Dublin Array
Generation for generations

EIAR Volume 4: Offshore Infrastructure Technical Appendices
Appendix 4.3.1-2a Geophysical and Geotechnical Desk Study for Dublin Array Wind Farm

Kish Offshore Wind Ltd

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Geophysical and Geotechnical Desk Study for Dublin Array Wind Farm

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List of Abbreviations

ASV	Assumed Seismic Velocity
BIIS	British and Irish Ice Sheet
BP	Before Present
BPI	Bathymetric Position Index
CPT	Cone Penetration Test
EIS	Environmental Impact Statement
EISMB	Eastern Irish Sea Mud Belt
FEED	Front End Engineering and Design
GIS	Geographical Information System
GSI	Geological Survey of Ireland
HSL	Hydrographic Surveys Ltd
INFOMAR	Integrated Mapping For the Sustainable Development of Ireland's Marine Resource
INSS	Irish National Seabed Survey
ISIS	Irish Sea Ice Stream
LAT	Lowest Astronomical Tide
MBES	Multi Beam Echo Sounder
NMS	National Monuments Service
SI	Site Investigation
SSS	Side-Scan Sonar
UXO	Unexploded Ordnance
VORF	Vertical Offshore Reference Frame
WIID	Wreck Inventory of Ireland Database
WISMB	Western Irish Sea Mud Belt
WGS	World Geodetic System
WWTP	Wastewater Treatment Plant

1 Introduction

Gavin and Doherty Geosolutions Ltd. (GDG) was requested by Innogy Renewables Ireland Ltd to review, process, and interpret existing geophysical and geotechnical data pertinent to the Dublin Array offshore wind farm. This study considered both the array area and along the export cable corridors. The primary geophysical dataset available was gathered as part of the Integrated Mapping for the Sustainable Development of Ireland's Marine Resource (INFOMAR) programme and has been integrated with existing site data, as well as, other publicly available data where relevant. The intended function of the geophysical data processing is to generate a basic ground model and provide recommendations for future geotechnical/geophysical site investigations campaigns.

The primary objectives of this project are to:

- Review the available geophysical information and determine the usefulness of the various datasets;
- Process the data (where the resolution and data quality permits);
- Characterise the seabed, shallow soils and geology (where possible given the limitations of the data set) within the defined project boundaries;
- Identify and map the marine geohazards (natural or man-made, where possible given the limitations of the data set) including but not limited to:
    - Shallow gas and associated features (i.e. pockmarks, doming, etc.);
    - Ferromagnetic objects;
    - Any objects at or below seabed including potential unexploded ordnance (pUXO) that may influence possible offshore installations.

The final report can be used to inform decision making processes for the following project activities:

- Identifying optimal areas within the project boundaries for the development of fixed foundations;
- Inform the scoping and specifications for future geophysical and geotechnical investigations;
- Inform determination of foundation type and installation methodology.

1.1 Scope of current report

The current report provides a review of existing geophysical and geotechnical data available for the project site and the cable corridor. This report is divided into four main Sections, which will be updated as this study progresses:

i. *Background Information*: This section includes as overview of geological formations, soil units and geomorphological processes governing the study area in the Irish Sea. The geology of the Dublin Bay area is also discussed based on available literature. Previous survey works undertaken in the study area are highlighted, and reference to available data formats, data sources and coverage is provided.

ii. *Multibeam Echosounder Data:* This section includes a review of bathymetry and seabed morphology, as well as interpretation of sea surface sediments using grab-sampling and backscatter data. A discussion is provided on the quality of multi-beam echosounder data collected as part of the INFOMAR campaign. A comparative assessment is also provided between the bathymetry map from existing site data collected in 2008 (single-beam echosounder with 20m line spacing) and more recent INFOMAR data (multi-beam echosounder with 5m line spacing).

iii. *Magnetometer:* This section reviews available magnetometer data including interpretation of magnetic anomalies, where data quality and coverage permits.

iv. *Sub bottom Profile Data (INFOMAR):* This section includes a review of existing sub-bottom data (gathered as part of the INFOMAR campaign), cross-correlation against bathymetry and backscatter data, and interpretation of sub-surface units. An initial comparison is also provided between the results of sub-bottom interpretation from the existing 2008 campaign (boomer) and INFOMAR surveys (pinger).

v. Review of Borehole Data

vi. *Geotechnical Hazard Assessment:* A preliminary geotechnical hazard assessment is provided in this section, which highlight potential risks that the ground conditions pose to the successful construction/ deployment of the wind farm including, but not limited to, the following:
- Outcropping/subcropping till and/or bedrock;
- Shallow gas;
- Boulders.

1.2 Available Data

Table 1 provides a summary of data received from the client at the outset of this study. These include coordinates of the site boundary and export cable corridors to Shanganagh or to Poolbeg, as well as bathymetry data collected by Hydrographic Surveys Ltd between June and September 2008 as part of the original Environmental Impact Statement (EIS) process. The bathymetry data covers over 90% of the offshore wind farm area, and a narrow route within the proposed export cable corridor to Shanganagh.

Table 1 Datasets provided by Innogy

Item	File Name	Format
Project Coordinates	Boundary Coordinates.xlsx	Excel file
Bathymetry	Multiple files have been provided	XYZ
Bathymetry	Kish 26-28 July 08-CD	.xyz file

Bathymetry	Kish Bank 15-18Sep08_15x15 CD	.xyz file
Bathymetry	KishBank 14-15Jul08 10x10 CD	.xyz file
Bathymetry	KishBank 16,20Jun08 5x5-CD	.xyz file
Bathymetry	KishBank inshore 13,17Jun08 3x3 CD	.xyz file
Boreholes	HSL Borehole logs with field test data	.pdf

Additional data pertinent to the offshore wind farm area and proposed export cable corridors, including format of the data and associated source are listed in Table 2.

Table 2 Data sets sourced from public databases for Dublin Array and export cable corridors

Item	File Name	Format	Source
Bathymetry	cv_03_01_dublin_bay_vorf_5m_wgs84	Raster	GSI
Bathymetry	CV_08_03_Dublin_Bay_vorf_5m_wgs84	Raster	GSI
Bathymetry	CV_09_05_UCC_combined_East_Coast_5m_WGS84	Raster	GSI
Bathymetry	CV_10_01_EAST_COAST_5M_WGS84_VORF	Raster	GSI
Bathymetry	CV_10_01_WICKLOW_5M_WGS84_VORF	Raster	GSI
Bathymetry	CV_12_02_Codling_Bank_5M_WGS84	Raster	GSI
Bathymetry	CV_12_02_west_kish_5m_wgs84	Raster	GSI
Bathymetry	GEO_16_01_Wicklow_5m_WGS84	Raster	GSI
Bathymetry	KY_16_01_Codling_Bank_5m_WGS84	Raster	GSI
Backscatter	BS_CV_03_01_DUBLIN_5M_UTM29N_3B	Tiff	GSI
Backscatter	BS_CV_08_03_DUBLIN_BAY_5M_UTM29N_3B	Tiff	GSI
Backscatter	BS_CV_10_01_DUBLIN_10M_UTM29N_3B	Tiff	GSI
Backscatter	BS_CV_10_01_WICKLOW_5M_UTM29N_3B	Tiff	GSI
Backscatter	BS_KY_09_02_DUBLIN_5M_UTM29N_3B	Tiff	GSI

Backscatter	BS_KY_10_01_DUBLIN_5M_UTM29N_3B	Tiff	GSI
Backscatter	BS_CV_12_02_West_Kish_1M_UTM29N_3B	Tiff	GSI
Backscatter	BS_CV_12_02_Bray_Bank_1M_UTM29N_3B	Tiff	GSI
Backscatter	BS_KY_16_01_Codling_2m_U30N_3B	Tiff	GSI
Backscatter	BS_GEO_16_01_East_Coast_2m_U30N_3B	Tiff	GSI
Sediment Classification	sc_ec_10m_w	Raster	GSI
Survey Coverage	Tracklines_2003_Detailed	Shape file	GSI
Survey Coverage	Tracklines_2008_Detailed	Shape file	GSI
Survey Coverage	Tracklines_2009_Detailed	Shape file	GSI
Survey Coverage	Tracklines_2010_Detailed	Shape file	GSI
Survey Coverage	Tracklines_2011_Detailed	Shape file	GSI
Survey Coverage	Tracklines_2012_Detailed	Shape file	GSI
Survey Coverage	Tracklines_2016_Detailed	Shape file	GSI
Sub-bottom Profile	CV03_01	SGY	GSI
Sub-bottom Profile	CV08_03	SGY	GSI
Sub-bottom Profile	KRY09_02	SGY	GSI
Sub-bottom Profile	CV10_01	SGY	GSI
Sub-bottom Profile	CV12_02	SGY	GSI
Sub-bottom Profile	KRY16_01	SGY	GSI
Shipwrecks	Shipwrecks	Shape file	GSI
Shipwrecks	Shipwrecks	CSV	NMS
Samples	Samples_PSA	Shape file	GSI
Samples	Non_INFOMAR_Samples	Shape file	GSI

Seabed Substrate	infomar_emodnet_geology_wp3_seabed_substrate	Shape file	GSI
Boreholes	Borehole logs with field test data	.pdf	FUGRO
Test results	Laboratory test results	.pdf	FUGRO

Where possible, these datasets were loaded into a Geographical Information System (GIS), from which a number of additional layers were derived. These newly developed layers are listed in Table 3.

Table 3 Derived datasets

Item	File Name	Format
Hillshade	Hillshade_225_2, Hillshade_270_45, Hillshade_315_45	Raster
Slope	Slope_deg, Slope_per_rise	Raster
Contours	da_contour	Shapefile
Bathymetric Position Indices (BPI)	Broad_10_20_80,	Raster
Grab Samples	Samples_PSA	Shapefile
Seafloor Features	Banks, Exposed_Bedrock, Sed_Waves	Shapefile
Seabed Change	Cut_Fill	Raster

Additional information including (i) borehole logs (ii) field test data (Standard Penetration Tests), and (iii) laboratory tests along the cable corridor to Poolbeg was acquired following consultation with Dublin City Council, Irish Water, and the site investigation contractor (Fugro UK). These datasets were part of a Site Investigation campaign undertaken for an outfall pipe project in Dublin Bay. The information was extracted from the following reports:

Table 4 Derived datasets

Item	Format	Source
Borehole Log	Report	[26] [27] [28]
Standard Penetration Test	Report	[29] [28]
Laboratory Tests (Plasticity Index, Oedometer Test)	Report	[26] [29]

2 The site

The Dublin Array site is located in the Irish Sea, approximately 10km from the Irish coastline. The area of the site is 58km^2 and the area of the cable corridor is 104km^2. The planned capacity of the offshore wind farm is 600MW or higher. The project is being co-developed by Innogy and Saorgus Energy.

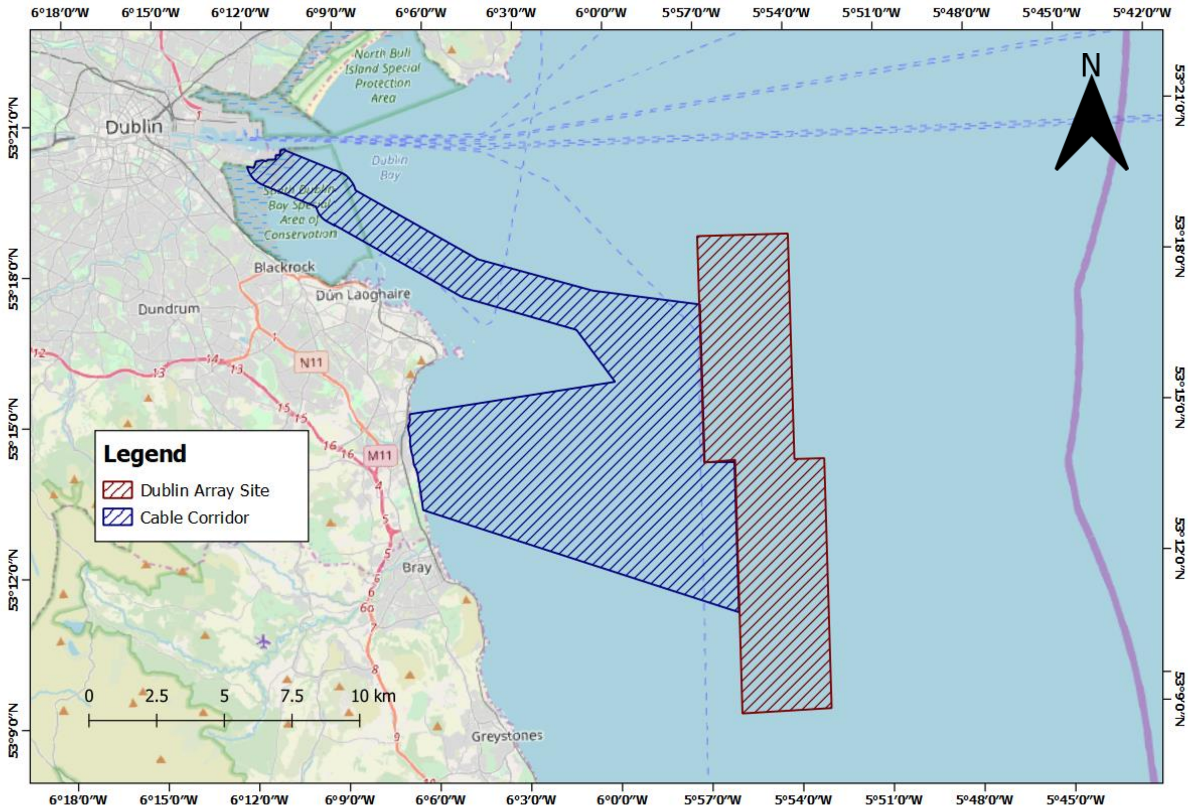


Figure 2-1 Site extents

3 Background Information

In this section, the geological history of the site and surrounding region is described, to provide context for subsequent discussions of the data and to inform conclusions with respect to ground conditions. This section also reviews and evaluates existing reports pertaining to the site and previous works carried out.

3.1 Irish Sea Geological History

Palaeozoic rocks are believed to underlie the main part of the site, consisting of Middle to Upper Triassic mudstone, sandstone and evaporates as well as Lower Jurassic age mudstone and limestone [1]. The bedrock of the cable route area is comprised of a mixture of Paleogene granitic rocks, Lower to Middle Ordovician slate, sandstone, greywacke and conglomerates and Viséan limestone & calcareous mudstone.

Whilst the geological history of Ireland extends back 1,900 million years before present (BP), it is the last 1.8 million years that has had the most impact on the present geological structure of the Irish Sea. In this period, referred to as the Quaternary, much of Northern Europe has experienced extensive ice-sheet cover during a number of glaciation events. During these events, glaciers and ice sheets formed in northern and upland areas before advancing across the landscape, marine and terrestrial, creating various glacial environments where sediments were deposited or eroded depending on the stage of ice sheet advance or retreat.

Figure 3-1 Maximum geographic extent of the BIIS during the Devensian(From: [4])

The last glacial event to have affected the Irish Sea (the Devensian) occurred from approximately 34,000 years BP to 12,000 year BP [2]–[4]. During the Devensian, ice sheets merged across much of northern Britain and Ireland to form the British and Irish Ice Sheet (BIIS). A large ice stream within the BIIS flowed through the Irish Sea, often referred to as the Irish Sea Ice Stream (ISIS) reaching its maximum geographic extent to the south at 24,000 – 23,300 years BP [3]–[8] (Figure 3-1).

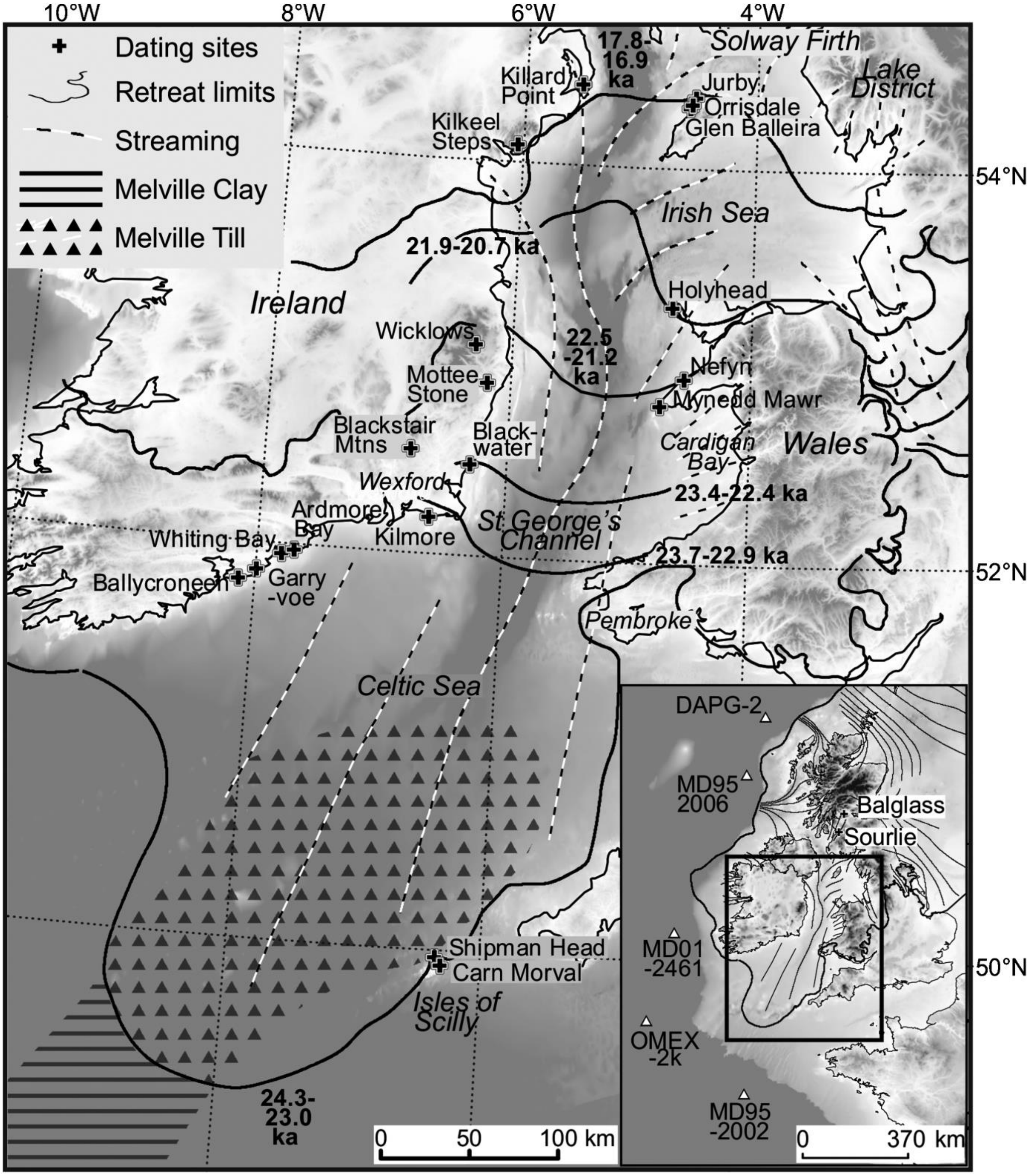


Figure 3-2 Map showing BIIS ice limits and ages (From: [3])

The extension of the ISIS across the Irish Sea during the last glaciation meant that significant amounts of sediment were eroded and reworked with variable thicknesses of glacigenic deposits formed [1], [9]. These deposits are generally referred to as 'The Irish Sea Till' (*sensu* [10]) and are composed of a shelly, grey and muddy, unsorted sediments with some angular clasts, and was deposited directly by the grounded ISIS. Ice retreat initiated shortly after this maximum extent and by approximately 22,500 – 21,200 years BP ice had retreated to a line just south of the site [3]. Ice sheet decay slowed thereafter with episodic meltwater discharge.

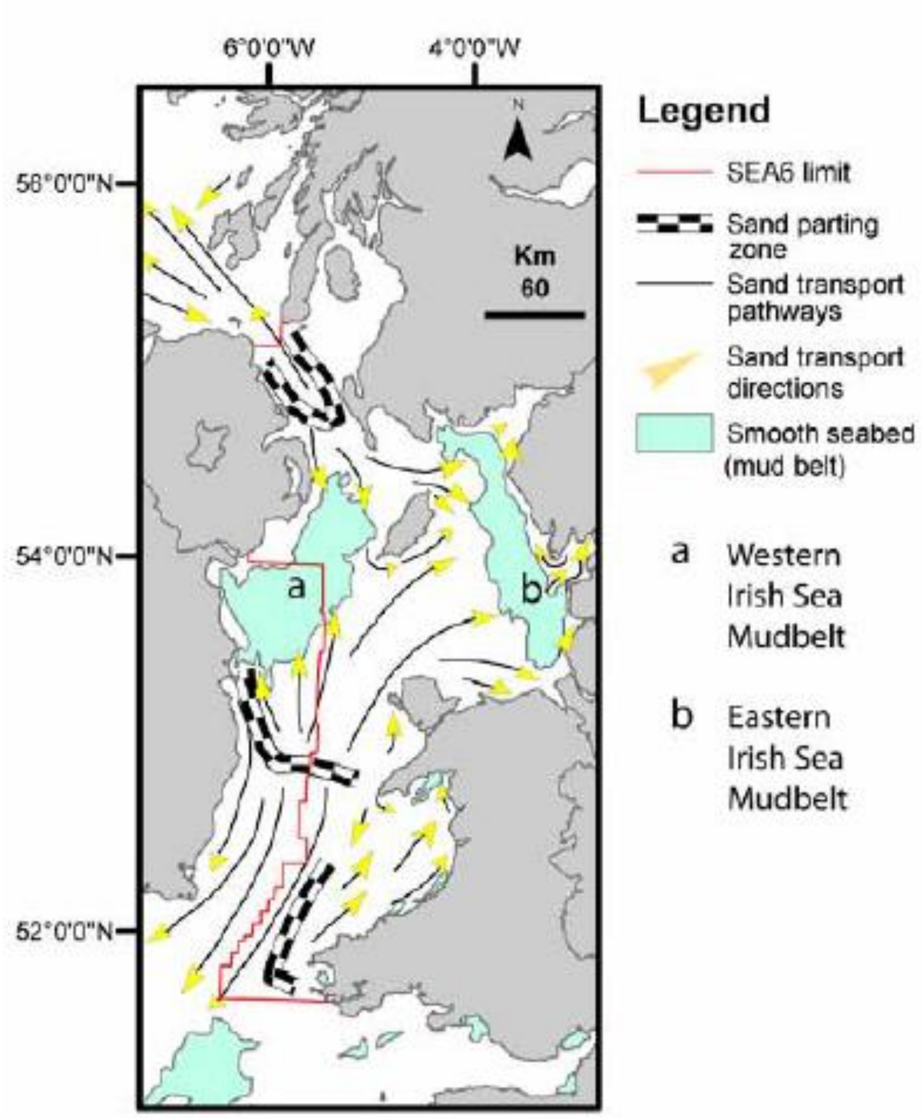


Figure 3-3 Map of the Irish Sea with generalised current transport paths and features (From: [15])

The end of the Devensian glacial period gave way to the Holocene approximately 11,200 years BP. During the Holocene, worldwide eustatic sea level rose with the disintegration of the ice sheets. This brought about the current configuration of the Irish Sea, which has access to the Atlantic Ocean through the North Channel to the north and St. George's Channel in the south with a central trough connecting the two running through the Irish Sea. It is through these two channels that tides enter the Irish Sea with the two tidal branches meeting to the southwest of the Isle of Man to form a standing wave field [11]. From the degenerate amphidrome (where a bedload parting zone has been inferred) at the Wicklow-Cahore Point interval of the Irish Coast, tidal ranges increase away from this location in a northerly and southerly direction [12], [13]. For the most part, the bed stress conditions created by these residual tidal currents exceed the energy thresholds that allow sediment to be actively eroded or induced to transport with the result that their direction are marked by migratory sediment-wave fields ending in areas of sediment accumulation; the Eastern and Western Irish Sea Mud Belt (EISMB and WISMB) in the north and Celtic Sea in the south [12], [14]. As a result, seafloor sediments of the Irish Sea can be divided into three types; lag or modern day erosion (sand parting zone), sediments in transport (sand transport pathways) and present day deposits (smooth seabed)[15] (Figure 3).

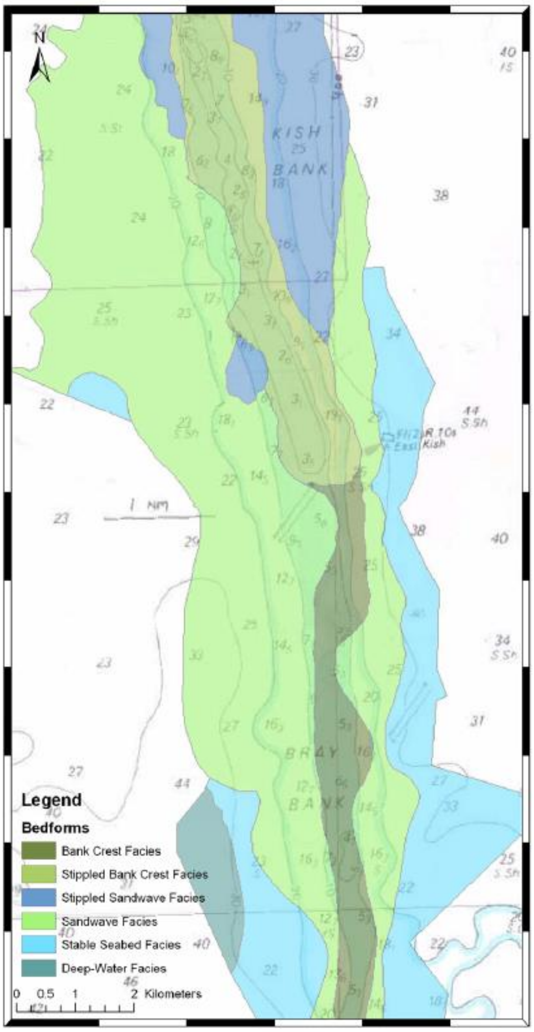


Figure 3-4 Seafloor facies distribution at proposed site (From: [18])

The proposed project comprises two sand bank features referred to as Kish and Bray Bank. Both are part of a chain of significant offshore sand bank running along the Irish Sea at a distance between 5 and 15km from the coast including Burford Bank, Fraser Bank, Codling/Greater Codling Bank, India Bank, Arklow Bank, Glassgorman Banks, Blackwater/Lucifer Bank, Long Bank/Holden's Bed and The

Ballies. These banks form a punctuated line parallel to the coast with breaks between them maintained by strong currents and sediment movement. The banks themselves are believed to be quasi-stable over historical time, in dynamic equilibrium with tidal and wave conditions, and offer important coastal protection [16]. The banks vary in their composition. Other authors have surmised the features as “banks and other sand bodies that may include stiff clay or gravel layers and mud and silt in some hollows”[17].

The review of sedimentary bedforms identified visually and through the use of side-scan sonar indicates that surficial sediments on the banks are actively mobile and migrating northwards. Sediment mapping, based on both sampling and sonar techniques, indicate that the banks are composed of extensive thickness of sand to gravel sized material. Five distinctive seabed facies were identified by [18] (Figure 3-4):

- **Stippled Bank Crest Facies** – Occurs in the north of the proposed development, on the crest of the Kish Bank. Represents a transition from sandwave dominated sediments on the bank margins, to environs dominated by planar beds with scattered patches of more highly reflective sediments interpreted to represent more gravel rich deposits. The morphology of sandwaves observed in this echo-facies was interpreted to indicate a northwardly transport direction.
- **Bank-crest Facies** – This echo-facies occurs on the crest of the Bray Bank, as is described as being similar in character to the previously detailed unit, but lacking the patches of increased reflectivity.
- **Stippled Sandwave Facies** – This unit occurs on the margins of the Kish Bank and represents areas dominated by sandwaves but also displaying areas of increased reflectivity, interpreted to represent more gravel rich deposits.
- **Sandwave Facies** – This unit describes a highly mobile seafloor environment occurring on the margins of the bank complex. The facies is characterised by widespread sandwaves and other bedforms, with bedform development decreasing with distance from the bank complex. Bedform morphology implies a northerly net transport of sediment, with stronger tidal flows adjacent to the banks.
- **Stable Seabed Facies** – The final facies is found at greater distances from the bank complex and represents regions where no bedforms were imaged. The unit is interpreted to represent a stable or non-mobile seafloor. While no bedforms were imaged, small scale ripples below the resolution of the sonar instrument may exist. Ground-truthing of this facies type indicates a sandy to silty composition.

3.2 Geology of the Dublin Bay Area

The geology in the immediate vicinity of Dublin Port is composed of four different layers of soil lying above limestone bedrock as shown in Figure 3-5. The estuarine and fluvial deposits are principally sand and gravel coming from sea level variation and tide change with pockets of soft silt/clay. Under the layer of estuarine and fluvial deposits, a layer of firm to stiff clay, known as Dublin Port Clay (DPC), can be observed. The DPC has previously been described as a post-glacial estuarine deposit but Gill (2008) argued it is more likely lacustrine sediment deposited during a warm interglacial period. The DPC is underlain by a glacial deposit composed of gravel and cobbles from the limestone bedrock. Hard glacial till, known as Dublin Boulder Clay, is also very common around the Dublin area. The limestone bedrock is situated between 20 to 50m below ground level. A pre-glacial channel in the limestone bedrock created due to the river erosion influences the port clay creation in the Dublin Bay Area.

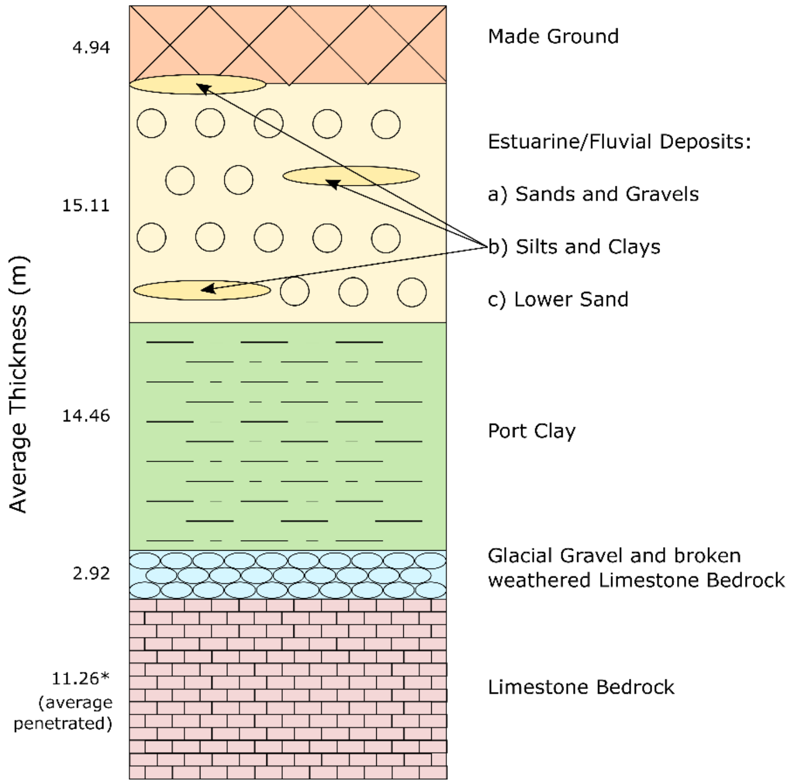


Figure 3-5 Dublin Port Geology (Based on Gill, 2008)

3.3 Previous Work

3.3.1 INSS/INFOMAR

The Dublin Array offshore wind farm site and the proposed export cable corridors were surveyed in 2003, 2008, 2008, 2010, 2012 and 2016 as part of the ongoing INFOMAR project (formerly Irish National Seabed Survey or INSS), a joint seabed mapping project between the Geological Survey of Ireland (GSI) and the Marine Institute. Figure 3-6 depicts all the surveys performed at the sites of interest. As shown, the INFOMAR campaigns covered most of the site and gathered multibeam bathymetry, backscatter, single beam echosounder, sub-bottom profiling, magnetometer data and seabed sampling. The INFOMAR surveying programme includes the following publicly available dataset for the Dublin Array offshore wind farm site and export cable corridors (Figure 3-6):

1. CV_03_01
2. CV_08_03
3. KY_09_02
4. KY_10_01
5. CV_10_01

6. GEO_11_02
7. CV_12_02
8. KY_16_01
9. GEO_16_01
10. TON_16_01

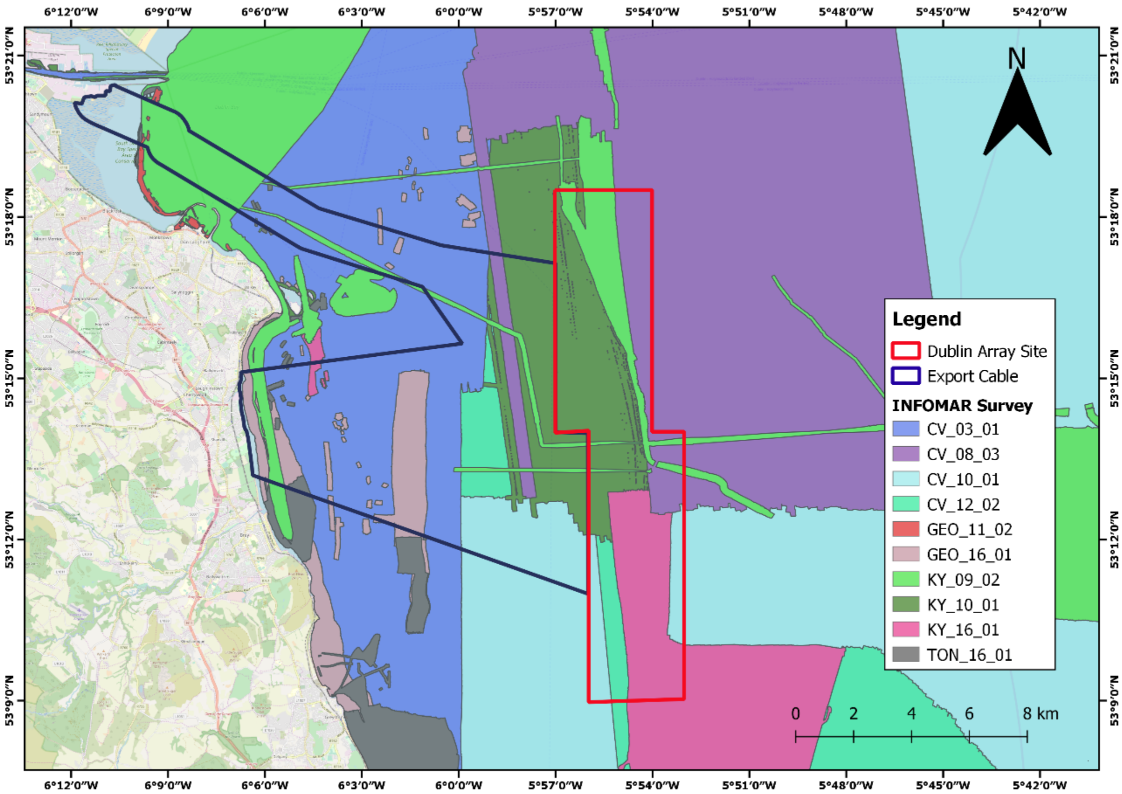


Figure 3-6 INFOMAR survey coverage

3.3.2 Existing Site Data

3.3.2.1 Geophysical Data (HSL 2008)

Bathymetric data (single beam echosounder) and sub-bottom data was collected by Hydrographic Surveys Ltd (HSL) between June and September 2008 as part of the original Environmental Impact Statement (EIS). The data has been provided by the client. The extent of the survey is shown in Figure 3-7.

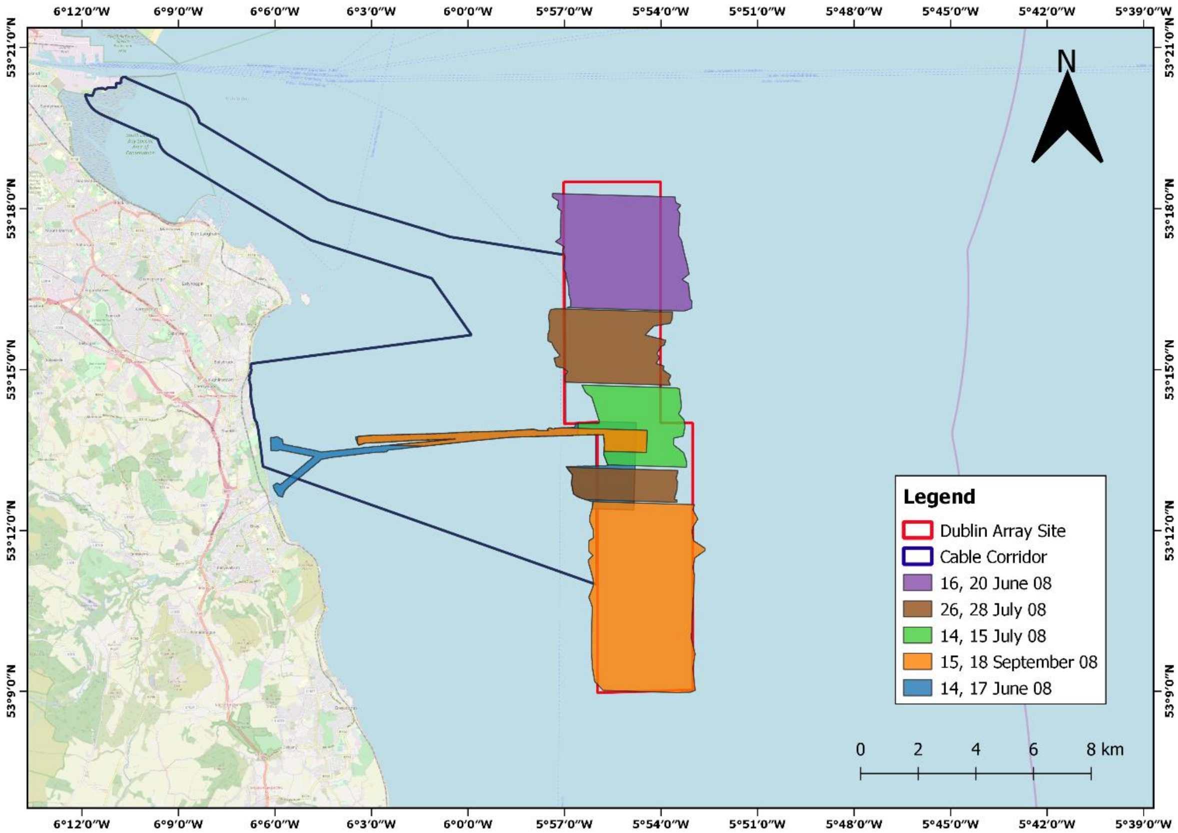


Figure 3-7 Existing Site Data acquired as part of the original EIS process by Hydrographic Survey Ltd.

3.3.2.2 Borehole Data (Glover 2008)

Three boreholes are available in the offshore wind farm area as a result of site investigation campaign by Glover Site Investigations Ltd in September 2008 (Figure 3-8). A sequence of loose to medium dense sand, dense sand, and very dense sand is believed to constitute the bank structure based on this data. The details of borehole logs are provided in Appendix B.

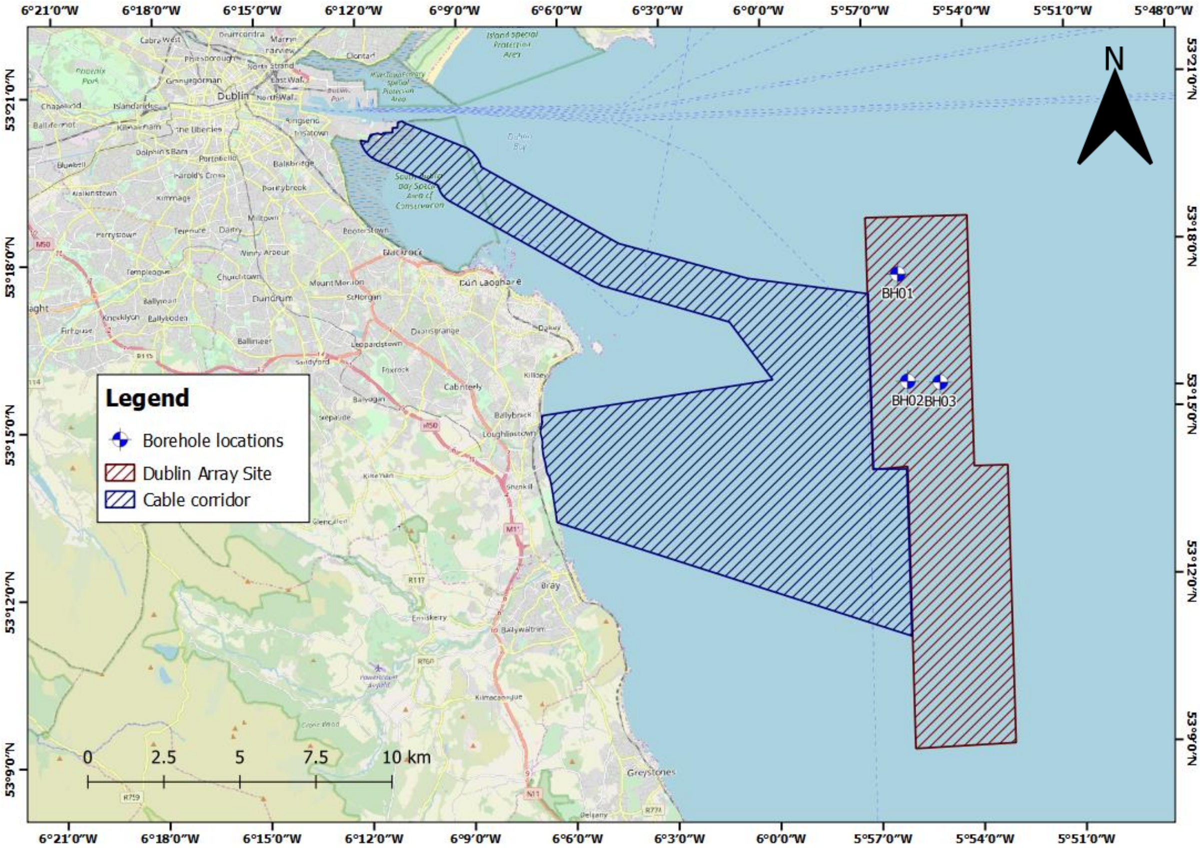


Figure 3-8 Plan view of boreholes conducted at the site as part of the EIS process

3.3.3 Marine Institute Survey 1998

Bathymetric (single beam echosounder), sidescan sonar (SSS), Boomer (SBP) and grab sample (Van Essen Grab) data was collected as part of a geological appraisal of the Kish, Burford, Bray and Fraser Banks in the outer Dublin Bay area. Operations were carried out using the MV Kilquade as part fulfilment of contract 97.IR.MR.013 of the Marine Research Measure (Operational Programme for Fisheries (1994-1999)) administered by the Marine Institute. Surveying took place during spring tides to enable the vessel clear the banks at high tide between 3rd and 10th November 1998.

While it has not been possible to access the actual geophysical data acquired, a comparison is provided between the findings presented in that report [5] and interpretation derived from INFOMAR data. The extent of the survey is shown in Figure 3-9 below.

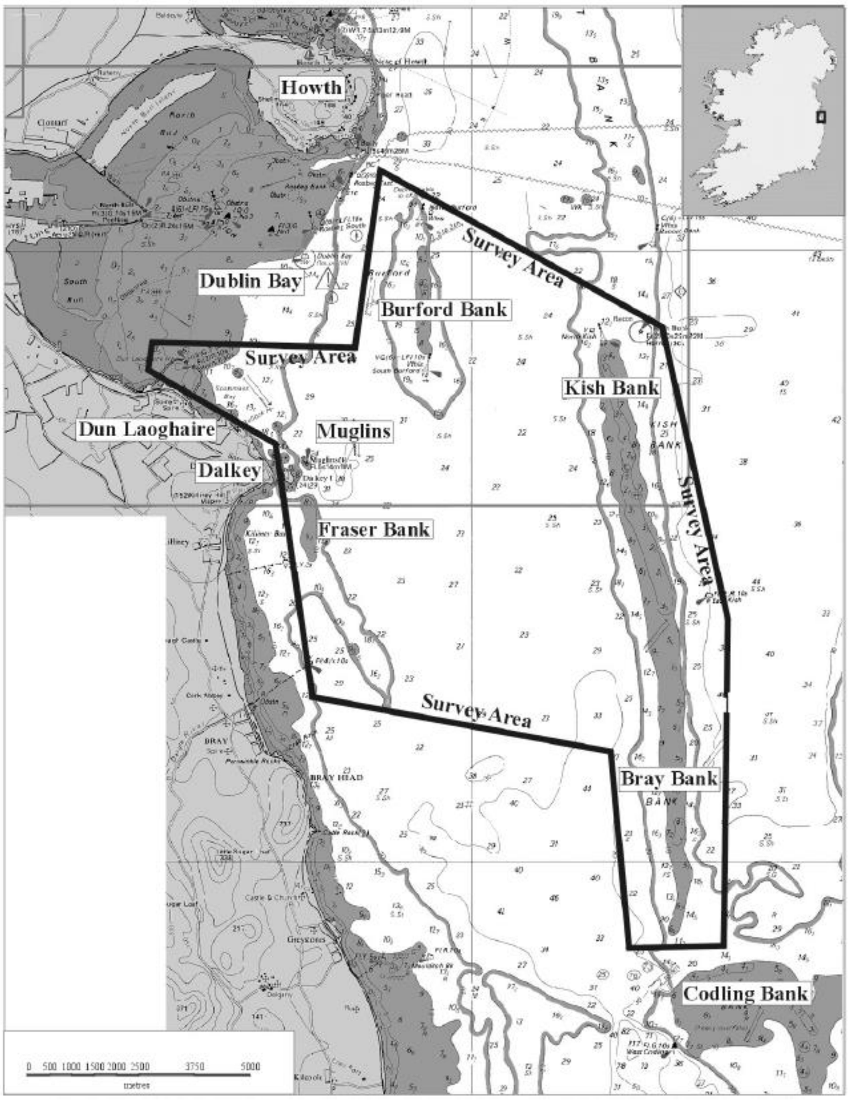


Figure 3-9 Marine Institute survey area

3.3.4 Geotechnical campaign in the Dublin Bay Area

In October 2010 Dublin City Council commissioned a geotechnical campaign in the approaches to and within Dublin Bay to inform and facilitate the Ringsend Wastewater Treatment Plant (WWTP) works. This geotechnical campaign consisted of 21 boreholes and a bathymetric survey. The vessels used for the borehole drilling were the jack-up barges 'Aran 250' and the 'Excalibur', while the catamaran “Xplorer” was used for the bathymetric survey of the Bay. The rock cores from the drilling campaign are stored within the Pigeon House complex in Ringsend.

Figure 3-10 illustrates the locations of the boreholes relative to the Dublin Array site and cable corridor. Five of the boreholes are located within the cable route (to Poolbeg) area.

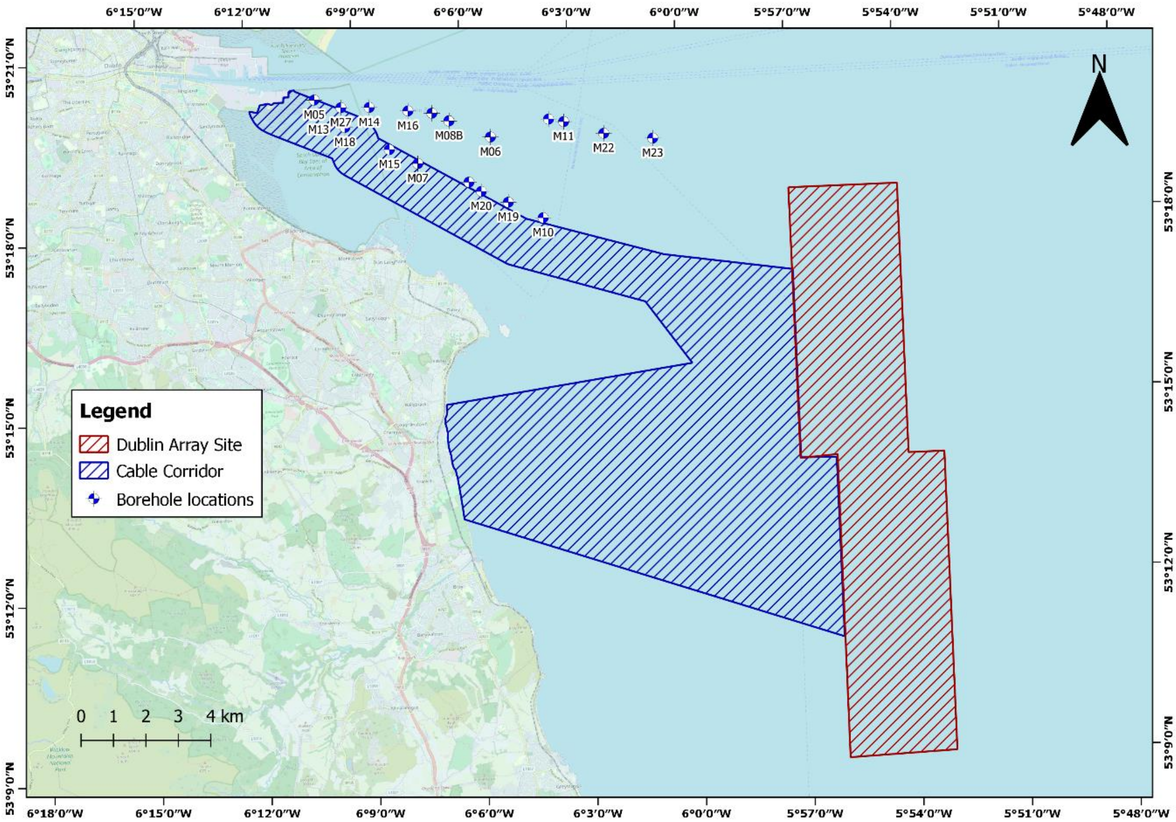


Figure 3-10 Borehole location map

Based on Fugro Engineering Services Ltd site report four cross sections (Figure 0-2 to Figure 0-5) were generated to illustrate encountered succession of strata. Locations of the profiles are shown on Figure 0-1.

On the western side of the profiles, in the majority of the boreholes, the surface layer is sand. It changes to clay in the eastern part. Underneath there are bands of clay, gravel and sand in various combinations. Bedrock was encountered from 10 to 52mBSF and is made of limestone.

4 Multibeam Echosounder (MBES) Data

4.1 Discussion on Data Quality (INFOMAR)

INFOMAR multibeam surveys are designed to meet internationally recognised standards for data quality. Acoustic soundings must be processed by a Hydrographer before these standards can be met. During acquisition, multibeam data quality can be affected by several variables. The type of vessel, its survey speed, weather conditions and composition of the water column are just some of the factors which produce "noise" artefacts in multibeam datasets. The soundings (including associated vertical uncertainties) fall within the threshold of IHO S44 Order 1 a, which is sufficient for most users. The noise which usually appears as depth-spikes in the data must be cleaned and rejected from the final dataset. Initial processing of the data was done in Qimera software to apply filters, tidal and refraction corrections. It was then converted to Caris software to perform final cleaning and QC to verify its Order 1a status. Once the processing was complete, the depths were levelled to their shallowest possible occurrence at "lowest astronomical tide" (LAT). This is done according to a Vertical Offshore Reference Frame (VORF) datum. In the case of INFOMAR, all data uses VORF rev 2.0 as standard.

All the MBES bathymetry data used for this project was collected by INFOMAR and processed to the same standard (Order 1a status). Individual datasets were merged in ArcGIS using the "mosaic" tool. Mosaics are useful when two or more adjacent raster datasets need to be merged into one entity. In the case of INFOMAR data, datasets were typically adjacent with very little overlap. Where there was overlap, overlapping cell values were blended and a mean value attributed. Given the high standard to which the INFOMAR data was processed, and minimal overlap, there is strong confidence in the results. It is important to note, that GDG were not involved in the original data collection and had no visibility on the hardware or procedures that were followed.

4.2 Bathymetry/Seabed Morphology (INFOMAR)

Water depths at the array site vary from approximately 2 m to 57 m (LAT) (Figure 4-1 and Figure 4-2) with water depths for the cable route between near inshore to 42 m. Water depths at the site are generally shallowest at the crest of the banks that run north south through the area (Figure 4-1). The slope across the site is generally less than 5° (9%) and typically less than 0.5° (Figure 4-3 and Figure 4-4). The east side of the bank shows a steep slope of between 10 – 15°. Areas of high slope (15 – 35° approximately) are associated with areas of sediment waves where they constitute the steep crests of the individual waves.

Changes in seabed morphology are best observed when hillshade rasters are derived from the MBES data and applied as a semi-transparent layer. This allowed the identification of more subtle changes in seabed morphology including banks and sediment wave areas (Figure 4-5).

A 3D visualisation of the bathymetry data obtained from the INFOMAR campaign is provided in Figure 4-7 where the bank is clearly illustrated, and the relatively flat nature of the cable route is apparent.

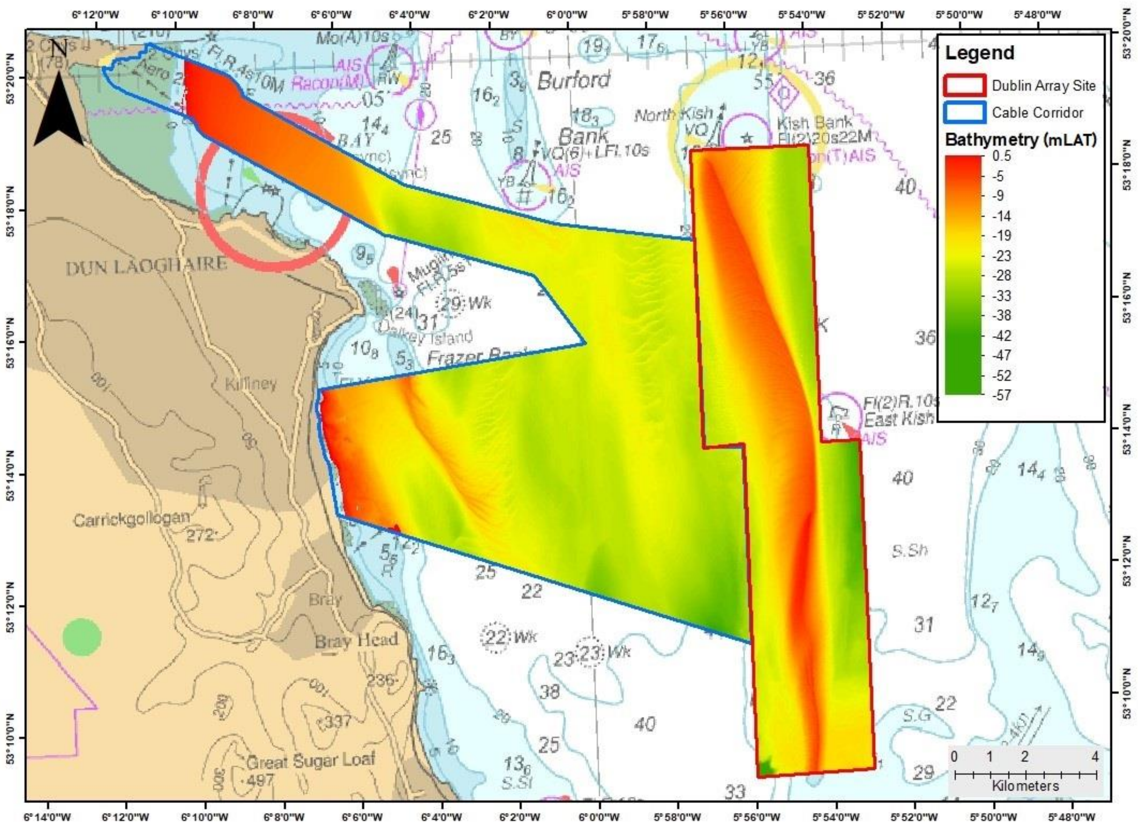


Figure 4-1 Bathymetry (LAT VORF) at the Dublin Array site from INFOMAR data

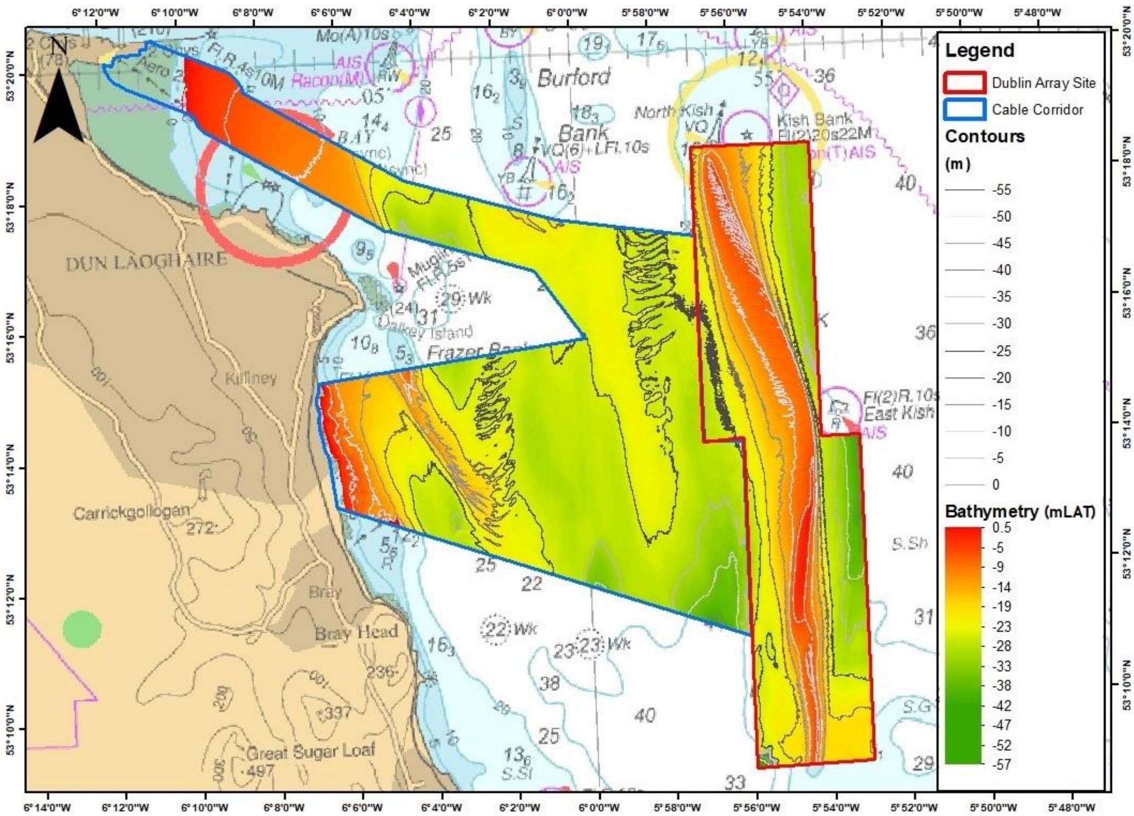


Figure 4-2 Bathymetry at Dublin Array site with 5m contours

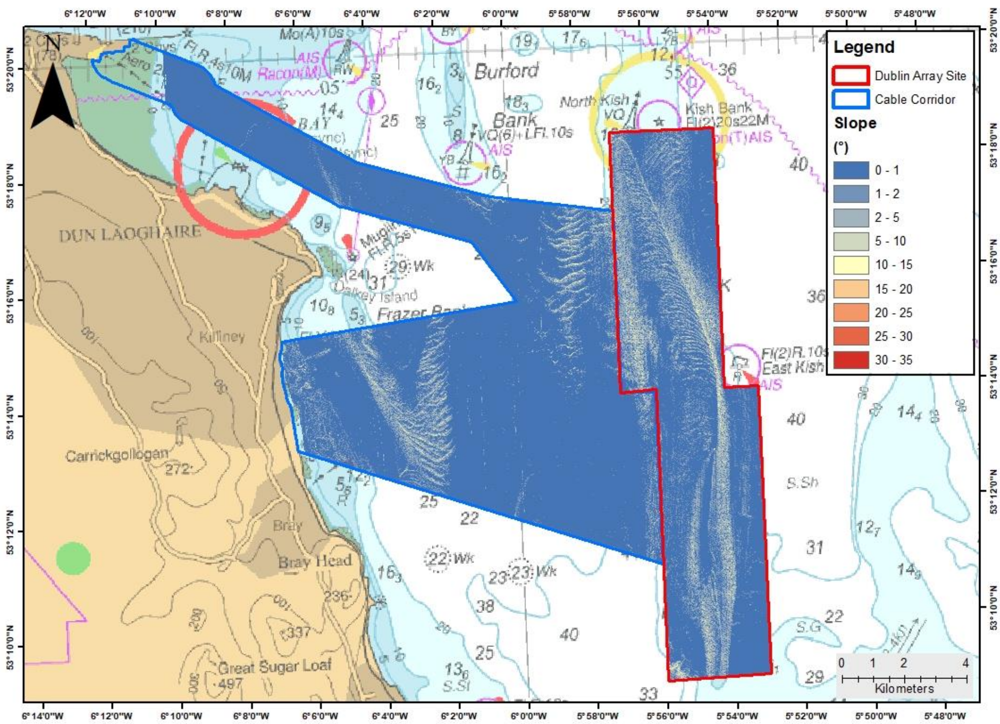


Figure 4-3 Slope map (degrees) for Dublin Array site

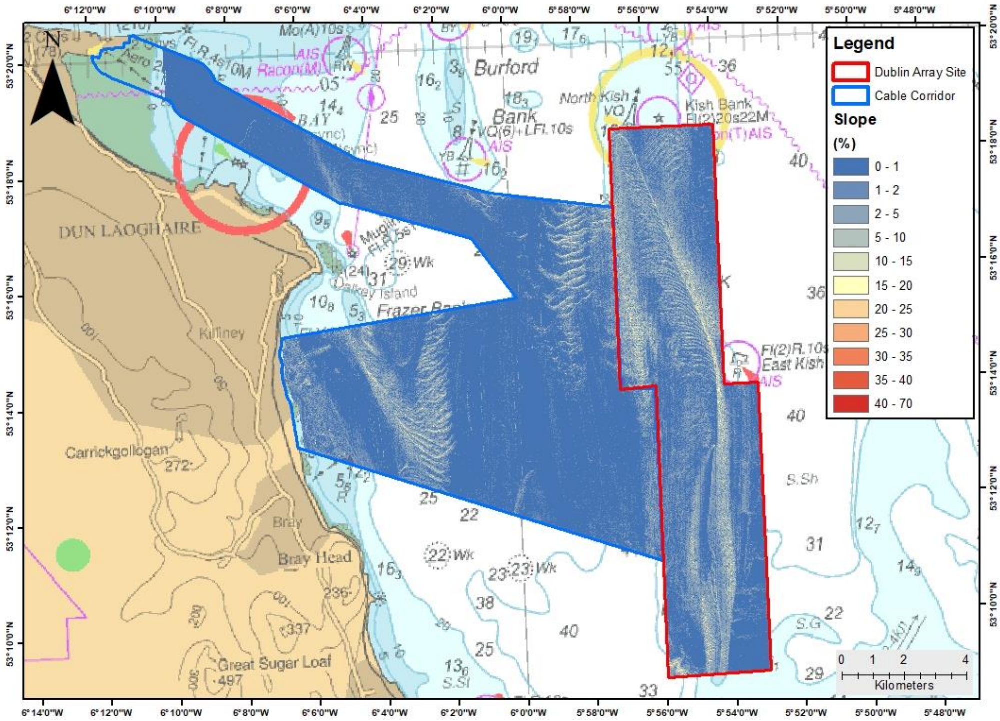


Figure 4-4 Slope map (percentage rise)

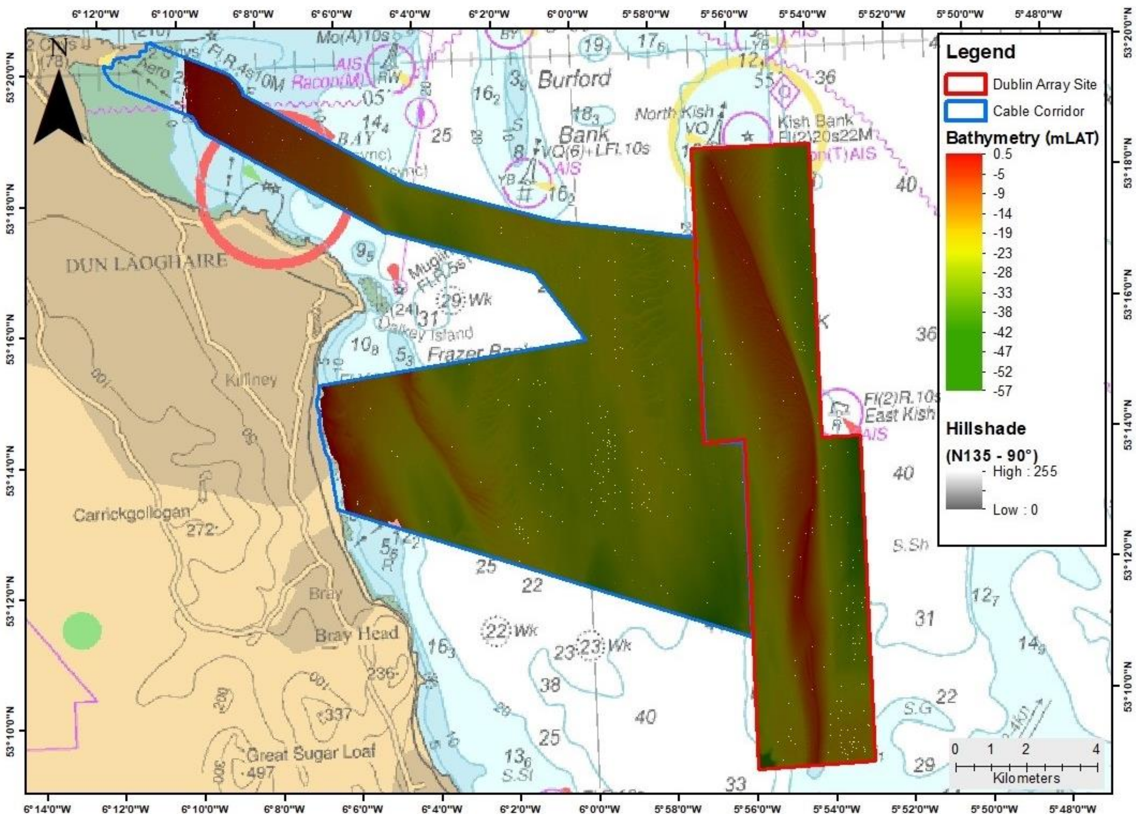


Figure 4-5 Bathymetry at Dublin Array site with hillshade (N135 - 90°)

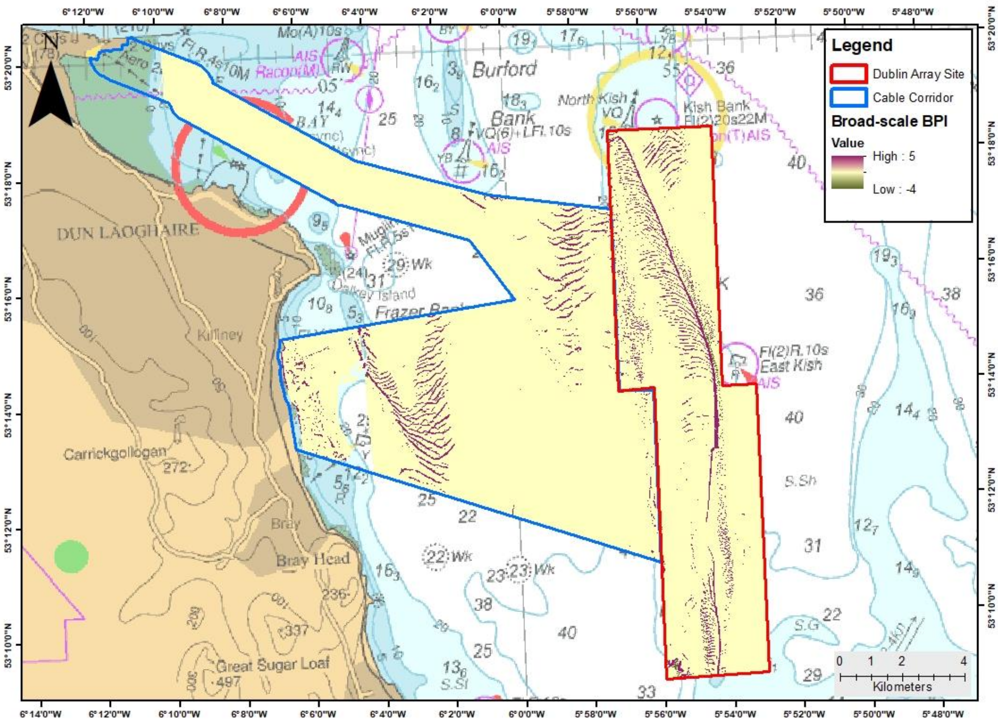


Figure 4-6 Bathymetric Position Indices (BPI) (elevation) at the Dublin Array site

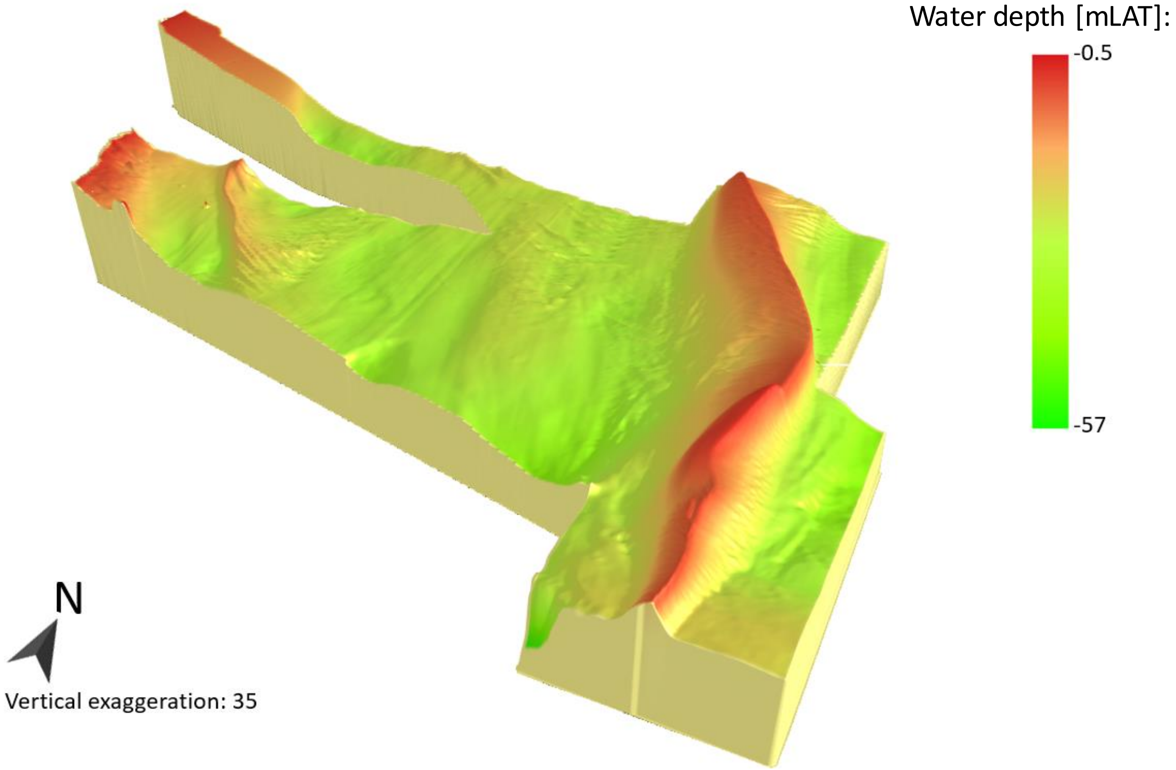


Figure 4-7 3D model of INFOMAR bathymetry data.

The Bathymetric Position Index (BPI) is used to define the elevation of a particular location relative to the overall landscape. BPI is therefore useful in characterising geomorphological features like slopes, depressions, crest lines and flat areas. [19]. This data is displayed in Figure 4-6 where it highlights flat area denoted by the white/cream colour, with bathymetric highs (purple colour) corresponding to sediment waves and the bank structures. Bathymetric lows (green colours) indicate areas of scour or depression, mostly associated with the troughs of sediment waves.

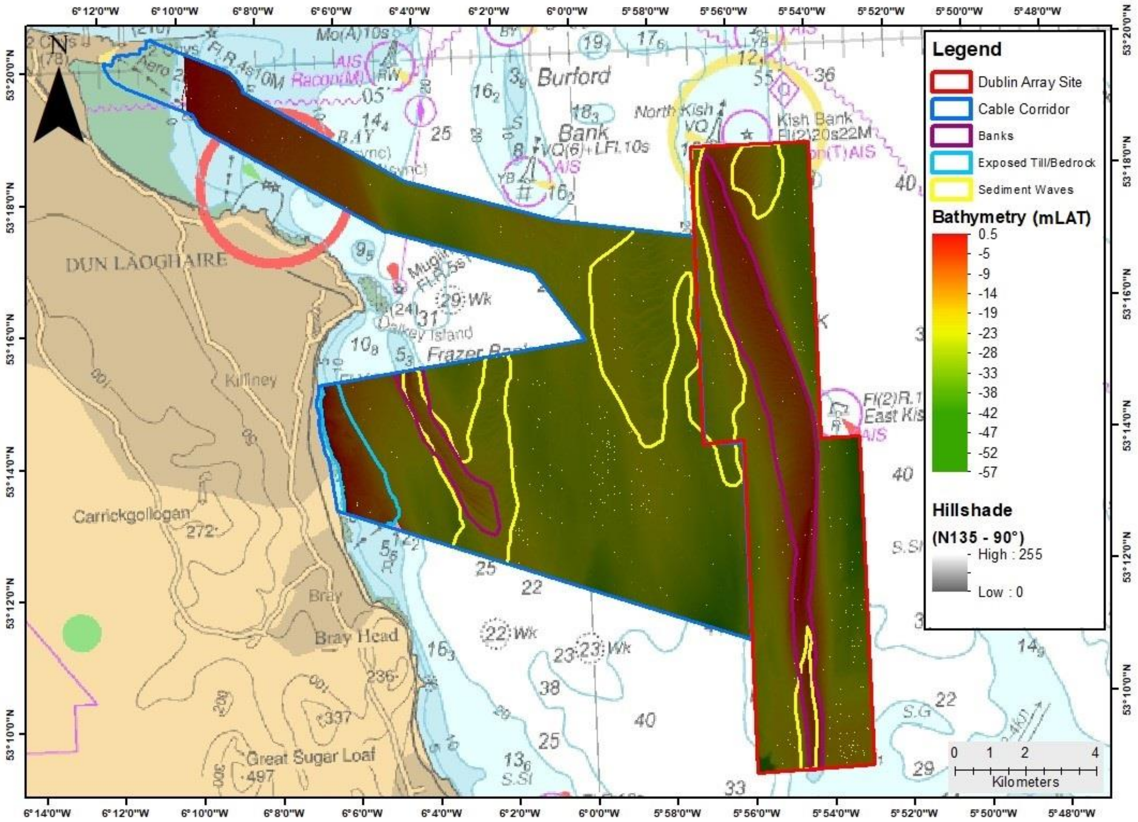


Figure 4-8 Dominant seabed features at the Dublin Array site

Based on this data, the key seabed features identified are sediment waves and sand banks forming bathymetric highs (Figure 4-8). Areas perceived as exposed bedrock were also identified within the export cable route to shanganagh and close to the shoreline. These seabed features are also illustrated on a 3D visualisation of the site (Figure 4-9).

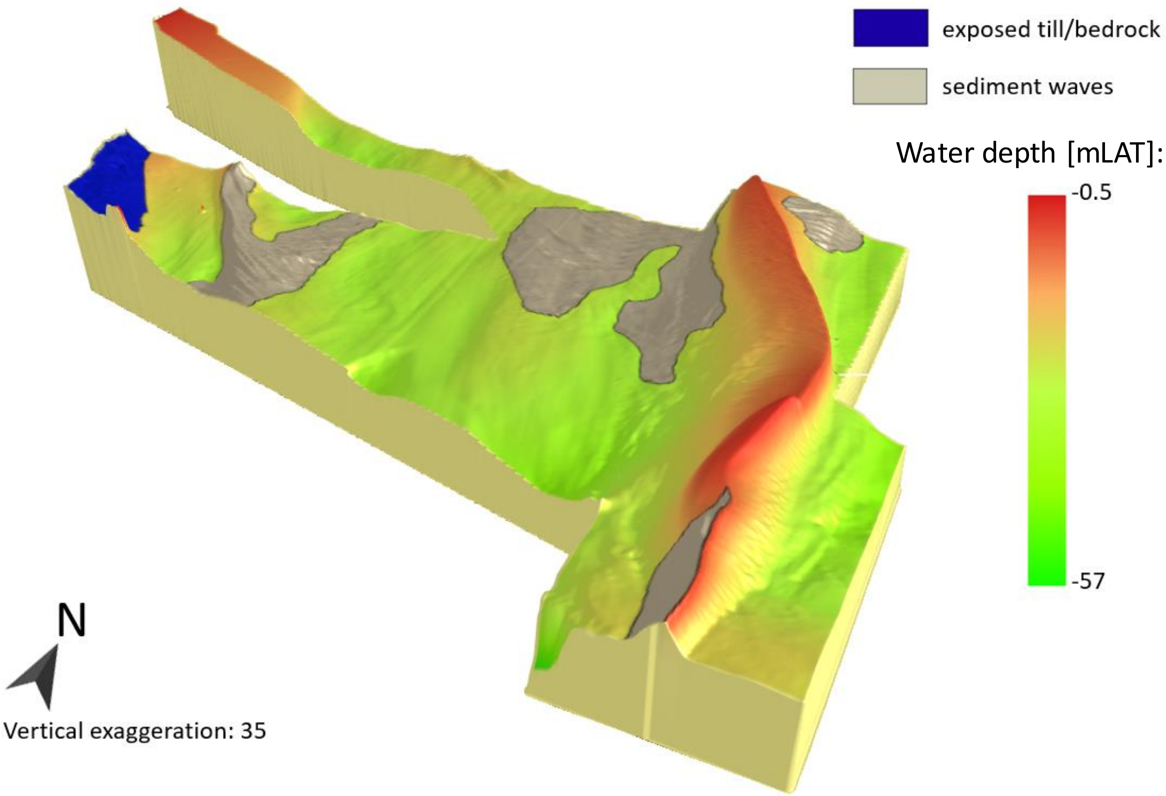


Figure 4-9 3D INFOMAR bathymetry model with seabed features marked.

4.2.1 Exposed hard surfaces: Outcropping/subcropping till and/or bedrock

From MBES data, it is possible to identify features in the western area of the cable route to Shanganagh that can be interpreted as exposed, or outcropping, bedrock or till. This inference is deduced based on a number of sources:

1. The relief of the features derived from hillshading of bathymetry is consistent in appearance with exposed bedrock/till surfaces displaying a rugged topography;
2. Outcropping rock is recorded locally in the area both on Admiralty charts and the INFOMAR shoal database;
3. Backscatter values derived from MBES suggest a hard substrate consistent with bedrock or till, which is corroborated by a lack of sampling due to the hard nature of the material (see Section 4.2);

Based on the above statements, areas of exposed hard surfaces are expected to be found in the western area of the cable route to Shanganagh. These areas are typically rough and undulatory, forming minor topographic highs including linear, NW-SE trending, ridges (Figure 4-8 and Figure 4-10). The till is most likely a product of the last Irish Sea Ice Stream (ISIS) and is comprised of stiff or hard clay with clasts that are likely to range in size from sand grains to cobbles and boulders that are up to 1 m in diameter [1]. The extent of the boulder content cannot be inferred from the available information but onshore deposits of Dublin Boulder Clay would typically yield a minimal boulder fraction.

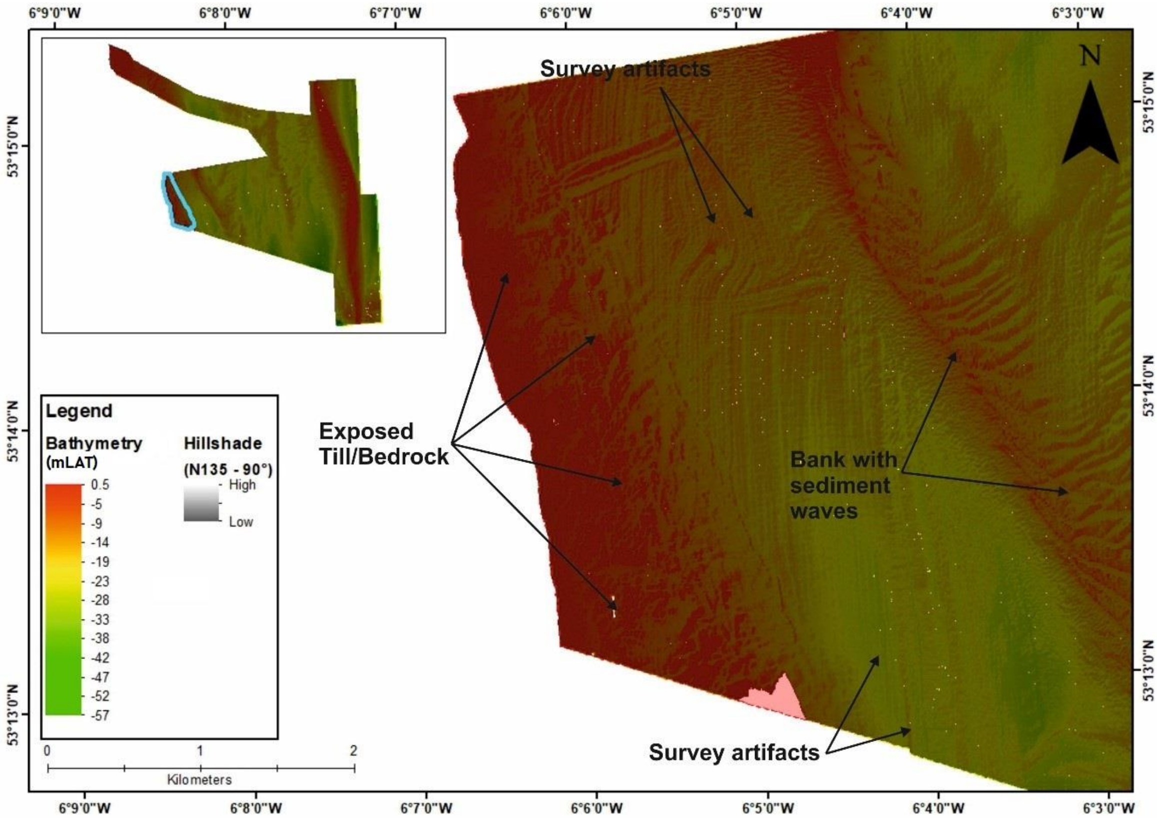


Figure 4-10 Areas of exposed bedrock/till

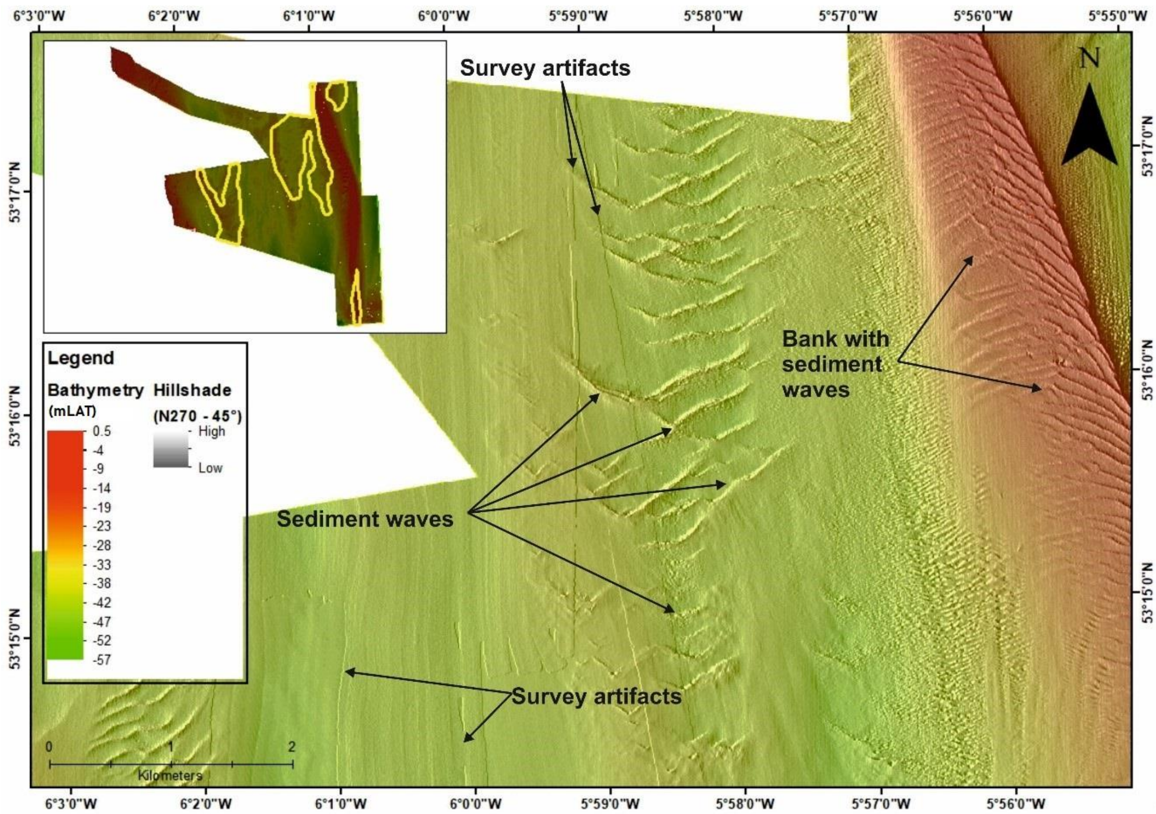


Figure 4-11 Sediment waves at Dublin Array site

4.2.2 Sediment Waves

Sediment waves occur throughout the site both as standalone features and as part of bank structures (Figure 4-8). Their size varies from under a meter up to 6m within the export cable routes area and from under a meter up to 3m within the OWF site. Their orientation is generally E-W, in places SW-NE or SE-NW. Given the hydrodynamics of the area, observed sediment waves are likely to be mobile (Figure 4-11). Four profiles have been derived from the locations of sediment waves (see Figure 4-12). Individual profiles are shown in Figure 4-13 to Figure 4-16.

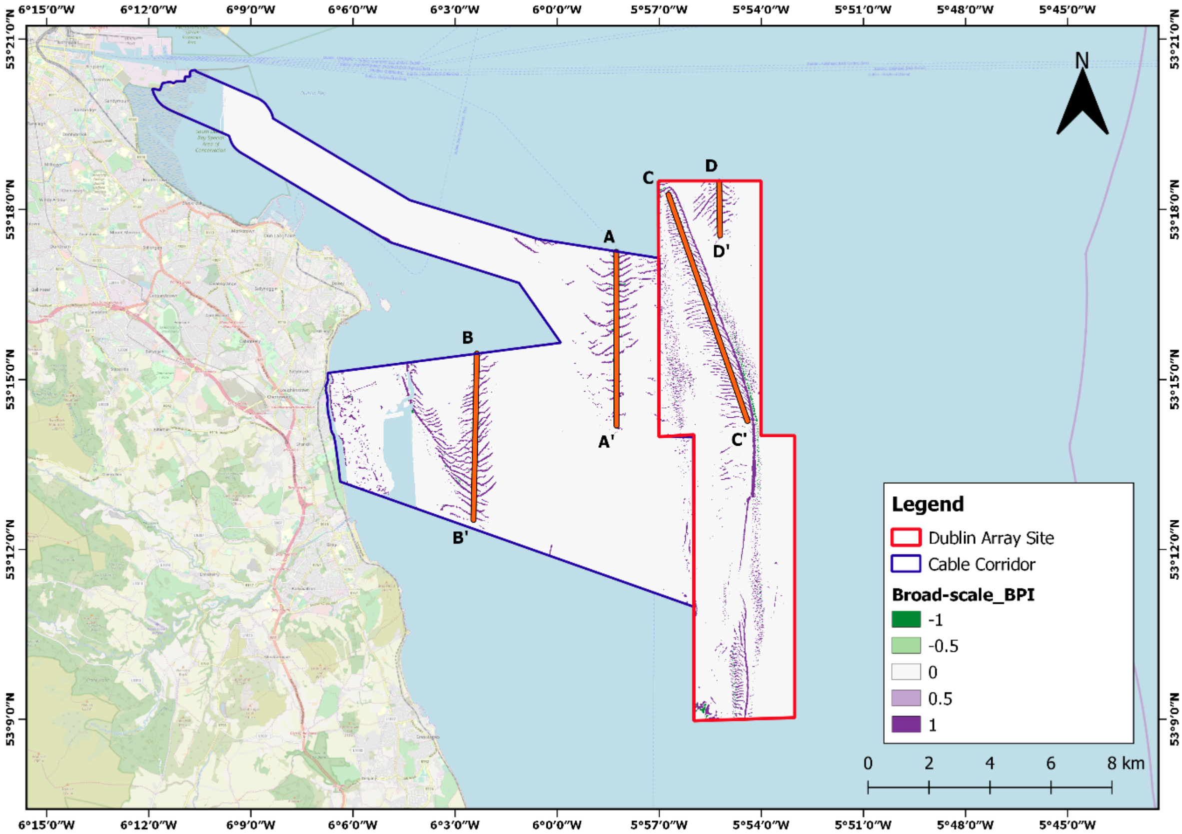


Figure 4-12 Profile Lines

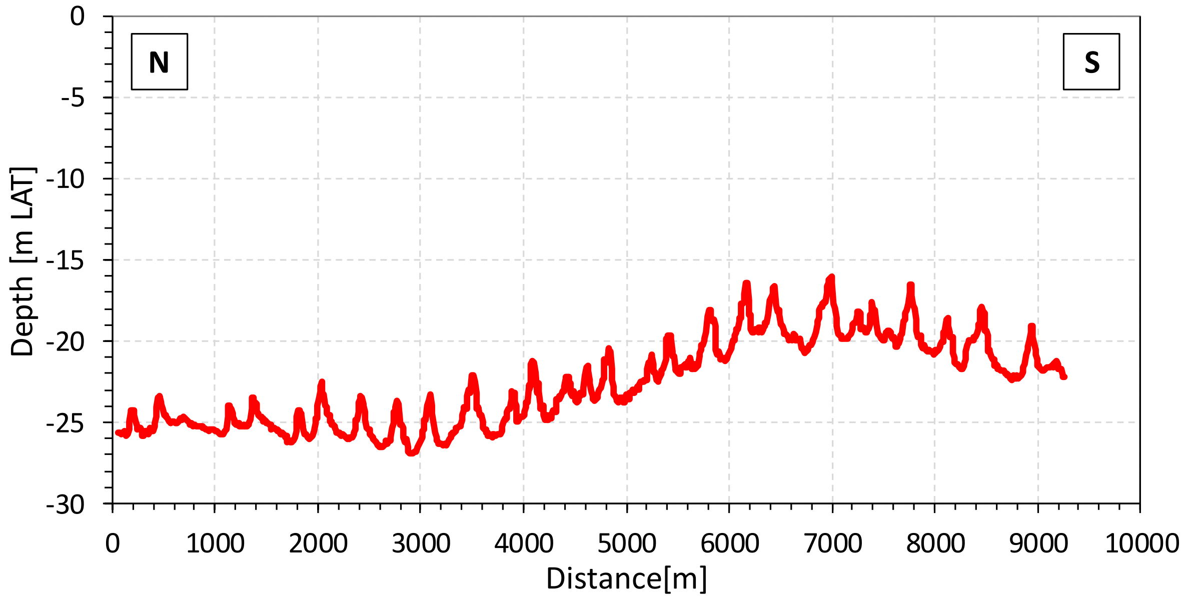


Figure 4-13 Profile A

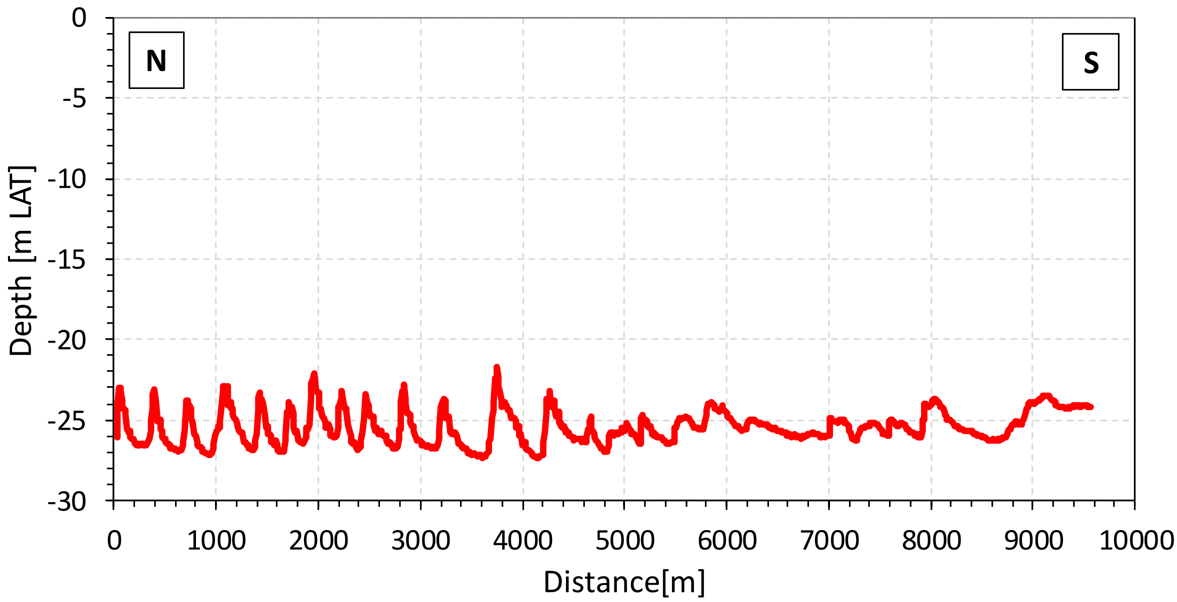


Figure 4-14 Profile B

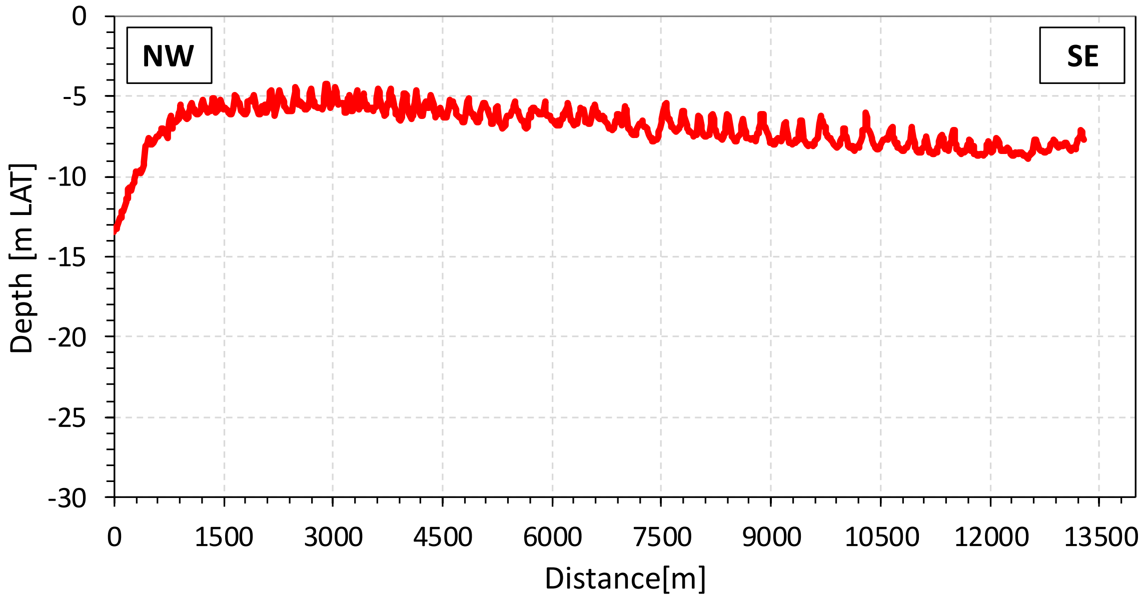


Figure 4-15 Profile C

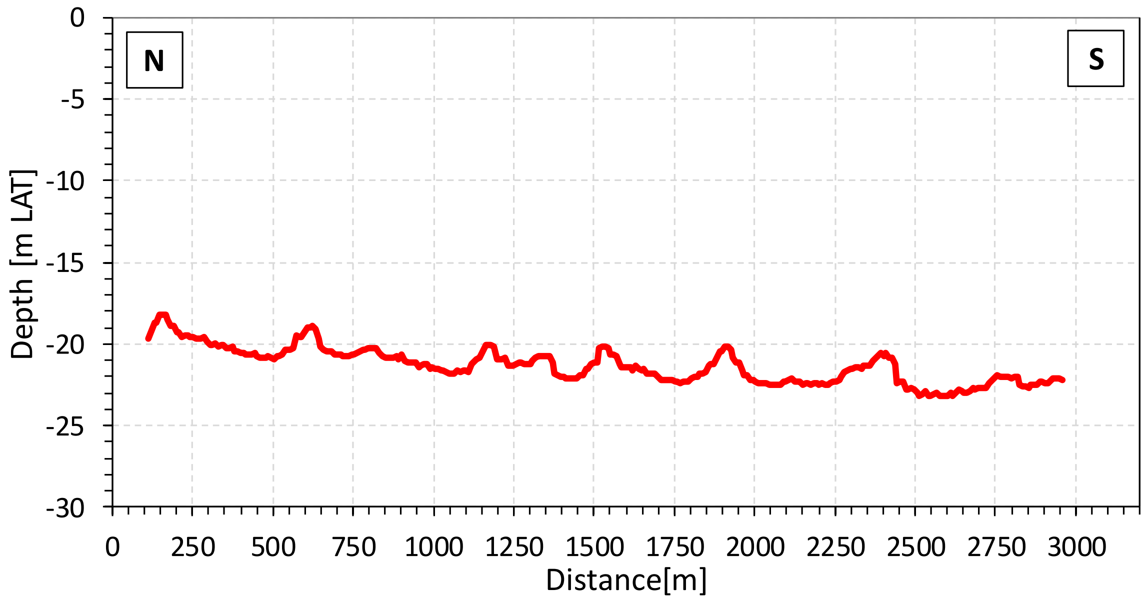


Figure 4-16 Profile D

4.2.3 Banks

The Bray and Kish Banks form the central part of the main site, while the Frazer Bank is found in the western part of the Export Cable route to Shanganagh (Figure 4-8 and Figure 4-17).

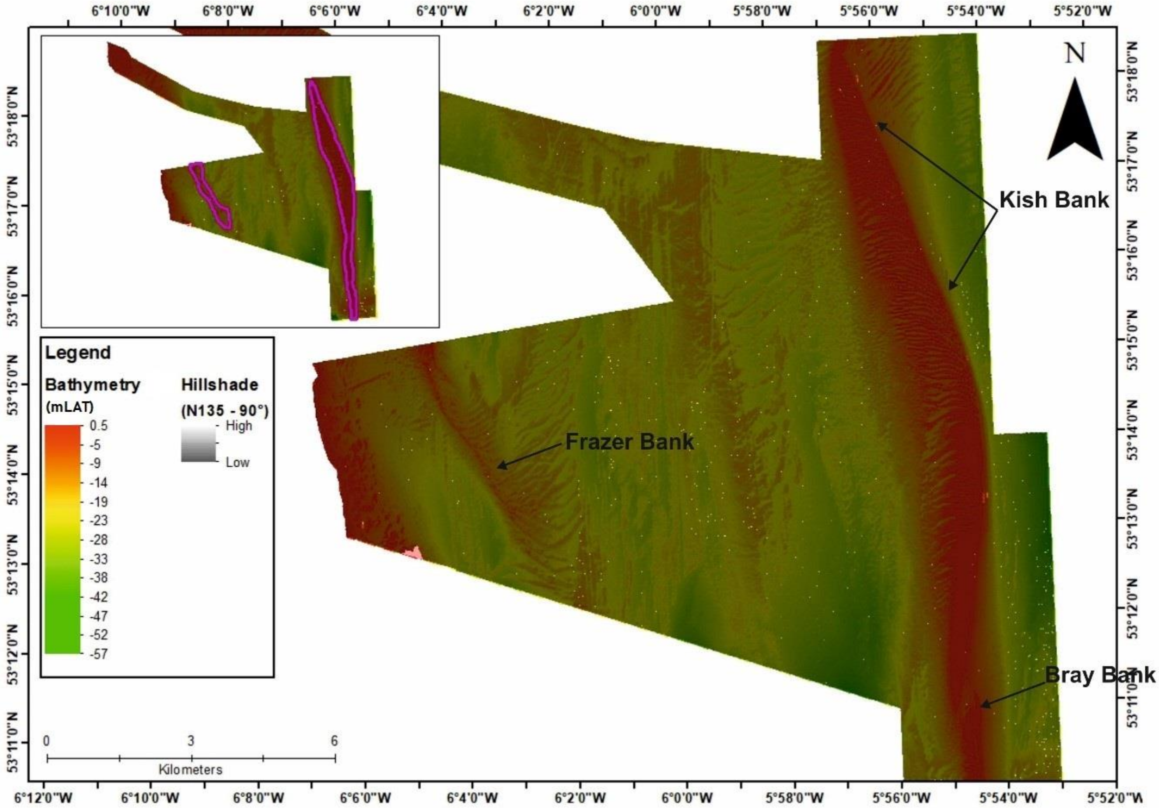


Figure 4-17 Sediment banks at Dublin Array site

4.2.4 Anthropogenic Impacts

Anthropogenic constraints such as known pipelines, cables and shipwrecks were mapped to identify any constraints at the site. No pipelines were found to cross the site although an underwater cable transects part of the northern area of the cable route to Poolbeg (Figure 4-18).

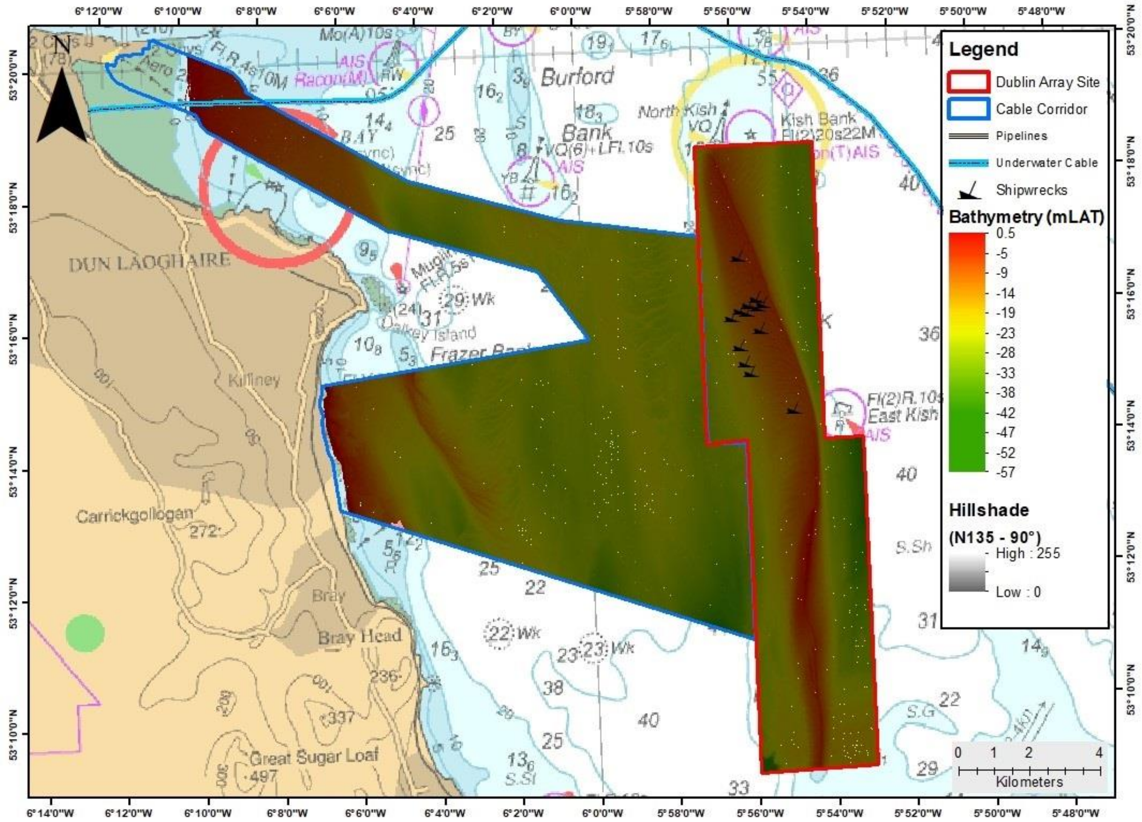


Figure 4-18 Anthropogenic constraints at the Dublin Array site

Based on the INFOMAR, the National Monuments Service (NMS)/Wreck Inventory of Ireland Database (WIID) and wrecksite.eu databases, 41 shipwrecks have been recorded at the site, primarily near the crest of the bank where water depth is shallowest (Figure 4-19). A zone extending 500m outside of the array area was taken to ensure two shipwrecks close to the site limits were included in this analysis. Details of each wreck have been compiled and can be found in Appendix B.

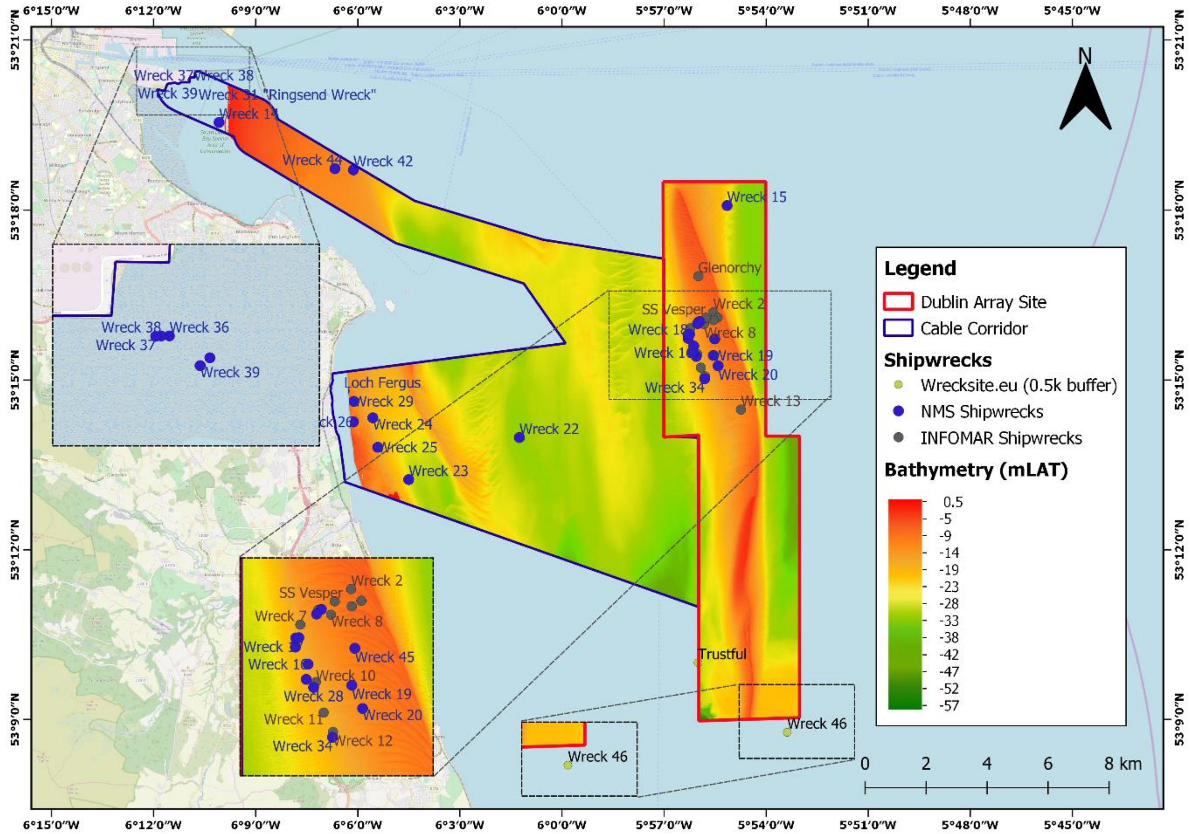


Figure 4-19 Shipwrecks at Dublin Array site

4.2.5 Profiles and Seabed Changes: Comparative Study between INFOMAR Data and 2008 EIS

Bathymetric data collected by Hydrographic Surveys Ltd between June and September 2008 as part of the original Environmental Impact Statement (EIS) was provided to this project. This data covers the majority of the Dublin Array site with a narrow area within cable route to Shanganagh also covered. According to this data, water depth across the site varies from 2 to 51 m (LAT) approximately (Figure 4-20).

Compared to the INFOMAR data, which was gathered using multibeam echosounder (MBES) and gridded to approximately 5 m resolution, the 2008 EIS data was relatively coarse, gathered using a single-beam echosounder (SBES) and gridded to approximately 20 m resolution. As a result, the INFOMAR data not only has greater coverage, but is a better-resolved and more detailed dataset. Still, the comparison of different temporal datasets can provide preliminary insight into seabed morphological changes. It is important to remember, however, that given the fact that the collection source and resolution of both datasets is different there may well be discrepancies and overestimation in the comparison and so the results should be viewed with caution and considered as a preliminary, indicative comparison. The assessment can be further detailed and validated upon availability of future high-resolution bathymetry data. Another important point to mention here is that the INFOMAR dataset is a composite of temporally different datasets in itself, which further limits the accuracy of analysis of temporal seabed changes. In the area covered by EIS 2008 survey, several INFOMAR campaigns took place in years: 2008, 2009, 2010, 2012 and 2016. Initially, net changes in seabed change were analysed between the two datasets (Figure 4-21). Generally, it is observed that the top and eastern flank of the bank (Kish) that comprises the main part of the site has experienced net gain of sediment or deposition. By contrast, the western flank of the site has experienced net sediment loss or erosion. This is consistent with sediment waves on that part of the site, indicative of sediment mobility.

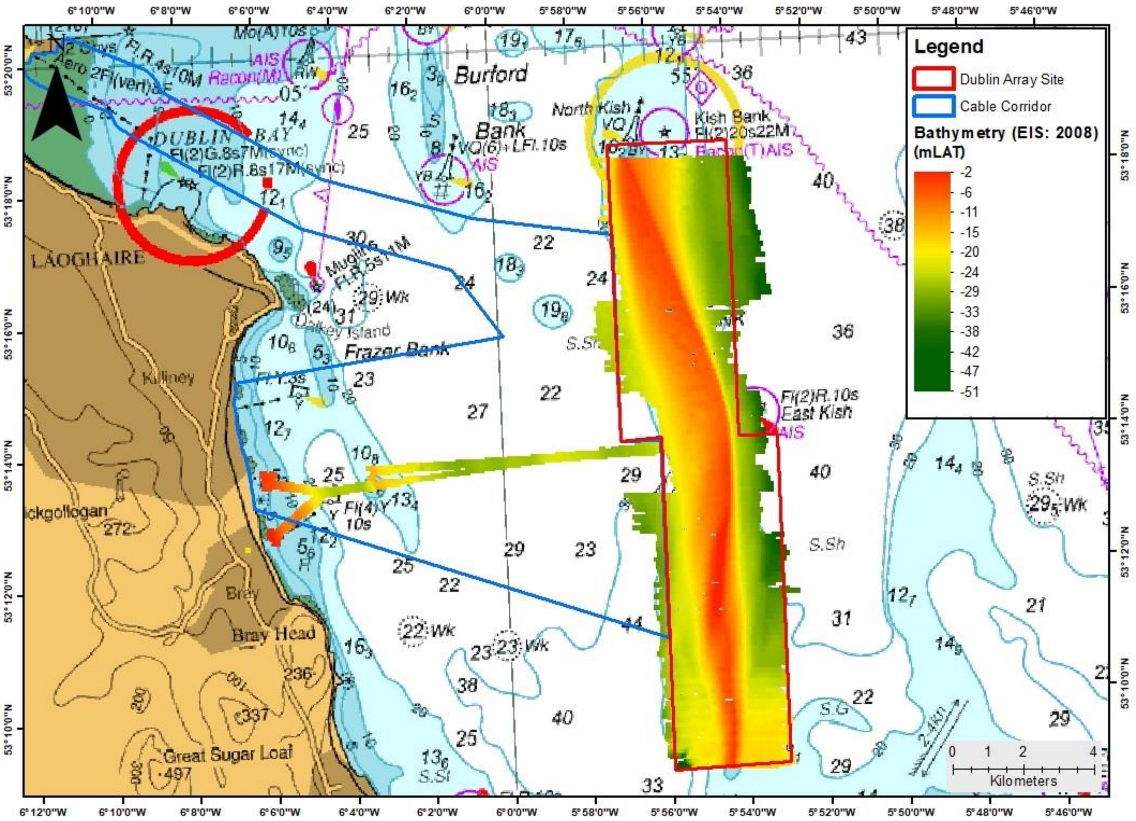


Figure 4-20 Bathymetry from Dublin Array Environmental Impact Statement (EIS: 2008)

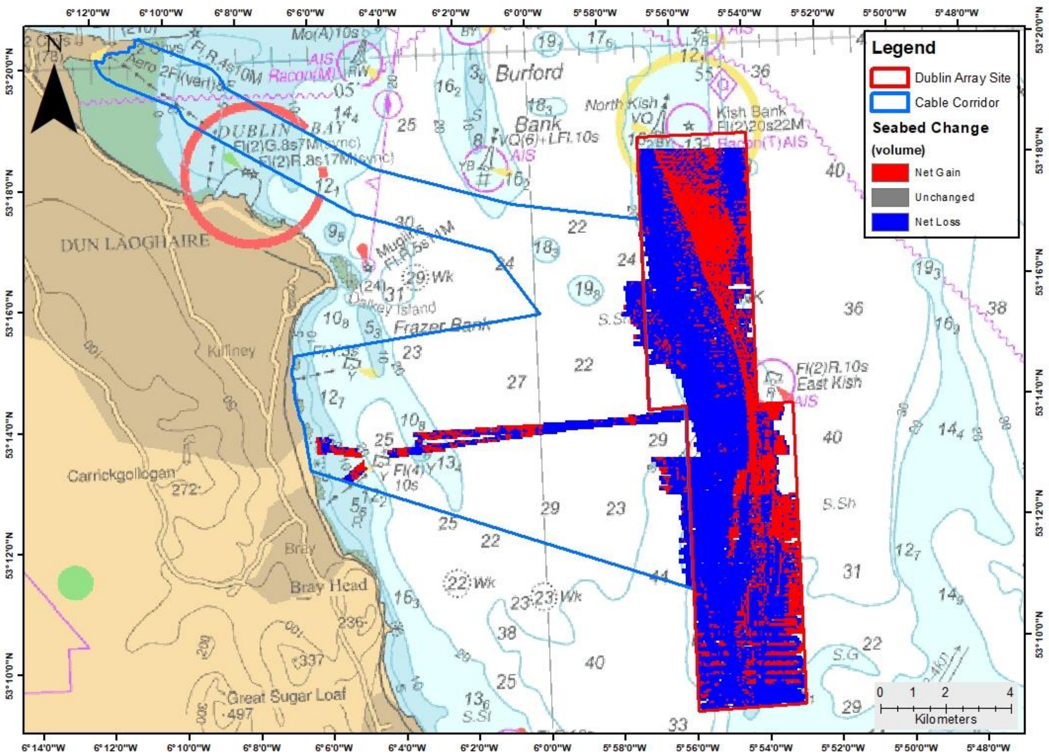


Figure 4-21 Volumetric change in the seabed at the Dublin Array site between the EIS and INFOMAR dataset

In addition to the seabed change data presented in Figure 4-21, five cross-sections were created along profile lines illustrated on Figure 4-22 to compare the INFOMAR and EIS 2008 bathymetry data (Figure 4-23 to Figure 4-27).

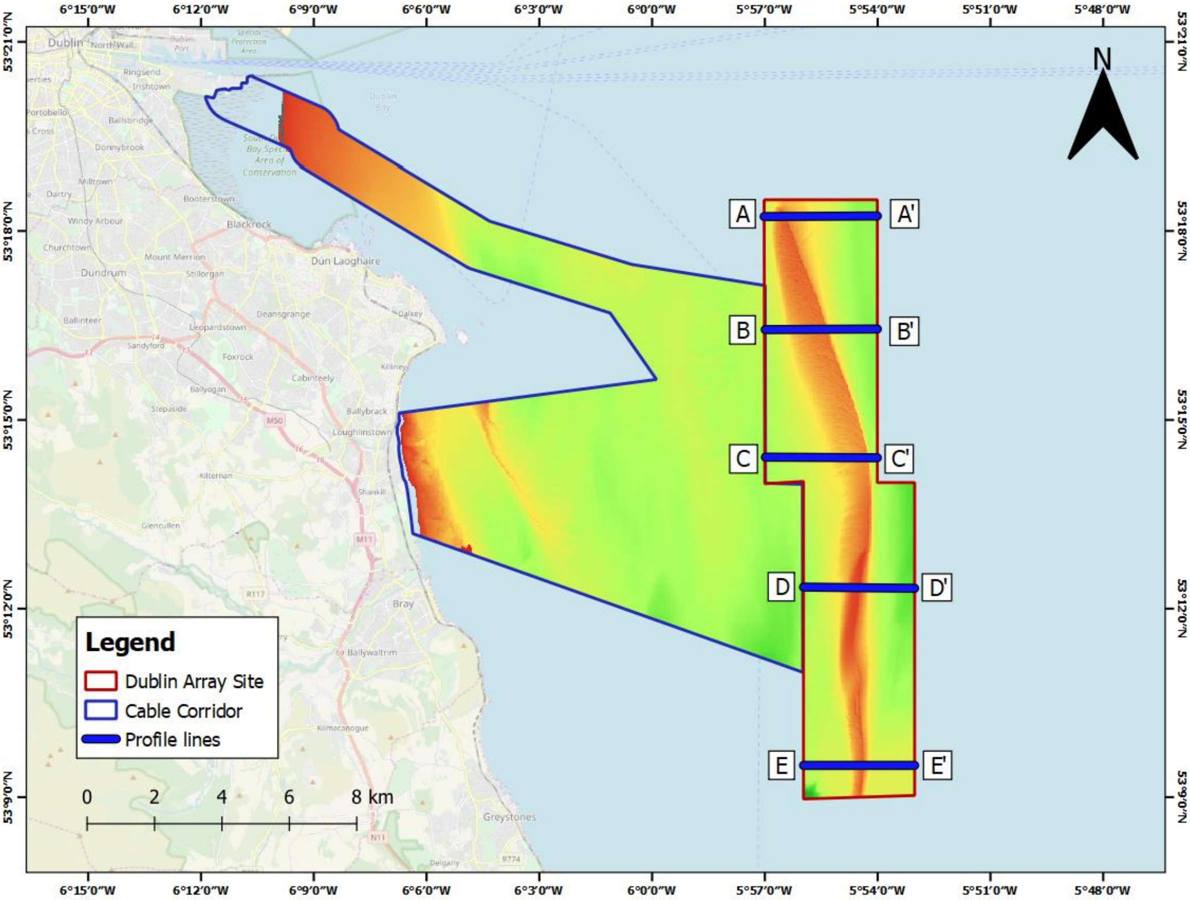


Figure 4-22 Location of profile lines presented as bathymetry cross sections below

Figure 4-23 Line A bathymetric profile with the INFOMAR 2008, 2009 and 2010data (orange) and 2008 EIS data (in blue). The year in which INFOMAR data was collected is shown at the bottom.

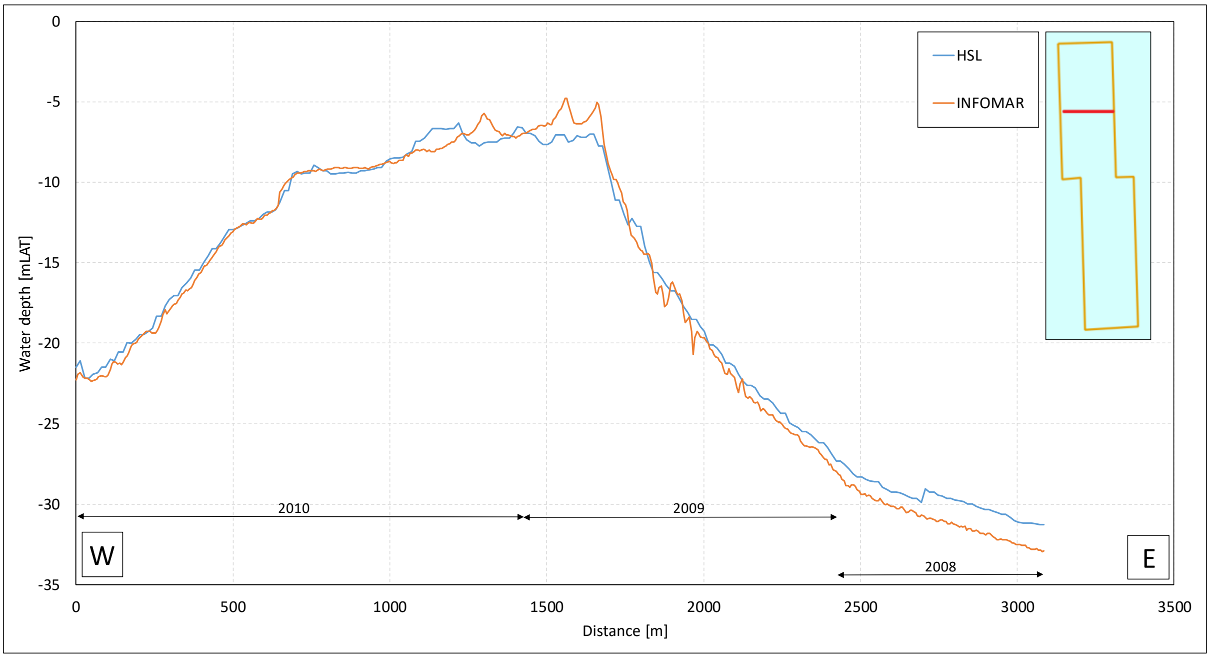


Figure 4-24 Line B bathymetric profile with the INFOMAR 2008, 2009 and 2010 data (orange) and 2008 EIS data (in blue). The year in which INFOMAR data was collected is shown at the bottom.

Figure 4-25 Line C bathymetric profile with the INFOMAR 2008, 2009 and 2010 data (orange) and 2008 EIS data (in blue). The year in which INFOMAR data was collected is shown at the bottom.

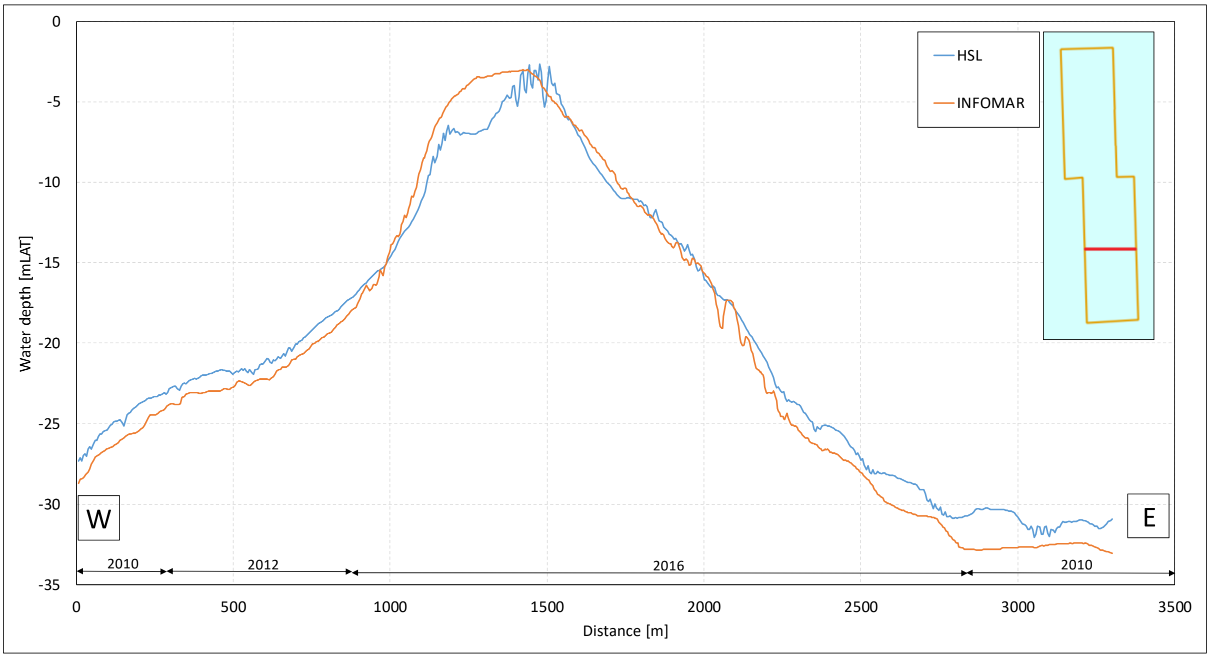


Figure 4-26 Line D bathymetric profile with the INFOMAR 2010, 2012 and 2016 data (orange) and 2008 EIS data (in blue). The year in which INFOMAR data was collected is shown at the bottom.

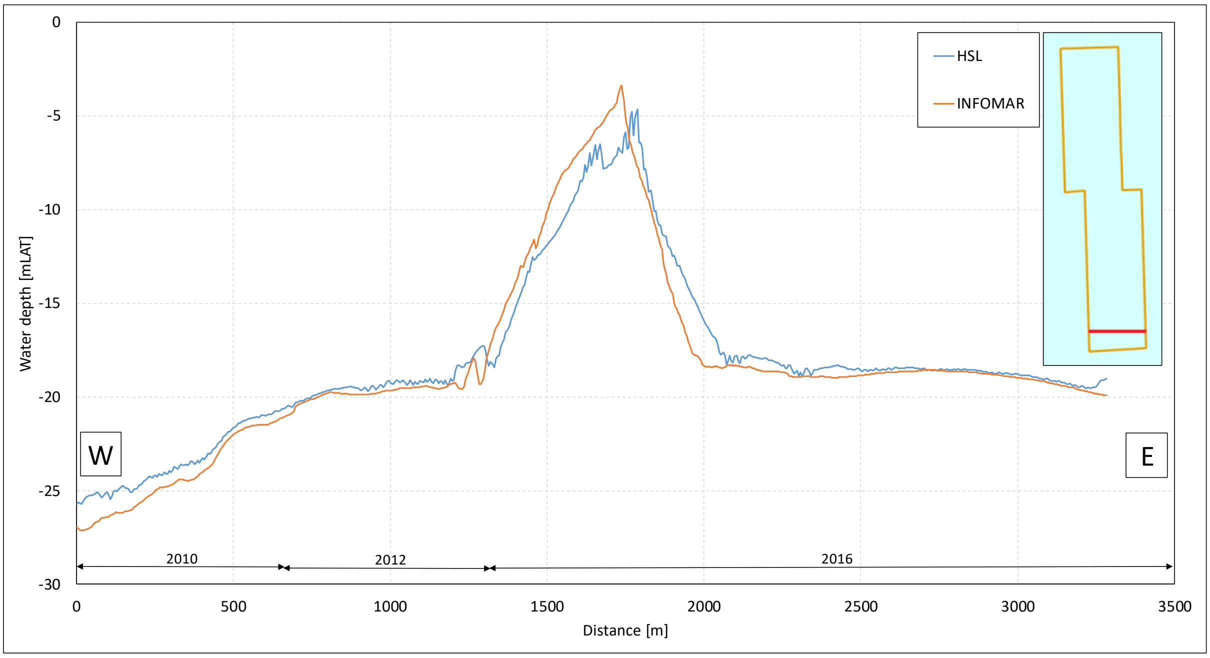


Figure 4-27 Line E bathymetric profile with the INFOMAR 2010, 2012 and 2016 data (orange) and 2008 EIS data (in blue). The year in which INFOMAR data was collected is shown at the bottom.

The majority of the INFOMAR data used to create the cross-sections comes from surveys conducted later than the HSL survey (2008). It is observed that during the period between the surveys the southern bank has shifted westwards – it is visible on the D and E profiles, while the northern part of the bank shifted eastwards or remained in the same place – it is visible on the A, B and C profiles. On either side of the bank the erosion of sediments is observed. Accumulation of the sediments is recognized at the top of the bank on profiles A, B, D and E (see Figure 4-23 to Figure 4-27).

4.3 Backscatter

Backscatter data coverage was available for the entire site and associated cable route except for a small area in the northwest corner of cable route to Poolbeg (Figure 4-28). The data suggests that the top of the bank is dominated by softer sediment, which comes coarser on the bank flanks, especially to the east. To the west, and along the cable corridor, there is a mosaic of sediment types which gradually become softer towards the shore.

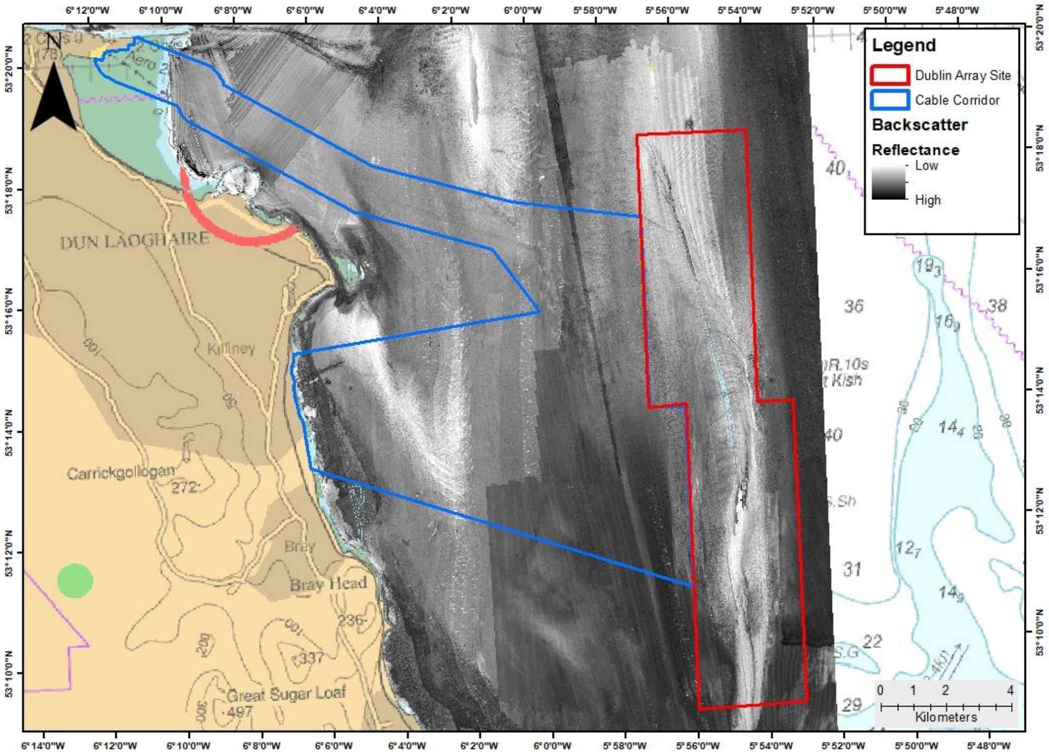


Figure 4-28 Backscatter values at the offshore wind farm site and export cable corridors

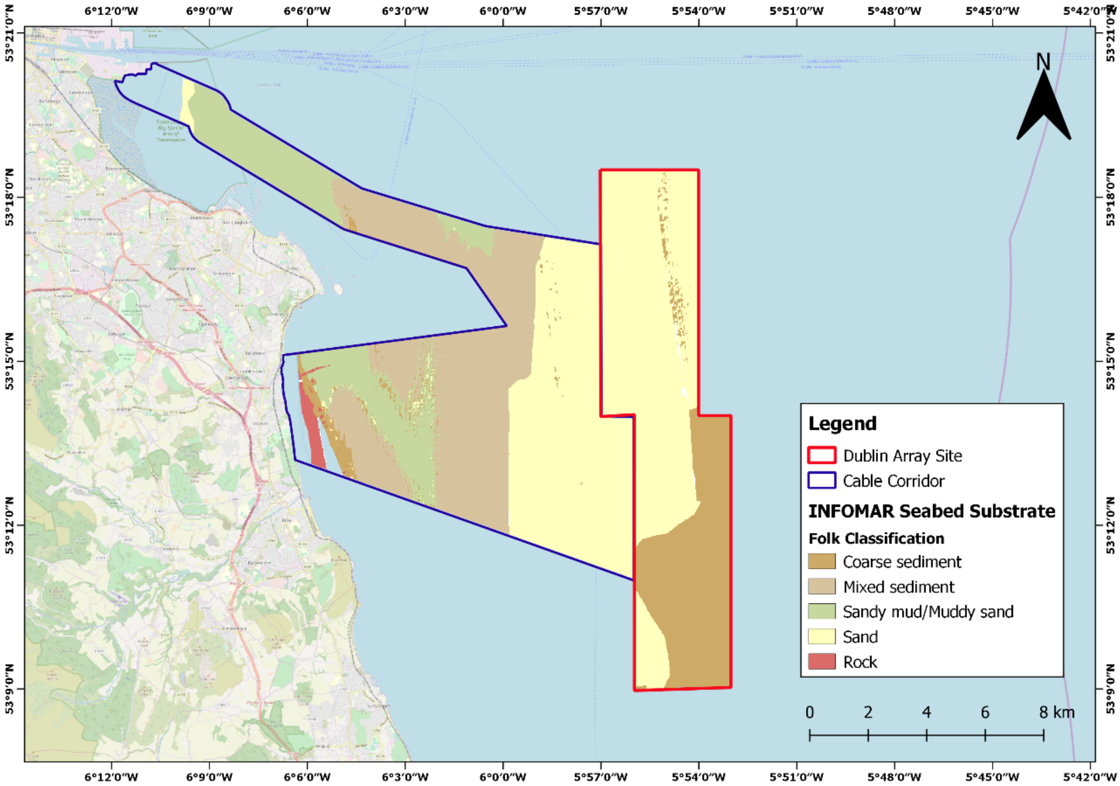


Figure 4-29 GSI QTC Sediment Classification for the Dublin Array site

The GSI, as part of the EMODnet project, have analysed this backscatter data using QTC Multiview software to provide a sediment classification division based on backscatter values, modified according to the Folk and Ward classification [20]. This classification is a broad, regionally indicative approach to sediment classification. The classification identifies sediments as: 1. Mud to muddy sand; 2. Sand; 3. Coarse substrate; 4. Mixed sediment, and; 5. Rock & Boulders. The Dublin Array site is dominated by sediment classed as Sand, with some coarse sediment found to the south of the bank (Figure 4-29). Closer to shore, along the cable corridor, the northern part (to Poolbeg) becomes more dominated by mud to muddy sand material. To the south of the cable corridor (to Shanganagh), closer to shore there are instances of coarse sediments and potentially rock exposure (Figure 4-29).

4.3.1 Grab samples

There are very few ground samples with which to ground truth these data. In total 34 grab samples across the site and cable corridor were found, mainly concentrated in the central part of the cable corridor to Shanganagh (Figure 4-30 and Figure 4-31). Of these 34 samples, 11 samples were graded as Gravelly Sand (41%) which corresponds well with the inferred substrate from backscatter and sediment classification. Areas of coarse substrate and rock close to shore on the southern part of the cable corridor (to Shanganagh) are classified as Sand or had No Recovery according to grab samples, suggesting there may be a thin veneer of sand over a harder or coarser substrate in that area (Figure 4-30 and Figure 4-31). On the Bank itself, grab samples are dominated by Sand and Slightly Gravelly

Sand (Figure 4-30 and Figure 4-31). The sediment type analysis results can be seen in Appendix C, Table 7 and sample spatial distribution can be seen in Figure 4-32.

In addition, a set of grab samples were retrieved from the study 'Geological Appraisal of the Kish, Burford, Bray and Fraser Banks, Outer Dublin Bay Area', done by A. J. Wheeler, J. Walshe and G. D. Sutton in 2000 [23]. This study was done as part of the project 'Reconnaissance Assessment of Coastal Seabed Sand and Gravel Resources' whose objective was to fill a gap in the existing geological data pertinent to Irish offshore sand and gravel resources. There were 16 samples in total that fall inside Dublin Array and cable corridor site and these were mainly located in the northern part of the windfarm site. According to the report, the sampled sediment was mainly classified as sand, with some appearance of gravel. Sample numbers KB27, KB31-KB43 were dominated by sand; slightly gravelly sand appeared in several samples and muddy sand only within one sample. The sediment type analysis that is extracted from the mentioned study can be seen in Appendix C, Table 9 and sample spatial distribution can be seen in Figure 4-32.

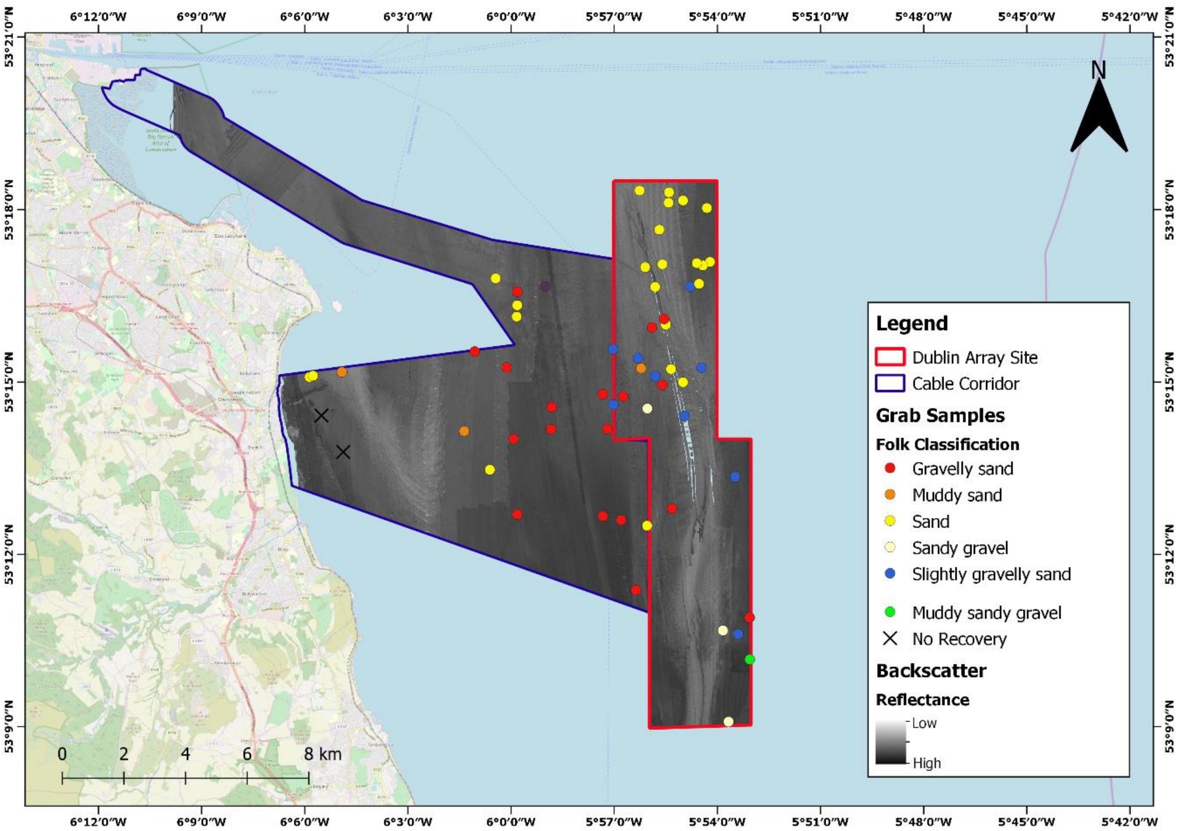


Figure 4-30 Grab samples used to ground-truth backscatter data

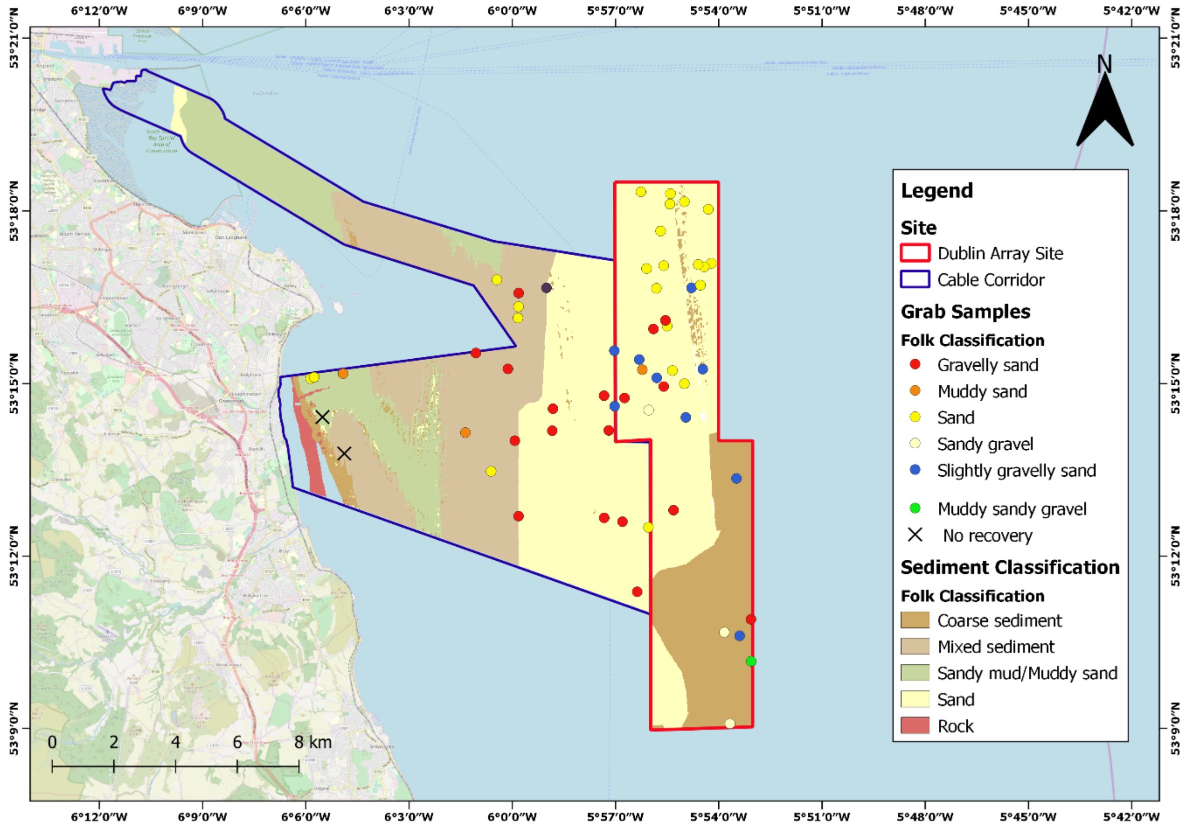


Figure 4-31 Grab Samples used to ground-truth QTC sediment classification

A set of grab samples were retrieved from the 2005 Benthic study for the Department of the Environment [22] (not used for ground truthing). The sediment sampled was classified as sand, ranging from medium to very fine sand. The majority of stations were dominated by fine sand (KB2, KB3, KB5, KB6, KB7 and KB8). Stations KB4, KB10 and KB11 were dominated by medium sand. Station KB10 contained the highest percentage of gravel (16.48%). Station KB4 contained the highest percentage of medium sand (55.34%). Station KB3 contained the highest percentage of fine sand (87.28%) and station KB6 contained the highest proportion of very fine sand (26.08%). The sediment type analysis results can be seen in Appendix C and the sample spatial distribution can be seen in Figure 4-32.

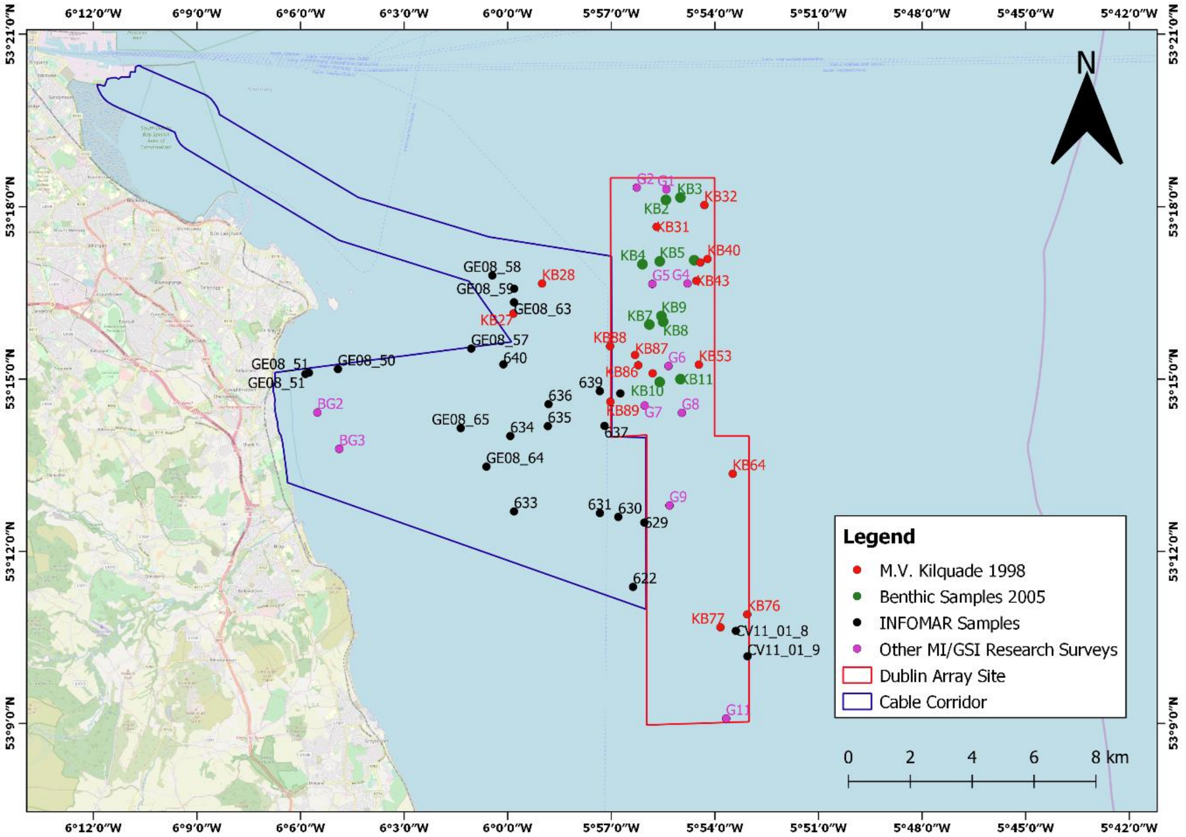


Figure 4-32 - Sample groups and names within the OWF and proposed EC areas

4.3.2 Faunal Assemblage

Faunal analysis was carried out on the Non-INFOMAR samples and the 2005 Benthic survey data sets (Figure 4-33) [6].

Univariate statistical analyses were carried out on 2005 benthic survey faunal data. The following parameters were calculated and can be seen in Table 5; species numbers, number of individuals, richness, evenness and diversity. Species numbers ranged from 13 (KB1) to 49 (KB12). Number of individuals ranged from 51 (KB1) to 351 (KB12). Richness ranged from 3.05 (KB1) to 8.19 (KB12). Evenness ranged from 0.69 (KB3) to 0.91(KB10). Diversity ranged from 1.91 (KB3) to 2.89 (KB12).

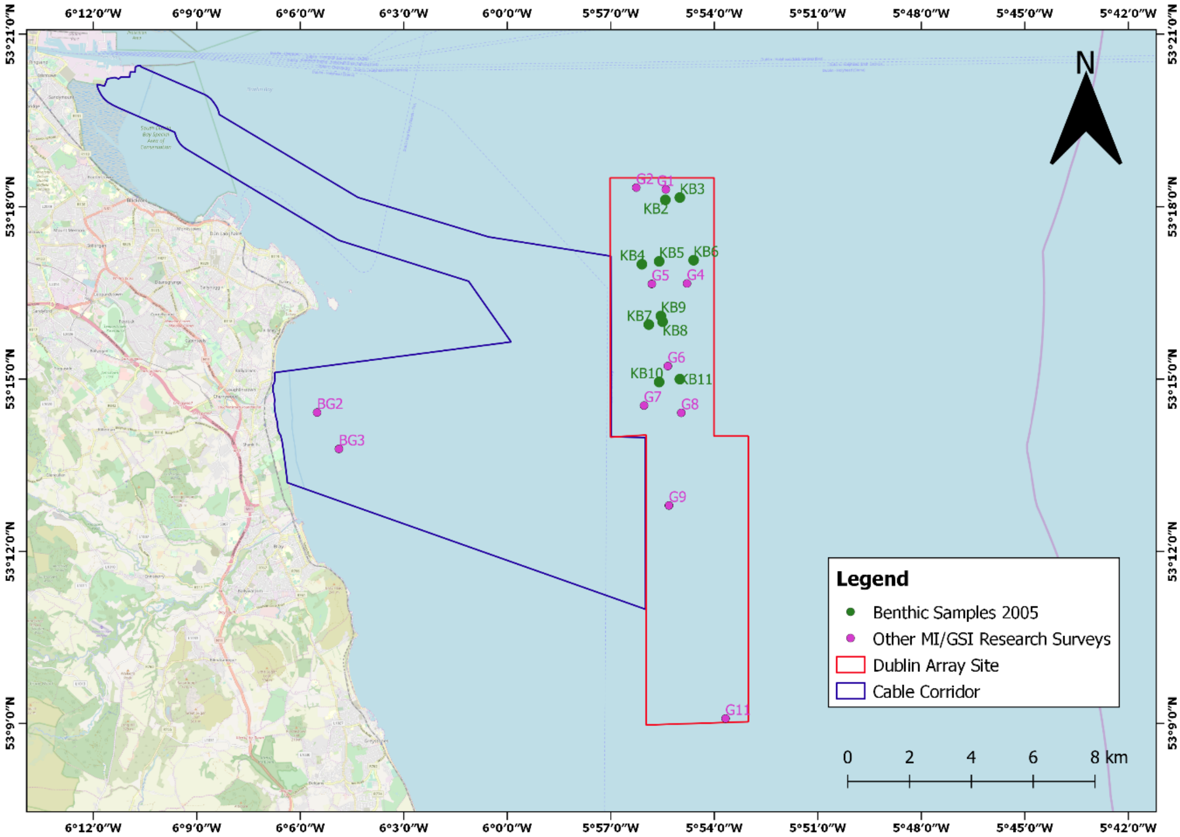


Figure 4-33 - Faunal analysis locations on Non-INFOMAR and 2005 Benthic survey data sets

Table 5 - 2005 Benthic Survey Results

Station	Species	Individuals	Richness	Evenness	Diversity
KB1	13	51	3.05	0.82	2.12
KB2	37	203	6.78	0.76	2.76
KB3	16	115	3.16	0.69	1.91
KB4	27	86	5.84	0.82	2.71
KB5	24	148	4.6	0.71	2.24
KB6	27	89	5.79	0.83	2.74
KB7	22	121	4.38	0.86	2.66
KB8	16	91	3.33	0.8	2.23
KB9	20	80	4.34	0.85	2.54
KB10	17	67	3.81	0.91	2.57
KB11	22	88	4.69	0.83	2.57
KB12	49	351	8.19	0.74	2.89

Non-INFOMAR grab samples show the number of species encountered range from 1 to 63. The most prevalent habitat classes are SS.SSa.IFiSa.NcirBat *Nephtys cirrosa* and *Bathyporeia* spp. in infralittoral sand, see Appendix C for details.

5 Magnetometer

Magnetometer data relevant for the site was collected during INFOMAR 2008 and 2010 surveys. These campaigns offer only a very sparse coverage of the site and cable route. They cover approximately 18.5% of the site and 8.5% of the cable route within the route to Shanganagh (Figure 5-1).

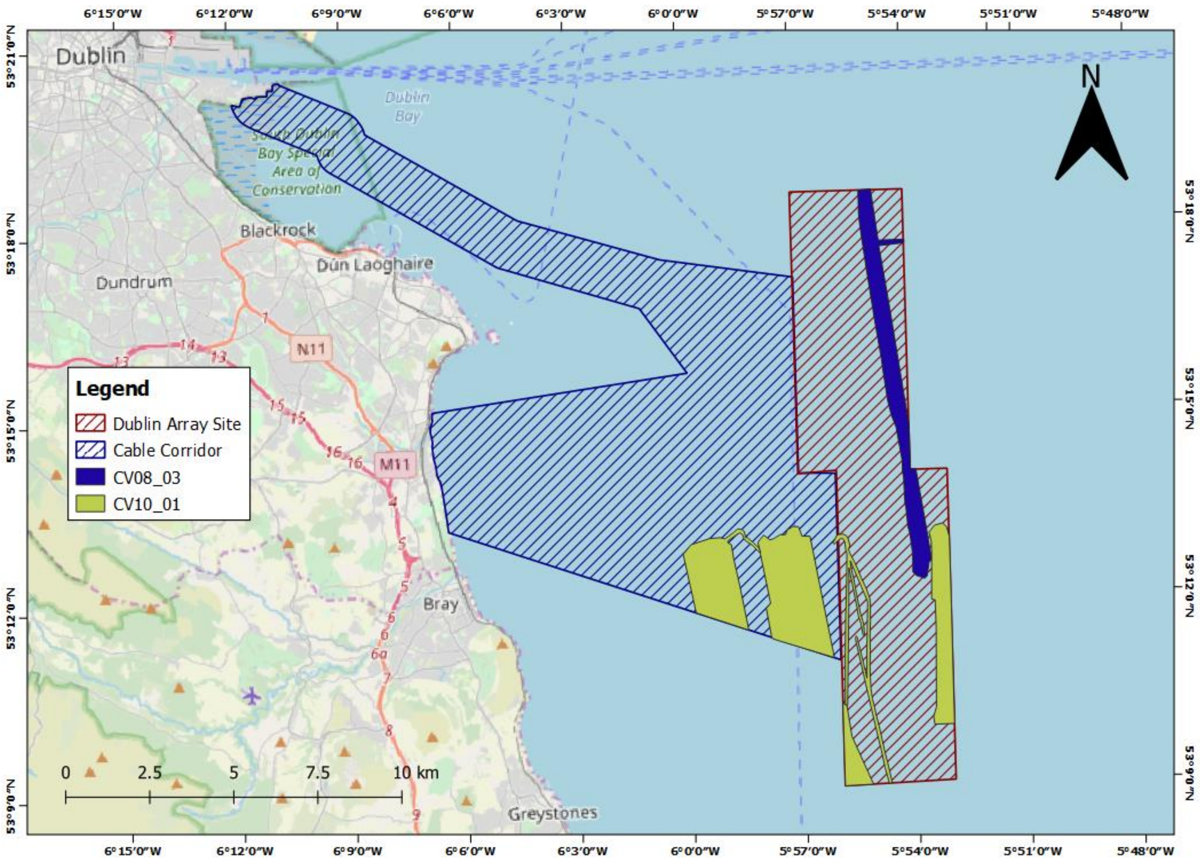


Figure 5-1 Magnetometer data site coverage

The sparse coverage of the surveys relevant to the site makes interpretation of the full site impossible. From the limited data available one linear anomaly appears in the southern part of the cable route to Shanganagh (Figure 5-2), which needs to be verified using future detailed magnetometer surveys. It should be noted that changes in total magnetic field values between different areas of the site can be attributed to changes in surface geology.

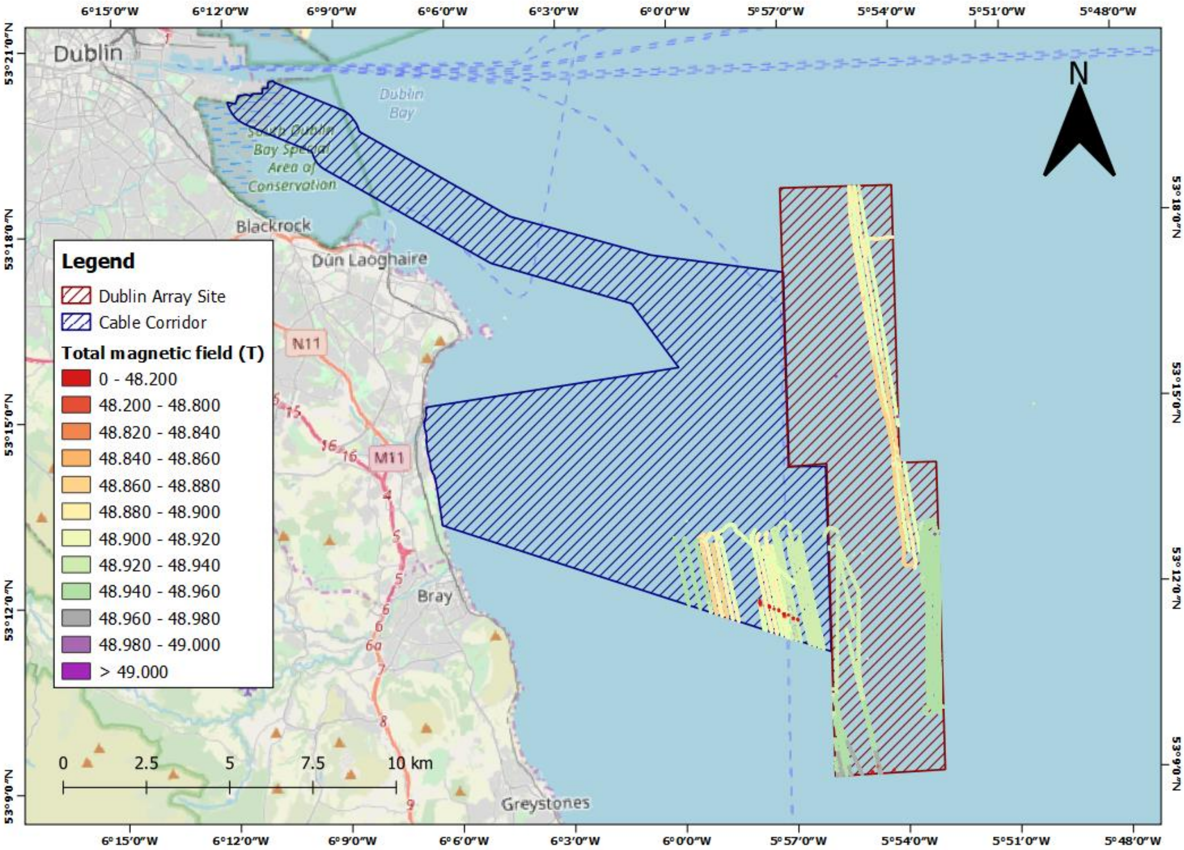


Figure 5-2 Magnetics map with total field data

6 Sub Bottom Profile (SBP) Data – INFOMAR Campaign

This section will outline the SBP interpretation process. As discussed in Section 3, this site was surveyed in 2003, 2008, 2009, 2010 and 2012 as part of the INSS and INFOMAR projects (Figure 3-6). Available geophysical lines for each survey leg were reviewed and a group of lines has been selected for processing and interpretation for every survey year as shown in Figure 6-1.

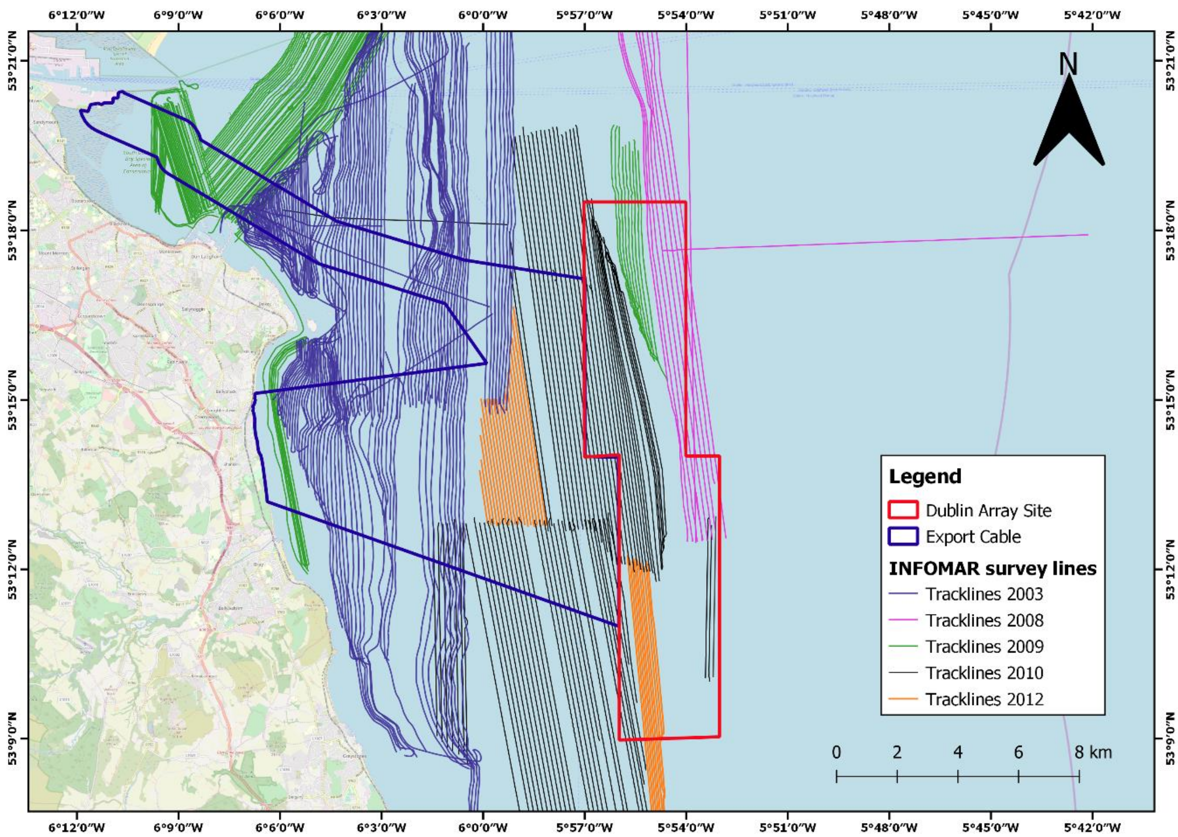


Figure 6-1 Overview of processed lines from all relevant datasets

It is worth noting that due to the shallow water near the crest of the banks, it is difficult for the survey boats to transit these parts of the site and as a result there are significant data gaps in the shallows.

6.1 Discussion on Data quality

A common issue across most of the datasets where the seabed shoals is the presence of shallow multiples on the seismic records. This frequently appears higher up in the record than the base of the uppermost unit (Unit 1), making it very difficult (or sometimes impossible) to track this horizon through the site. Acoustic blanking was also frequently observed within the uppermost unit with associated enhanced reflectors. The acoustic blanking appears to migrate from the base of the uppermost unit and is trapped at laminations present within this unit. For further discussion regarding possible nature of the acoustic blanking please refer to Section 7.2. It is worth noting that acoustic blanking was identified across the centre of both Export Cable corridors to Shanganagh and Poolbeg, as well as, on the northeast flank of the Kish Bank. This accounts for over 21.7% of the site area (including the offshore wind farm site and export cable corridors). A brief discussion of the quality of different sub-bottom datasets is provided below, and issues that arose during the processing and interpretation of the data are highlighted.

- **CV03_01:** This dataset provided most of the on-site geophysical data coverage and the data quality was typically good, although there were some minor weather effects (aeration) observed throughout. Generally, it was possible to distinguish the laminations in Unit 1 (uppermost unit) and, where the overlying sediment type and thickness permitted, the base of Unit 3 (the deepest resolved unit). The main issues that affected this dataset were the presence of acoustic blanking and attenuation of the pinger signal over the Frazer Bank, where the overlying sediments tend to become thicker. Furthermore, some of the lines within the dataset had time shift issues, which needed to be corrected as interpretation was ongoing. Line spacing for this dataset varies between 40m and 270m approximately.

- **CV08_03**: Eleven lines from this dataset run in the northeast area of the wind farm site in the area of the Kish Bank. Data quality was generally good with only minor weather affects (aeration) observed. However, as the lines approached the bank and the overlying sediments began to thicken it became difficult to identify the base of sub-bottom units. Also acoustic blanking caused issues in identifying the base of the uppermost unit. Line spacing for this dataset varies between 100m and 170m approximately.

- **KRY09_02**: The majority of the lines in this dataset run on the nearshore section of the proposed Export Cable route to Poolbeg, with six more lines running on the nearshore section of the proposed Export Cable route to Shanganagh and nine lines running on the northeast slope of the Kish Bank. Most lines have a lot of interference on the data extending from the bottom of the record to above the multiple, affecting the data quality. However, on the lines running in the nearshore areas, it is generally possible to delineate sub-bottom units. Whereas on the nine lines on the northeast of the Kish Bank slope, it was not possible to identify the base of any units due to the thickness of the overlying sediments. Line spacing for this dataset varies between 40m and 100m approximately.

- **CV10_01**: Data quality was generally good with only some weather affects (aeration) and acoustic blanking masking reflectors below. Line spacing for this dataset is approximately 150m.

- **KRY10-01**: The majority of these lines run over the Kish Bank. The data quality is poor and there is a lot of interference on the data, extending from the bottom of the record to above the multiple. Also as the thickness of Unit 1 increases on the Kish Bank, attenuation of the signal is quite common which affects the penetration of the signal, making delineation of sub-bottom horizons very difficult. The data quality of this dataset meant it was not possible to reliably pick any horizons from it. Also there were Time Increment issues on some lines where the increment was set to twice the normal value and these needed to be individually corrected. Line spacing for this dataset is approximately 150m.

- **CV12_02:** The first part of this dataset was recorded in the southeast of the site over the Bray Bank. Data quality was generally good with some weather noise (aeration) present on the data. However as overlying sediments thickened over the bank it became impossible to delineate the base of the upper unit. The second part of this dataset was recorded in the centre of the survey area, on the western flank of the Kish Bank. Data quality was generally good with some weather affects (aeration) observed. As observed previously, as the sediments in the upper unit thickened approaching the bank slope, attenuation of the signal resulted in the base of the unit becoming indistinguishable. Acoustic blanking masking underlying units was also an issue. Line spacing for this dataset varies between 70m and 100m approximately.

6.2 Initial assessment of SBP and MBES data

Initially, a select number of representative seismic lines from across the site were reviewed and compared against existing multibeam (see Figure 6-2), backscatter (see Figure 6-3) and sediment classification data (see Figure 6-4). The aim was to build an overall understanding of the sub-bottom conditions present on-site in order to enable an informed approach to the subsequent SBP interpretation to be prepared.

Geophysical lines near the shore on the southern cable route (to Shanganagh) showed a horizon approaching the seabed which is subsequently exposed at the seabed. This tied-in with evidence from the Backscatter and Multibeam data which appeared to show seabed sediments in the same area being composed of coarse sediments and potentially till/rock exposure.

Also the multibeam data showed areas of large sand banks in the east of the site. Sub bottom horizons at depth that are present beneath these banks were generally not delineated on the geophysical data due to the density of the material increasing on the banks which in turn impeded the depth of penetration by attenuating the acoustic signal. One explanation for this is that the sand layer making up the bank is sufficiently thick that the pinger SBP data could not penetrate to the depth of the first significant reflector – this implies the sand is reasonably thick.

From this initial assessment and comparison with existing multibeam and backscatter data, and background geology of the area, four sub-bottom units present across the site were delineated. Seismic profiles of the six representative survey lines are presented in Figure 6-5 to Figure 6-10. Distinguished units and their inferred unit boundaries, where observed, are highlighted. As interpretation of the geophysical data progressed, reference was constantly made to the multibeam and backscatter data, as well as the Sediment Classification Charts, to ensure consistency with existing data. It should be noted that additional geophysical survey data with an associated dedicated geotechnical sampling programme would be required to ground truth the geophysical interpretation presented here.

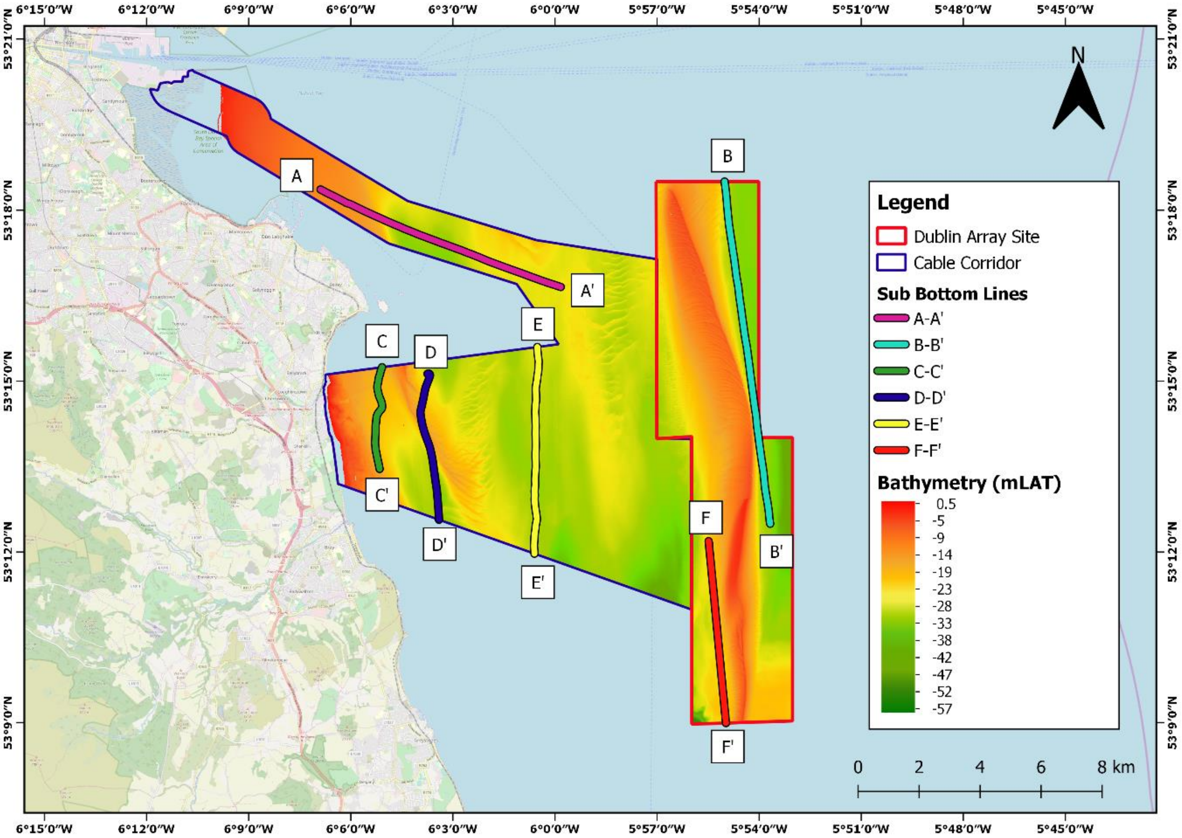


Figure 6-2 Bathymetry map displaying location of six representative lines on site.

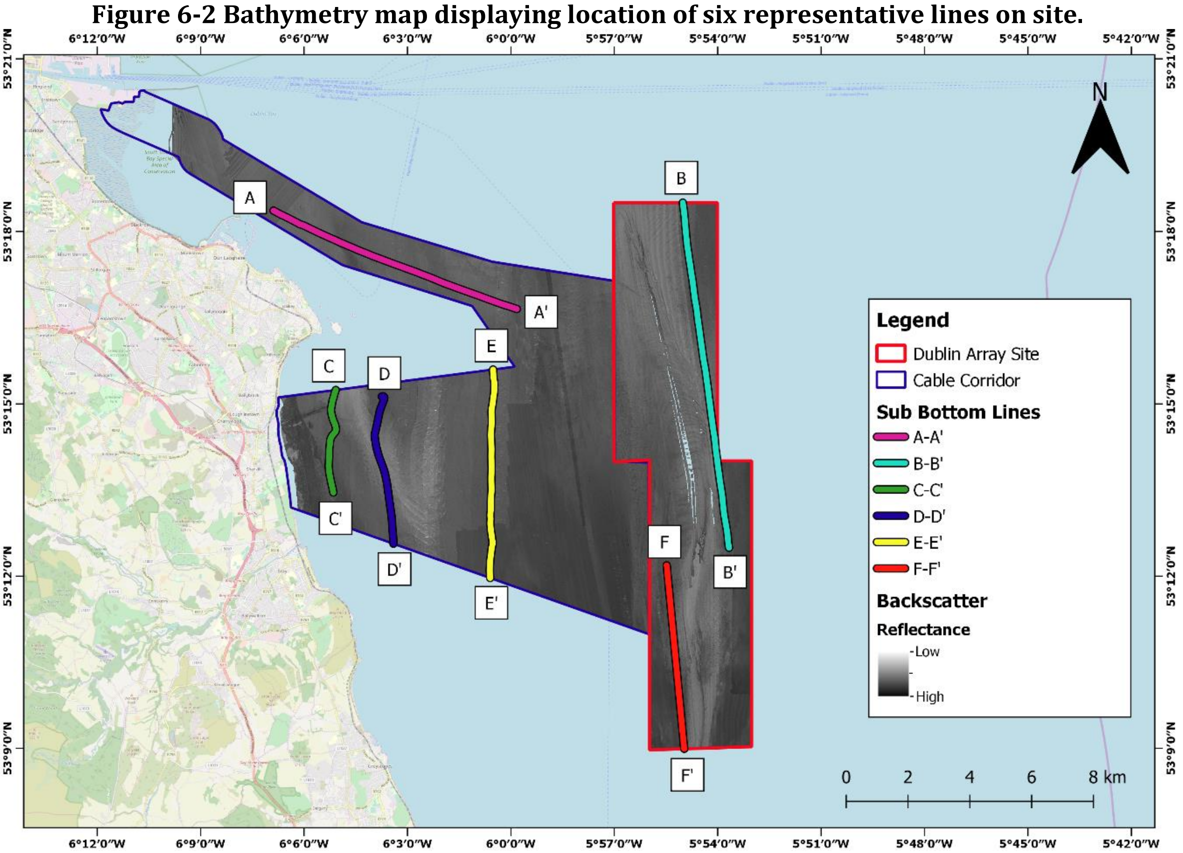


Figure 6-3 Backscatter map displaying location of six representative lines on site.

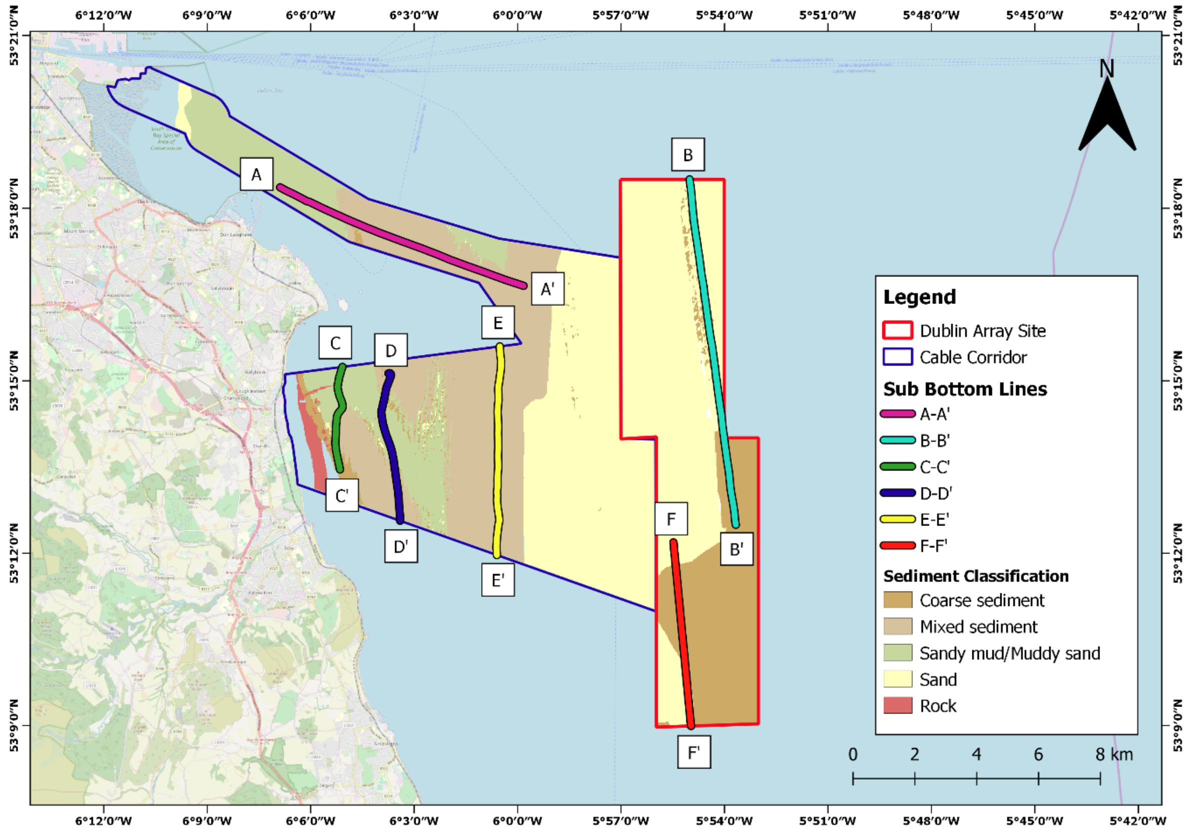


Figure 6-4 GSI QTC Sediment Classification Chart displaying location of six representative lines on site.

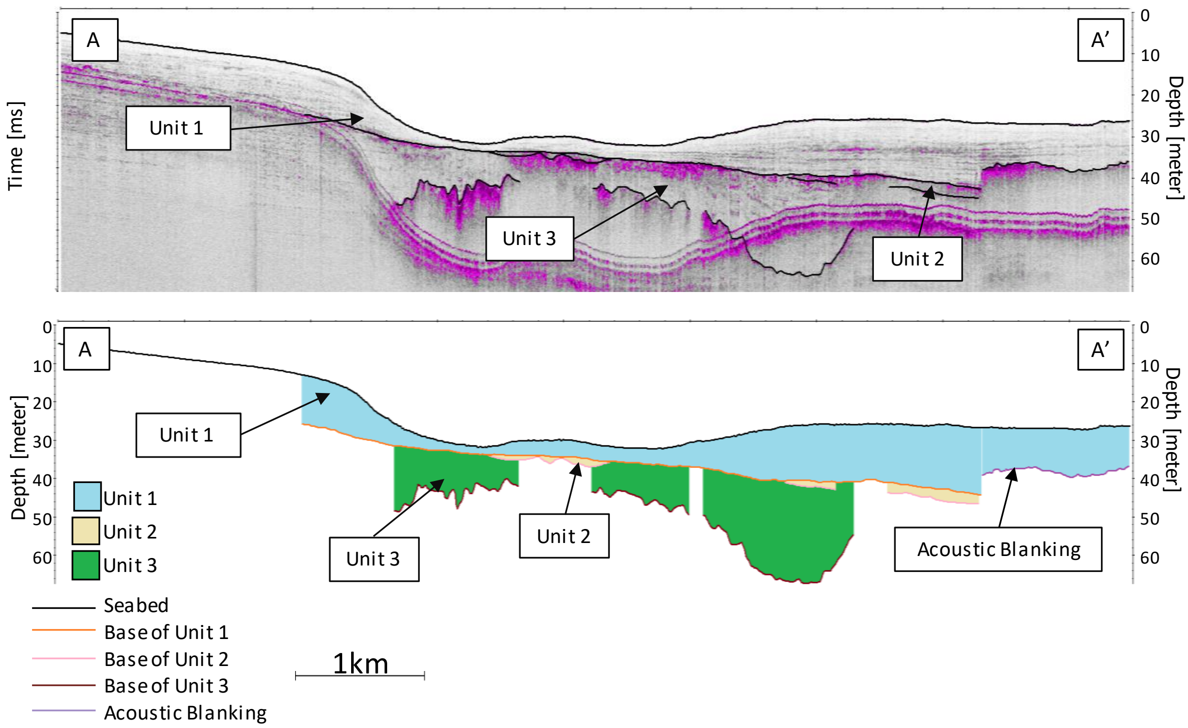


Figure 6-5 Line A to A'

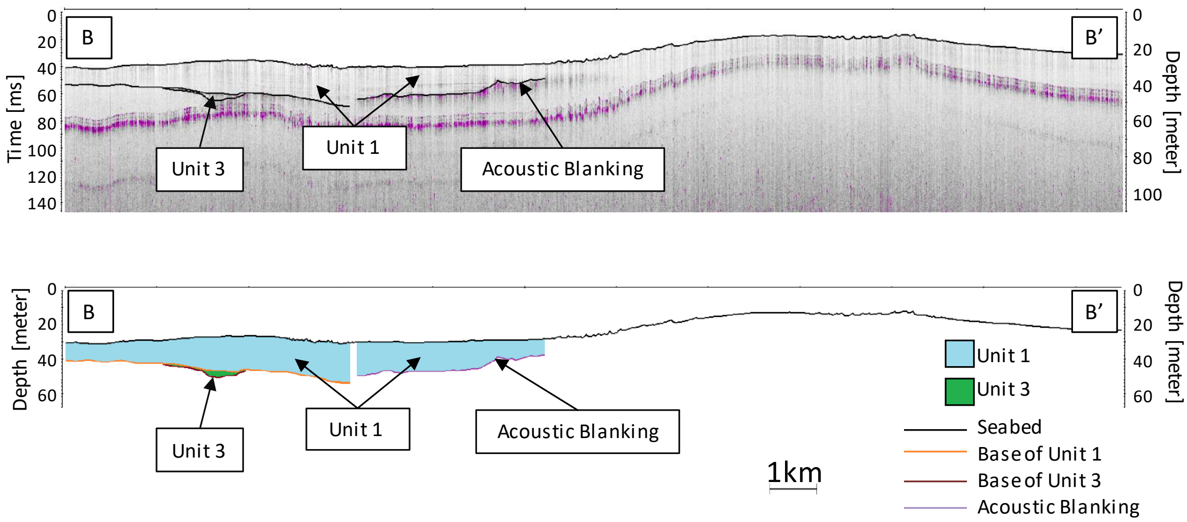


Figure 6-6 Line B to B'

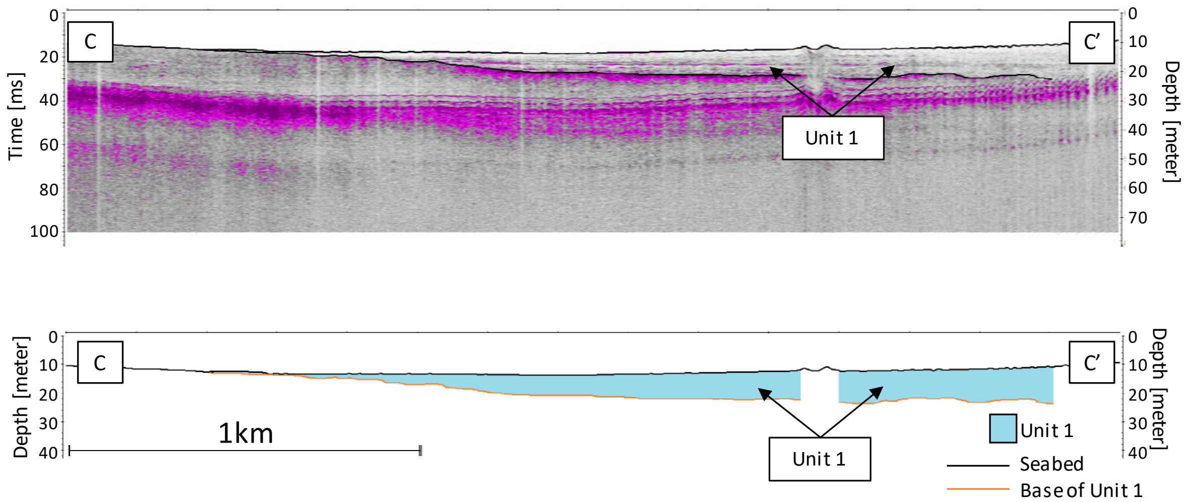


Figure 6-7 Line C to C'

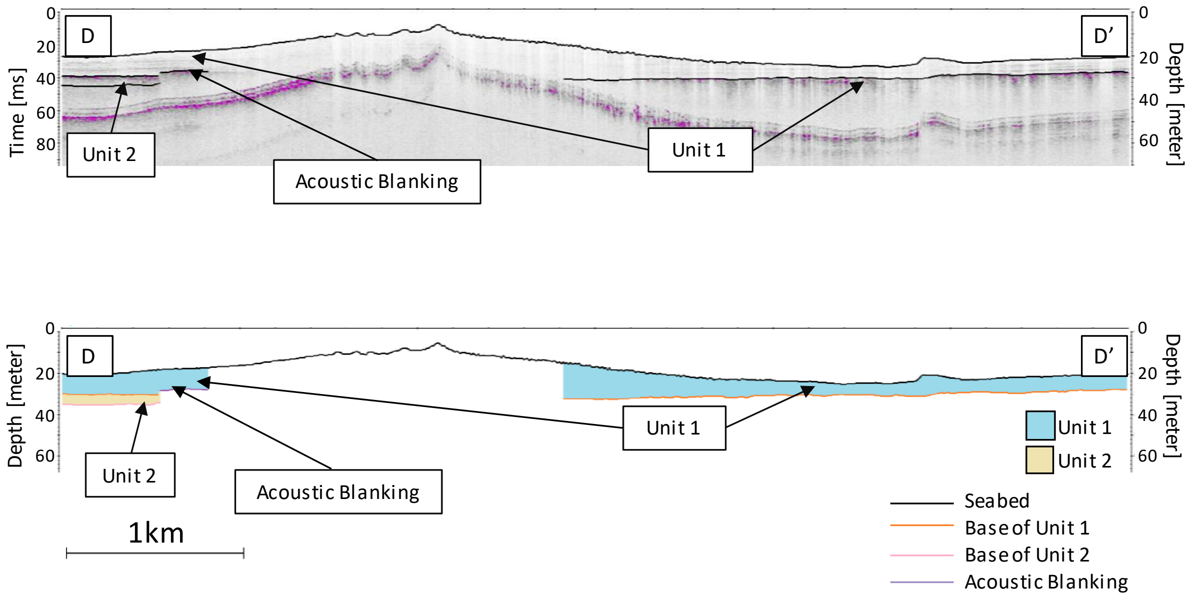


Figure 6-8 Line D to D'

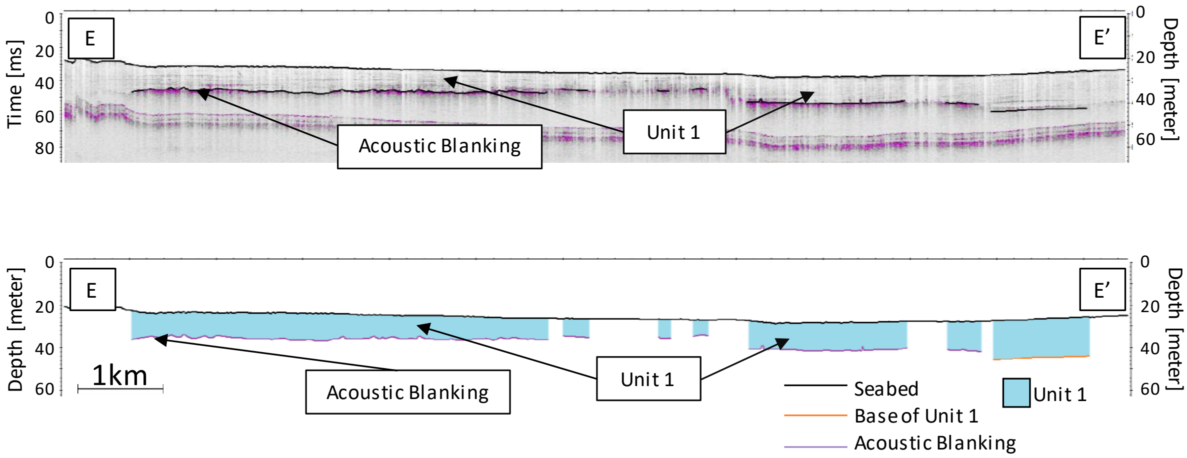


Figure 6-9 Line E to E'

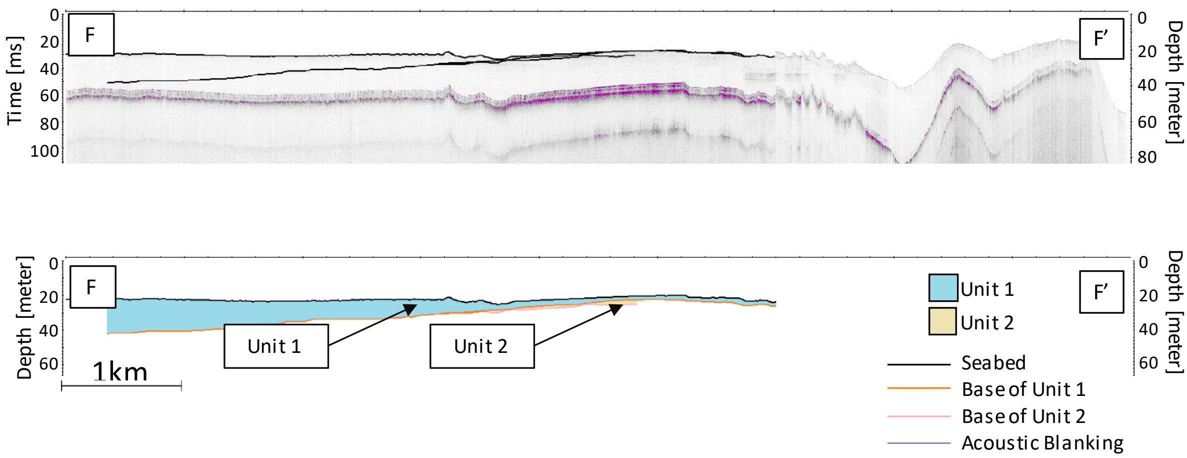


Figure 6-10 Line F to F'

6.3 SBP Interpretation

From the review, processing and interpretation of the pinger datasets, four main acoustic units were identified within the proposed offshore wind farm site and export cable corridors. These were labelled from surface to base as:

- Unit 1 (interpreted to comprise alternating laminations of clay and sand with occasional cobbles, shells and fine gravel)
- Unit 2 (interpreted to comprise fine grained sediments (muds to fine sands))
- Unit 3 (interpreted sandy deposits, occasionally layered)
- Acoustic Basement (possible top till/bedrock)

An assumed seismic velocity (ASV) of 1650m/s was used in the interpretation of the thickness of Units 1, 2 & 3.

6.3.1 Unit 1

This unit is the uppermost observed within the site and is generally a well layered unit interpreted to be comprised of alternating laminations of clay and sand with occasional cobbles, shells and fine gravel. However, as this unit thickens towards and beneath the three major banks onsite (i.e. the Kish, Bray and Frazer Banks), the laminations become harder to distinguish as does the base of the unit, due to attenuation of the signal. There may be an increased sand content and less laminations present in the shallow section beneath the banks. The base of Unit 1 is relatively flat except where it is in direct contact with the lowest distinguishable horizon on site (i.e. the acoustic basement interpreted as till/bedrock). Here the base of Unit 1 undulates due to the sharp, irregular nature of the top of the underlying unit. The base of Unit 1 (where resolved) is predominantly observed in the nearshore sections of the proposed export cable routes to Shanganagh or to Poolbeg, and also in the eastern and south western part of the proposed offshore wind farm site. The thickness of this unit ranges between 0 and 18.4m with an average thickness of 8m as shown in Figure 6-11. Unit 1 was observed over 21.12% of the combined offshore wind farm site and proposed export cable corridors.

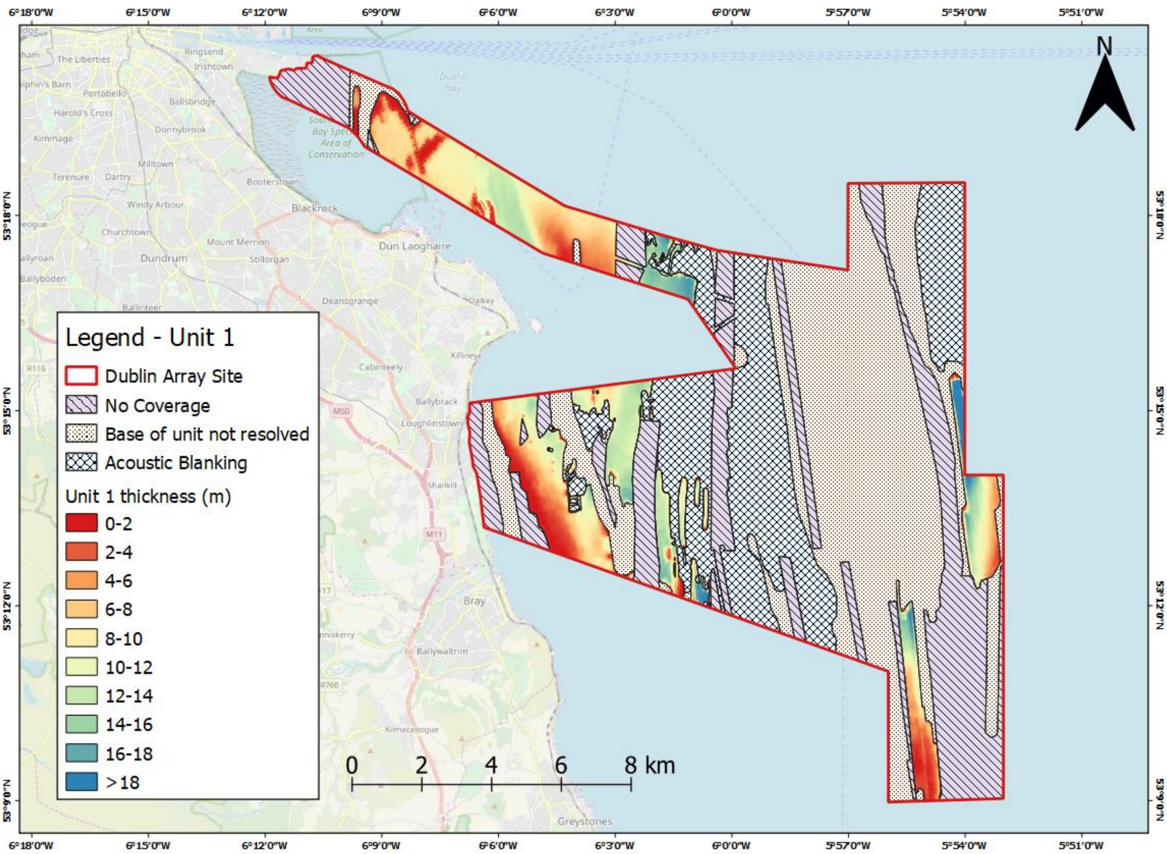


Figure 6-11 Isopach (thickness) map Unit 1

6.3.2 Unit 2

This unit is present intermittently across the site, frequently observed hanging from the base of Unit 1. It is interpreted to comprise acoustically transparent material, containing little internal structure. A preliminary interpretation suggests this unit is composed of fine grained sediments (muds to fine sands). The base of this unit (where resolved) was predominantly observed on the central section of the proposed export cable route to Poolbeg and the south of the proposed windfarm site, with a small area observed on the northern margin of the export cable route to Shanganagh. The thickness of this unit ranges between 0 and 18.1m with an average thickness of 1.5m as shown in Figure 6-12. Unit 2 is observed over 7.54% of the combined offshore wind farm site and export cable corridors.

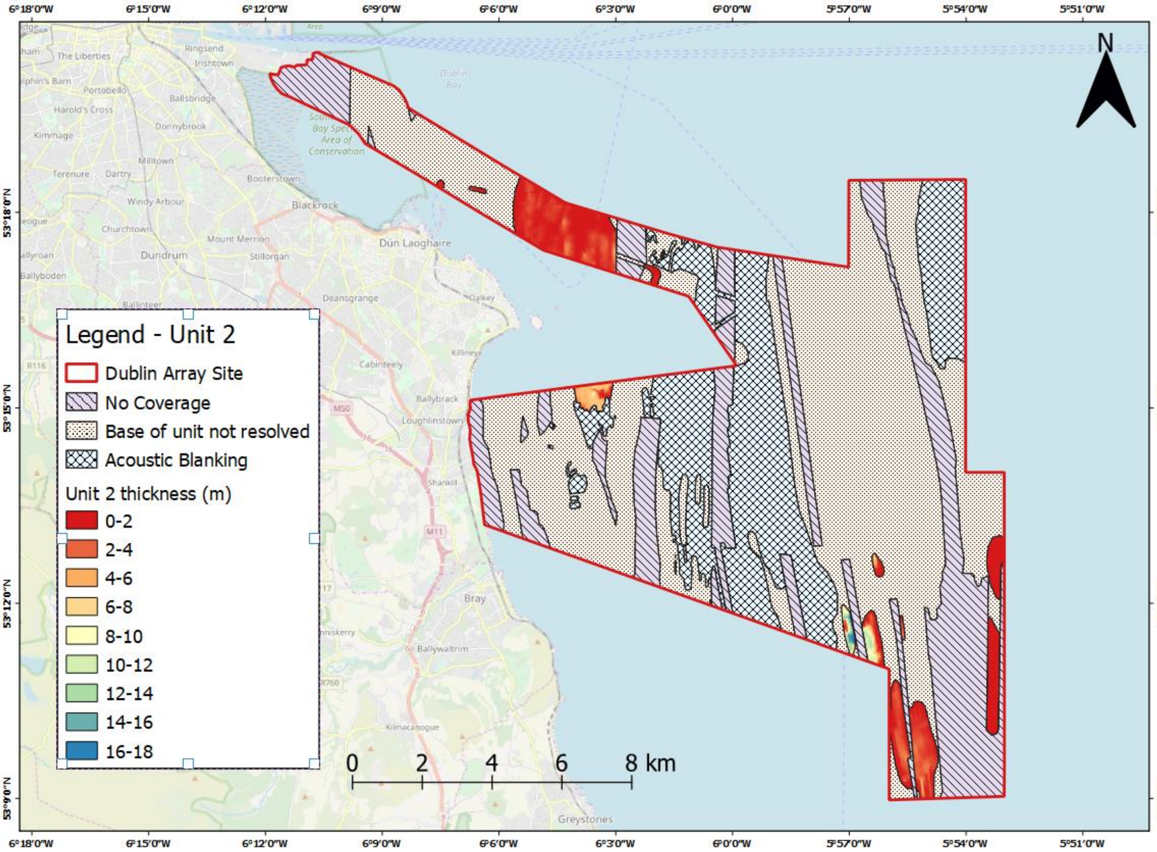


Figure 6-12 Isopach (thickness) map Unit 2

6.3.3 Unit 3

Unit 3 typically underlays Unit 1, with the interface between the two units marked by a strong boundary making it easy to differentiate them. Occasionally, it has a stratified signature with clear, sub-parallel, and laterally continuous reflectors. This type of acoustic characteristics could suggest layered sandy deposits that are consistent with the Prograding Facies of the Western Irish Sea Formation [1]. The contact between the base of Unit 3 and the acoustic basement below is unconformable; with Unit 3 typically infilling the sharp, irregular undulating top of the underlying layer interpreted till/bedrock. The base of Unit 3 (where resolved) is predominantly observed on central section of the proposed export cable route to Poolbeg and in the east of the offshore wind farm site. The thickness of this unit ranges between 0 and 33.1m with an average thickness of 4.5m as shown in Figure 6-13. Unit 3 is observed over 5.18% of the combined offshore wind farm site and proposed export cable corridors.

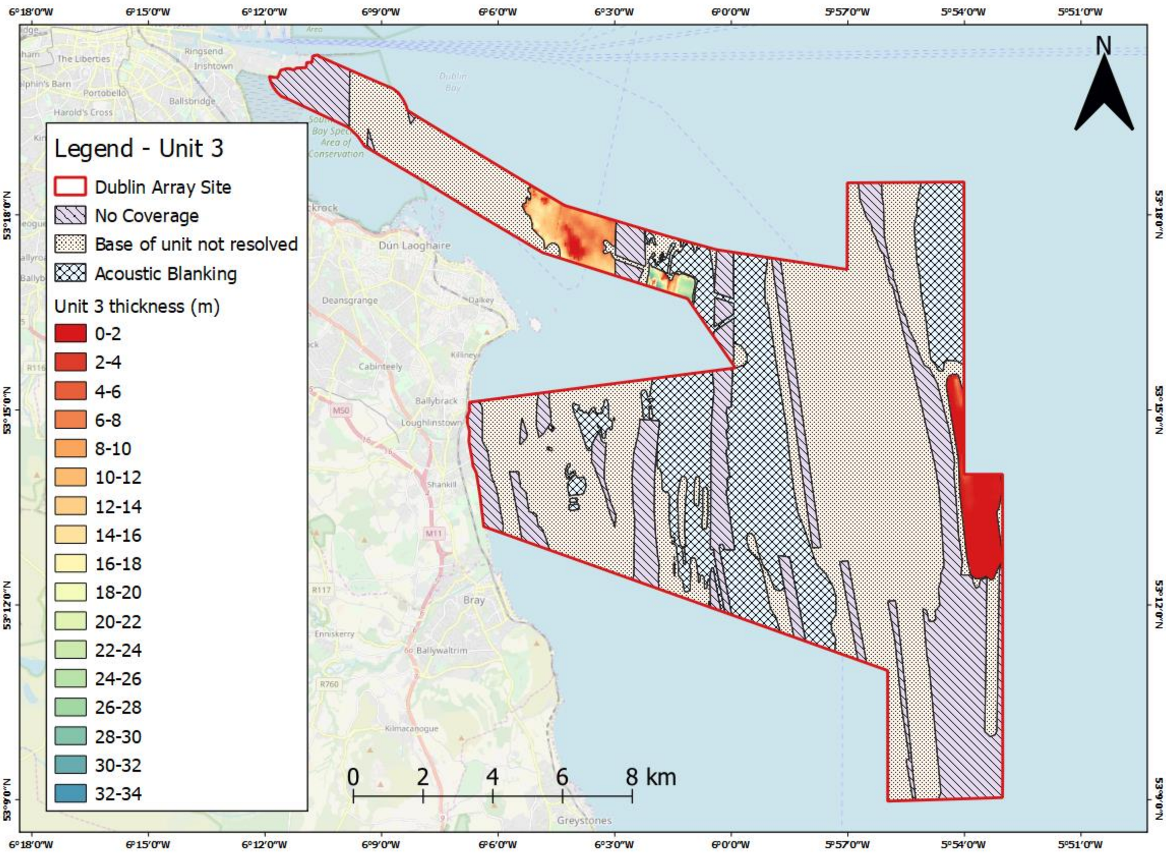


Figure 6-13 Isopach (thickness) map Unit 3

6.3.4 Top of Acoustic Basement

The acoustic basement is defined as the lowest continuous resolvable boundary observed across the site. This reflector varies in depth below the seabed between 0 and 47.1m across the site as shown in Figure 6-14.

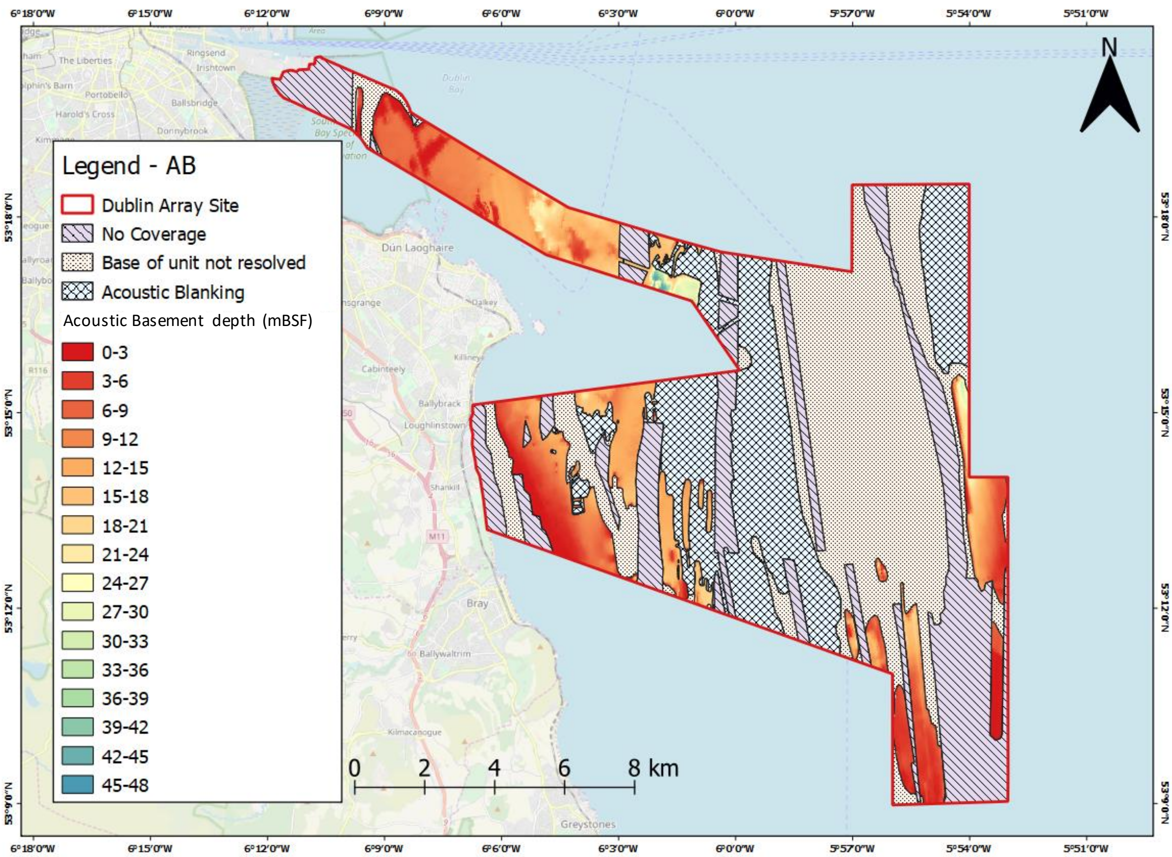


Figure 6-14 Isopach (depth below the seabed) map for acoustic basement.

6.4 Initial comparison between previous SBP surveys and INFOMAR data

6.4.1 Comparison between EIS 2008 survey & INFOMAR data.

As discussed earlier, the bathymetric (single beam echosounder) and sub-bottom (boomer) data were collected by Hydrographic Surveys Ltd (HSL) between June and September 2008 as part of the original Environmental Impact Statement (EIS). At this stage of reporting, it has not been possible to review the raw boomer data collected due to the unavailability of the original dataset. However, an initial comparison between representative cross sections presented in the HSL report and selected overlapping lines from the INFORMAR campaign was carried out to cross-reference interpretations. It is important to note that these comparison lines were recorded almost perpendicular to each other with the two INFOMAR lines orientated north-northwest to south-southeast and the three HSL lines orientated west to east.

Figure 6-15 shows that the interpretation carried out for Kish Section 6 approximately matches with that done for CV08_03 Line 1629. The interpreted depth to the shallow horizons encountered at that intersection on both profiles differs by approximately 2-3m, being slightly shallower on Line 1629. This difference in depth to horizon is expected considering two different seismic profilers (pinger & boomer) were used and the data quality of the HSL dataset and the ASV used is not known.

However, the interpretation carried out at the intersection of Line 1629 and Kish Section 2 does differ. The pinger data for Line 1629 would appear to show only an enhanced reflector area of interpreted acoustic blanking at a similar depth to a shallow geological horizon highlighted in the Kish Section 2 profile. This creates some uncertainty on the original interpretation of the HSL boomer data, which warrants further investigation.

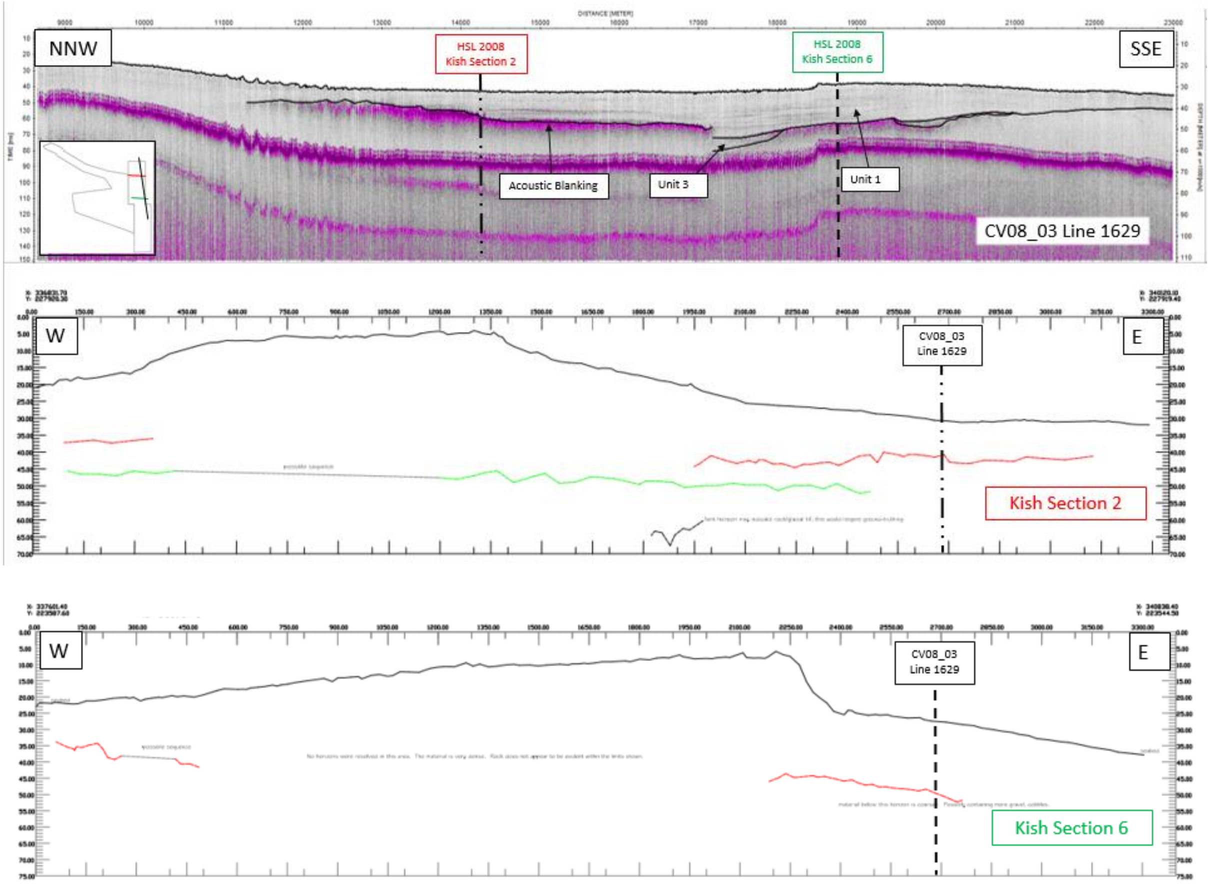


Figure 6-15 Comparison between CV08_03 Line 1629 and HSL 2008 boomer cross sections 2 and 6 with inset map showing location of lines on site.

The comparison between CV12_02 Line 488 and Kish Section 11 shows good agreement between the two interpretation results, see

Figure 6-16 Comparison between CV12_02 Line 488 and HSL 2008 boomer cross sections 11 with inset map showing location of lines on site.

. Although, the shallow Unit 1 horizon highlighted on the INFOMAR line was not observed on the HSL profile. The absence of this shallow horizon in the HSL profile may be due to the thickness of the boomer seabed pulse or weather effects. Also a slightly deeper horizon was observed solely on the HSL profile.

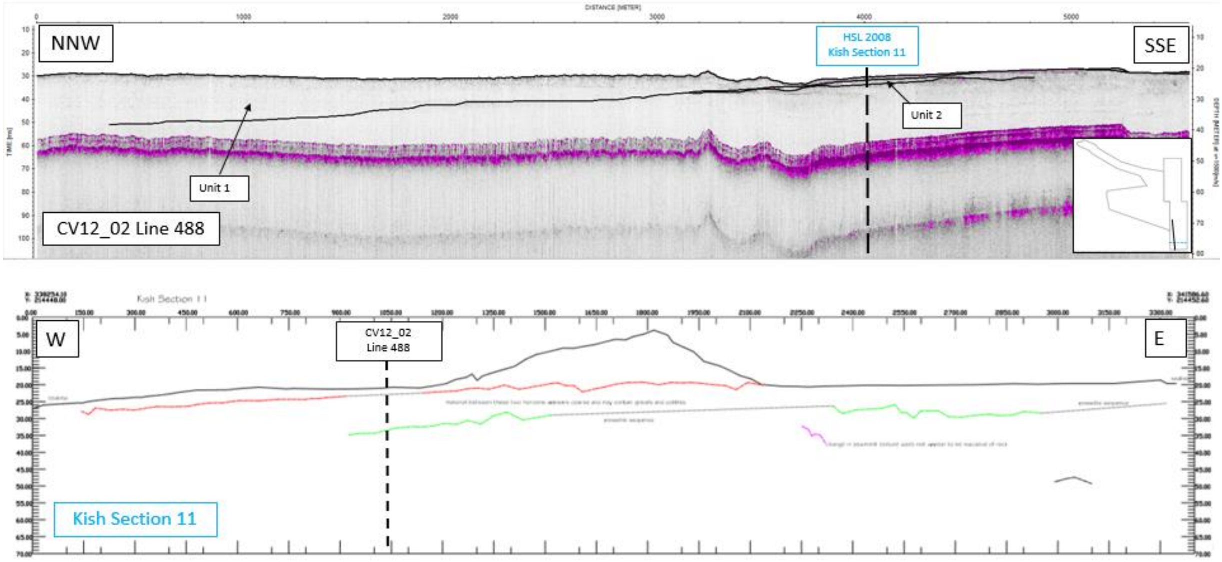


Figure 6-16 Comparison between CV12_02 Line 488 and HSL 2008 boomer cross sections 11 with inset map showing location of lines on site.

6.4.2 Comparison between Marine Institute 1998 Survey & INFOMAR data.

As discussed earlier in Section 3.3.3, bathymetric (single beam echosounder), sidescan sonar (SSS), Boomer (SBP) and grab sample (Van Essen Grab) data was collected as part of a geological appraisal of the Kish, Burford, Bray and Fraser Banks in the outer Dublin Bay area between 3rd and 10th November 1998 as part of Marine Institute survey of the seabed banks in the area.

It has not been possible to review the raw data acquired as part of this survey. However, an initial comparison was carried between the results presented in that survey report [5] and the interpretation carried out on the INFOMAR SBP data for this report. Geophysical survey tracklines run as part of this 1998 survey are presented in Figure 6-17.

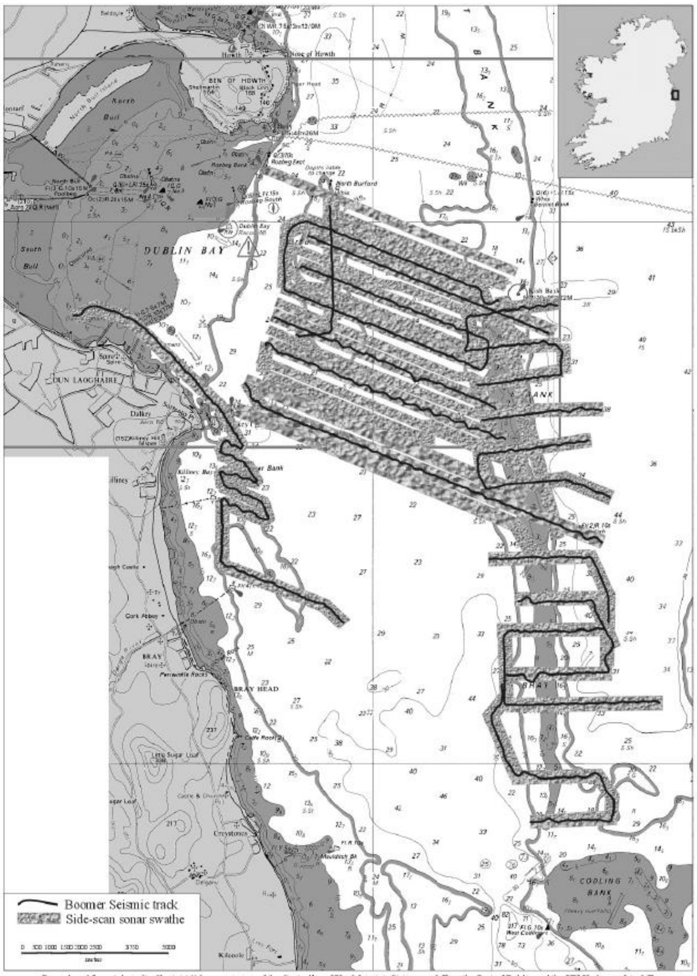


Figure 6-17 Marine Institute survey side-scan sonar and boomer seismic coverage.

The 1998 report reports the presence of three geological units in the shallow geological section (Figure 6-18):

- Unit A defined as an upper unit of sand with weak internal reflectors.
- Unit B defined as thin unit with a strong response.
- Unit C defined as a poorly imaged strata with few internal reflectors which occasionally contain other thin beds comparable to Unit B although spatially discontinuous.

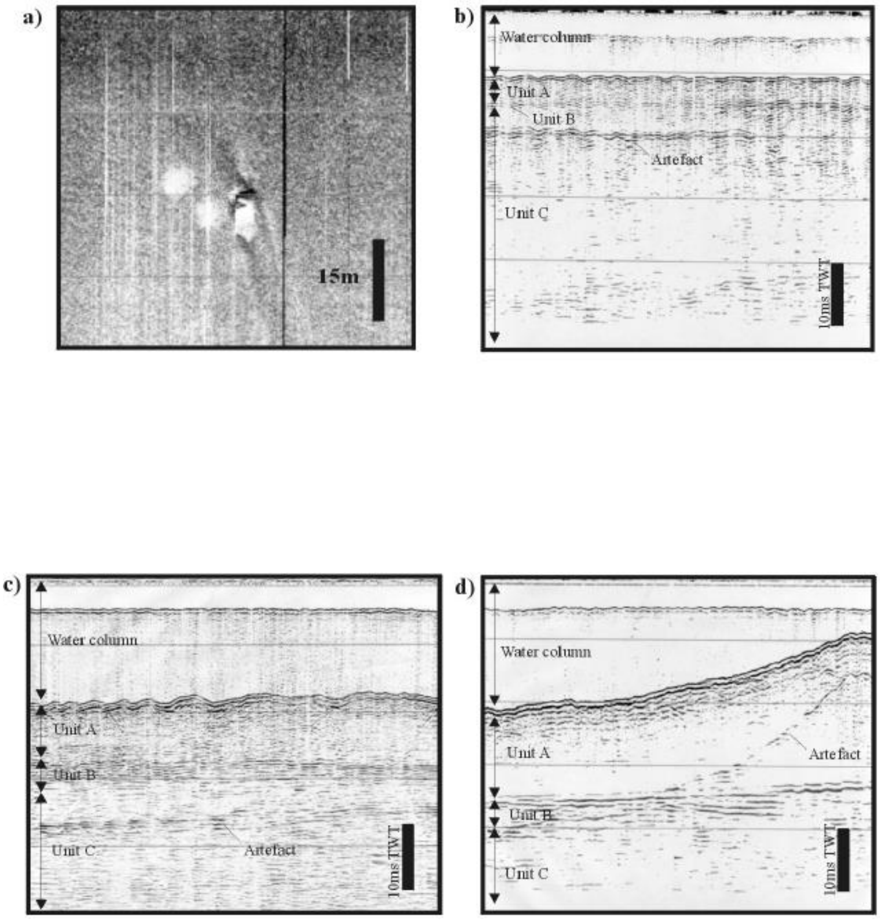


Figure 6-18 Marine Institute survey boomer data examples.

It is interpreted that Unit 1 presented as part of this report is comparable with the 1998 reported Unit A. Although it would appear that the INFOMAR Pinger data resolved the laminations a lot clearer in this unit than the Boomer did for the 1998 report. This would be expected as the Boomer lines were generally acquired over the seabed banks where there is interpreted to be an increased sand content in the upper section of Unit 1 beneath the banks. Also the Pinger is a higher frequency profiler capable of defining finer detail than the lower frequency Boomer SBP.

One difference between these units is there is no mention of acoustic blanking within the 1998 surveys uppermost unit, Unit A. However, as mentioned above, the Boomer lines were generally acquired over the seabed banks. In this area, the INFOMAR dataset was very poor and the base of the unit could not be resolved nor internal features be identified due to acoustic blanking.

When the isopach chart from the 1998 survey report showing the thickness of Unit A (Figure 6-19) is compared with the isopach chart of Unit 1 (Figure 6-11) compiled from the interpretation done from the INFOMAR data as part of this report, it can be seen that very similar thicknesses are presented in both charts.

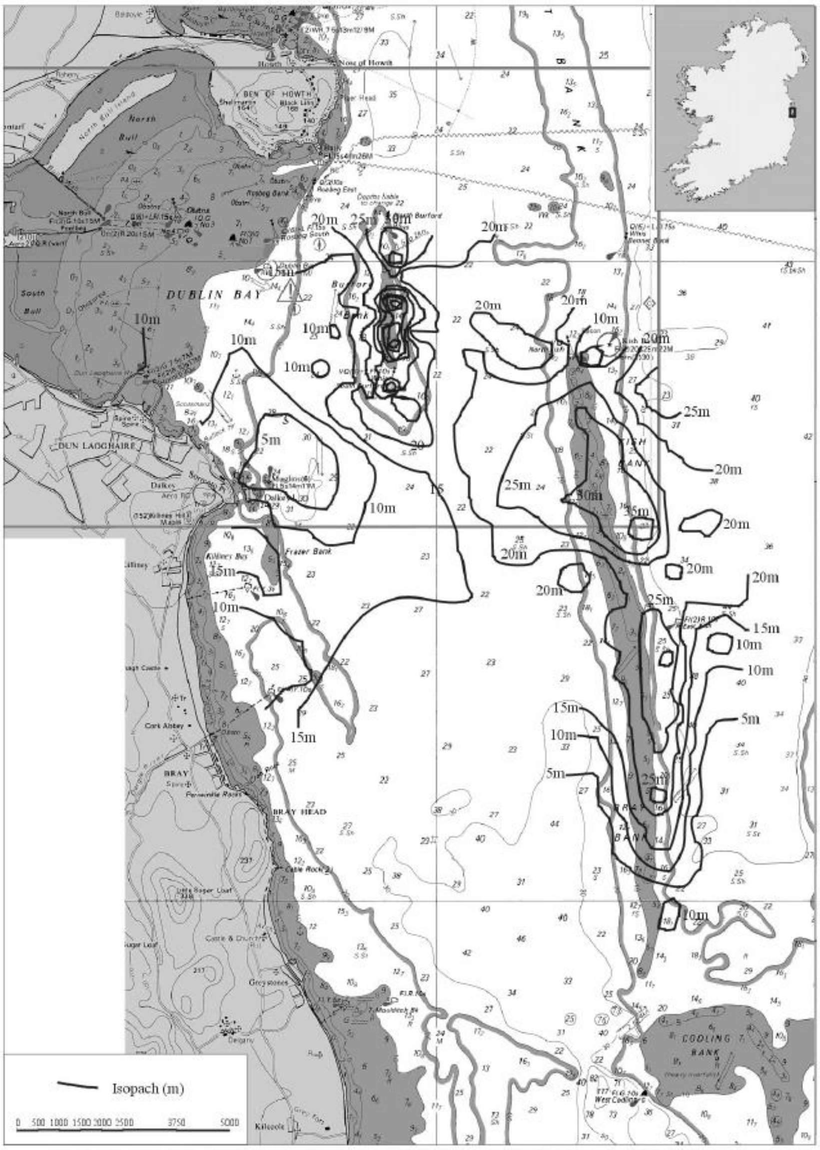


Figure 6-19 Marine Institute survey Unit A isopach map.

It is interpreted that Unit 2 as presented as part of this report is comparable with the 1998 reports Unit B. A preliminary interpretation of Unit 2 suggests it is composed of fine grained sediments (muds to fine sands). The 1998 report quotes a regional stratigraphy for the area presented in a paper [7] based on nearshore survey data south of Dublin. The 1998 survey paper interprets their Unit A & B to correlate with Unit IV from the 1977 paper. Unit IV is interpreted to comprise banks and other sand bodies that may include stiff clay or gravel layers and mud and silt in some hollows. Therefore, Unit 2 as presented in this report is interpreted to correlate with Unit B from the 1998 survey report and the lower sections of Unit IV as described in the 1977 journal paper.

7 Review of Borehole Data and Integration with Geological Context

7.1 Boreholes in the Offshore Wind Farm Area (Glover 2008)

A site investigation campaign was undertaken by Glover Site Investigations Ltd in the offshore wind farm area in September 2008. Based on the review of these boreholes, the sand bank structure can be described by a sequence of three units [21], see Appendix B.

- **Sand bank unit 1:** Seafloor to 3-6mBSF – Uppermost unit of loose to medium dense silty fine to medium sands with traces of gravel and occasional shells and cobbles.
- **Sand bank unit 2:** 3-6mBSF to 10-15mBSF – Dense silty fine to medium sands with traces of fine gravel and occasional shells
- **Sand bank unit 3:** 12-15mBSF to 20mBSF – Very dense silty fine to medium sands with occasional shells

These units are believed to correlate with the Estuarine Coarse deposits also observed in the upper most soil layer along the export cable area. It should be noted that no seismic reflector was observed on the sand bank and in the vicinity of these boreholes to allow further correlation with seismic units.

7.2 Boreholes in the Dublin Bay Area (Fugro 2011)

A site investigation campaign including marine boreholes was undertaken by Fugro between October 2010 and April 2011 in the Dublin Bay area including seventeen boreholes (see Figure below).

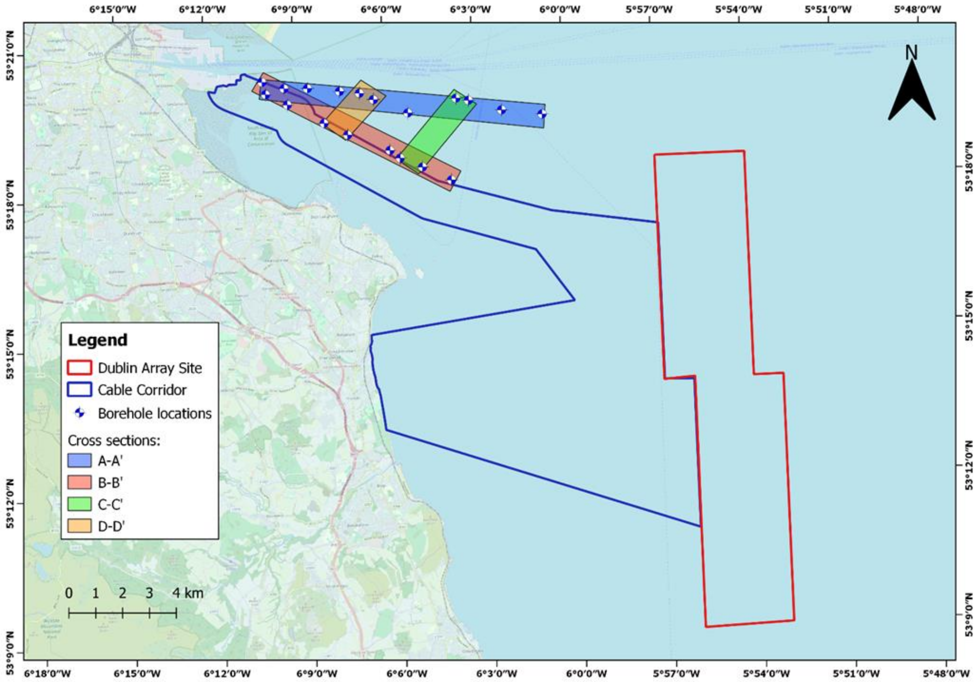
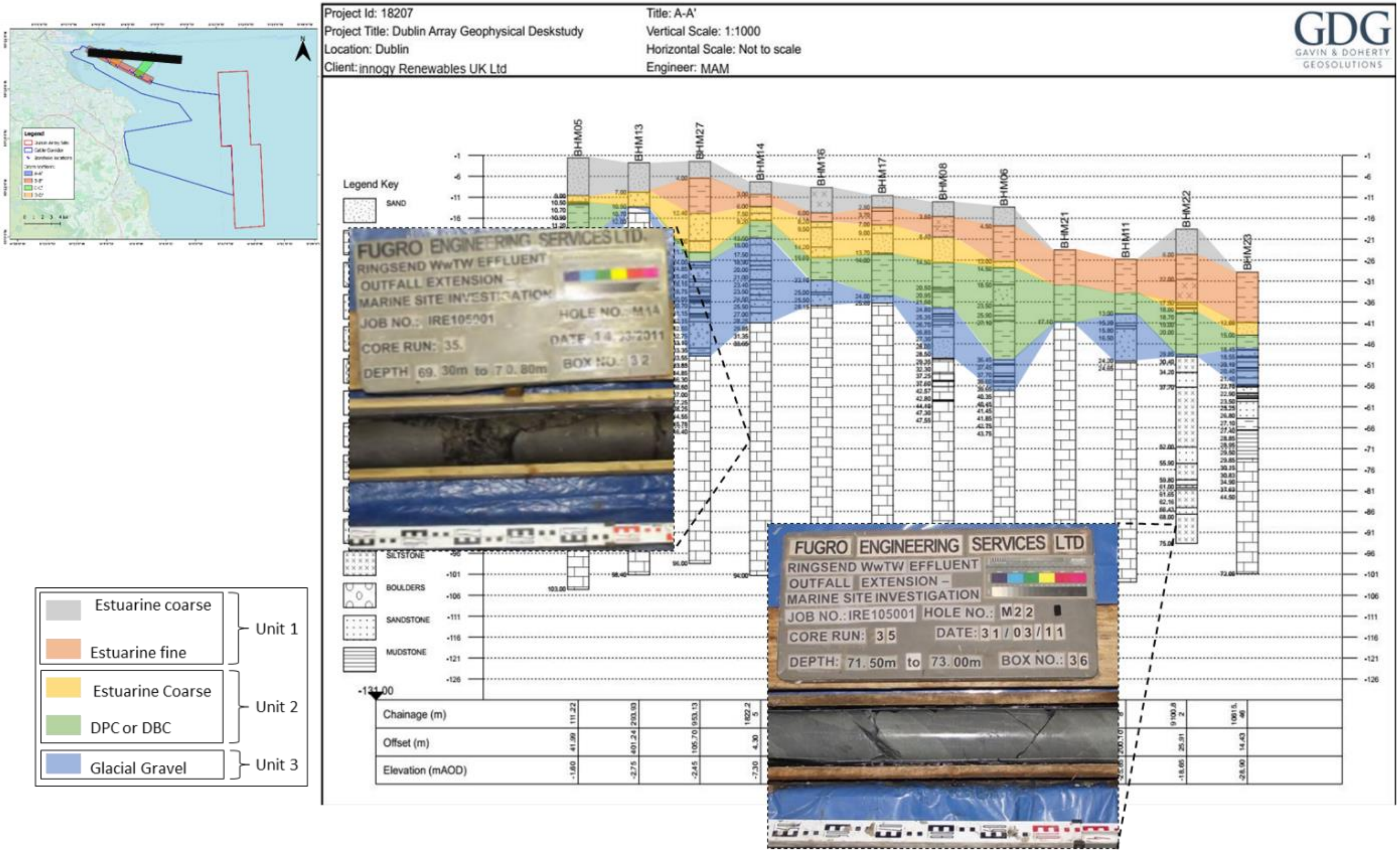


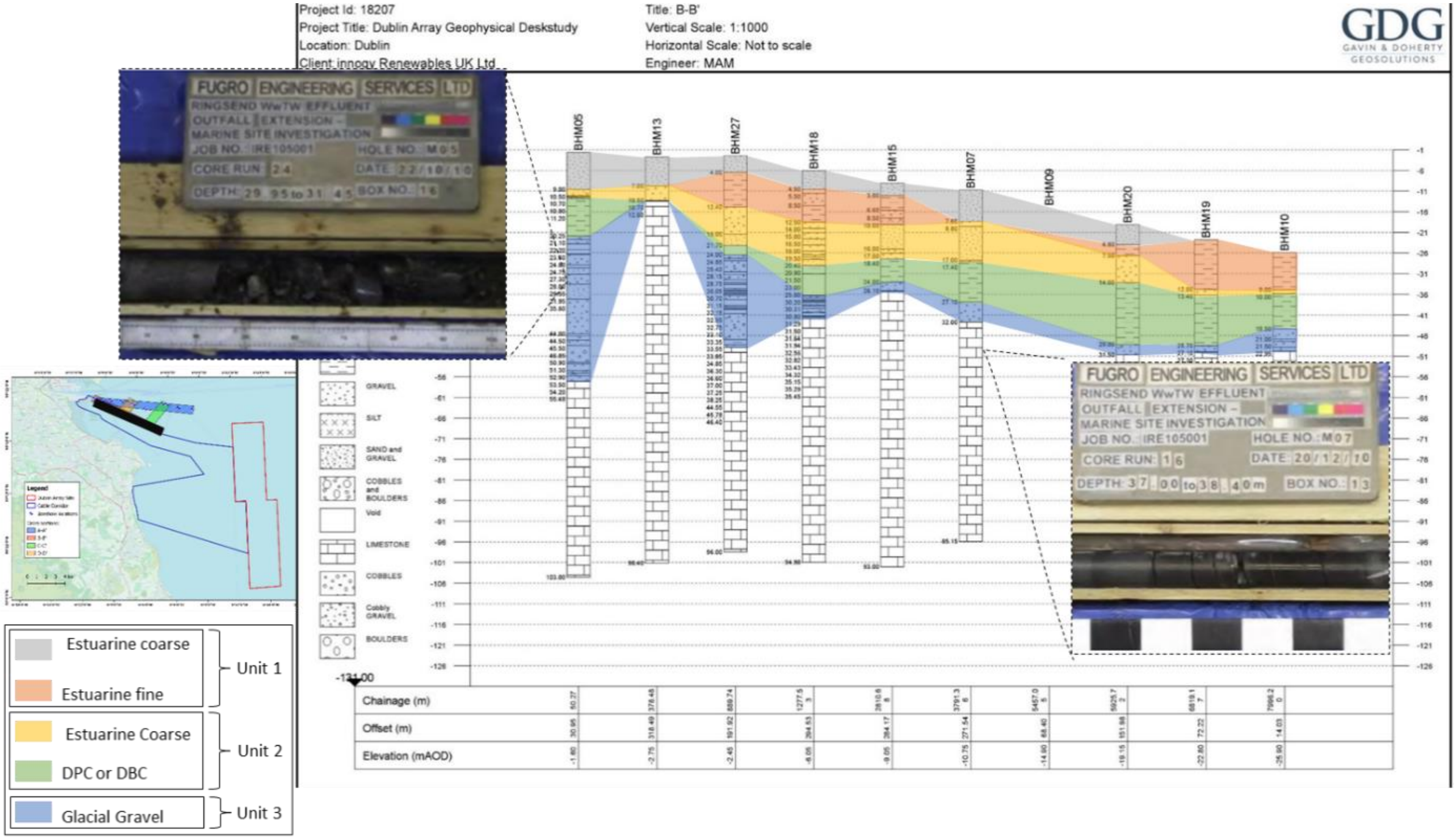
Figure 7-1 Borehole locations in the Dublin Bay area (Fugro in 2011)

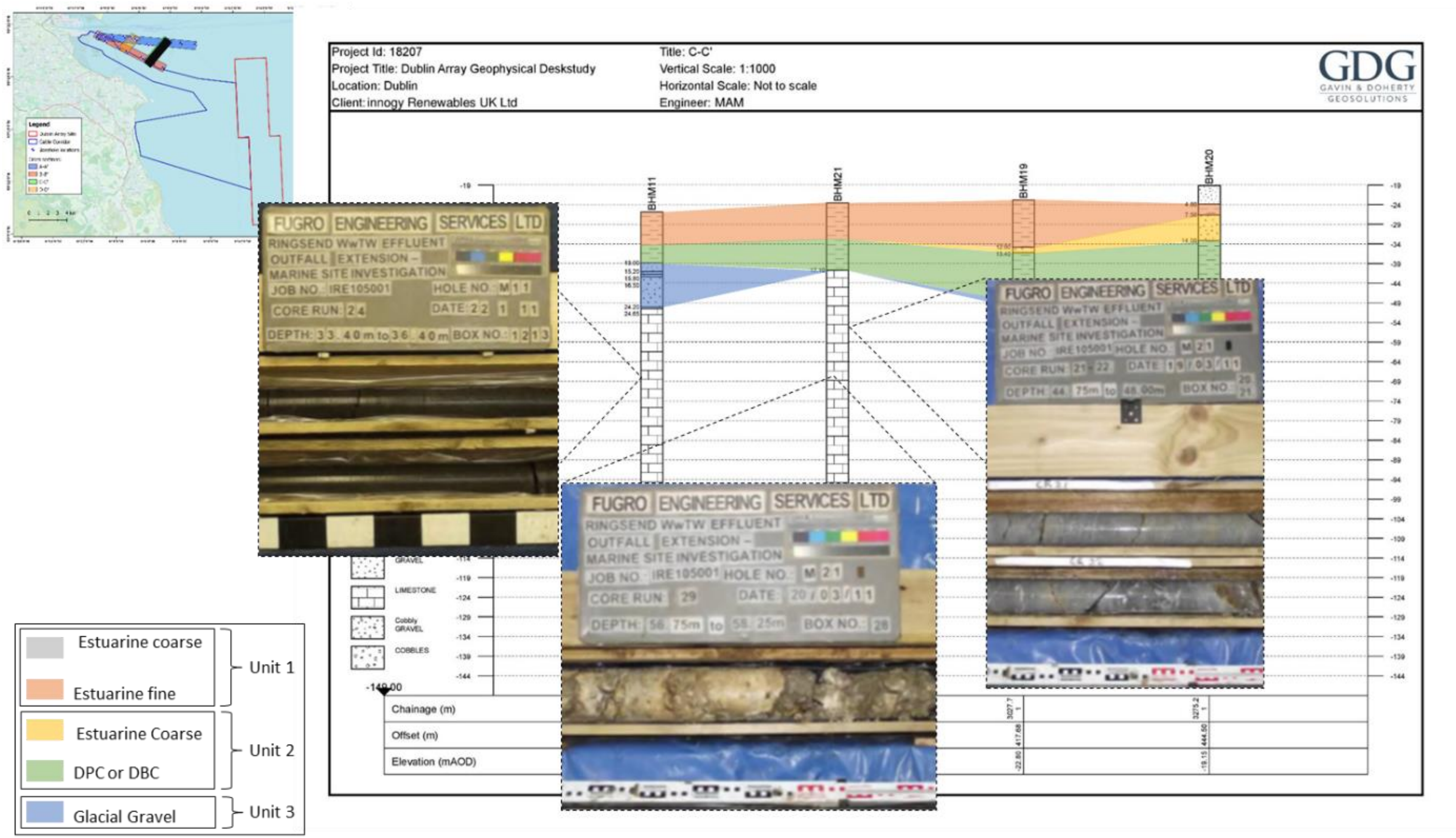
The review of borehole cross sections suggest a sequence of geological units, which correlate well with the geology of the Dublin Bay area described earlier in Section 3.2.

- **Coarse-Grained Estuarine Deposits:** The first layer is composed of coarse estuarine deposit mostly composed of grey and dark grey slightly gravelly SAND with frequent shells and shell fragments.
- **Fine-Grained Estuarine Deposits:** Then a layer composed of fine estuarine deposit, Soft grey slightly sandy CLAY, sand is fine to medium.
- **Coarse-Grained Estuarine deposits:** The third layer encounter is composed of Dark grey silty SAND and GRAVEL; this is also an estuarine deposit.
- **Boulder Clay:** The fourth and fifth layer is till. The fourth one is composed of Stiff locally firm dark grey CLAY.
- **Glacial Gravel:** Then the last layer of soil is composed of Dark grey and brownish Gravel with Cobbles. Cobbles are medium strong dark grey limestone. This layer overlay the bedrock.

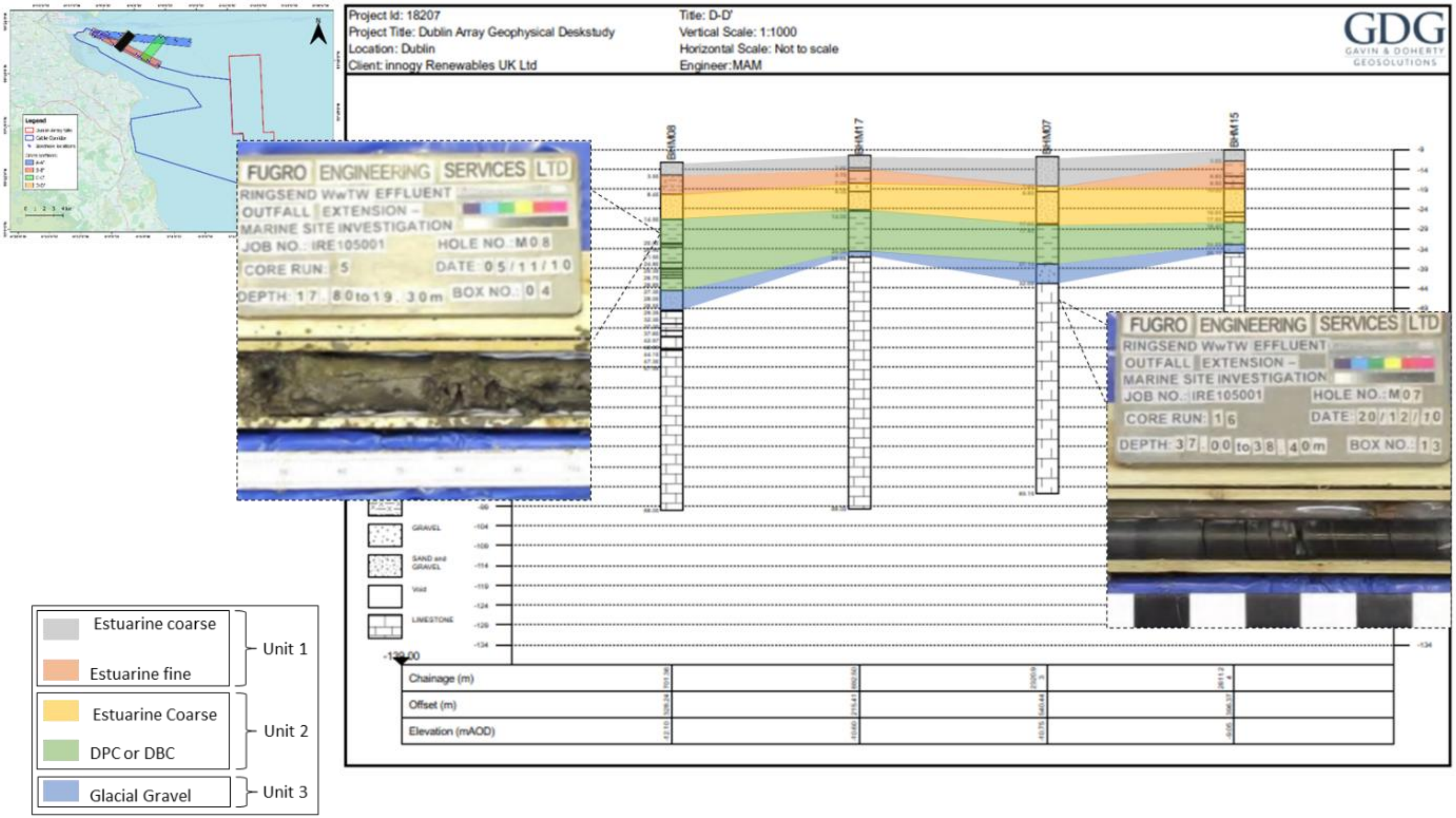
The correlation between different geological units identified from the borehole data in the Dublin Bay area and seismic units obtained from the review of INFOMAR data is provided in the following Section.


Project Id: 18207
Project Title: Dublin Array Geophysical Deskstudy
Location: Dublin
Client: innogy Renewables UK Ltd
Title: A-A'
Vertical Scale: 1:1000
Horizontal Scale: Not to scale
Engineer: MAM
GDG GAVIN & DOHERTY GEOSOLUTIONS
Legend Key
SAND
SILTSTONE
BOULDERS
SANDSTONE
MUDSTONE
BHM05
BHM13
BHM27
BHM14
BHM16
BHM17
BHM08
BHM06
BHM21
BHM11
BHM22
BHM23
Chainage (m)
Offset (m)
Elevation (mAOD)
FUGRO ENGINEERING SERVICES LTD.
RINGSEND WwTW EFFLUENT
OUTFALL EXTENSION –
MARINE SITE INVESTIGATION
HOLE NO.: M14
CORE RUN: 35
DEPTH: 69.30m to 70.80m
BOX NO.: 32
FUGRO ENGINEERING SERVICES LTD
RINGSEND WwTW EFFLUENT
OUTFALL EXTENSION –
MARINE SITE INVESTIGATION
JOB NO.: IRE105001
HOLE NO.: M22
CORE RUN: 35
DATE: 31/03/11
DEPTH: 71.50m to 73.00m
BOX NO.: 36
Estuarine coarse
Estuarine fine
Unit 1
Estuarine Coarse
DPC or DBC
Unit 2
Glacial Gravel
Unit 3


Project Id: 18207
Project Title: Dublin Array Geophysical Deskstudy
Location: Dublin
Client: innogy Renewables UK Ltd
Title: B-B'
Vertical Scale: 1:1000
Horizontal Scale: Not to scale
Engineer: MAM
GDG GAVIN & DOHERTY GEOSOLUTIONS
FUGRO ENGINEERING SERVICES LTD
RINGSEND WwTW EFFLUENT
OUTFALL EXTENSION –
MARINE SITE INVESTIGATION
JOB NO.: IRE105001
HOLE NO.: M05
CORE RUN: 24
DATE: 22/10/10
DEPTH: 29.95 to 31.45
BOX NO.: 16
BHM05
BHM13
BHM27
BHM18
BHM15
BHM07
BHM09
BHM20
BHM19
BHM10
GRAVEL
SILT
SAND and GRAVEL
COBBLES and BOULDERS
Void
LIMESTONE
COBBLES
Cobbly GRAVEL
BOULDERS
FUGRO ENGINEERING SERVICES LTD
RINGSEND WwTW EFFLUENT
OUTFALL EXTENSION –
MARINE SITE INVESTIGATION
JOB NO.: IRE105001
HOLE NO.: M07
CORE RUN: 16
DATE: 20/12/10
DEPTH: 37.00 to 38.40m
BOX NO.: 13
Chainage (m)
Offset (m)
Elevation (mAOD)
Estuarine coarse
Estuarine fine
Unit 1
Estuarine Coarse
DPC or DBC
Unit 2
Glacial Gravel
Unit 3



Project Id: 18207
Project Title: Dublin Array Geophysical Deskstudy
Location: Dublin
Client: innogy Renewables UK Ltd
Title: C-C'
Vertical Scale: 1:1000
Horizontal Scale: Not to scale
Engineer: MAM
GDG GAVIN & DOHERTY GEOSOLUTIONS
BHM11
BHM21
BHM19
BHM20
FUGRO ENGINEERING SERVICES LTD
RINGSEND WwTW EFFLUENT OUTFALL EXTENSION - MARINE SITE INVESTIGATION
JOB NO.: IRE105001
HOLE NO.: M11
CORE RUN: 24
DEPTH: 33.40m to 36.40m
HOLE NO.: M21
CORE RUN: 29
DEPTH: 56.75m to 58.25m
BOX NO.: 28
CORE RUN: 21-22
DEPTH: 44.75m to 48.00m
GRAVEL
LIMESTONE
Cobbly GRAVEL
COBBLES
Chainage (m)
Offset (m)
Elevation (mAOD)
Estuarine coarse
Estuarine fine
Unit 1
Estuarine Coarse
DPC or DBC
Unit 2
Glacial Gravel
Unit 3


Project Id: 18207
Project Title: Dublin Array Geophysical Deskstudy
Location: Dublin
Client: innogy Renewables UK Ltd
Title: D-D'
Vertical Scale: 1:1000
Horizontal Scale: Not to scale
Engineer: MAM
GDG GAVIN & DOHERTY GEOSOLUTIONS
FUGRO ENGINEERING SERVICES LTD
RINGSEND WwTW EFFLUENT
OUTFALL EXTENSION -
MARINE SITE INVESTIGATION
JOB NO.: IRE105001
HOLE NO.: M08
CORE RUN: 5
DATE: 05/11/10
DEPTH: 17.80 to 19.30m
BOX NO.: 04
HOLE NO.: M07
CORE RUN: 16
DATE: 20/12/10
DEPTH: 37.00 to 38.40m
BOX NO.: 13
GRAVEL
SAND and GRAVEL
Void
LIMESTONE
Chainage (m)
Offset (m)
Elevation (mAOD)
Estuarine coarse
Estuarine fine
Unit 1
Estuarine Coarse
DPC or DBC
Unit 2
Glacial Gravel
Unit 3

7.3 Correlation Between Seismic Units and Soil Layers

A comparison between borehole logs and seismic data along the export cable route to Poolbeg was performed (Figure 7-2). In general, most of the survey lines show a good correlation between units encountered and those highlighted during the interpretation. Unfortunately, no boreholes were in an area of acoustic blanking so they cannot provide any information about the cause of the blanking.

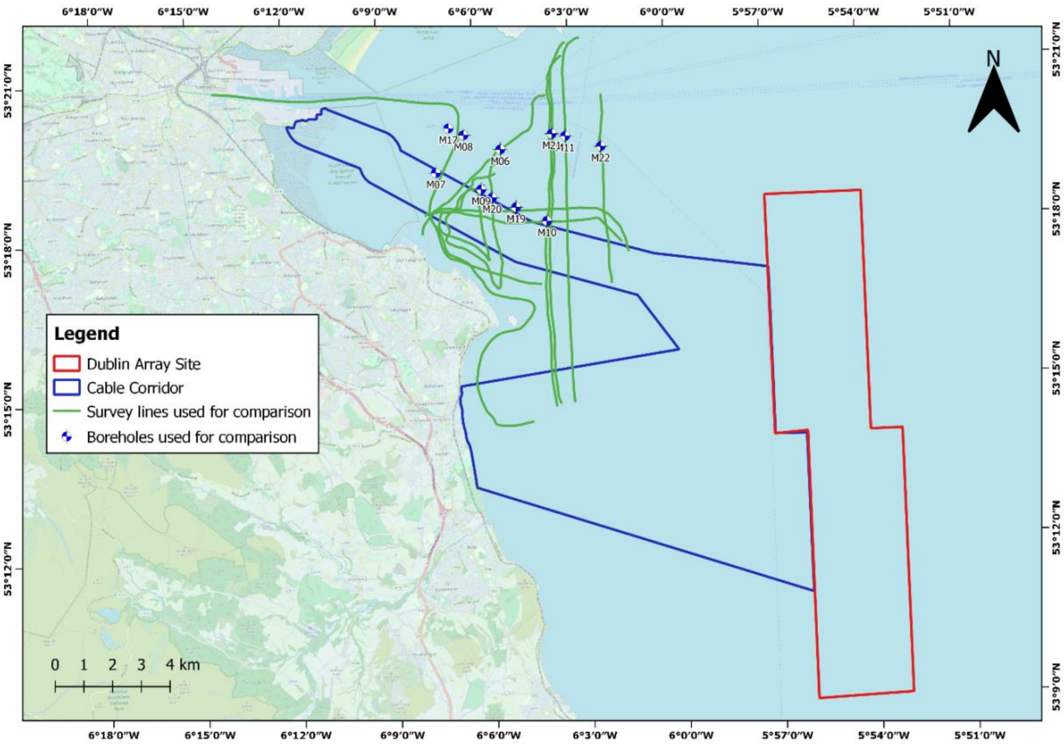


Figure 7-2 Survey lines and boreholes used for comparison

The review of Figure 7-3 to Figure 7-6 suggests that:

- By overlaying the different boreholes on the geophysics lines we can see that the first seismic unit corresponds to the first soil layer, sand with shell, and the second layer, soft clay. The seismic wave is reflected by the top of the coarse estuarine layer then some of them pass through the sand and the clay layer. Clay has a lower density and therefore lower speed wave. This is most likely why the seismic waves aren't reflected by the change of lithology between sand and clay layers.
- The second unit identified by the seismic interpretation starts at the top of the third estuarine deposit within the borehole records composed primarily of gravel. The second unit continues through the stiff to firm clay layer. This layer generally isn't detected by the seismic data because the units could have the same density and speed wave to the gravel layer.
- The third seismic unit is associated with the glacial Gravel and Cobbles layer.

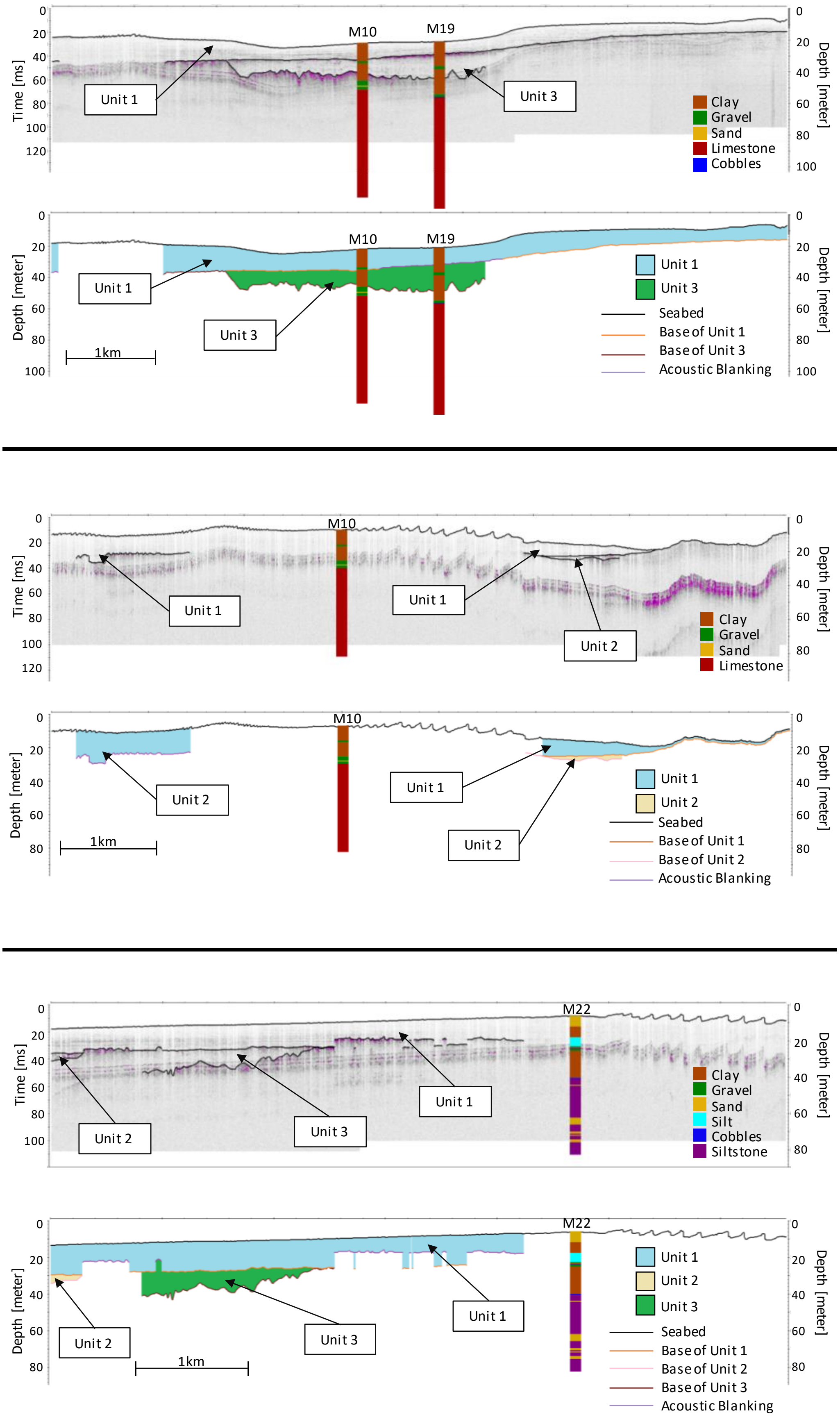


Figure 7-3 Comparison between the seismic data interpretation and boreholes (on the top line 47, in the middle line 62, on the bottom line 73)

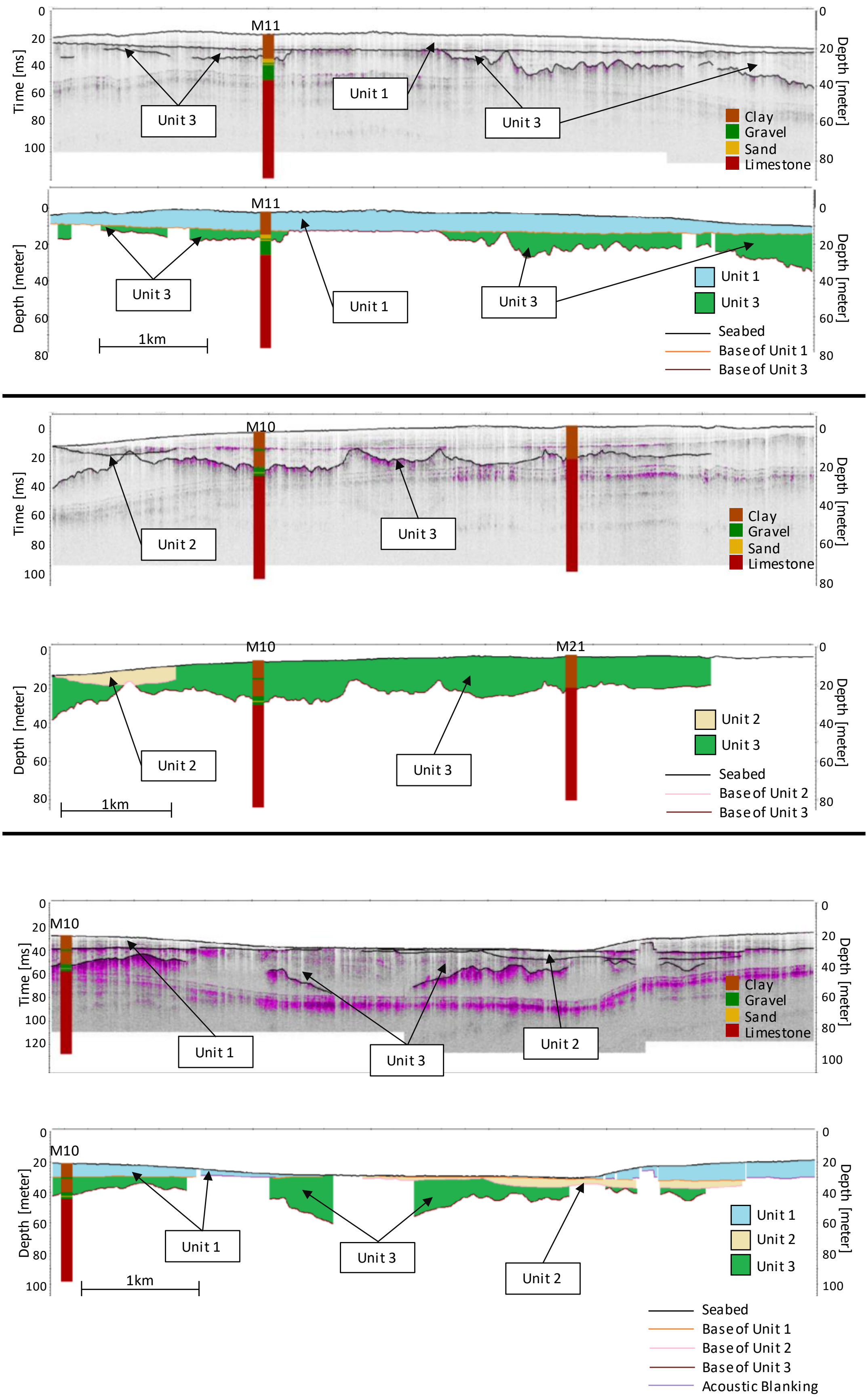


Figure 7-4 Comparison between the seismic data interpretation and boreholes (on the top line 88, in the middle line 93, on the bottom line 94)

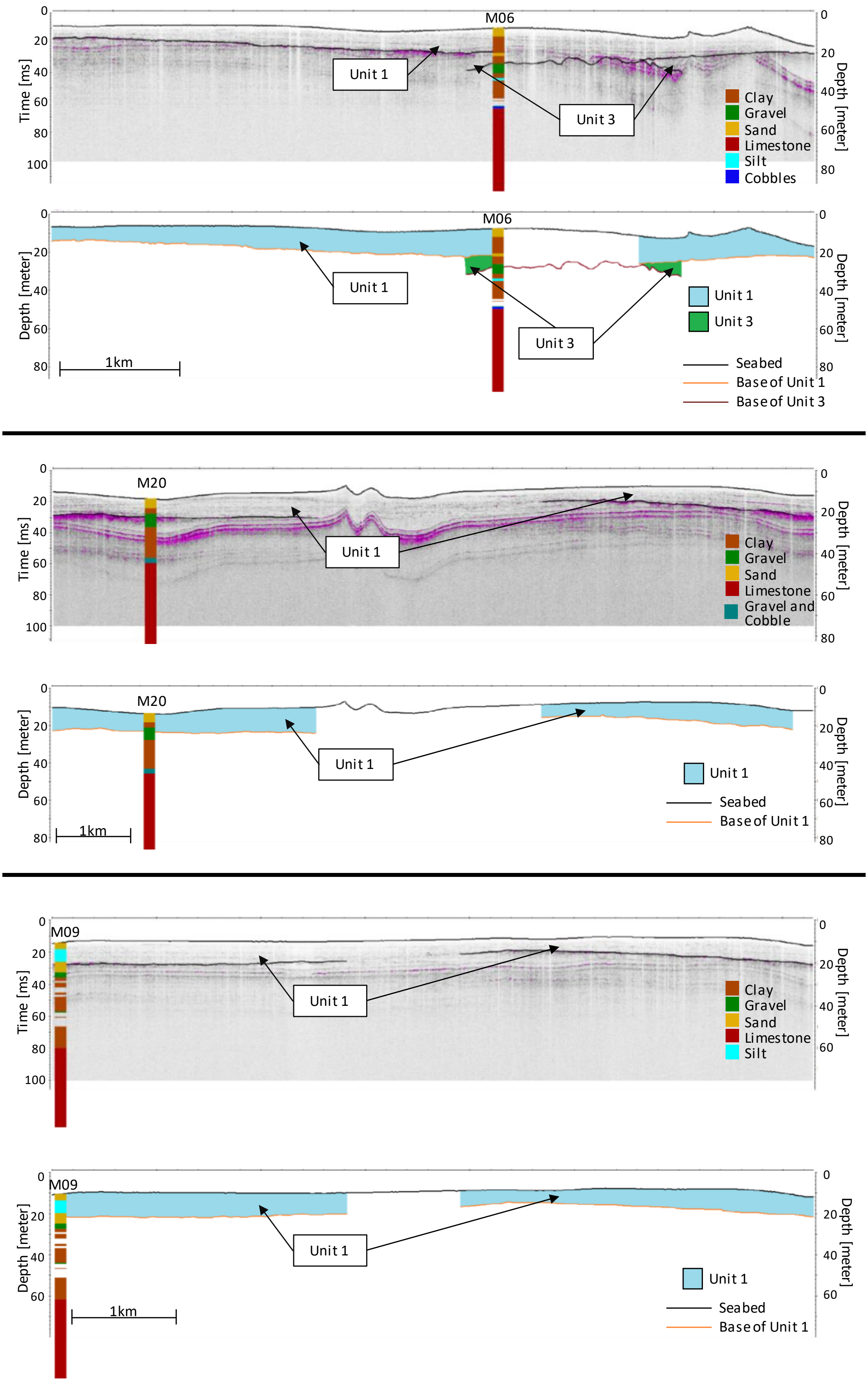


Figure 7-5 Comparison between the seismic data interpretation and boreholes (on the top line 103, in the middle line 146, on the bottom line 150)

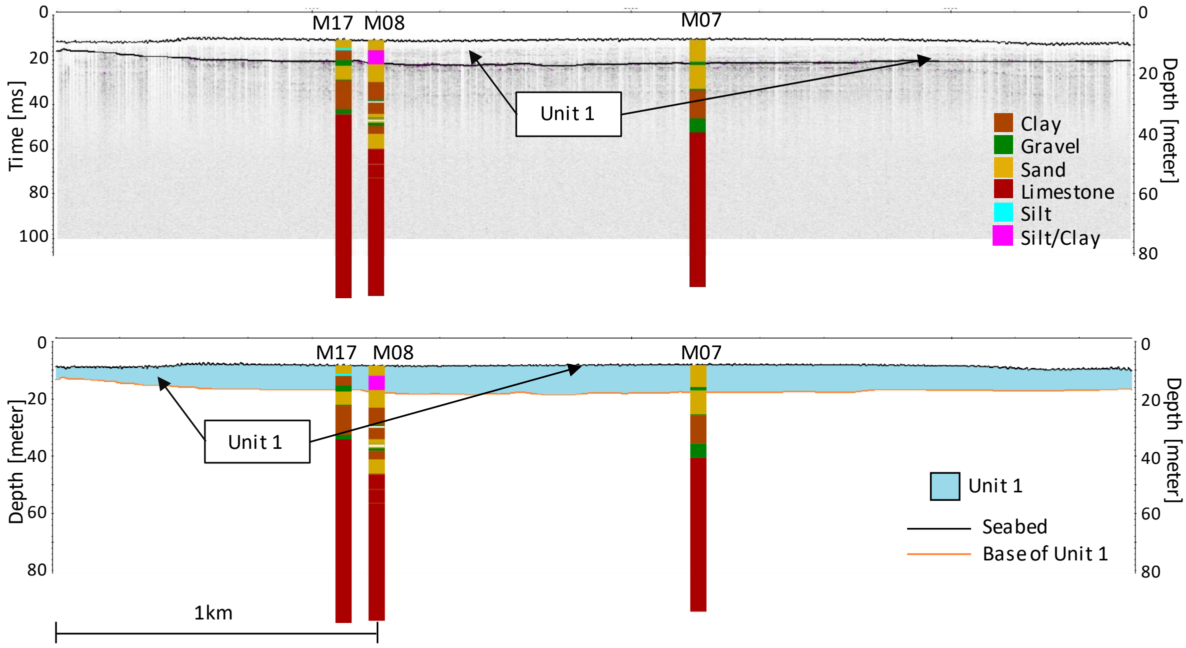


Figure 7-6 Comparison between the seismic data interpretation and boreholes (line 241)

Seismic Unit	Soil Layer	Geological Unit	Description
Unit 1	Grey and dark grey slightly gravelly SAND with frequent shells and shell fragments	estuarine and fluvial deposit	Grey and dark grey slightly gravelly SAND with frequent shells and shell fragments
	Soft grey slightly sandy CLAY, sand is fine to medium		Soft grey slightly sandy CLAY, sand is fine to medium
Unit 2	Dark grey silty SAND and GRAVEL		Dark grey silty SAND and GRAVEL
	Stiff locally firm dark grey CLAY	Port/Boulder Clay	Stiff locally firm dark grey CLAY
Unit 3	Dark grey and brownish Gravel with Cobbles. Cobbles are medium strong dark grey limestone	Glacial Gravel	Dark grey and brownish Gravel with Cobbles. Cobbles are medium strong dark grey limestone
Acoustic Basement*	Limestone	Bedrock (inter-bedded)	Limestone
	Sandstone/Siltstone (40/60)		Sandstone/Siltstone (40/60)
***Note:** The Acoustic Basement here refers to the lowest resolvable layer based on assessment of SBP data obtained in the nearshore area of the export cable corridor to Poolbeg.			

8 Geotechnical Parameters

8.1 Field Test – Standard Penetration Tests

A wide range of equipment is used to undertake SPT testing which influences the amount of energy transferred to the sampler with each blow of the drop hammer. The constitutive properties of a given soil deposit should not vary with the equipment used, and so *N* is conventionally corrected to a value N_{60}. The blow-count also needs to be corrected for the size of the borehole and for tests done at shallow depths (<10m). These corrections are achieved using

$$N_{60} = N * \zeta * (ER/60)$$

Where ζ is the correction factor for rod length (i.e. test depth) and borehole size, and *ER* is the Energy Ratio of the equipment used.

In sands and gravels, the corrected blow-counts are further normalised to account for the overburden pressure at the test depth. The normalised blow-count $(N_1)_{60}$ are obtained from following equation:

$$(N_1)_{60} = C_N N_{60}$$

Where C_N is the overburden correction factor and is calculated as follows:

$$C_N = \frac{A}{B + \sigma'_{v0}}$$

A and *B* vary with density, coarseness and OCR. For dense to very dense sands and gravels *A = 300* and *B = 200*, otherwise *A* and *B* are assumed equal to 200 and 100 respectively.

8.1.1 Glover Boreholes

Three boreholes were drilled at the site in 2008 by Glover Site Investigations Ltd as part of the EIS process. Boreholes are located on the bank in the northern part of the site (Figure 3-8) during drilling, the only strata observed were sands of various density. SPT tests were carried out every 1m from 0 up to 12mBSF and then every 1.5m up until termination of the borehole.

SPT N value and corrected $(N_1)_{60}$ values are presented on the charts below.

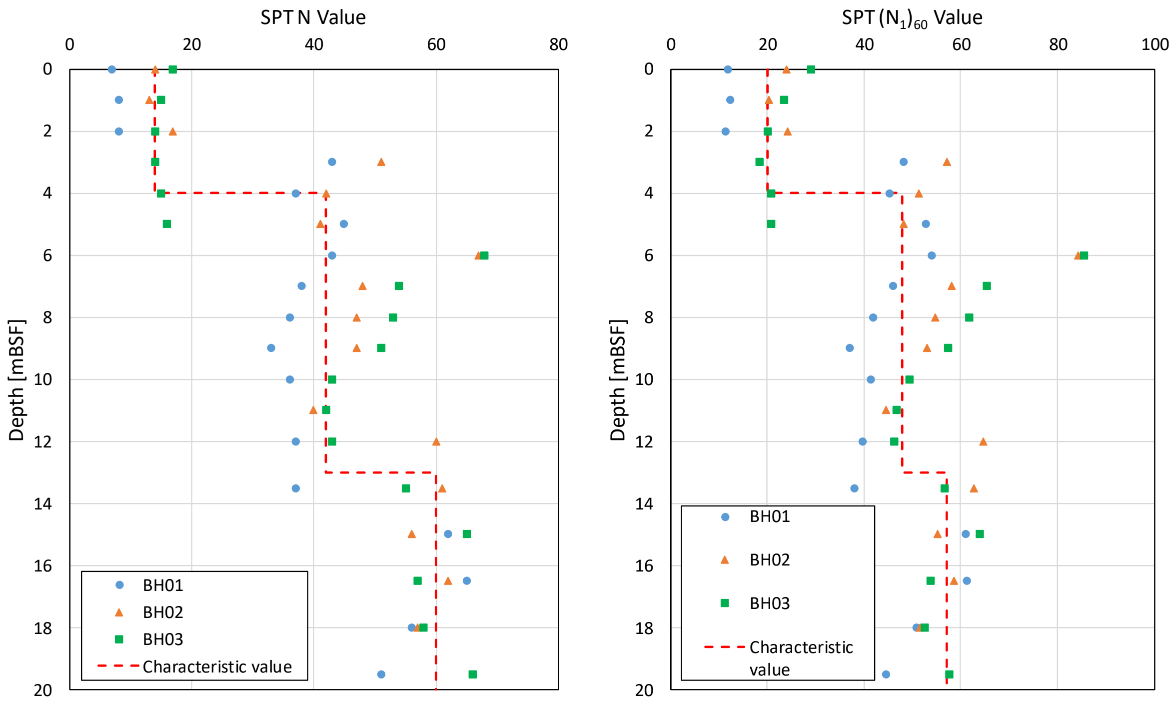


Figure 8-1 SPT N Values for Offshore Glover Boreholes

SPT tests show, that from 0 to 4m sands are loose to medium dense. From that depth, up until termination of the boreholes sands are dense to very dense.

8.1.2 Fugro boreholes

In October 2010 Dublin City Council commissioned a geotechnical campaign in the approaches to and within Dublin Bay to facilitate the Ringsend Wastewater Treatment Plant (WWTP) works. This campaign consisted of 21 boreholes and a bathymetric survey. Borehole drilling was accompanied by SPT tests.

The tests results are plotted below. Lithology units were divided into estuarine and fluvial deposits, Dublin port/boulder clay and glacial gravels.

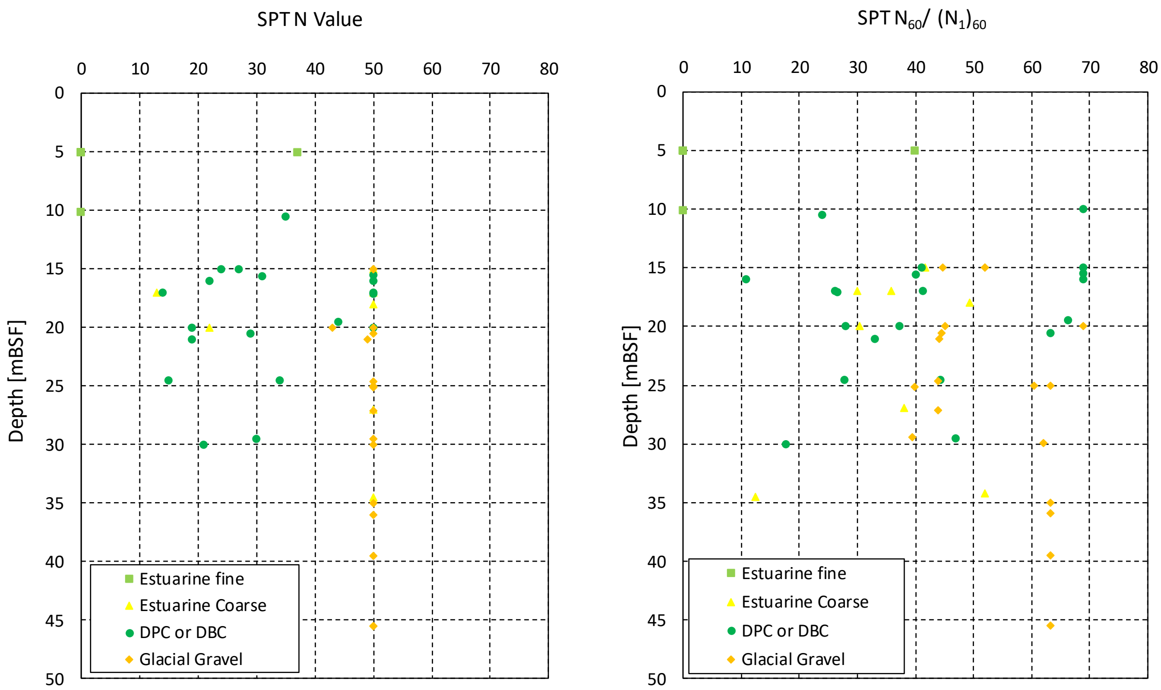


Figure 8-2 SPT N Values for Nearshore Fugro Boreholes

Two cohesive units were distinguished – an upper clay comprising Fine estuarine and fluvial deposits, and a lower Clay layer. Moreover, two non-cohesive units has been resolved – Coarse estuarine and Glacial Gravel.

8.2 Parameters for Unit 1

8.2.1 Estuarine Coarse deposits

In granular soils, SPT test results can be used to calculate effective friction angle. Results of the calculations are plotted below.

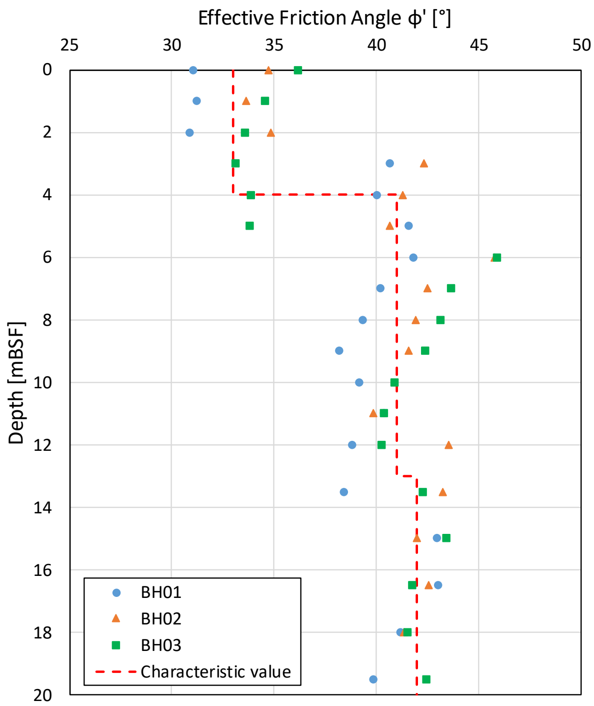


Figure 8-3 Friction Angles for the Offshore Glover Boreholes

Effective friction angle in the loose sands in the main array area are approximately 33°. In dense and very dense sands it exceeds 40°.

8.2.2 Estuarine Fine deposits

Estuarine deposits were observed in the nearshore boreholes along the cable route. The SPT N values of those units were used to calculate shear strength based on following correlation (Stroud, 1989):

$$c_u = N_{60} * f_1$$

Value of f_1 is determined based on plasticity index characterizing the given soil. Plasticity indices of the encountered estuarine fine deposit are presented on the plots below:

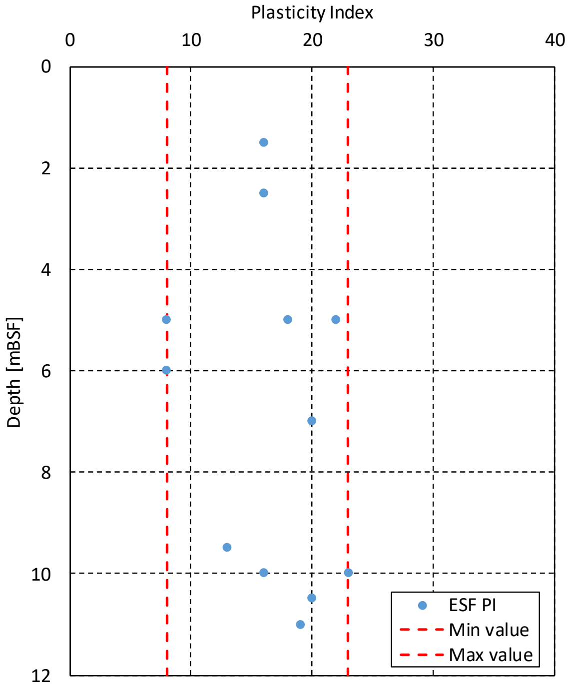


Figure 8-4 Plasticity Index Values for the Nearshore Fugro Boreholes

For estimating the undrained shear strength (s_u) the following equation was used:

$s_u \approx 5.8 * N_{60}$ (kPa) Estuarine Fine

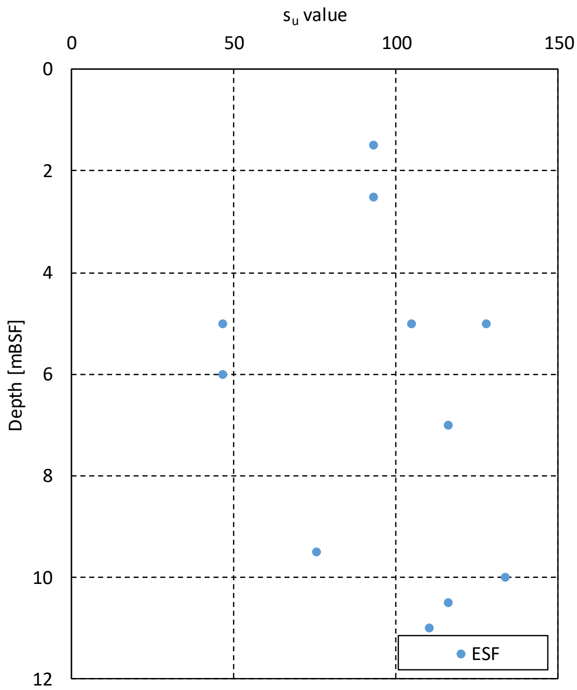


Figure 8-5 Undrained Shear Strength Values for the Nearshore Fugro Boreholes

8.3 Parameters for Unit 2

8.3.1 Estuarine Coarse deposits

In granular soils, SPT test results can be used to calculate effective friction angles. Results of the calculations are plotted below.

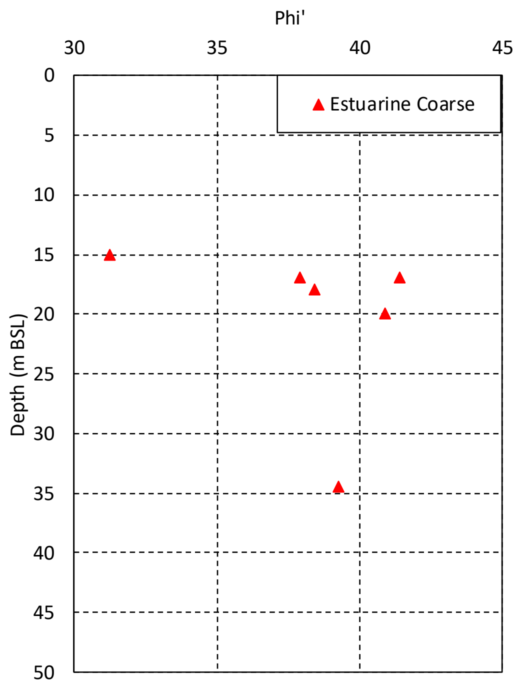


Figure 8-6 Friction Angle Values for the Nearshore Fugro Boreholes

Stroud (1989) suggested a correlation between SPT *N* values and the drained Young's Modulus (E'), which has been used for correlating the drained modulus.

$$E' = 2 * N_{60}\ (MPa) \text{ for non-cohesive soils}$$

According to this equation, the drained Young's Modulus (E') charts have been plotted below.

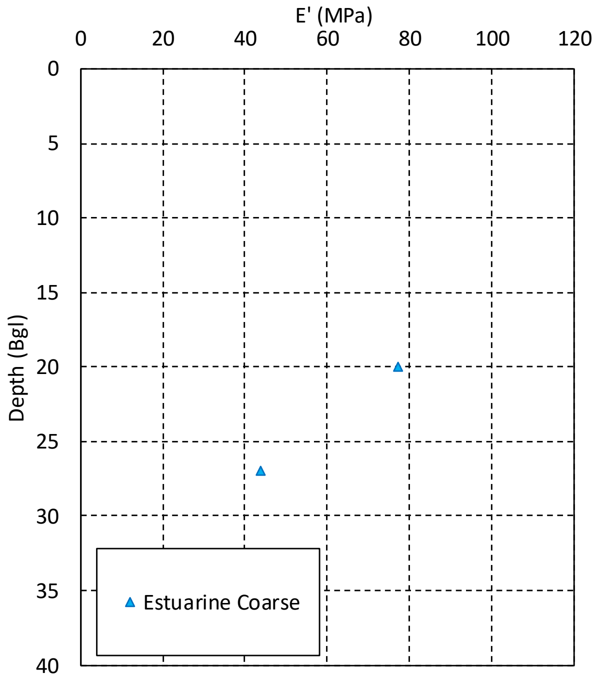


Figure 8-7 Stiffness Moduli Values for the Nearshore Fugro Boreholes

8.3.2 Cohesive Clay Layer

Plasticity indexes of these units were used to calculate shear strength when combined with the results of SPT tests based on the following correlation (Stroud, 1989):

$$c_u = N_{60} * f_1$$

The value of f_1 is determined based on the plasticity index characterizing a given soil. Plasticity indices of the encountered Clay are presented on the plots below:

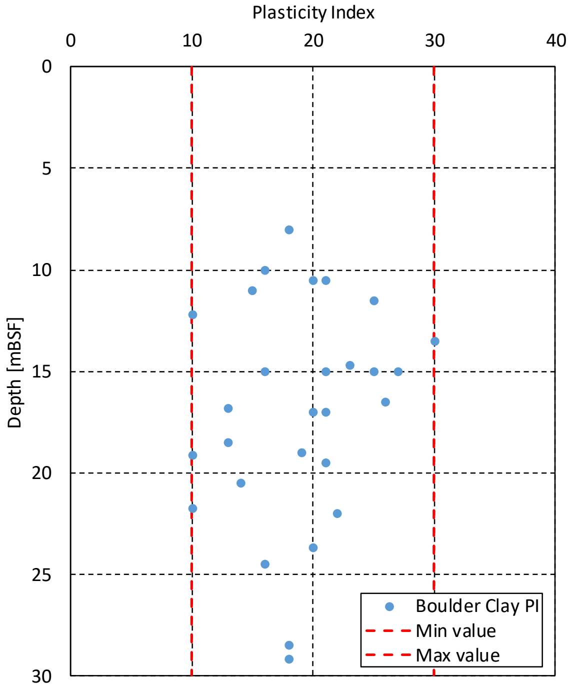


Figure 8-8 Plasticity Index Values for the Nearshore Fugro Boreholes (lower clay layer)

For estimating the undrained shear strength (s_u) the following equation was used:

$$s_u \approx 5.9 * N_{60} \quad \text{(kPa) for Clay}$$

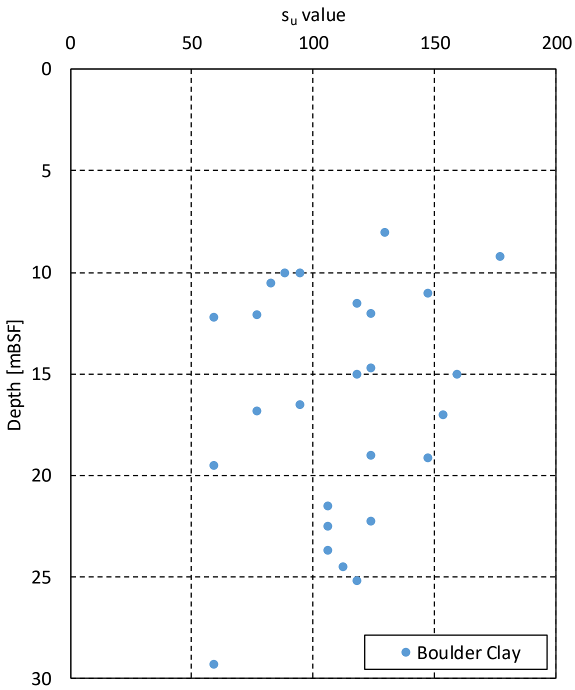


Figure 8-9 Undrained Strength Values for the Nearshore Fugro Boreholes (lower Clay Layer)

Stroud (1989) suggested a correlation between SPT *N* values and the drained Young's Modulus (E'), which has been used for correlating the drained modulus.

$$E' = 0.8 * N_{60}\ (MPa) \text{ for cohesive soils}$$

According to this equation, the drained Young's Modulus (E') charts have been plotted below.

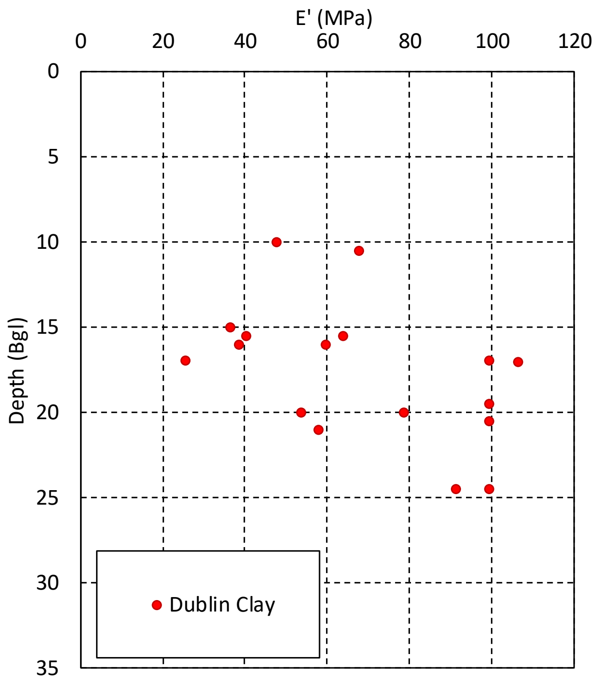


Figure 8-10 Stiffness Values for the Nearshore Fugro Boreholes (lower clay layer)

8.4 Parameters for Unit 3

8.4.1 Glacial Gravel

In granular soils, SPT test results can be used to calculate effective friction angle. Results of the calculations are plotted below.

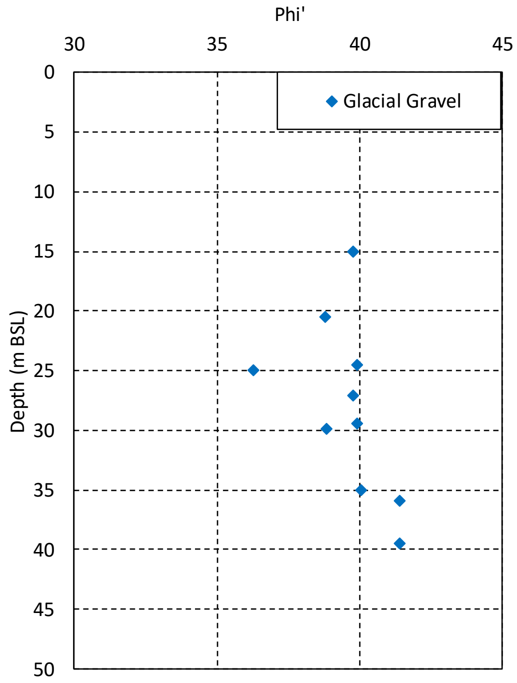


Figure 8-11 Friction Angle Values for the Nearshore Fugro Boreholes (Glacial Gravel)

Stroud (1989) suggested a correlation between SPT *N* values and the drained Young's Modulus (E'), which has been used for correlating the drained modulus.

$$E' = 2 * N_{60}\ (MPa) \text{ for non-cohesive soils}$$

According to these equations, the drained Young's Modulus (E') has been plotted below.

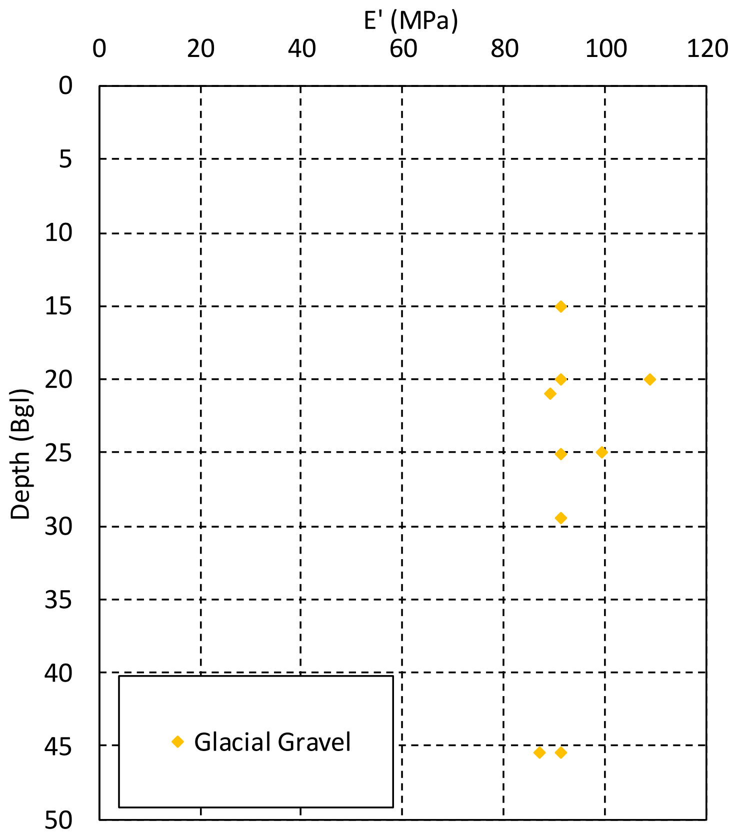
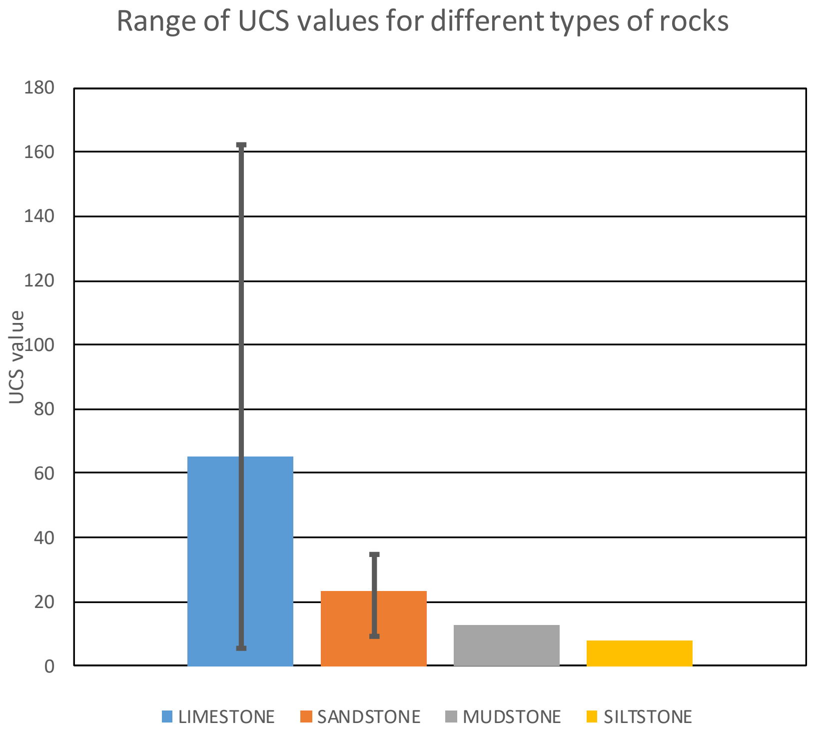


Figure 8-12 Stiffness Values for the Nearshore Fugro Boreholes (Glacial Gravel)

8.5 Rock Parameters

The nearshore boreholes recorded a range of strength values for the rock samples, which are illustrated below as a function of rock type recorded.



8.6 Likely Range of Parameters for different soil units

8.6.1 Friction angle

	Estuarine Coarse	Estuarine Coarse	Glacial Gravel
Source	Glover	Fugro	Fugro
Number of samples	51	6	11
Min	30.91	31.25	36.29
Max	45.90	41.42	41.42
Average	39.66	37.85	39.64
Median	40.68	38.60	39.80

8.6.2 Plasticity Index

	Estuarine Fine	Clay
Source	Fugro	Fugro
Number of samples	28	11
Min	10	8
Max	30	23
Average	18.86	16.37
Median	19.50	18

8.6.3 Undrained Shear Strength (su)

	Estuarine Fine	Dublin Clay
Source	Fugro	Fugro
Number of samples	28	11
Min	59	46.4
Max	177	133.4
Average	111.26	96.49
Median	115.05	104.4

8.6.4 Unconfined Compression Strength [UCS]

	Limestone	Sandstone	Mudstone	Siltstone
Source				
Number of samples	71	3	1	1
Min	5.4	8.9	-	-
Max	162.1	34.7	-	-
Average	111.26	23.67	-	-
Median	115.05	26.5	12.5	7.7

8.6.5 Stiffness Modulus E'

	Estuarine Coarse	Estuarine Fine	Estuarine Coarse	Dublin Clay	Glacial Gravel
Source	Glover	Fugro	Fugro	Fugro	Fugro
Number of samples	51	4	7	17	19
Min	22.93	47.69	35.88	25.5	86.94
Max	171.05	99.36	138	99.36	138
Average	91.94	66.03	99.63	67.49	91.37
Median	97.68	63.76	126.5	63.76	126.5

8.6.6 SPT-N Values

	Estuarine Coarse	Estuarine Fine	Estuarine Coarse	Dublin Clay	Glacial Gravel
Source	Glover	Fugro	Fugro	Fugro	Fugro
Number of samples	51	4	7	18	19
Min	7	24	13	14	43
Max	68	50	50	50	50
Average	41.4	35.25	37.57	35.78	49.6
Median	43	33.5	50	32.5	50

A summary of the soil parameters for different seismic units and associated geological layers are provided in the Table below. Additional discussion of these values is provided in Section 9.

<table>
<tr><th>Corresponding Seismic Layer</th><th>layer</th><th>Description</th><th>SPT-N (-)</th><th>Phi (deg)</th><th>PI (-)</th><th>Su (kPa)</th><th>OCR (-)</th><th>UCS (MPa)</th><th>E’ (MPa)</th></tr>
<tr><td rowspan="2">Unit one</td><td rowspan="3">estuarine and fluvial deposit</td><td>Grey and dark grey slightly gravelly SAND with frequent shells and shell fragments</td><td>7-68</td><td>30.91-45.90</td><td>-</td><td>-</td><td></td><td>-</td><td>22.93-171.05</td></tr>
<tr><td>Soft grey slightly sandy CLAY, sand is fine to medium</td><td>24-50</td><td>-</td><td>10-30</td><td>56-177</td><td>1 [M23-1]</td><td>-</td><td>47.69-99.36</td></tr>
<tr><td rowspan="2">Unit two</td><td>Dark grey silty SAND and GRAVEL</td><td>13-50</td><td>31.25-41.42</td><td>-</td><td>-</td><td></td><td>-</td><td>35.88-138</td></tr>
<tr><td>Dublin Clay</td><td>Stiff locally firm dark grey CLAY</td><td>14-50</td><td>-</td><td>8-23</td><td>46.4-133.4</td><td>2.2 [M06-7]</td><td>-</td><td>25.5-99.36</td></tr>
<tr><td>Unit three</td><td>Glacial Gravel</td><td>Dark grey and brownish Gravel with Cobbles. Cobbles are medium strong dark grey limestone</td><td>43-50</td><td>36.29-41.42</td><td>-</td><td>-</td><td></td><td>-</td><td>86.94-138</td></tr>
<tr><td rowspan="2">Acoustic Basement</td><td rowspan="2">Bedrock (inter-bedded)</td><td>Limestone</td><td></td><td></td><td></td><td></td><td></td><td>5.4-162.1</td><td></td></tr>
<tr><td>Sandstone/Siltstone (40/60)</td><td></td><td></td><td></td><td></td><td></td><td>7.7-34.7</td><td></td></tr>
</table>

9 Summary of Data Review

A review of existing geophysical and geotechnical data available for the project site and the cable corridor was undertaken.

A detailed assessment of bathymetry and seabed morphology, using high-resolution seabed mapping data (MBES) was undertaken, which highlights features including banks, sediment waves, exposed till/bed rock across the wind farm site and export cable corridors. The Bray and Kish banks are the most dominant features of the site with implications for both constructability and site investigations works. Figure 9-1 shows the area of the site with water depth less than 10m (left) and 25m (right), which have limitations for site investigation and construction. In particular areas with water depth less than 10m may pose limitation to the operation of offshore turbine installation vessels; therefore there may be a need to consider implementing exclusion zones. In addition, areas with water depth shallower and deeper than 25m respectively, may require separate geotechnical investigation strategies involving vessels with jack-up (in shallow water) and dynamic positioning (DP2) capabilities in depths above 25m, respectively.

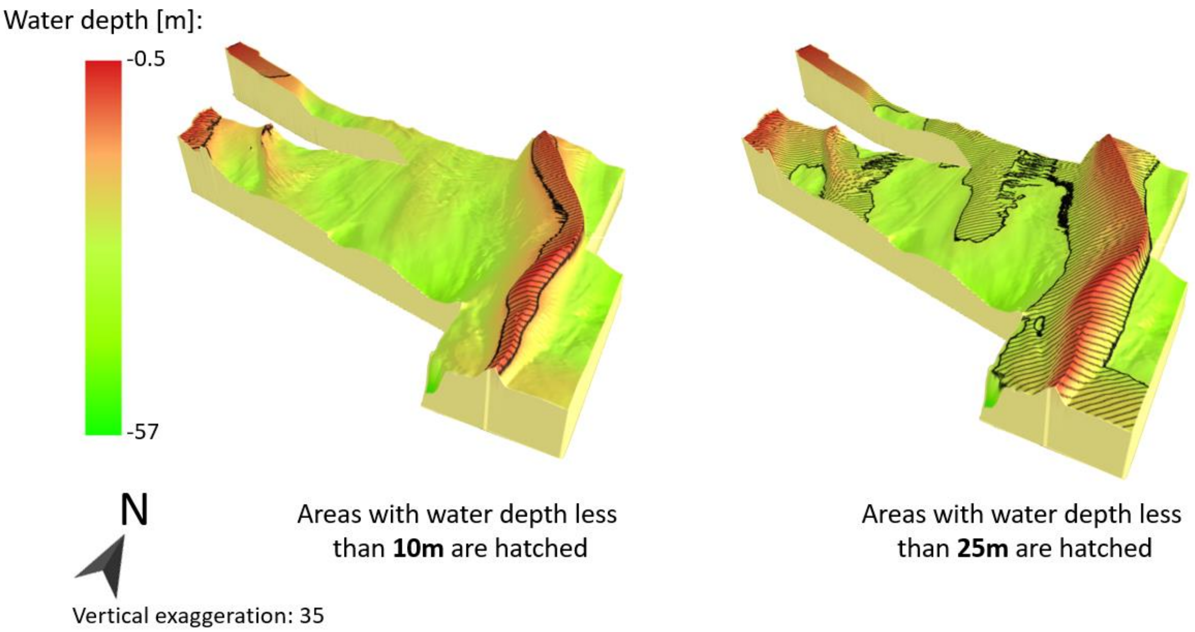


Figure 9-1 Shallow water constraint areas with water depth less than 10m (left) and 25m (right).

A comparative assessment was also undertaken between MBES data obtained from the INFOMAR campaign and SBES data acquired as part of the EIS process to inform indicative temporal changes in the seabed. While the datasets are not conclusive, the evidence suggests that a dynamic sediment environment is present over much of the site area.

The seabed surface was critically assessed, however it should be noted that there is limited grab sampling (34 samples across an area of 160km^2, or one every 4.7km^2) to allow for ground truthing of the backscatter dataset. These samples generally correspond with backscatter data and derived sediment classification values, which allow for a strong confidence in the seabed sediment distribution where surface samples are available. At locations where surface sampling was not possible due to the indurated nature of the seabed material, this was corroborated with hard substrate derived from the analysis of backscatter data. Lastly, it should be noted that despite the high confidence in the sediment classification maps, the levels of active sediment migration are uncertain due to a lack of site-specific metocean data and repeat survey coverage.

The INFOMAR SBP data was acquired at the site in the form of pinger data. The six available relevant geophysical datasets from the INFOMAR programme were reviewed and interpreted where possible. In general data quality was reasonably good; although poor data quality was observed within a few datasets, see Section 6.1. The review of the SBP data enabled three units to be delineated in the shallow geology (above the acoustic basement). Areas of poor data quality, areas of acoustic blanking, as well as signal attenuation in the proximity of the three main banks Kish, Bray and Frazer were the main issues encountered with the datasets. It should be noted that areas of interpreted till/bedrock at or near the surface on the nearshore sections of the proposed export cable route to Shanganagh should be taken into consideration during planning of subsequent phases of work. A comparative assessment was also undertaken between overlapping INFOMAR pinger data and the boomer profiles (available from the EIS 2008 campaign). An overall good agreement was observed between the two datasets, although differences in interpretation of potential acoustic blanking should be further investigated upon availability of further geophysical site investigation data.

9.1 Geological Summary

The geological and environmental conditions of the site can be summarised as follows:

- The geological history of the area is dominated by glacial advance and retreat during the last glaciation, resulting in (what is interpreted as) the deposition of glacial and post-glacial sediments at the site on top of largely Palaeozoic sedimentary rocks, which form the bedrock.
- Water depths at the site vary from approximately 2 m to 57 m with the Kish and Bray Banks forming bathymetric shallows that dominate the main part of the site.
- On the crests and flanks of these banks are loose, fine grained sediments which are mobilised into sedimentary bedforms.
- Large sediment wave features are identified to the east of the Export Cable corridor to Poolbeg, and also to the west of the export cable corridor to Shanganagh (in the vicinity of the Frazer Bank).
- The original Glover EIS boreholes (located generally in the shallower site areas) show sand deposits to depths of circa 20m, however how these deposits vary laterally as we move away from the crest of the sand bank is unknown. It is unclear whether the sandbank itself is purely driven by the metocean conditions and tidal regime or whether there is a geological control at its core. This is a key area of uncertainty that needs to be investigated in subsequent surveys to ensure that shallow bedrock does not present a risk to foundation installation.
- Potentially exposed or sub-cropping bedrock or till was identified in the nearshore area on the southern part of the cable corridor (to Shanganagh).

- Sub-bottom data was generally good but was occasionally affected by weather noise during recording, attenuation of the seismic signal due to thickening of overlying sediments on the banks and acoustic blanking resulting in masking of the shallow geology below.
- Three units were identified above the Acoustic basement: Unit 1, Unit 2 and Unit 3.
- Unit 1 typically comprises alternating laminations of clay and sand with occasional cobbles, shells and fine gravel. The base of Unit 1 is relatively flat except where it is in direct contact with the lowest distinguishable horizon (interpreted till/bedrock). Here the base of Unit 1 undulates due to the sharp, irregular nature of the top of the underlying unit. Unit 1 is up to 18.4m thick.
- Unit 2 is interpreted to comprise acoustically transparent material, containing little internal structure. A preliminary interpretation suggests this unit is composed of fine grained sediments (muds to fine sands). Unit 2 is between 0m and 18.1m thick.
- Unit 3 is interpreted to comprise sandy deposits with occasional sub-parallel, and laterally continuous reflectors. The base of Unit 3 generally marks the top of the acoustic basement and as such is infilling the sharp, irregular, undulatory nature of the top of this interpreted till/bedrock. Unit 3 is between to 33m thick.
- Acoustic blanking was observed in the central part of both Export Cable corridors (o Shanganagh and Poolbeg) and also on the northeast flank of the Kish Bank. The depth to the acoustic basement varies between 0 and 47.1m below the seabed.

9.2 Geotechnical Hazard Assessment

A preliminary geotechnical hazard assessment was undertaken based on the desk study review completed in previous sections. This incorporates seabed surface data, manmade and natural hazards and additional information from interpretation of sub-bottom data.

The shallow water near the crest of Kish and Bray banks can pose a general risk to navigation for any vessels transiting the area. This includes vessels that may be involved in survey work, wind farm construction, and wind farm service vessels during the operational phase.

Furthermore, the shallow water near the crest of Kish and Bray banks (<10m) can pose significant limitations for turbine installation vessels, as the draughts of these vessels may not be accommodated in the shallower areas.

In addition, the large range of variation in water depth across the site may necessitate a two-vessel strategy for geotechnical site investigation works involving jack-up platforms at shallow waters (<25m) and dynamic positioning vessels at deeper locations (>25m). The water depth thresholds are indicative only, and may be subject to change depending on specific capabilities of geotechnical investigation vessels.

Slopes of up to >5° were identified as part of the site, mainly associated with sediment waves and bank structures. The vast majority of the site is below 0.5° (Figure 4-3). No evidence of slope instability or previous slope failure was found based on the available information.

There is evidence for sediment transport in the form of sediment waves, although the extent of their mobility is unknown at present. Similarly, there is evidence for seabed morphodynamic change at the bank from repeat survey changes (Figure 4-21), although this is caveated by the fact that the repeat data was collected using different sources (SES and MBES) and at different resolutions. But it is a preliminary indication of potential change at the site over time. Scour marks was noted at various shipwreck sites across the site suggesting there is a potential for scour Figure 4-18.

Exposed till and/or bedrock was also identified in the nearshore area of the export cable corridor to Shanganagh (Figure 4-10). Till can be over-consolidated, highly heterogeneous and may also contain boulders and cobbles, which will need to be considered in further cable engineering studies.

Is should also be noted that depth to bedrock could not be definitively established based on current data, which poses a significant risk to the construction of offshore wind turbines. This needs to be mitigated through future geophysical and geotechnical site investigation works that will determine depth to bedrock across the OWF site.

No evidence for shallow gas has been found on surface (i.e. MBES) data to date. However acoustic blanking was observed in Unit 1. This acoustic blanking appears to have a migratory nature and seems to be present within different levels of the laminations within Unit 1, interpreted to be alternating laminations of clay and sand. Where this acoustic blanking is present, associated enhanced horizons/laminations are observed overhead. Also the laminations, as well as all other sub-bottom detail beneath these enhanced horizons, terminate abruptly on the limits of this acoustic blanking and cannot be followed beneath. While it is difficult to confirm whether the cause of this acoustic blanking is shallow gas from seismic data alone, further in-depth investigation with a lower frequency seismic source (sparker or mini-airgun) may give more definitive results as to the source of the acoustic blanking. It also needs to be considered that this data was collected during campaigns spread over 5 different years with the oldest dating back to 2003. Also 2 different vessels and pinger profilers were used, as well as recording the data in varying states of good and marginal weather. All of these variables make a definitive source for this acoustic blanking difficult to verify. A dedicated two profiler survey, possibly pinger and sparker, would be recommended so as to get an updated and clearer view of this acoustic blanking. Also a side scan sonar and updated multibeam dataset would be required to see if there are any surface indicators indicating shallow gas release at the seabed. Due to its apparent migratory nature from the base of unit 1, an organic source e.g. Peat, seems less likely but cannot be ruled out at this stage. Also accumulations of cobbles can also be a source of acoustic blanking. A geotechnical sampling investigation, CPT or borehole, would provide more conclusive results. However, as the pressure of any potential shallow gas is not known, a CPT investigation would be the safer option with the added benefit of being a combined geotechnical and geohazard risk investigation which would verify the geophysical results and remove uncertainties regarding the source of the acoustic blanking.

It should be noted that the BGS chart of quaternary geology for the area quotes the presences of "gas blanking" within the Quaternary deposits (Figure 9-2).

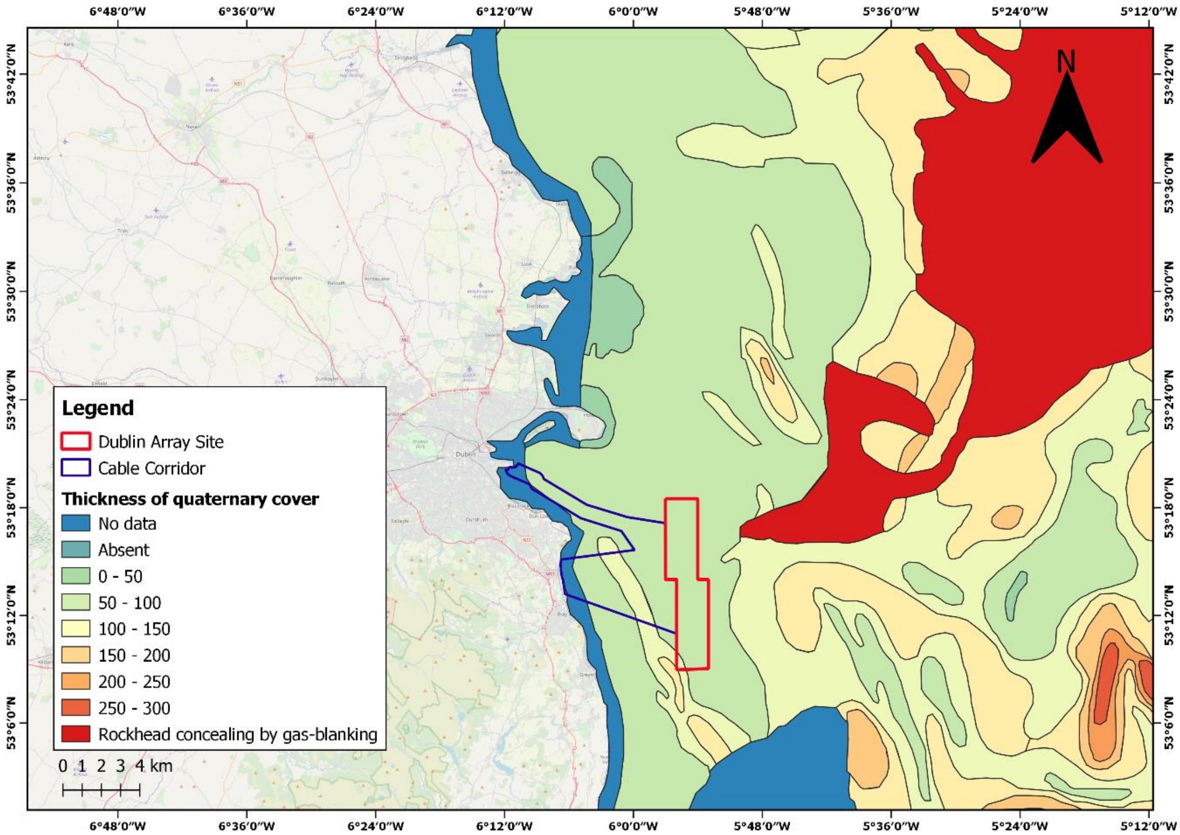


Figure 9-2 Thickness of quaternary deposits, gas blanking (BGS GSI ANGLESEY)

10Conclusions and Recommendations

10.1 Reliance on the Existing Data

Bathymetric data was collected by Hydrographic Surveys Ltd between June and September 2008 as part of the original Environmental Impact Statement (EIS) and provides more than 90% coverage of the offshore wind farm site, and a narrow route within the proposed Export Cable corridor to Shanganagh. The data was gathered using single-beam echosounder (SBES) at an approximate line spacing of 20m. Additional surveys were undertaken across the offshore wind farm area and proposed export cable corridors in 2003, 2008, 2008, 2010, 2012 and 2016 as part of the INFOMAR programme, which provide 100% coverage of the Dublin Array site and close to 100% coverage of export cable corridors. The data was acquired using multi-beam echosounder (MBES) gridded to approximately 5m resolution, which details site bathymetry and sediment classification through backscatter analysis. This data was processed to INFOMAR standards (International Hydrographic Organisation) and provides satisfactory quality, allowing for the identification of features to a high resolution. The data is of high quality and can be relied upon. However, the data would need to be updated considering that the oldest dataset used dates back to 2003. The existing data is of suitable quality for route selection and early stage design; however it is recommended that a confirmation bathymetric survey is completed in advance of the construction along the preferred export cable route and within the offshore wind farm site.

The sub-bottom profiler (SBP) data was acquired at the site using pinger equipment. The six available relevant geophysical datasets from the INFOMAR programme provide over 78% coverage of the combined offshore wind farm site and proposed export cable corridors. As discussed in Section 6.1, the different datasets were of varying quality resulting in areas of survey lines which have no associated geophysical interpretation. Also 21.8% of the survey area was affected by acoustic blanking, which masked underlying shallow geological layering. Considering the percentages of the site where actual geological units were picked (see Section 6), it is recommended that a dedicated two profiler surveys, possibly pinger and sparker, be undertaken so as to get an updated and clearer view of areas of acoustic blanking, areas with no SBP coverage, and locations where no seismic reflectors could be resolved at depth. These recommendations are expanded upon in subsequent sections.

10.2 Considerations for offshore wind development

Based on the review of available data and the associated ground model, the following development issues and preliminary geological and geotechnical constraints are noteworthy in the context of offshore wind development:

- Monopiles - The combination of relatively shallow water and the presence of sands at shallow depths suggests that traditional driven Monopiles are likely to be the preferred foundation type for this project. It is recommended that a foundation concept design study is undertaken to explore the foundation engineering further, however the potential for shallow bedrock within the main array area remains a project risk that needs to be resolved as a high priority. In the event that bedrock was encountered within the upper 35m, this could prevent driven monopiles being viable, resulting in a step change increase in foundation costs and a significant negative impact on the project LCOE.

- The shallow water present at the site has a wide range of impacts on the project development:
    - These waters may not meet the minimum draft requirements for turbine installation vessels requiring the site to be delineated into buildable development zones and exclusion zones ;
    - If exclusion zones are applied, then the bank features will have a significant impact on the array layout ;
    - The bank features represent a risk to navigation with the potential for vessel grounding during survey work, construction of the wind farm and generally during the operations phase as vessels transit around the site ;
    - The shallow waters at the bank crest need to be considered with respect to the installability of offshore array cables ;
    - The shallow water also have a negative impact on the applicability of conventional offshore seismic testing due to the presence of shallow multiples as well as practical limitations with respect to towing survey equipment in minimum water depths ;
- The large variation in water depths may have some practical implications for the geotechnical site investigation strategy, where a combination of Jackup and DP2 vessels may be warranted.
- Sediment mobility in the form of potential sediment wave migration and scour around seabed objects represent a significant risk to the project and could have impacts on (i) the foundation design; (ii) the array layout; (iii) inter-array cable burial design and (iv) export cable burial design.
- While not as likely as the sediment dynamic impacts noted above, there is also potential for larger scale morphodynamic changes to the sand-bank itself and associated slope instability, which will need to be explored in future studies.
- The source of the acoustic blanking observed on the sub-bottom data should be delineated before any construction takes place, as recommended in Section 9.2. A detailed assessment of this can only be explored in conjunction with a detailed geophysical survey involving both pinger and sparker sources. This is critical to rule in or rule out the potential for shallow gas.
- Exposed bedrock or till along the potential cable route to Shanganagh may have an impact on the export cable route and landfall design.

10.3 Recommendations for further site investigations

The following is recommended to provide more confidence in the ground model:

i. A preliminary geotechnical site investigation campaign including a combinations of boreholes, deck-mounted CPTs, and seabed CPTs to provide ground-truthing for existing geophysical data, and enable preliminary characterisation of parameters for different units to be used as part of the FEED process – this may involve a two-vessel strategy to accommodate the range of water depth across the site. A select number of boreholes should extend to 70m with a view to identifying rockhead elevation and therefore derisking the foundation concept design.

ii. Targeted surface-sampling as part of a wider geotechnical campaign would help better understand seabed distribution and assist sediment dynamics studies;

iii. Due to the presence of acoustic blanking observed on the sub-bottom data, consideration should be given to the types of seismic profilers to be mobilised for any subsequent geophysical surveys as well as the type of CPT cones to be used. A dedicated two profiler seismic survey, possibly pinger and sparker, combined with side scan sonar and updated multibeam surveys would provide a clearer view into the nature of the acoustic blanking. Additional CPT investigation incorporating shallow gas probe would also enable verification of the geophysical results and remove uncertainties associated with the source of the acoustic blanking.

iv. Given the presence of exposed till and/or bedrock along the Shanganagh export cable corridor, the potential presence of shallow/surface boulders cannot be ignored and therefore a detailed geophysical survey specifically targeting large boulder identification may be required, should the client pursue this export cable route option;

v. We also recommend a site specific metocean survey be undertaken as a priority to gather available data on seabed current conditions and wave loading parameters

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APPENDIX A – Geohazard risk register

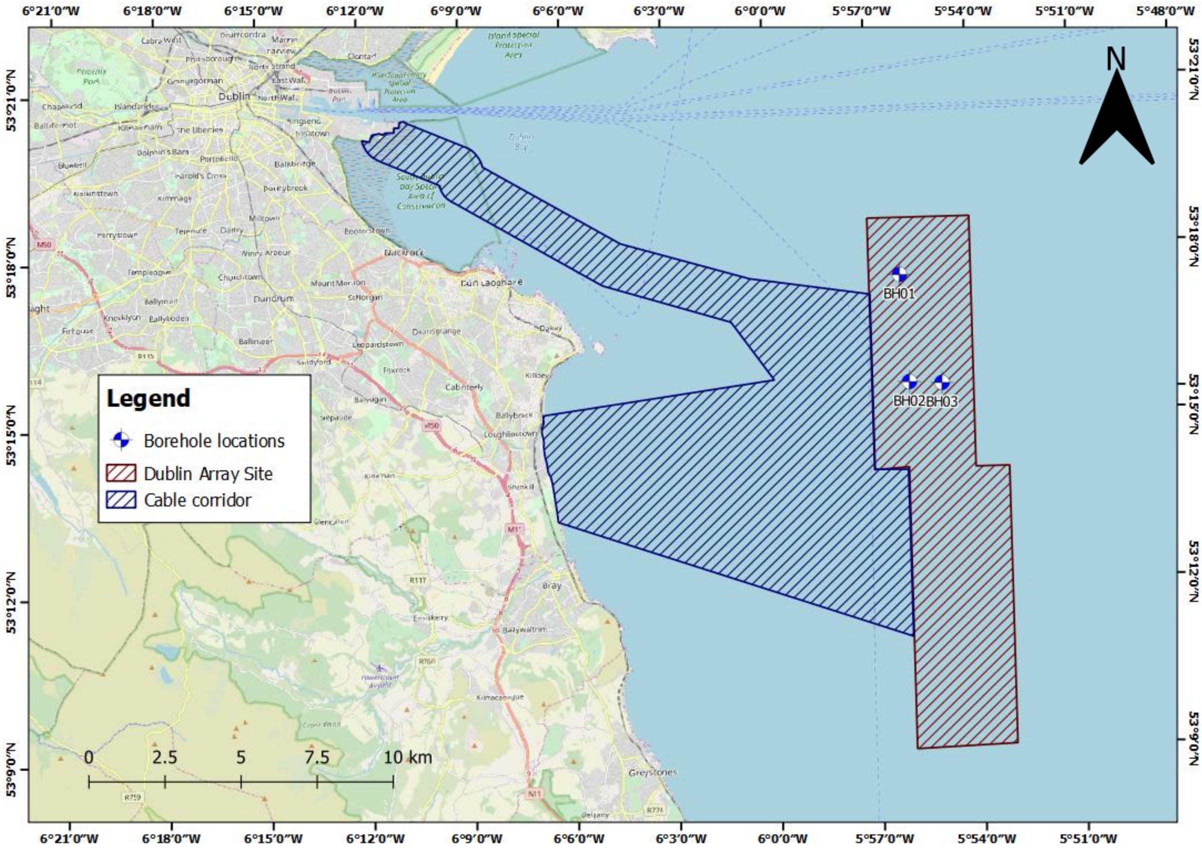
Ref	Hazard	Risk	Mitigation
1	Shallow bedrock within the Export Cable Route area	Cable installation risks including ploughing and cable burying.	Cable burial analysis to be completed and adoption of adequate subsea cable installation equipment.
2	Depth to bedrock within the OWF could not be determined	Poses significant risk to the construction of offshore wind turbines	A dedicated geophysical survey to determine the depth to bedrock within the OWF area
3	Dynamic seabed regime	Scour potential	Scour analysis to be undertaken, and scour mitigation measures adopted, where necessary. Implement scour monitoring regime after foundations are installed
4	Seabed mobility	Risk of reducing the burial cover or exposing a previously buried cable which can lead to damaging the cable from an external threat	Additional dedicated MBES campaign would help to assess the mobility rate and allow undertaking a more detailed study to mitigate the hazard. Undertake a dedicated sediment dynamics transport study
5	A shallow bank structure (Fraser Bank), traversing the cable route to Shanganagh	May be problematic for certain types of burial equipment	Avoid the structure if possible
6	Shallow water depths created by bank features within the OWF site and large depth variation across the site	Can pose a significant limitation for operation of turbine installation vessels. Can also impact on general vessels transiting the site	The large range of variation in water depth across the site may necessitate a two-vessel strategy for geotechnical site investigation works involving jack-up platforms at shallow waters and dynamic positioning vessels at deeper locations.
7	Shipwrecks within the cable routes	Not possible to lay the cable in places where shipwrecks are located and in their vicinity	Need to be avoided during cable laying including a certain buffer. Establish buffer zone around all wrecks.
8	Slopes greater than 5° - cable route	Steep slopes may be problematic for certain types of burial equipment	Ideally should be avoided to maximize cable stability and minimize areas of free span.
9	Slopes greater than 5° - OWF	Steep slopes may be problematic for installation of the turbines	Consider array layout to avoid if possible
10	Potential Explosive Ordnance (pUXOs)	Risk of potential UXO contact leading to explosion during either SI campaign or construction	Complete UXO desktop study. Avoid locations where UXO risk is identified by adopting adequate buffer zones.
11	Acoustic blanking –	•H&S risks during site	Carry out a dedicated two

Ref	Hazard	Risk	Mitigation
	potential presence of shallow gas	investigations & foundation piling / installation; • Project certification / verification for WTG foundations; • Alleviating concerns of a lender's technical advisor for project financing; • Ongoing monitoring and management of issue during O&M phase.	profiler survey to get an updated and clearer view of this acoustic blanking. Side scan sonar and updated multibeam dataset would be required to see if there are any surface indicators indicating shallow gas release at the seabed. A CPT investigation would also be recommended with the added benefit of being a combined geotechnical and geohazard risk investigation which would verify the geophysical results and remove uncertainties regarding the source of the acoustic blanking.
12	Unknown seabed archeology / wrecks	Risk of obstructions impacting on array layout and/or best practice.	Undertake further geophysical site investigation including multi-beam echosounder (MBES), side scan sonar (SSS) and magnetometer survey across the site. Undertake archaeological assessment of the geophysical results (SSS and magnetometer contacts) to determine the historical or archaeological value of contacts, and validate the coordinates, and size of known wrecks. Establish exclusion buffers around potential wrecks in accordance with best practice, where possible.
13	Unforeseen ground conditions	Foundation design not appropriate for the conditions encountered or alternatively installation process not appropriate for the conditions encountered.	Complete sensitivity study during design phase to build some robustness into the foundation design/installation process

APPENDIX B – Borehole logs in the offshore wind farm area (Glover 2008)

Glover 2008 Borehole Locations

Borehole ID	Latitude [°]	Longitude [°]
BH01	53.2934	-5.9364
BH02	53.2605	-5.9324
BH03	53.2601	-5.9184



BH01

Depth [m]	SPT N Value	Level [mCD]	Depth [m] (Thickness)	Description	Legend
0.00-0.45	7			Loose grey silty fine to medium SAND with a trace of fine gravel and occasional shells	
1.00-1.45	8		(3.00)		
2.00-2.45	8				
3.00-3.45	43	-7.50	3.00	Dense grey silty fine to coarse SAND with a trace of fine to medium gravel and occasional shells	
4.00-4.45	37				
5.00-5.45	45				
6.00-6.45	43				
7.00-7.45	38		(7.00)		
8.00-8.45	36				
9.00-9.45	33				
10.00-10.45	36	-14.50	10.00	Dense grey slightly silty fine to medium SAND with occasional shells	
11.00-11.45	42				
12.00-12.45	37		(5.00)		
13.50-13.95	37				
15.00-15.45	62	-19.50	15.00	Very dense grey slightly silty fine to medium SAND with occasional shells	
16.50-16.95	65				
18.00-18.45	56		(5.00)		
19.50-19.95	51	-24.50	20.00		

BH02

Depth [m]	SPT N Value	Level [mCD]	Depth [m] (Thickness)	Description	Legend
0.00-0.45	14			Medium dense grey slighly silty fine to medium SAND with occasional cobbles	
1.00-1.45	13				
2.00-2.45	17		(3.20)		
3.00-3.45	51	-16.30	3.20		
4.00-4.45	42			Dense grey slightly silty fine to coarse SAND with a trace of fine to medium gravel and occasional shells	
5.00-5.45	41				
6.00-6.45	67				
7.00-7.45	48		(6.80)		
8.00-8.45	47				
9.00-9.45	47				
		-23.10	10.00		
11.00-11.45	40		(2.00)	Dense grey slightly silty fine to medium SAND with occasional shells	
12.00-12.45	60	-25.10	12.00	Very dense grey slightly silty fine to medium SAND with occasional shells	
13.50-13.95	61				
15.00-15.45	56		(7.10)		
16.50-16.95	62				
18.00-18.45	57				
		-32.20	19.10		

BH03

Depth [m]	SPT N Value	Level [mCD]	Depth [m] (Thickness)	Description	Legend
0.00-0.45	17			Medium dense grey silty fine to medium SAND with occasional shells	
1.00-1.45	15				
2.00-2.45	14				
3.00-3.45	14		(6.00)		
4.00-4.45	15				
5.00-5.45	16				
6.00-6.45	68	-13.30	6.00	Very dense grey slightly silty fine to medium SAND with occasional shells	
7.00-7.45	54				
8.00-8.45	53		(4.00)		
9.00-9.45	51				
10.00-10.45	43	-17.30	10.00	Dense grey slightly silty fine to medium SAND with occasional shells	
11.00-11.45	42		(2.30)		
12.00-12.45	43	-19.60	12.30	Very dense grey slightly silty fine to medium SAND with occasional shells	
13.50-13.95	55				
15.00-15.45	65		(7.70)		
16.50-16.95	57				
18.00-18.45	58				
19.50-19.95	66	-27.30	20.00		

APPENDIX C – Borehole logs in the Dublin Bay Area (Fugro 2011)

Based on Fugro Engineering Services Ltd site report four cross sections (Figure 0-2 to Figure 0-5) were generated to illustrate encountered succession of strata. Locations of the profiles are shown on Figure 0-1.

On the western side of the profiles, in the majority of the boreholes, the most superficial layer is sand. It changes to clay in the eastern part. Underneath there are bands of clay, gravel and sand in various combinations. Bedrock was encountered from 10 to 52mBSF and is made of limestone.

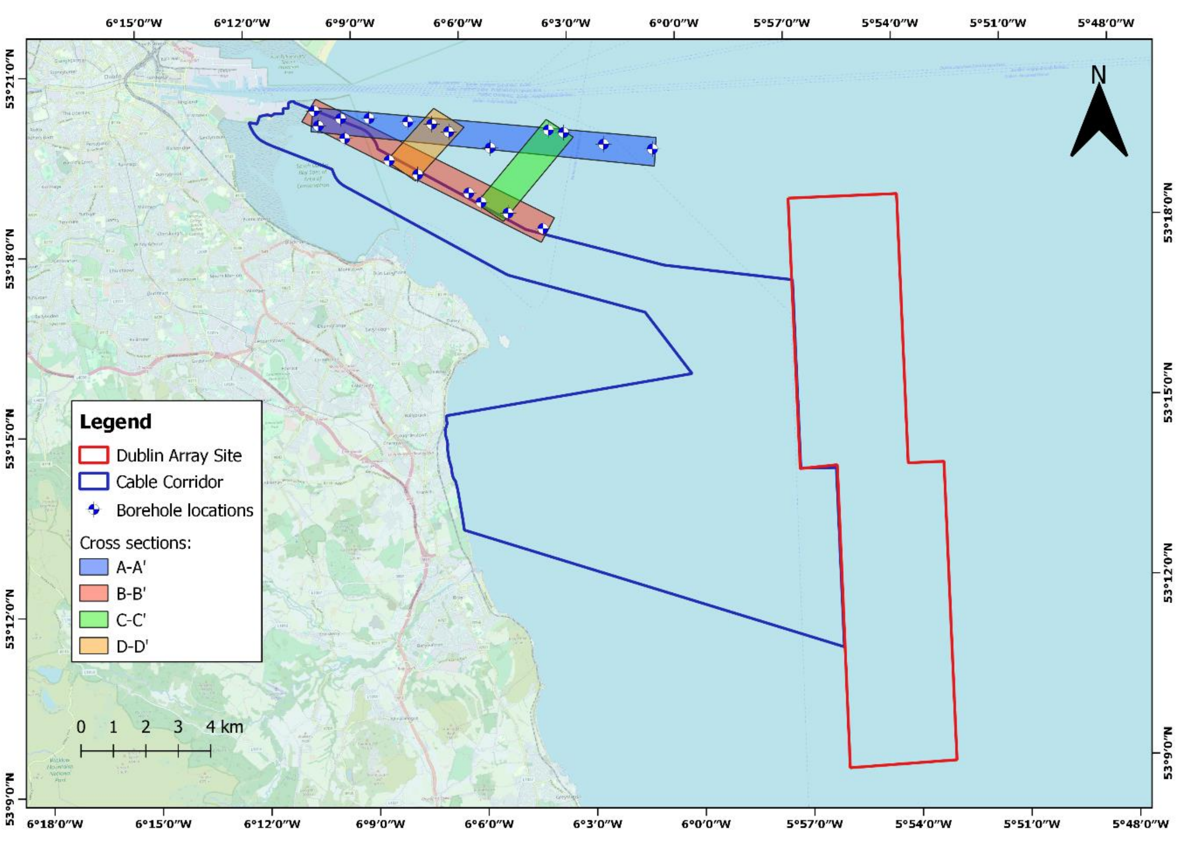


Figure 0-1 Cross sections locations

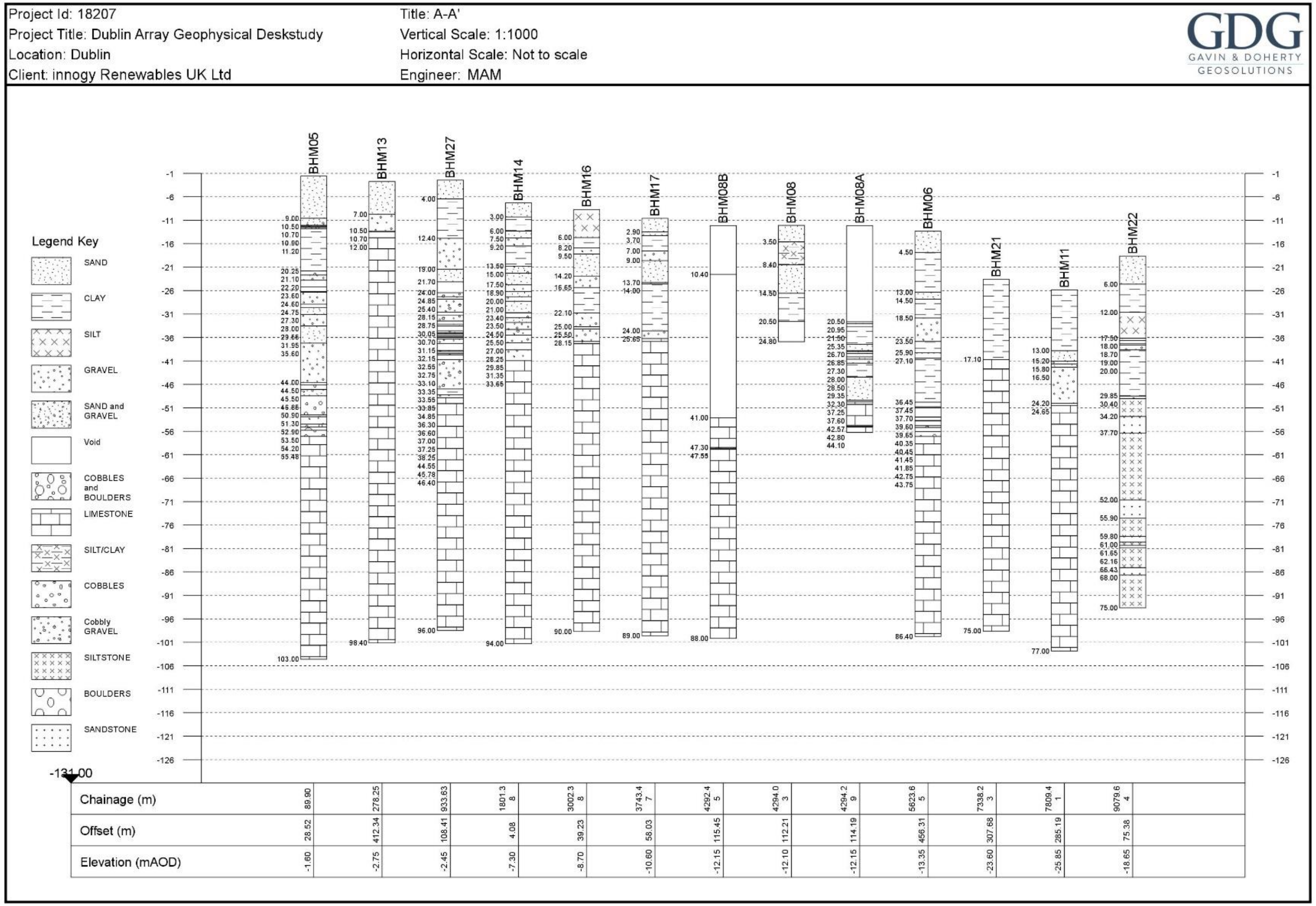


Figure 0-2 A-A' cross section

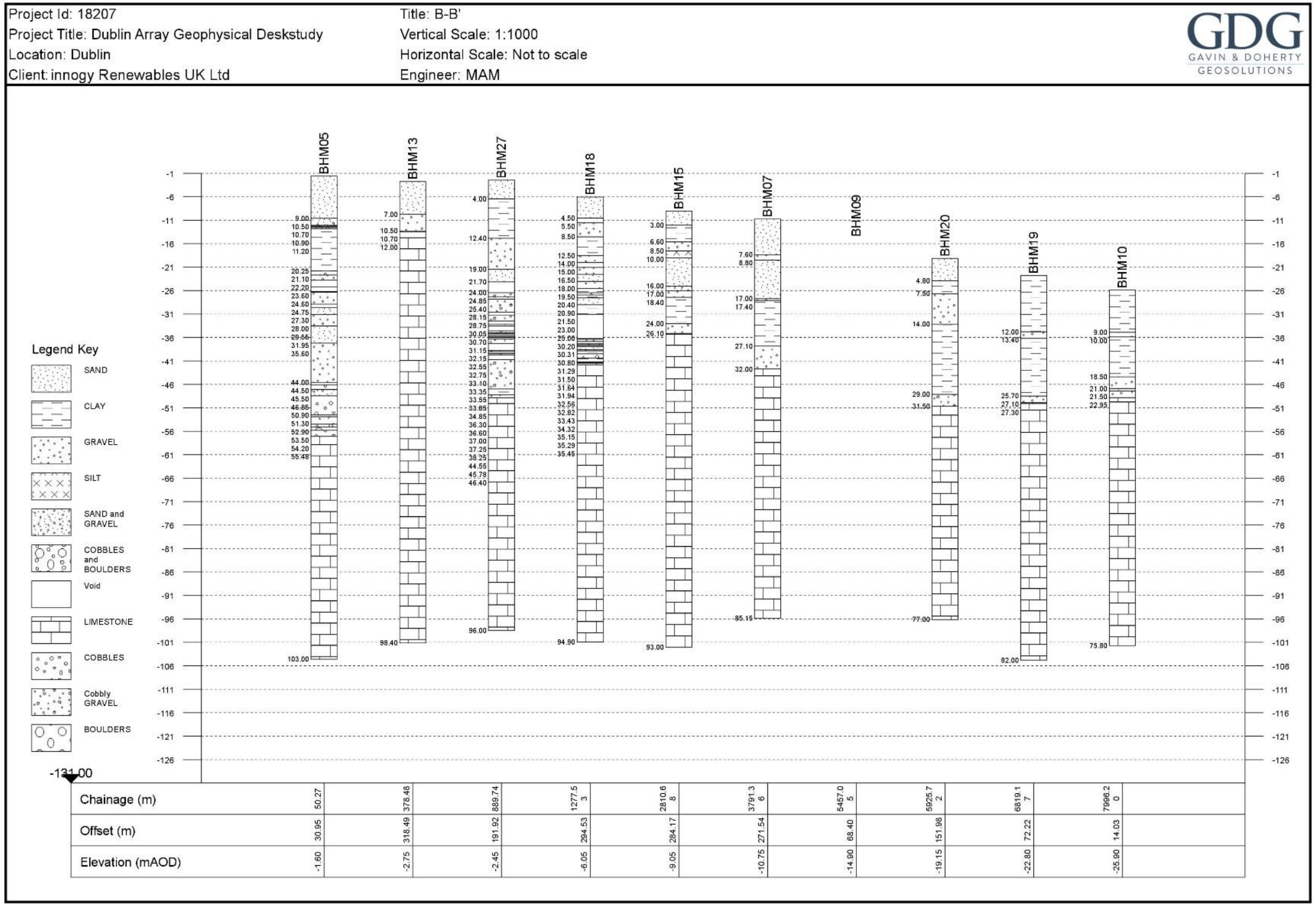


Figure 0-3 B-B' cross section

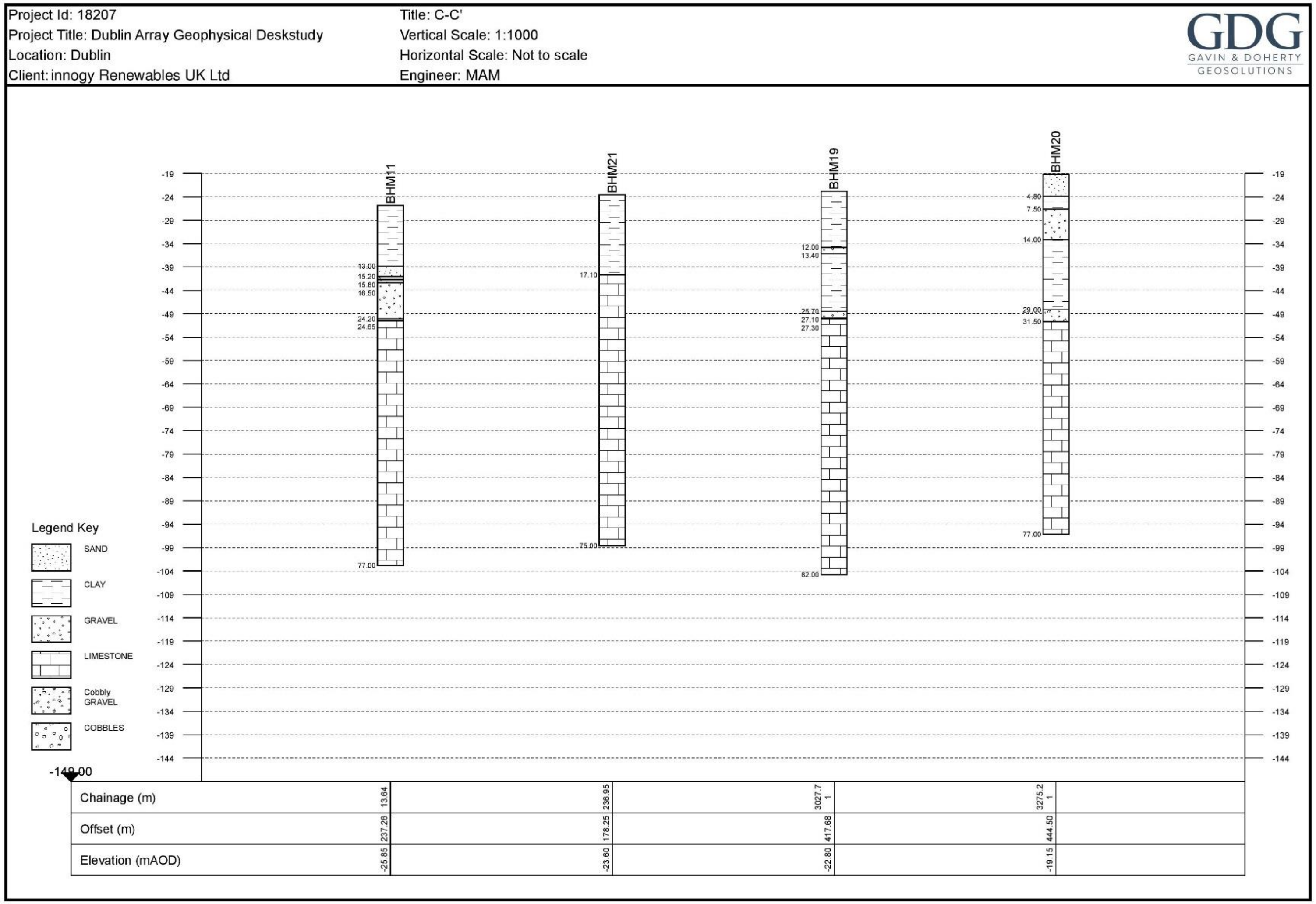


Figure 0-4 C-C' cross section

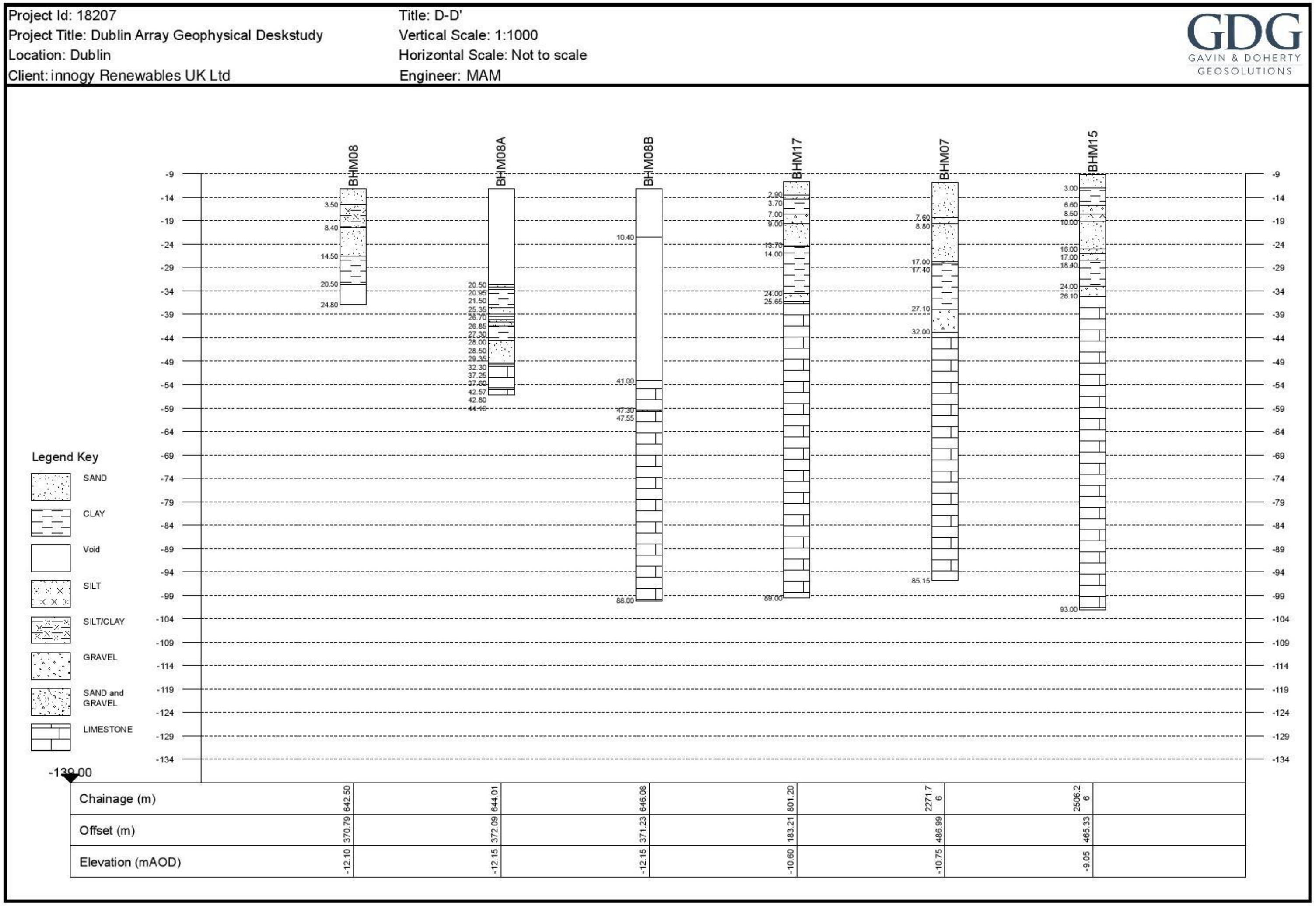


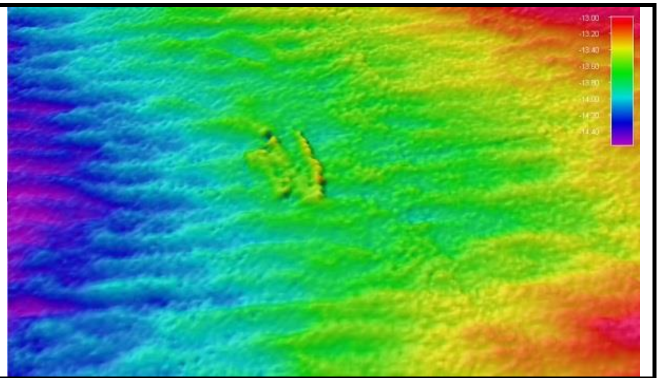
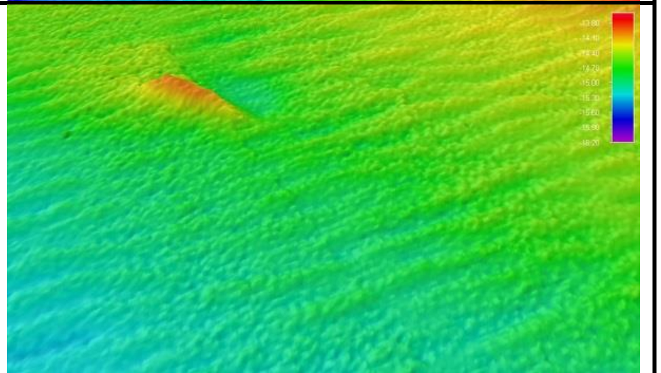
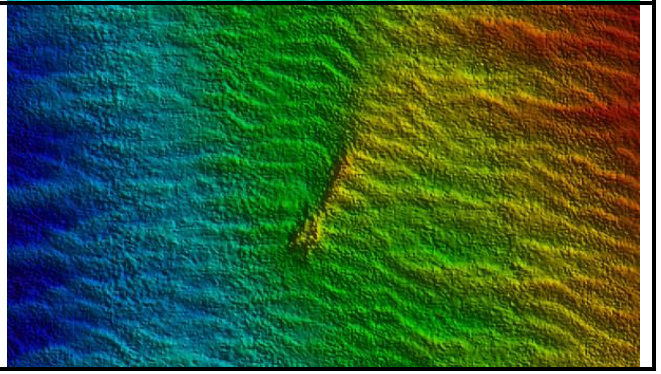
Figure 0-5 D-D' cross section

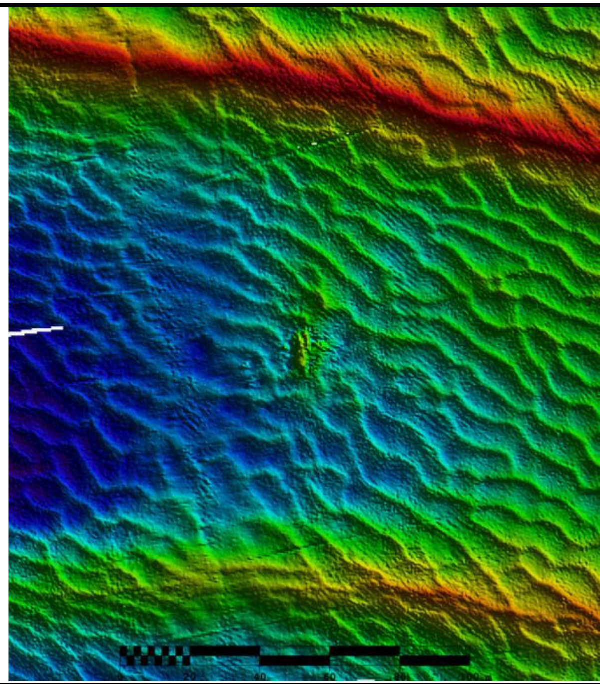
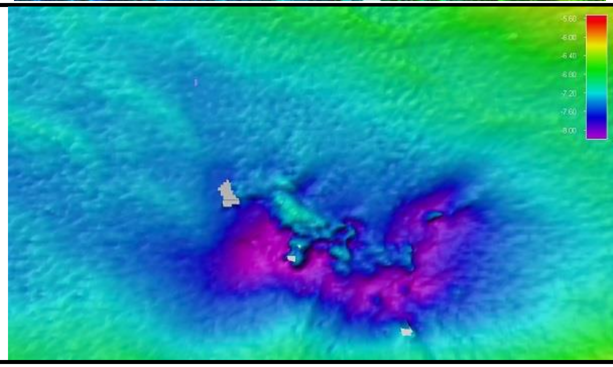
APPENDIX C – Shipwreck location, dimensions, description and image

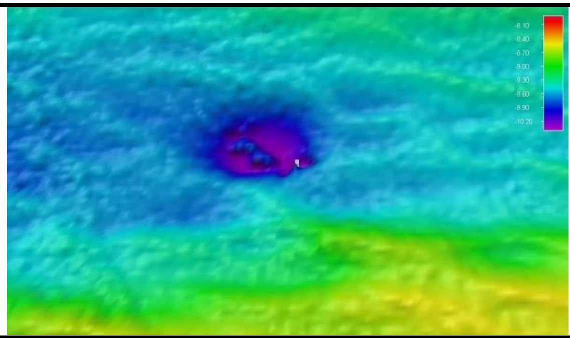
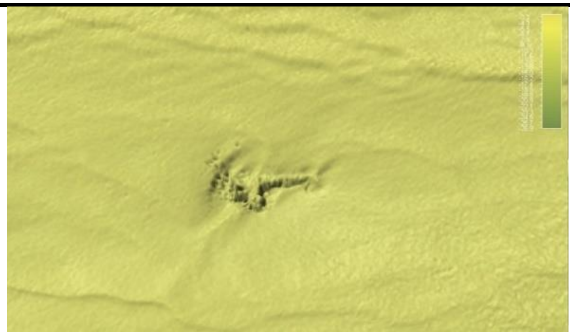
Wreck Name/No.	Source	NMS/GSI Ref.	Lat. (DD)	Long (DD)	Feature length (m)	Feature Width (m)	Water Depth (m)	Description/Image
Loch Fergus	NMS	W01828	53.24667	-6.10667	---	---	---	874 tons, 23/24 year old Iron barque of Liverpool / Glasgow. Classed as 100 A1 by Lloyds.
Wreck 14	NMS	W01544	53.32575	-6.16793	---	5	---	Dutch dredging company discovered a wreck in June 1989 while excavating route for new sewerage pipe. Wreck lay exposed in the southern bank of the trench, measuring c. 15ft across and consisting of a wooden framework.
Wreck 15	NMS	W11334	53.30132	-5.9191	---	---	---	Not known
Wreck 16	NMS	W11333	53.26	-5.93542	---	---	---	Not known
Wreck 17	NMS	W11338	53.26346	-5.93812	---	---	---	Not known
Wreck 18	NMS	W11337	53.26226	-5.93818	---	---	---	Not known
Wreck 19	NMS	W10297	53.25722	-5.92583	---	---	---	Not known
Wreck 20	NMS	W10276	53.25417	-5.92347	---	---	---	Not known
Wreck 21	NMS	W11331	53.2666	-5.93355	---	---	---	Not known
Wreck 22	NMS	W10597	53.23305	-6.02083	---	---	---	Not known
Wreck 23	NMS	W11365	53.22067	-6.07505	---	---	---	Not known
Wreck 24	NMS	W11361	53.23887	-6.09263	---	---	---	Not known

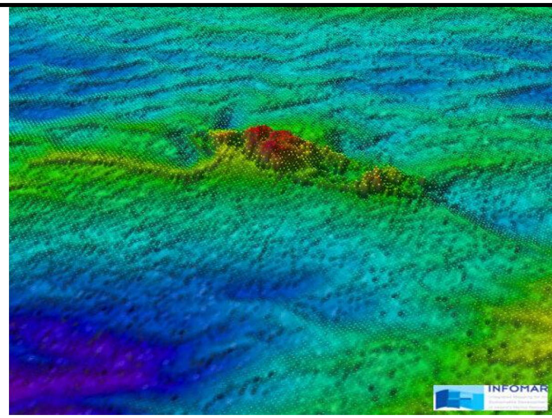
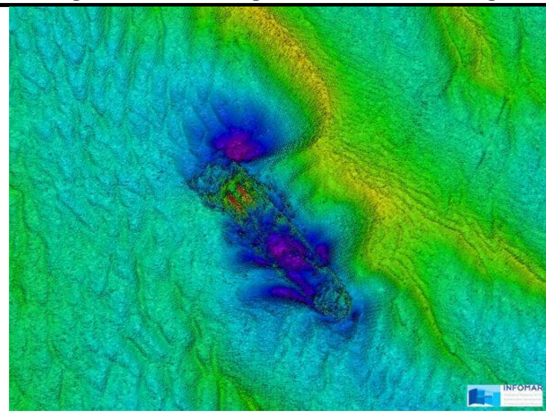
Wreck 25	NMS	W11367	53.23018	-6.0902	---	---	---	Not known
Wreck 26	NMS	W11366	53.23766	-6.10212	---	---	---	Not known
Wreck 27	NMS	W11340	53.258	-5.93581	---	---	---	Not known
Wreck 28	NMS	W11339	53.25694	-5.9342	---	---	---	Not known
Wreck 29	NMS	W11360	53.24372	-6.10193	---	---	---	Not known
Wreck 30	NMS	W11341	53.26349	-5.93744	---	---	---	Not known
Wreck 31 "Ringsend Wreck"	NMS	W11571	53.33646	-6.17801	---	---	---	Wooden wreck.
Wreck 32 "Ringsend Wreck"	NMS	W11570	53.33625	-6.17844	---	---	---	Wooden wreck.
Wreck 34	NMS	W11581	53.25038	-5.93005	---	---	---	Wooden wreck known as the '9.5 fathom wreck'.
Wreck 35	NMS	W11567	53.33705	-6.18	---	---	---	Re-deposited ship timbers.
Wreck 36	NMS	W11566	53.33704	-6.1798	---	---	---	Re-deposited ship timbers.
Wreck 37	NMS	W11569	53.33703	-6.18041	---	---	---	Re-deposited ship timbers.
Wreck 38	NMS	W11568	53.33704	-6.18016	---	---	---	Re-deposited ship timbers.
Wreck 39	NMS	W01734	53.33625	-6.17844	---	---	---	Wooden wreck, known as the Ringsend Wreck became exposed during dredging operations for the Dublin Bay pipeline in April 2001.

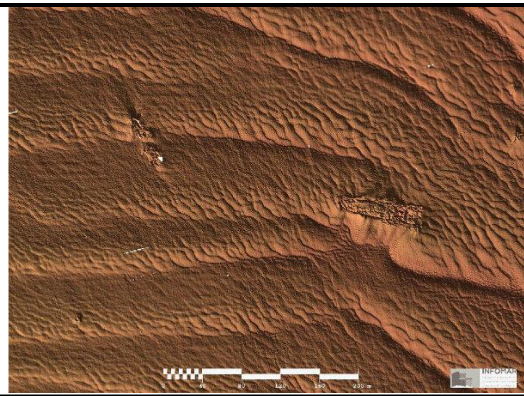
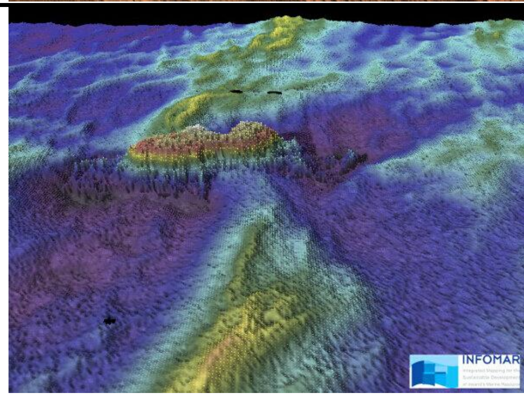
Wreck 40	NMS	W01630	53.26722	-5.9325	17	---	8 to 10	Wooden wreck discovered by Marlin Sub Aqua Club in 2003. The wreck is partially exposed on the seabed in 8-10m of water and is upside down. Hull is copper-sheeted.
Wreck 42	NMS	W01533	53.3118	-6.10214	---	---	10	One of four wrecks marked on a chart (Admiralty Chart 1415) of Dublin. It is located in about 10m of water.
Wreck 44	NMS	W01532	53.31217	-6.11119	---	---	10	One of 4 wrecks marked on a chart (Admiralty Chart 1415) of Dublin. It is located in about 10m of water.
Wreck 45	NMS	W01629	53.2621	-5.92517	---	---	8 to 10	Remains of a 300-400 ton vessel (approx.) wooden wreck. Discovered by Marlin Sub Aqua Club in 2003. The vessel is partially exposed on the seabed in 8-10m of water.
Wreck 46	NMS	W11350	53.14619	-5.88965	---	---	---	Not known
Trustful	NMS	W01593	53.16667	-5.93333	---	---	---	Sprang a leak during a SW gale while fishing off Bray Head. Crew took to the life boat and were picked up by the Dun Laoghaire Pilot boat a few hours later.

Wreck 7	INFOMAR	282	53.265	-5.937	19	5	13.67	
Wreck 10	INFOMAR	286	53.258	-5.934	18.3	4.5	14.92	
Wreck 11	INFOMAR	287	53.254	-5.932	26.5	4.3	15.4	

Wreck 13	INFOMAR	289	53.2411	-5.91233	13.5	3.5	10.04	
Wreck 2	INFOMAR	278	53.270	-5.926	13	4	7.49	
Wreck 6	INFOMAR	281	53.267	-5.933	17	3	10.1	N/A

Wreck 8	INFOMAR	285	53.2655	-5.9305	4	1.8	10.3	
Wreck 12	INFOMAR	288	53.251	-5.930	21.2	3.7	15.1	N/A
MV Bolivar (Bow)	INFOMAR	279	53.268	-5.924	6	2	7.51	 Built by Akers of Oslo, she grossed 5,230 tons and was owned by the Fred Olsen Line. Struck the Kish Bank 4th March 1947during a severe snowstorm and freezing conditions. Despite attempts to pull herself off the bank, she broke in two.

SIR Charles Napier	INFOMAR	280	53.262	-5.925	30	7.5	7.94	 The Sir Charles Napier was a full-rigged, 3-masted, sailing ship, of 638 tons. Built in 1841 and wrecked on the Kish Bank in 1857. Her cargo was cast iron goods when she ran aground
MV Bolivar (Stern)	INFOMAR	283	53.268	-5.926	84	17	9.13	 See MV Bolivar (Bow) description

SS Vesper	INFOMAR	284	53.268	-5.930	54.8	7.8	8.65		
Glenorchy	INFOMAR	277	53.280	-5.933	69	13	6.75		 GLENORCHY iron sailing ship. 1,284 tons. Cargo was iron, coal and spirits.

APPENDIX D - Grab Samples Attributes and Faunal Data Results

Table 6 - INFOMAR Grab samples attributes (see Section 4.3.1)

Sample ID	Survey	Year	Longitude	Latitude	Depth (mLAT)	% Mud	% Sand	% Gravel	Folk Class
622	IMAGIN_05_02	2005	5° 56' 22" W	53° 11' 23" N	36.0	0	88	11	gravelly SAND
629	IMAGIN_05_02	2005	5° 56' 3" W	53° 12' 30" N	29.2	0	99	0	SAND
630	IMAGIN_05_02	2005	5° 56' 48" W	53° 12' 36" N	31.7	0	90	9	gravelly SAND
631	IMAGIN_05_02	2005	5° 57' 20" W	53° 12' 40" N	29.1	0	93	6	gravelly SAND
633	IMAGIN_05_02	2005	5° 59' 49" W	53° 12' 42" N	27.8	0	91	7	gravelly SAND
634	IMAGIN_05_02	2005	5° 59' 56" W	53° 14' 01" N	27.0	0	98	1	gravelly SAND
635	IMAGIN_05_02	2005	5° 58' 50" W	53° 14' 11" N	22.9	0	98	1	gravelly SAND
636	IMAGIN_05_02	2005	5° 58' 49" W	53° 14' 34" N	22.7	2	97	0	gravelly SAND
637	IMAGIN_05_02	2005	5° 57' 12" W	53° 14' 11" N	29.3	0	93	6	gravelly SAND
638	IMAGIN_05_02	2005	5° 56' 44" W	53° 14' 45" N	26.3	5	90	3	gravelly SAND
639	IMAGIN_05_02	2005	5° 57' 20" W	53° 14' 47" N	27.6	0	96	3	gravelly SAND
640	IMAGIN_05_02	2005	6° 0' 8" W	53° 15' 15" N	26.2	0	98	1	gravelly SAND
GE08_63	GE08_02	2008	5° 59' 49" W	53° 16' 20" N	23.9	8	91	0	SAND
GE08_64	GE08_02	2008	6° 0' 37" W	53° 13' 29" N	29.1	8	90	0	SAND
GE08_65	GE08_02	2008	6° 1' 22" W	53° 14' 09" N	29.3	13	86	0	muddy SAND
GE08_50	GE08_02	2008	6° 4' 55" W	53° 15' 11" N	14.8	17	81	1	muddy SAND
GE08_51	GE08_02	2008	6° 5' 52" W	53° 15' 05" N	12.6	9	89	1	SAND
GE08_51	GE08_02	2008	6° 5' 46" W	53° 15' 07" N	13.2	9	89	1	SAND
GE08_57	GE08_02	2008	6° 1' 3" W	53° 15' 32" N	27.6	2	83	14	gravelly SAND
GE08_58	GE08_02	2008	6° 0' 27" W	53° 16' 48" N	23.8	0	98	1	Sand
GE08_59	GE08_02	2008	5° 59' 49" W	53° 16' 34" N	23.5	1	81	17	gravelly SAND
CV11_01_8	CV11_01	2011	5° 53' 24" W	53° 10' 37" N	28.4	0	97	2	slightly gravelly SAND
CV11_01_9	CV11_01	2011	5° 53' 3" W	53° 10' 10" N	24.1	10	54	34	muddy sandy GRAVEL

Table 7 – Other MI/GSI Research surveys grab samples attributes, habitat class and number of species (see Section 4.3.1).

Sample ID	Year	Longitude	Latitude	Depth (mLAT)	PSA Description	Folk Class	Habitat Class	Number of Species
BG2	2011	6° 5' 31" W	53° 14' 25" N	16	-	No core recovery	-	-
BG3	2011	6° 4' 53" W	53° 13' 47" N	21	-	No core recovery	-	-
G2	2012	5° 56' 16" W	53° 18' 20" N	10	Fine sand with shell	SAND	SS.SSa.IFiSa.NcirBat Nephtys cirrosa and Bathyporeia spp. in infralittoral sand	10
G1	2012	5° 55' 24" W	53° 18' 18" N	19	Fine sand with shell	SAND	SS.SSa.IFiSa.NcirBat Nephtys cirrosa and Bathyporeia spp. in infralittoral sand	5
G4	2012	5° 54' 48" W	53° 16' 40" N	28	Fine sand with shell	slightly gravelly SAND	SS.SSa.IFiSa.NcirBat Nephtys cirrosa and Bathyporeia spp. in infralittoral sand	13
G5	2012	5° 55' 49" W	53° 16' 39" N	7	Fine sand with shell	SAND	No Equivalent	1
G6	2012	5° 55' 21" W	53° 15' 14" N	12	Fine sand with shell	SAND	SS.SSa.IFiSa.IMoSa Infralittoral mobile clean sand with sparse fauna	2
G7	2012	5° 56' 2" W	53° 14' 32" N	21	Fine sand with shell+ pebble	sandy GRAVEL	SS.SSa.CFiSa.ApriBatPo Abra prismatica, Bathyporeia elegans and polychaetes in circalittoral fine sand	15
G8	2012	5° 54' 57" W	53° 14' 25" N	12	Fine sand with shell	slightly gravelly SAND	SS.SSa.IFiSa.IMoSa Infralittoral mobile clean sand with sparse fauna	1
G9	2012	5° 55' 19" W	53° 12' 48" N	20	Fine shell with sand	gravelly SAND	SS.SSa.CFiSa.ApriBatPo Abra prismatica, Bathyporeia elegans and polychaetes in circalittoral fine sand	6
G11	2012	5° 53' 41" W	53° 09' 05" N	20	Cobbles and fine sand	sandy GRAVEL	SS.SMx.CMx.OphMx Ophiothrix fragilis and/or Ophiocomina nigra brittlestar beds on sublittoral mixed sediment	63

Table 8 - Sediment Analysis Results from the 2005 Benthic Survey [22]

Station Number	Longitude	Latitude	Depth (mLAT)	% Gravel	% Very Coarse Sand	% Coarse Sand	% Medium Sand	% Fine Sand	% Very Fine Sand	% Silt/Clay	Folk Class
KB2	5°55.42' N	53°18.12' W	18.0	3.44	5.02	0.74	2.25	78.37	10.08	0.09	SAND
KB3	5°55.00' N	53°18.16' W	23.8	0	0.13	0.43	1.47	87.28	10.41	0.28	SAND
KB4	5°56.10' N	53°17.00' W	6.0	0	0.91	0.95	55.34	41.59	0.99	0.27	SAND
KB5	5°55.60' N	53°17.05' W	11.2	1.11	0.85	0.85	3.45	84.36	9.04	0.36	SAND
KB6	5°54.60' N	53°17.07' W	29.7	1.21	1.34	1.01	1.61	67.85	26.08	0.88	SAND
KB7	5°55.90' N	53°15.95' W	9.2	12.32	15.37	1.84	8.04	51.67	10.68	0.79	gravelly SAND
KB8	5°55.50' N	53°16.00' W	7.6	3.65	3.11	4.1	26.03	57.15	5.47	0.34	SAND
KB9	5°55.55' N	53°16.10' W	7.8	---	---	---	---	---	---	---	---
KB10	5°55.60' N	53°14.95' W	13.7	16.48	7.68	10.62	41.34	23.45	0	0.43	gravelly SAND
KB11	5°55.00' N	53°15.00' W	9.1	0	2.62	6.65	47.17	40.85	2.32	0.39	SAND

Table 9 - Sediment analysis results from the study 'Geological Appraisal of the Kish, Burford, Bray and Fraser Banks, Outer Dublin Bay Area', 1998 [23]

Sample Number	Latitude	Longitude	Depth (mLAT)	% Gravel	% Sand	% Mud	Folk Class
KB 27	53° 16' 8.49" N	5° 59' 50.22" W	24.2	0	97	3	SAND
KB 28	53° 16' 39.85" N	5° 59' .44" W	23.8	31	68	1	GRAVEL
KB 31	53° 17' 39.03" N	5° 55' 41.41" W	13.6	0	100	0	SAND
KB 32	53° 18' 1.74" N	5° 54' 18.32" W	30.3	0	95	5	SAND
KB 40	53° 17' 5.46" N	5° 54' 12.99" W	30.7	0	100	0	SAND
KB 41	53° 17' 1.80" N	5° 54' 25.34" W	31.1	0	100	0	SAND
KB 43	53° 16' 42.69" N	5° 54' 32.03" W	30.1	0	100	0	SAND
KB 53	53° 15' 15.12" N	5° 54' 27.92" W	26.2	3	96	1	slightly gravelly SAND
KB 64	53° 13' 21.12" N	5° 53' 29.15" W	33.0	3	94	3	slightly gravelly SAND
KB 76	53° 10' 54.05" N	5° 53' 3.85" W	28.7	18	81	1	gravelly SAND
KB 77	53° 10' 40.56" N	5° 53' 50.32" W	27.6	52	47	1	sandy GRAVEL
KB 85	53° 15' 6.07" N	5° 55' 48.25" W	15.3	3	96	1	slightly gravelly SAND
KB 86	53° 15' 14.54" N	5° 56' 13.30" W	19.5	0	90	10	muddy SAND
KB 87	53° 15' 25.18" N	5° 56' 18.75" W	19.5	1	99	0	slightly gravelly SAND
KB 88	53° 15' 34.36" N	5° 57' 2.22" W	25.9	1	99	0	slightly gravelly SAND
KB 89	53° 14' 36.42" N	5° 57' 1.68" W	28.7	1	98	1	slightly gravelly SAND