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APPENDIX EE

Potential Scour Analysis

Prepared for

Beacon Wind LLC

Photo credit: Matt Goldsmith, Equinor

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Abbreviations and Acronyms

Acronym	Definition
ac	acre
BOEM	Bureau of Ocean Energy Management
BW1	Beacon Wind 1
BW2	Beacon Wind 2
CFR	Code of Federal Regulations
cm	centimeters
COP	Construction and Operations Plan
CY	Cubic yard
D	Pile or Suction Bucket Diameter
ft	feet
FHWA	Federal Highway Administration
GIS	Geographic Information System
H	Horizontal
ha	hectare
HEC-18	Hydraulic Engineering Circular Number 18
HEC-23	Hydraulic Engineering Circular Number 23
HVAC	High Voltage Alternating Current
HVDC	High Voltage Direct Current
HSV	Horseshoe Vortex
IHO	International Hydrographic Organization
ISO-NE	Independent System Operator New England
in	inches
KC	Keulegan-Carpenter Number
km	kilometer
kV	Kilovolt
m	meters
MBES	Multi Beam Echo Sounder
mi	mile
MMT	MMT Sweden AB
MLLW	Mean Lower-Low Water
MW	Megawatt
nm	Nautical mile
NOAA	National Oceanographic and Atmospheric Administration
NY ISO	New York Independent System Operator
NYSERDA	New York State Energy Research and Development Authority
OCS	Outer Continental Shelf
OWF	Offshore Wind Farm
PDE	Project Design Envelope
POI	Point of Interconnect
ROV	Remotely Operated Vehicle
Std	Standard Deviation

Abbreviations and Acronyms	
Acronym	**Definition**
SSS	Side Scan Sonar
TSHD	Trailing Suction Hopper Dredge
USACE	United States Army Corps of Engineers
USGS	United States Geologic Survey
V	Vertical
WEA	Wind Energy Area

EE.1 Introduction

EE.1.1 Beacon Wind Project Background

Beacon Wind LLC (Beacon Wind) proposes to construct and operate an offshore wind facility located in the designated Renewable Energy Lease Area OCS-A 0520 (Lease Area). The Lease Area covers approximately 128,811 acres (ac; 52,128 hectares [ha]) and is located approximately 20 statute miles (mi) (17 nautical miles [nm], 32 kilometers [km]) south of Nantucket, Massachusetts and 60 mi (52 nm, 97 km) east of Montauk, New York. The Lease Area was awarded through the Bureau of Ocean Energy Management (BOEM) competitive renewable energy lease auction of the Wind Energy Area (WEA) offshore of Massachusetts. Beacon Wind is indirectly owned by Equinor U.S. Holdings Inc. and bp Wind Energy North America Inc.

Beacon Wind proposes to develop the entire Lease Area in two wind farms, known as Beacon Wind 1 (BW1) and Beacon Wind 2 (BW2) (collectively referred to hereafter as the Project). The individual wind farms within the Lease Area will be electrically isolated and independent from the other via transmission systems that connect two separate offshore substations to two onshore Points of Interconnection (POIs). However, if BW1 and BW2 both interconnect with the New York Independent System Operator (NY ISO), the Project will assess the possibility of cable linkage between BW1 and BW2. T Each wind farm will gather the power from the associated turbines to a central offshore substation and deliver the generated power via a submarine export cable to an onshore substation for final delivery into the local utility distribution system at the selected POI. The purpose of the Project is to generate renewable electricity from an offshore wind farm(s) located in the Lease Area. The Project addresses the need identified by northeast states to achieve offshore wind goals: New York (9,000 megawatts [MW]), Connecticut (2,000 MW), Rhode Island (up to 1,000 MW), and Massachusetts (5,600 MW).

BW1 will be developed first and constitutes the northern portion of the Lease Area. It covers approximately 56,535 ac (22,879 ha). The BW1 wind farm has a 25-year offtake agreement with the New York State Energy Research and Development Authority (NYSERDA) to deliver the power to its identified POI in Queens, New York.

BW2 spans the southern portion of the Lease Area and will be developed after BW1. It covers approximately 51,611 ac (20,886 ha). Beacon Wind is considering an Overlap Area of 20,665 ac (8,363 ha) that may be included in either wind farm. BW2 is being developed to addresses the need for renewable energy identified by states across the region, including New York, Massachusetts, Rhode Island, and Connecticut. The interconnectedness of the New England transmission system, managed by the New England ISO (ISO-NE), allows a single point of interconnection in the region to deliver offshore wind energy to all of the New England states (Connecticut, Rhode Island, Massachusetts, Vermont, New Hampshire, and Maine). The magnitude of regional targets for offshore wind and the limited amount of developable area, given current and reasonably foreseeable BOEM leasing activity, demonstrates a need for full-build out of the Lease Area.

Illustration of BW1, BW2, as well as the interarray and submarine export cables of the Project are shown in **Figure EE.1-1**.

Beacon Wind has adopted a Project Design Envelope (PDE) approach to describe Project facilities and activities. A PDE is defined as "a reasonable range of project designs" associated with various components of the Project (e.g., foundation and wind turbine generator [wind turbine] options) (BOEM

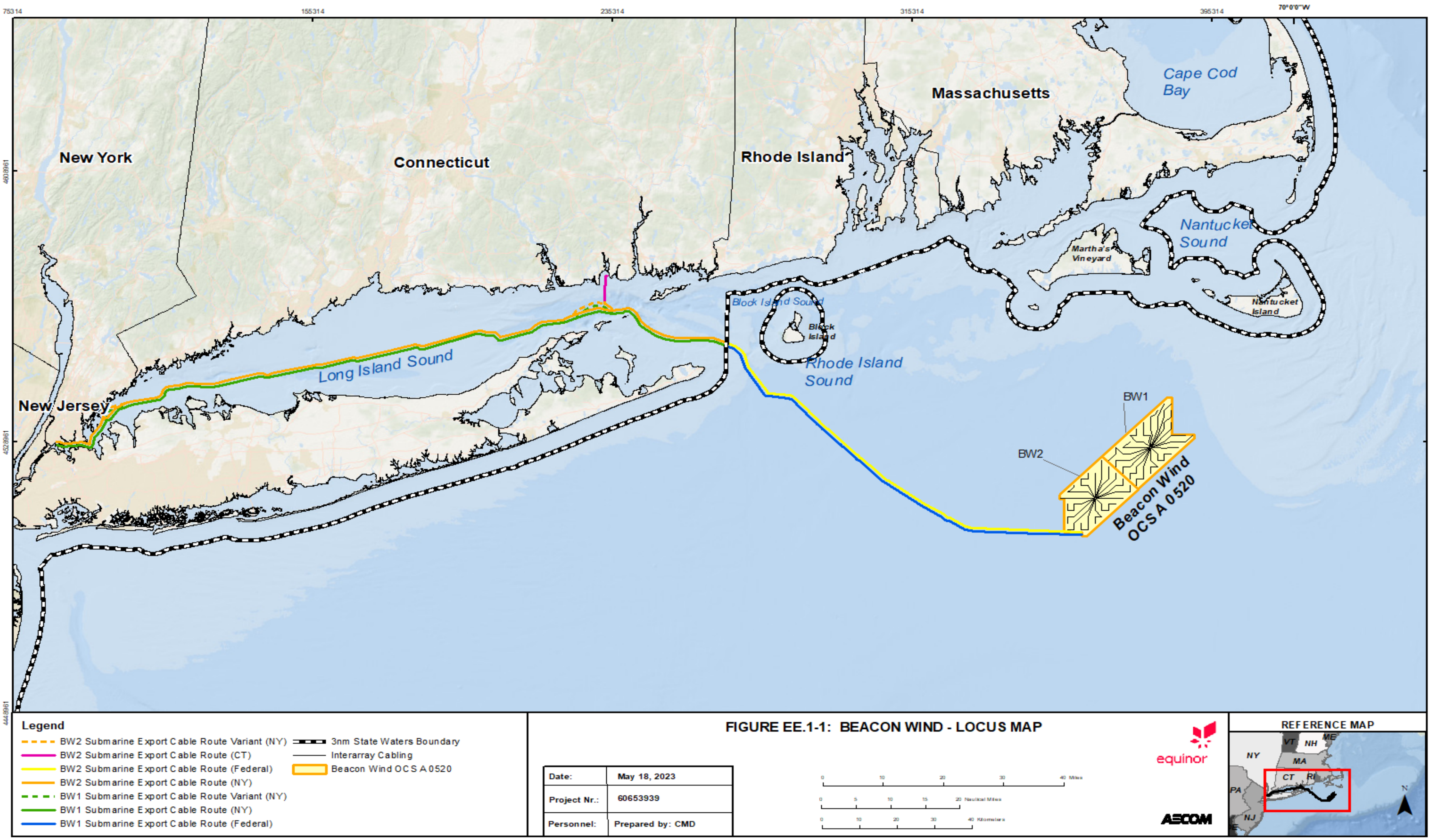
2018). The design envelope is then used to assess the potential impacts on key environmental and human use resources (e.g., marine mammals, fish, benthic habitats, commercial fisheries, navigation, etc.) focusing on the design parameter (within the defined range) that represents the greatest potential impact (i.e., the "maximum design scenario") for each unique resource (BOEM 2017). The primary goal of applying a design envelope is to allow for meaningful assessments by the jurisdictional agencies of the proposed project elements and activities while concurrently providing the Leaseholder reasonable flexibility to make prudent development and design decisions prior to construction.

This appendix is being submitted as a supplemental filing to the Construction and Operation Plan (COP) submitted to BOEM in February 2022. The appendix evaluates the potential scour associated with the foundation structures for wind turbines and offshore substation facilities in the Lease Area due to sediment movements by currents and waves. The appendix also evaluates the potential exposure for the buried cables which is commonly attributed to the mobile seabed and bedform migration. Scour protection countermeasure recommendations are presented for both the foundation structures and Project submarine export and interarray cables.

This appendix is organized as follows:

- **Section EE.1** provides a description of the Beacon Wind Project and its associated infrastructure, as well as overviews of environmental and regulatory framework.
- **Section EE.2** details the different types of foundation scour that can occur at OWFs and engineering controls for scour protection. Potential scour depths were estimated for monopiles and pile jackets at the Beacon Wind Lease Area; and preliminary dimensions were estimated for scour protection design at monopile, piled jacket, and suction bucket foundations.
- **Section EE.3** provides an overview of the regional physiography across Long Island Sound and the New England OCS. Sand wave and boulder field features along ECRs corridors were identified to aid cable installation to achieve desired burial depth.

FIGURE EE.1-1. PROJECT OVERVIEW AND LOCUS MAP



EE.1.2 Overview of Project Foundation and Cabling Designs

Figure EE.1-1 provides an overview of the Project, including the Beacon Wind Lease Area (OCS-A 0520) and the submarine export cable routes. The Lease Area is broadly located in the Southern New England Outer Continental Shelf (OCS) directly south of the islands of Martha's Vineyard and Nantucket.

Beacon Wind is developing up to 155 wind turbines and supporting tower structures, and up to two offshore substation facilities, using up to 157 foundations in the Lease Area (encompassing both BW1 and BW2). BW1 will include between 70 and 94 wind turbines and BW2 will include between 61 and 85 wind turbines. The Overlap Area includes 24 wind turbines that could be incorporated into either BW1 or BW2. The Beacon Wind PDE includes options of up to three types of foundations to support the wind turbines and up to two for the offshore substation facilities (piled jackets and suction bucket jackets). These foundation types are defined below and depicted in **Figure EE.1-2**.

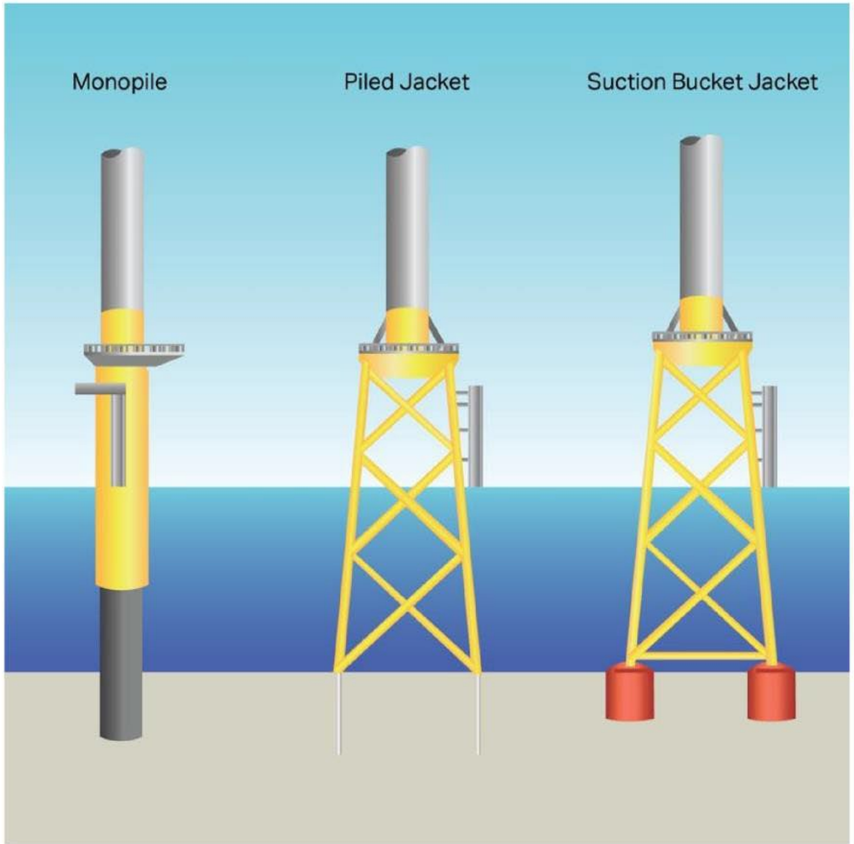
- **Monopile:** A single vertical, broadly cylindrical steel pile driven into the seabed to support a wind turbine. The monopile has a base diameter of 49 feet (ft) (15 m) and a penetration depth of about 180 ft (55 m).

- **Piled Jacket:** A vertical steel lattice structure consisting of three or four legs to support a wind turbine, or up to eight legs to support an offshore substation facility, secured into the ground with steel pile foundations. Jackets supporting wind turbines will be supported on pre-installed piles and connected to the turbine tower by a transition piece. For wind turbines, the pile diameter on the seabed is 14.7 ft (4.5 m), the seabed penetration depth is approximately 217 ft (66 m), and the leg spacing at the seabed is approximately 147 ft (45 m). For offshore substation facilities, the pile diameter on the seabed is 9.8 ft (3 m), the seabed penetration depth is approximately 328 ft (100 m), and the leg spacing at the seabed is approximately 230 ft (70 m).

- **Suction Bucket Jacket:** A vertical steel lattice structure consisting of three or four legs to support a wind turbine, or up to eight legs to support an offshore substation, with inverted bucket-like steel structures at the base. For wind turbines, each suction bucket has a diameter of 59 ft (18 m), a seabed penetration depth of approximately 52.5 ft (16 m), and a leg spacing at the seabed of approximately 147 ft (45 m). For offshore substation facilities, each suction bucket has a diameter of 65.6 ft (20 m), a seabed penetration depth of approximately 59 ft (18 m), and a leg spacing at the seabed of approximately 230 ft (70 m).

FIGURE EE.1-2. BEACON WIND FOUNDATION TYPES

Wind Turbine Foundation Types



Extracted from Beacon Wind COP, Volume 1

FIGURE EE.1-2: FOUNDATION TYPES

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Personnel:	Prepared by: MCM

Each wind turbine will be connected to one offshore substation facility via an interarray cable, which delivers power to the respective POIs via a submarine export cable. Interarray cables will consist of up to 132-kilovolt (kV) High Voltage Alternating Current (HVAC) submarine cables, installed at a depth of 3-6 ft (0.9-1.8 m) below the seabed of the Lease Area. Submarine export cables have a transmission rate up to 320-kV High Voltage Direct Current (HVDC) for the bulk transmission of power from the offshore substation facility to the onshore substation, installed to a depth of approximately 3-6 ft (0.9-1.8 m). Routes for the BW1 and BW2 submarine export cable are summarized below.

- BW1: HVDC submarine export cable route to the State of New York:
  - Up to 202 nm (375 km) to the BW1 landfall, in Queens, New York, of which 87 nm (162 km) is in federal waters and 115 nm (213 km) is in state waters; and
- BW2: HVDC submarine export cable route to a landfall location in the State of New York or State of Connecticut:
  - Up to 202 nm (375 km) to the BW2 landfall in Queens, New York, of which 87 nm (162 km) is in federal waters and 115 nm (213 km) is in state waters, or
  - Up to 113 nm (209 km) to the BW2 landfall in Waterford, Connecticut, of which 87 nm (162 km) is in federal waters and 26 nm (47 km) is in state waters with 21 nm (39 km) in New York state waters and 5 nm (9 km) in Connecticut state waters.

EE.1.3 Environmental Setting

EE.1.3.1 Sedimentology

The Atlantic OCS is diverse in sedimentology and seafloor bathymetry, and consists almost entirely of nonconsolidated, mobile sediments with very few significant outcrops of bedrock. Three distinct sources of sediment are represented along the Atlantic Coast, based on region and geologic process. River-contributed (fluvial) wash-off of terrestrial sands and silts is the main source of sediment for the majority of the Atlantic OCS, responsible for the sediments stretching from the northern Florida coastline to the Gulf of Maine. Biogenic sources, including shells, corals, and other biologic calcium carbonate-generating biota are the predominant source of sediments along the southern Floridian coastline and the Bahamas Islands. Glacial sources, including sediment and debris deposited via ice-rafting are typical for the Gulf of Maine and the Nova Scotia OCS (USGS 1966).

The Beacon Wind Project area includes the Lease Area OCS-A 0520 located just west of the Nantucket Shoals, and the submarine export cables extending from the Lease Area through Long Island Sound to Astoria, New York and/or Waterford, Connecticut (**Figure EE.1-1**). The sediments that make up this portion of the Atlantic OCS consist mostly of sand and sandy silt deposited by rivers draining meltwater from larger glacial systems (USGS 1966). The Beacon Wind Project surveys support this classification, and details are provided in **Section EE.3.2.2** of this report.

EE. 1.3.2 Sediment Transport

The Atlantic OCS is dominated by a complex sediment transport regime characterized by the shifting and migration of sediments and bedform features in a constant state of dynamic equilibrium. The relationship between the bottom currents produced by the various oceanographic conditions and the seafloor sediment characteristics, leads to the seafloor morphodynamics at various spatial and temporal scales. These changes can be observed in the shifting of sandbars or barrier islands during storm events and in the longer-term migration of sand waves and other bedforms over periods of months and years. On the local scale, sediment transport can lead to scouring phenomena by modified hydrodynamics in the vicinity of obstruction structures. In the Northern Atlantic OCS, the potential for natural sediment transport and seabed scour is dominated more by tidal currents than by extreme storm events (FUGRO Atlanic 2011).

For the purposes of this report, scour is defined as the erosion of sediments in the vicinity of an obstruction due to the turbulence induced as waves and currents interact with the obstruction. Scour is subject to hydrodynamic forcing (current stresses, wave stresses, or a combination of the two), water depth, fluid and seabed condition (bottom roughness, kinematic viscosity, water density, and seafloor slope, etc.), and sediment characteristics (sediment size, fine content, density, and condition, etc.). At offshore wind farms (OWFs), these scour processes can be observed in the vicinity of structure foundations of all types, as well as along the boundaries of various scour protection features. These processes threaten the stability and protection of the turbine foundations and any associated features (cabling, J-tubes, etc.).

For the purposes of this report, bedform migration is defined as the movement of local-scale bedform features, such as sand waves, ripples, and dunes, due to the regional hydrodynamic patterns of a given area. At OWFs, the migration of bedforms carries the potential to expose OWF-associated cables that may have been installed underneath said bedform.

EE.1.4 Regulatory Guidance and Methodological Framework

This report serves to address, in part, the requirements for COP Submittals set forth in 30 CFR § 585.626(a)(6), “Overall site investigation”, which includes analyses for scouring of seabed (30 CFR § 585.626(a)(6)(i)) and the occurrence of sand waves (30 CFR § 585.626(a)(6)(iii)).

In 2011, BOEM and FUGRO Atlantic released a report entitled “Seabed Scour Considerations for Offshore Wind Development on the Atlantic OCS”, outlining considerations and recommendations to counter potential scour impacts to marine structures (both foundational and cabling) associated with OWFs (FUGRO Atlanic 2011). The recommendations set forth in this report include specific factors to be taken into consideration in the design of OWFs, including cable burial, cable exposure avoidance, and foundation scour protection measures. The FUGRO Atlantic report provides the methodological framework for the analysis described in this report for the Beacon Wind Project.

Historically, the development of OWFs has been limited to the European coastline, with installations mostly located close to shore and in shallow waters (shallower than 30 ft (10 m)). Such near-shore locations are typically subject to significant hydrodynamic forcings from wind and waves. Many scour and bedform migration studies have been performed at these European OWFs in recent history. Matutano et.al. (2013) summarizes the different methods used for scour prediction and scour protection design in these installations. The procedures for scour prediction and scour protection design, as outlined in the research by Zanke et. al. (2011) and den Boon et. al. (2004), are widely referenced and provide the basis for the analyses performed here for Beacon Wind. As there is no precedent for such analyses specific to the Atlantic OCS, most initial evaluations of scour potential and bedform migration on the Atlantic OCS performed to date have relied on hind cast evaluations, laboratory-scale experimental analyses, and/or site-specific data of limited duration. This is the approach adopted in this study.

EE.2 Potential for Foundation Scour at Beacon Wind Structures

As described in **Section EE.1**, three foundation types (monopiles, piled jackets, and suction bucket jackets) are being considered to support wind turbines and the offshore substation facilities in the Beacon Wind lease area. These foundations, once installed, will be subject to scour at the sea floor due to the obstructing effect that the structures will have on the hydrodynamic regime in their vicinity. This section describes the types of foundation scour that are known to occur at OWFs. Potential scour depths and preliminary scour protection sizing are then estimated for the proposed Project foundation types using data developed from a hindcast metocean modeling analysis.

EE.2.1 Types of Scour at Offshore Structural Foundations

The effects of foundation scour can be observed at both local and regional scales, variable both spatially and temporally. This section provides an overview of the four main types of scour commonly associated with offshore structures, each of which is illustrated in **Figure EE.2-1**.

FIGURE EE.2-1. TYPES OF FOUNDATION SCOUR

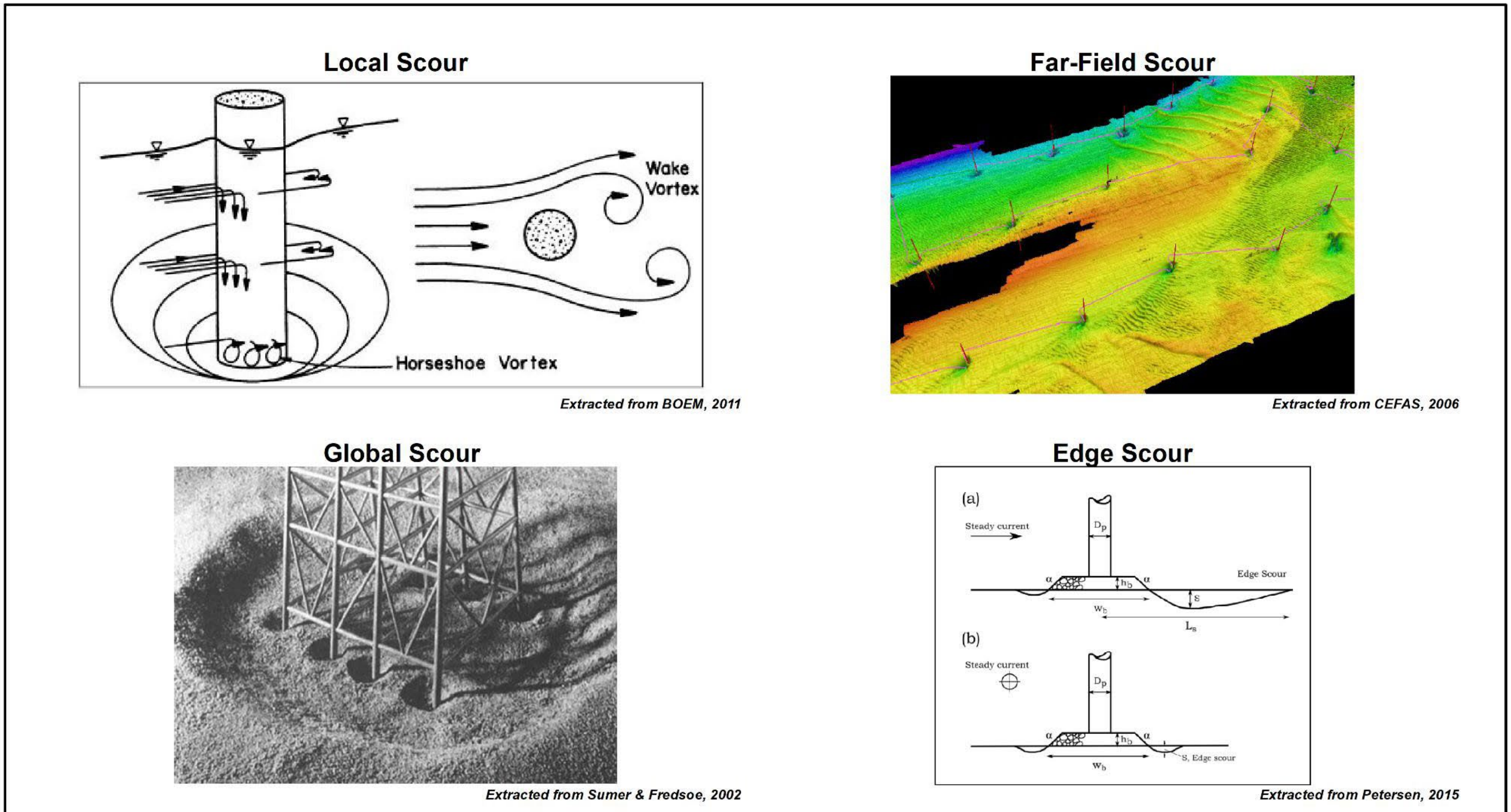

FIGURE EE.2-1: TYPES OF FOUNDATION SCOUR

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EE.2.1.1 Local Scour

Local scour refers to depressions in seabed topography that develop around the base of piers, piles, and other in-flow obstructions due to turbulence and increased velocities where the contraction of streamlines occur as flow moves around obstructions. The extent of scour development depends on the hydrodynamic conditions near the seabed, which in coastal environments can be a factor of currents, waves, or a combination of both.

Under current-only environments, local scour is formed by a U-shaped turbulent vortex called a horseshoe vortex (HSV) that develops around the base of an obstruction as flow is forced downwards and around the object. The turbulence associated with the HSV scours a hole into the seabed upstream of the obstruction, depositing the scoured material just downstream. The shape of the resultant scour pit is roughly shaped like an inverted cone, with a depth and lateral extent determined in equilibrium with the with the intensity of the HSV over time. The maximum depth of this equilibrium scour hole is generally accepted to be a function of the upstream current velocity, water depth, and obstruction geometry (FHWA 2015).

Under wave-dominated environments, local scour is formed by “lee-wake vortices” that develop on the downstream side of the obstruction, along with similar HSVs to those that form under current-only conditions. These lee-wake vortices shed from the obstruction and act like cyclones, sweeping sediment into the center of the vortex and lifting the grains away via updrafts. The size of scour holes that form under wave-dominated environments is a function of the Keulegan-Carpenter (KC) number, which is itself a function of the obstruction diameter, wave orbital velocity, and peak wave period (Qi and Gao 2020).

Under combined wave-and-current conditions, such as those observed in many European wind farms today, a combination of the above two mechanisms drive the development of local scour. Where the KC number is low (KC<6), the scour environment is driven by currents alone and local equilibrium scour depth can be calculated using current-only methods (FHWA 2015). Under higher KC regimes (KC>6) scour is driven by a combination of waves and currents, and equilibrium scour depth is calculated using methods that consider both driving forces (Zanke, et al. 2011).

EE.2.1.2 Global Scour

At more complex foundation structures, such jacket structures, a wider area of the seabed can be subject to scour due to the additional piles and braces associated with the foundation. This is referred to as the global scour. Cross-bracing structures designed to connect jacket components and provide rigidity cause flow through the structure to contract, increasing velocities and bed shear stresses in the vicinity of the foundation. Turbulent vortices that form downstream of these cross-braces further increase the erosive potential on the seabed generated by these structures. The overall design of the jacket structure contributes to a general blockage effect that influences scour development around the structure as a whole in addition to the local scouring effect of each individual pile component (Welzel, et al. 2019).

While significant effort has been made to advance methods for estimation of scour around monopile structures, comparatively little work has been done to develop a reliable method to quantify the depth of global scour around jacket structures. This is primarily due to the broad range in configurations and sizes of this foundation type. Simple empirical relationships based on the jacket pile diameter are used to estimate the depth of global scour that forms around jacket structures.

EE.2.1.3 Edge Scour

As part of the design of both jacket and monopile-type foundations, beds of crushed stone and riprap are often installed where the foundation meets the seabed to prevent the development of local and global scour (see **Section EE.2.2** for discussion on scour prevention implementations). While the placement of these armor layers is effective at preventing scour development, the placed stone itself can trigger the formation of scour around its perimeter. This scouring effect, called “edge scour”, is caused as small HSVs that form at the front of the armor layer and compressed streamlines that form as flow compresses around the obstructing armor layer erodes the native bed. As the edge scour develops, the depressions can begin to undermine the armor layer causing armor stone to fall into the edge scour depression (Petersen, et al. 2014).

No analytical methods have been developed to predict the extent of formation of edge scour; but some treatments have been observed to be effective to prevent edge scour development (see **Section EE.2.2**).

EE.2.1.4 Far Field Scour

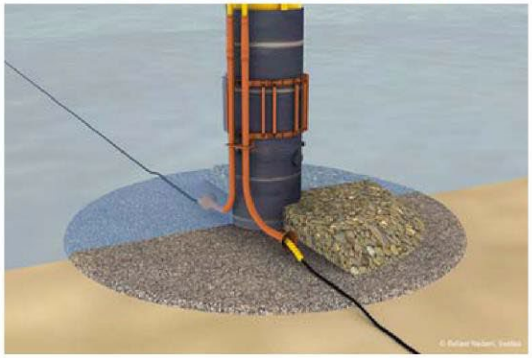
Far-field scour is the least understood and studied scour mechanism of those listed in this report. Taken as a whole, offshore wind farms present a number of in-water obstructions to flow and waves that move through the far field. Far-field scour is a general term used to describe the erosion and deposition that occurs at larger distances within these environments, due to the complexity added to the seabed and hydrodynamic environment by these features.

EE.2.2 Foundation Scour Prevention

As described above, foundation scour is an erosional process. It follows, then, that scour processes can be prevented through the implementation of seabed armoring measures by placement of materials that are stable under design wave and current conditions. This section provides an overview of potential scour protection measures applicable to the OWF structures in Atlantic OCS. **Figure EE.2-2** shows diagrams of scour protection measures commonly used for scour prevention in marine applications.

FIGURE EE.2-2. FOUNDATION SCOUR MITIGATION MEASURES

Loose Stone Placement



Extracted from BOEM, 2011

Frond Mats

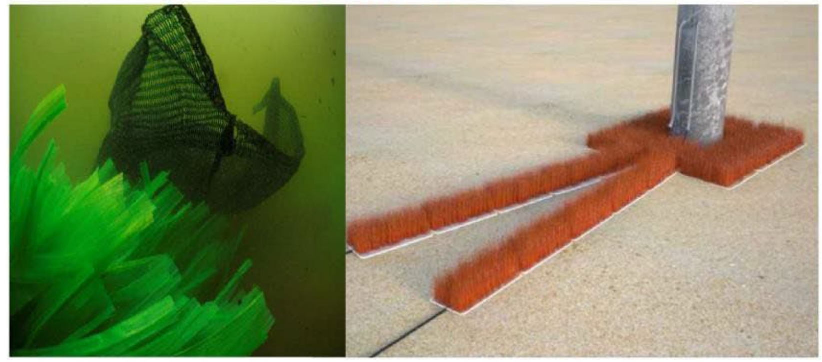


Image source: sscsystems.com

Bagged Stone Placement

Image source: subseaprotectionsystems.co.uk

Grout Bags

Image source: synthetex.com

FIGURE EE.2-2: FOUNDATION SCOUR MITIGATION MEASURES

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Project Nr.:	60653939
Personnel:	Prepared by: CMD

EE.2.2.1 Local & Global Scour Prevention

To prevent scour formation at monopile and jacket structures, the erosive impacts caused by HSVs and lee-wake vortices must be countered. This can be done through a number of different measures that armor the seabed, the most common of which is the placement of loose stone at the base of the structure. This scour protection method has historically been the most used at European wind farms due to the low cost of material and availability (Matutano, et al. 2013). However, special considerations need to be taken to ensure effectiveness in the long term. The loose stone needs to be placed to a sufficient extent (in thickness and diameter) that any undermining at the edges will not reduce the effectiveness of the armoring at the foundation itself. To prevent winnowing, where the stone sinks into the finer native sediment over time, the armor can be installed in two or more layers. When installed in layers of increasing gradation, the coarse topmost (armor) layer of stone can effectively rest on the finer bottom (filter) layers without sinking into the native fine-grained bed (FUGRO Atlanic 2011).

In place of loose stone, several other measures can be used to mitigate the formation of local and global scour around wind turbine foundations. The placement of bagged rock and crushed stone provides similar benefit to loose stone armoring and performs well against edge scour and bed winnowing while flexibly adapting to irregular bed morphology. Grout bags, also referred to as fabric concrete mattresses, are geotextile or fabric bags that can be placed on the seafloor where needed and pumped with hardening aggregate or concrete to protect the underlying bed material from erosion. Frond mats, are artificial seagrass beds created using chemically inert materials, add drag and energy dissipation to the hydrodynamic environment they are placed in. When successfully installed, these implementations promote deposition and can create sand bars in the vicinity of the mats (FUGRO Atlanic 2011).

EE.2.2.2 Edge Scour Prevention

To prevent the development of edge scour where stone armoring is installed, experimental studies and field observations have demonstrated the effectiveness of an underlying filter layer that extends beyond the perimeter of the stone armor layer (Petersen, et al. 2014). As edge scour develops, the finer filter layer material will slump into the developing scour holes, creating a "falling apron" that forms a protective slope against future scouring around the edge. The installation of an extended filter layer pushes the erodible part of the seabed farther away from the foundation, where the erosive effects of the HSVs and lee-wake vortices are weaker. In the experimental setting, the largest reduction in edge scour formation was observed when the extent of the filter layer from the structure foundation was 1.5 times greater than that of the armor layer (**Figure EE.2-2**) (Petersen, et al. 2014). In areas where clear directional currents dominate the hydrodynamic environment, the filter layer can be asymmetrically extended in the direction of dominating flow. In areas where the directions of flow are fairly isotropic (such as OCS-A 0520), a symmetrical filter layer extension may be preferred.

EE.2.3 Estimating Potential Scour at Beacon Wind Structures

To provide context to the level of scour that can be expected at foundations installed as part of the Beacon Wind Project, potential local and global scour depths were estimated for monopile and piled jacket structures based on the preliminary design parameters included in the PDE. These calculations follow the procedures developed by Zanke et. al. (2011) for the estimation of scour at piles under the combined influence of current and waves.

As comparable analytical procedures have not yet been developed for suction bucket structures, scour depths were not estimated for these structures. Suction bucket foundations are designed to reduce the effect of HSV compared to that created around jacket piles, resulting in more limited scour development.

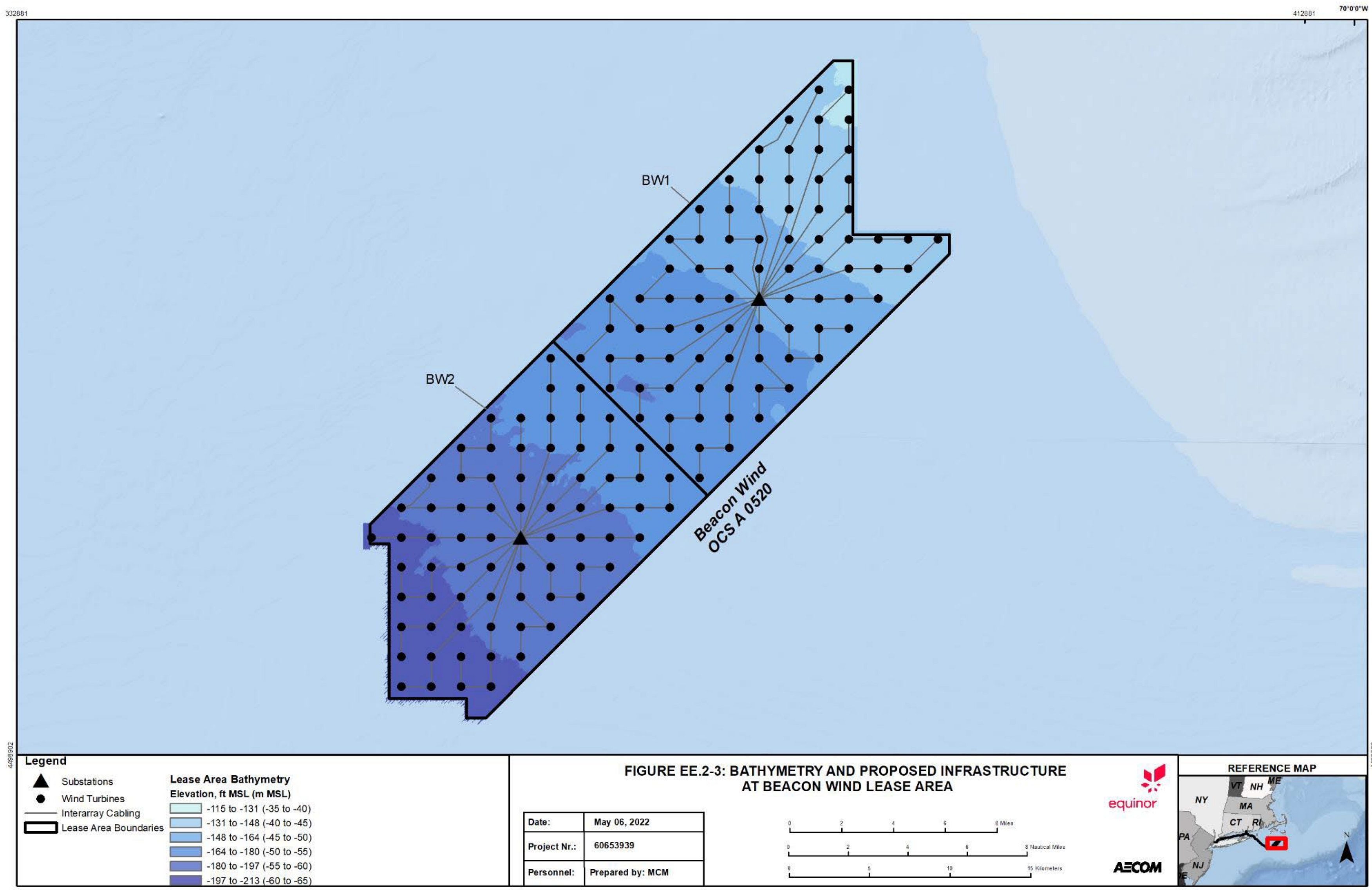
Note that the final design of all three foundation structures is still ongoing at the time of this report.

EE.2.3.1 Methods & Data Sources

To support the estimation of local scour, an oceanographic hindcast dataset produced by DHI for the Beacon Wind Project was used (DHI Group 2021). This dataset provides a 20-year long time series of current speed, current direction, wave height, wave period, and water surface elevation at multiple locations within the Beacon Wind Lease Area. As water depth is critical to the magnitude of foundation scour depth, scour and scour protection analyses were performed at representative locations every 16.4 ft (5 m) of bathymetric elevation between depth range of 115 ft (35 m) and 213 ft (65 m) in the lease area. **Figure EE.2-3** demonstrates these representative depth intervals atop a schematic of proposed infrastructure within the Lease Area. This approach ensures that the full range of scour conditions experienced across the Lease Area is considered. Additional details regarding the DHI hindcast dataset can be found in the modeling deliverable report (DHI Group 2021).

It should be noted that the period of record included in the DHI hindcast dataset spans the period of 1999-2019. During this time span, while several tropical storms passed in the vicinity of Lease Area OCS A-0520, no hurricanes passed within 60 nautical miles of the site (NOAA 2022). Further, the model used to develop the DHI database was not configured to model the impacts of cyclonic wind and storm events on the oceanic environment (DHI Group 2021). So, this dataset alone is not a reliable source of historical data to define the conditions associated with extreme hurricane or cyclonic events.

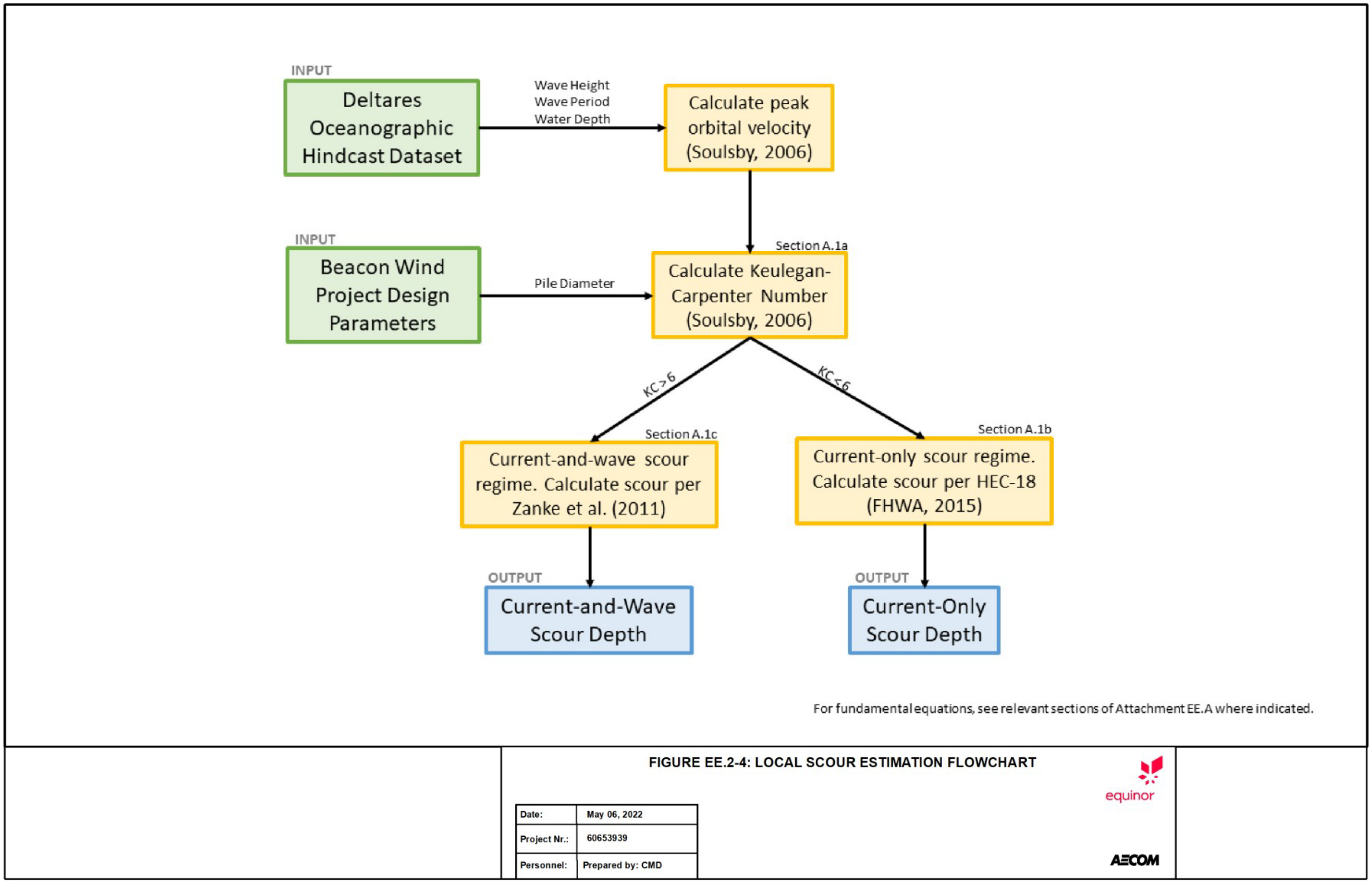
FIGURE EE.2-3. BATHYMETRY AND PROPOSED INFRASTRUCTURE AT BEACON WIND LEASE AREA



As described in **Section EE.2.1.1** the formation of local scour is driven by currents, waves, or a combination of the two. The effect of waves on scour development is determined by the KC number, which is a function of obstruction diameter, peak wave height, and peak near-bed peak orbital velocity. Scour is driven by the combined forces of waves and currents when the KC number is greater than 6. When the KC number is less than 6, scour is driven by currents alone. To estimate the potential scour depth at Beacon Wind structures, the 20-year hindcast dataset provided by DHI was used to calculate scour depth at each hourly timestep. The statistics of the resultant scour depth distribution were analyzed following the guidelines in the Fugro Atlantic Report (2011). A flowchart showing the local scour calculation procedure is demonstrated in **Figure EE.2-4** and summarized as follows. Key equations used in this analysis are provided in **Section A.1** of **Attachment EE.A**.

- Calculate the KC number of the flow around an obstruction.
- If KC is less than 6, scour is current-driven, and local scour is calculated using current-only equations (FHWA 2015; Matutano, et al. 2013).
- If KC is greater than 6, scour is driven by the combined effects of currents and waves, and local scour is calculated using combined current-and-wave methods (Zanke, et al. 2011).
- If a jacket structure is being analyzed, global scour is added into the total scour depth based on obstruction width.

FIGURE EE.2-4. LOCAL SCOUR ESTIMATION FLOWCHART



EE.2.3.1 Results

Following the procedure summarized in **Figure EE.2-4**, the potential scour at monopile and jacket structures was estimated for every 16.4 ft (5 m) interval of water depth across the Lease Area, as displayed in **Figure EE.2-3**. In their guidance report, BOEM and FUGRO recommend that "the mean, mean + 1 standard deviation (Std), and mean + 2 Std flow conditions are useful in defining the conditions of normal dynamic equilibrium as well as long-term sediment transport and scour effects" (FUGRO Atlanic 2011). **Table EE.2-1** below reports the potential local scour depths estimated for monopile foundations (with 49-ft [15-m] diameter piles per the PDE) for the mean, mean + 1 Std, and mean + 2 Std of conditions modeled by DHI. **Table EE.2-2** below reports the potential global and total scour depths estimated for the wind turbine piled jacket foundations (with 14.7 ft [4.5-m] diameter piles per the PDE). **Table EE.2-3** below reports the potential global and total scour depths estimated for the offshore substation facility piled jacket foundations (with 9.8 ft [3-m] diameter piles per the PDE).

TABLE EE.2-1. ESTIMATED LOCAL SCOUR DEPTHS AT MONOPILE FOUNDATIONS

	Estimated Local Scour Depths at Monopile Foundations, ft (m)		
Seafloor Depth Range	**Mean**	**Mean + 1Std**	**Mean + 2Std**
115 – 131 (35 – 40)	21.7 (6.6)	24.7 (7.5)	27.7 (8.4)
131 – 148 (40 – 45)	21.4 (6.5)	24.4 (7.4)	27.4 (8.4)
148 – 164 (45 – 50)	20.9 (6.4)	23.8 (7.2)	26.7 (8.1)
164 – 180 (50 – 55)	20.5 (6.3)	23.5 (7.2)	26.5 (8.1)
180 – 197 (55 – 60)	19.3 (5.9)	22.4 (6.8)	25.4 (7.7)
197 – 213 (60 – 65)	18.7 (5.7)	21.9 (6.7)	25.1 (7.7)

TABLE EE.2-2. ESTIMATED GLOBAL & TOTAL SCOUR DEPTHS AT WIND TURBINE PILED JACKET FOUNDATIONS

Seafloor Depth Range	Global Scour Depth*	Estimated Total Scour Depths at Turbine Piled Jacket Foundations, ft (m)		
		Mean	**Mean + 1Std**	**Mean + 2Std**
115 – 131 (35 – 40)	6.1 (1.9)	16.2 (4.9)	17.6 (5.4)	19.0 (5.8)
131 – 148 (40 – 45)	6.0 (1.8)	15.8 (4.8)	17.2 (5.2)	18.6 (5.7)
148 – 164 (45 – 50)	6.0 (1.8)	15.6 (4.7)	16.9 (5.1)	18.2 (5.6)
164 – 180 (50 – 55)	6.0 (1.8)	15.4 (4.7)	16.8 (5.1)	18.1 (5.5)
180 – 197 (55 – 60)	6.0 (1.8)	14.8 (4.5)	16.2 (5.0)	17.7 (5.4)
197 – 213 (60 – 65)	6.0 (1.8)	14.6 (4.4)	16.0 (4.9)	17.5 (5.3)

Note:
Global scour depth calculated uniformly for each depth interval.

TABLE EE.2-3. ESTIMATED GLOBAL & TOTAL SCOUR DEPTHS AT OFFSHORE SUBSTATION PILED JACKET FOUNDATIONS

Seafloor Depth Range	Global Scour Depth*	Estimated Total Scour Depths at Offshore Substation Piled Jacket Foundations, ft (m)		
		Mean	Mean + 1Std	Mean + 2Std
115 – 131 (35 – 40)	4.1 (1.3)	11.9 (3.6)	13.0 (4.0)	14.1 (4.3)
131 – 148 (40 – 45)	4.0 (1.2)	11.6 (3.5)	12.7 (3.9)	13.7 (4.2)
148 – 164 (45 – 50)	4.0 (1.2)	11.4 (3.5)	12.4 (3.8)	13.5 (4.1)
164 – 180 (50 – 55)	4.0 (1.2)	11.3 (3.4)	12.3 (3.8)	13.4 (4.1)
180 – 197 (55 – 60)	4.0 (1.2)	10.8 (3.3)	11.9 (3.6)	13.0 (4.0)
197 – 213 (60 – 65)	4.0 (1.2)	10.6 (3.2)	11.8 (3.6)	12.9 (3.9)

Note:
Global scour depth calculated uniformly for each depth interval.

Throughout this analysis, the KC number observed at both monopile and jacket foundations never exceeded 5.6, indicating that the local scour was entirely driven by currents alone at all times. This stands in contrast to many European wind farms, where high KC numbers were commonly observed, indicating that foundation scour was driven by a combination of both current and wave effects (Matutano, et al. 2013). The primary reason for the difference in scour physics between the Beacon Wind OWS and its European counterparts is the water depths characteristic of the Atlantic OCS. Many OWFs developed along the European coastline sit in 66 ft (20 m) or less of water, where the seafloor is much more exposed to impacts from the waves. As the energy associated with surface waves decrease exponentially with increasing water depth (Dean and Dalrymple 1991), it follows that in in environments with more than three times the water depth than many European wind farms, such as the Beacon Wind Lease Area, the impacts of waves on foundation scour would be substantially smaller.

The above tables show a general pattern of decreasing scour potential with increasing water depth, reflecting the general trends of decreasing bottom current with increasing depth. At the Beacon Wind monopile foundations, the mean + 2 Std of local scour was estimated to range between about 56 percent and 51 percent of the proposed pile diameter across the six depth ranges investigated. This stands in comparison to European wind farms, where local scour at monopile foundations has been observed to range between 46 percent and 166 percent of the pile diameter (Matutano, et al. 2013). At Project wind turbine jacket foundations, the mean + 2 Std of total scour depth was determined to range between about 128 percent and 118 percent of the pile diameter in the shallowest range investigated. At Project offshore substation jacket foundations, the mean + 2 Std of total scour depth was determined to range between about 128 percent and 118 percent of the pile diameter in the shallowest range investigated.

It should be noted again that the hydrodynamic parameters for wind and current used in this scour analysis relied on the DHI's hindcast database, spanning 1999-2019. Over this 20-year period, no hurricanes passed within approximately 50 nautical miles of the OCS-A 0520 Lease Area. Therefore, the approach taken here of using the mean + 1 Std and mean +2 Std of conditions covered in this dataset may not serve to adequately represent "maximum" and "extreme-event" oceanographic conditions.

EE.2.4 Scour Protection

To counter the formation of scour around the foundations of Beacon Wind turbine and substation structures, loose stone aprons (as depicted in **Figure EE.2-2**) will be installed. In this section, the dimensions and extents of these scour protection measures are conservatively estimated for permitting purposes. Detailed sizing, including stone grading and layer thicknesses, will be finalized as the project design matures.

As described in **Section EE.2.2.1**, loose stone scour prevention pads (also referred to as aprons) primarily consist of two layers. The topmost "armor" layer consists of coarse-grained material that withstands the erosive forces exerted by waves and currents. The underlying "filter" layer sits atop the seafloor and extends laterally beyond the armor layer to minimize edge scour (**Section EE.2.2.2**).

The dimensions of scour protection aprons are typically based on the diameter of the piles or buckets that support the foundation of the offshore wind turbine and substation structure. Specifically, the lateral extent of armoring (as measured radially from the outer edge of the pile or bucket to the outer edge of stone placement) is defined as a function of the structural pile diameter, or D. Note that the lateral extent of stone placement reported in this section reflect the top extent of scour protection. A bottom-to-top side slope (2H:1V or similar depending on stone gradation) is often employed in practice, which could result in a slightly larger footprint for the overall scour protection implementation.

Based on project conceptual designs and research by Fredsoe & Sumer, baseline armor extents are adopted as 1.5*D for monopiles, 1.65*D for piled jacket structures, and 0.75*D for suction bucket jacket structures (Fredsoe and Sumer 1997). Per the guidelines on streambank armoring listed in the United States Federal Highway Administration (FHWA) Hydraulic Engineering Circular No. 23 (HEC-23), *Bridge Scour and Stream Instability Countermeasures*, a safety factor of 1.2 will be incorporated (FHWA 2009). As a result, the final extent of the armor layer for Beacon Wind foundations is conservatively assumed to be 1.8*D for monopiles, 2*D for piled jacket structures, and 0.9*D for suction bucket jacket structures. The thickness of the armor layers is conservatively assumed to not exceed 4.6 ft (1.4 m) to match the maximum armor layer thickness installed off the European coastline (Matutano, et al. 2013).

The armor layer dimensions described above are summarized in **Table EE.2-4** and are shown to scale in **Figure EE.2-5**. It should be noted that the values presented here are conservative and are subject to change as the project design matures.

TABLE EE.2-4. ESTIMATED SCOUR PROTECTION ARMOR LAYER DIMENSIONS

Foundation Type	Pile Diameter at Seabed, ft (m)	Stone Armor Layer Dimensions, ft (m)	
		Lateral Extent*	Thickness
Monopile	49.2 (15.0)	88.6 (27.0)	4.6 (1.4)
Wind Turbine Piled Jacket	14.8 (4.5)	29.5 (9.0)	4.6 (1.4)
Offshore Substation Piled Jacket	9.8 (3.0)	19.7 (6.0)	4.6 (1.4)
Wind Turbine Suction Bucket Jacket	59.1 (18.0)	53.1 (16.2)	4.6 (1.4)
Offshore Substation Suction Bucket Jacket	65.6 (20.0)	59.1 (18.0)	4.6 (1.4)

Note:
Lateral extent indicates the radial extent of the top of the scour protection, as measured from the outermost edge of the pile or bucket, as shown in **Figure EE.2-5.**

As discussed in **Section EE.2.2.2**, the filter layer provides a countermeasure against edge scour when extended laterally beyond the armor layer. Petersen et al. recommend installing the filter layer to a lateral extent 1.5 times that of the armor layer (Petersen, et al. 2014). Based on the armor extents described previously, the lateral extent of the filter layers at Beacon Wind structures is conservatively assumed to be 2.7*D for monopiles, 3*D for piled jacket structures, and 1.35*D for suction bucket jacket structures.

The thickness of the filter layer is typically determined based on the size of stone used in the filter itself, as well as the grain size of the native bed sediment, and is chosen to prevent the movement of bed sediment through the scour protection, commonly referred to as winnowing. Based on work by De Sonneville et al. and preliminary recommendations by the project foundation design team, a conservative filter layer thickness of 2.5 ft (0.75 m) is assumed (De Sonneville, Verheij and Joustra 2014).

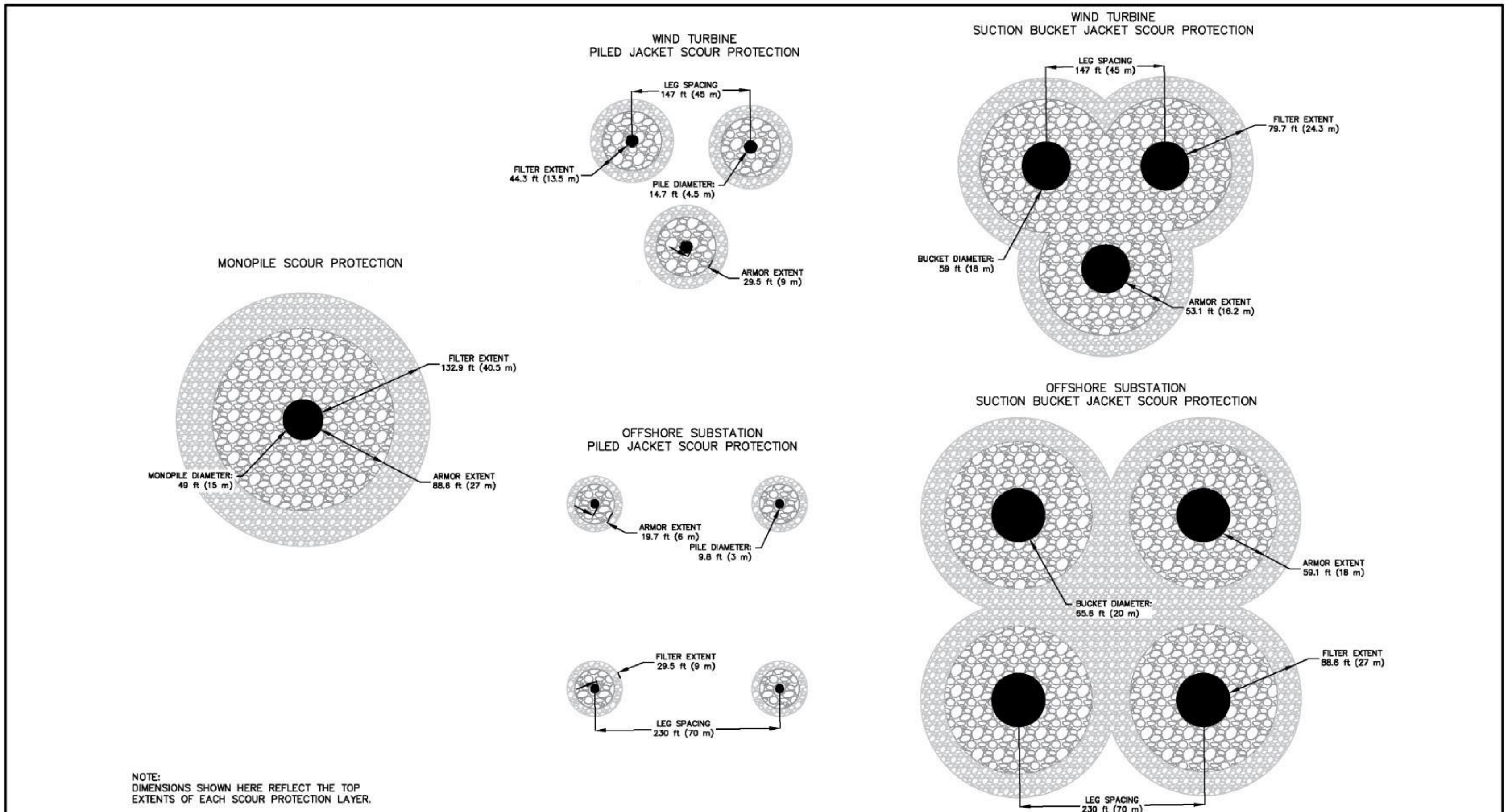
The filter layer dimensions described above are summarized in **Table EE.2-5** and are shown to scale in **Figure EE.2-5**. It should be noted that the values presented here are conservative and are subject to change as the project design matures.

TABLE EE.2-5. ESTIMATED SCOUR PROTECTION FILTER LAYER DIMENSIONS

Foundation Type	Pile Diameter at Seabed, ft (m)	Stone Filter Layer Dimensions, ft (m)	
		Lateral Extent*	Thickness
Monopile	49.2 (15.0)	132.9 (40.5)	2.5 (0.75)
Wind Turbine Piled Jacket	14.8 (4.5)	44.3 (13.5)	2.5 (0.75)
Offshore Substation Piled Jacket	9.8 (3.0)	29.5 (9.0)	2.5 (0.75)
Wind Turbine Suction Bucket Jacket	59.1 (18.0)	79.7 (24.3)	2.5 (0.75)
Offshore Substation Suction Bucket Jacket	65.6 (20.0)	88.6 (27.0)	2.5 (0.75)

Note:
Lateral extent indicates the radial extent of the top of the scour protection, as measured from the outermost edge of the pile or bucket, as shown in Figure EE.2-5.

FIGURE EE.2-5. SCOUR PROTECTION EXTENTS & DIMENSIONS



NOTES:
1) Structure dimensions are based on the Beacon Wind PDE.
2) Scour protection dimensions shown here and summarized in Tables EE.2-4 & EE.2-5 are estimated based on the foundation structural dimensions as described above. Scour protection dimensions are preliminary for the purposes of COP submittal and are subject to change as the project design matures.

FIGURE EE.2-5: PRELIMINARY SCOUR PROTECTION EXTENTS & DIMENSIONS

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Personnel:	Prepared by: CMD

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EE.3 Bedform Migration along Beacon Wind Cable Routes

The Beacon Wind Project includes significant lengths of cabling that will be installed below the seafloor in both the Lease Area and along the submarine export cable routes. Within the Lease Area, two interarray cabling networks will link wind turbines within each BW1 and BW2 area to an offshore substation facility. Each interarray network will include up to 162 nm (300 km) of HVAC cable buried to a target depth of 3-6 ft (0.9-1.8 m) below the seabed, installed using jet plow dredge methods (or similar). Along the submarine export cable routes, cable will be installed to connect each offshore substation facility to the landside POI, delivering power generated by each wind farm to the end user. As described in **Section EE.1.2**, the submarine export cable for BW1 will be up to 202 nm (375 km) in length, connecting the Lease Area to Queens, New York. The submarine export cable for BW2 will either parallel BW1 to Queens, New York for the same distance or be up to 113 nm (209 km) in length, connecting the Lease Area to Waterford, Connecticut. All submarine export cabling will consist of HVDC cable installed at a target depth of 3-6 ft (0.9-1.8 m) using jet plow installation methods (or similar).

In all, almost 648 nm (1,200 km) of cabling will be installed within the Atlantic OCS and Long Island Sound as part of the Beacon Wind Project. **Figure EE.1-1** provides an overview of all Project cabling proposed as part of BW1 and BW2. The proposed submarine export and interarray cables span across a broad range of conditions with varying depths, currents, and seabed conditions. This section will provide an assessment of the bedform migration processes at play in the Atlantic OCS, which carry the potential to expose cables buried as part of the Project.

EE.3.1 Dynamic Equilibrium Sediment Transport

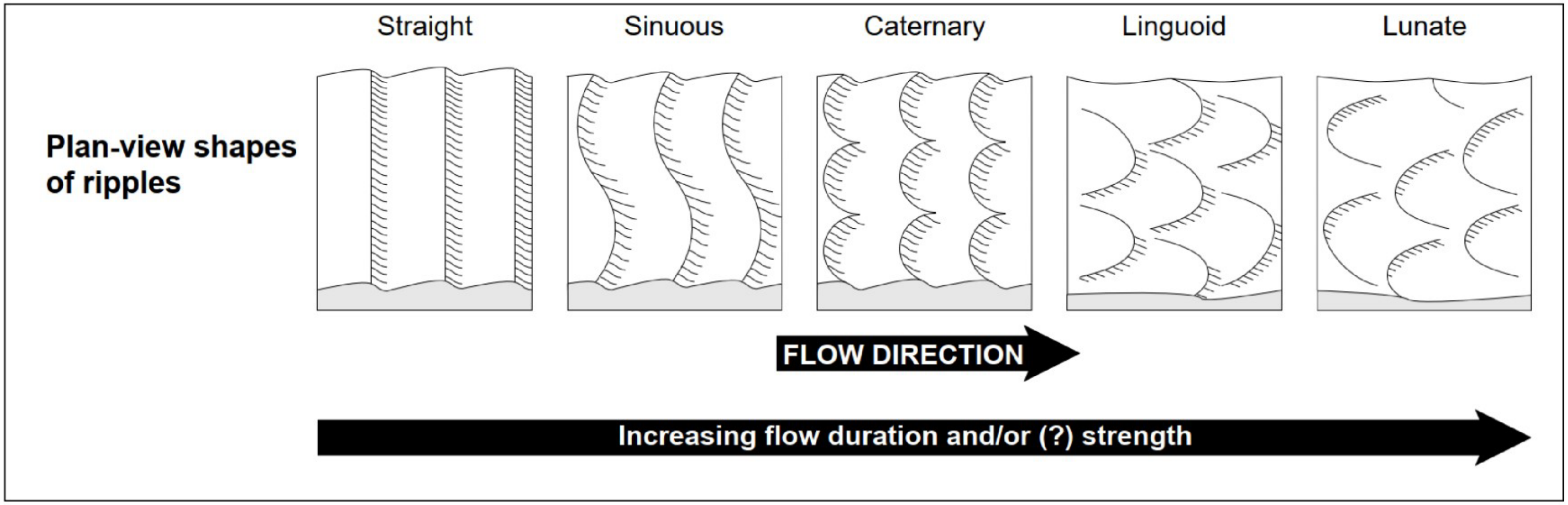
EE.2.2.1 Sand Waves in the OCS

Marine sand waves are bedform features that are created by sediment transport processes induced by waves and currents. In coastal environments, the size, shape, and rate of migration of these bedforms depend on the surrounding environmental conditions, including the current speed and direction, water depth, and bed sediment characteristics. Sand waves are sedimentary structures which constantly migrate in the dominant direction of flow and change shape in response to changes in hydrodynamic conditions.

Sand waves that develop in areas of dynamic equilibrium sediment transport can be classified into two groups. Ripples typically refer to sand wave features that have wave heights of less than 3.9 in (10 cm) and spacings of less than 3.3 ft (1 m). Dunes and sand waves typically refer to bedforms with wave heights of greater than 3.9 in (10 cm) and spacings of more than 3.3 ft (1 m). Ripples and dunes can coexist (with smaller ripples often observed on the banks of larger dunes). As shown in **Figure EE.3-1**, these features take on increasingly complex geometry as flow duration and strength increases (Cheel 2005). As shown in **Figure EE.3-2**, these sand wave patterns have all been identified in the Project survey data collected along the submarine export cable route. Along the submarine export cable route, the sand wave patterns were observed to become increasingly complex and pronounced as the bottom current increases from outer OCS into the Long Island Sound (**Figure EE.3-2**).

As described in **Section EE.1.2** of this report, the composition of bedforms within the Atlantic OCS bedforms is dominated by fluvially-contributed sediments, with few outcroppings of bedrock limited to the northern Atlantic OCS. Sand waves and other bedform features are frequently formed along the OCS seafloor, especially in straits and areas that experience high-velocity currents (both sustained and tidally-reversing).

FIGURE EE.3-1. SAND WAVE GEOMETRIES AND CLASSIFICATIONS



Modified from Cheel, 2005

FIGURE EE.3-1: SAND WAVE GEOMETRIES & CLASSIFICATIONS

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FIGURE EE.3-2. SAND WAVES AND BOULDER FIELD TYPES

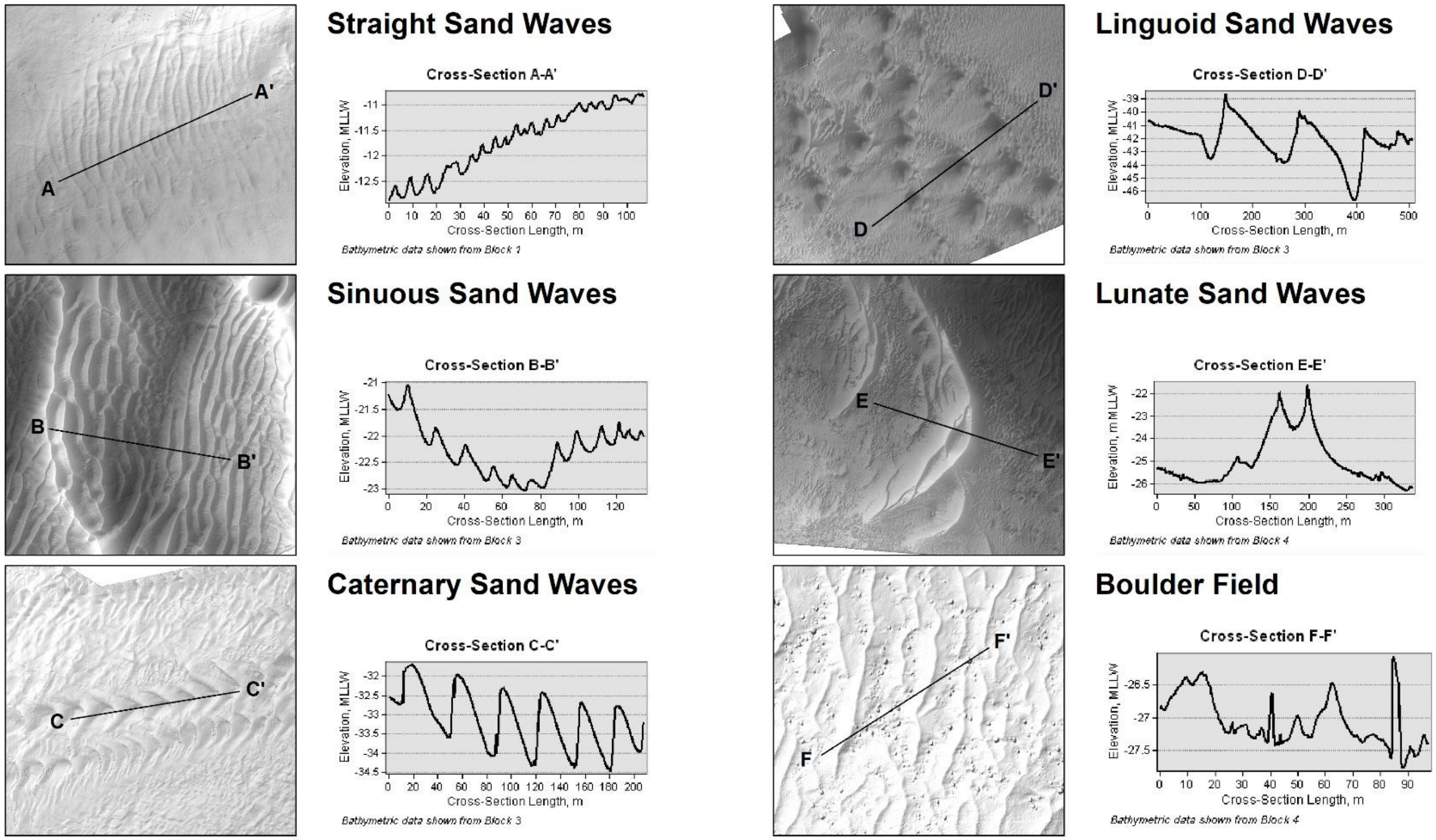

FIGURE EE.3-2: SAND WAVES AND BOULDER FIELDS IDENTIFIED IN BEACON WIND ECR BATHYMETRIC SURVEY

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EE.3.1.2 Mitigating Sand Wave Impacts on Seafloor Cabling

In the installation of HVAC and HVDC cabling for the Beacon Wind Project, cables will be installed at a target depth of 3-6 ft (0.9-1.8 m) below the seafloor. The primary reason for cable burial is to provide protection from fishing, anchoring activities, and current abrasion, as almost 70 percent of all submarine cable faults between 1958 and 2008 are attributable to fishing incidents alone (FUGRO Atlanic 2011). As described further in **Section EE.3.2.2** of this report, bottom-fishing activities are very common in the Lease Area and along the submarine export cable routes, with trawl scars evident along much of the OCS portion of the Project area.

Given the importance of adequate burial to provide protection to subsea transmission cables, attention must be given to the seafloor environment to prevent the submarine export cables from becoming exposed over time. Bedform features that migrate across a submarine cable route could potentially expose the cable if not identified and managed prior to installation. For example, a cable buried 3-6 ft (0.9-1.8 m) into a 6.5 ft (2 m) tall, migrating sand wave will become fully exposed once the sand wave migrates away from the buried cable. Pre-installation analyses of bedforms along planned submarine export cable routes can identify these threats before mobilization, and mitigation measures can be chosen to reduce risk to cabling (FUGRO Atlanic 2011).

In areas where bedform features are identified, pre-construction sweeping can be performed to flatten the installation corridor to remove mobile bedforms from the installation area and ensure the design burial depth is met. This sweeping can be conducted with the use of a pre-sweep plough device that is dragged behind a vessel or using a trailing suction hopper dredge (TSHD) for targeted removal of bedform features. Additionally, in areas where the target depth is not met during installation due to site conditions or cable exposure is still a risk, cable shielding implementations can be installed to protect the cable from exposure (see **Section EE.3.3**) (FUGRO Atlanic 2011).

EE.3.2 Evaluation of Site Conditions

To provide context to the potential hazards to Beacon Wind submarine export and interarray cabling posed by bedform migration, this section presents an overview of the regional physiography followed by a detailed assessment of Project survey data in both the Lease Area and along the submarine export cable route. Local-scale bedform features along the submarine cable route are then identified to support to construction planning and Project design.

EE.3.2.1 Description of Regional Physiography

The Beacon Wind Project area spans the entirety of Long Island Sound and a significant portion of the Southern New England OCS (see **Figure EE.1-1** for a Project map). This section provides an overview of the regional physiography and bedforms across and beyond the Project area, moving from east to west.

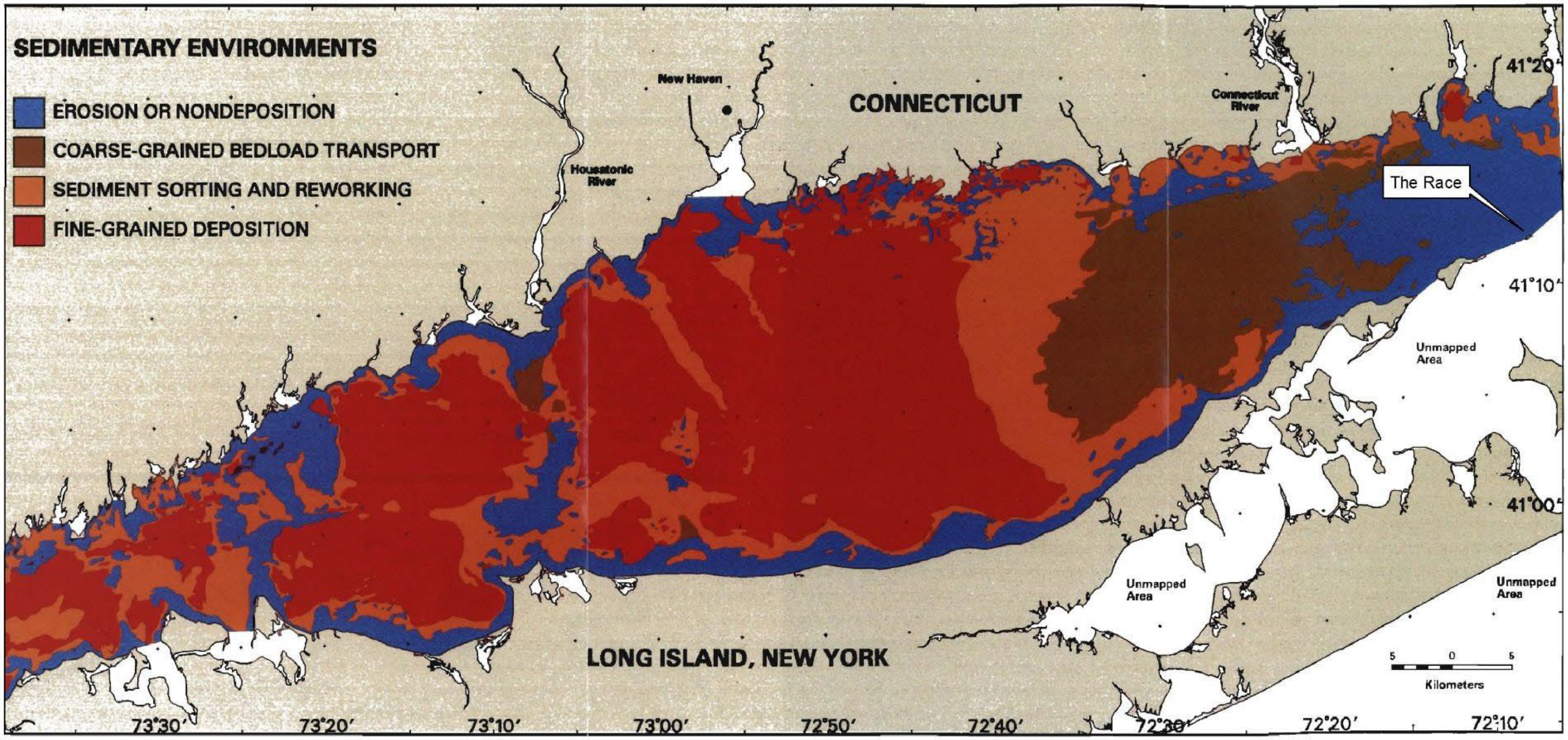
EE.3.2.1.1 Long Island Sound

Long Island Sound is a large but narrow body of water encapsulated by the southern Connecticut coastline to the north and New York’s Long Island to the south. The Sound is approximately 120 mi (193 km) long by 21 mi (34 km) wide (at its widest point), with an average depth of about 66 ft (20 m). Long Island Sound was created by glacial activity, when the Harbor Hill and Ronkonkoma moraines that form Long Island were deposited by several cycles of glacial advance and retreat (USGS 1968). The sound is open to the Atlantic Ocean on both ends: to the east through a narrow stretch of water called “the Race”, and to the west through the East River and New York Harbor.

Flow through Long Island Sound is driven by the tidal fluctuations of the Atlantic Ocean at either end of the sound. As a result, currents in Long Island Sound are generally aligned in the east-west direction, alternating every six hours as the tide fluctuates (O'Donnell, et al. 2013). High-energy hydrodynamic regions are created where the sound constricts (at the East River and the Race), with the bedforms dominated by erosion and migration processes. In low-energy hydrodynamic areas where the sound is the less constricted, the bottom currents are calm, and the seafloor is characterized by a depositional environment (NOAA Ocean Service Collaborative 2015). **Figure EE.3-3** provides a visual depiction of the range of sedimentary environments present across the sound (Knebel and Poppe 2000).

The Race, one of the highest-energy areas of the sound, is characterized by some of the sound's deepest bathymetry (more than 100 ft [30 m] in depth). These depths were formed by the long-term scouring effects of the tidally driven currents flowing through the Race over time. While also a high-energy environment, the bathymetry of the East River is maintained at a fixed depth by the United States Army Corps of Engineers (USACE) for navigational consistency.

FIGURE EE.3-3. SEDIMENTARY ENVIRONMENTS IN LONG ISLAND SOUND



ure 12. Composite regional map which shows the distributions of the four categories of sea-floor environments identified within the Long Island

Extracted from Knebel & Poppe, 2000

FIGURE EE.3-3: SEDIMENTARY ENVIRONMENTS IN LONG ISLAND SOUND

REFERENCE MAP

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EE.3.2.1.2 Southern New England OCS

The continental shelf south of the New England coastline is a broad plain broken up by minor irregularities; gently sloping from the coastlines of Connecticut, Rode Island, and Massachusetts to the continental shelf break some 81 nm (150 km) beyond the coast. Within the Beacon Wind Project area, the southern New England OCS contains several shallow erosional channels that do not extend across the entire shelf. A broad and gentle depression is present along the OCS to the south of Block Island, an ancient erosional channel formed by a mass-movement event long ago. These features are preserved in the present-day bathymetry of the OCS to create a relatively stable bedform due to a lack of sustained sediment supply to the region (USGS 1968).

Seaward extensions of the Long Island ridge can be seen to the island's east, likely extensions of the Ronkonkoma and Harbor Hill moraines that created the island (see **Section EE.3.2.1.1**). Similarly, shallow banks to the southwest of Martha's Vineyard and to the east of Block Island are likely seaward extensions of the morainic ridge that lies along the southwest side of Martha's Vineyard (USGS 1968).

The Nantucket Shoals, the most striking depositional feature on the southern New England OCS, is located just east of the Beacon Wind Lease Area. This shallow area (as little as 3.3 ft [1 m] in depth in places) is characterized by constantly shifting, complex dune topography created by the strong tidal currents present across the area. The crests and troughs of each shoal are characterized by innumerable smaller waves and ripples aligned at right angles to the direction of the predominant flood and ebb tide currents. The shoals consist primarily of reworked glacial sediment deposits, with additional sediment supplemented by the erosion of the shoreline of Cape Cod, Massachusetts (USGS 1968).

EE.3.2.2 Project Survey and Data Collection

To support the overall COP filing for the Beacon Wind Project, bathymetric, geophysical, and benthic surveys were commissioned for the Lease Area and submarine export cable routes. This survey work was conducted by MMT Sweden AB (MMT) between the summers of 2020 and 2021, and deliverables included full bathymetric and side scan sonar (SSS) coverages of the Lease Area as well as a 1,640-ft (500-m) corridor on either side of the submarine export cable routes. Bathymetric data was collected using a remotely-operated submersible vehicle (ROV) outfitted with a 2040D Kongsberg multi-beam echo sounder (MBES) device. In addition, SSS data was acquired using an Edgetech 2200 system, with two transducers mounted to either side of the ROV. The ROV was run at a height of 19.7 ft (6 m) above the seabed and advanced at a speed of 3.5-4.5 knots to achieve a target resolution of 0.82 ft (0.25 m) (MMT Sweden AB 2021).

The bathymetric data collected by MMT met specifications set forth by BOEM and the International Hydrographic Organization (IHO). All survey products were returned using the Mean Lower-Low Water (MLLW) datum (MMT Sweden AB 2021).

In the survey report, MMT provides an initial review of the geophysical features, along with primary indicators of active bed movement observed over the course of their survey work. Figure 22 of their report (reproduced in **Figure EE.3-4.a** here) show differences in sand ripple patterns and boundaries observed during survey passes from the same areas which were collected during different time periods, indicating evidence of active sediment mobility within the Lease Area. Sand ripples with heights of about 9.8 in (25 cm) and wavelengths of 2.6-4.9 ft (0.8-1.5 m) in these areas were observed to be aligned in various directions between survey passes collected five months apart, indicating a mobile bed in pockets of sorted bedforms located in the Lease Area (MMT Sweden AB 2021).

Several regions of the Lease Area are marked by extensive patterns of trawl scars, created by fishing vessels as equipment is dragged across the seafloor. Similar to the patterns of shifting sand ripples observed in the sorted bedforms, evidence of sediment mobility was also noted in the fading of these trawl scars over sequential survey passes through the same areas. As shown in Figure 26 of the MMT report (reproduced here as **Figure EE.3-4.b**) sets of paired trawl scars observed in August 2020 are almost indistinguishable by survey passes conducted in March of 2021 (MMT Sweden AB 2021).

FIGURE EE.3-4. CHANGES IN BED CHARACTERISTICS OBSERVED DURING SURVEY ACTIVITY

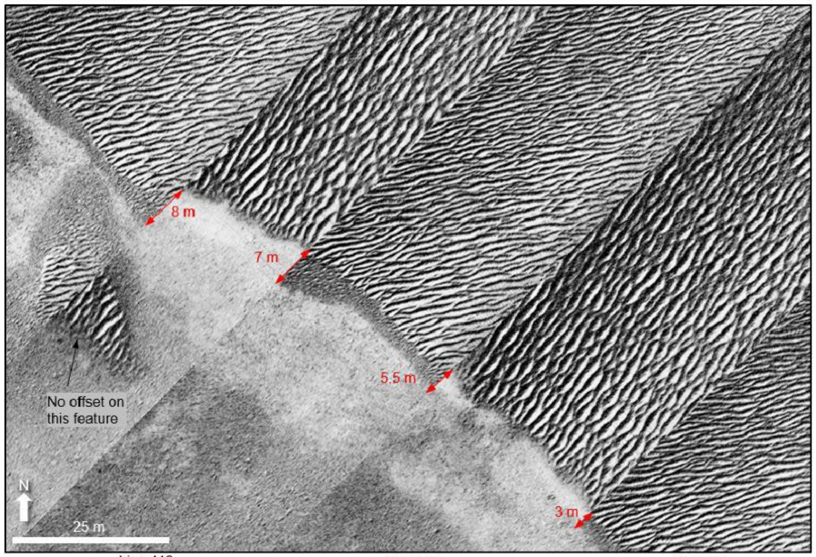

Figure EE.3-4.a Side-scan sonar imagery showing time-variant offset along the edge of a sorted bedform within the lease area.

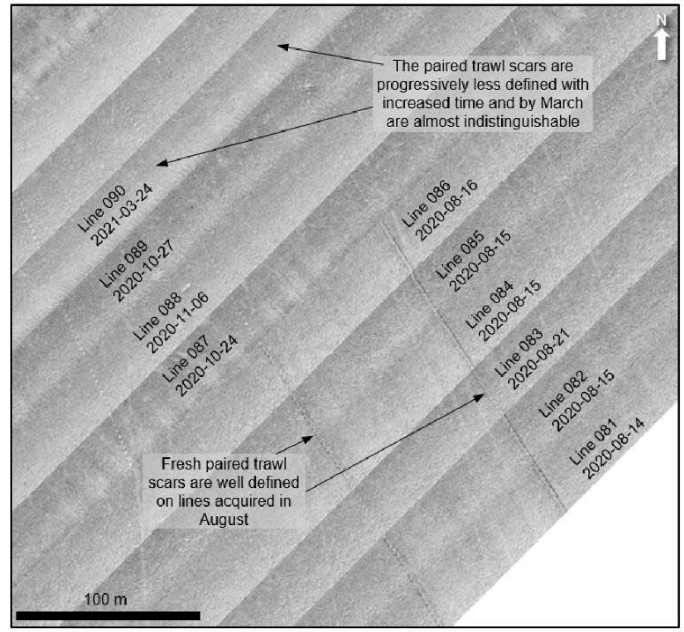

Figure EE.3-4.b Side-scan sonar imagery showing the dissolution of a paired trawl scar through time within the lease area.

Extracted from MMT Sweden AB 2021

FIGURE EE.3-4: CHANGES IN SAND WAVE MORPHOLOGY AND SEABED TRAWL SCARS OBSERVED DURING SURVEY ACTIVITIES

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Personnel:	Prepared by: CMD

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EE.3.2.3 Localized Bedform Feature Assessment

To assess the seafloor environment for the presence of bedform features critical to proposed cable installation, the bathymetric data collected by MMT along the submarine export cable routes was analyzed using the 3D Analyst tool in ArcMap Geographic Information System (GIS) software. Geophysical features appearing on or near the proposed submarine export cable routes with a height of 2.9 ft (0.9 m) or greater (heights exceeding half of the target cable burial depth) were flagged for further review. This assessment was performed for the six “Blocks” of BW1 submarine export cable connecting to Astoria, New York POI as well as for the BW2 submarine export cable segment connecting to the Waterford, Connecticut POI.

Project bathymetry collected within the Lease Area was also analyzed, and no discrete bedform features meeting this 2.9-ft (0.9-m) threshold were identified. However, rippled scour depressions and shallow sorted bedform features were identified in several parts of the Lease Area and are described in further detail in the MMT survey report (MMT Sweden AB 2021).

In the review of the submarine export cable route bathymetry, AECOM identified two general classes of bedform features that may impact cable installation: sand wave and boulder fields. Sand wave features (as described in **Section EE.3.1.1** of this report) greater than 2.9-ft (0.9 m) in height that were often observed in clusters, primarily in Blocks 3 and 4, with others in Blocks 1 and 6. Boulder fields, referred to here as areas with rough bed surface and large boulder features visible in the MBES data, were observed in three areas of Blocks 3 and 4, with one other identified in Block 1. The location of these bedform features in the six submarine export cable route Blocks, as well as the BW2 segment to Waterford, Connecticut are shown in **Figure EE.3-5** through **Figure EE.3-11**, respectively.

Characterization of the localized bedform features along the submarine export cable routes and Lease Area provides useful information for cable installation planning as well as the design of measures to protect Project cabling where needed. Both local sand waves and boulder fields may prevent cable installation from achieving the target burial depth or cause cable exposure, necessitating micrositing or engineered cable protection measures where these features are present.

FIGURE EE.3-5. BEDFORM FEATURES IDENTIFIED IN BLOCK 1

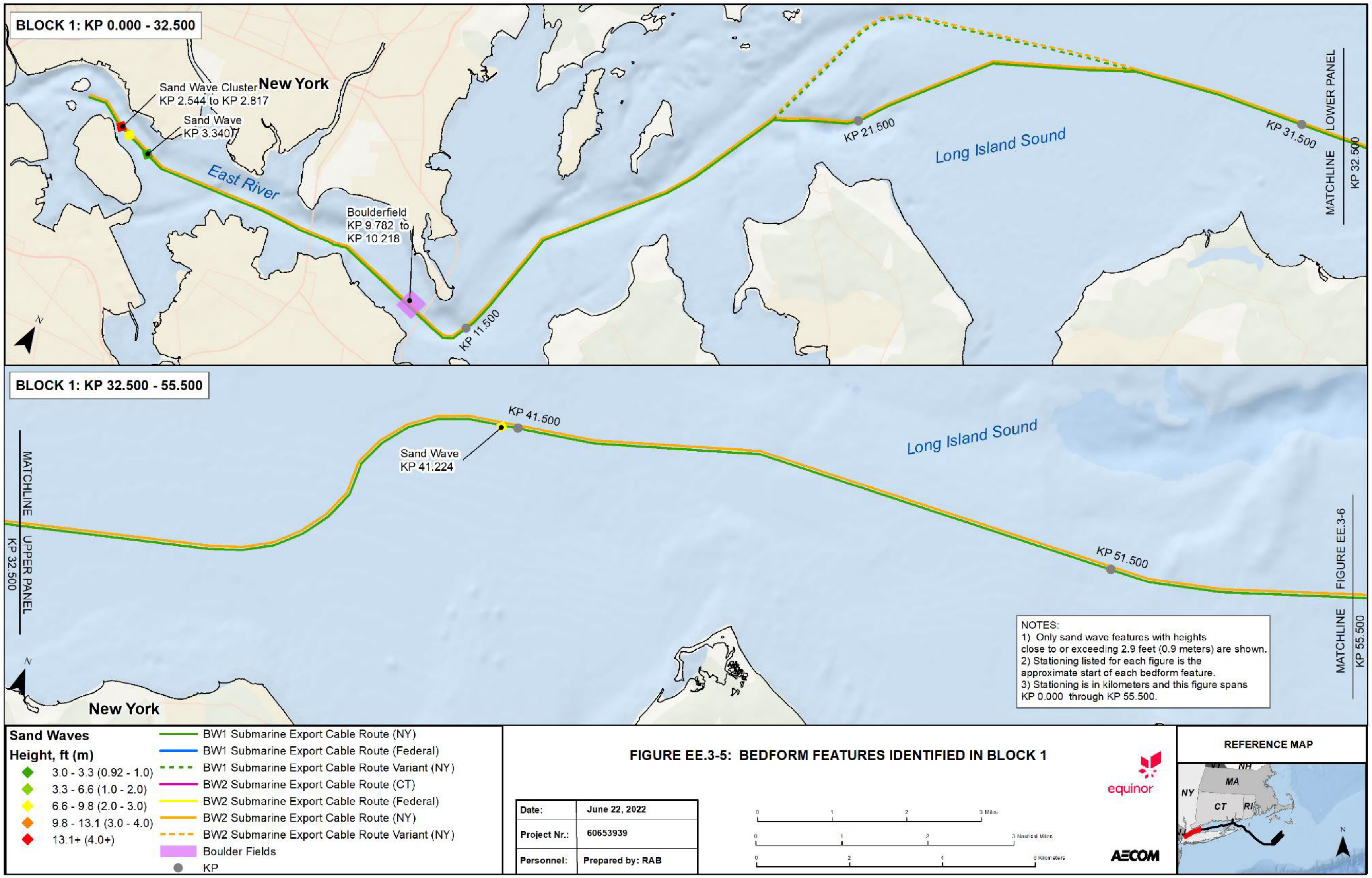


FIGURE EE.3-6. BEDFORM FEATURES IDENTIFIED IN BLOCK

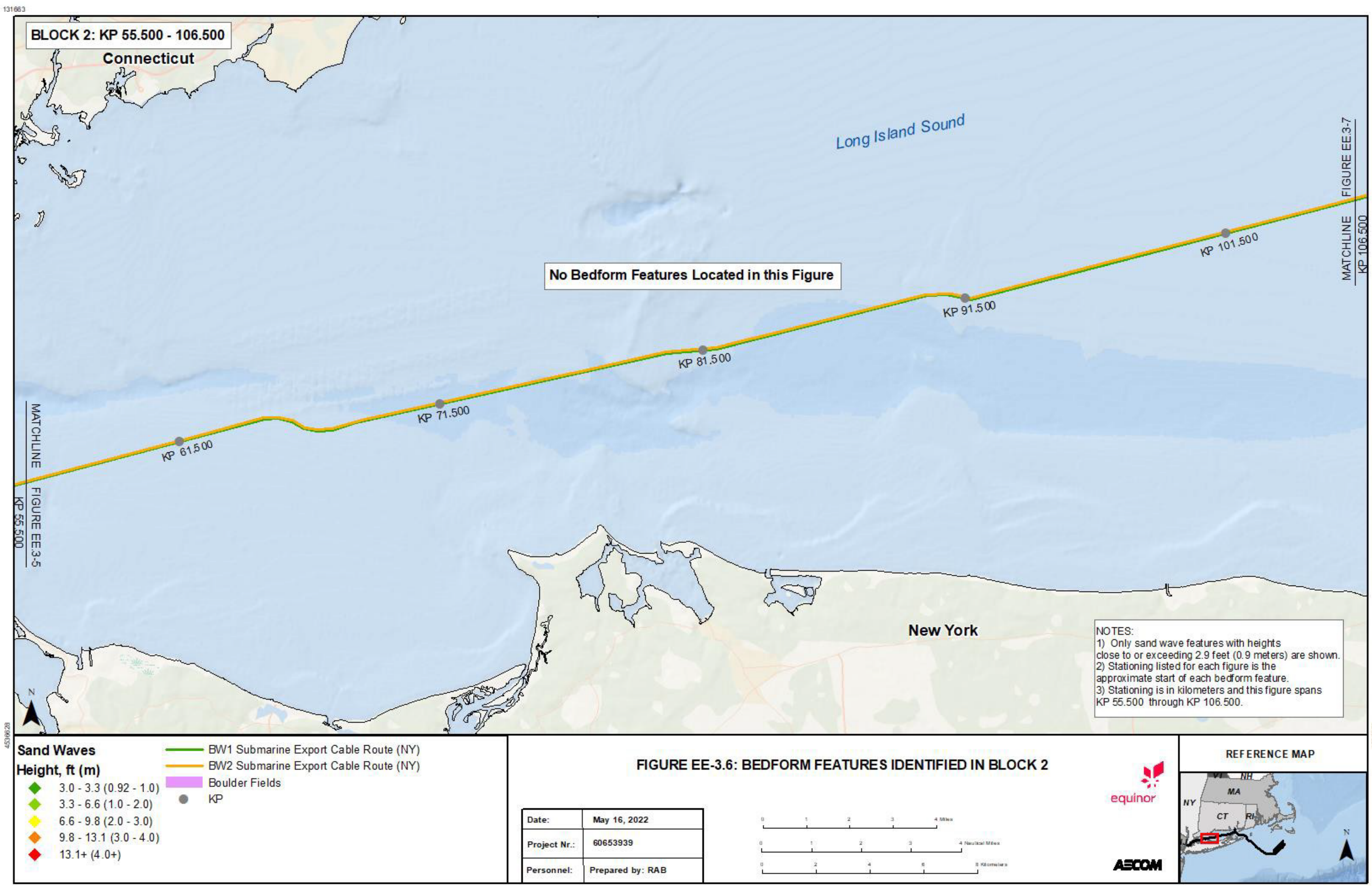


FIGURE EE.3-7. BEDFORM FEATURES IDENTIFIED IN BLOCK

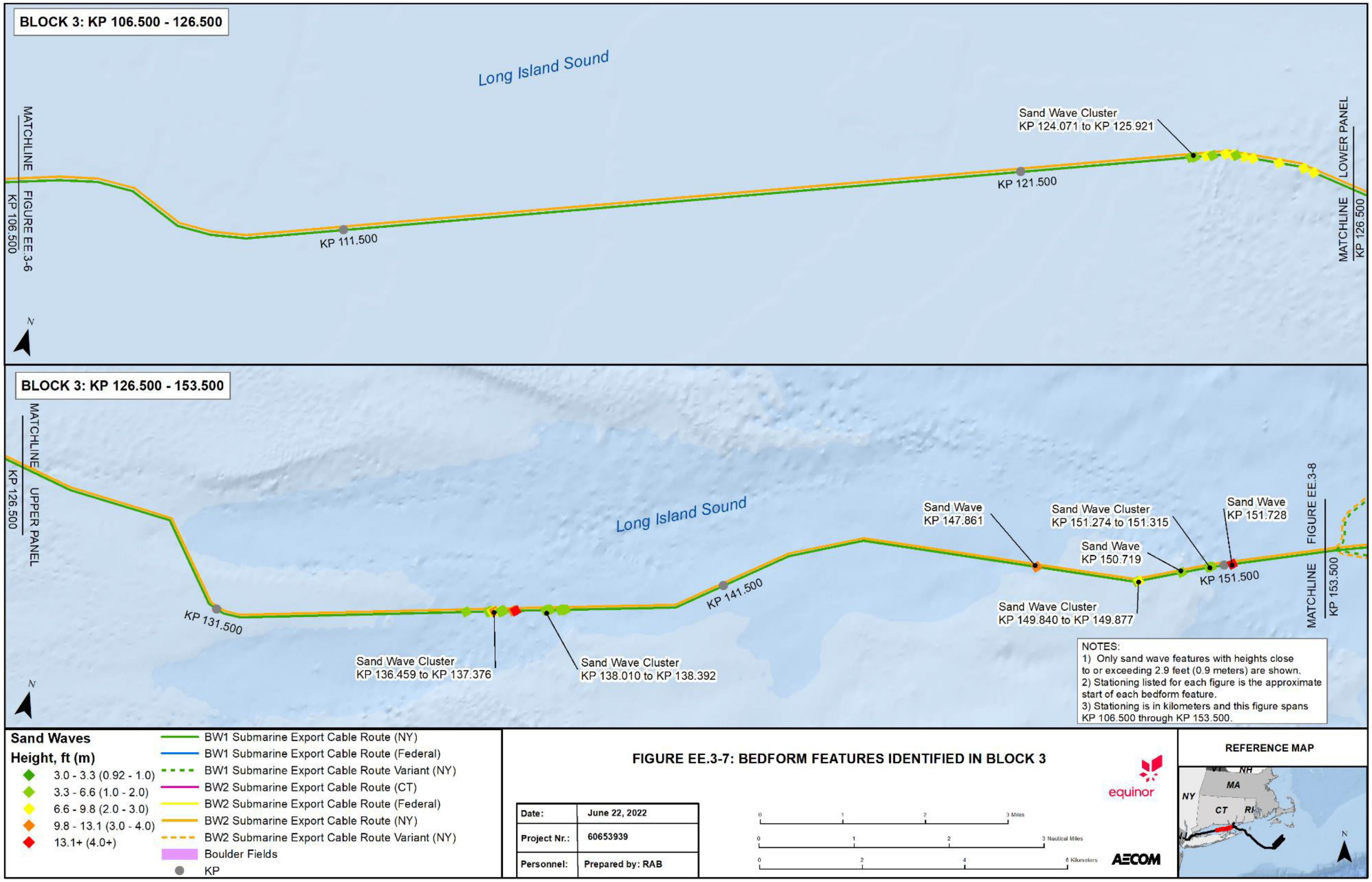


FIGURE EE.3-8. BEDFORM FEATURES IDENTIFIED IN BLOCK

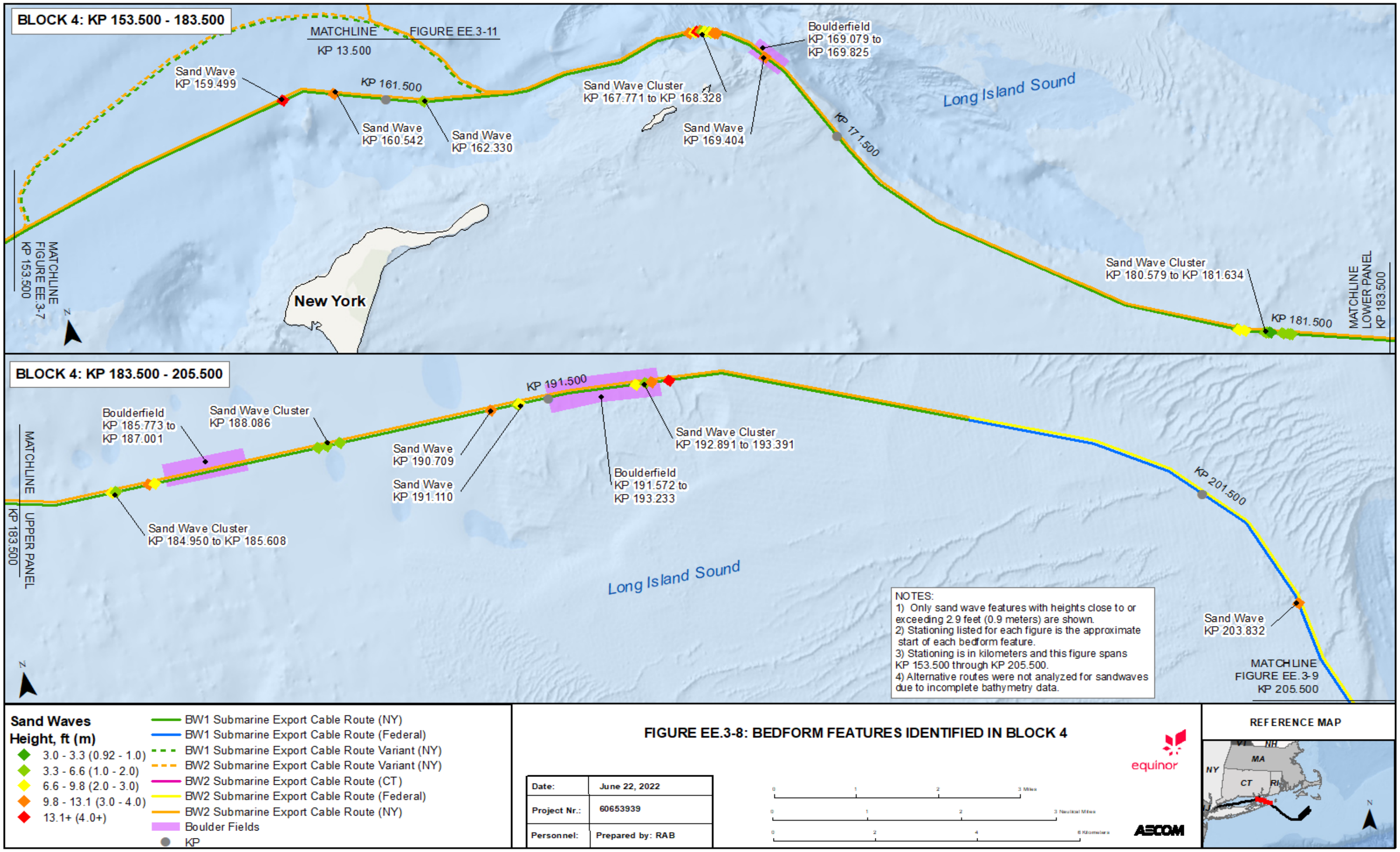


FIGURE EE.3-9. BEDFORM FEATURES IDENTIFIED IN BLOCK

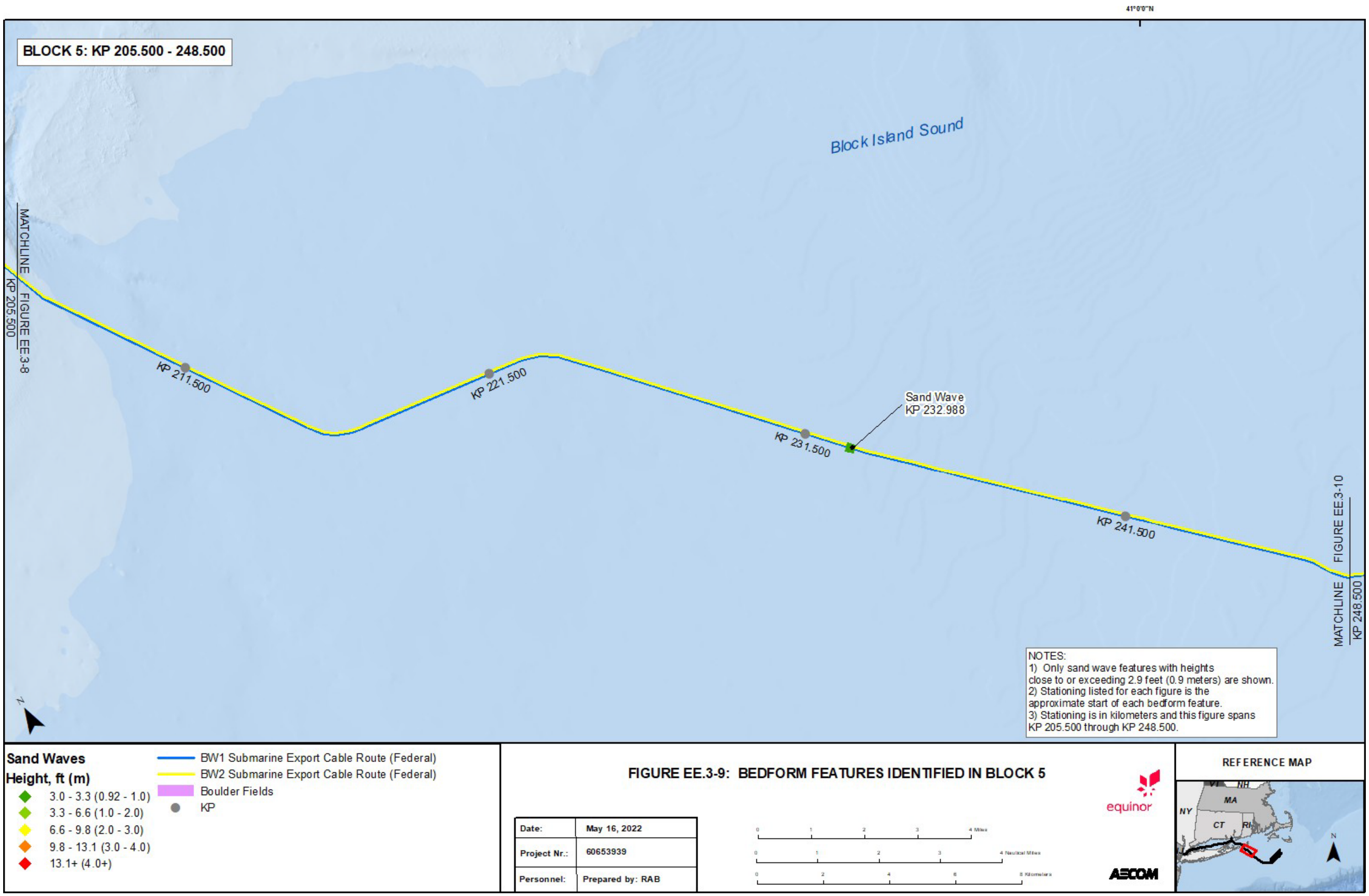


FIGURE EE.3-10. BEDFORM FEATURES IDENTIFIED IN BLOCK 38

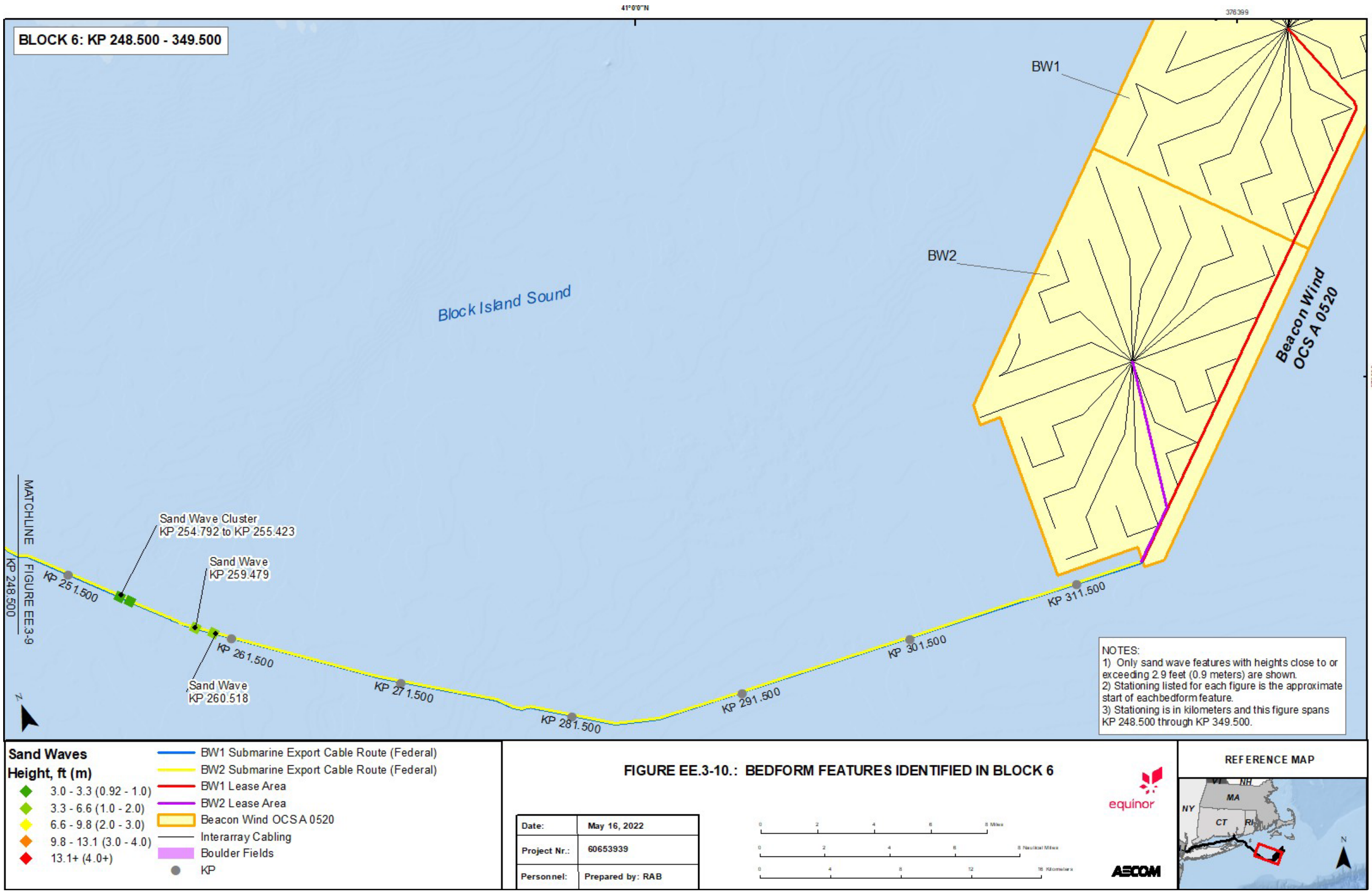
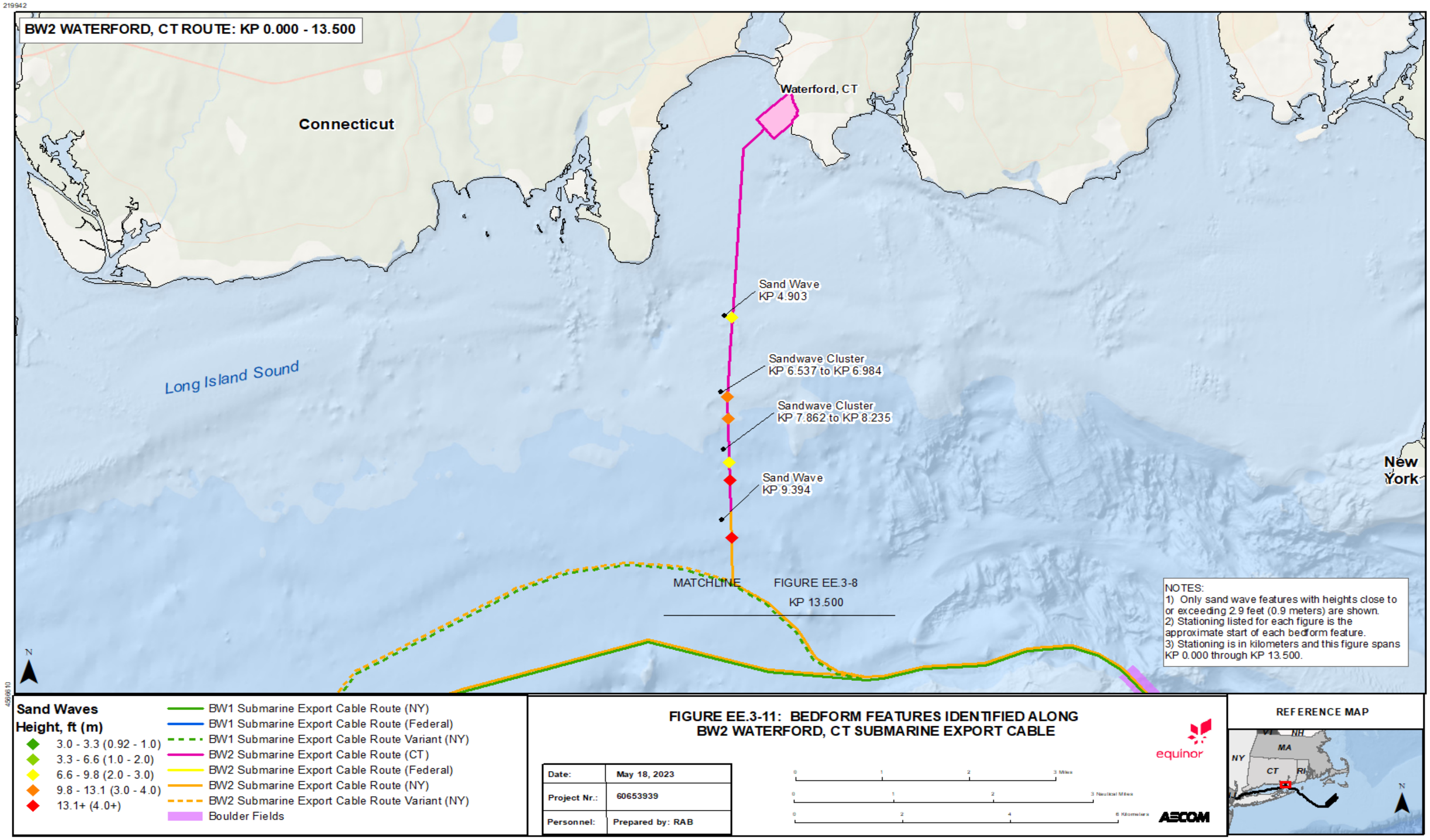


FIGURE EE.3-11. BEDFORM FEATURES IDENTIFIED IN BW2 WATERFORD, CONNECTICUT ALIGNMENT



EE.3.2.3.1 Sand Wave Features

As shown in **Figure EE.3-5** through **Figure EE.3-11**, local sand wave features were identified across the submarine export cable routes, and with the greatest frequency and magnitude (height) within Blocks 3 and 4. The majority of sand wave features observed along the submarine export cable routes were either linear or sinuous in geometry, indicating relatively low-energy and less active sediment transport environments (per **Figure EE.3-1**). However, caternary, lunate, and linguoid features were identified within eastern Long Island Sound (Blocks 3 and 4), indicating relatively high-energy and more active sediment transport environment.

The sand wave features flagged for review in this analysis (features greater than 2.9-ft [0.9 m] in height) had an average feature height of 6.6 ft (2 m), and generally ranged from 2.9-16.4 ft (0.9 to 5 m) in height. In addition, a 19.0 ft (5.8-m) high linguoid bedform was identified in Block 3, and a 25.6 ft (7.8-m) high ridge was identified along the BW2 alignment to Waterford, Connecticut.

EE.3.2.3.2 Boulder Field Features

As described in **Section EE.3.2.2**, boulder fields were identified in the bathymetric survey data collected in Blocks 1 and 4. These boulder field areas are characterized by a prevalence of boulders detected in the survey data. **Figure EE.3-2** displays a sample boulder field area identified in Block 4, with accompanying cross-sections. The four boulder field areas that were identified along the submarine export cable routes are located within the high-energy erosional areas of Long Island Sound described in **Section EE.3.2.1** and shown in **Figure EE.3-3.** These areas may have developed by long-term scouring of these higher-velocity areas over time, revealing glacial till and boulders beneath the finer depositional sediment.

Boulder fields pose a potential for obstructing the cable installation and may require installation-phase micrositing or engineering controls to mitigate potential risk to Project submarine export and interarray cabling. **Section EE.3.3** of this report summarizes potential cable protection and shielding implementations that may be applied in these areas to meet these requirements.

EE.3.2.4 Sand Wave Migration Analysis

To assess bedform mobility along the submarine export cable routes, MMT performed duplicate geophysical and bathymetric surveys at various locations along Blocks 3 and 4 of the submarine export cable routes in April/May 2021 and in January 2022. Comparison of bedform changes between the two surveys were performed at 10 locations in Blocks 3 and 4 of the submarine cable route. The field memorandum of this investigation is included as **Attachment EE.B**. Figures 4 through 23 of **Attachment EE.B** depict the results of bedform comparison (MMT Sweden AB 2022).

MMT's field investigation confirms the mobility of bedforms along submarine export cable route Blocks 3 and 4. Across the 10 locations surveyed, measured seabed elevation was observed to change by about +/- 1.5 ft (0.45 m) over the 8-month time span between surveys. Bedform features along the submarine export cable routes centerline at some locations migrated significantly in this time span; with bedform crests laterally migrating up to 42.6 ft (13 m) at Location 2 (Block 3) and up to 25.6 ft (7.8 m) at Location 7 (Block 4) (MMT Sweden AB 2022).

EE.3.3 Cable Protection and Shielding Measures

This section discusses cable protection and shielding measures that can be used to protect subsea cabling from exposure due to bedform movement and from reduced installation depth in hard-substrate and boulder field areas.

EE.3.3.1 Cable Protection in Mobile-Bed Areas

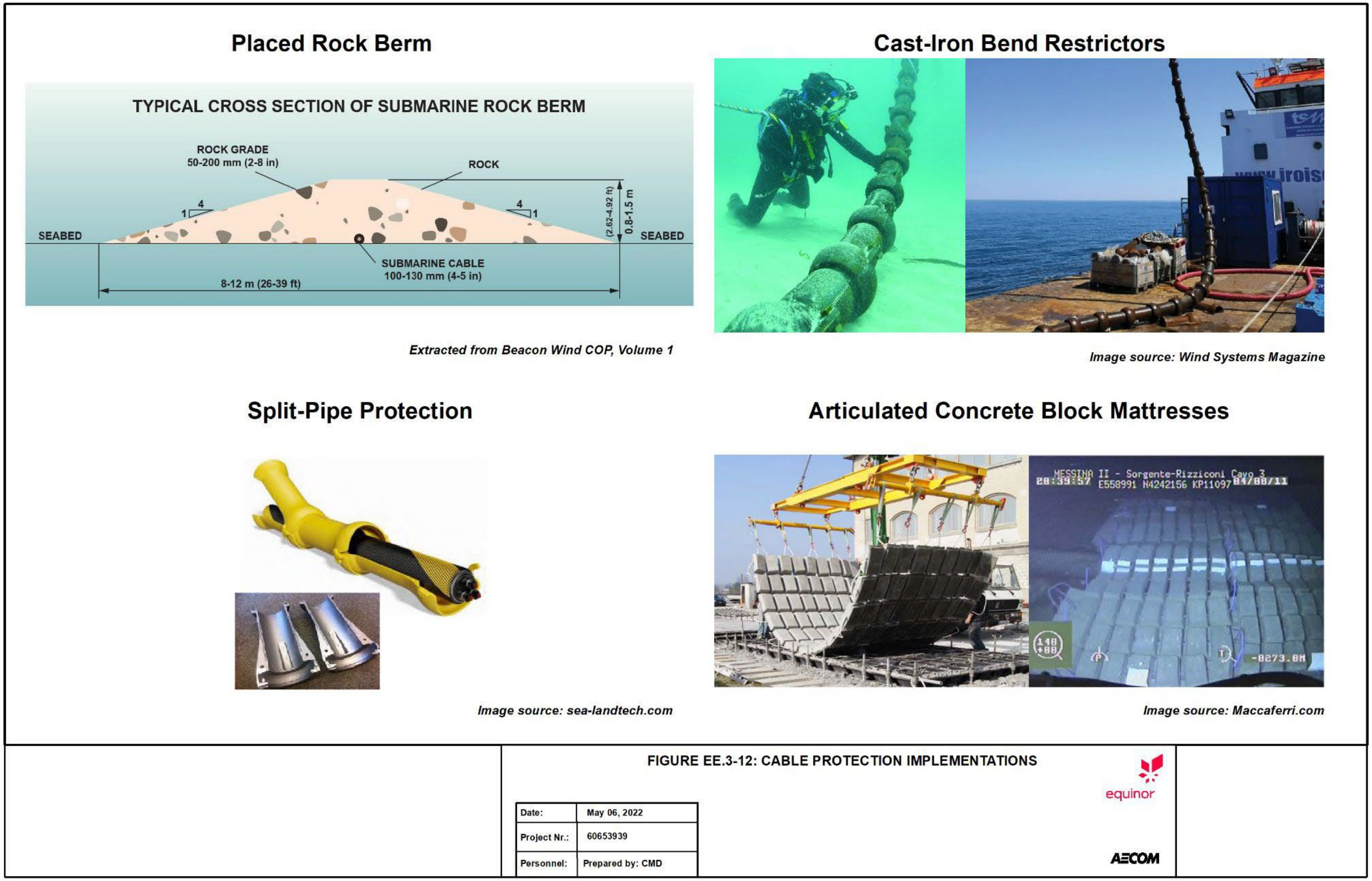
As described in **Sections EE.3.2.1** and **EE.3.2.3**, several regions of the seafloor across the Beacon Wind submarine export cable routes are characterized as high-energy, mobile bed sediment transport environments. In these areas (such as the bedform-laden portions of Blocks 3 and 4, near the Race), the installation of submarine export cabling along the existing seafloor would risk exposure in the troughs of the sand waves over time as these bedforms migrate. In these areas, the practice of pre-dredging or pre-sweeping can be used to remove the highly mobile top layer of sediment and to allow cable installation to a lower depth below the seabed. Depending on the rates of sediment transport and bedform movement, cable installation may need to occur soon after pre-sweeping to avoid the infilling of a newly cleared area (FUGRO Atlanic 2011).

EE.3.3.2 Cable Shielding Implementations

Where hard-bottomed, obstruction-laden, or other irregular seafloor conditions prevent the installation of Project cabling to the intended design depth, shielding implementations can be installed to protect the submarine export cable from the various hazards discussed in this report. **Figure EE.3-12** provides sample diagrams of cable shielding measures commonly in practice.

Articulated concrete mats, also referred to as concrete mattresses, harden the seafloor and prevent the erosion of bed material, but can be more susceptible to edge scour effects. As the concrete mats are flexible, they form around the cable when placed. The technique is frequently used where cables are installed atop existing utility assets, as they can be used to provide a level of protection to both the new and existing utility lines. Simple placed aggregate and rock can be used to build a berm atop the installed submarine export cables, providing the design depth of pipe cover in the form of stable aggregate rock. Cast iron shells and other bend restrictors or stiffeners can be applied to the outside of submarine export cables placed on the seafloor to ballast the cable, minimize the bend radius to reduce cyclic loading stresses, and armor the cable against abrasion and impact. Finally, split-pipe implementations essentially place the submarine export cables within larger pipe segments to provide rigidity and protection from abrasion and impact (Peycheva 2019).

FIGURE EE.3-12. CABLE PROTECTION IMPLEMENTATIONS



EE.4 Conclusions

This appendix presented an evaluation of potential foundation scour, as well as potential sour protection measures, for the foundation structures proposed for installation in the Lease Area OCS-A 0520 as part of the Beacon Wind Project. It also presented an assessment of bedform migration present along the Project submarine export cable route and in the Lease Area.

For the wind turbine and offshore substation facility foundation structures proposed for installation within the Lease Area, potential scour depths were estimated using an analytical method to account for the combined wave- and current-driven hydrodynamics environment of the Atlantic OCS. A 20-year hindcast hydrodynamic dataset was used to support these scour estimations, and to derive key statistics representing the normal dynamic equilibrium and extreme-event conditions in the Lease Area. As offshore energy development in the Atlantic OCS has been limited to date, field-measurements and region-specific analytical tools that could be used to verify these predictions are limited. When compared to similar analyses conducted at Europe OWFs, the foundation scour depths estimated in this analysis are much smaller, attributable to the difference in water depths, wave impacts, and bottom currents typically seen between the two regions. One limitation of the hindcast dataset used in this analysis is its lack of representation of extreme events, as no hurricane passed within 50 nautical miles of the Lease Area during the time period covered by the dataset. For foundation structure scour protection using loose stone, preliminary dimensions for armoring layer and filter layer were conservatively estimated for permitting purposes.

For interarray and submarine export cabling proposed as part of the Beacon Wind Project, bedform features were assessed using bathymetric survey data collected in support of the Project. Localized sand waves and boulder field bedforms were identified across the submarine export cable route, primarily in high-energy hydrodynamic regions such as the mouth of the Long Island Sound where flow in and out of the sound is most constricted. Understanding of the mobility of these bedforms supports the planning for cable installation, and identification of areas where engineering implementations may be required to meet the desired burial depth or to protect the cable from potential exposure.

Seabed scour is a constant potential hazard to offshore wind developments. Scour is inherently related to oceanographic and seabed parameters, many of which vary both in time and in space. Therefore, the estimations of potential scour discussed here carry uncertainty and considerations such as occurrence probability and design safety tolerance should be practiced. Post-construction surveys and long-term monitoring are recommended to validate or adjust scour protection measures, if necessary, through the life of the wind farm facilities as part of an overall adaptive operations approach once constructed and operational.

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Attachment EE-A

Overview of Analytical Approaches

A.1. Potential Scour Calculation for Monopiles

Per Zanke et al. (2011), scour is induced by *currents only* if the Keulegan-Carpenter (KC) number is below 6, and by *the combined effects of currents and waves* if the KC number is above 6. Following a review of analytical scour procedures determined by Matutano et al (2013), scour depths shall be determined for current-only conditions per the United States Federal Highway Administration's (FHWA) Hydraulic Engineering Circular (HEC) Number 18 (FHWA, 2018), and for current-and-wave conditions per Zanke et al. (2011).

A.1a. Determine Dominant Scour Regime

$KC = U_w T_P D_{eff}$ *Determine Keulegan-Carpenter number.* *(A.1a-1)*

$KC < 6$ *If KC < 6, current-only scour. Section A.1b.* *(A.1a-2)*

$KC > 6$ *If KC > 6, current-and-wave scour. Section A.1c.* *(A.1a-3)*

Where: *U_w= Near-Bed Peak Orbital Velocity, meters per second*
T_p= Peak Wave Period, seconds
D_{eff}= Effective foundation diameter including marine growth, meters

A.1b. Determine Scour under Current-Only Conditions: KC < 6

$$Fr = \frac{U_A}{\sqrt{gh}}$$ *Determine Froude number* *(A.1b-1)*

$$H = 2K_1K_2K_3\left(\frac{h}{D_{eff}}\right)^{0.35} Fr^{0.43}$$ *Calculate local scour depth* *(A.1b-2)*

Where: Fr = Froude number (dimensionless)
U_A = Depth-Averaged Current Speed, meters per second
g = Gravity Constant, 9.81 meters per second^2
h= Water Depth, meters
K_1 = HEC-18 correction factor for pier nose shape (assumed to be 1.0)
K_2 = HEC-18 correction factor for angle of attack flow (assumed to be 1.0)
K_3 = HEC-18 correction factor for bed condition (assumed to be 1.1)

A.1c. Determine Scour under Current-and-Wave Conditions: KC > 6

$$U_c = 1.4\left(2\sqrt{\left(\frac{\rho_s-\rho}{\rho}\right) g d_{50}} + 10.5\frac{\nu}{d_5}\right)$$ *Depth-avg. critical velocity of bed sediment* *(A.1c-1)*

$$x_{eff} = 0.03\left(1 - 0.35\frac{U_c}{U_{nb}}\right)(KC - 6)$$ *(A.1c-2)*

$$x_{rel} = \frac{x_{eff}}{1 + x_{eff}}$$ *(A.1c-3)*

$$H = 2.5\left(1 - 0.5\frac{U_{nb}}{U_c}\right) x_{rel} D_{eff}$$ *Calculate local scour depth* *(A.1c-4)*

Where:
U_c = Depth-averaged critical velocity of native bed sediment, meters per second
ρ_s = Density of armor stone, 2,750 kilograms per meter^3
ρ = Density of water, 1,026.8238 kilograms per meter^3 (Seawater at 11^{o}C)
d_{50} = Median grain diameter of bed sediment, meters (Grain Size Database)
ν = Kinematic viscosity of water, 1.3230E-6 meters^2 per second (Seawater at 11^{o}C)
x_{eff} = Interim variable in calculation of equilibrium scour depth
U_{nb} = Observed near-bed current velocity, meters per second
X_{rel} = Interim variable in calculation of equilibrium scour depth
H = Local scour depth, meters

A.2. Scour Protection Sizing

To size the design D_{50} for the scour protection armor layer to be installed at each turbine, a failure design methodology using applied bed shear stress and the Shields stability approach is utilized. Maximum applied bed shear stress is calculated as a function of combined wave and current flows following the DATA2-method procedures outlined in *Bed Shear Stresses under Combined Waves and Currents on Smooth and Rough Beds* (Soulsby, 2005). Here, shear stresses are calculated separately for wave and current flow regimes, and then combined based on differences in direction of each.

The critical Shields parameter of the design armor stone will be determined for combined wave and current effects (Soulsby, 1997; USGS, 2012). Then, the stability of this stone under the conditions specified above will be assessed using the Opti-Pile stability approach developed specifically for wind farm applications (den Boon, 2004; Wu, 2020). Following guidance from previous Beacon Wind project documentation, a *Stab* parameter of 0.362 will be adopted for design, incorporating a safety factor of 1.2 into the minimum *Stab* parameter for stone design of 0.435 (den Boon, 2004).

A.2a. Derivation of Maximum Applied Bed Shear Stress

$$\tau = \{[\tau_m + \tau_w \cos(\varphi)]^2 + [\tau_w \sin(\varphi)]^2\}^{0.5}$$ *Total shear under waves & currents* *(A.2a-1)*

$$\tau_m = \tau_c \left[1 + 1.2 \left(\frac{\tau_w}{\tau_c + \tau_w}\right)^{3.2}\right]$$ *Mean bed shear stress under waves & currents* *(A.2a-2)*

$$\tau_w = \frac{1}{2}\rho f_w {U_w}^2$$ *Wave-induced bed shear stress* *(A.2a-3)*

$$\tau_c = \frac{1}{2}\rho f_c {U_A}^2$$ *Current-induced bed shear stress* *(A.2a-4)*

Where:
τ = Total bed shear stresses during a wave cycle under combined waves or currents
τ_m = Mean bed shear-stresses during a wave cycle under combined waves and currents
τ_w = Wave-induced bed shear stresses
φ = Angle between Wave and Current Directions, radians
τ_c= Current-induced bed shear stresses
f_w= Friction factor for determining wave-induced bed shear stress
f_c = Friction factor for determining current-induced bed shear stress

2c. Scour Protection Stone Sizing

$$D_* = \left[\frac{g(\frac{\rho_s}{\rho}-1)}{\nu^2}\right]^{1/3} D_{50}$$ *Calculate dimensionless grain size* (A.2b-1)

$$\theta_{cr} = \frac{0.30}{1+1.2D_*} + 0.055(1 - e^{-0.020D_*})$$ *Calculate critical Shields parameter* (A.2b-2)

$$\theta_{max} = \frac{\tau}{g(\rho_s-\rho)D_{50}}$$ *Calculate maximum Shields parameter*
(A.2b-3)

$$Stab = \frac{\theta_{max}}{\theta_{cr}} < 0.362$$ *Iterate D_{50} such that* Stab < *0.362* (A.2b-4)

Where:
D_* = Dimensionless grain size
D_{50} = Median grain diameter of scour protection armor layer, meters
θ_{cr} = Critical Shield's parameter for sediment under wave and current conditions
θ_{max} = Maximum applied Shield's parameter based on maximum applied bed shear
Stab = Shield's parameter stability factor for armor layer design

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Attachment EE-B

MMT Bedform Migration Analysis

FIELD MEMO
SEDIMENT MOBILITY
MV DEEP HELDER

103746-EQU-MMT-SUR-REP-SEDMOBIL
ISSUE FOR REVIEW
JANUARY 2022

BEACON WIND EXPORT CABLE SURVEY 2022
INFILL SURVEY

US EAST COAST
JANUARY 2022

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1| SURVEY AREA OVERVIEW

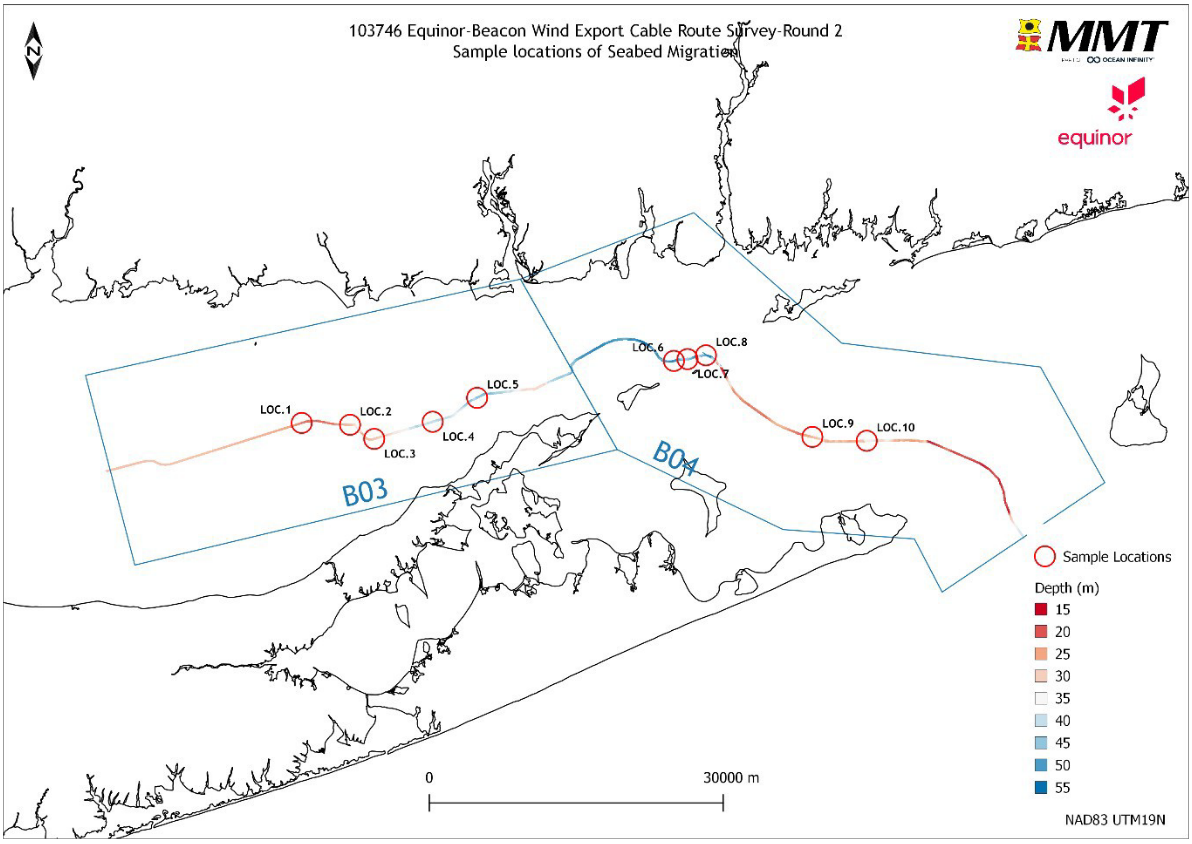

Figure 1. Overview of B03 & B04 as well as sample locations for sediment mobility.

Table 1. B03 reference Coordinates, Depths and KPs of locations

B03 - Location number	Easting	Northing	Depth	KP
LOC.1	198320.86	4560651.45	22.71	124.01
LOC.2	203254.50	4560464.54	28.53	129.00
LOC.3	205721.18	4559024.18	29.48	132.13
LOC.4	211692.83	4560773.32	39.29	138.35
LOC.5	216220.37	4563216.64	45.20	143.59

Table 2. B04 reference Coordinates, Depths and KPs of locations

B04 - Location number	Easting	Northing	Depth	KP
LOC.6	236304.62	4566983.01	51.27	166.48
LOC.7	237697.19	4567166.48	44.75	167.89
LOC.8	239580.18	4567549.04	50.74	169.83
LOC.9	250436.49	4559230.87	27.50	184.03
LOC.10	255984.78	4558833.77	33.64	189.63

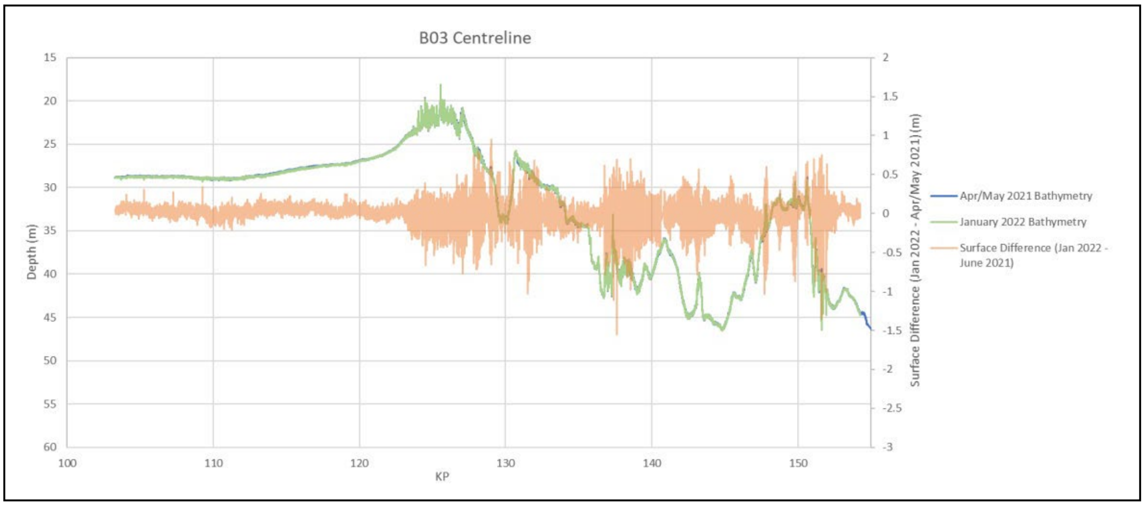

Figure 2. Long Profile along B03 Centreline and Surface Difference

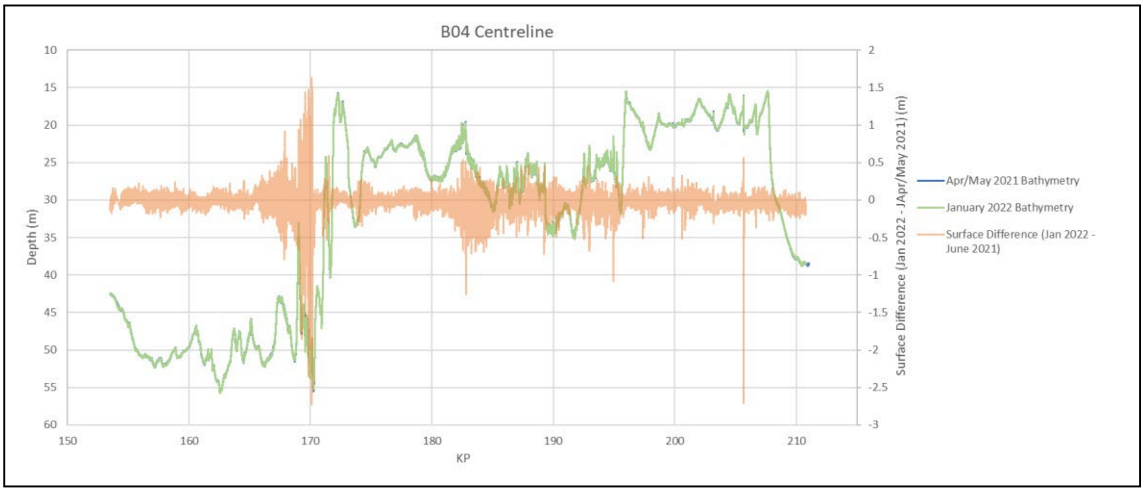

Figure 3. Long Profile along B04 Centreline and Surface Difference

2| SEDIMENT MOBILITY B03

2.1 | LOC.1

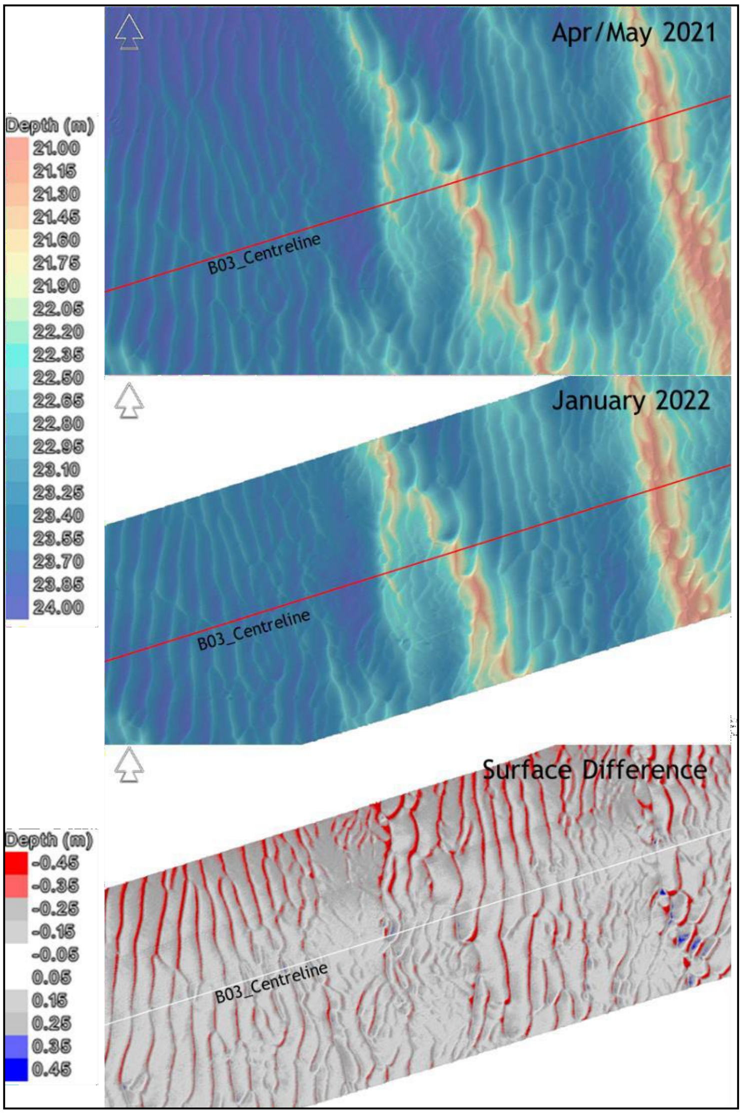

Figure 4. Location 1

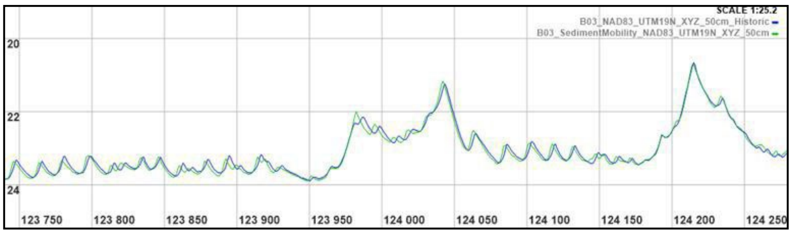

Figure 5. Profile graph, Blue line is Historical data and Green line is January survey data.

2.2 | LOC.2

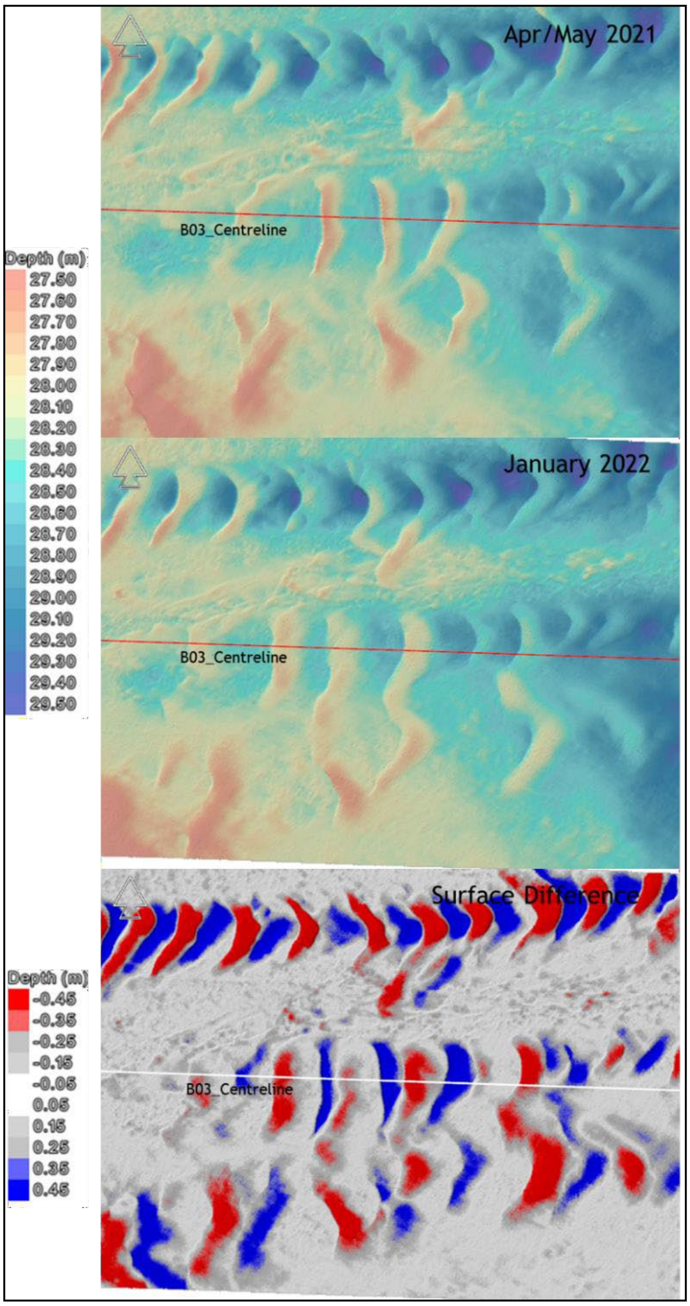

Figure 6. Location 2

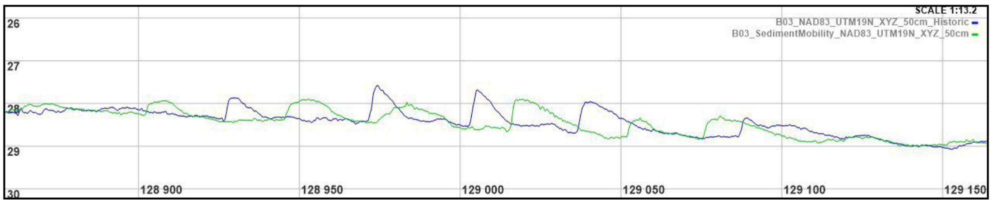

Figure 7. Profile graph, Blue line is Historical data and Green line is January survey data.

LOC.3

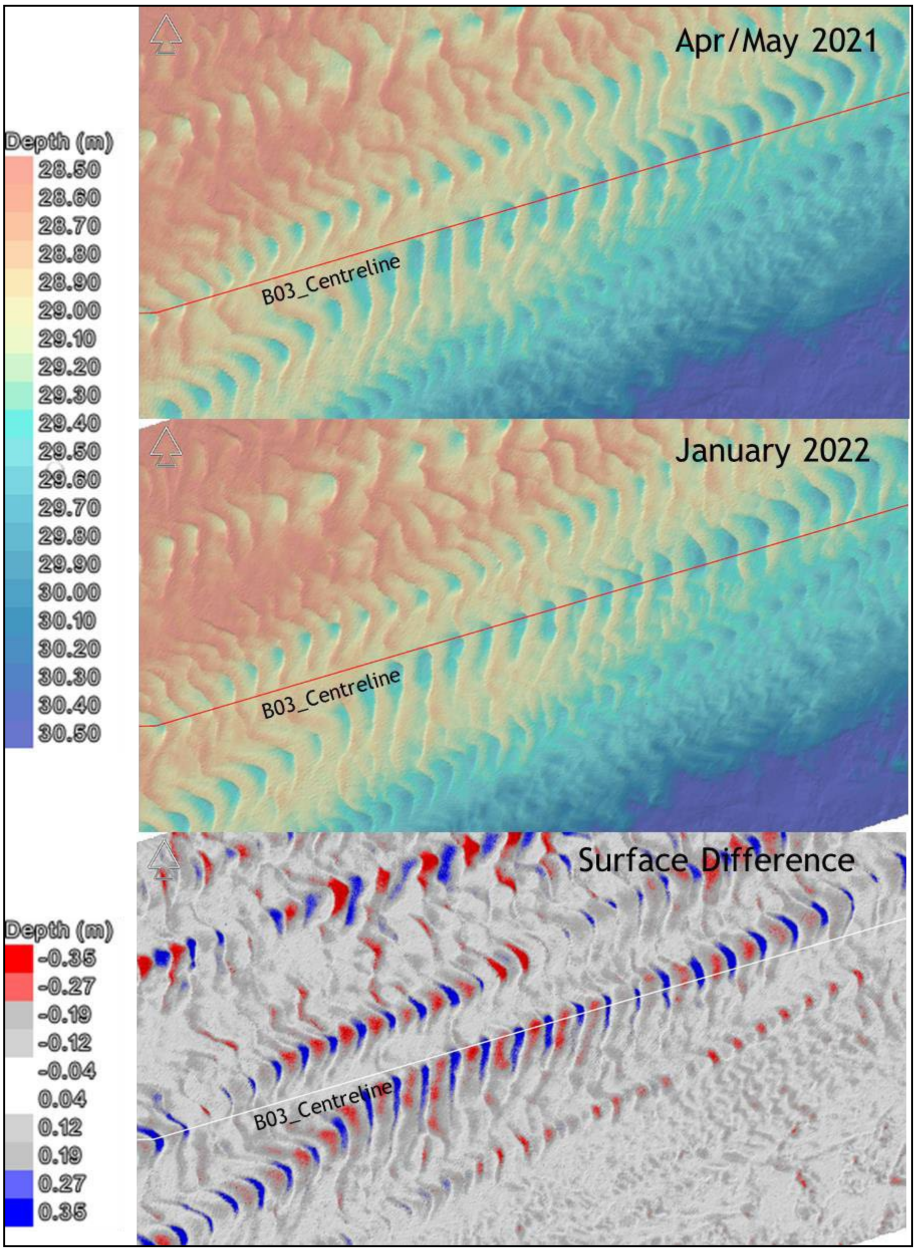

Figure 8. Location 3

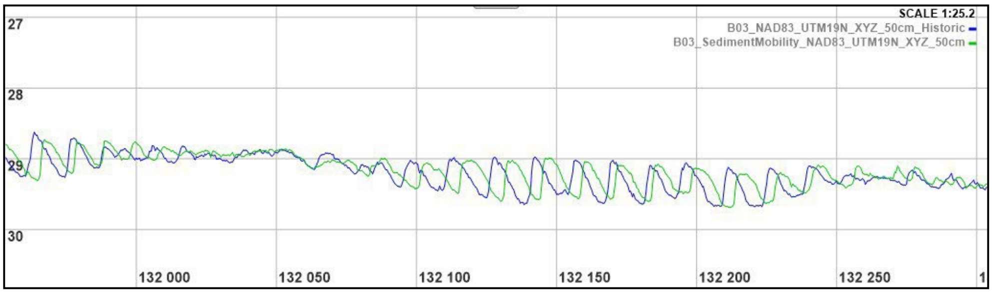

Figure 9. Profile graph, Blue line is Historical data and Green line is January survey data.

2.3 | LOC.4

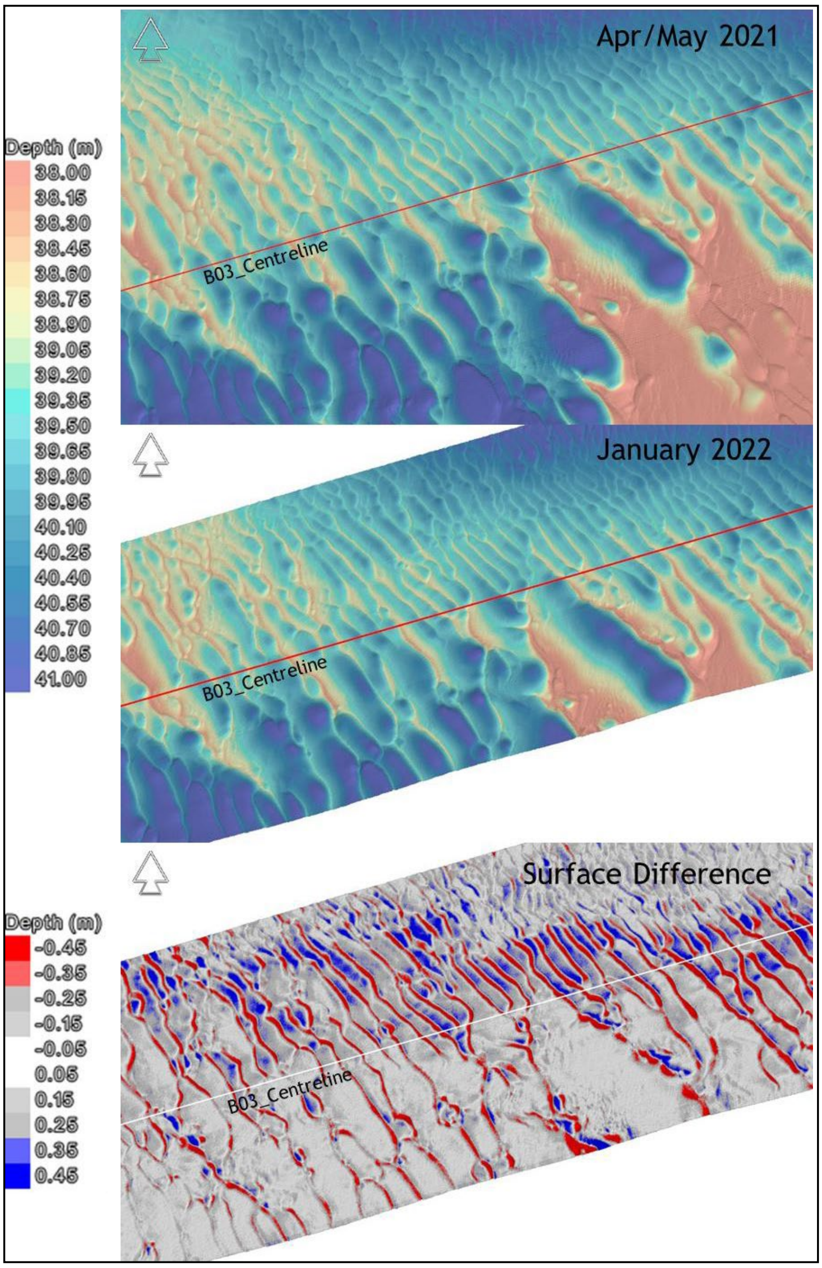

Figure 10. Location 4

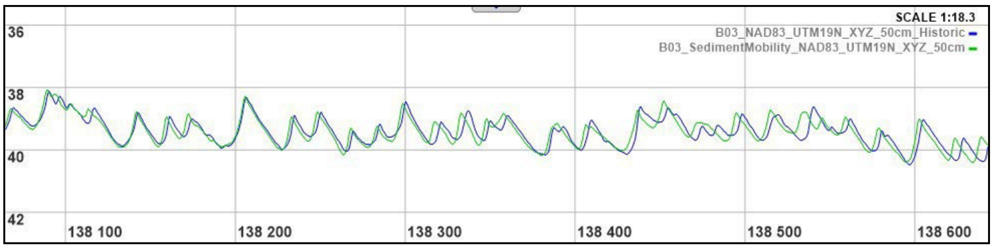

Figure 11. Profile graph, Blue line is Historical data and Green line is January survey data.

2.4 | LOC.5

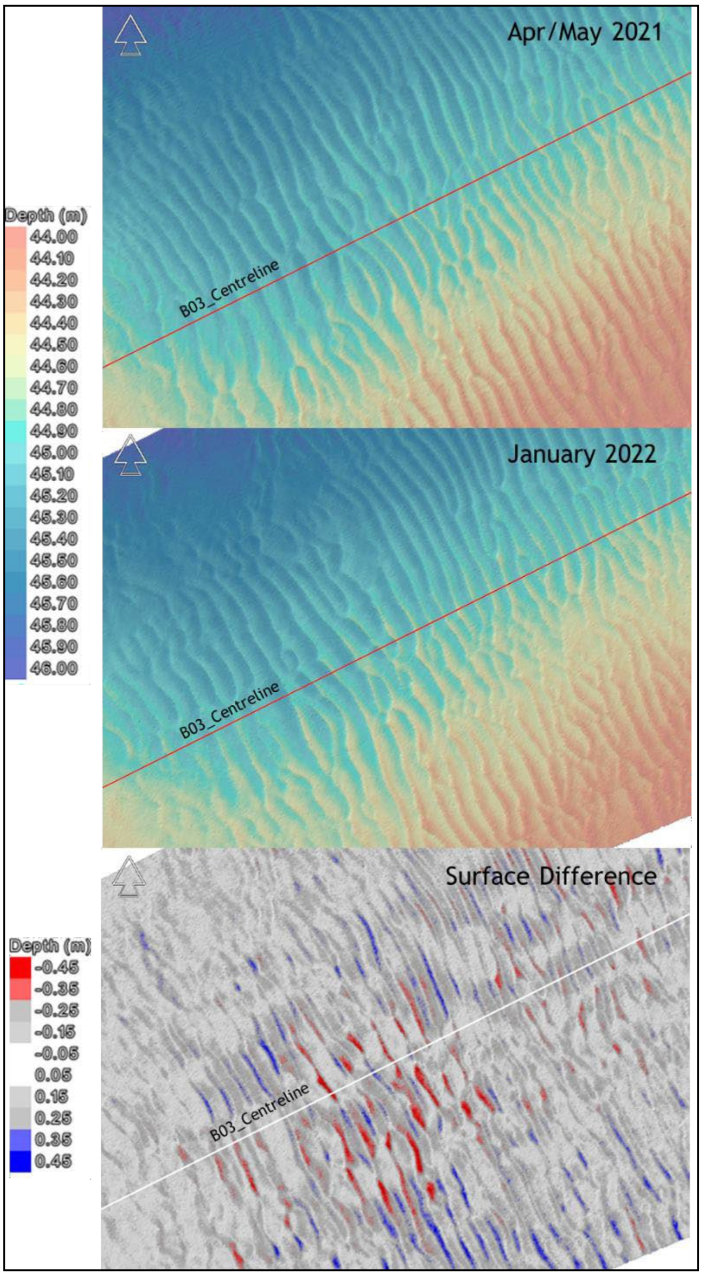

Figure 12. Location 5

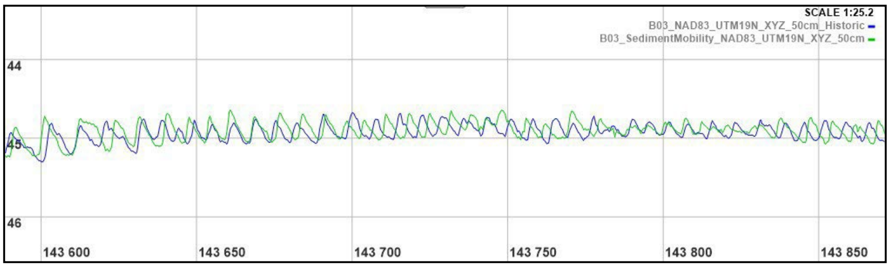

Figure 13. Profile graph, Blue line is Historical data and Green line is January survey data.

3| SEDIMENT MOBILITY B04

3.1 | LOC.6

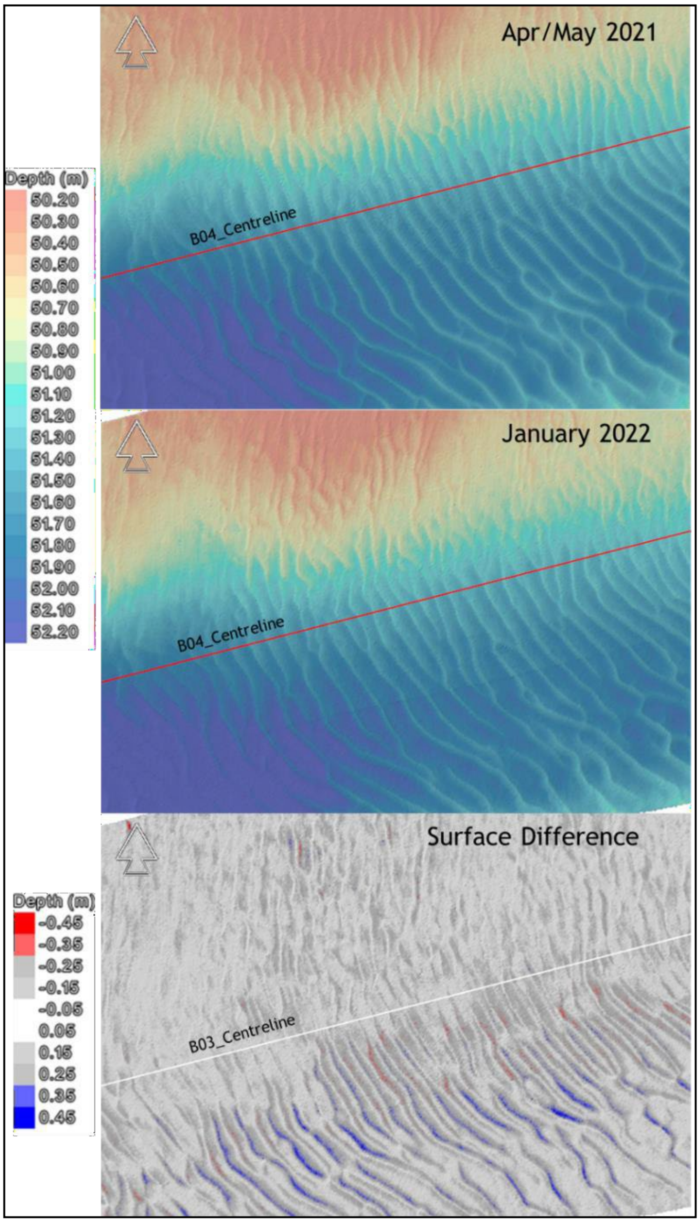

Figure 14. Location 6

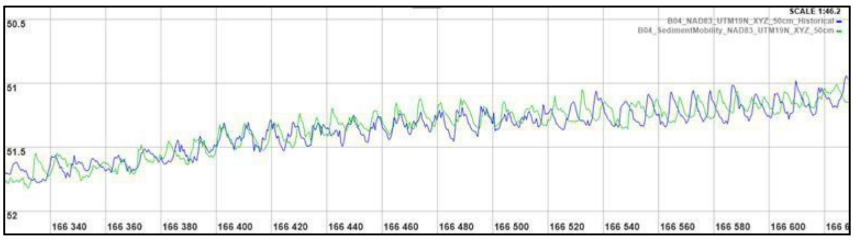

Figure 15. Profile graph, Blue line is Historical data and Green line is January survey data.

3.2 | LOC.7

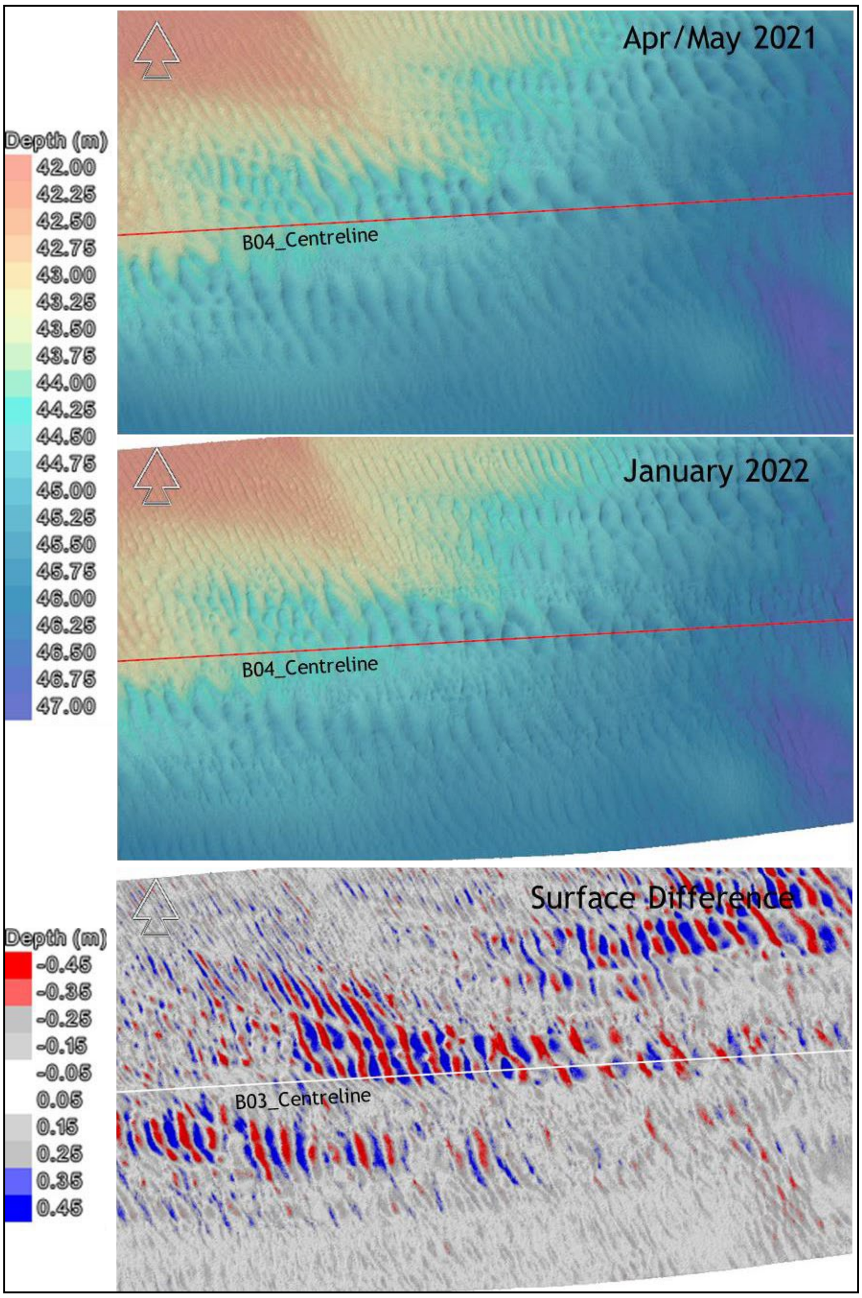

Figure 16. Location 7

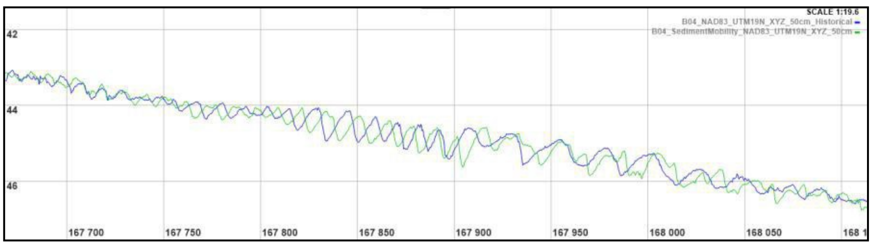

Figure 17. Profile graph, Blue line is Historical data and Green line is January survey data.

3.3 | LOC.8

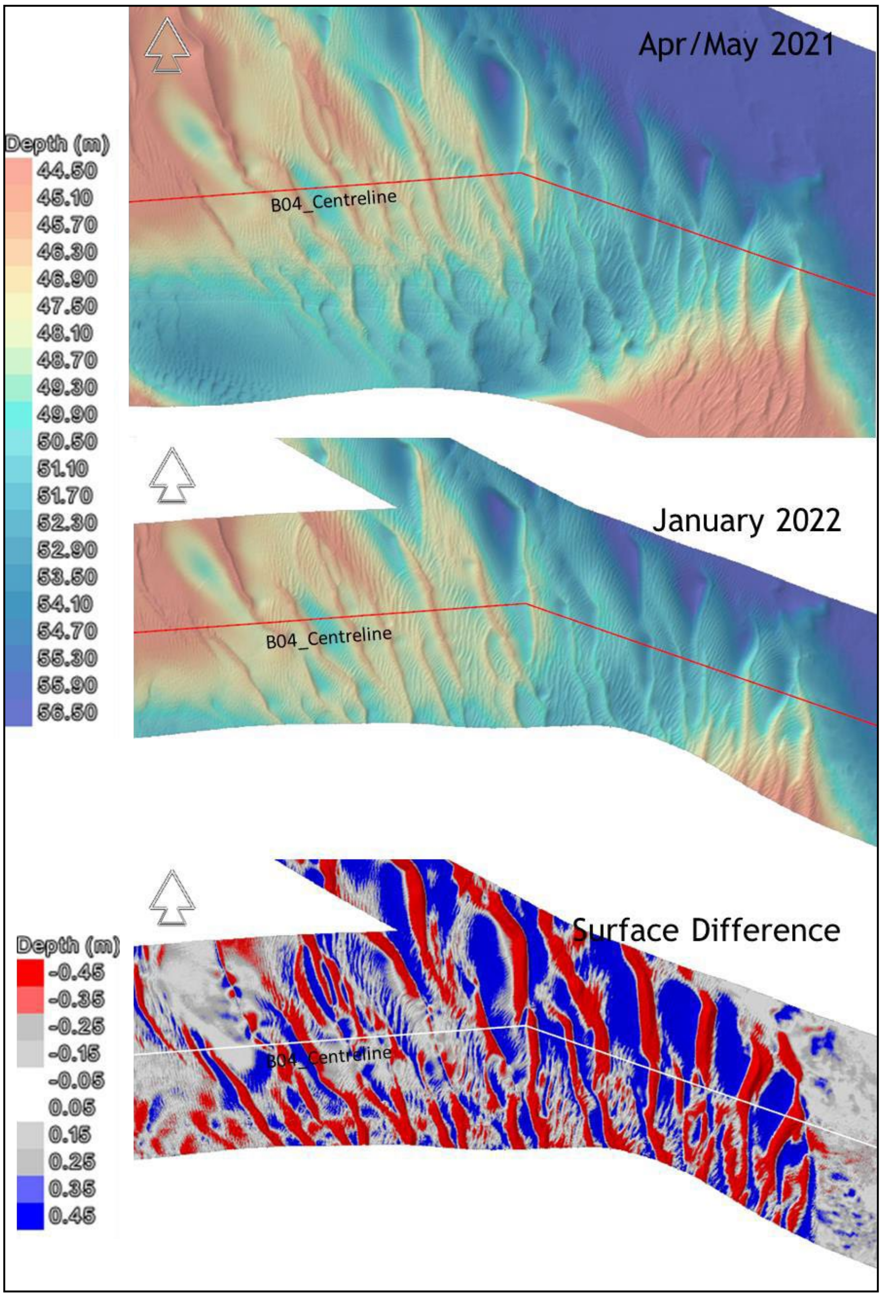

Figure 18. Location 8

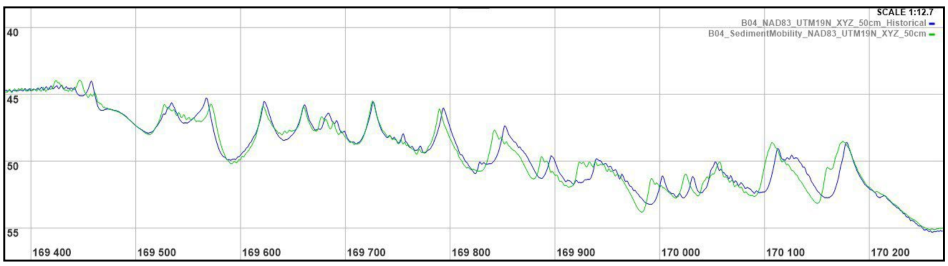

Figure 19. Profile graph, Blue line is Historical data and Green line is January survey data.

3.4 | LOC.9

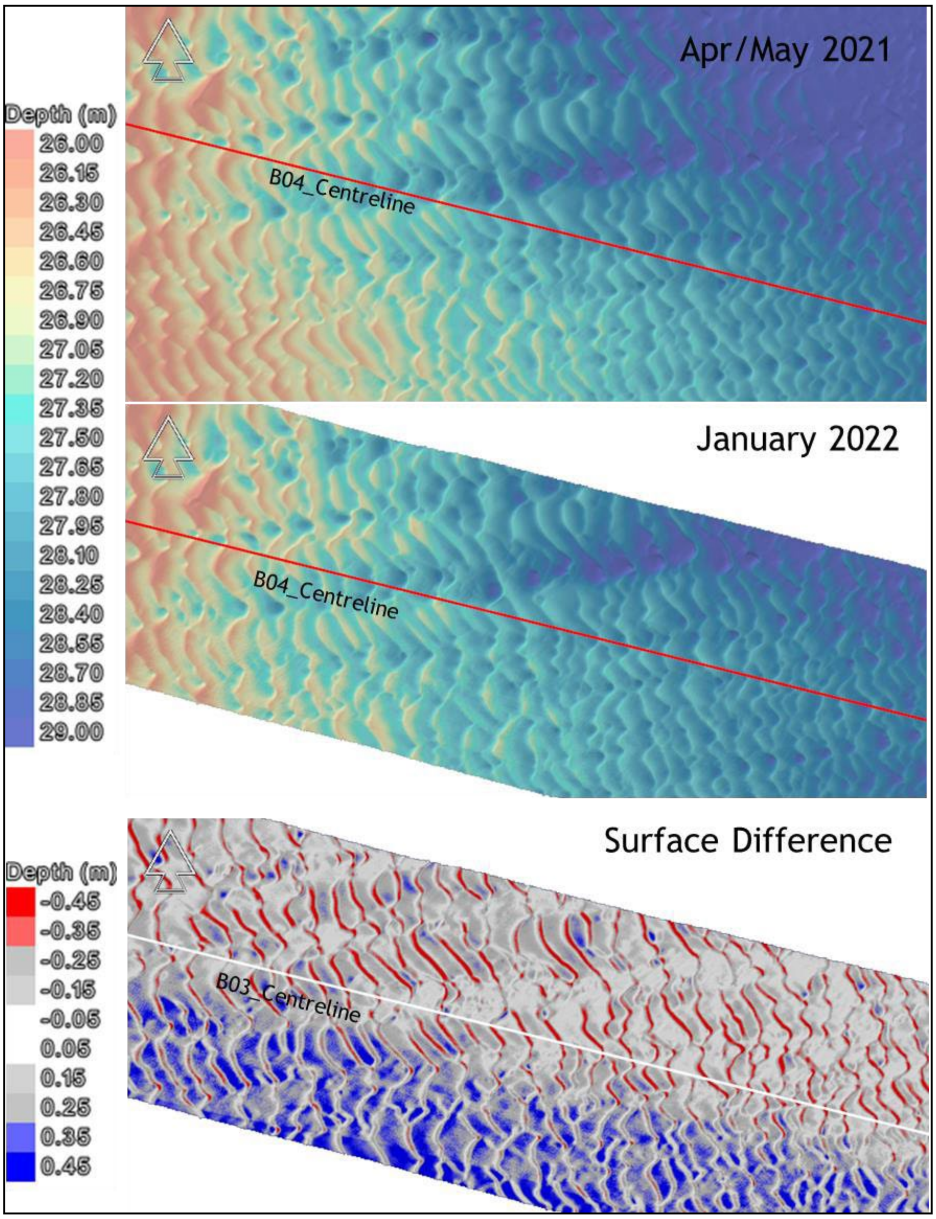

Figure 20. Location 9

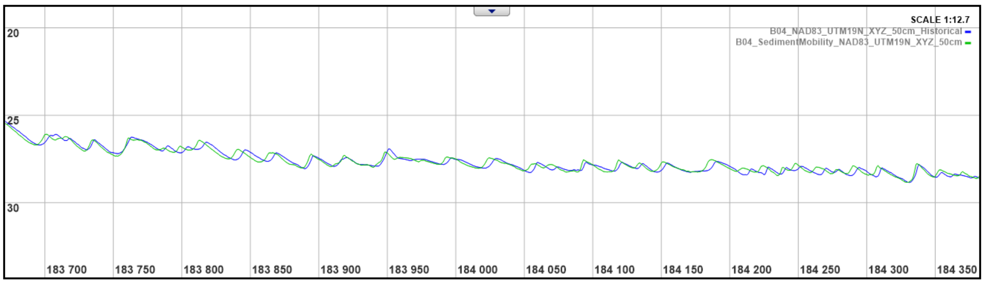

Figure 21. Profile graph, Blue line is Historical data and Green line is January survey data.

3.5 | LOC.10

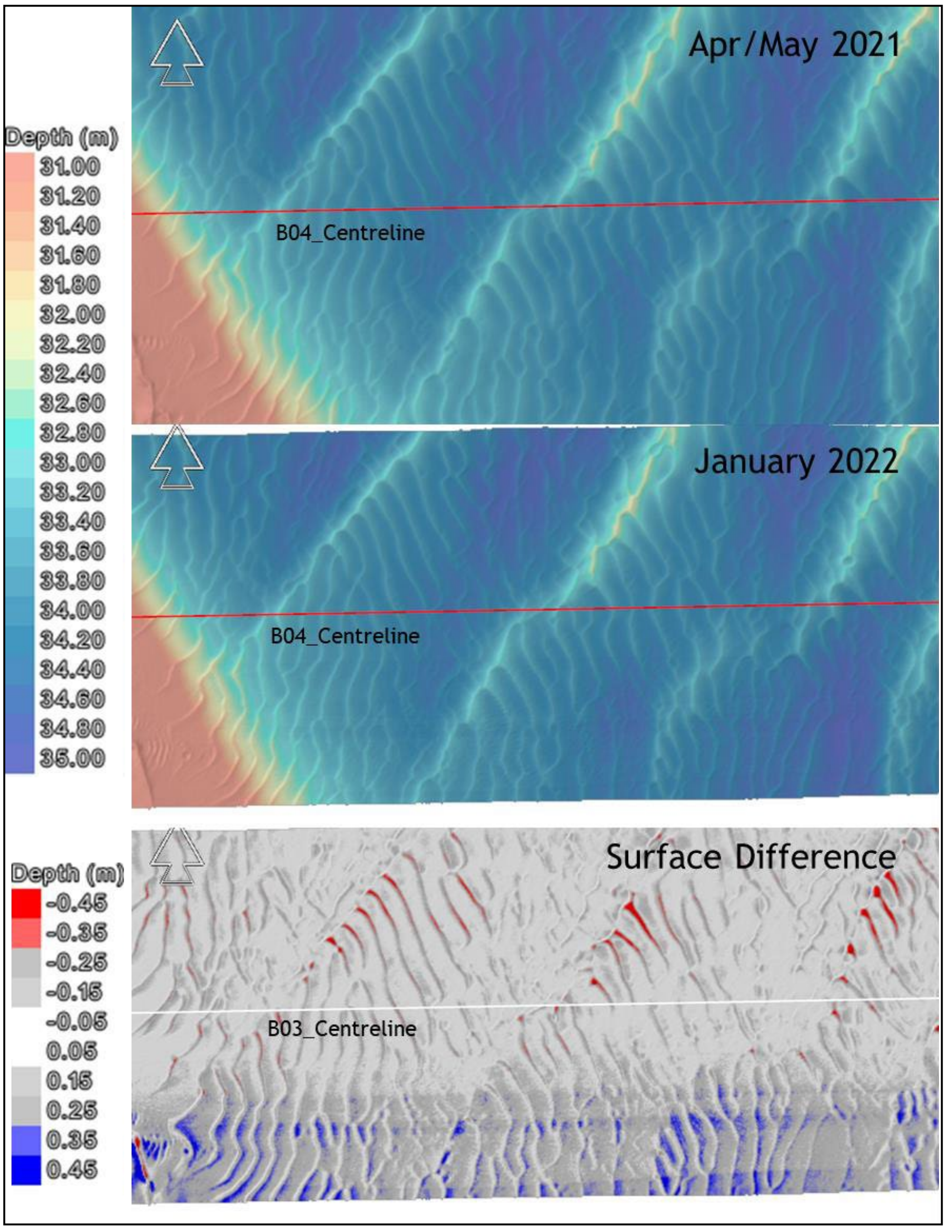

Figure 22. Location 10

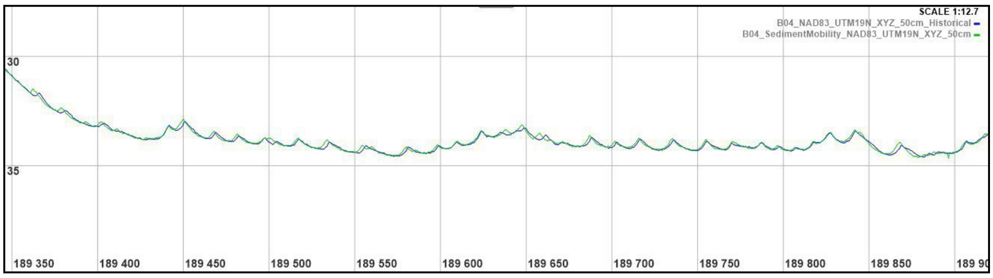

Figure 23. Profile graph, Blue line is Historical data and Green line is January survey data.

Photo credit: Matt Goldsmith, Equinor