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Caithness Moray (LT21) HVDC Cable Burial Plan

Caithness Moray (LT21) HVDC Link

Scottish Hydro Electric Transmission plc

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Acronyms and Abbreviations

Abbreviation	Meaning
AIS	Automatic Identification System
BC	Box Core
BPI	Burial Protection Index
BSB	Below Seabed
CBRA	Cable Burial Risk Assessment
CFE	Controlled Flow Excavation
CMS	Caithness-Moray-Shetland HVDC Interconnector Project
CPT	Cone Penetration Test
DoC	Depth of Cover
DoL	Depth of Lowering
FLOWW	Fishing Liaison with Offshore Wind and Wet Renewable
GS	Grab Sample
HDD	Horizontal Directional Drilling
HVDC	High Voltage Direct Current
km	Kilometre
kPa	Kilopascal
KP	Kilometre Point
kV	Kilo-Volt
LAT	Lowest Astronomical Tide
m	Metre
MBR	Minimum Bend Radius
MBES	Multi Beam Echo Sounder
MSBL	Mean Seabed Level
MW	Mega-Watt
nm	Nautical Mile
ROV	Remotely Operated Vehicle
RPL	Route Position List
SHEFA	Shetland to Faroes
SPT	Standard Penetration Test
SSE	Scottish and Southern Energy
te	Metric tonne
VC	Vibrocore

Abbreviation	Meaning
WD	Water depth
UXO	Unexploded Ordnance

1. Introduction

1.1 General Overview

Scottish Hydro Electric Transmission Plc (SHE Transmission), a part of the Scottish and Southern Energy Plc (SSE) group of companies, is developing a High Voltage Direct Current (HVDC) transmission link between Shetland (Weisdale Voe), Caithness (Noss Head) and Moray (Portgordon), collectively known as the Caithness-Moray-Shetland (CMS) project.

In order to achieve the necessary electricity transmission system reinforcement currently required in the north of Scotland, the CMS project has been split into two distinct offshore circuits: The Caithness-Moray (LT21) circuit and the Caithness Shetland (LT09) circuit.

Additional onshore transmission links are also proposed, including HVDC land cable circuits between Noss Head and Spittal, as well as Portgordon and Blackhillock. A HVDC convertor and substation is also planned at Spittal.

This report relates solely to the Caithness-Moray (LT21) offshore HVDC cable circuit, between Noss Head and Portgordon respectively.

1.2 Scope

As part of the Marine Licence process for the Caithness-Moray (LT21) offshore HVDC circuit, Marine Scotland has requested that SHE Transmission provides a Cable Plan (this document) for the route, to fulfil two draft licence conditions (Condition 30 and Condition 31) as well as assist in facilitating further consultation with relevant stakeholders.

SHE Transmission has commissioned Lloyd's Register (LR, previously LR Senergy) to prepare this updated version of the Cable Plan.

The Cable Plan is to include the following information:

- Details of the cable, route and installation methodology
- Data acquired during the survey campaigns relevant to the route alignment
- A burial risk assessment and recommendations for cable protection where it is anticipated that the burial specification will not be achieved
- Survey recommendations to address the post-installation inspection requirements along the cable route

1.3 Marine Licence Application and Project Status

Four separate Marine Licence applications have been awarded by Marine Scotland for the offshore component of the Caithness-Moray (LT21) circuit. These are as follows:

1. Noss Head to 12NM – 04368/18/2 Ref. [1]
2. Outwith 12NM Moray Firth Area – 06043/18/3 Ref. [2]
3. Portgordon to 12NM – 04878/18/2 Ref. [3]
4. Additional Rock Protection Portgordon and Noss Head to 12NM – 06600/18/1 Ref. [4]

The cable has been installed from end to end and commissioned and entered commercial service in mid-December 2018. Due to issues encountered during backfilling, a replacement cable section is required to be installed in Q1 2019 between KP11 and KP16 and the cable requires additional backfilling to ensure the required depth of cover over some 33km of the 113km route.

Marine licence applications made during previous phases of the project referenced the previously proposed Hub Platform location. The offshore hub platform concept has now been discontinued, and the location is no longer a KP on the current alignment, however for continuity this report does make reference to this where necessary.

2. Offshore HVDC Cable Circuit Properties

The Caithness-Moray (LT21) interconnector features a ±320kV 1,200MW HVDC subsea circuit from Noss Head to Portgordon. Three cables emerge from separate Horizontal Directional Drill (HDD) break-out ducts at the Portgordon end of the route, at which point they are bundled together before entering a trench. At Noss Head the fibre optic and one power cable are bundled together and enter the HDD with the second power cable being installed in a separate duct.

The cable bundle consists of the following:

– 2 no. power cables (one positive pole and one negative pole) consisting of copper conductors with cross-linked polyethylene (XLPE) integral insulation, core screening, lead alloy sheath and steel wire armour.
– 1 no. fibre-optic cable for transmission network operational purposes only (i.e. no commercial traffic)

The nominal HVDC cable properties are presented in Table 1.

Cable Parameter	Cable Property
Conductor Material	Copper
Conductor Cross-Sectional Area	2,200mm^2
Conductor Diameter	54.6mm
Single Cable Outside Diameter	132mm
Single Cable Minimum Bend Radius (MBR)	3m
Combined Cable Bundle Outside Diameter	270mm
Combined Cable Bundle MBR	3m
Weight of Cable Bundle	100kg/m (air) 75kg/m (water)

Table 1 : Nominal HVDC Cable Properties

Figure 1 and Figure 2 present a visual representation of the overall cable bundle and the properties of the individual HVDC cables.

Note that the power cables, as well as the fibre optic cable, are not oil / fluid filled.

Figure 1 : Overview of Caithness-Moray (LT21) Cable Bundle

Conductor	
Type / material	profiled strands / copper
Cross-section	2200 mm^2
Diameter	54.6 mm
Conductor screen	
Material	semi-conductive polymer
Thickness / Diameter	1.5 mm / 58.7 mm
Insulation	
Material	cross-linked DC polymer
Thickness / Diameter	20.0 mm / 98.7 mm
Insulation screen	
Material	semi-conductive polymer
Thickness / Diameter	1.4 mm / 101.5 mm
Longitudinal water barrier	
Material	swelling tape
Thickness / Diameter	0.6 mm / 102.7 mm
Metal sheath	
Type / material	extruded / lead alloy
Thickness / Diameter	2.9 mm / 108.5 mm
Inner sheath	
Type / material	extruded / HDPE
Thickness / Diameter	2.5 mm / 113.5 mm
Tensile armour	
Type / material	wire / galvanized steel
Thickness (wire diameter)	5 mm
Number of wires	69 pcs
Diameter	124.0 mm
Outer serving	
Type	polypropylene yarn, 2 layers
Thickness	4 mm
Complete cable	
Diameter	132 mm
Weight in air	49.4 kg/m
Weight in water	35.7 kg/m
	All values are nominal

Figure 2 : Caithness-Moray (LT21) HVDC Cable Properties

3. Caithness-Moray Locations & Route Alignment

The route was developed from the various route development surveys. During 2016, MMT undertook pre-lay survey and UXO survey in order to refine the route alignment for construction activities within the licenced corridor.

Following boulder clearance activities, the route was re-centred on the as-cleared route for pre-cut trenching.

The route was originally envisaged to have a single offshore set of joints in the middle at KP56. However due to operational issues, the route will feature additional inline and hairpin joints at Portgordon, KP11 and KP15 all of which have their own local Route Position List (RPL). At Portgordon the power and fibre optic cable are jointed as a pair with a second hairpin joint for the single power cable.

The route alignment is shown in Figure 3.

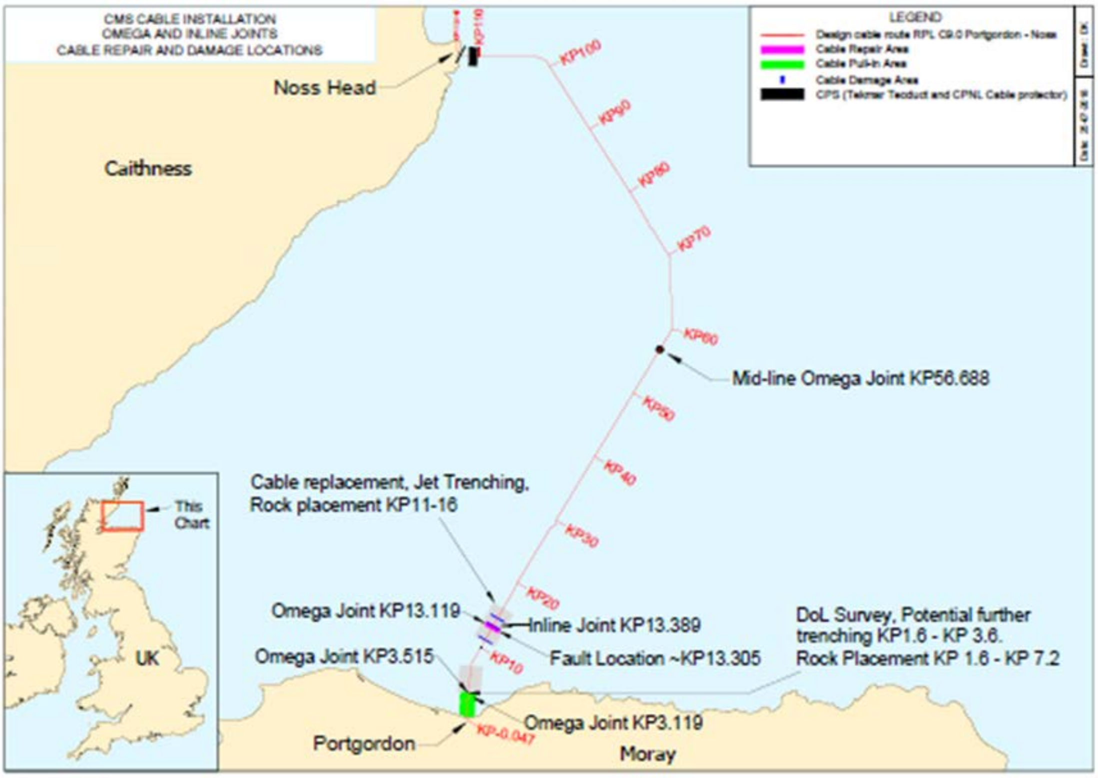

Figure 3 : As-laid Route Alignment (NKT)

4. Survey and Geotechnical Datasets

4.1 Summary of Survey Phases

Numerous survey phases, which have also included geotechnical sampling operations, have been undertaken as part of the CMS project to date. Those which are relevant to the current Caithness-Moray (LT21) route are detailed in Table 2.

Contractor / Year	Report Ref.	Route	Relevance to Caithness-Moray Circuit
MMT (2008)	100364	Shetland to Moray	Nearshore section at Portgordon
MMT (2010)	100711	Hub Platform to Caithness (Noss Head)	Survey Route from Hub to Noss Head
MMT (2012)	101044	Hub Platform to Moray (Portgordon)	Survey Route from Hub to Portgordon
MMT (2016)	101594	Caithness (Noss Head) to Moray (Portgordon)	Pre-lay and UXO survey
iSurvey (2018)	13194	Portgordon to Noss Head	Post-lay Pangeo / MBES survey

Table 2 : Overview of Survey Phases Completed to Date

In addition to the above, numerous additional surveys have been completed following construction activities.

The various route corridors associated with these survey phases are presented in Figure A 1. The following sections detail the various survey phases in more detail.

4.2 MMT 2008: Shetland to Moray Survey

MMT was commissioned in 2008 by SHE Transmission to undertake a geophysical, geotechnical and environmental cable route survey between Shetland and the Scottish Mainland at Portgordon in Moray ref [5]. This survey reflected, at that time, the proposed HVDC interconnector route, which has now been superseded by the CMS project which includes the Caithness-Moray (LT21) circuit.

The survey was performed in 2008 with a key aim to establish the seabed topography, as well as identify and map potential geological features, man-made objects, shallow soils and environmental constraints. The proposed route was surveyed using a combination of multibeam echo sounder, side scan sonar, sub-bottom profiler, magnetometer and environmental sampling equipment. The geotechnical programme comprised the acquisition of both vibrocore (VC) and sediment grab samples. However, it should be noted that the coverage / location of this data, relative to the currently defined Caithness-Moray (LT21) circuit, is only relevant to an approximate 7.3km section of route, heading offshore from the Portgordon landfall, with only two vibrocores applicable to the new route. Key points relating to this survey are summarised as follows:

- Within the survey corridor, potential eastern and western alignment options were defined.
- 2 no. vibrocore samples were obtained that are relevant to the current Caithness-Moray (LT21) route:
  - F-E5-001-VC: located at approximately KP7.100, approaching Portgordon.

  - o F-W4-023-VC: located at approximately KP77.665, near the discontinued Hub Platform location.
- No Cone Penetration Tests (CPT) were undertaken as part of the survey programme.
- A very limited quantity of laboratory tests were performed on recovered samples.
- No samples were retained for future laboratory testing.

MMT reported the survey in three volumes ref. [5]. Volumes 1 and 2 comprised the results of the offshore survey (Western & Eastern Route Options) whilst Volume 3 comprised the results of the nearshore surveys, including the landing options at Portgordon and Shetland.

4.3 MMT 2010: Hub Platform to Noss Head Survey

MMT was commissioned in 2009 by SHE Transmission to undertake a geophysical, geotechnical and environmental cable route survey between the proposed Hub Platform location and the Caithness Coast. Note that this included landfalls at Noss Head (as per current route alignment) and Sinclair's Bay (now discounted) in Caithness.

The survey was performed in 2010 and the aim was to establish the seabed topography and identify / map potential geological features, man-made objects, shallow soils and environmental constraints. The proposed route was surveyed using a combination of multibeam echo sounder, side scan sonar, sub-bottom profiler, magnetometer, and environmental equipment – including digital photography.

Within the survey route corridor, three alignments were defined: north (starboard), centre and south (port).

The geotechnical programme comprised the acquisition of both vibrocore and sediment grab samples:

- 7 no. vibrocores were acquired along the proposed Hub Platform to Noss Head route.
- No CPTs were undertaken as part of the survey programme.
- 6 no. grab samples were acquired in the nearshore section at Noss Head.
- A limited number of standard tests were performed on recovered samples.
- No samples were retained for future laboratory testing.

MMT's report Volume 1 ref. [6] comprises the results of the offshore and nearshore survey between the proposed Hub Platform and Noss Head.

4.4 MMT 2012: Hub Platform to Portgordon Survey

A further survey based on the Hub Platform to Portgordon route section (additional to that undertaken by MMT during 2008) became necessary due to Round 3 offshore wind farm licence agreements in the Moray Firth. The previous Hub Platform to Portgordon alignment ran through the proposed Moray Offshore Wind Farm site. The purpose of the MMT 2012 survey was to re-route a section of the cable east around the wind farm site, but west of the in-service SHEFA telecommunications cable, joining the proposed Hub Platform location to Portgordon. This new route corridor is highlighted in Figure A 1.

MMT was commissioned in 2011 by SHE Transmission to undertake the survey, comprising the acquisition of geophysical, geotechnical and environmental data ref. [7].

The new survey between the Hub Platform and Portgordon was performed during 2012, the aim of which was to establish the seabed topography and identify / map potential geological features, man-made objects, shallow soils and environmental constraints that may have the potential to influence the installation and / or operation of the HVDC cable. The proposed route was surveyed using a combination of multibeam echo sounder, side scan sonar, sub-bottom profiler magnetometer, and environmental equipment – the environmental survey included video and still photography transects.

As with the 2008 survey, within the survey route corridor there were two alignments defined: east and west.

The geotechnical programme comprised the acquisition of vibrocores, CPTs and box core sediment samples, summarised as follows:

- 68 no. vibrocore samples and 2 no. box cores were acquired at 70 locations along the survey route corridor, distributed along the eastern and western alignments in a staggered manner at separations of approximately 1km:
- 35 no. vibrocore samples, 15 no. CPTs and 1 no. box core were acquired along the western route.
- 33 no. vibrocore samples, 20 no. CPTs and 1 no. box core were acquired along the eastern route.
- All in situ tests were logged. Note that very limited testing was performed on the recovered samples.
- It is understood that no samples were retained to facilitate future laboratory testing.

In addition to the aforementioned data acquisition for the Hub Platform to Portgordon route section, during the 2012 campaign a detailed re-survey of the Noss Head landfall approach was undertaken – as shown in Figure A 5.

MMT reported the survey works in numerous volumes. Volumes 1 and 2 comprise the results of the offshore survey for the Hub Platform to Portgordon, Western & Eastern Route Options respectively. Volume 3 detailed the environmental survey results. Volume 4 comprises the results of the nearshore re-survey at Noss Head.

4.5 MMT 2016: Portgordon Pre-lay and UXO Survey

A further survey was carried out by MMT on behalf of ABB in 2016. This comprised multibeam, sub-bottom profiler, side scan sonar and magnetometer surveys along the length of the proposed cable route between Caithness and Portgordon. Additional survey work of Horse Mussel beds and geophysical survey at Noss Head were also carried out. Additional nearshore ROV inspections were also undertaken.

Visual inspection of potential Unexploded Ordnance (UXO) objects was carried out using a remotely operated vehicle (ROV). No sediment sampling was carried out during the survey.

MMT reported the survey work in a report dated July 2016 Ref. [8]. The report was presented in two volumes, Volume 1 recorded survey data, Volume 2 the environmental report.

4.6 Fugro 2016: Portgordon HDD Alignment

This investigation comprised marine boreholes undertaken from a jack-up platform along the alignment of the proposed landfall at Portgordon ref [9]. Nine exploratory boreholes were completed by cable percussion and rotary techniques to a maximum depth of 30.4m below sea level (bsl). Geotechnical data included in situ standard penetration testing and laboratory soil and rock testing.

4.7 Aspect 2018 Portgordon Vibrocores

Five vibrocores were undertaken at Portgordon to inform the design of the Omega east and West joints. The results are presented in a technical note prepared by Xodus Ref. [10].

4.8 iSurvey 2018: Post Construction Survey

A survey was commissioned in 2018 to assess the as-laid cable at specific locations along the cable route ref. [11] . The survey employed ROV-mounted MBES and Pangeo Sub Bottom Imager. The survey covered the following locations:

– Portgordon Omega Loops East and West
– KP1.617 - 11.256
– KP16.190 -18.533
– KP41.330 – 59.710
– KP59.710 – 83.433
– KP83.433 - 107.876

The survey excluded those sections of the route where the design depth of cover had been achieved.

5. Analysis of Geophysical and Geotechnical Survey Data

5.1 Introduction

The following sections detail an analysis of the acquired survey datasets, detailing the interpreted route seabed and shallow sub-seabed conditions.

Data interpretation was carried out and presented in the 2017 issue of this report ref. [12]. A subsequent data assessment was carried out by LR in a Route Alignment Chart, Geotechnical and Seismic Data Review ref. [13]. It concluded that the data presented on contemporaneous alignment charts had been interpreted with a reasonable degree of confidence, however some minor inconsistencies were noted. Given this, the interpretation presented in the following sections has not been updated in the light of the data review.

With reference to draft Marine Licence Condition 31b, it is noted that SHE Transmission has procured a significant quantity of survey data to date. For the purposes of this updated Cable Plan, the relevant geophysical and environmental survey alignment sheets and the associated geotechnical borehole, vibrocore, CPT and grab sample / box core logs have not been appended. Reference should be made to the appropriate survey reports as detailed above.

5.2 Geophysical Data Analysis

Bathymetry and side scan sonar data for the offshore route from approximately KP7.2 to KP77.7 were acquired during the MMT 2012 geophysical survey ref. [7] and from KP77.7 to KP112.5 during the MMT 2010 survey ref. [6]. Bathymetry and side scan sonar data within the Portgordon nearshore zone (KP0.000 to KP7.2) were acquired during the MMT 2008 geophysical survey ref. [5].

In addition, further nearshore Noss Head survey data was acquired as part of the MMT 2012 survey programme Ref. [7] and as part of the MMT 2016 survey ref. [8]. Further geophysical data were collected during the iSurvey 2018 survey.

Sections 5.2.1 and 5.2.2 discuss the bathymetry and seabed features along the cable route.

Interpretation of the bathymetry and side scan data is summarised in Table 3 – note that this is presented based on route soil zones, as discussed in Section 5.3 (Geotechnical data analysis). The table presents the minimum and maximum water depths and seabed gradient along the specific route section, as well as the seabed features that have been recorded.

It should be noted that the terms used by MMT to describe seabed conditions, such as ‘rough’, are not clearly defined within the survey reports. The use of these terms has not been amended by LR.

Analysis of the sub-bottom geophysical data for the cable route is presented in Table 5.

5.2.1 Bathymetry

The water depth along the route section ranges from 6.0m Lowest Astronomical Tide (LAT) at KP1.561 at Portgordon to a maximum of 99.3m LAT at KP29.7.

From Portgordon the seabed is generally flat with a gentle slope up to KP18.6 where a more pronounced slope is seen with water depths increasing from 34m LAT to 90m LAT over a distance of 3 km. Small geological features and depressions are found throughout the corridor as well as scattered boulders of varying sizes. Between KP33.0 and KP67.0 the seabed decreases in depth from approximately 87.8m to approximately 52.6m (LAT) and is characterised by a generally flat seabed with a few geological features, mainly in the north, and depressions throughout the corridor. The gradient is generally less than 2° with the maximum gradient of 3.7° along the route recorded at approximately KP12.0.

The water depth gently increases from approximately 52.6m LAT at KP77.7 to 54.5m at KP84.5. The seabed is relatively flat along this section of route with a gradient generally less than 1°. Between KP83.5 and KP86.0, the seabed is slightly rougher, with a gradient generally between 1° and 2°, peaking at approximately 4° at KP 85.0. Average water depth is approximately 54.0m LAT.

Water depth tends to increase from KP85.0, although the seabed undulates slightly, reaching 63.5m LAT at KP91.6 and 65.0m LAT at KP96.0, where localised gradients of up to 3.1° are also witnessed. A maximum water depth of 67.0m LAT is present close to KP102.5.

Water depth generally decreases as the Noss Head landfall is approached. A localised maximum gradient of around 5° and localised maximum water depth of 67.0m LAT is recorded along this final section close to KP109.0 before seabed gradients increase significantly, up to 20° adjacent to the Noss Head offshore break-out point where water depths of 9m LAT were recorded in the 2016 survey.

5.2.2 Seabed Features

A summary of the seabed features present in this section of the route is presented in Table 3.

5.2.3 Existing Infrastructure

No existing infrastructure is crossed along the alignment of the Caithness-Moray (LT21) offshore HVDC circuit route. However, the SHEFA cable does run parallel to the east edge of route corridor for approximately 9km, between KP60.7 and KP69.7. The cable export route for the Beatrice offshore windfarm also passes within 500m of the CMS cable route.

Soil Zone	KP Range (m)		Water Depth (m)		Seabed Gradient (°)	Seabed Description
	From	To	Min	Max		
PG1	0.0	9.2	6.0	22.9	Less than 2°	The seabed is relatively 'rough' and uneven along this section of the route. Boulders are indicated on the alignment sheets at KP1.5 to KP4.7, KP5.7 to KP6.7 and KP7.3 to KP9.2.
PG2	9.2	21.0	22.9	85.0	Generally less than 2° with a max. of 5° at KP12.0	The seabed is relatively 'rough' and uneven along this section of the route. Boulders are indicated on the alignment sheets at KP9.2 to KP10.7, KP14.3 to KP14.9 and KP16.3 to KP18.4.
PG3	21.0	41.2	73.7	99.3	Less than 2°	A mound approximately 14m high above surrounding seabed is located close to KP29.7, with an associated depth of 99.3m LAT. East of KP41.0, a depression with a diameter of 70m and a depth of 0.7m is located. Surrounding water depth is approximately 73.7m. The seabed is generally smooth and featureless. Trawl marks are noted at seabed at numerous route locations, most notably between KP22.6 and KP37.8
PG4	41.2	77.7	51.7	73.7	Generally less than 2° with a max. of 5° at KP61.2	A wreck is located at approx. 180m from the route, close to KP43.0. An area with minor irregularities (ripples) is located between KP60.0 and KP61.2. These features extend approximately 0.5m above the surrounding seafloor. Boulders are indicated on the route alignment sheets between KP71.3 to KP71.5 and KP71.7 to KP72.9. Between KP61.0 and KP71.0 the seabed is gently undulating with depths between 50.0m LAT and 55.0m LAT. The seabed is relatively featureless and smooth. From KP71.5 to 77.7 the seabed is relatively 'rough' and uneven when compared to the rest of the route.
NH1	77.7	84.5	52.0	55.0	Generally less than 1°	Seabed is generally flat and featureless in this zone. Boulders are indicated on the alignment sheets between KP78.6 to KP79.9.

Soil Zone	KP Range (m)		Water Depth (m)		Seabed Gradient (°)	Seabed Description
	From	To	Min	Max		
NH2	84.5	92.5	54.0	63.5	Generally less than 2° but a local peak of 2.5°	The seabed is slightly rougher between KP83.5 and KP86.1, with a gradient generally between 1° and 2°. From KP86.1, the seabed undulates slightly, with shallow gradients (less than 1°).
NH3	92.5	110.4	47.0	67.0	Generally less than 2° but up to a maximum of 3.5°	A 4.0m deep depression is found between KP94.7 and KP96.7. Sand ripples from KP93.5 to KP95.7 and KP96.1 to KP104.6. At KP104.7, a sandwave 6m above surrounding seabed runs parallel to the survey centre alignment. A section with ripples and sandwaves follows between KP105.0 and KP109.4 as well as a prolonged sandwave running parallel to the survey alignment along this section. Cable route engineering avoids these features. Boulders are indicated on the alignment sheets from KP107.4 to approximately KP109.9.
NH4	110.4	113.1	~8	50.5	Less than 3°	Biological reflectivity noted on the alignment charts – associated with the Horse Mussel bed. Water depth decreasing to approximately 8m based on the 2016 survey alignments end point. Water depth at HDD break-out location approximately 15.0m LAT based on 2016 nearshore survey chart.

Table 3 : Bathymetric Data and Seabed Features Summary

5.3 Geotechnical Data Analysis

5.3.1 MMT 2008

One vibrocore sample was acquired along the nearshore Portgordon section of the route (KP0.0 to KP7.2) during the MMT 2008 survey ref. [5]. This vibrocore is identified as F-E5-001-VC and is located at approximately KP7.1. A recovery of 3.0m was achieved.

In addition, one further vibrocore from the MMT 2008 survey is also relevant to the route, being located at approximately KP77.7. This vibrocore is identified as F-W4-023-VC and achieved 3.0m recovery.

5.3.2 MMT 2012 Survey

Geotechnical sampling and in situ testing was carried out from approximately KP7.2 to KP77.7 during the MMT 2012 survey ref. [7]. In total, 68 no. vibrocores, 35 no. CPTs and 2 no. box cores were acquired.

The distribution of the vibrocore samples acquired equates to approximately 1km separation along the survey corridor, although data gaps at three locations (approximately KP12.7 to KP14.5, KP55.5 to KP75.0, and KP73.7 to KP74.9) extend to between 1,500m and 1,800m. The CPTs are distributed along the full length of the 2012 survey route, although there are numerous occurrences of extended gaps between each test of approximately 2,500m.

All of the vibrocore tests acquired during the MMT 2012 survey achieved recoveries of at least 1.5m and all but four achieved recoveries in excess of 2.0m. All of the CPTs achieved a minimum penetration of at least 1.99m.

It is evident from examining the geotechnical datasets that an extremely limited quantity of laboratory testing was undertaken on the acquired vibrocore samples. In particular, there is a lack of classification testing, such as particle size distribution (PSD) tests. Furthermore, it is understood that none of the samples were retained for future testing. The geotechnical analysis therefore relies somewhat disproportionately on the visual descriptions presented on the field logs, particularly for cohesionless soils and the associated fines content. Fines content can have a significant impact on trenching performance and therefore this lack of PSD data presented a risk to the project.

5.3.3 MMT 2010 Survey

A limited number of geotechnical samples were collected during the MMT 2010 survey ref. [6]. No CPT data has been acquired to date.

Seven vibrocores were acquired between KP92.5 and KP110.4 at a variable spacing of between approximately 650m and 4.0km. No on-route data was acquired between KP77.7 and KP92.5.

Vibrocore 100711 VC 0311A achieved 0.68m recovery whilst all other vibrocores achieved at least 2.0m.

A total of six sediment grab samples (GS) were also acquired in the nearshore section at Noss Head during the 2010 survey.

As with the MMT 2012 survey between the Hub Platform and Portgordon only very limited laboratory testing of the 2010 Hub to Noss Head vibrocore samples was undertaken and none of the samples were retained for further testing.

It should be noted that the MMT 2012 and 2016 survey report describes certain soils as "Diamicton". In LR experience, use of this term within the survey industry is unique to MMT and whilst arguably geologically correct it is a very much a 'catch all' phrase, defined by MMT as a 'very poorly sorted sediment containing different fractions of sediment from clay to fragments of rock and shells'. From an installation assessment perspective, this term is not especially helpful as it provides no real insight into the nature and / or properties of the seabed.

5.3.4 Fugro 2016 Investigation

An intrusive geotechnical investigation of the nearshore area (KP0.0 to KP1.5) was undertaken by Fugro Geoservices Ltd in 2016 ref [9]. The investigation comprised nine marine boreholes advanced by cable percussion techniques and continued by rotary coring. Boreholes were sunk to depths between 10.60m below seabed level (bsl) and 30.40m bsl. In situ Standard Penetration Tests (SPTs) were carried out in all boreholes. Laboratory testing of soil samples acquired during the investigation comprised particle size distribution (PSD) analysis and index property tests. Rock testing included the determination of point load strength, unconfined compressive strength, Cerchar abrasivity and thermal conductivity.

5.3.5 Aspect 2018 Investigation

Vibrocore sampling operations were performed at 5No. locations between approx. KP1.68 and KP3.51 in 2018 ref. [10]. Minimum acceptance criteria were not achieved and the results are of poor quality.

5.3.6 Geotechnical Summary

LR has completed an interpretation of the route section shallow soils (within top 2m below seabed), based on the vibrocore log descriptions and CPTs, with due consideration given to the associated geophysical data presented on the survey alignment sheets. Further information on the geophysical results is presented in Table 5.

Table 4 presents a summary of the route soil conditions, split into a number of soil zones[1], noting that the actual transition between these zones will in all likelihood be gradual. Where there is no geotechnical data, the interpretation has been based on survey alignment sheets. In these locations there is difficulty in accurately estimated where soil layer boundaries may occur since the level of geotechnical data is not suitable to accurately define the soil conditions. The lack of laboratory test data also presents an increased risk of adverse soil conditions and plough behaviour being experienced during installation.

Approximated ranges of key soil parameters are also presented, based on the limited laboratory data available. Values of Relative Density (D_r) for cohesionless soils and Undrained Shear Strength (S_u) for cohesive soils are defined in accordance with BS5930 ref. [14] and BS EN ISO 14688-2 ref. [15].

Geotechnical locations are presented in Figures A 2, A 3, A 4 and A 5.

[1] Note that the soil zones presented are partly based on the original survey extents defined by the discontinued 'Hub' location. For continuity the reference system has been retained.

Geotechnical parameters have been estimated based on the available data but due to the limited quantity, should be independently reviewed by any end user rather than adopted verbatim.

Soil Zone	KP Range (m)		Route Zone Length (km)	Depth (mBSL)		General Soil Description	Dominant Soil Type	Typical Range	
	From	To		From	To			D_r	S_u (kPa)
PG1	0.0	9.2	9.2	0.0	24.6	Dense sandy GRAVEL and SAND	GRAVEL	Dense	-
				4.0	18.4	Firm to stiff gravelly CLAY	CLAY	-	40 – 150
PG2	9.2	21.0	11.8	0.0	2.0	Loose to dense gravelly medium to coarse SAND and sandy GRAVEL. Occasional thick laminations of gravelly clay	SAND	Loose to Dense	-
PG3	21.0	41.2	20.2	0.0	2.0	Very soft to soft silty CLAY and clayey SILT	CLAY	-	2 – 24
PG4	41.2	77.7	36.5	0.0	0.7 – 1.4	Loose to dense gravelly fine to medium SAND and sandy GRAVEL	SAND	Loose to Dense	-
				0.4 – 1.4	2.0	Very soft to firm sandy SILT and sandy silty CLAY	SILT / CLAY	-	4 - 40
NH1	77.7	84.5	6.8	0.0	2.0	Sandy GRAVEL with localised clayey SAND	GRAVEL	*No Data*	-
NH2	84.5	92.5	8.0	0.0	2.0	Silty CLAY overlying sandy GRAVEL	CLAY	*No Data*	*No Data*
NH3	92.5	110.4	17.9	0.0	2.0	Sandy GRAVEL	GRAVEL	*No Data*	-
NH4	110.4	113.1	2.7	0.0	2.0	Sandy GRAVEL and SAND overlying 'DIAMICTON' Locally BEDROCK at surface	GRAVEL & BEDROCK	*No Data*	-

Table 4 : Geotechnical Data Summary and Soil Zones ref. [12]

Soil Zone	KP Range (m)		Geotechnical Data	Seabed Features & Bathymetry	Soil Description (Geotechnical Data)	Soil Description (Geophysical Data)	Comments
	From	To					
PG1	0.0	9.2	BH01, BH02, BH02B, BH02C, BH02D, BH03, BH04, BH05, BH06 F-E5-001-VC 101044-BC-201 VC1_2, VC2_3, VC3_1, VC4_1, VC5_1	The seabed ascends gently towards landfall. Gradient is less than 2°. Water depth decreases from 0 at landfall to 22.9m LAT at KP9.2. Boulders are indicated on the alignment sheets between KP7.3 and KP9.2.	Sandy GRAVEL and SAND overlying firm to stiff CLAY	Seabed sediments generally comprise sandy GRAVEL.	Limited geotechnical data in this zone apart from nearshore BH's (1no. VC and 1no. BC).
PG2	9.2	21.0	101044-VC-057, VC-058, VC-059, VC-060, VC-061, VC-062, VC-063, VC-064, VC-065, VC-066, VC-067, VC-068 101044-BC-200 101044-CPT-128, CPT-129, CPT-130, CPT-131, CPT-132, CPT-133, CPT-134	Water depth increases from 22.9m LAT at KP9.2.to approximately 85.0m LAT at KP20.7 From KP9.2 to KP17.7, the seafloor is relatively 'rough' and uneven. A gentle feature with low edges, perpendicular to the route, rising around 0.5m from the surrounding seabed, is located here. The seabed is smooth without any outstanding features between KP18.3 and KP21.0. Between KP16.2 and KP18.4, numerous boulders are present. Seabed gradient is generally less than 2°, with a maximum of 5° at KP12.0.	Loose to dense gravelly medium to coarse SAND and sandy GRAVEL. Gravel is medium to coarse. Occasional thick laminations of gravelly clay and thick beds of fine sand.	Sandy GRAVEL with possible soft fine-grained sediment dominates from Portgordon to KP 11.2, with areas of "DIAMICTON" recorded between KP7.6 and KP10.6. From KP11.2 to KP21.0, gravelly SAND dominates.	VC 060, VC 061 and VC 067 – Silt and clay dominated profile. Su = 82kPa and 100kPa recorded in VC-061. Su = 68kPa to 110kPa recorded in VC-067.
PG3	21.0	41.2	VC-060, VC 061 and VC 067 – Silt and clay dominated profile. Su = 82kPa and 100kPa recorded in VC-061. Su = 68kPa to 110kPa recorded in VC-067.	Water depth decreases from approximately 81.5 LAT at KP21.0 to 73.5m LAT at KP41.2. A localised deep of 99.3m LAT is located close to KP29.7. 60m east of KP41.0, a depression with a diameter of 70m and a depth of 0.7m is located. A mound, approximately 14m high above surrounding seabed, is located close to KP29.7. This has been interpreted as clay overlying a hard acoustic unit (potentially bedrock). Trawl marks are present between KP22.5 and KP39.5. Seabed gradient is less than 2°.	Very soft to soft silty CLAY and clayey SILT with occasional medium gravel-sized shell fragments.	From KP21.7 to KP41.2 the sediment is soft fine grained sediments noted as clay and silt on the alignment sheets. Bedrock interpreted to be encountered at a shallower depth (potentially <2.0m) around KP29.7.	Locally gravelly CLAY around VC-044 and VC 51 to VC54.

Soil Zone	KP Range (m)		Geotechnical Data	Seabed Features & Bathymetry	Soil Description (Geotechnical Data)	Soil Description (Geophysical Data)	Comments
	From	To					
PG4	41.2	77.7	101044-VC-001, VC-002, VC-003, VC-004, VC-005, VC-006, VC-007, VC-008, VC-009, VC-010, VC-011, VC-012, VC-013, VC-014, VC-015, VC-016, VC-017, VC-018, VC-019, VC-020, VC-021, VC-022, VC-023, VC-024, VC-025, VC-026, VC-027, VC-028, VC-029, VC-030, VC-031, VC-032, VC-033, VC-034, VC-035 F-W4-023-VC 101044-CPT-100, CPT-101, CPT-102, CPT 103, CPT-104, CPT-105, CPT-106, CPT-107, CPT-108, CPT-109, CPT-110, CPT-111, CPT-112, CPT-113, CPT-114, CPT-115, CPT-116	Depressions with diameters of approximately 10m and mounds around 0.5m above surrounding seabed can be found along the route. The water depth decreases from 73.5m LAT at KP41.2 to 53.7m LAT at KP61.7. Between KP61.7 and KP71.5 and the seafloor is gently undulating with water depths between 50.0m LAT and 55.0m LAT. The seafloor is relatively featureless and smooth. From KP71.5 KP to KP77.7 the seafloor is relatively 'rough' and uneven compared to the rest of the zone. Water depth is generally between 50.0m LAT and 55.0m An area of ripples is located between KP 60.0 and KP 61.7. These features extend approximately 0.5m above the surrounding seabed. Similar features also located at KP 54.7. Seabed gradient is generally less than 2°, with a maximum of 5° at about KP61.2, on a well-defined edge. Boulders are indicated on the alignment sheets between KP71.3 to KP71.5 and KP71.7. A wreck is located 180m offset from the route at KP42.7.	Loose to dense fine to medium gravelly SAND and sandy GRAVEL (gravel is medium to coarse with many shell fragments), overlaying very soft to firm sandy SILT and sandy silty CLAY with occasional gravel and shell fragments.	SAND dominates from KP41.2 to KP77.7. This surface unit thickness varies from approximately 0.5m to 2.0m. Ripples and occasional boulders are present. The surface sediments consist of gravelly SAND / sandy GRAVEL with localised occurrences of fine sediment. Shallow geology notes that the surface sediments of SAND and GRAVEL overlie silt and clay with localised diamicton.	VC-004 - 1.20m 180kPa Clay – Test potentially influenced by gravel and silt content. VC-031 - Interbedded clay and gravel. VC-035 – Transition zone – VC shows silt profile within top 2.0m.
NH1	77.7	84.5	*No Data*	Seabed is generally flat and featureless in this zone. Boulders are indicated on the alignment sheets between KP78.6 to KP79.9.	*No Data*	Sandy GRAVEL with localised clayey SAND	Potential variability in soil layer thickness
NH2	84.5	92.5	*No Data*	The seabed is slightly rougher between KP83.5 andKP 86.1, with a gradient generally between 1° and 2°. From KP86.1, the seabed undulates slightly, with shallow gradients (less than 1°).	*No Data*	Silty CLAY overlying sandy GRAVEL	Potential variability in soil layer thickness

Soil Zone	KP Range (m)		Geotechnical Data	Seabed Features & Bathymetry	Soil Description (Geotechnical Data)	Soil Description (Geophysical Data)	Comments
	From	To					
NH3	92.5	110.4	100711-VC-0305, VC-0306, VC-0307, VC-0308, VC-0309, VC-0310, VC 0311A	A 4.0m deep depression is found between KP94.7 and KP96.7. Sand ripples between KP93.5 and KP95.7, as well as between KP96.1 and KP104.6. At KP104.7, a sand wave 6m above surrounding seabed runs parallel to the survey centre alignment. A section with ripples and sandwaves follows between KP105.0 and KP109.4 as well as a prolonged sandwave running parallel to the survey alignment along this section. Boulders are indicated on the alignment sheets from KP107.4 to approximately KP109.9.	Sandy GRAVEL	Sandy GRAVEL with underlying 'DIAMICTON'	-
NH4	110.4	113.1	GS-NN4, GS_NN5, GS_NN6, GG_NS7, GS_NS8, GS_NS9	Biological reflectivity noted on the alignment charts - associated with the Horse Mussel bed. Water depth decreasing to 15.0m at HDD break-out location.	*No Data*	Sandy GRAVEL and SAND overlying 'DIAMICTON' Locally BEDROCK at surface	Soils based on survey data – negligible grab sample recovery

Table 5 : Geophysical and Geotechnical Survey Data Analysis

5.4 Environmental Survey Conclusions

The objective of the 2010 and 2012 environmental surveys was to investigate the habitats along the HVDC cable route between Portgordon and the former Hub Platform, with the emphasis on identifying and classifying habitats, biotopes and species diversity and on identifying areas of special interest such as Special Areas of Conservation as well as UK Biodiversity Action Plan areas. The bottom substrates were investigated with a drop camera equipped with both video and still camera. In total, 406 no. close-up photo images were taken along 11.7km of the route. All photos were further analysed identifying biota to lowest taxonomic level and abundances in each photo. The high photo resolution makes it possible to identify the epifauna common in these areas. The photo technique is also a non-destructive method of hard bottom substrate survey. The result from the analyses of photo and video transects together with information from bathymetry and side scan sonar is the base for the interpretation and classification of habitats of the entire route.

Along this route section, a wide range of habitats are present, from stony reefs to muddy sediments. The most common habitat is sandy mud (SS.SSa.CMuSa) and fine mud (CFiMu.SpnMeg) which occurs over a large part of the surveyed area. The diversity and species composition primarily varies with sediment type, but also factors such as currents and depth have an impact on the biological composition.

The habitat classification is based only on sediments and species identified from photo images and video. No infauna is included in the interpretation, and therefore biotopes with high infauna biodiversity, usually soft sediments, are not acknowledged.

The results from this survey are in line with what can be expected. The habitats in the nearshore area are patchier than the offshore areas where long parts of the surveyed route are similar. Not surprisingly, the distribution of species was found to be highly correlated with the substrate and depth.

Additional survey was carried out in 2016 to assess the extent of the Horse Mussel bed in the Marine Protected Area outside of Noss Head. In total, a length of 1800 m, between KP109.83 and KP111.63, were surveyed with drop down video system and a remotely operated vehicle. A total of 263 stills were collected along the section of route and 44 were selected as representative locations.

A summary of the environmental surveys is also presented in the MarineSpace environmental appraisal report Ref. [16].

6. Cable Burial Risk Assessment

6.1 Introduction

As part of the Marine Licence application process for the Caithness-Moray (LT21) circuit, a Burial Risk Assessment ref [17]. was carried out on behalf of SHE Transmission by LR Senergy in 2015. This covered the entire length of the cable route and was based on contemporaneous datasets and studies, and the understanding of the project methodology at that time.

The output of the study was the requirement to discharge Condition 31 (d) of the Marine Licence, as described below:

"A burial risk assessment to ascertain if the burial depths can be achieved. In locations where this is not possible then suitable protection measures shall be provided in line with best industry practices and guidelines and with reference to Crown Estate FLOWW guidelines where they appropriately apply."

The Caithness-Moray (LT21) cable circuit underwent comprehensive design development prior to construction commencing in Q2 2017. This included acquisition of additional survey data, refinement of the route alignment and changes to construction methods.

The Burial Risk Assessment ref. [17] was carried out using the Burial Protection Index methodology, considered industry standard practice during the timeframe of the project development. A Cable Burial Risk Assessment Update ref. [18] was produced by LR in 2017 which presented an updated assessment and was carried out using the updated methods defined in the Carbon Trust report CTC835 published in 2015 ref. [19], which was developed to address limitations and generally acknowledged conservatism in previous methods.

The detailed methodology and assumptions in the updated CBRA are not reproduced here, but a summary of the method and results are presented in the following sections.

Note that this burial assessment has not been updated since 2017, in which time windfarm construction has taken place within the Moray Firth, however this is expected to have a negligible impact on the results of the assessment.

6.2 Standard Trenching Terminology

Within the subsea cable and trenching industry, there is commonly confusion as to the precise meaning of the term 'burial'. For the purposes of this report, the following definitions are applicable:

- Burial – generic term used to describe the activity of cable trenching
- Mean Seabed Level (MSBL) – the elevation of undisturbed seabed, as determined away from any potential changes induced by the burial vehicle itself
- Depth of Lowering (DOL) – the vertical distance between the top of the cable and MSBL
- Depth of Cover (DOC) – the vertical distance between the top of cable and seabed directly above the cable following final trenching pass

The key terms are illustrated in Figure 4.

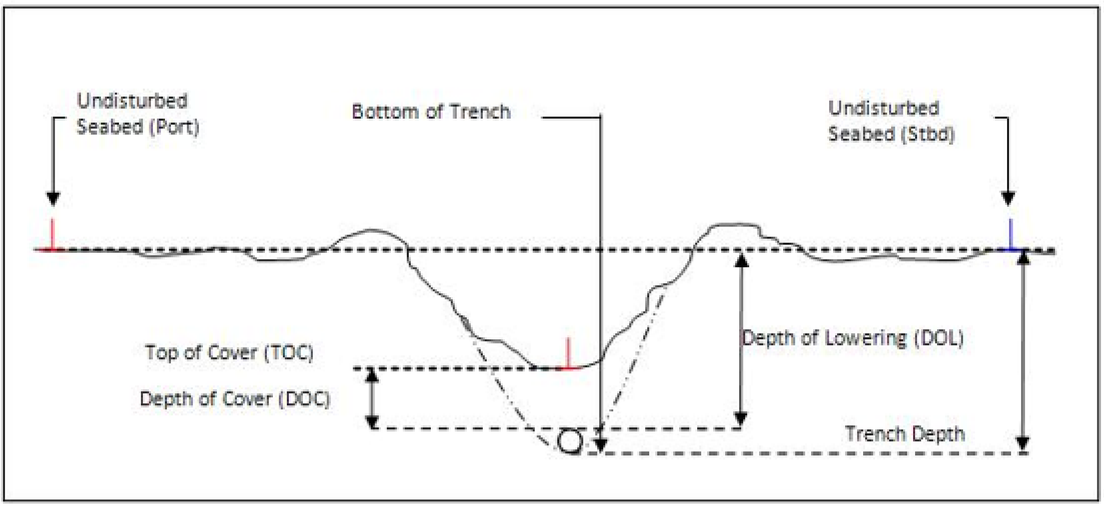

Figure 4 : Trenching Terminology

6.3 CBRA Overview

The Burial Assessment carried out in 2015 ref. [17] assessed the likely risks that may cause cable damage for the Caithness-Moray (LT21) circuit. A summary of this assessment is given below:

Threat	Assessment
Submarine landslides	Not considered a risk due to geological / geomorphological setting
Sediment mobility	Assessment carried out by LR Senergy [20]. Risk posed to cable protection particularly during construction operations
Seismic activity	Not considered a risk due to seismic setting
Fishing gear interaction	Considered to be a primary risk
Anchoring	Considered to be a primary risk
Dropped objects	Low probability event due to sheltered nature of the route
Military training	Mitigated through route engineering
Foundering	Low probability event; impractical to design against in a cost-effective manner

Table 6 : Summary of Risks to CMS (LT21) Circuit

The primary risks to the Caithness-Moray (LT21) offshore circuit are considered to be:

– Fishing gear interaction (planned and regular operations)
– Vessel anchoring activities (primarily unplanned deployments)

Fishing risk was assessed through review of historic site-specific fishing data, the associated likely fishing gear penetration risk and recommendations made in CTC835 ref. [19]. This recommends a fixed Depth of Lowering of 300mm with an additional clearance of 300mm (total 600mm).

Vessel anchoring risk was calculated using historic AIS vessel data and the statistical method set out in CTC835.

The CBRA estimates the probability of a cable strike in relation to an optimum Depth of Lowering (DoL). In addition to the shallow soil geology, this method generally takes into account the water depth, the probability of incidents involving anchors deployment and frequency and size of the vessels in transit over the cable route.

All vessels with a deadweight >300 te are fitted with Automatic Identification System (AIS) transponders. For the CBRA, AIS data are collected and the cable route is subdivided in different sections based on shallow geology, water depth, and vessels traffic.

The probability of a cable strike (i.e. an anchor dragging over the cable), P_{strike}, is then calculated as:

$$P_{strike} = P_{traffic} P_{wd} \sum_{1}^{No.ships in section} \frac{D_{ship}}{V_{ship} \times 8760 hrs per year} P_{incident}$$ **Equation 1**

$P_{traffic}$= probability modifier based on tolerable level of risk

P_{wd}= probability modifier for nature and depth of seabed

V_{ship}= ship speed (m/hr)

D_{ship}= distance travelled by ship in area under consideration (m)

$P_{incident}$= probability of incident occurring for that vessel size and type

8670 hrs per year= factor to annualize the results

This probabilistic approach is intended to be iterative as follows.

- Initially, P_{strike} is calculated considering $P_{traffic}$=1 (cable not buried). If P_{strike} is acceptable, no further analyses are required as the vessels in transit represent a low risk for the cable route and cable burial is not required for anchoring protection.
- Agree the value of P_{strike} that would be acceptable to the stakeholders.
- Subsequently, if P_{strike} is higher than the acceptable value, $P_{traffic}$ is modified in order to achieve a tolerable risk level. The value of '(1-$P_{traffic}$) x 100' represents 'the percentage of vessels for which cable burial is required for protection' ref. [19] and the corresponding vessel size, anchor size and depth of lowering is taken from appropriate distribution curves.

6.4 CBRA Results

The probability of a cable strike has been calculated for each section of the route based on a DoL of 0.6m. A summary of the results obtained is presented in Table 7.

For comparison, analysis of a DoL of 0.9m, (to reflect typical burial depth achieved in the pre-cut section) has been has been considered and the probability of cable strike is also presented.

KP (From)	KP (To)	DoL = 0.6m P_{strike} (annual)	DoL = 0.9m P_{strike} (annual)
1.717	4.7	$3.6x10^{-7}$	$7.4x10^{-8}$
4.7	18.5	$1.8x10^{-7}$	$3.7x10^{-8}$
18.5	21.0	$3.6x10^{-8}$	$7.4x10^{-9}$
21.0	41.3	$8.8x10^{-8}$	$8.8x10^{-8}$
41.3	59.7	$1.3x10^{-8}$	$8.0x10^{-9}$
59.7	92.5	$2.9x10^{-8}$	$1.7x10^{-8}$
92.5	110.337	$1.5x10^{-8}$	$6.8x10^{-9}$
1.717	110.337	$7.2x10^{-7}$	$2.4x10^{-7}$

Table 7 : Cable Burial Risk Assessment Summary of Results ref. [18]

Note that the CBRA methodology specifically refers to Depth of Lowering (DoL). Given the overall breadth of the trench created during ploughing when compared to fishing gear geometry, it is considered that DoL and Depth of Cover (DoC) should be considered on the same basis.

Notwithstanding the satisfactory results of the probabilistic analysis, the greatest threat appears to come from those vessels in the 2,000 te to 10,000 te range, with a greater concentration around KP15 to KP25. This vessel size corresponds to typical anchor penetration of approximately 0.6 to 0.8m.

The following target annual return probabilities, with a conservative focus on human and environmental safety, for different consequence levels are recommended in CTC835 ref. [19].

Consequence Level	Low	Medium	High	Very High
Target annual probability for acceptance	10^{-2}	10^{-3}	10^{-3}	10^{-4}

Table 8 : Nominal annual target failure probabilities (after DNV-OS-F101) ref. [21]

The probability of cable strike (P_{strike}) is generally very low. The total probabilistic risk for the entire cable route, calculated as the sum of the probabilities at each route section, is in the range 7.2 x 10^{-7} to 2.4 x 10^{-7} (depending on depth of lowering). This corresponds to a return period of more than 1,000,000 years, which it is extremely low.

6.5 Commentary on Specification

The original project specification, based on the BPI method was:

– Minimum Depth of Lowering (DoL) of 1.5m (N.B. actual target DOL of 1.8m)
– Target Depth of Cover (DoC) of 1.0m

The revised specification, based on the Carbon Trust method is:

– Minimum Depth of Lowering (DoL) of 0.6m
– Minimum Depth of Cover (DoC) of 0.6m

Where the minimum DoL specification is not met that a minimum of 0.6m DoC is provided. Where trenching was not possible e.g. over the Horse Mussel Bed, then a cable protection system was used to provide protection in lieu of lowering the cable into the seabed.

A summary of the degree of compliance with the above specification limits is given in Table 9. The figures relate to the achieved performance to date, prior to any additional works. It can be seen that the majority of the cable route meets the current minimum DoL and a significant proportion of the route meets the previously specified DoL. The outstanding lengths of the route which do not meet the currently specified DoC will be addressed through further works, detailed in Section 7.3.

Specification (m)	DoL (km)	DoL (%)	DoC (km)	DoC (%)
>0.6	105.2	94%	70.7	63.2
>1.0	60.2	53.7	17.4	15.6
>1.5	20.9	18.6	-	-

Table 9 : Summary of Specification Compliance Prior to Current Proposed Scope of Work

Note that the achieved DoL excludes the Horse Mussel Bed located near to the Noss Head landfall.

Given the probability of cable strike identified in Table 7 previously it is considered that once additional works are completed, the residual risk to the cable is exceedingly low.

7. Trenching Methodology

7.1 Overview

Pre-cut trenching along the route alignment was originally carried out using the Ecosse Subsea Systems' (subsequently Oceaneering) SCAR plough between Q1 2017 and Q3 2017. Cable installation into the pre-cut trench was carried out during Summer 2017. Due to the achieved trench depth being shallower than the contract specification it was decided to place rock in the trench prior to backfilling using the SCAR backfill plough. Backfill using the SCAR backfill plough commenced in February 2018 but was demobilised from the project by the contractor following exceedance of the specified lateral tolerance.

Following a period of re-engineering, modification and upgrades of the SCAR backfill plough, additional offshore trials were undertaken. It was not possible for the contractor to demonstrate compliance with the specified lateral tolerances. As a result of this, the contractor was required to adopt alternative backfill methodologies. These alternative methodologies are presented in Section 7.3.

Due to technical reasons the cable was surface laid and jet trenched between KP18.489 and KP41.400.

Where the cable was not laid into a pre-cut trench, for example Portgordon East and West Omega loops, the cable was lowered into the seabed using Controlled Flow Excavation (CFE) techniques. In specific other locations where trenching was not possible the cable was surface laid with cable protection systems i.e. Tekduct or surface laid with blanket rock protection.

Between KP11 and KP16 the cable was intermittently damaged and cable replacement is required. In this location the contractor proposes to surface-lay and jet trench the cable using similar equipment as was used between KP18.489 and 41.400.

The original Cable Plan ref. [12] carried out a detailed assessment of the anticipated performance of the SCAR plough with respect to the project specification. This assessment will not be reproduced here; actual installation performance data is available which supersedes this information.

Between KP83 and KP86.5, the cable was backfilled using the SCAR backfill plough. No additional cable protection is proposed along this section of the route.

At Noss Head, additional rock armour was placed in the area defined as TZ1 between KP112.441 and KP112.608 to protect the cable immediately adjacent to the HDD exit point.

In the location of the Horse Mussel Beds between KP110.245 and KP111.355 the cable was protected using a TekDuct protection system. This is a proprietary cable protection system which provides impact and abrasion protection. It comprises two identical half shell mouldings configured to closely match the cable system.

Since the completion of the cable lay operations, backfill of the trench has occurred through natural sediment transport processes. This has resulted in localised sections of the route where the required depth of cover has been provided by natural infill.

7.2 Construction History

A timeline summary of the construction of the cable showing key events is given below:

Date	Activity
Feb. 2017	Route clearance using SCAR plough carried out
Mar to Jul 2017	Pre-cut trenching operations using SCAR plough, excluding soft ground section KP18.489 to 41.400, Portgordon landfall KP1.608 to KP1.722 and Noss Head TZ1 section KP110.338 to KP112.617
May 2017	Cable pull in at Noss Head
May 2017	Cable lay operations from Noss Head to mid-route Omega joint
July 2017	Cable pull in failure at Portgordon with cable becoming jammed in one of the HDD ducts
Aug 2017	Cable wet stored at Portgordon and laid to mid-route Omega joint
Oct to Dec 2017	Cable burial by jet trenching in soft ground section KP18.489 to 41.400
Oct to Dec 2017	Rock placement in trench
Feb. to Apr. 2018	Remedial works to HDD ducts at Portgordon to enable cable pull in and jointing
Oct 17 and Nov 2018	TZ1 rock placement operations at Noss Head
Feb / Mar 2018	Backfill plough operations attempted.
May 2018	CFE backfill trials
Sept / Oct 2018	Backfill trials for acceptance of SCAR 2 backfill plough resulted in failure
Dec 2018	Post-cable lay survey undertaken using Pangeo & MBES
Dec 2018	CFE excavation and inspection between KP11–16 and KP83-86 revealed cable damage at KP11.150–14.610. No damage found KP83-86.
Dec 2018	CFE trials undertaken

Table 10 : Summary of Construction Activity on CMS (LT21) Circuit

Based on the various construction activities undertaken to date the iSurvey post cable-lay survey ref. [11] identified that approximately 30.5km of the route does not meet the specified 0.6 DoC. Some partial trench backfilling has naturally occurred since cable lay was completed in August 2017. It is anticipated that 35km of the route will require further backfill. The following construction activities are proposed to ensure compliance with the specification.

7.3 Proposed Works

Given that the SCAR backfill plough is not to be used, alternative backfill methodologies will be used. The selected methodologies are CFE and rock placement. A summary of the proposed scope of work is given below and is presented in Figure A 6 to Figure A 11.

A detailed summary of the completed and proposed construction activities is presented in the NKT Single Line Diagram 1JND14006D005560 ref. [22] and in the NKT method statement ref. [23]

7.3.1 Controlled Flow Excavation

The use of CFE is proposed to backfill sections of the cable by displacing seabed material from spoil berms into the existing trench. Twin low pressure / high flow jetting tools will be aligned to run parallel to the trench as indicated in Figure 5. Pre- and post-backfill surveys will be used to assess efficacy and compliance with specifications.

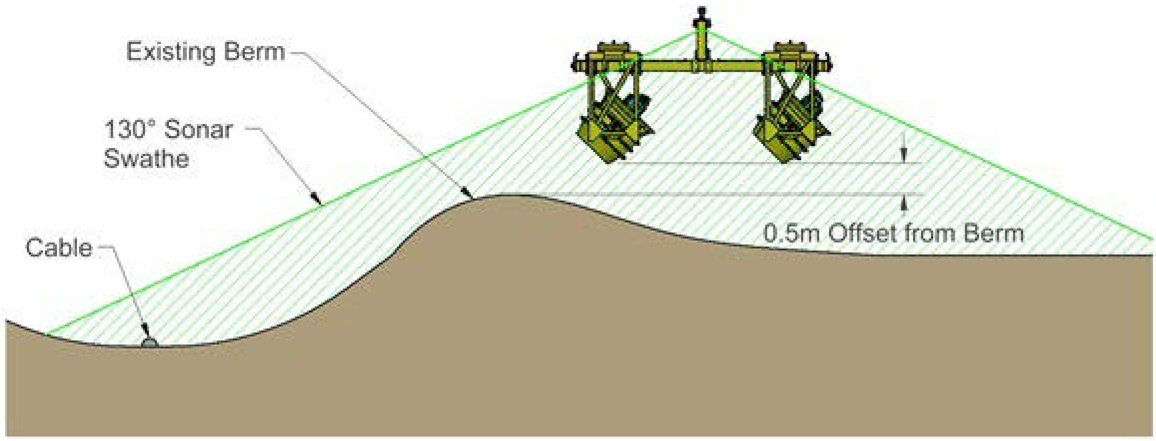

Figure 5 : Schematic Section of Proposed Controlled Flow Excavation

7.3.2 Rock Placement

Placement of rock is proposed in areas where CFE does not achieve the required DoC or is unsuitable. In areas where rock is installed in a pre-cut trench the purpose of this backfill work is to provide the required depth of cover protection to the cable bundle and also to return the seabed to its original profile or as close as reasonably practicable.

In addition, the use of cast iron half shell cable protection units is proposed as an alternative method of protection between the Portgordon HDD exit point and KP2.

7.3.3 Cable Replacement at KP11 - 16

Exploratory excavations were undertaken between KP11 and KP16 which uncovered a damaged section of cable. Replacement of the damaged section of cable is proposed. The replacement cable will be laid parallel to the currently installed cable and offset by approximately 20m.

An in-line joint will be installed at KP11 and an ‘Omega’ configuration will be necessary at KP15 at the end of the replacement section to enable recovery, jointing and re-lay of the cable bundle. The Omega joint will occupy an area of seabed of approximately 350m x 30m.

The replacement cable section will be buried using jet trenching, however some rock placement may be required where the target DoC is not achieved.

Details of the proposed cable replacement are presented in Figure A 12 and Figure A 13.

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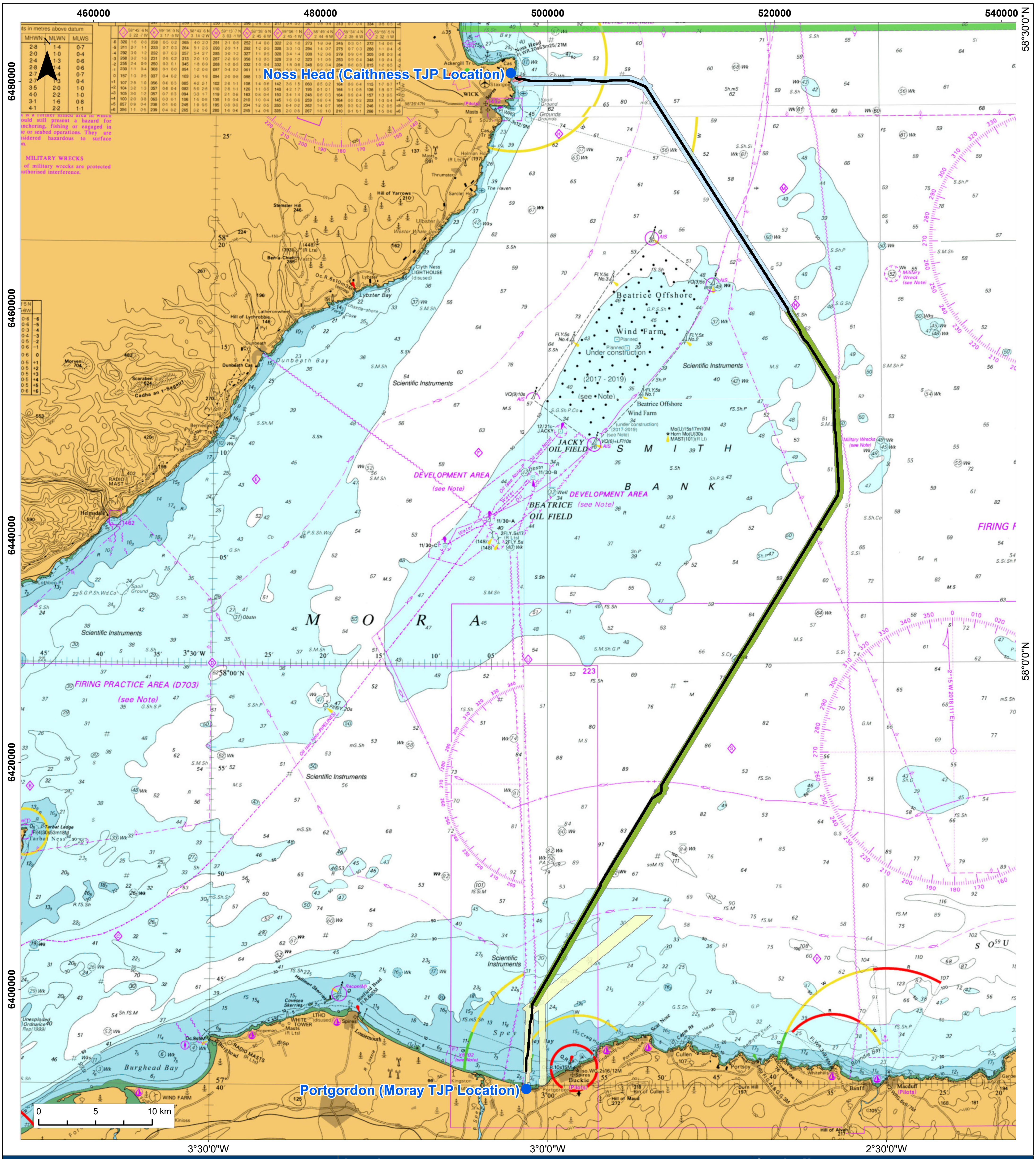
Appendices

Appendix 1 Drawings



Client

Legend

- Key Locations
- MMT 2008 Survey - Nearshore Portgordon
- MMT 2010 Hub to Noss Head Survey Corridor
- MMT 2012 Nearshore Survey Area
- MMT 2012 Hub to Portgordon Survey Corridor

MMT 2016 Survey Corridor

- MBES
- SSS

Overview Map

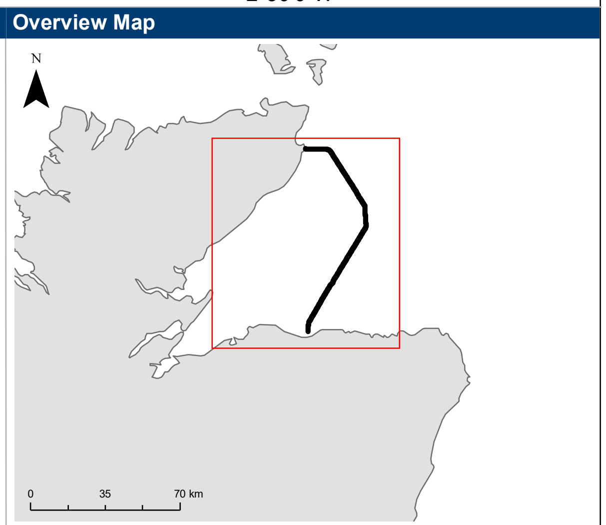


Figure Number & Title

Figure A1
Caithness-Moray (LT21) - Overview of Survey Datasets

Project/Report Information

Project Name : Caithness - Moray (LT21) Cable Plan
Project No : 2705
Location : UKCS, Moray Firth, Portgordon to Noss Head
Figure : 2705-SSE-FIG-A1-01

Geodetic Information

Coordinate Reference System: WGS 1984 UTM Zone 30N
Projection: Transverse Mercator (Central Meridian: 3°0'0"W)
Datum: WGS 1984 / **Ellipsoid:** WGS84
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Main Window Scale: 1:314,935

Data Sources, Acknowledgements & Notes

SSE, NKT

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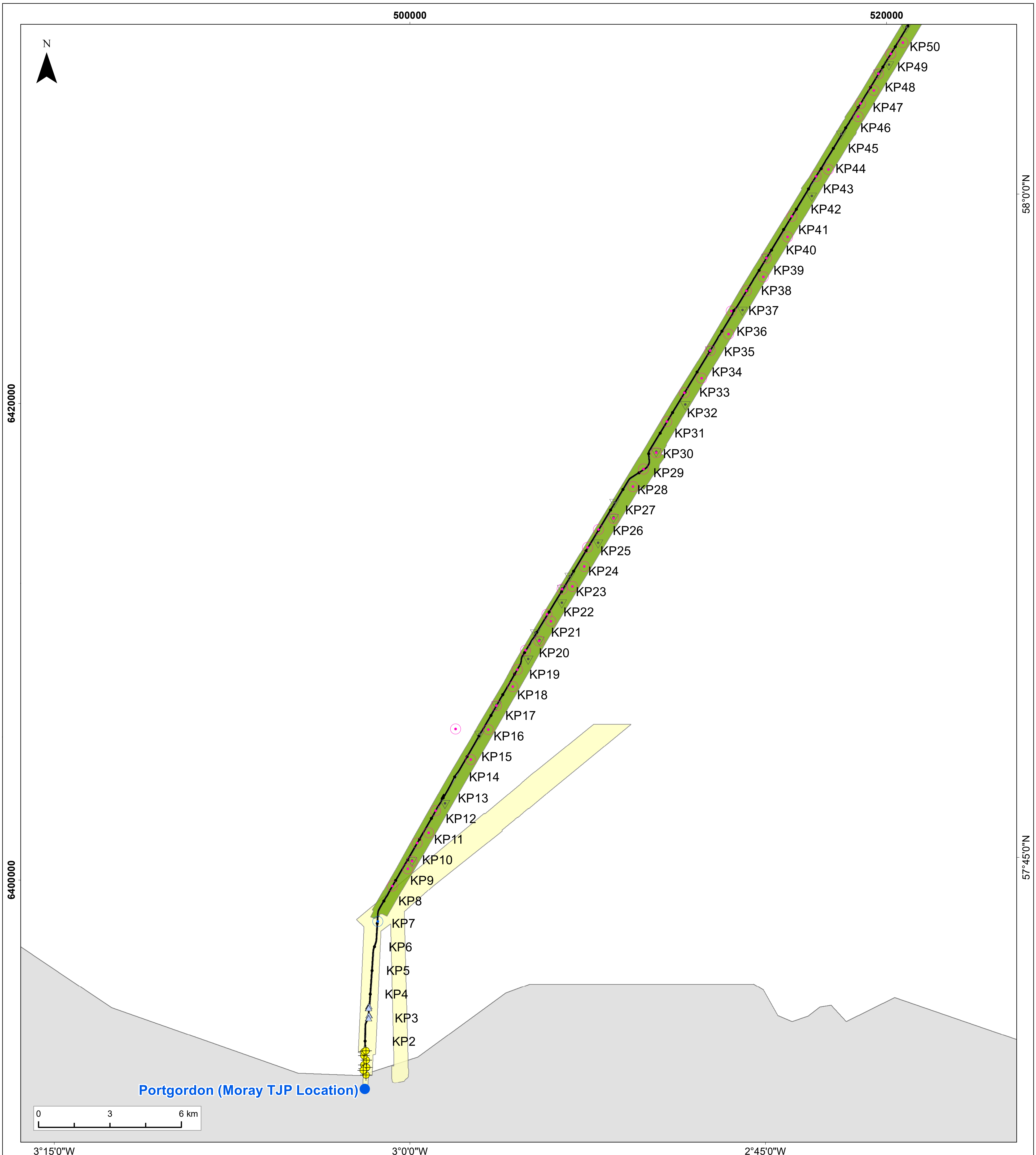


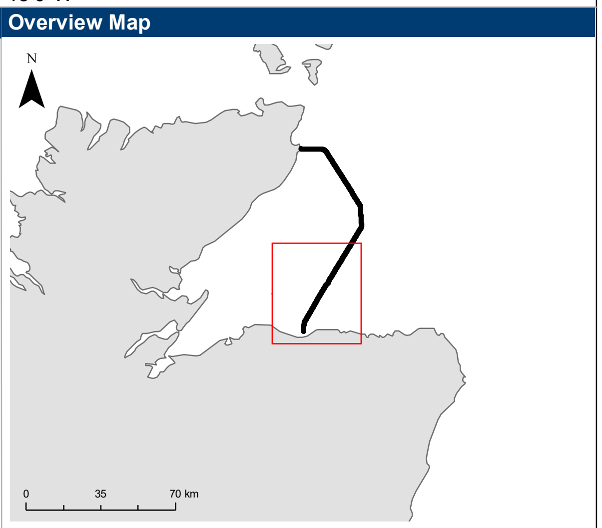
Client	Legend	Overview Map
Scottish & Southern Electricity Networks	Fugro 2016 Borehole Locations Aspect 2018 Vibrocore locations MMT 2010 VC Geotechnical Sampling Noss MMT 2010 GS Geotechnical Sampling Noss MMT 2008 Survey Geotechnical Location MMT 2012 VC & BC Locations MMT 2012 CPT Locations MMT 2012 Hub to Portgordon Survey Corridor MMT 2008 Survey - Nearshore Portgordon **MMT 2016 Survey Corridor** MBES SSS	

Figure Number & Title

Figure A2
Geotechnical Overview Sheet 1 of 4

Project/Report Information

Project Name : Caithness - Moray (LT21) Cable Plan
Project No : 2705
Location : UKCS, Moray Firth, Portgordon to Noss Head
Figure : 2705-SSE-FIG-A2-01

Geodetic Information

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Projection: Transverse Mercator (Central Meridian: 3°0'0"W)
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Data Sources, Acknowledgements & Notes

SSE
NKT, MMT, Fugro, Aspect

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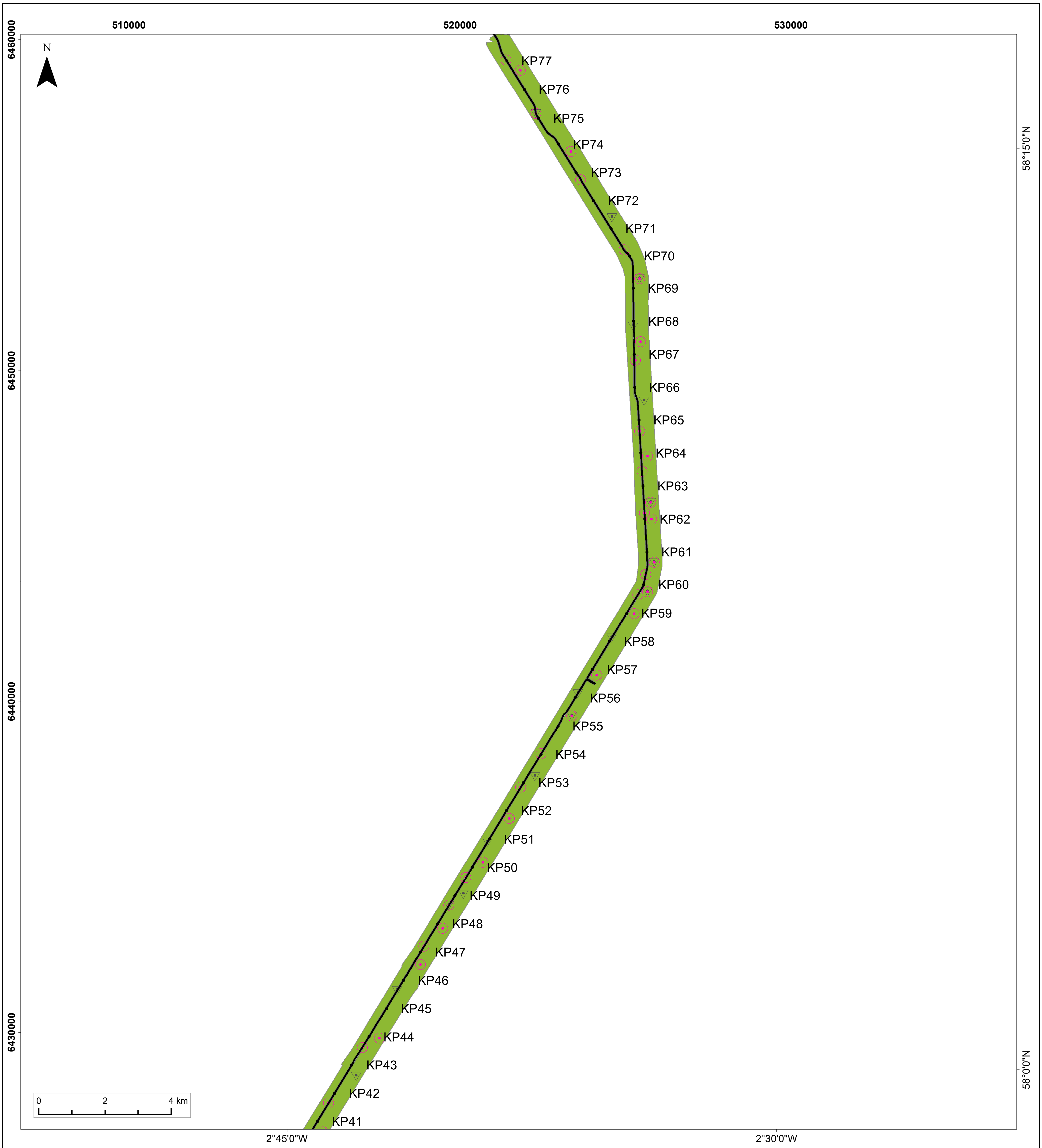

Client

Scottish & Southern Electricity Networks

Legend

- Fugro 2016 Borehole Locations
- Aspect 2018 Vibrocore locations
- MMT 2010 VC Geotechnical Sampling Noss
- MMT 2010 GS Geotechnical Sampling Noss
- MMT 2008 Survey Geotechnical Location
- MMT 2012 VC & BC Locations
- MMT 2012 CPT Locations
- MMT 2008 Survey - Nearshore Portgordon
- MMT 2012 Hub to Portgordon Survey Corridor

MMT 2016 Survey Corridor

- MBES
- SSS

Overview Map

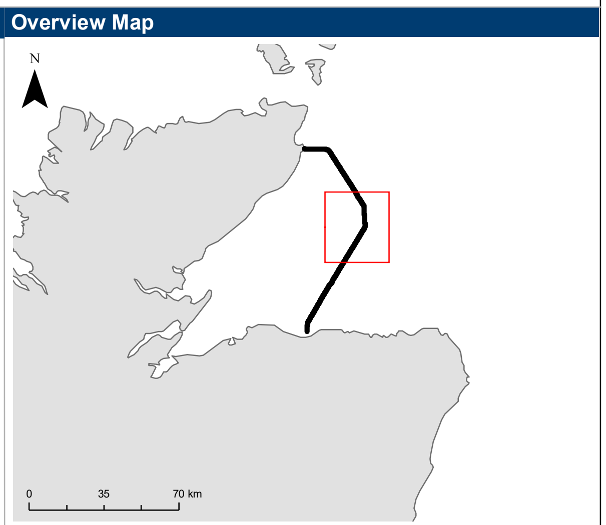

Figure Number & Title

Figure A3
Geotechnical Overview Sheet 2 of 4

Project/Report Information

Project Name : Caithness - Moray (LT21) Cable Plan
Project No : 2705
Location : UKCS, Moray Firth, Portgordon to Noss Head
Figure : 2705-SSE-FIG-A3-01

Geodetic Information

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Data Sources, Acknowledgements & Notes

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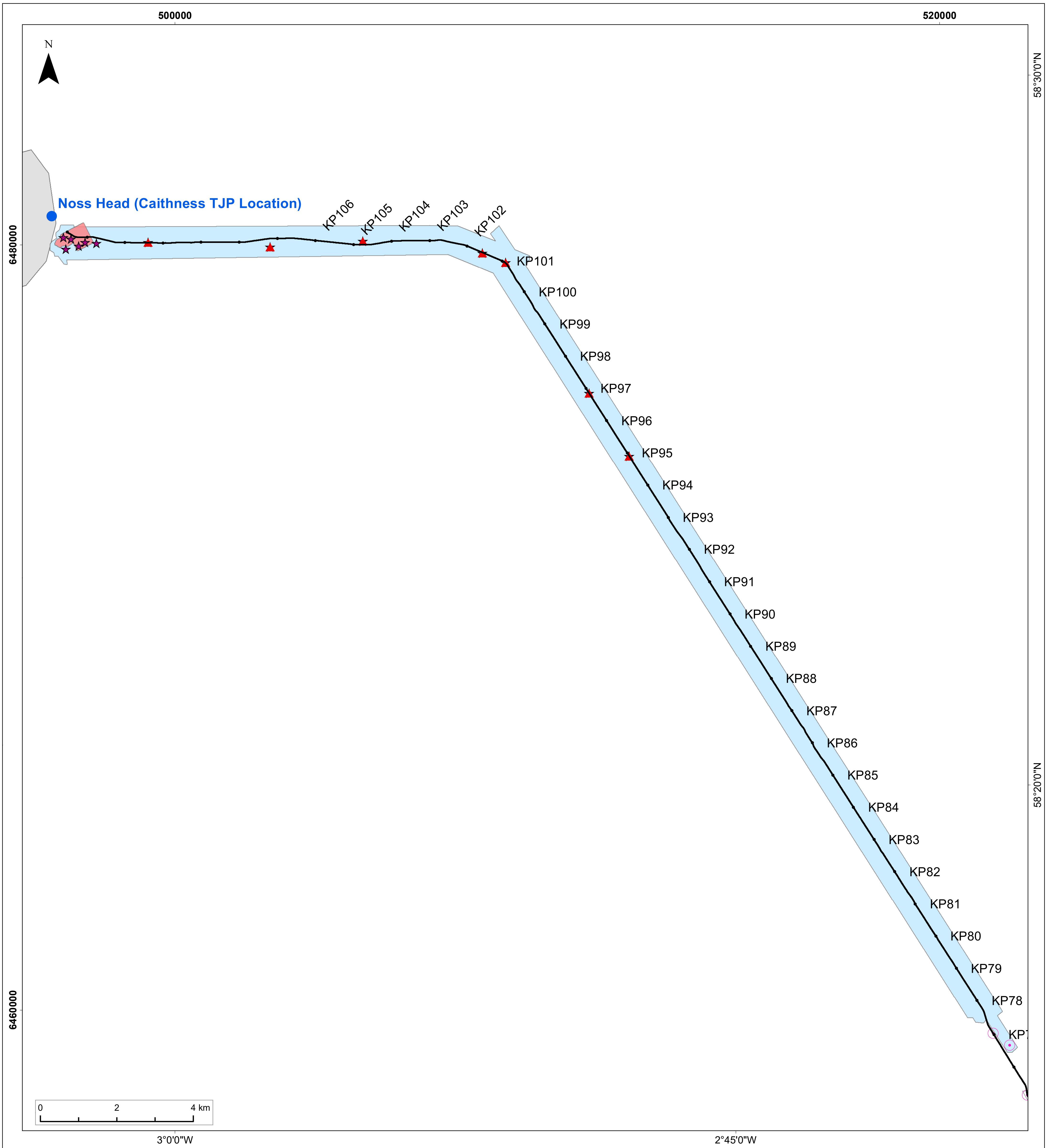

Client

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Figure Number & Title

Figure A4
Geotechnical Overview Sheet 3 of 4

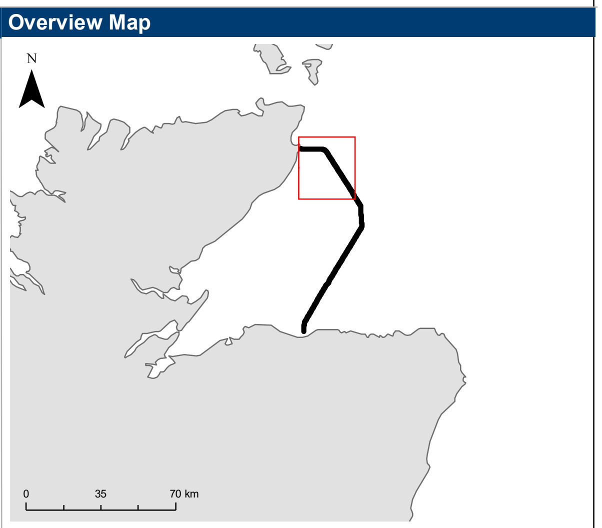
Project/Report Information

Project Name : Caithness - Moray (LT21) Cable Plan
Project No : 2705
Location : UKCS, Moray Firth, Portgordon to Noss Head
Figure : 2705-SSE-FIG-A4-01

Legend

- Aspect 2018 Vibrocore locations
- MMT 2010 VC Geotechnical Sampling Noss
- MMT 2010 GS Geotechnical Sampling Noss
- MMT 2008 Survey Geotechnical Location
- MMT 2012 VC & BC Locations
- MMT 2012 CPT Locations
- MMT 2010 Hub to Noss Head Survey Corridor
- MMT 2012 Nearshore Survey Area

Overview Map



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Main Window Scale: 1:94,457

Data Sources, Acknowledgements & Notes

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NKT, MMT, Fugro, Aspect

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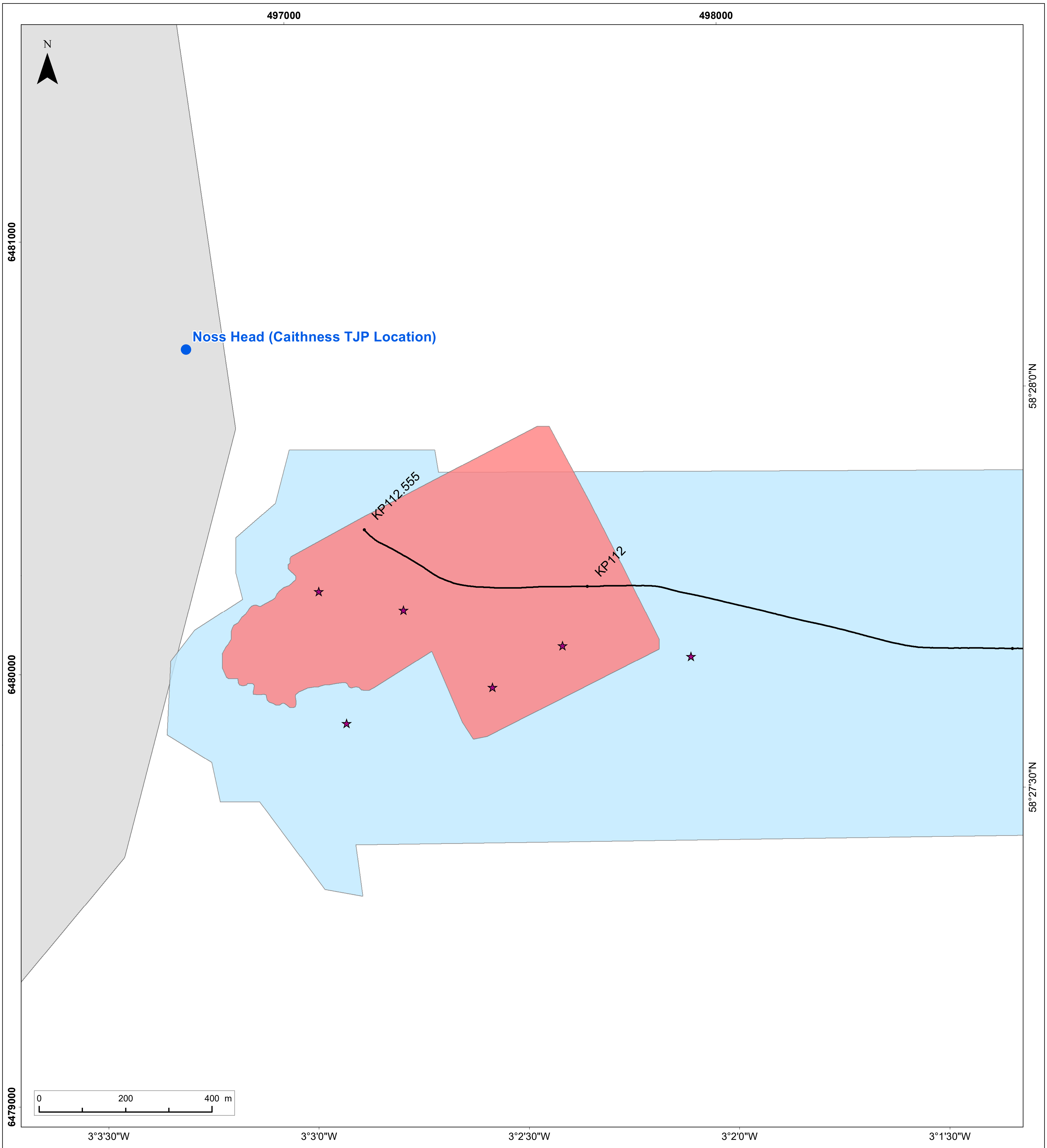

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Legend

- Aspect 2018 Vibrocore locations
- MMT 2010 VC Geotechnical Sampling Noss
- MMT 2010 GS Geotechnical Sampling Noss
- MMT 2008 Survey Geotechnical Location
- MMT 2012 VC & BC Locations
- MMT 2012 CPT Locations
- MMT 2010 Hub to Noss Head Survey Corridor
- MMT 2012 Nearshore Survey Area

Overview Map

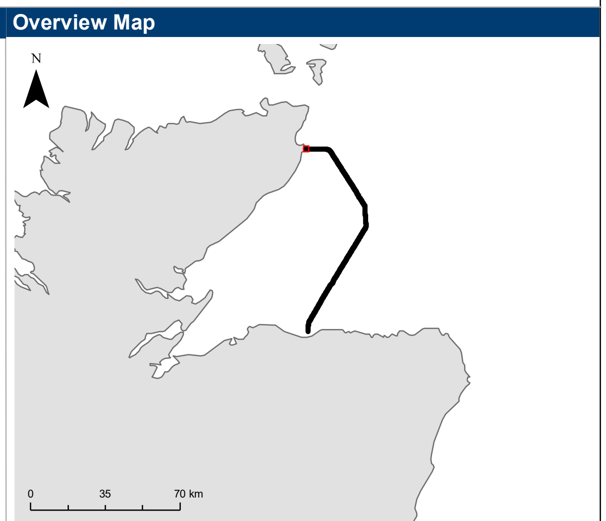

Figure Number & Title

Figure A5
Geotechnical Overview Sheet 4 of 4

Project/Report Information

Project Name : Caithness - Moray (LT21) Cable Plan
Project No : 2705
Location : UKCS, Moray Firth, Portgordon to Noss Head
Figure : 2705-SSE-FIG-A5-01

Geodetic Information

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Data Sources, Acknowledgements & Notes

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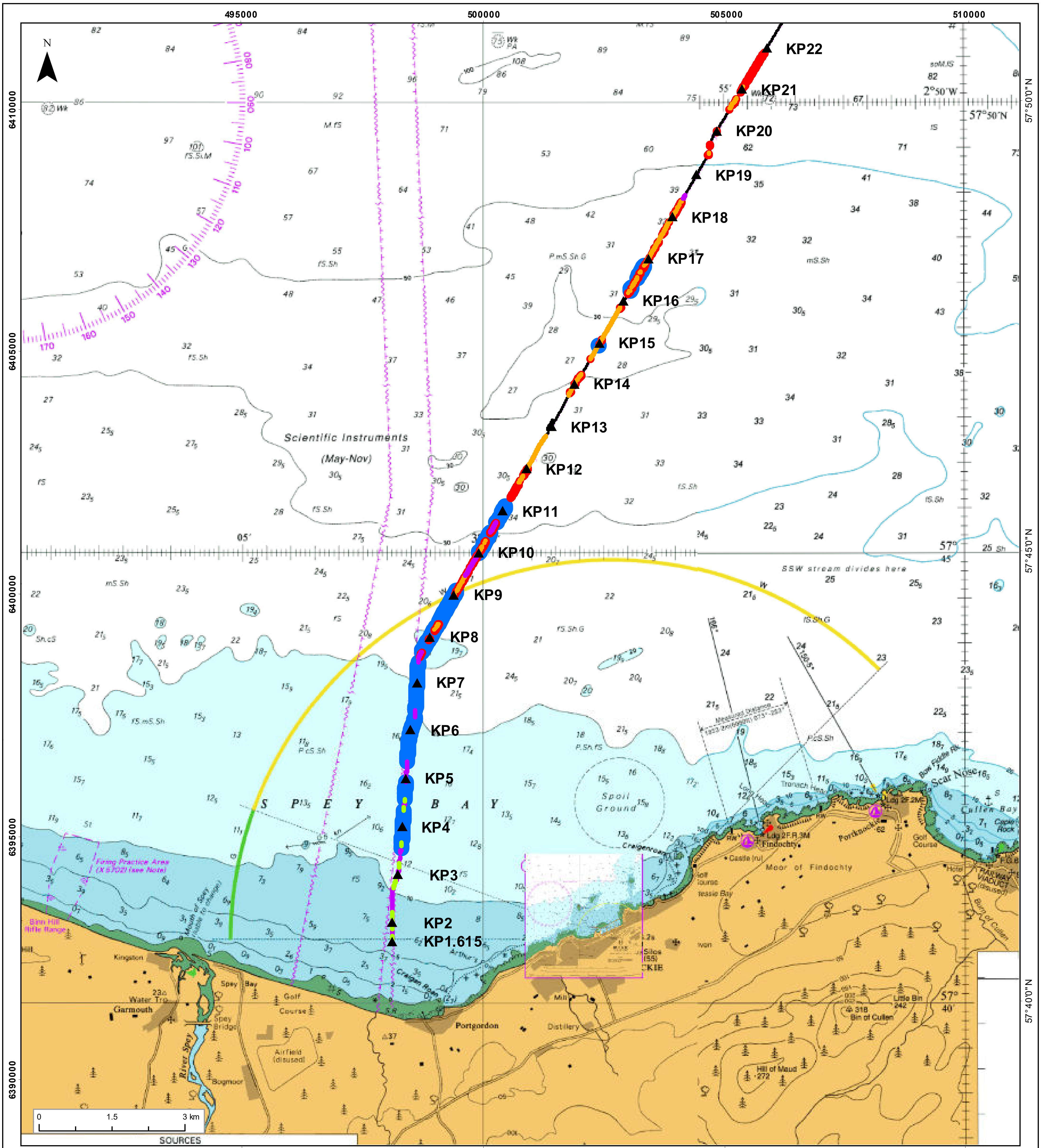

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Figure Number & Title

Figure A6
Caithness-Moray (LT21) Cable Burial Proposal
KP 1.615 to KP 22

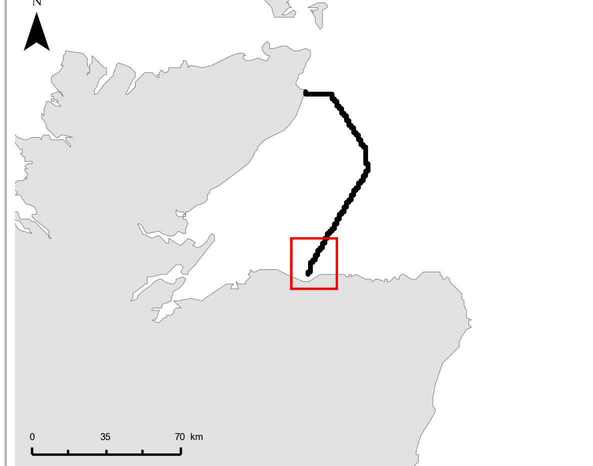
Project/Report Information

Project : Caithness-Moray (LT21) HVDC
Figure : 2705 Cable Burial Plan

Legend

- Proposed rock above mean seabed level
- Proposed rock below mean seabed level
- As-built rock above mean seabed level
- As-built rock below mean seabed level
- As-Built CM MFE Sections
- Rev B-As-built CM route

Overview Map



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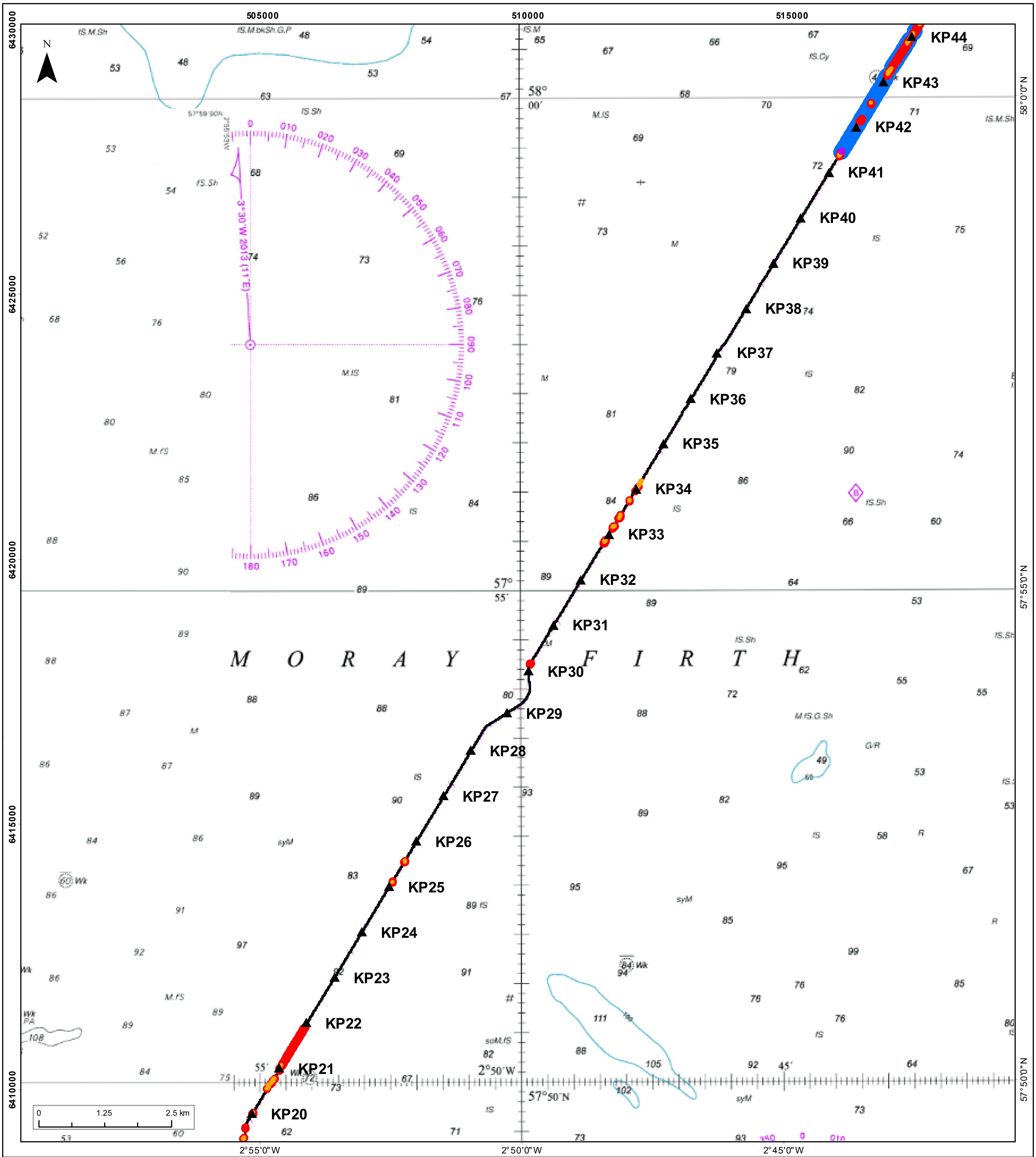

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Figure Number & Title

Figure A7
Caithness-Moray (LT21) Cable Burial Proposal
KP 20 to KP 44

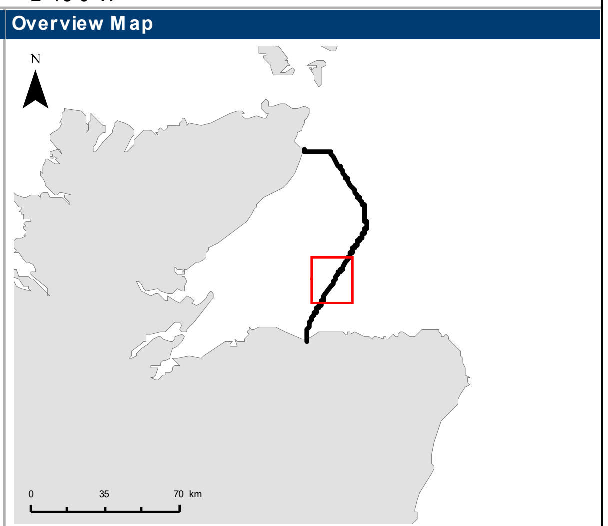
Project/Report Information

Project : Caithness-Moray (LT21) HVDC
Figure : 2705 Cable Burial Plan

Legend

- Proposed rock above mean seabed level
- Proposed rock below mean seabed level
- As-built rock above mean seabed level
- As-built rock below mean seabed level
- As-Built CM MFE Sections
- Rev B-As-built CM route

Overview Map



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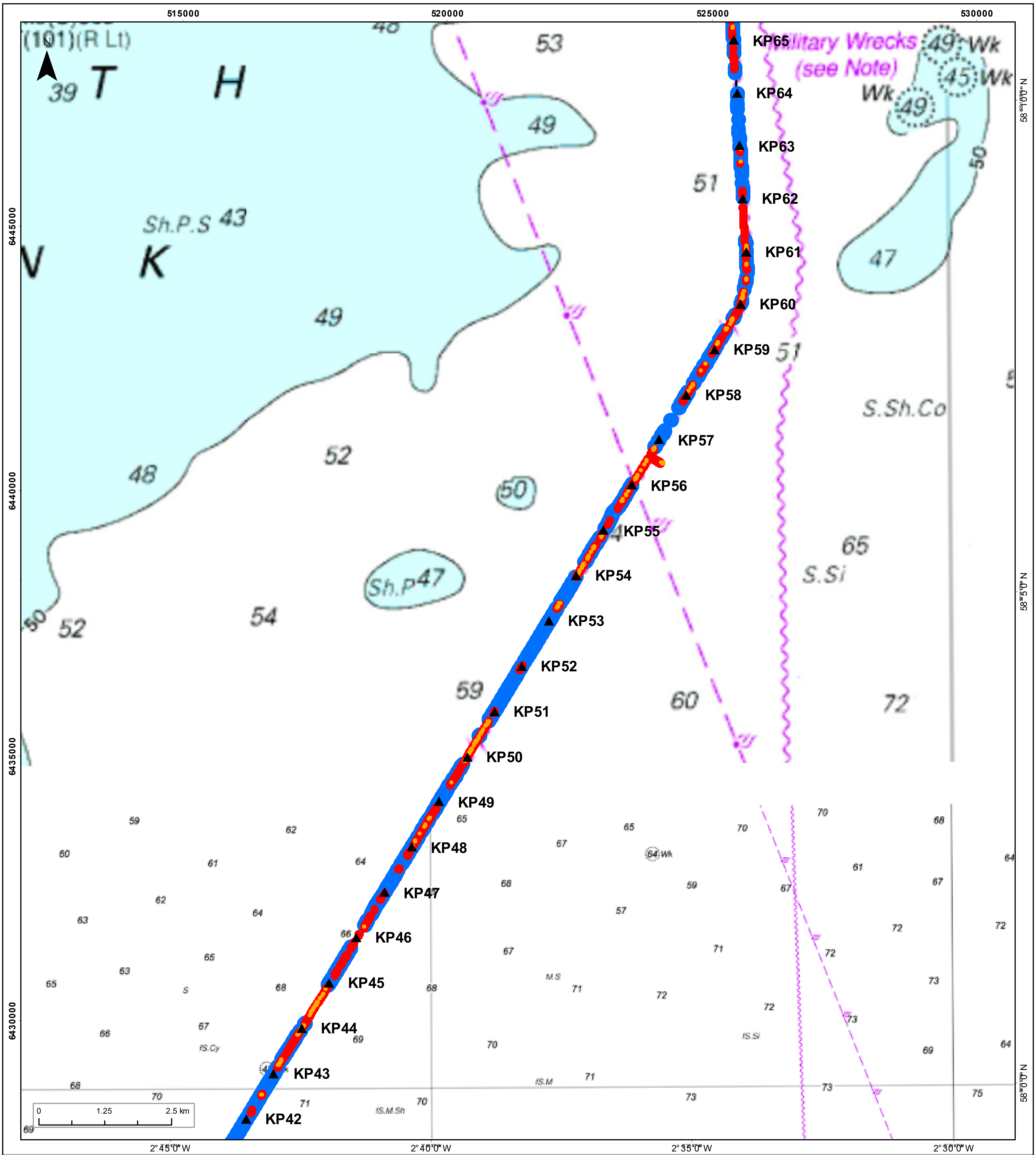

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Figure Number & Title

Figure A8
Caithness-Moray (LT21) Cable Burial Proposal
KP 42 to KP 65

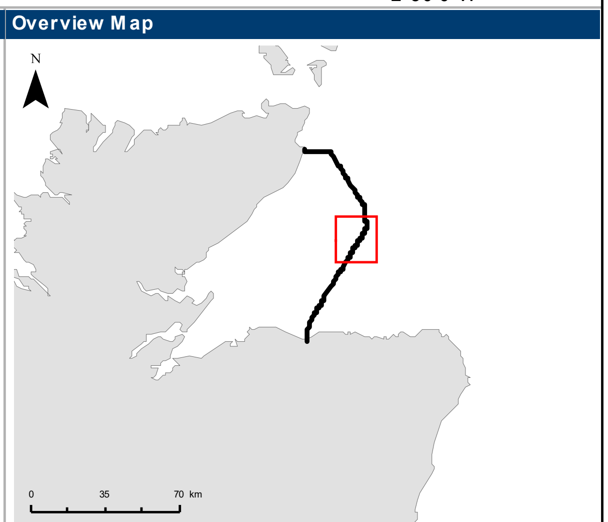
Project/Report Information

Project : Caithness-Moray (LT21) HVDC
Figure : 2705 Cable Burial Plan

Legend

- Proposed rock above mean seabed level
- Proposed rock below mean seabed level
- As-built rock above mean seabed level
- As-built rock below mean seabed level
- As-Built CM MFE Sections
- Rev B-As-built CM route

Overview Map



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Main Window Scale: 1:67,434

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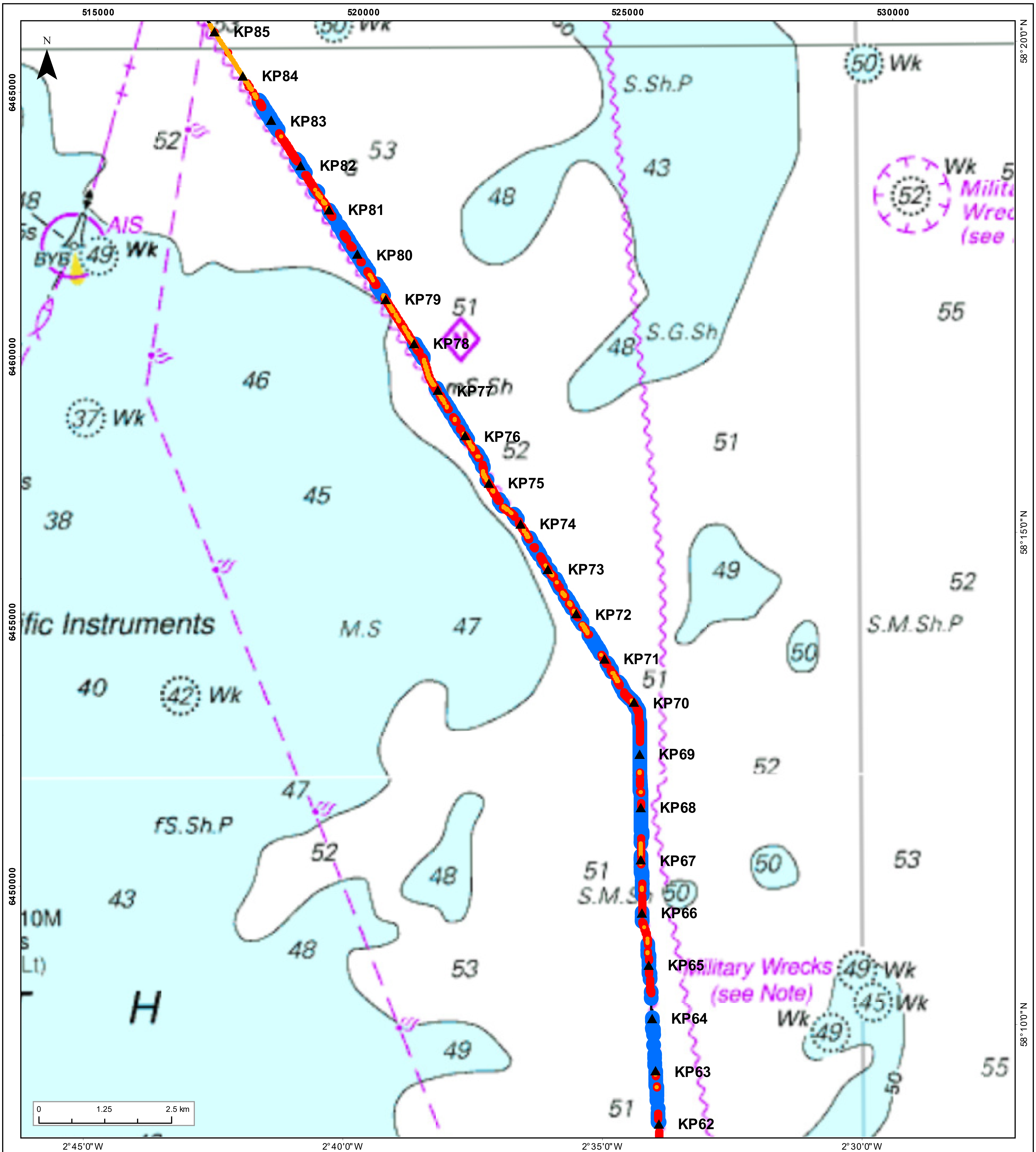

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Figure Number & Title

Figure A9
Caithness-Moray (LT21) Cable Burial Proposal
KP 62 to KP 85

Project/Report Information

Project : Caithness-Moray (LT21) HVDC
Figure : 2705 Cable Burial Plan

Geodetic Information

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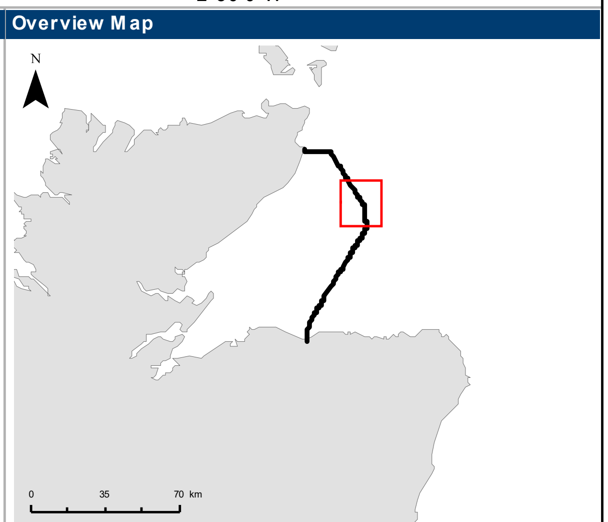
Projection: Transverse Mercator (Central Meridian: 3°0'0"W)
Datum: WGS 1984 / **Ellipsoid:** WGS84
Suitable for printing @ A3 Main Window Scale: 1:67,434

Legend

- Proposed rock above mean seabed level
- Proposed rock below mean seabed level
- As-built rock above mean seabed level
- As-built rock below mean seabed level
- As-Built CM MFE Sections
- Rev B-As-built CM route

Overview Map



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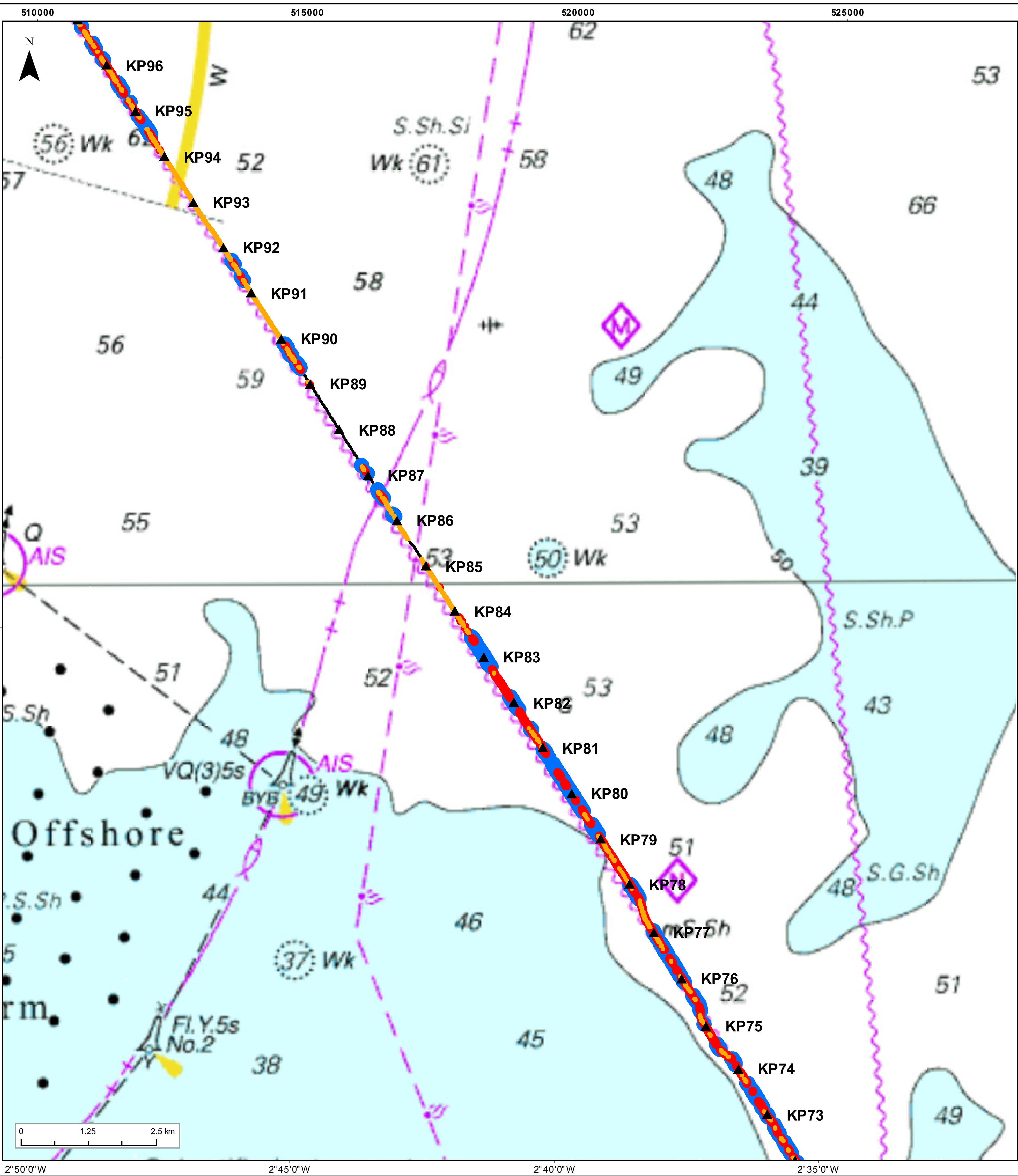

Client

Scottish & Southern Electricity Networks

Figure Number & Title

Figure A10
Caithness-Moray (LT21) Cable Burial Proposal
KP 73 to KP 96

Project/Report Information

Project : Caithness Moray (LT21) HVDC
Figure : 2705 Cable Burial Plan

Geodetic Information

Coordinate Reference System: WGS 1984 UTM Zone 30N
Projection: Transverse Mercator (Central Meridian: 3°0'0"W)
Datum: WGS 1984 / **Ellipsoid:** WGS84
Suitable for printing @ A3 Main Window Scale: 1:67,434

Legend

- Proposed rock above mean seabed level
- Proposed rock below mean seabed level
- As-built rock above mean seabed level
- As-built rock below mean seabed level
- As-Built CM MFE Sections
- Rev B-As-built CM route

Data Sources, Acknowledgements & Notes

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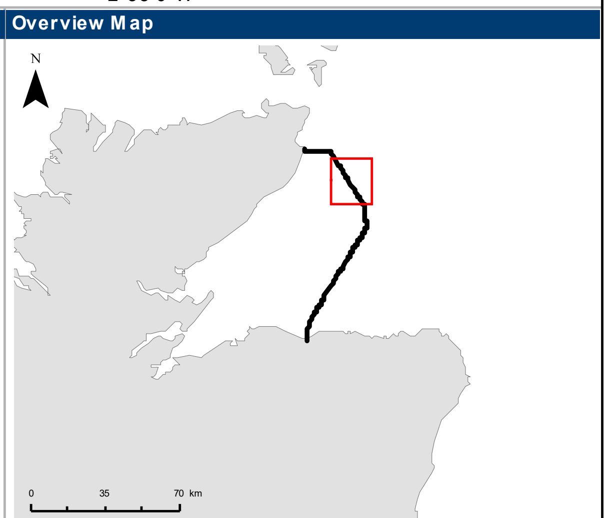
Overview Map



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Date : 31/01/2019

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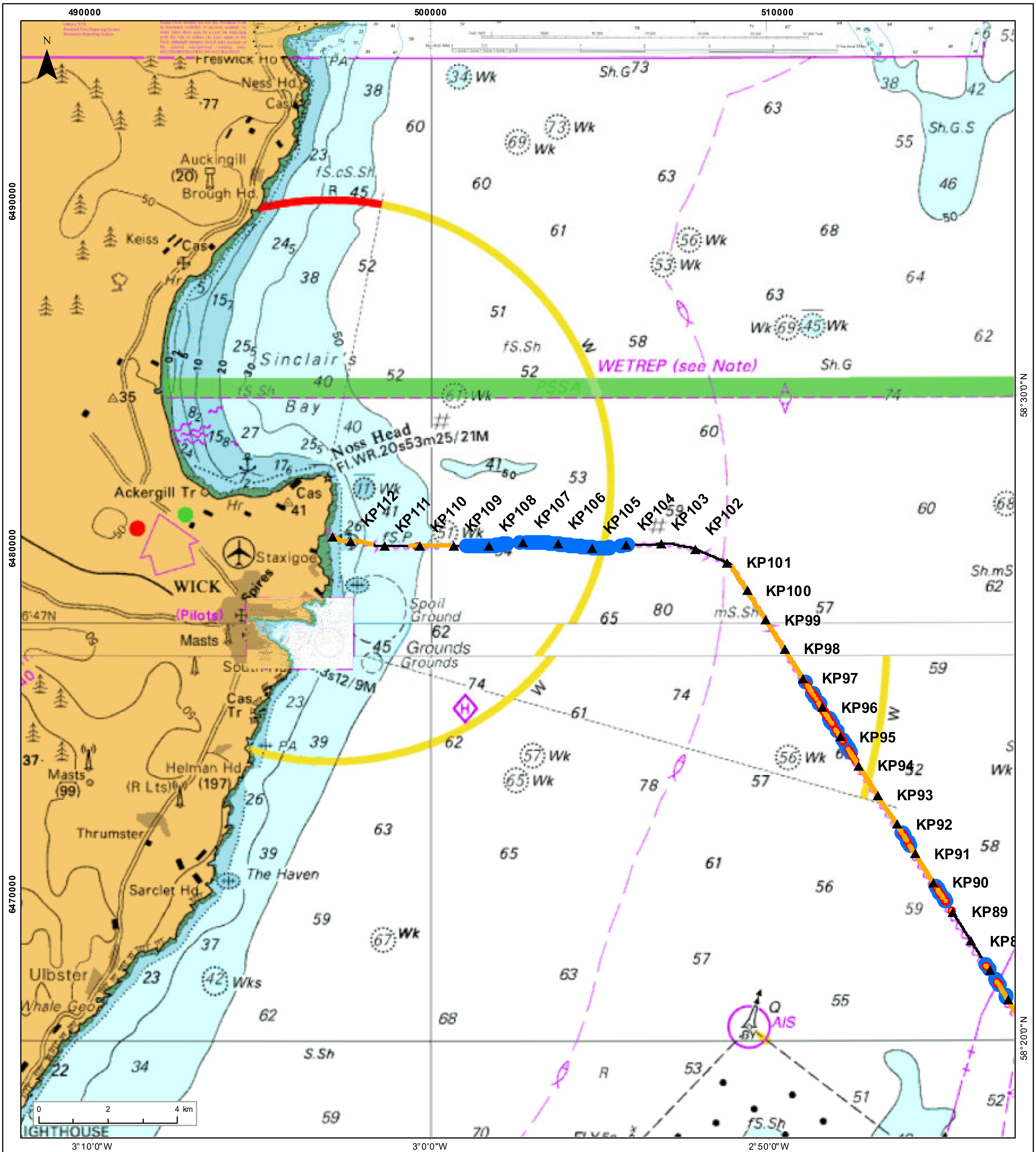


Client

Scottish & Southern Electricity Networks

Figure Number & Title

Figure A11
Caithness-Moray (LT21) Cable Burial Proposal
KP 89 to KP 112.555

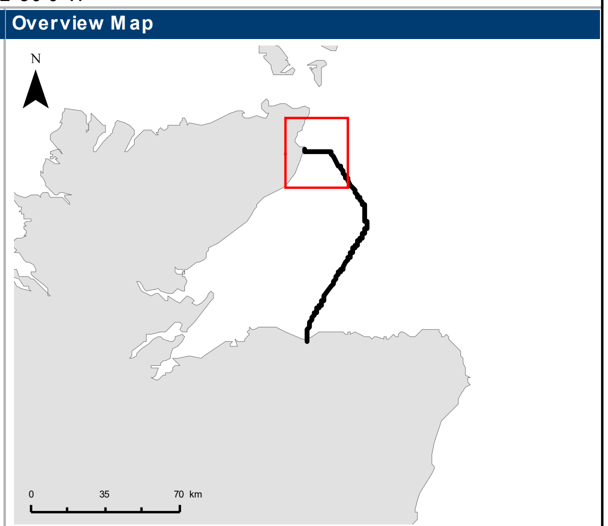
Project/Report Information

Project : Caithness Moray (LT21) HVDC
Figure : 2705 Cable Burial Plan

Legend

- Proposed rock above mean seabed level
- Proposed rock below mean seabed level
- As-built rock above mean seabed level
- As-built rock below mean seabed level
- As-Built CM MFE Sections
- Rev B-As-built CM route

Overview Map



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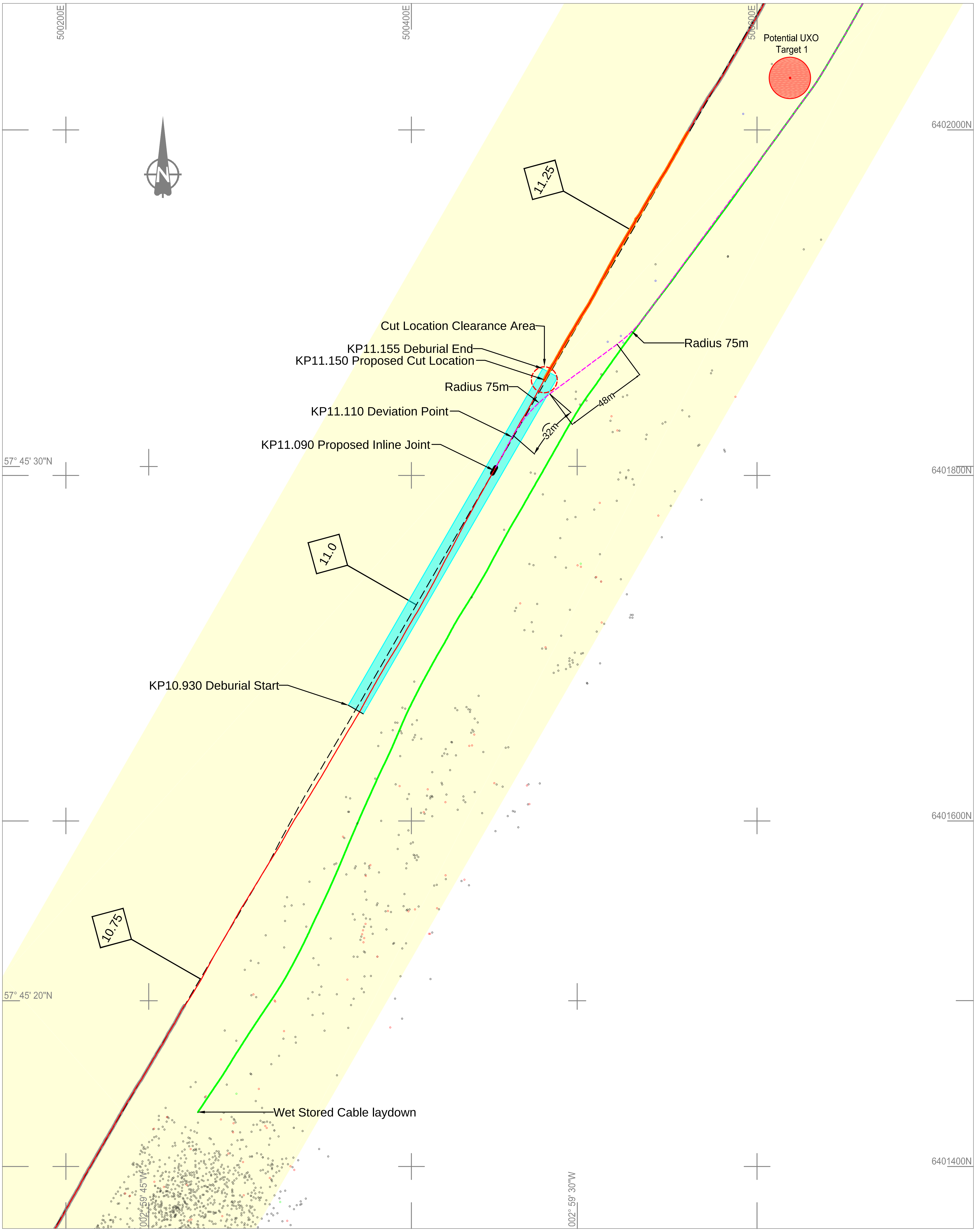


LEGEND

- Design route RPL D10.0
- Aslaid Cable
- Aslaid Wet Stored Cable
- Proposed Post Jointing Cable
- Rock Dump Extents
- Proposed Deburial Area
- 100m Consent Corridor
- Potential UXO target
- Target - Boulder 0.3-0.9m
- Target - Boulder >1.0m
- Target - Seabed Depressions
- Target - Sonar Contact

NOTES

1. Cable configuration based on lengths for omega joint configurations.
2. For for full details of UXO Alarp corridor refer to RPS report EES0606-R-07-09_Caithness_to_Moray_ALARP-Certificate.
3. Layout of cable ends may be adjusted if necessary to suit as-found conditions and cable lengths.

Figure A12

GEODETIC PARAMETERS

Datum	: WGS84
Projection	: UTM 30N
Ellipsoid	: WGS84
Semi-major Axis	: 6378137.000 m
Inverse Flattening	: 298.25722
False Easting	: 500000 m
False Northing	: 0 m
Scale Factor (at CM)	: 0.9996
Central Meridian (CM)	: 3°W
Vertical Datum	: LAT

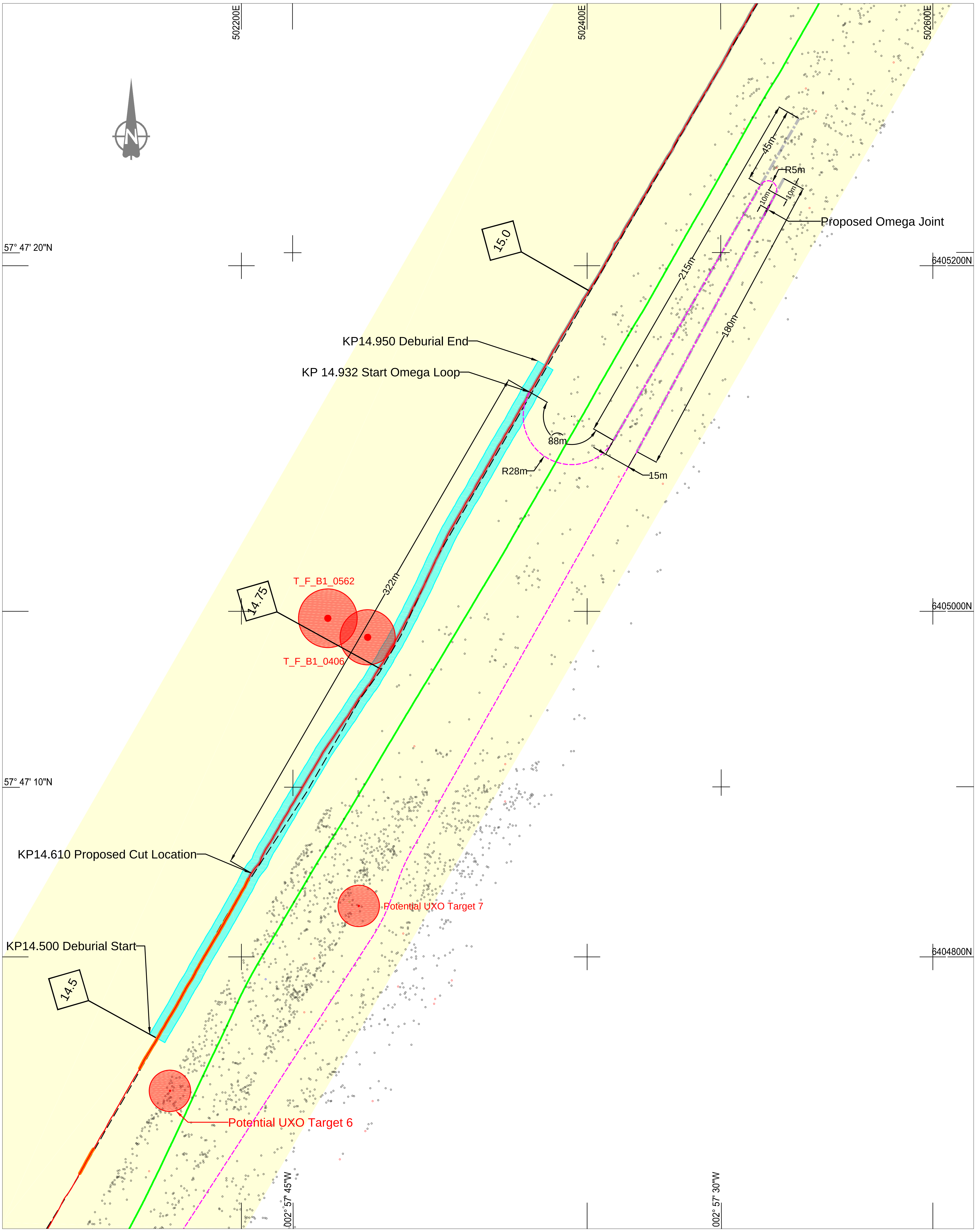
Rev.	Date	Description	Drwn	Ch'd	Appd
A3	19-11-2018	Issued for Internal review			
A2	15-11-2018	Issued for Internal review			
A1	06-08-2018	Issued for Internal review			

Contractor: NKT

Project: CMS

Dwg Title: CMS PORTGORDON - NOSS
LAYOUT OF CABLE FOR INLINE JOINTING
KP 11.090

Drawing scale	Drawing size	Project No.	NKT Drawing No.	Sheet No.	Rev.
1 : 2000	A3	G14006	1JND14006D006712	01 of 03	A3



LEGEND

- Design route RPL D10.0
- Aslaid Cable
- Aslaid Wet Stored Cable
- Proposed Post Tie-in Cable
- Rock Dump Extents
- Target - Boulder 0.3-0.9m
- Target - Boulder >1.0m
- Target - Seabed Depressions
- Target - Sonar Contact
- Proposed Deburial Area
- 100m Consent Corridor
- Potential UXO target

NOTES

1. Cable configuration based on lengths for omega joint configurations.
2. For for full details of UXO Alarp corridor refer to RPS report EES0606-R-07-09_Caithness_to_Moray_ALARP-Certificate.
3. Layout of cable ends may be adjusted if necessary to suit as-found conditions and cable lengths.

Figure A13

GEODETIC PARAMETERS

Datum	: WGS84
Projection	: UTM 30N
Ellipsoid	: WGS84
Semi-major Axis	: 6378137.000 m
Inverse Flattening	: 298.25722
False Easting	: 500000 m
False Northing	: 0 m
Scale Factor (at CM)	: 0.9996
Central Meridian (CM)	: 3°W
Vertical Datum	: LAT

Rev.	Date	Description	Drwn	Ch'd	Appd
A3	19-11-2018	Issued for Internal review			
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Contractor: NKT

Project: CMS

Dwg Title:
CMS PORTGORDON - NOSS
LAYOUT OF CABLE ENDS FOR OMEGA JOINTING
KP 15

Drawing scale	Drawing size	Project No.	NKT Drawing No.	Sheet No.	Rev.
1 : 2000	A3	G14006	1JND14006D006711	02 of 03	A3

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