e. <70m deep). Areas within <200m were considered suitable for floating wind development and <70m considered for fixed-bottom development. One such work package included a review of existing data with data gap analysis and recommendations for future data collection in strategi areas. A meta-analysis review of data requirements was carried out identifying a list of 22 variables relevant to offshore wind [21]. Their assessment characterised data gaps and short comings under four separate headings:

1. Omitted data.
2. Unavailable data.
3. Data with inadequate resolution.
4. Data with inappropriate file types.

Of relevance to this study, the report identified three geological variables with significant omissions, namely:

- Surface sediment lithology.
- Depth to bedrock.
- Stratigraphy.

The variable “Seabed morphology and slope” was identified as suffering from availability issues. Following two targeted data collection surveys, Peters, Wheeler and Cummins [22] reported an improved in resolution and coverage of seabed and surficial sediment data in specific key areas compared to the baseline. However, the report conceded that coverage in general remained variable. The EirWind report generally concluded that:

1. A combination of INFOMAR data and EMODnet data gives 100% coverage of the Irish EEZ, with the high-resolution INFOMAR data is preferable for site specific studies, although there are recognised spatial gaps.
2. More prominent spatial and data-quality gaps exist in relation to seabed morphology and sediment lithology which require:
    a. Increased coverage of high-quality seismic data to calculate depth to bedrock;
    b. Increased density and coverage of seabed sampling to improve sediment distribution.

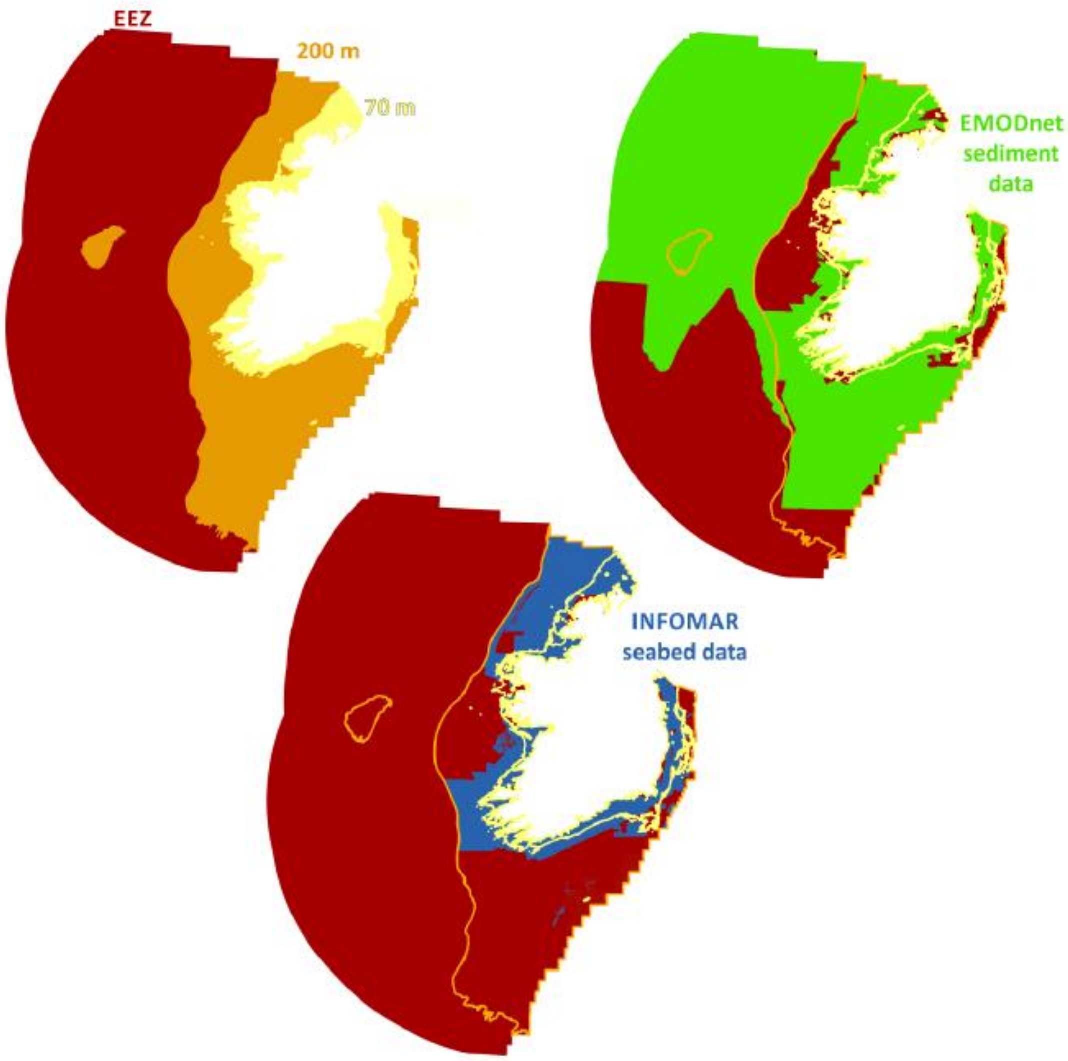

Figure 6-1 Maps showing coverage of INFOMAR and EMODnet data coverage [21].

6.3 Geotechnical data

Grab sampler and vibrocorer coverage has increased since the reviews described in Sections 6.2.1 and 6.2.2. However, the density of sample locations is still variable with some gaps in key areas. As yet, collection of PCPT and borehole data has not been added to the INFOMAR programme, so the geotechnical data coverage gap referenced in both reviews is still outstanding.

From Section 4.2.2.2 in particular, it is notable that INFOMAR bathymetry data are sufficient for site selection and foundation optioneering, and INFOMAR seismic data are sometimes sufficient (depending on depth of interest and type of seismic coverage). Conversely, INFOMAR geotechnical data types and coverage are not sufficient to provide sufficient information on ground strength to inform foundation optioneering studies, requiring estimates and assumptions to be made (e.g. from shore-based data or adjacent sites) that mean there is an inevitable amount of uncertainty attached to the foundation optioneering results. The foundation optioneering process for Irish offshore wind developments could be significantly enhanced should INFOMAR add collection of deeper geotechnical data (e.g. PCPT) data to the programme. There is a significant value associated with the collection of such data: should sufficient geotechnical data be available to inform foundation optioneering and conceptual foundation design, some developments could potentially avoid the need to undertake any geotechnical surveying prior to RESS auction; a significant early-stage cost saving.

6.4 Geophysical and hydrographic data

6.4.1 Hydrographic data

The resolution of INFOMAR bathymetry grids, at 5x5m, is sufficient to understand water depths over a site, and the backscatter data provides extremely useful information on seabed sediments that are an invaluable input to early-stage offshore wind site identification and foundation optioneering studies, particularly in conjunction with Folk seabed sediment classification maps. Higher-resolution bathymetry and backscatter data are generally required at later stages of wind farm developments, but high-resolution data is also useful from an early stage to inform later change-point studies to examine bedform mobility.

Bathymetry DTMs and backscatter data are not currently provided on a 'plug-and-play' basis for the needs of most ORE developments format. INFOMAR MBES and Backscatter data are supplied as a High Dynamic Range (HDR) format raster, which must then be imported to a GIS package and exported as a Geotiff. MBES data can also be provided in xyz format if requested specifically. These files are also normally supplied with WGS 1984 geodetics, and with grid cells in fractions of a degree. These data formats are usable but do require some reformatting, resampling, and reprojection first.

SSS data is not routinely acquired during standard INFOMAR surveys, being acquired only on request for commercial and archaeological purposes [23].

6.4.2 Seismic data

INFOMAR seismic data have significant value for cable route planning in the nearshore areas. The depth penetration of the data is generally sufficient for cable planning, while the data have high vertical resolution. Line spacings tend to be tighter closer to shore, which is an advantage in areas of shallow bedrock with high top bedrock surface topography. However, a disadvantage is that lines tend to run parallel to the coast, whereas for export cable routing it is preferable to have lines oriented perpendicular to the coastline. Where there are limited crosslines, the preferential orientation of lines perpendicular to the coast can complicate the geological interpretation along a cable route, due to the number of seismic lines that must be processed and the necessity to extent the interpretation parallel to the coast in order to intersect tie lines.

Within areas designated for potential turbine installation, the limited penetration of SBP data comparted to the depth of interest for fixed-bottom foundations is a limitation on the usefulness of the data. Theoretically, high-frequency SBP systems may reach up to 50mbsf penetration in soft soils. However, this maximum penetration depth is not anticipated over the majority of the area covered by INFOMAR due to the presence of coarse seabed sediments and shallow gas. GDG have worked with multiple INFOMAR shallow SBP datasets (Pinger, Chirp, and parametric [Innomar]) for Irish wind farm developments. After signal processing, penetration varies within and between datasets. The average penetration per dataset varies between 10mbsf and 25mbsf, while the penetration locally varies within datasets from a couple of metres to generally no greater than 30mbsf, depending on acquisition conditions, seabed substrate, and water depths.

Where SCS Sparker data have been acquired, the penetration can be tens of metres. However, the line spacing of these Sparker surveys are generally large compared to the SBP line spacing. They can thus provide a good guide to bedrock depths on a site but are of limited use in detailed bedrock surface mapping. The Sparker data is generally of good quality, being acquired using a source very suitable for the conditions encountered in the INFOMAR survey areas (a Geo-Source 200) and an optimum survey speed of ~4kn [24].

The key seismic data gap with respect to near-term foundation considerations is therefore in the 25-100mbsf depth range in areas where top of competent rock is >25mbsf. The vertical data gap is less significant for long-term (floating) developments due to the shallower foundation/anchor requirements.

In terms of data quality, many of the INFOMAR Pinger and Chirp SBP datasets suffer from variable interpretability due to the presence of cavitation. The presence of cavitation may be partly related to the speed of acquisition. For surveys where SBP data is a primary output, a speed of 3-4kn is preferred. INFOMAR acquisition speeds are understood to be on the order of 6-8kn to enable efficient MBES data collection, with SBP data being collected as 'data of opportunity'.

SBP data are susceptible to heave and swell motions, which cause vertical displacements of the data. Pinger and parametric (Innomar) data generally are supplied with heave data in the headers, which means that these artefacts can be easily processed out. However, Chirp data from the *RV Keary* do not contain heave information, requiring significant additional processing time to filter out these heave effects.

Both shallow SBP data and Sparker data are sometimes provided with changes in recording delay both between lines in a survey and within lines, with time delays not always accurately recorded in the seismic data files. Correction of variable time delays must be carried out manually in these cases, on a line-by-line basis, which adds significant processing time.

Tidal correction is also a preferred processing step prior to seismic interpretation. Water depth information is not present in Chirp SEG-Y files that GDG have seen to date, which increases the time required to tidal correction processing.

As the State moves to an increasingly more centralised model, the drive for the State to provide detailed G&G data increases. There will likely be a requirement at a point in the future for the INFOMAR data to be integrated into future gathered data. In fact, it is also possible that INFOMAR data may be used by Government in the initial stages of site selection under a centralised model where the quality of that data and its reliability will be a key component of a successful centralised ORE programme. In this scenario, any seismic data collected by or on behalf of governments will be regarded as a primary resource and will almost certainly need to be obtained to commercial data collection standards, rather than as data of opportunity.

6.4.3 Magnetometer data

Magnetometer coverage is limited, as magnetometer data are not acquired on all surveys.

For commercial cable and pipeline detection, a single magnetometer is towed at a target depth of 4m above seabed, and preferably less than 7m. Such a close proximity to the seabed is necessary for the detection of relatively low-amplitude anomalies for seabed and shallow buried infrastructure and wrecks. The constant tow height means that anomalies can be compared to examine their relative strength (although strength is also affected by the lateral offset of the causative feature from the survey line). At a latitude of 53°N It is also preferable to collect magnetometer data for object detection in a N-S orientation.

INFOMAR collects magnetometer data by towing the magnetometer just below the sea surface [25]. Line orientations are variable. Such data can be useful for large-scale geological investigations but has limited utility for seabed obstruction detection. INFOMAR magnetometer data and identify large anomalies (e.g. caused by wrecks with significant metallic content) and infrastructure and objects in shallow water (where the tow height is proportionally reduced), but INFOMAR magnetometer data are not suitable for site-wide object or infrastructure detection.

6.5 Other data

Currently INFOMAR data forms part of the wider pool if existing information used in characterising the baseline for the physical processes element of Environmental Impact Assessment (EIA) Reports as well as a source of information used to inform the design of benthic characterisation surveys.

In the near-term it is most probable that ORE projects have examined INFOMAR's outputs or those products that INFOMAR has contributed to in a greater or lesser extent (e.g. maps and data on INFOMAR website, and EMODnet). Therefore, data generated from the programme is already being used. In the longer term there will be a greater opportunity for INFOMAR to cater for the ORE industry's needs as the Irish government considers a more centralised approach to the development of offshore wind in particular in the medium to long-term. In the near-term, ORE projects and especially offshore wind projects are currently planning or conducting specific geophysical, geotechnical, metocean, ecological (including benthic) surveys to inform the design of their proposed projects as well as define the baseline and parameterise the models upon which their EIA Report and Development Consent applications will be based upon.

INFOMAR's scale of operation is not at present at the level of detail required for an ORE project. It is useful to give a high-level overview of an area at the very early stages of project development in terms of site selection as well as forming part of the existing baseline data that is drawn upon for data gathering desk study exercises. However, as Ireland investigates a more centralised approach to governing ORE projects, INFOMAR will have a larger role to play and is suitably capable of undertaking the type of site- or region-specific surveys that will provide very useful data for ORE projects.

6.6 Geographic areas

The INFOMAR data archive has excellent bathymetry and seismic data coverage. However, data gaps have been identified with respect to near-term and long-term developments.

Bathymetry coverage has been expanded since the reviews described in Sections 6.2.1 and 6.2.2., but the 2019 EirWind review results [22] are generally still valid. Data gaps are generally found with respect to longer-term developments off parts of the west coast and in water depths greater than 75mbsf off the east and south coasts. INFOMAR seismic data coverage is more limited than bathymetry data coverage, as not all INFOMAR survey campaigns collect SBP data in addition to hydrographic data (Section 3.3). However, the coverages are broadly comparable.

6.7 Data delivery

The INFOMAR website and data portals provide easy access to processed data deliverables (bathymetry grids, sediment mapping, etc.) and spatial coverage information (survey polygons and line plans). In addition, INFOMAR's Web Map Service (WMS) layers can be used by anyone with a GIS system. INFOMAR's web map portal is also user-friendly and enables stakeholders to easily visualise data coverage and key spatial deliverables without having to download data to their own systems. However, seismic data must still be obtained through direct request to the GSI.

6.8 Summary

The gap analysis with respect to data types is summarised in Table 6-1. The key data gaps compared to near- and long-term ORE data needs are:

- Lack of geotechnical data for sub-surface ground truthing beyond the first few metres below seabed.
- Limitations on the ability of INFOMAR geophysical data to characterise the sub-surface geology from ~10mbsf to ~50mbsf, with coverage decreasing with depth below seabed.
- No geophysical or geotechnical information at depths greater than ~50mbsf.

Geographic data gaps have been identified related to near- and long-term developments. In addition, some differences in data quality, resolution, and formats have been identified relative to standard ORE commercial deliverables.

Table 6-1 ORE geophysical, geotechnical and hydrographic data gap analysis summary.

DATA NEED		SUITABILITY	COMMENTARY
General water depths		GOOD	• INFOMAR bathymetry grids are provided at a resolution sufficient to understand water depths across a site, and the presence of sandwaves, sand ridges, and sand banks.
Seabed mobility		OK	• Can be used as input to sediment transport modelling. • Limited survey overlap to inform bed level change analysis. • Bathymetry data have a shelf life. • Grids are lower resolution than would be preferred for site-specific bedform mobility analysis.
Geology/ depth to bedrock within depth of interest	*Up to ~10mbsf*	GOOD	• Seabed geology can be inferred from INFOMAR backscatter data via seabed sediment classification, including likely areas of outcropping bedrock and glacial till. • Pinger/Chirp/parametric data should be sufficient to produce shallow geological interface depth/elevation grids with a resolution of 10-100 m, depending on line spacings. • Line orientations are not optimal for interpreting cable route geology. • Differentiation of top competent bedrock may be difficult due to an absence of geotechnical ground truthing.
	~10-25 mbsf	OK	• Pinger/Chirp/parametric data should be sufficient to produce shallow geological interface depth/elevation with a resolution of 10-100 m, depending on line spacings, but coverage may be incomplete. • Differentiation of top competent bedrock may be difficult due to an absence of geotechnical ground truthing.
	~25-50mbsf	POOR*	• SCS Sparker seismic data should be sufficient to produce interface elevation ribbon plots, but line spacing is generally insufficient for gridding with sufficient resolution to adequately image interface topography. • SCS Sparker data coverage is limited to a few areas. • Differentiation of top bedrock from top till may be difficult based on seismic data alone, due to an absence of geotechnical ground truthing.
	~50-100mbsf	UNSUIT-ABLE	• Generally beyond the penetration depth of INFOMAR seismic datasets.
Geotechnical parameters		UNSUIT-ABLE	• The INFOMAR programme does not acquire as standard geotechnical data that is suitable for ground truthing sub-bed geology below the first few metres.
Environmental baseline data		OK*	• Very limited temporal coverage. • Bathymetry data have a shelf life.
Ecological baseline data		POOR*	• Bathymetry data have a shelf life. • Additional benthic ecology survey, analysis and reporting would be required.
Obstructions		POOR*	• Large wrecks can be identified in grids • Bathymetry and backscatter grid resolutions are too poor for detection of obstructions to standard offshore wind requirements (minimum threshold 0.3-0.5m). • No SSS data.
Infrastructure mapping		OK*	• Depends on vintage – newer installations may not be observed. • Surface only, reliably (magnetometer data not suitable).

**Depending on data coverage and/or age.*

7 Bridging the gap – INFOMAR recommendations

7.1 Overview

Recommendations for the INFOAMR programme have been made from the perspective of G&G data needs for the ORE sector. However, the INFOMAR programme has many different responsibilities and has no obligation to implement any of these recommendations. The goal of this section is to highlight areas where amendments to the programme could benefit the ORE sector and indicate their potential value, to inform INFOMAR's own internal assessment of which of these recommendations it would be feasible to implement, if any.

Recommendations have been made in three broad categories:

- Changes to data handling: indexing, formats, distribution.
- Changes to data collection methodologies.
- Geographic area prioritisation.

7.2 Data indexing

INFOMAR already has in place a robust and user-friendly portal through which survey and data coverages can be interrogated. However, some minor adjustments to provided spatial data could improve data usability, particularly with respect to seismic data.

- When annual vector tracklines are downloaded, attribute fields are not fully aligned; for example, the line name fields contain text entries for some survey trackline files, and integer entries for others. Text names are preferred to avoid date-based names such as '201108.174300' being treated by indexing or processing software as decimal numbers, or names like '0123' losing leading zeroes.
- Seismic file names are not always clearly linked to trackline/hydrographic trackline line names.
- As not all vessel tracks will have an associated seismic file, even for a survey for which seismic data were collected. Specific seismic trackline files automatically generated from file headers would be a useful addition to the INFOMAR portal, allowing users to accurately identify the correct subset of seismic lines relevant to their area of interest before contacting the GSI to obtain seismic data files.
- An overall line naming convention that identified survey, line number, and data type could improve data accessibility, for example using the pattern 'Survey_Line_Type_Subtype' (giving e.g. 'CV12_02_0137_SBP_PI' or 'KRY16_01_0514_SBP_CH'). For older surveys, it is recognised that renaming thousands of files would be a large task, but if this recommendation were to be implemented, the work could be semi-automated by using bulk renaming software.

7.3 Data formats

7.3.1 Hydrographic

Formats are generally usable in common analytical software.

7.3.2 Seismic

Currently, INFOMAR seismic data are made available in a mix of formats, as highlighted in Table 7-1. The ORE industry standard format seismic data processing and interpretation is SEG-Y, which is an open standard developed by the Society of Exploration Geophysicists. SEG-Y files can be read by most seismic processing and interpretation software. The SEG-Y file format standard is on its second revision [26], and most seismic processors with either an Oil and Gas background or a background in renewables will be comfortable with processing data in SEG-Y format. There are many acquisition-independent seismic processing packages available, all of which take SEG-Y format data as input and produce SEG-Y outputs.

GDG strongly recommend that data from all surveys is converted to SEG-Y data prior to distribution. In addition, it is recommended that the INFOMAR implementation of the SEG-Y standard (i.e. what values are stored in which SEG-Y headers) is formalised and published in the INFOMAR website. This would represent a time and cost saving for developers and associated consultants, who would receive data in a format ready to plug straight into their seismic processing software, to which standard processing flows could then be applied. In addition, there is a cost implication for some proprietary data formats such as *.cod, which require the developer's software to convert to SEG-Y format. It would also represent a time saving to INFOMAR by reducing the amount of time spent fielding enquiries from developers and consultants concerning file formats and content.

Table 7-1 INFOMAR seismic data formats.

DATA TYPE	FORMAT	NOTES
Pinger	CODA (*.cod)	CODA files can only be processed in CODA Octopus software. A paid licence is required for CODA Octopus software to convert to SEG-Y
	SEG-Y (*.sgy)	'Standard' seismic data format, read by most seismic processing and interpretation software. Usually provided with additional information on water levels in the headers.
Chirp	Joint Sensor Format (*.jsf)	JSF files contain both waveform and envelope data. JSF can be read and converted by several software programs, but some will only output envelope data. Full-waveform data is preferred for advanced processing purposes.
	SEG-Y (*.sgy)	'Standard' seismic data format, read by most seismic processing and interpretation software. Not usually provided with water level information.
Innomar	SES (*.ses) and RAW (*.raw)	RAW and SES files contain waveform and envelope data, respectively. RAW (full-waveform) data is preferred for advanced processing purposes. RAW files can be processed in Innomar's ISE post-processing software or converted to SEG-Y using SES Convert (free software) for processing in other software. Usually provided with additional information on water levels in the headers.
Sparker	SEG-Y (*.sgy)	'Standard' seismic data format, read by most seismic processing and interpretation software.

7.3.3 Geotechnical

Should INFOMAR begin to collect or store PCPT or borehole data, GDG recommend that data are stored in AGS 4.0 format. The AGS Data Format (*.ags) is a text file format developed by the Association of Geotechnical and Geoenvironmental Specialists (AGS) to facilitate geotechnical data transfer independently of software, hardware, or operating system [27] which is commonly used in site investigations. The AGS format can store raw, processed, and interpretative geotechnical data. The two primary pieces of software used to analyse geotechnical data are gINT (Bentley) and HoleBASE (Keynetix/Bentley), both of which can import and export AGS format data.

It is recommended that, where available, Grain Size Analysis (GSA) data are linked with grab sample locations on the INFOMAR delivery portal. Preferably all samples would have GSA carried out so end-users can utilise the data for a range of grain-size distribution calculations and applications other than solely Folk classification.

7.4 Data delivery

INFOMAR already has in place a robust and user-friendly portal through which data can be distributed. This portal is proven to be sufficient for near-term development needs. Should the Irish market move to a more centralised regime in which the State might take over pre-development data management, storage and distribution, it would be natural to look at developing the existing INFOMAR portal rather than developing a new system from scratch. If this were to occur, then consideration would need to be given in the long term to the effect on site traffic and volumes of data being transferred.

7.5 Survey scopes

7.5.1 Co-ordinate systems and datums

INFOMAR data is usually provided in WGS84, WGS84 UTM Zone 29N, or WGS84 UTM Zone 30N. The use of ETRS89 would be preferred to WGS84 given the period of the INFOMAR programme compared to the rate of divergence between the ETRS89 and WGS84 datums. The rate of divergence is approximately 2.5 cm annually, due to continental drift. Although this is insignificant compared to the resolution of any one dataset, the total divergence between the oldest datasets in the INFOMAR archives (2004) and developments coming online in 2030 and beyond could be over half a metre. This is potentially enough to start imparting small biases into seabed mobility assessments, for example.

7.5.2 Hydrographic

7.5.2.1 Bathymetry and backscatter

As a primary deliverable of the INFOMAR programme, the bathymetry data is already of excellent quality. With respect to maximising efficiency, INFOMAR could potentially leverage the emergence of commercial USVs for the acquisition of high-resolution bathymetry and backscatter data without the requirement to mobilise additional survey vessels. This could have particular applications in shallow waters to provide a link between onshore topography and vessel-based bathymetry coverage, as demonstrated by previous pilot studies.

7.5.2.2 Sidescan Sonar

Acquisition of SSS data is not currently a standard INFOMAR deliverable. In the near-term, full-coverage, high-resolution SSS coverage would probably have a prohibitive impact on survey costs and efficiency. GDG propose that, in the long term, the acquisition of high-resolution backscatter may prove an easier and cheaper way of identifying seabed obstructions at early project stages.

7.5.2.3 Acoustic Doppler Current Profiler

The deployment of Acoustic Doppler Current Profiler (ADCP) has value for the ORE sector, as understanding of current velocities and turbulence is an important consideration for calculation of transient loadings on marine structures. GDG recommend ADCP deployments for survey durations for ongoing data collection (in conjunction with Marine Institute).

7.5.3 Seismic

7.5.3.1 Single-channel Pinger/Chirp/parametric

If the time-stamped tide-files could be delivered with survey seismic archives, this would be a valuable tool to enable the seismic data to be easily reduced to datum, without requiring any additional processing on INFOMAR’s part. Similarly, for seismic files from hull-mounted instruments that are not populated with heave data, if time-stamped vessel heave data could be provided this would be similarly helpful.

To maximise the value of the data to the ORE industry, it is recommended that source settings and recording delay times are not altered during surveying of individual lines.

It is understood that the seismic data are acquired as data of opportunity in the current INFOMAR programme. However, should the Irish market move to a more centralised regime for delivery of ORE targets, then seismic data may be seen as a primary data product. In this case, there may be justification for the weighting of data quality compared to survey efficiency (vessel speed) to be increased.

With respect to maximising efficiency, INFOMAR could potentially leverage the emergence of commercial USVs for the acquisition of high-resolution, shallow penetration SBP data, without the need to mobilise additional survey vessels.

7.5.3.2 Single Channel Survey Sparker

Single Channel Survey (SCS) Sparker data acquired by the INFOMAR programme are already of high quality. To maximise the value of the data to the ORE industry, it is recommended that source settings and recording delay times are not altered during surveying of individual lines.

7.5.3.3 Multi-Channel Survey

Potential value to the ORE sector in the near term of acquiring targeted MCS data has been identified. In the case that MCS surveying is added to the INFOMAR programme, then it is recommended that specifications follow commercial templates, to maximise the value of the data. The use of sources and streamers developed primarily for shallow geological investigations in the ORE sector, such as broadband multi-level Sparkers, would be advantageous.

7.5.4 Magnetometer

Amending standard INFOMAR acquisition procedure to tow a magnetometer at a constant height above seabed could be investigated. However, towing the magnetometer at depth will have implications for survey efficiency and may not be viable, given that lack of magnetometer data has not been identified as a major data gap in the INFOMAR programme with reference to ORE G&G data needs.

7.5.5 Geotechnical and environmental

7.5.5.1 Seabed samples

The distribution of seabed samples is irregular. It is suggested that a systematic, gap filling approach is developed, using automated backscatter seabed classification maps in order to target ground-truthing locations as effectively as possible and maximise cost-effectiveness, with acquisition being undertaken following INFOMAR’s existing strategy [28].

7.5.5.2 Boreholes

With particular regards to ground truthing depth to bedrock datasets and improving both resolution of bedrock mapping and uncertainties over differentiation over top bedrock and top of till it would be beneficial to undertake boreholes to depths of at least 30m below the seabed.

These boreholes should be systematic, targeting areas of greatest uncertainty within the existing datasets.

The most common method of undertaking such boreholes are from dynamically positioned geotechnical drill vessels. Such marine drilling spreads are often quite expensive to mobilise for small, targeted campaigns. In order to maximise the cost effectiveness of gathering deep borehole information it would be recommended to establish contact/relationships with existing contractors with a goal of undertaking ‘fly-by’ investigations or agreeing to share historical borehole information within the areas of interest.

Alternatively, a reach out programme to a bigger audience could be undertaken, similar to that undertaken recently by the BGS – ‘The Big Borehole Dig’. This should assist with building up a database of historical offshore borehole data in Association of Geotechnical and Geoenvironmental Specialists (AGS) file format.

7.5.5.3 CPTs

Piezocone Penetration Tests (PCPTs) are probably the most versatile and convenient method performed to calibrate geophysical information and to acquire geotechnical parametric data for ORE projects.

The greatest advantage of PCPTs is that it permits the evaluation of important physical characteristics of soil in its natural state. It provides a continuous profile of derived geotechnical parameters over the length of the test, whereas laboratory testing provides only discrete data points.

Measuring the pore pressure provides valuable additional information on a soil's stratification, permeability and stress history, i.e. whether it is "under"-, "normally" or "over"-consolidated.

It should be noted that PCPTs do not measure engineering parameters directly, but instead require empirical correlations to derive them.

CPTs can be undertaken from a variety of units, however, for the required purpose a lightweight PCPT unit (>100kN thrust capacity) would be the most suitable solution for acquisition. These units are the most versatile and well-proven of the in-situ seabed testing systems available. The high productivity and reliability of most systems means they provide a very cost-effective method for geotechnical data acquisition. The ability to evaluate results in real time provides for greater programme flexibility, if required, and minimises the possibility of leaving site with insufficient data.

The lightweight systems can be deployed from most geophysical survey vessels and a wide range of other, suitably equipped, vessels of opportunity. The largest of the lightweight systems (>150kN thrust Capacity) require vessels with heavier deployment capabilities, such as drill ships, diving support vessels and other construction support vessels, but their penetration capability is unsurpassed and can reduce the requirement for borehole data.

In the 2012's Foundation Risk and Geotechnical Uncertainty Mapping for future Offshore Wind Farm Developments report [17], GDG have previously assessed that the East coast is most suitable for a PCPT survey, with a couple of bays near Galway and Donegal also proving suitable for testing. In this report, GDG recommended that to establish a holistic geotechnical and geological interpretation of the underlying soil deposits and to develop a baseline understanding of the offshore deposits, it would be useful if the first few PCPTs deployed were undertaken at well characterised areas with significant amounts of geophysical and ground truthing information. Ideally, a number of PCPTs would be conducted adjacent to existing borehole records where a complete vertical stratification profile has already been established to a significant depth. This information could then be used as a calibration and validation exercise to confirm the reliability of the PCPT test in the Irish deposits. The subsequent PCPT tests could then be used with confidence to both characterise the soil deposits and to confirm their detailed engineering properties.

7.5.5.4 Other data

In the context of other data that the INFOMAR Programme could potentially supply that is needed for offshore wind farm development consent applications, and specifically the EIA element of applications, there is potential to obtain and supply more benthic ecology data for specific areas of interest for ORE development. There is great potential to collect more of the following data:

- Grab sampling and collection of biological samples to establish habitat type and species present to give a good indication over a more focussed spatial area of the benthic community.

- Image/video data of sufficient quality to identify flora and fauna species can be a good starting point in the early stages of project development. Indeed, if this information is processed, interpreted and reports generated it would be of high value to the ORE industry.
- Consistently supplement remote mapping methods with dropdown video or Remotely Operated Vehicle (ROV) video to determine and map the characterising habitat complex and biotope complex.

Van Veen/Day Grab/Double van Veen should be used for soft sediments for quantitative benthic infauna analysis and for physio–chemical analysis. Colonial and epifaunal species should be recorded qualitatively. Sediment samples for physio–chemical analysis should be acquired for later laboratory analysis. Physio–chemical analysis would include the following standard parameters:

- Particle size analysis
- Sediment organic matter and carbon analysis
- Major trace element analysis
- Hydrocarbon analysis

If the quantitative grab sampler cannot gather a sufficient sample of minimum 5cm due to nature of sediment (coarser sediments), then a Hamon grab should be used for qualitative benthic fauna collection and particle size analysis (PSA). In this case the minimum sample retention should be 7cm. Three grab samples will be retrieved for benthic fauna analysis. An additional grab sample will be collected for physio–chemical analysis. This will ensure sufficient data for quantitative analysis of benthic fauna and physio–chemical analysis. To minimise repetition of benthic sampling approaches, a double van Veen grab/double Day grab can be used, where suitable. This will provide two samples for each grab therefore minimising the number of deployments needed to obtain the required four samples.

It is also worth consideration more integration with other surveys and particularly the departments that define those surveys. Indeed, even if there is a low level of other surveys taking place by government departments/agencies, it would be very useful to collaborate with and involve those departments and individuals that will be imparting advice to ORE developers on the requirements of EIA Reports to input into the survey design for the INFOMAR Programme.

7.6 Geographic areas

Based on both near-term and long-term ORE requirements, GDG recommend:

- Repeat MBES survey coverage at targeted areas of known sediment mobility and morphodynamic change off the east coast (Figure 7-1).
- Targeted SCS Sparker data collection in areas where bedrock is >25mbsf.
- Targeted MCS Sparker data in shallow water areas where depths are greater than the water depth, where bedrock is at >50mbsf, and in areas of acoustic blanking (Figure 7-2).
- Targeted PCPT data to determine geotechnical and engineering parameters in key areas.

As a general guide, additional MCS Sparker acquisition in water depths relevant to fixed foundations would be a near-term goal, as the additional depth penetration is less important for floating wind sites, and the seabed multiple is not the primary limiting factor on depth penetration where water depths are >50m. Acquisition of targeted SCS Sparker data in water depths greater than 50m should be both a near- and long-term goal, as the data will be relevant for both fixed-bottom and floating installations.

Previously, GDG have recommended PCPT tests should be targeted at the areas located between the 5km and 20km distance-from-shore contour lines in water depths up to 50m, when considering fixed-bottom (near-term) foundation solutions, and assessed that the East coast is most suitable for a PCPT survey, with a couple of bays near Galway and Donegal also proving suitable for testing [17]. However, tests in deeper waters may also be appropriate to serve the long-term development potential off the east, south and west coasts. It is suggested that an updated PCPT strategy is developed based on the near-term and long-term ORE needs identified in this report.

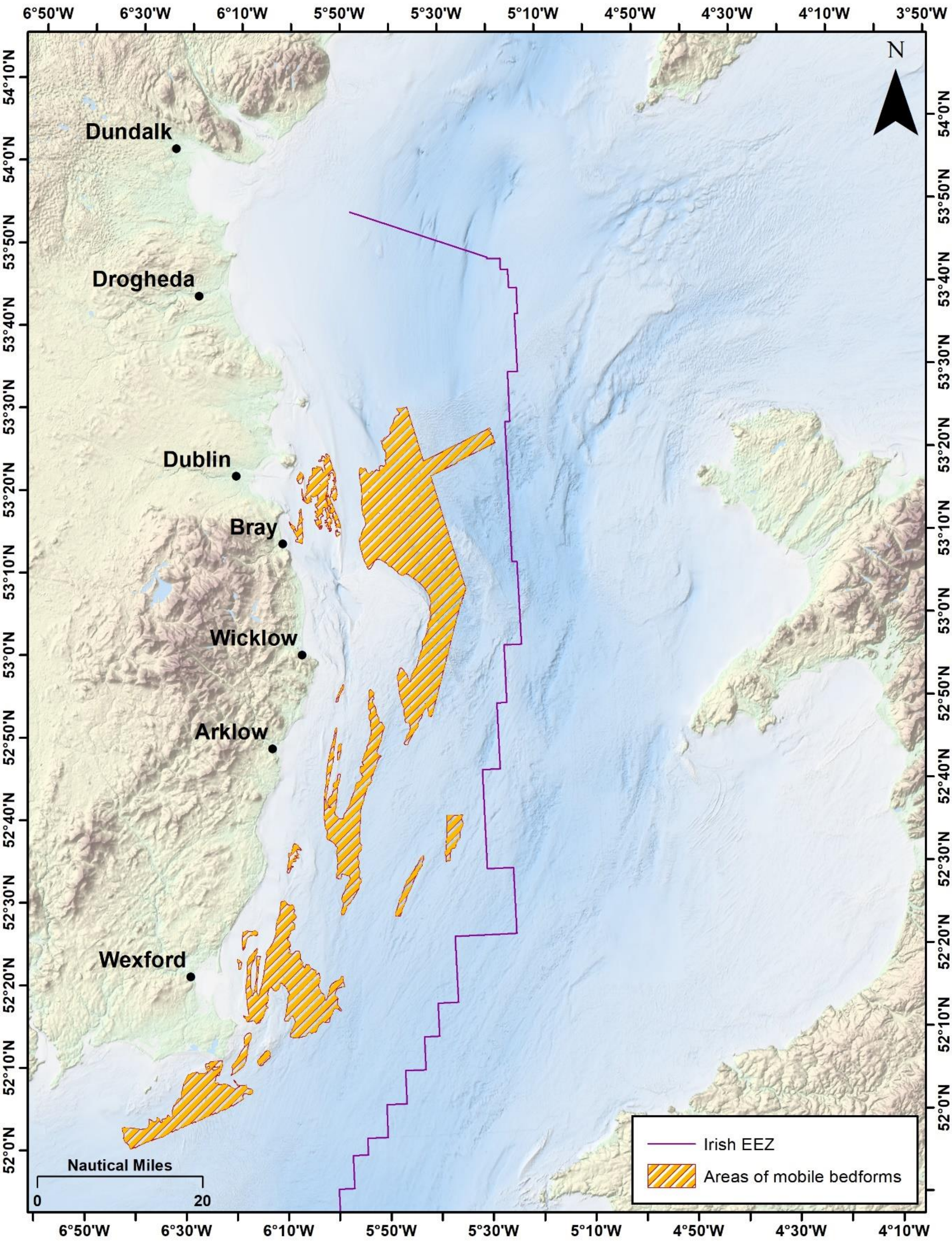

Figure 7-1 Areas of bedforms in the Irish Sea understood to be mobile [29].

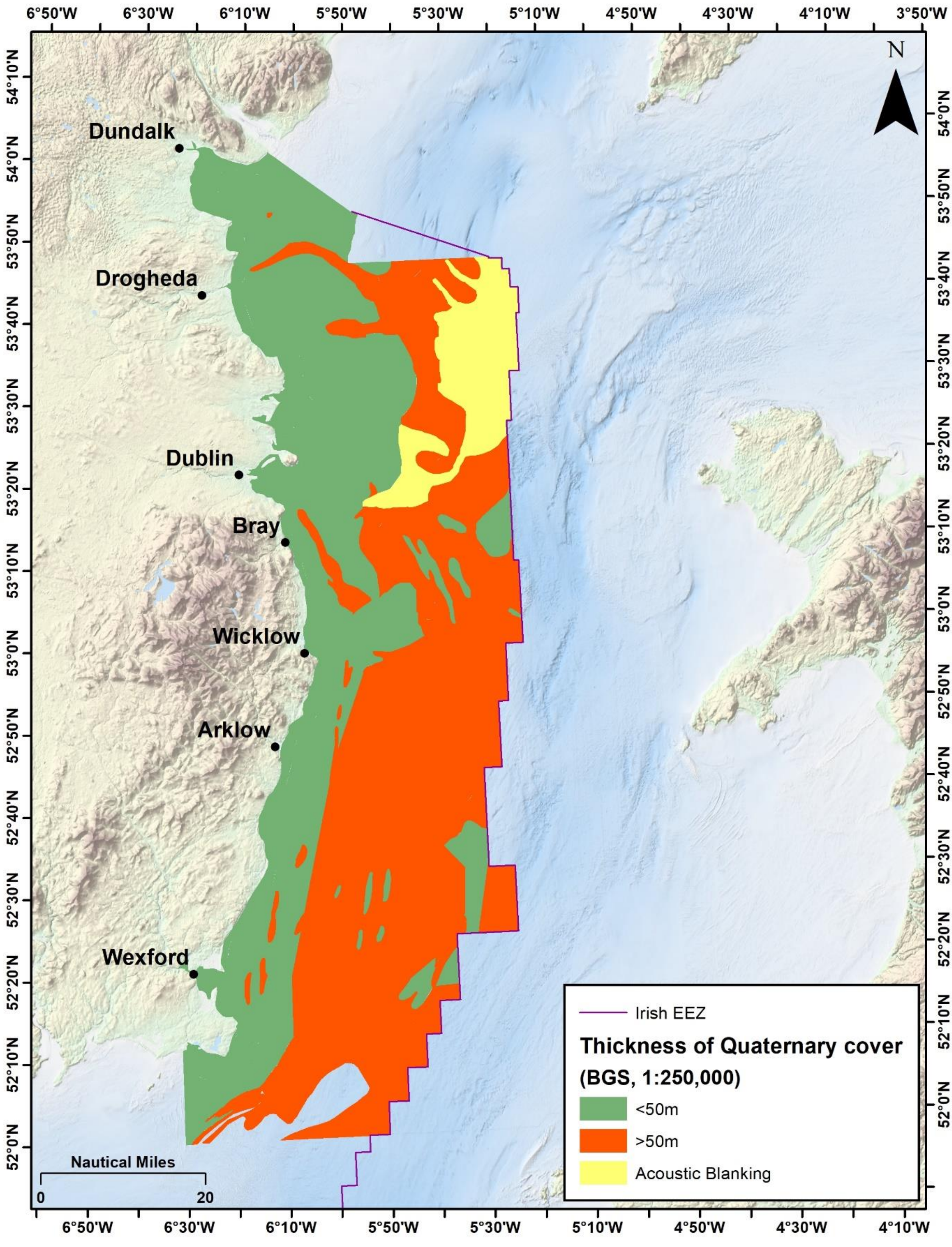

Figure 7-2 Quaternary cover in the Irish Sea (from BGS 1:250,000 map series, Anglesey, Sheet 53°N -06°W).

7.7 Summary

Recommendations have been made in three broad categories (data handling, data collection, and geographic areas) and the potential value for near-term and long-term ORE developments have been discussed. Some of these recommendations are pertinent to the ongoing INFOMAR Phase 2 work, up to 2026, and others may be more relevant following the completion of this Phase.

8 Bridging the gap - complementary information

8.1 Overview

The purpose of this section is to increase awareness of additional data sources that could be used to add value to the INFOMAR data archive, via gap-filling and via generation of derived data products, with particular reference to ORE sector needs.

8.2 Open Access

8.2.1 Publications and research

Applied research in synthesising spatially large, regional datasets into assessments for the feasibility of offshore wind has proven successful in other European countries such as Belgium [30] and the UK (e.g. [31]). Previously, data collected under the auspices of INFOMAR, and it's precursor, the INSS, have been used to generate mapping products related to geomorphology and habitat mapping exercises (e.g. [32], [33], [34], and [35]). Typically, these studies focus on certain geographic areas using the high-quality multibeam echosounder bathymetry and backscatter data.

The application of INFOMAR data in generating 'blue knowledge' for a number of key marine sectors including ORE was well highlighted by O'Toole *et al.* in 2020 [36]. This includes the use of combined INFOMAR datasets, such as MBES bathymetry, backscatter, shallow seismic profiles and grab samples to characterise offshore features, as well as the use of repeat MBES bathymetry data to assess the risk of mobile sediment to potential ORE sites.

Efforts in utilising INFOMAR data for characterising or assessing Irish seabed conditions for ORE are included in [37] and [29]. Both have focused on the east coast (Irish Sea) area. A high-level environmental analysis and site identifcation process using a geographic information systems (GIS) based approach to identify potentially suitable areas, were completed [37]. Within these areas, INFOMAR data for a number of sites were interrogated to develop representative ground models of the geological conditions, and their implications for offshore wind development. This included using MBES bathymetry to charcterise geomorpholoy and seabed features, backscatter and sediment grab samples to describe sediment distribution and seabed and shallow seismic data to generate isopachyte maps of sub-surface units.

A 1:1,000,000 map of the Irish Sea [29], within the Irish Economic Exclusion Zone highlighting the spatial distribution of potential geological and geotechnical constraints to offshore wind energy development (Figure 8-1). These constraints are identified and charactised using a combination MBES and derived datasets.

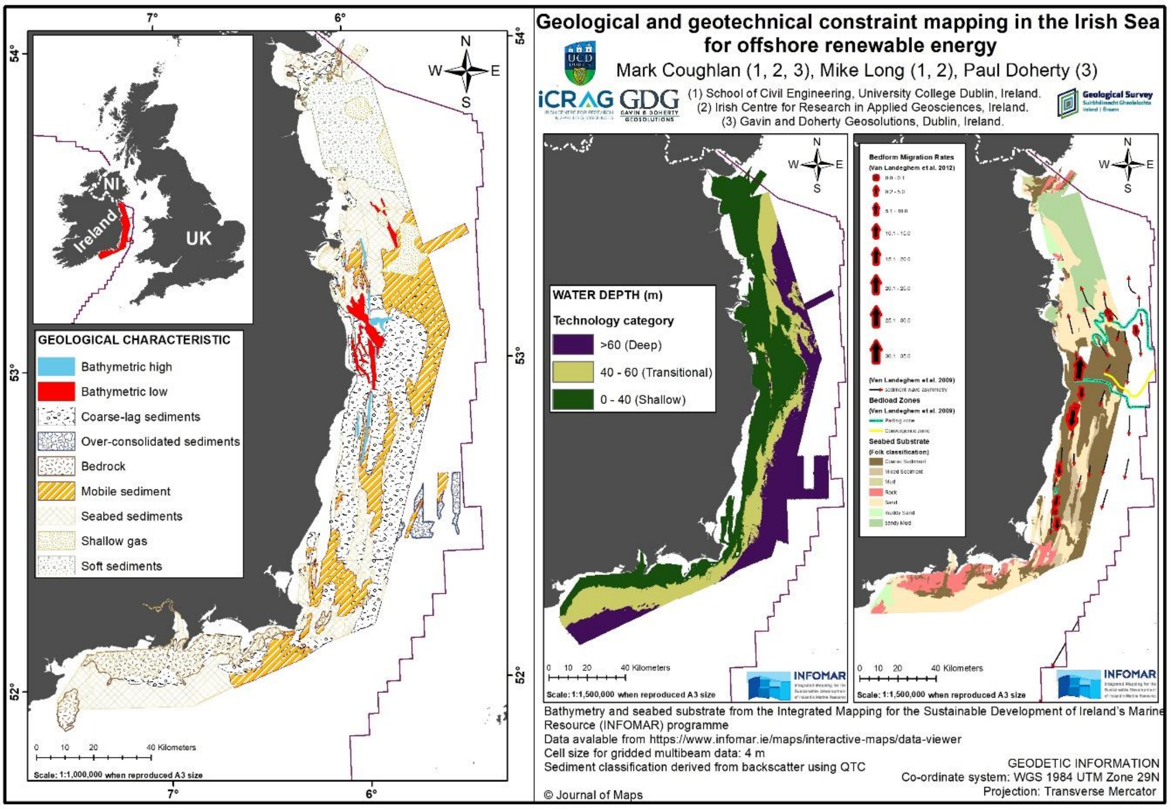

Figure 8-1 Constraint mapping products from Coughlan, Long and Doherty (2020) [29].

INFOMAR data has also been used by Peters *et al.* [38] as part of the Eirwind project to develop a seabed stability model for informing ORE site selection. This involved utilising 1,495 data points in the INFOMAR sediment sampling database, alongside bathymetry and seabed substrate data from EMODnet. This integration of INFOMAR data with the EMODnet portal offers a valuable tool with which to guide regional marine spatial planning for ORE, as well as site selection and characterisation using MBES and sediment substrate data [39]. An overview of EMODnet data is given in 8.2.2.

8.2.2 EMODnet

The European Marine Observation and Data Network (EMODnet) [40] was initiated by the European Commission in response to the EU Green Paper on Future Maritime Policy in 2006. The purpose is to make available to public and private organisations marine data, metadata and value-added products that are quality-assured, standardised and harmonised at a variety of scales. The EMODnet deliver system consists of seven thematic portals covering the areas of:

- Bathymetry.
- Geology.
- Seabed Habitats.
- Chemistry.
- Physics.
- Biology.
- Human Activities.

Of these the most applicable to ORE development are Bathymetry and Geology.

In the Bathymetry portal, EMODnet have release a harmonised Digital Terrain Model (DTM) for European sea regions. This dataset is developed from selected bathymetric survey data sets, composite DTMs, Satellite Derive Bathymetry (SDB) from individual national surveys. Areas with no data coverage have been completed using GEBCO Digital Bathymetry. This dataset offers full coverage of the European area at a grid resolution of 1/16x1/16 arc minutes (approximately 115x115 meters). The portal allows the user to view where higher resolution datasets are available.

The EMODnet Geology portal offers data layers with information on the seabed substrate, including rate of accumulation of recent sediments, the seafloor geology (bedrock and Quaternary geology), coastline behaviour, geological events and probabilities, mineral resources, and submerged landscapes.

INFOMAR has been contributing data to the EMODnet project for the last number of years, along with a network of other organisations. The data from all these organisations is integrated into a singular deliverable for theme or data layer to give regional coverage as best as is possible. In this regard, when seeking data available from EMODnet across the seven thematic portals, it is advisable to first engage with the INFOMAR deliver portals as they offer the best resolution data applicable to the Irish offshore.

8.3 Commercial

8.3.1 ORE developers

A feature of the Irish sector is that more than one developer can express interest in an area of seabed (Figure 4-1). As different developers have different development preferences and appetites for risk, competition for particular sites may decrease as projects progress. Where a developer drops out of a project, there may be potential for any ground modelling or survey deliverables to be repurposed. Clearly, there are commercial sensitivities around such repurposing in a developer-led, competitive market. However, should the market transition to a more centralised model then opportunities may open up for legacy project data to be passed on to the State.

8.3.2 Pipelines and cables

Pipeline and cable operators may be willing to share site investigation data. Pre-installation surveys will have included at minimum high-resolution bathymetry data, high-resolution SSS data, seabed obstruction mapping, shallow seismic data, shallow geotechnical data, and geological/geotechnical interpretation. They may also have acquired thermal conductivity and benthic information. Post-installation Depth of Burial (DoB) surveys may also be available, and for pipelines Annual Pipeline Inspection (API) surveys will acquire as a minimum high-resolution bathymetry and high resolution SSS data that it may also be possible to obtain. The value of such datasets relative to ORE data requirements is summarised in Table 8-1.

Table 8-1 Pipeline and cable data usage summary.

PROS	CONS
• High resolution bathymetry data (1x1 m or better). • High-resolution SSS sonar data that will have been collected to a standard suitable for seabed obstruction detection and can provide valuable obstruction density information. • Commercial data will have been subject to quality control and delivered in standard deliverables formats. • Seismic data have been collected as a primary dataset rather than data of opportunity, so will have been collected to high quality standards. • Optimised for the cable lay depth of interest. • Includes shallow geotechnical data. • Covers nearshore/intertidal areas not addressed by INFOMAR coverage. • DoB and API survey data are potentially valuable for understanding sediment movement and scour potential.	• Only shallow, so not likely to address foundation needs unless shallow bedrock • Limited spatial extent along narrow corridor (only a few 100's m wide) • Quality of older data deliverables will be limited by technology available at the time of acquisition. • Time and cost to obtain data and agree to usage terms.

8.3.3 Oil and Gas

Significant volumes of 2D and 3D MCS Oil and Gas seismic data exist in the Irish Sea and further offshore in the Celtic Sea and Atlantic Ocean. These data generally do not extend far enough towards the coast to be of use for developments in waters of <50m, but coverage generally increases with water depth. Figure 8-2 shows 2D Oil and Gas data coverage information collected by the Petroleum Affairs Division (PAD).

In their archived form, such data are of limited use for offshore wind developments, as processing has been optimised for investigation depths of several kilometres. However, repurposing of oil and gas data for the offshore wind industry is beginning to be offered as a commercial service [41]. Such data have limited use in the top 10's meters below sea level, but on a case-by-case basis offer the potential to extend the seismic depth coverage for a site. Due to geographic distribution and limited near-seabed application, the sites for which such data would be most useful are those looking to exploit fixed-bottom foundations, particularly driven jackets, in deeper waters.

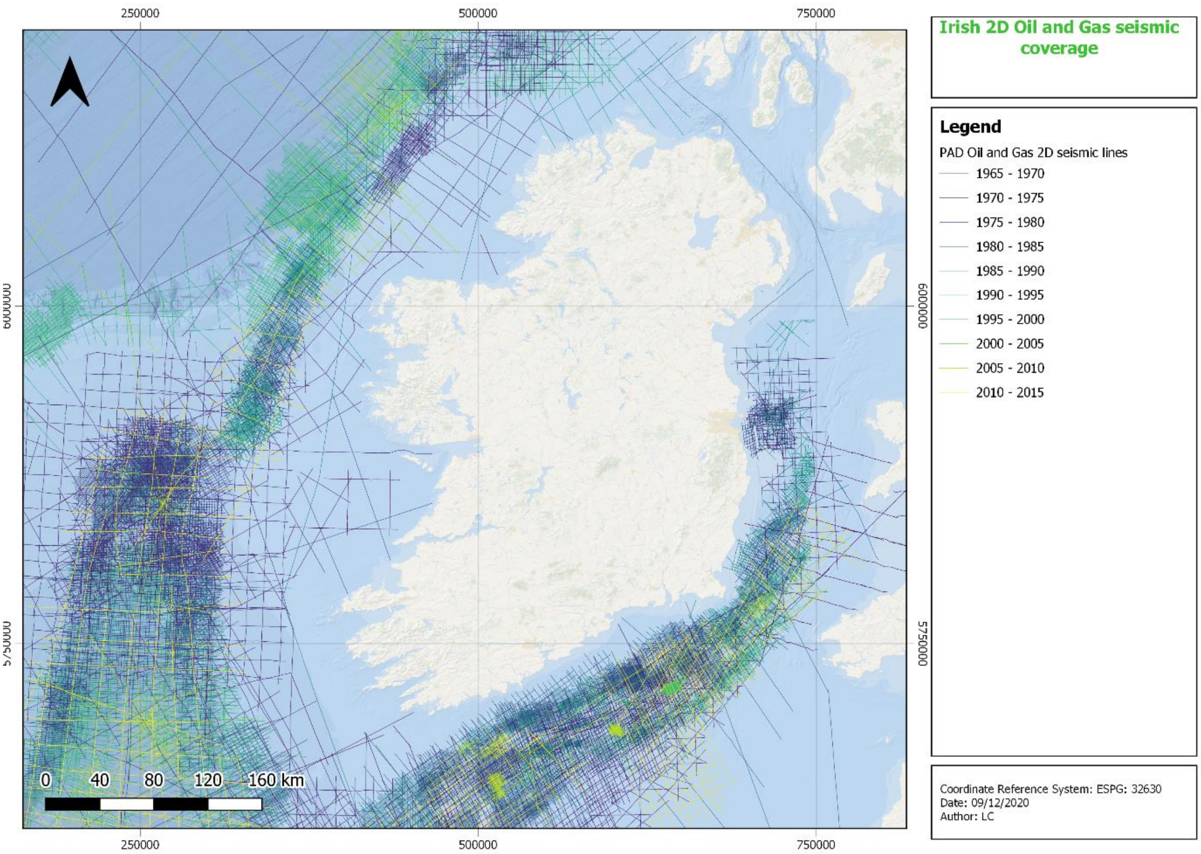

Figure 8-2 PAD 2D data coverage [42].

Table 8-2 Oil and gas seismic data usage summary.

Pros	Cons
• Deep penetration, to top bedrock and below. • Commercial data will have been subject to quality control and delivered in standard deliverables formats. • Coverage in deeper-water offshore areas off the east coast where INFOMAR seismic coverage is partial.	• Low lateral and vertical resolution. • Requires licencing (time and cost implications). • In existing processed form, of very limited use. Requires specialist reprocessing to optimise usability. • Quality of older data deliverables will be limited by technology available at the time of acquisition. • Many older datasets may not be available. • Limited ability to resolve shallow geology, even reprocessed.

8.4 Maps and memoirs

Within the context of G&G data, invaluable data at an early project development stage includes geological maps, memoirs, and datasets that can indicate likely seabed and sub-bed sediment types, probable bedrock type and depths to bedrock. In terms of data needs, BGS rockhead depth mapping can be very valuable: however, coverage of this information is restricted mainly to the east coast (Figure 7-2), and users should be aware that Quaternary cover thickness is not necessarily the same as depth to competent bedrock (Section 4.2.2).

9 Bridging the gap – industry responsibilities

9.1 Overview

In a developer-led regime, the developer is responsible for making sure that the right data is gathered at the right time. INFOMAR data are helpful to the ORE industry, but INFOMAR data have not been collected primarily for ORE industry use.

Desk studies should be undertaken as soon as possible to identify data gaps and inform a G&G survey strategy, as described in Section 4.2.2.1. Pre-auction, additional G&G surveying will be needed for most projects to supplement INFOMAR data: primarily geotechnical data (Section 6.3). Post-auction, collection of additional G&G data will be required for all developments, regardless of INFOMAR coverage.

Survey needs prior to RESS auction will almost always include geotechnical surveys, and will often include infill geophysical surveys and repeat hydrographic surveys. Collection of additional archaeological and UXO data, and environmental and ecological and baseline data, may also be necessary, as identified through development of the survey strategy and preliminary ground model.

In areas of geographic data gaps, developers will need to ensure that they monitor INFOMAR's ongoing survey planning to ensure that they are aware of recent and upcoming surveys [43].

9.2 INFOMAR data processing and analysis

INFOMAR provide processed bathymetry data and derivatives such as seabed sediment mapping. However, developers will need to undertake additional processing and analysis to maximise the value of INFOMAR data to their projects pre-auction:

- Seismic data processing.
- Seismic data interpretation.
- Ground model construction.
- Bathymetry derivative calculations (slope, rugosity).
- Foundation optioneering.

INFOMAR data availability should be determined at the Desk Study phase of the project to ensure that this work is done as early and efficiently as possible. Progressing ground model development from INFOMAR data at an early stage is essential to enable targeting of any additional G&G surveys that may be required to fill information gaps at an early stage, including for EIA purposes.

9.3 Surveying

In the case that the INFOMAR seismic data allows full characterisation if the depth if interest for a development, further geophysical surveys may not be required pre-auction for ground modelling purposes (although EIA requirements may necessitate additional geophysical data collection). Even where INFOMAR coverage is good, it may not be sufficient to characterise the geology to the full depth of interest for a development, in which case additional geophysical surveying will probably be required to complete foundation optioneering. As geotechnical surveying is likely to be required in either case, it is good practice to undertake additional geophysical survey first, followed by a ground model update which is then used to target geotechnical surveys. Development of a survey strategy should be prioritised at early stages even for sites with good INFOMAR coverage.

Collection of site-specific environmental baseline data will also be required. Environmental baseline data for ORE projects is designed with a specific site in mind and involves tailored survey design strategies that take into account existing information available, as well as building in robust statistical power and ensuring that the particular site of interest is adequately surveyed.

10 Case study – A Morphodynamic Study of the Irish Sea

10.1 Overview

A key consideration in the siting of ORE is the nature of the seabed and its stability of time with regard to sediment dynamics. Such change is driven by the interaction of hydrodynamic phenomena with physical seafloor geology. The Morphodynamic Study of the Irish Sea (MSIS) study is a 2-year project led by GDG, in collaboration with the Centre for Energy, Climate and Marine research (MaREI) with the aim of developing a more detailed understanding of seabed morphodynamics and sediment mobility in the Irish Sea, and the potential implications for offshore engineering. To achieve this aim, the project has a number of objectives including:

- Reviewing existing databases for the Irish Sea and identify areas of historic seabed change and significant morphodynamic development.
- Characterise selected sites using seabed mapping data such as multi-beam echosounder (MBES) and sub-bottom profiling.
- Where possible, perform repeat surveys on selected sites to assess temporal changes in seabed morphodynamics.
- Compute hydrodynamic conditions at selected sites through sediment mobility modelling such as MIKE 21.
- Develop a risk register associated with quantified and predicted outputs.

As part of this project, GDG and MaREI have extensively used INFOMAR datasets at various stages.

10.2 Bedform Morphodynamic Assessment

One work package within the MSIS project comprised an assessment of mobile bedforms in the Irish Sea. As part of an initial desktop study, a number of key areas featuring notable bedforms were identified and characterised using existing INFOMAR MBES bathymetry (Figure 10-1).

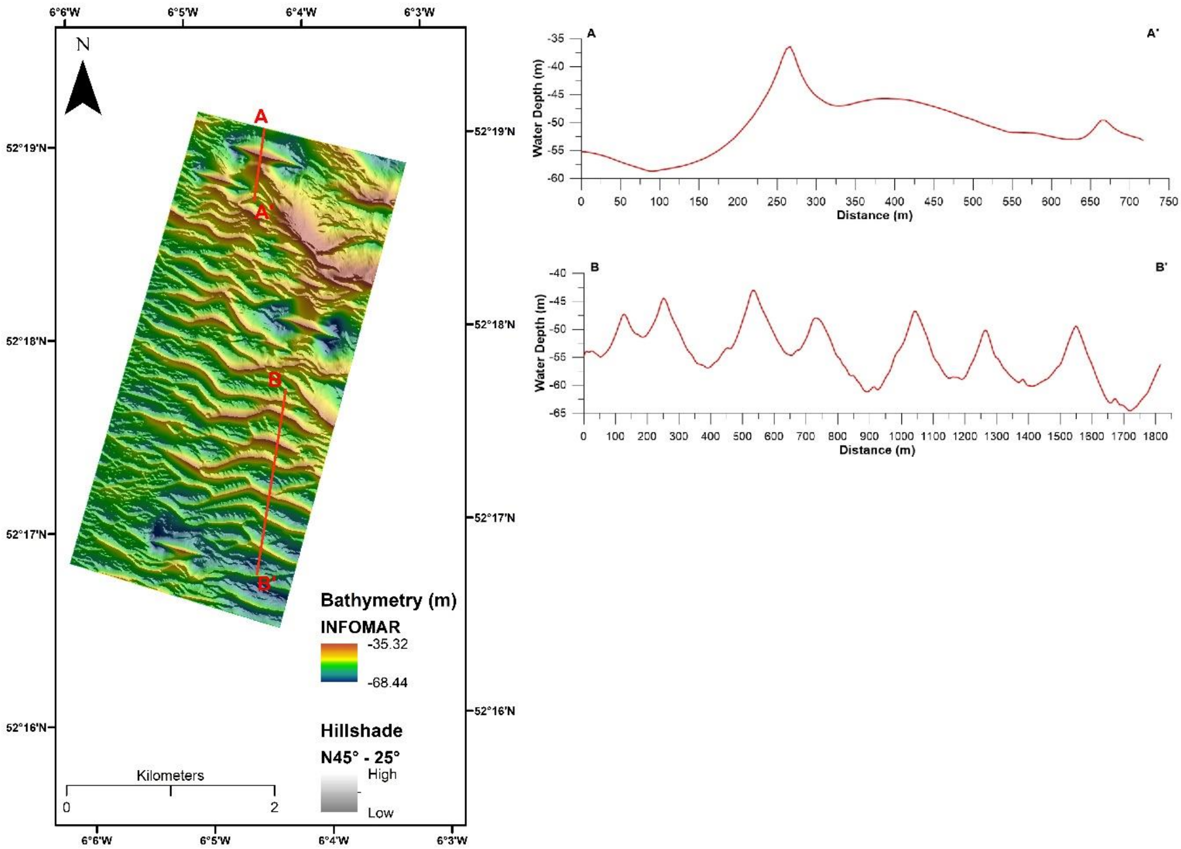

Figure 10-1 Typical INFOMAR dataset (2012) from the Irish Sea with notable sedimentary features.

As part of a targeted survey onboard the *RV Celtic Voyager* in October and September 2020, repeat MBES and grab sample data were collected at these sites. In a Geographical Information System (GIS) analysis was carried out to determine crest displacement rates on sediment waves to work out migration patterns of these features (Figure 10-2).

Further in GIS, temporal changes in bed-level are calculated spatially between the two datasets (i.e. 2012 and 2020) allowing qualification as well as quantification of seabed change (Figure 10-3).

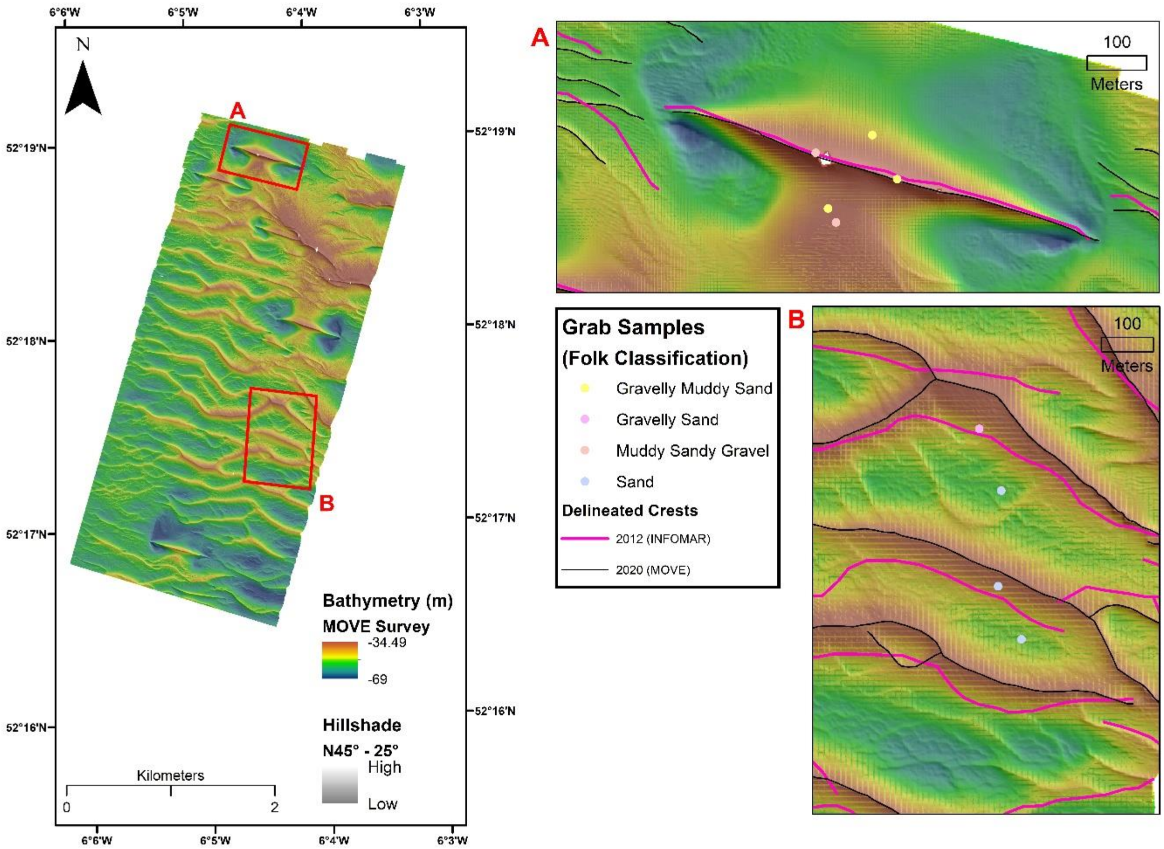

Figure 10-2 Same area as Figure 10-1, but with repeat survey data presented. Comparison of changes in crest morphology from selected sites are shown in box A and B. Also shown are grab samples collected as part of the survey classified according to Folk.

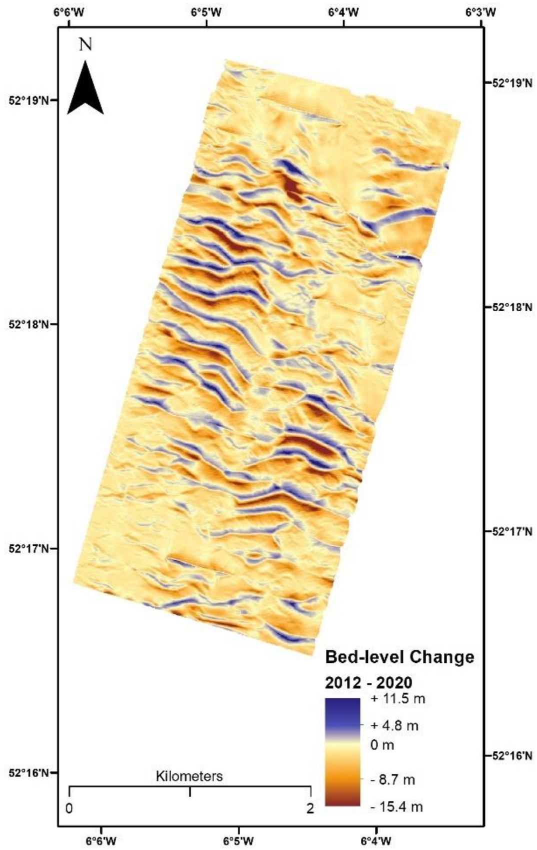

Figure 10-3 Calculated changes in seabed bed-level between 2012 and 2020 datasets.

10.3 Sediment Mobility Assessment

A further work package in the MSIS project aimed to calculate levels of seabed sediment mobility by comparing sediment thresholds from grab sample data against modelled seabed bed stress data. In this work package the provision of grain-size analysis (GSA) data from the INFOMAR programme was invaluable. Of the 2,318 GSA sediment samples used in the study, 604 (26%) were provided through INFOMAR (Figure 10-4A). Using these samples, and supplementary samples, it was possible to map grain-size distribution in a meaningful way across the Irish Sea using the median grain-size (i.e. D50). Using this D50 value, thresholds for initiating sediment mobility were calculated and compared with modelled outputs of current, wave and combined (i.e. current and wave) induced bed stress to quantify how often (percentage of time) thresholds are exceeded in a given time frame allowing for sediment to be mobilised (Figure 10-4B).

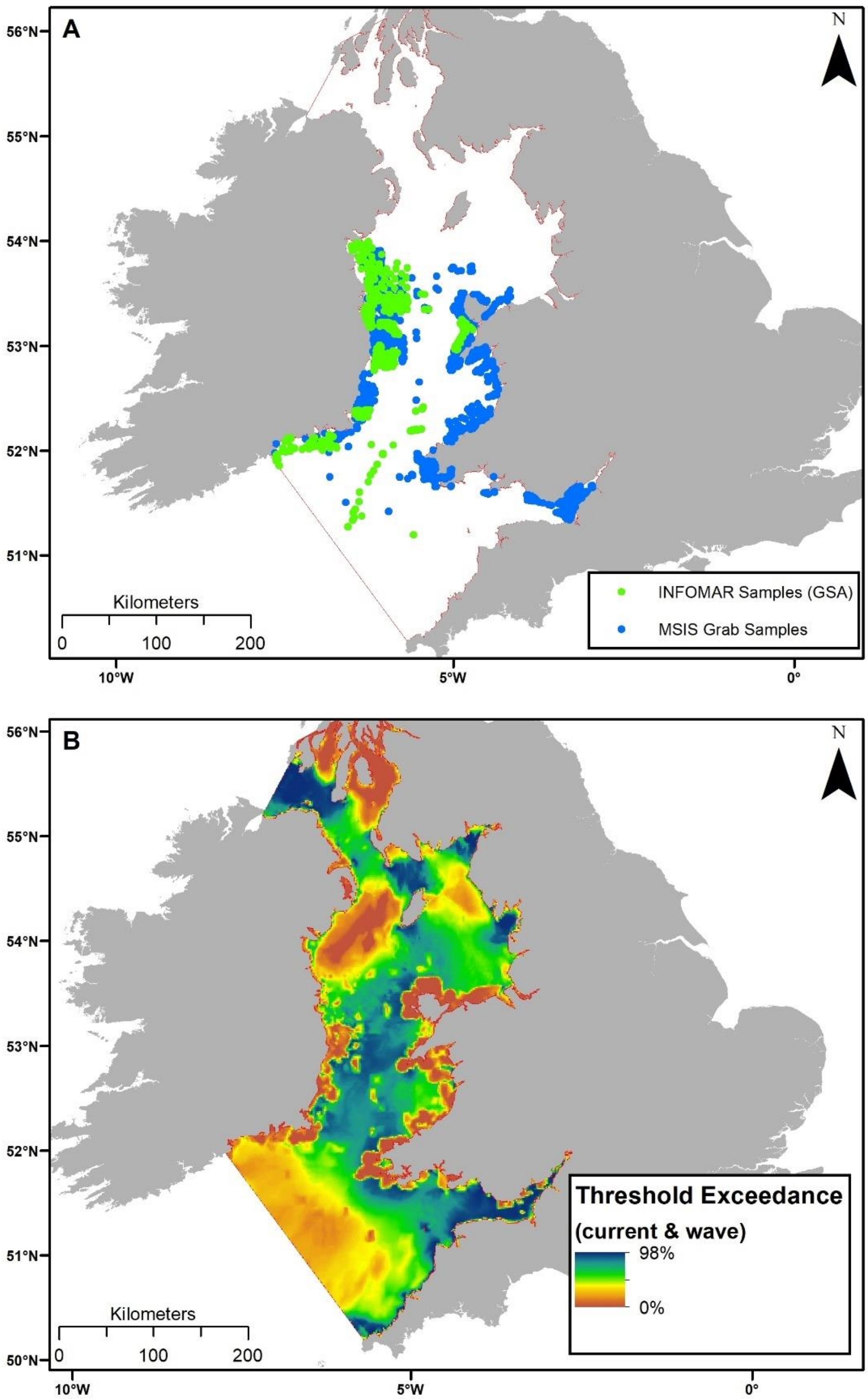

Figure 10-4 A map of sediment grab samples with GSA used in MSIS study. INFOMAR samples are in green and other samples in blue. B highlights the yearly exceedance (% of time) combined current and wave induced bed stress exceeded sediment thresholds to allow for sediment to be mobilised.

10.4 INFOMAR in the project

The primary INFOMAR dataset used in this study were:

- MBES bathymetry.
- Seabed sediment data (grab samples with grain-size analysis).

MBES bathymetry data was easily accessed download through the standard INFOMAR portals in a format suitable for integration with GIS.

The INFOMAR Seabed and Sediment data portal highlights where samples have been collected and gives a Folk Classification and percentages of mud, sand and gravel where available. However, there is no ready access to the raw granulometric data behind the analysis and contact had to be made with GSI representatives to secure the GSA data, which came in a number of different formats. Furthermore, the unstructured distribution of sediment samples meant there were significant geographic gaps for which there were no sediment samples with GSA data.

Key recommendations from this case study would be:

I. Where available, link GSA data with grab sample locations on INFOMAR delivery portal.
II. Preferably all samples would have GSA carried out so end-users can utilise the data for a range of grain-size distribution calculations and applications other than solely Folk classification.

A strategic approach to future grab sample collection in order to ensure a representative distribution throughout the EEZ.

11 INFOMAR data value to the ORE sector

11.1 Overview

With an aim of delivering seabed mapping data for the entire Irish offshore area by 2026, the INFOMAR programme is being delivered in two phases. Phase 1 was undertaken between 2006 and 2016 with Phase 2 to be delivered by 2026. An initial cost benefit analysis (CBA) of the programme reported a four to six times return on investment over the duration of the programme across all marine sectors [44]. A subsequent programme review found that many of the deliverables of the programme, including hydrographic and seabed sediment classification maps, were required to underpin economic growth in many areas critical to ORE development including environmental impact assessments, marine spatial planning (MSP) and foreshore licensing activities [45]. Following the completion of Phase 1, an evaluation recognised the high-quality of INFOMAR data and expertise and their use in ORE development, amongst other sectors, with key recommendations made for future development of the programme in critical operational areas [46].

The value of INFOMAR to the ORE sector can be measured at various different stages in the development process (for reference, see Figure 4-8). For a 1GW offshore wind farm in the UK, it is estimated that development activities cost approximately £120m [14]. This includes:

- Development and consenting services.
- Environmental surveys.
- Resource and metocean assessment.
- Geological and geotechnical surveys.
- Engineering and consultancy.

Whilst INFOMAR data will not be used in all these stages, it can provide significant value in certain areas. For example, seabed surveys to analyse the seafloor and sub-seabed environment of the proposed wind farm site and export cable route to assess its geological condition and engineering characteristics (see Figure 4-7) typically cost in the region of £8.3m [14]. They are important as they aid in optimising windfarm design and minimising risk during installation (see Figure 4-9). Typically, investigations comprise a number of stages:

1. Geophysical and hydrographic surveys to establish seafloor bathymetry, seabed features, water depth and sediment stratigraphy, as well as identifying hazardous areas on the seafloor and manmade risks such as unexploded ordnance (UXO). This type of survey can cost about £2.3m for a 1 GW wind farm.
2. Geotechnical surveys to target sediment/rock strata boundaries and gather engineering data or target specific seafloor features. This type of survey can cost about £6m for a 1 GW wind farm.

GDG’s recent experience in the Irish Sea indicates that the costs above are underestimates for Irish sites, with typical survey costs ranging from 10% to 30% higher than the equivalent costs in more established markets.

Geophysical and hydrographic surveys in particular are required before, during and after construction to establish a baseline upon which environmental impacts can be predicted/assessed, validated and monitored. In that regard, the availability of baseline INFOMAR data for a specific area is highly valuable and may negate the need for an initial survey. Inevitably, any ORE development will need to undertake its own hydrographic, geophysical and geotechnical surveys, but the initial costs of these can be significantly reduced by incorporating INFOMAR data and using it efficiently to plan subsequent campaigns.

11.2 Near-term

For near-term developments, the primary value of INFOMAR data as delivered under Phase 1 and Phase 2 of the programme is in the pre-auction stages:

- assessing site viability and foundation optioneering for sites where bedrock is <25mbsf;
- understanding export cable route geology to the full depth of interest; and.
- reducing the scope of pre-auction G&G surveys.

INFOMAR seismic data has greater value greater in export cable route areas due to typical INFOMAR seismic depth penetration comparing favourably to the cable route depth of interest. Value is comparatively less in potential turbine installation areas where the depth of interest extends beyond ~25mbsf, due to the comparatively limited average seismic depth penetration of INFOMAR SBP data.

11.3 Long-term

For long-term (floating wind) developments, the primary value of INFOMAR data as delivered under Phase 1 and Phase 2 of the programme are also at the pre-auction stages. However, the value in the potential turbine installation areas is potentially greater due to the reduced depth of interest for floating wind foundations/anchors compared to fixed-bottom foundations. This means that a higher proportion of floating wind projects may be able to complete their foundation optioneering studies based primarily on INFOMAR seismic data than for fixed-wind developments.

More broadly, long-term value for the INFOMAR project and its legacy may be derived by the current INFOMAR programme infrastructure being built on or used as a template for a more centralised ORE data strategy post-2030.

Should the key recommendations in this report be implemented with respect to deeper G&G investigations, then this would ensure a level platform for potential developers to better evaluate the balance of plant, and turbine solutions: in particular by assessing site viability and foundation optioneering for sites by improving the confidence in the deeper soils which are critical to evaluating foundation designs, i.e. at depths greater than 25mbsf.

11.4 Summary

As developers will have to undertake site-specific surveys prior to detailed foundation design regardless of the available INFOMAR data, the maximum value of INFOMAR data to the ORE sector is at the pre-auction phases of an ORE development, as discussed in Section 6.7. To maximise the value of the INFOMAR programme to the ORE sector, focus should be on obtaining data to inform these initial stages, with targeting of specific geographic areas. The value to the ORE sector in terms of the current INFOMAR strategy is summarised qualitatively in Table 11-1. Although it is not anticipated that it will be feasible to implement all recommendations, a qualitative summary of potential value if the recommendations in Section 7 are implemented is presented in Table 11-2.

Table 11-1 Qualitative INFOMAR data value to the ORE sector (0-5, with 5 being the most useful and 0 being of no use).

PHASE	DEPTH OF INTEREST (MBSF)			
	<10	10-25	25-50	50-100
Buildability assessment, Foundation optioneering/ Conceptual foundation design	4	3	1	1
Environmental Impact Assessment (EIA)	3	3	3	3
FEED, layout optimisation, cable route selection	2	1	1	0
Detailed foundation design, Cable Burial Risk Assessment (CBRA)	2	1	1	0

Table 11-2 Qualitative potential INFOMAR data value to the ORE sector, all recommendations implemented (0-5, with 5 being the most useful and 0 being of no use).

PHASE	DEPTH OF INTEREST (MBSF)			
	<10	10-25	25-50	50-100
Buildability assessment, Foundation optioneering/ Conceptual foundation design	5*	4*	3^	2^
Environmental Impact Assessment (EIA)	3	3	3	3
FEED, layout optimisation, cable route selection	2	1	1	1^
Detailed foundation design, Cable Burial Risk Assessment (CBRA)	2	1	1	1^

*Depending on geotechnical data coverage.

^Depending on SCS Sparker/MCS coverage.

12 Industry engagement recommendations

12.1 Overview

If developers and associated businesses (such as environmental and engineering consultants) are unaware of the INFOMAR programme, or are not aware of the benefits and limitations of the data, this will increase the costs of the Irish drive to meet ORE goals. The primary value of engaging further with industry is to ensure that maximum use is made of INFOMAR data to (a) maximise the return on investment and (b) minimise Irish ORE development costs. This section makes some high-level recommendations on strategies for industry engagement.

12.2 Relevant parties

Relevant parties for engagement include:

- Developers: Including both those currently in the Irish market and those who have not yet entered the market. For those in the market, improving awareness of INFOMAR resources is desirable to ensure that the overall ORE development costs in Ireland are minimised. For those considering the market, awareness of the value of the INFOMAR resource, particularly at the early stages of development, may increase their appetite to compete in the market.
- Consultants: Covering those parties providing geotechnical, geophysical and engineering services to the Irish offshore wind sector, again including both those currently in the Irish market and those who have not yet entered the market.
- Stakeholders: In particular, increased engagement with the UAU to harmonise geophysical and hydrographic requirements for archaeological investigations pre-auction. It is the authors opinion that the availability of high-quality data at consistent levels of coverage combined with a detailed underwater archaeology risk assessment by an experienced underwater archaeologist could be an alternative to an early full coverage survey.
- Survey contractors: Covering those parties providing geotechnical, geophysical and environmental services to the Irish offshore wind sector to make them aware of INFOMAR data as a valuable resource to:
    - Guide contractors who are unfamiliar with local conditions to select the most appropriate equipment.
    - Allow contractors to optimise the value of their data by tying into existing survey coverage.
    - Form the basis potential INFOMAR partnerships for opportunistic data collection or development of improved survey strategies and/or technologies.

12.3 Recommended outreach methods

Engagement is recommended with organisations focused on the promotion of renewable energy both in Ireland and Europe, including:

- The Irish Wind Energy Association (IWEA): via training courses and webinars aimed at relevant parties.

- The Society for Underwater Technology (SUT) and the Offshore Site Investigation and Geotechnics (OSIG) special interest group: via conference presence.
- RenewableUK: via event participation, particularly the annual Global Offshore Wind conference.
- Offshore Wind specialist publications:
  - ReNEWS.
  - Offshore WIND Group (www.offshorewind.biz).

A user survey is also recommended in order to obtain feedback on current INFOMAR data usage and inform prioritisation for the various data management changes recommended in Section 7, using a similar template to that of the survey circulated by risksolutions in 2016 [46] to enable comparison of results.

Publication of a brief guide to INFOMAR data usage for developers that could be hosted on the INFOMAR website and distributed at conferences and events would be beneficial to improve developer awareness.

12.4 Collaboration opportunities

Potential collaboration opportunities include:

- Shallow bedrock depth mapping, to complement existing BGS Quaternary thickness maps.
- Proof of concept work for combining INFOMAR and repurposed Oil and Gas seismic data to extend seismic depth coverage.
- Working with non-standard technology providers to improve survey efficiency and coverage.
- Establish locations of notable species (rare, unusual, sensitive, Annex II species or Annex I habitats) via a dedicated study of grab samples, to improve information available to inform EIAs for ORE developments.

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