Comparative Assessment for the Stella FPF-1 Mooring Lines

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	Names	**Signature**	**Date**
Prepared by:	S. Axon	S. Axon	04 Aug 2025
Reviewed by:	E. Grant	E. Grant	04 Aug 2025
Approved by:	D. Dunn	D. Dunn	04 Aug 2025

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Figures and tables

Table of Abbreviations

Acronym	Description
~	Approximately, circa
AHV	Anchor Handling Vessel
Angle of repose	The angle of repose, or critical angle of repose, of a granular material is the steepest angle of descent or dip relative to the horizontal plane on which the material can be piled without slumping. At this angle, the material on the slope face is on the verge of sliding
CA	Comparative Assessment
CEFAS	Centre for Environment, Fisheries and Aquaculture Science
CNS	Central North Sea
CSV	Construction Support Vessel
Ø	Outside diameter (anchor piles)
dia.	Diameter
DP	Decommissioning Programme
EUNIS	European Nature Information System
FPF	Floating Production Facility
FPV	Fall Pipe Vessel (rock dumper)
GMG	Global Marine Group (Statutory Consultee), formerly Global Marine Systems
ICES	International Council for the Exploration of the Seas
in	Inch (25.4mm)
JNCC	Joint Nature Conservation Committee
kg	Kilogramme
MFE	Mass Flow Excavator
NCMPA	Nature Conservation Marine Protected Area
NFFO	National Federation of Fishermen's Organisations (Statutory Consultee)
NIFPO	Northern Ireland Fish Producer's Organisation (Statutory Consultee)
m	Metre (1,000mm)
ML	Mooring Line
mm	Millimetre
MPA	Marine Protection Area
O/A	Overall
OPRED	Offshore Petroleum Regulator for Environment and Decommissioning
PLL	Potential Loss of Life. The PLL metric estimates the number of fatalities that could arise from a hazardous event. It combines event frequencies, consequences, and population data to provide an understanding of the potential human impact. It is calculated as the probability of a fatality (per year) from a hazard or as the probability of a fatality during the execution of a scope of work.
PMF	Priority Marine Feature
SAC	Special Area of Conservation
SFF	Scottish Fishermen's Federation (Statutory Consultee)
SNS	Southern North Sea
Te	Metric Tonne (1,000 kg)
UKCS	United Kingdom Continental Shelf
UNO	Unless Noted Otherwise
WT	Wall thickness
x	Number of

Comparative Assessment colour scheme

The colour scheme used in the comparative assessment summary tables (refer Appendix A) is presented in Table 1.1.1 below. The intention is that the colour scheme shows - at a glance, which option performs best for the specific aspect being assessed.

Table 1.1.1: Comparative Assessment colour scheme

Assessment[1]		Description
On balance this is the best option	Broadly Acceptable / Low & most preferred	The performance of this option the best overall and 'broadly acceptable'. This is the best option. For cost this is the cheapest option.
⬆	Broadly Acceptable / Low & less preferred	The performance of this option is marginally worse than the best option or slightly more expensive (i.e. less than 2x as expensive) than the cheapest cost.
	Tolerable / Medium Non-preferred	Risks are tolerable and managed to ALARP. Implement controls and measures to reduce risks to ALARP; requires identification, documentation, and approval by responsible leader. For cost, an item highlighted orange means that the cost would be more than twice the cost of the cheapest option.
On balance this is the worst option	Intolerable / High not acceptable	Impacts are intolerable. Implement controls and measures to reduce the risks to ALARP (at least to medium); requires identification, documentation, implementation, and approval by responsible leader. For cost, an item highlighted red means that the cost would an order of magnitude (i.e. 10x) higher than the cheapest option.

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[1] The options are compared in absolute terms. For a preferred option the "Broadly Acceptable / Low & most preferred" shade of green is used. If both / all options are deemed acceptable, a choice of one of the two shades of green are used to provide further differentiation. The colour orange is used in the comparative assessment summary tables to show that the impact would be significantly higher and non-preferred of the options.

1. EXECUTIVE SUMMARY

1.1 Overview

A Comparative Assessment (CA) of the severance of the mooring lines is a key consideration within the Stella Floating Production Facility (FPF-1) Decommissioning Programmes (DPs) that are submitted to the Offshore Petroleum Regulator for Environment and Decommissioning (OPRED).

The mooring system for the Stella FPF-1 comprises twelve mooring lines (ML) grouped in four clusters of three, each of which is connected to an anchor pile. The mooring lines comprise a combination of cables, chains, link-plates and shackles. Each ML is secured to a padeye mounted on an anchor pile 7 m below the seabed.

1.2 Stella FPF-1 mooring system

The mooring system that serves the Stella FPF-1 is summarised in Table 1.2.1 below.

Table 1.2.1: Mooring system details

Description	No.	Size / Dimensions, Mass (Te) of each component	Comments / Status
Anchor pile(s)	12	2.133mØ70mmWT, 35.5m long, 130.45 Te Overall mass of the piles is 12x130.45 = 1,565.4 Te	'As-built' data records that each pile was driven to a depth such that the top of pile is 0.5 m above the seabed.
Mooring lines	12	159m (120mm chain), 3x120m (127mm chain), 670m (115mm Sheathed Spiral Stand Wire (SSS) wire), 125m (115mm SSS wire) & 60m (120mm studless chain) c/w links, tri-plates, closed-sockets and anchor shackles. Nominal overall length 1,145.5 m. The cumulative length of the mooring lines is 12x1,145.5 = 13,746 m. The mass of each mooring line is 253.9 Te. The overall mass of the mooring lines is 12x253.9 = 3,046.9 Te.	The 60 m length of chain quoted for the 120mm stud link chain is final section of the mooring line that connects a padeye on the anchor pile positioned 7 m below seabed. It is estimated that ~33 m of mooring chain is buried as it approaches the padeye. Refer Figure 2.3.1 and Figure 2.3.2 in section 2.3.

1.3 Decommissioning options for the mooring lines

The offshore oil and gas decommissioning guidance notes [2] that certain aspects of mooring systems are identified as subsea installations (e.g. mooring lines), and are considered to fall within the definition of "steel installation" for the purposes of OSPAR Decision 98/3, such that they should be fully removed. It is a policy objective that a clear seabed is left, such that any element of moorings which are not buried, should be removed.

Two options are considered in this CA in relation to the section of the mooring lines buried on the approach to the anchor pile padeyes at 7 m depth below seabed. These are:

- **Removal to 1 m below seabed** – This would involve excavating each mooring line in the lower chain section locally to 1.5 m below seabed using tracked mechanical dredging equipment or similar, to enable access to cut the chain 1 m below seabed. Deposited rock would then be used to backfill the excavation.
- **Removal to 3 m below seabed** – This would involve excavating each mooring line in the lower chain section locally to 3.5 m below seabed using tracked mechanical dredging equipment or similar, to enable access to cut the chain 3 m below seabed. Deposited rock would then be used to backfill the excavation.

The anchor piles will be cut internally at 3 m below seabed in accordance with the offshore decommissioning oil and gas guidance notes [2] unless difficulties are encountered, in which case OPRED will be consulted. Therefore, decommissioning of the piles is not a subject of this CA.

1.4 Method

The assessment is qualitative and considers five criteria for both the short-term decommissioning activities and the longer-term ‘legacy’ related activities. The criteria were: technical feasibility with three sub-criteria, safety related risks with three sub-criteria, environmental with five sub-criteria, societal effects with three sub-criteria and cost.

1.5 Conclusions

There is a significant difference between the partial removal options from a technical and environmental perspective. The volume of excavation and requirement for backfill material is significantly greater for the cutting at -3 m option; but both options would require remediation in the form of deposited rock – as backfill to the excavation as well as to remediate the local seabed where lumps of clay from the excavation had been deposited. More vessel time and energy would be required for the -3 m option compared to the -1 m option although the difference is not significant. Disturbance to the seabed for the -1 m option would generally be significantly lower.

From a health and safety perspective there is little to differentiate the options. The decommissioning works for both options would be conducted using remotely operated equipment. There would be a marginally higher threat posed by PLL for the -3 m option simply due to the slightly longer vessel time and a slightly increased possibility of a vessel collision. Mitigations involve use of standard procedures and protocols and these would probably render the difference between the options as being insignificant. The nature of the seabed material (stiff to very stiff clay) is such that before remedial works had been completed, a potential snagging risk could remain from any excavated material remaining on the seabed. However, once remedial works - involving deposition of rock in the excavated areas and to cover the lumpy clay berms had been completed no snagging risk would arise from the lumpy soil berms or the severed mooring chains for either option.

The difference[2] between the -3 m and -1 m options in material being brought to shore for recycling is minimal, so there would be little to choose from a waste perspective.

There is little to choose between the options from a commercial and employment perspective. Any associated work would be an extension of existing workloads rather than a creation of new and sustainable employment.

Finally, the cost of the -3 m option would be higher than the -1 m option, but less than twice as much. Both options would involve the deployment of CSV and FPV in addition to a AHV to execute the work. The -3 m option would need slightly more CSV time because of the higher volume of work. There is little to choose in FPV time because of the large dumping capacity of such vessels in relation to the amount of rock required. Future burial surveys for the -1 m option would be conducted as part of a wider survey campaign and so would not be significant.

1.6 Recommendations

Excavate and cut the lower chain section of the mooring line such that it will be cut 1 m below the seabed on the basis that no snagging risk would remain, and the environmental impact – particularly to the seabed, would be minimised.

Proposals for monitoring and remediation of any potentially exposed sections of the cut chain ends will be explained in the decommissioning Close Out Report following completion of decommissioning activities and a post-decommissioning survey.

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[2] 30 Te vs. 3.047 Te overall. The -3 m option would result in the recovery of slightly more material than the -1 m option (Table 2.3.1)

2. INTRODUCTION

2.1 Overview

A comparative assessment of the severance of the mooring lines is a key consideration within the Stella FPF-1 DPs being submitted to OPRED.

The Stella FPF-1 floating production facility is located in block 30/6a in the United Kingdom Continental Shelf (UKCS) in the North Sea. The Greater Stella Development Area lies about 256 km east south east of Aberdeen, Scotland, and ~25 km from the UK/Norway median line in the UK Central North Sea, in water depths of ~89 m.

The Stella, Harrier and Abigail Fields are each tied back to the Stella FPF-1 via a single dedicated subsea manifold separate from the Vorlich field. The Vorlich field is tied-back to the Stella FPF-1 via its own dedicated subsea manifold.

The Stella FPF-1 itself is a spread moored floating production facility that is kept on a set heading. The 12-point mooring system is arranged in four groups of three and uses a combination of chain and rigging arrangements from each corner column connected to chains fixed to the seabed by anchor piles. All the anchor piles are ~1.2 km from the Stella FPF-1.

There are no windfarms in the locality, and the Stella FPF-1 and mooring system is not located within any protected areas.

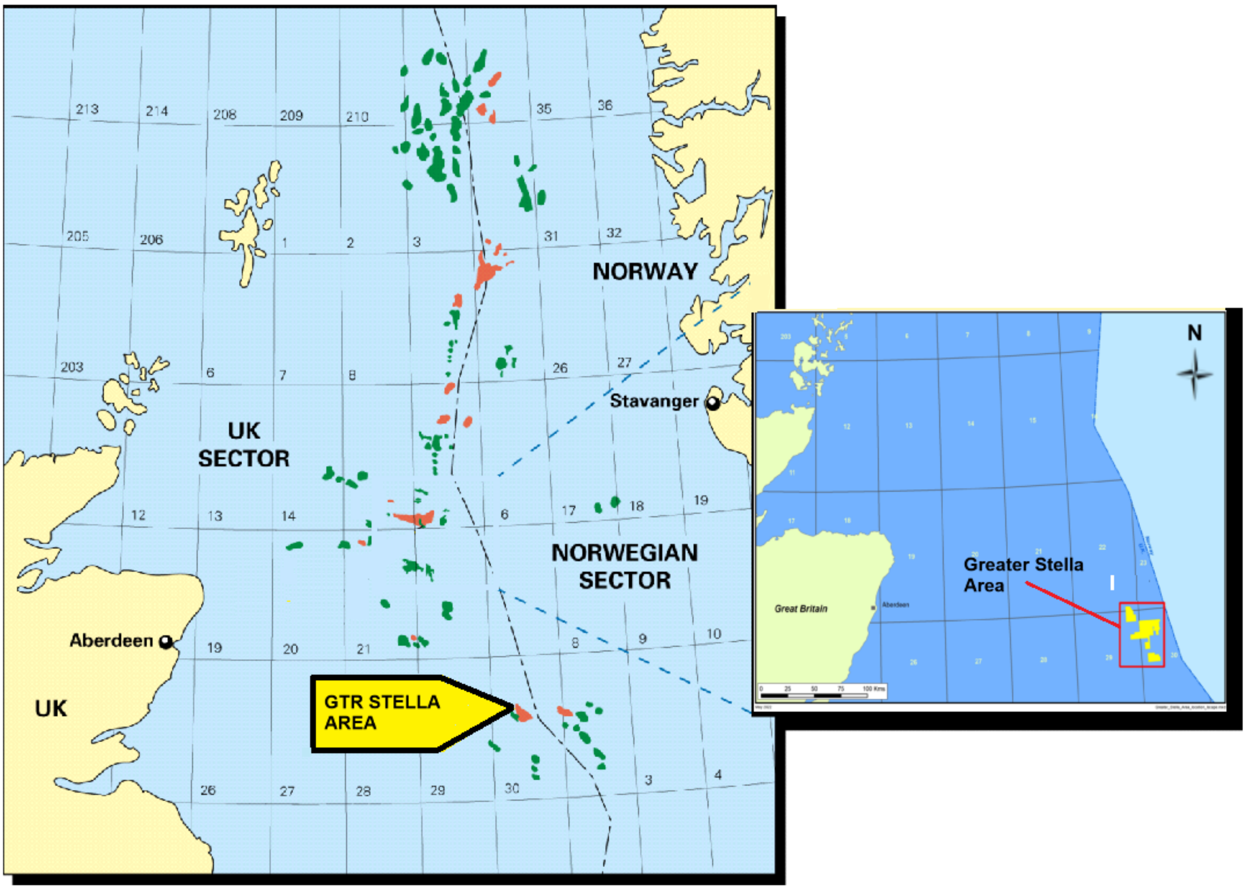
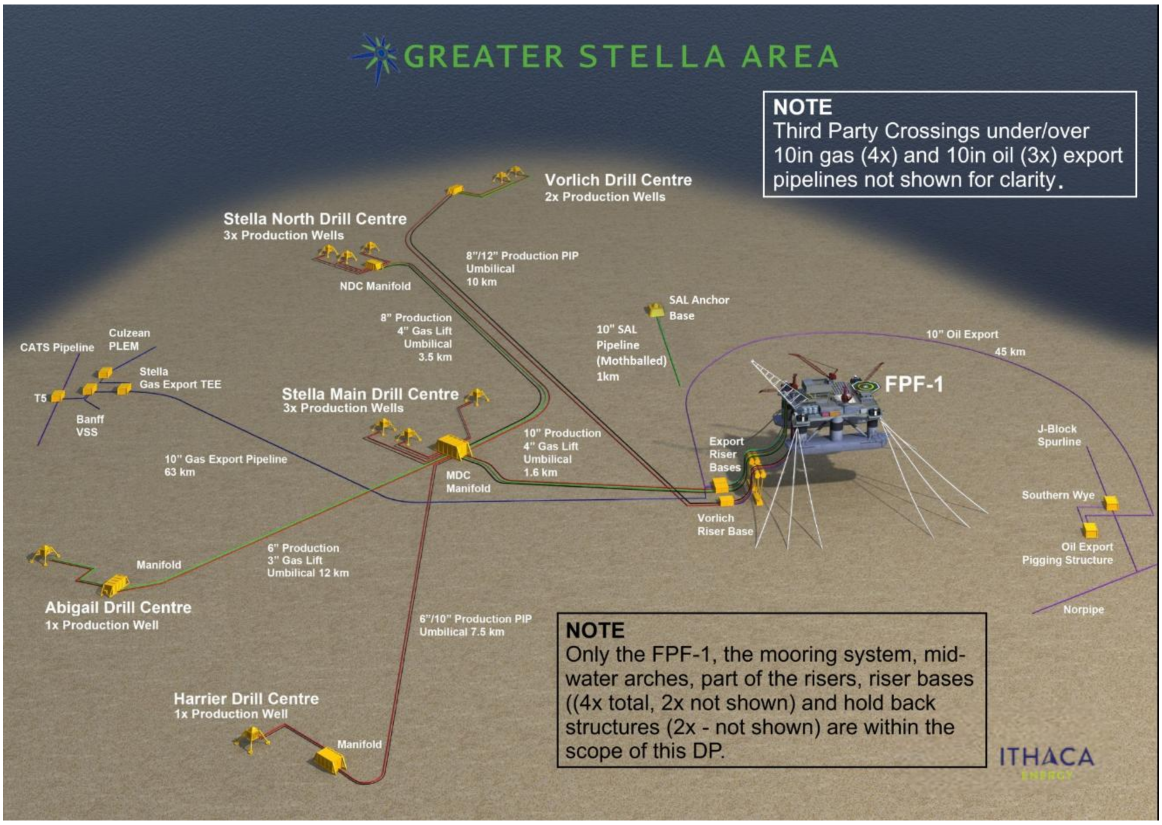


Figure 2.1.1: Location of Greater Stella Development Area in UKCS



NOTE
Third Party Crossings under/over 10in gas (4x) and 10in oil (3x) export pipelines not shown for clarity.

NOTE
Only the FPF-1, the mooring system, mid-water arches, part of the risers, riser bases ((4x total, 2x not shown) and hold back structures (2x - not shown) are within the scope of this DP.

Figure 2.1.2: Greater Stella field installations and infrastructure (not to scale)

2.2 Environmental setting

An overview of the environmental setting is presented below. More details and references may be found in the DP [1].

The water depth at the Stella FPF-1 location is ~89 m. The seabed in the area is generally flat and featureless, with the exception of some evidence of previous drilling and fishing activity. The sediment is predominantly rippled muddy, silty sand, with areas of coarse material (primarily bivalve shells) which form small ripples/waves, there are also areas of large shells and scattered cobbles. The EUNIS classification for the FPF-1 area is Atlantic offshore circalittoral sand. Geotechnical surveys around the Stella FPF-1 pile locations indicate that below the seabed is predominantly comprises firm to stiff to very stiff clays. In some areas the stiff to very stiff clays are overlain by a layer of silty sand between 0.2 m and 0.7 m thick.

Footage from the ROV inspection of the FPF-1 moorings (September 2024) indicated an absence of scour around the anchor piles, indicating low sediment mobility in the area (e.g. relative to the southern North Sea, where high energy currents results in significant sediment mobility).

The Priority Marine Feature (PMF) distribution maps report the PMF seabed features burrowed mud and offshore subtidal sands and gravels are known to occur within Block 30/06.

The ROV inspection footage shows rippled muddy sand around the mooring chains and anchor piles, with sea pens (both Virgularia mirabilis and Pennatula phosphorea) and burrowing fauna present, predominantly polychaetes; small mounds are evident, with lugworm like ejecta coils/lines, which make this 'sea pens and burrowing megafauna communities' habitat different to that of for example, the Fladen Ground where most of the burrowing is by crustacea. The sandy sediment at Stella may (in general) not be cohesive enough to support crustacean burrows (i.e. collapse of burrows).

However, taking a precautionary approach, and on the basis of evidence (the presence of fine slightly silty sand and muddy sand, and the presence of sea pens and burrows), and including survey data from the wider GSA (e.g. at the Abigail tie-back) it is considered, for the basis of assessment, that the sediments could constitute the “sea pens and burrowing megafauna communities” habitat as defined by OSPAR and expanded on by JNCC (2014).

The macrofaunal community found during the area surveys were dominated by *Galathowenia oculata, Echinoidea juveniles, Paramphinome jeffreysii, Ophiuroidea juveniles, Thyasira pygmaea* (bivalve), *Ampharetinae* juveniles (polychaete), *Eclysippe* (= *Pterolysippe*) cf. *vanelli* (polychaete), *Spiophanes kroyeri*, *Pholoe inornata* (polychaete), and *Minuspio cirrifera* (polychaete).

The visible fauna was sparse, predominately hermit crab (*Pagurus bernhardus*), sea pens (*Virgularia mirabilis*) and l*ebensspuren* related to crustacean burrows, vents and worm casts. Occasional large sea anemones (*Bolocera tuediae*) and soft corals (*Alcyonium sp.*) were observed, usually attached to large relict shells.

Arctica islandica were also recorded, however, these were in low numbers, with no aggregations identified.

The Stella FPF-1 is located within International Council for the Exploration of the Seas (ICES) rectangle 42F2 and this overlaps with reported spawning areas for mackerel, cod, whiting, Norway pout, plaice, lemon sole and sandeel. The area also supports nursery grounds for: herring, mackerel, cod, haddock, whiting, hake, Norway pout, ling, plaice, monkfish, sandeel, spurdog and spotted ray. Of these species, mackerel, cod, Norway pout, herring, ling, monkfish, sandeel and spurdog are PMFs in Scottish waters.

2.3 Stella FPF-1 mooring lines

The mooring system for the Stella FPF-1 comprises twelve mooring lines (ML) grouped in four clusters of three, each of which is connected to an anchor pile. The mooring lines comprise a combination of cables, chains, link-plates and shackles (Figure 2.3.1). Each ML is secured to a padeye mounted on an anchor pile 7 m below the seabed (Figure 2.3.2).

The nominal length of each mooring line is 1,145.5 m giving an overall length of 12x1,145.5=13,746 m. The mass of each mooring line is 253.9 Te, giving the overall mass of the mooring lines as 12x253.9 = 3,047 Te. Schematics of the mooring arrangements are presented in Figure 2.3.1 and Figure 2.3.2 below.

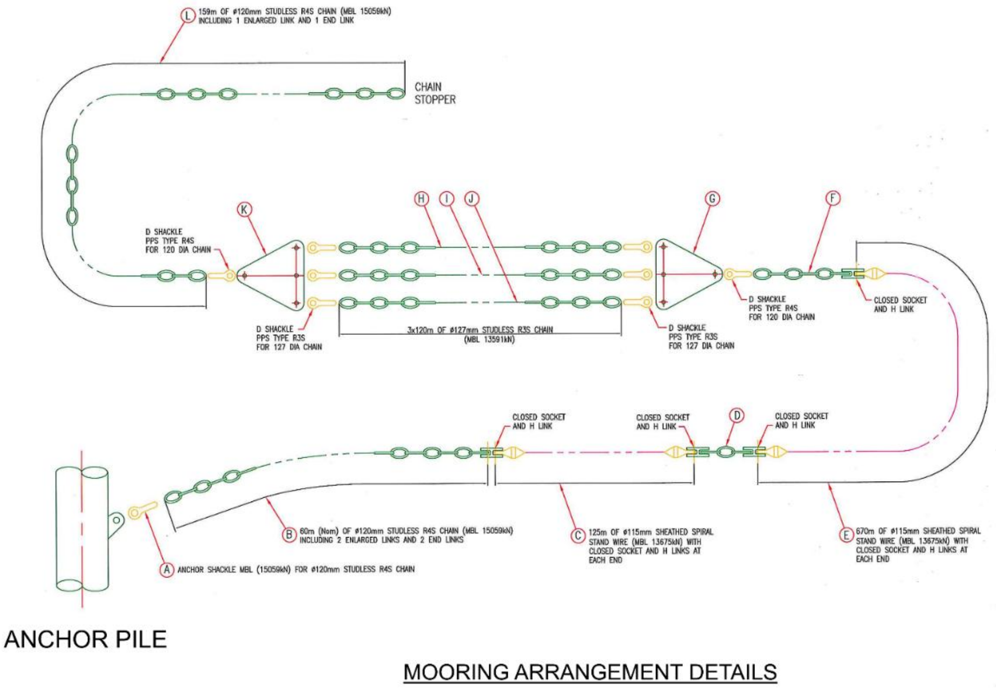


Figure 2.3.1: Stella FPF-1 – typical mooring arrangement

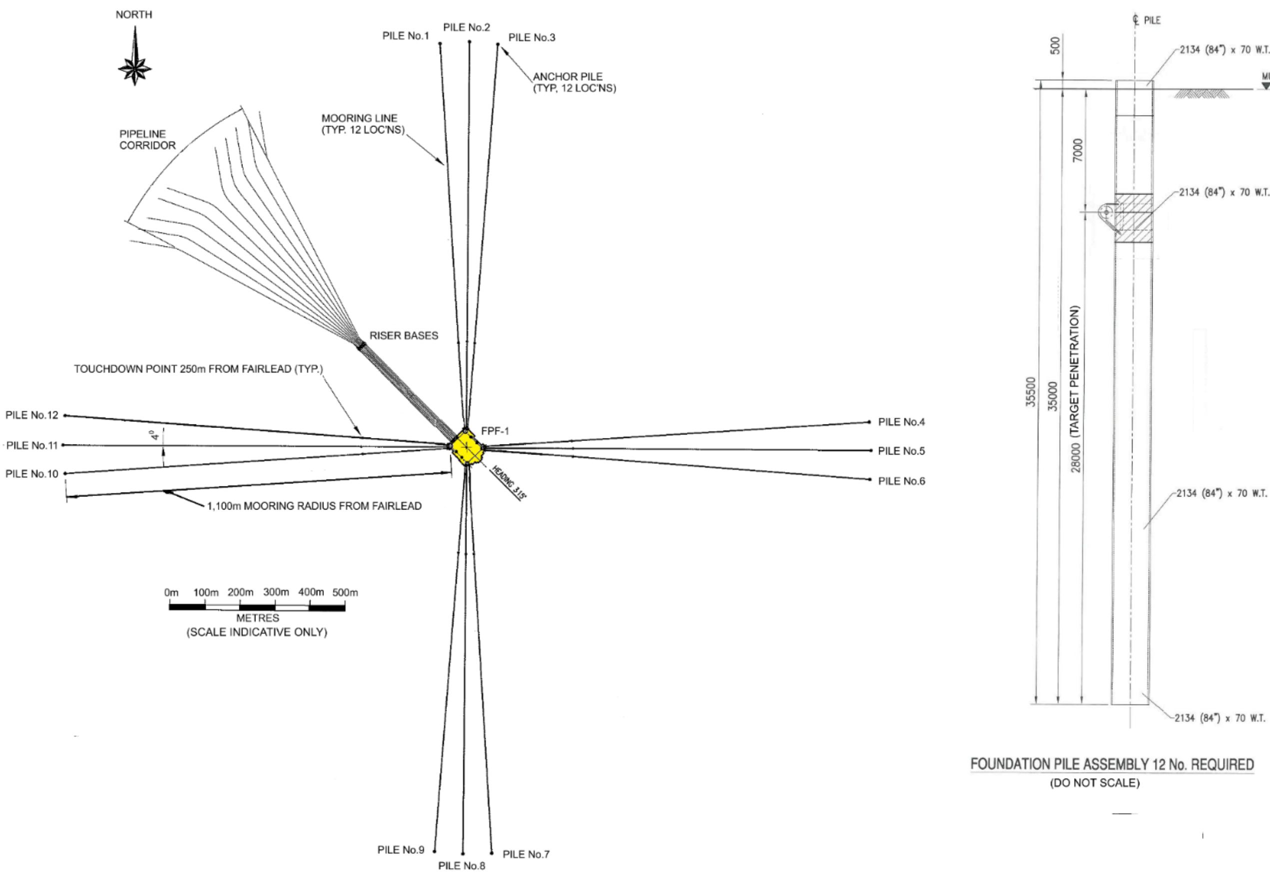


Figure 2.3.2: Stella FPF-1 – mooring anchor pattern and anchor pile profile

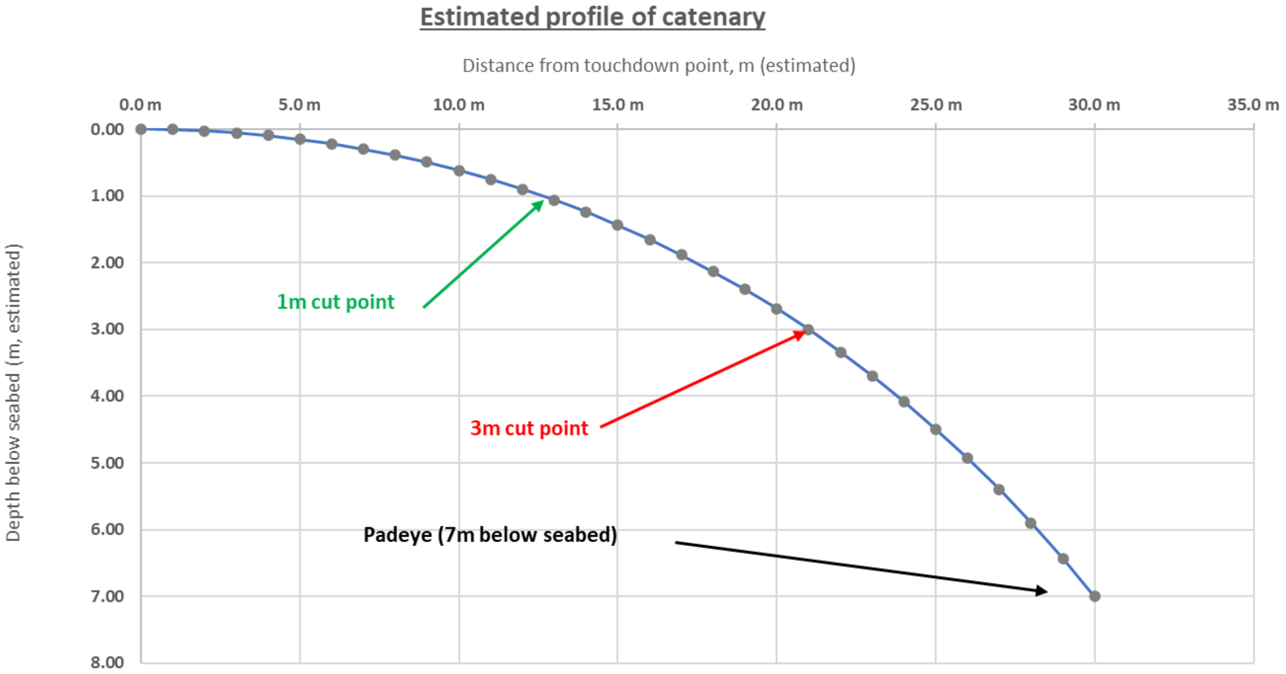


Figure 2.3.3: Stella FPF-1 – estimated profile of catenary below seabed

2.3.1 Decommissioning options

The offshore oil and gas decommissioning guidance notes [2] that certain aspects of mooring systems are identified as subsea installations (e.g. mooring lines), and are considered to fall within the definition of “steel installation” for the purposes of OSPAR Decision 98/3, such that they should be fully removed. It is a policy objective that a clear seabed is left, such that any element of moorings which are not buried, should be removed.

Two options are considered in this CA in relation to the ~33 m of the mooring lines buried at the approach to anchor pile padeyes at 7 m depth below seabed. These are:

- **Removal to 1 m below seabed** – This would involve excavating each mooring line in the lower chain section locally to 1.5 m below seabed using tracked mechanical dredging equipment or similar, to enable access to cut the chain 1 m below seabed. Deposited rock would then be used to backfill the excavation.
- **Removal to 3 m below seabed** – This would involve excavating each mooring line in the lower chain section locally to 3.5 m below seabed using tracked mechanical dredging equipment or similar, to enable access to cut the chain 3 m below seabed. Deposited rock would then be used to backfill the excavation.

The anchor piles will be cut internally at 3 m below seabed in accordance with the offshore decommissioning oil and gas guidance notes [2] unless difficulties are encountered, in which case OPRED will be consulted. Therefore, decommissioning of the piles is not a subject of this CA.

Table 2.3.1: Mooring line dimensions

Aspect	-3 m depth of severance	-1 m depth of severance
Length recovered per ML (1,145.5m)	1,131.0 m	1,123.0 m
O/A length recovered (13,746 m)	13,576 m	13,471 m
O/A mass recovered (3,047 Te)	2,997 Te	2,967 Te
O/A mass left *in situ*	50 Te	80 Te
O/A mass recovered as percentage of total	99.9%	99.8%
ANGLE OF REPOSE 50 DEG		
O/A estimated volume of excavated material[1, 2]	12 x 47 = 564 m^3	12 x 6 = 72 m^3
O/A estimated volume of disturbed material	Same as excavated material	Same as excavated material
O/A area of seabed impacted (assume 0.2m high berm)	564 / 0.2 = 2,820 m^2	72 / 0.2 = 360 m^2
O/A estimated quantity of rock required (excavation only)	12 x 70.5 = 846 Te	12 x 9 = 108 Te
O/A estimated quantity of rock required (berm)[3]	50% x 2,820 x 0.2 = 423 Te	50% x 360 x 0.2 = 54 Te
O/A estimated quantity of rock required	846 + 423 = 1,269 Te	108 + 54 = 162 Te

NOTE

1. Based on angle of repose for stiff clays. Firm to stiff to very stiff clay would typically have an angle of repose of 50 degrees.
2. Area of seabed affected by deposition of excavated material indicative only as this depends on the (average) height of the distributed material. In this instance is has been assumed that an average height of 0.2 m would result in an area of between 360 m^2 and 2,820 m^2 being impacted.
3. Assuming a bulk density of rock (e.g. crushed granite) in air of 1,500 kg/m^3. Note that it is not possible to estimate with certainty the volume of rock required to remediate areas of the seabed outside of the excavation where lumps of excavated material have been dumped on the seabed, but clearly the amount of rock required would increase with the volume of excavated material. For comparison purposes a quantity even out the lumps (say 50%) x covered area x berm height has been calculated.
4. All seabed disturbances will result in direct physical effects which may include mortality as a result of physical trauma, smothering and re-suspended sediment. Less impact and disturbance to the seabed would likely be preferred from an environmental perspective. The 1 m option would result in a much smaller area of disturbed seabed.

Figure 2.3.4 presents an indication of the overall area affected by deposition of excavated material for 12x mooring lines for the -3 m option. The total area affected is calculated by dividing the volume (47 m^3 for each ML) by the (average) berm height (0.1 m, 0.2 m, etc) and adding the area of excavation. Volume of rock needed to backfill the excavation =12 x 70.5 = 846 Te. The equivalent volume of rock to remediate lumpy clay berms (per ML) would equivalent to 50% x 2,820 x 0.2 x 1,500 kg/m^3 = 423 Te. Total volume of rock 846 + 423 = 1,269 Te. Note that due to the rudimentary nature of the excavation operations involved, sea currents, etc, the calculation is indicative only.

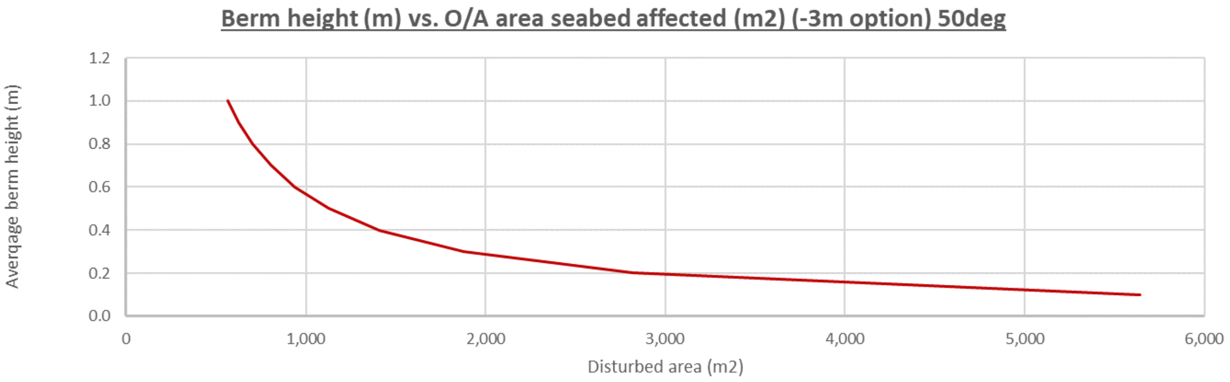


Figure 2.3.4: Mooring line recovery berm height vs. O/A area affected (-3 m option, 50 deg)

In Figure 2.3.5, presents an indication of the overall area affected by deposition of excavated material for 12x mooring lines for the -3 m option. The total area affected is calculated by dividing the volume (6 m^3 for each ML) by the (average) berm height (0.1 m, 0.2 m, etc) and adding the area of excavation. Volume of rock needed to backfill the excavation =12 x 9 = 108 Te. The equivalent volume of rock to remediate lumpy clay berms (per ML) would equivalent to 50% x 360 x 0.2 x 1,500 kg/m^3 = 54 Te. Total volume of rock 108 + 54 = 162 Te. Note that due to the rudimentary nature of the excavation operations involved, sea currents, etc, the calculation is indicative only.

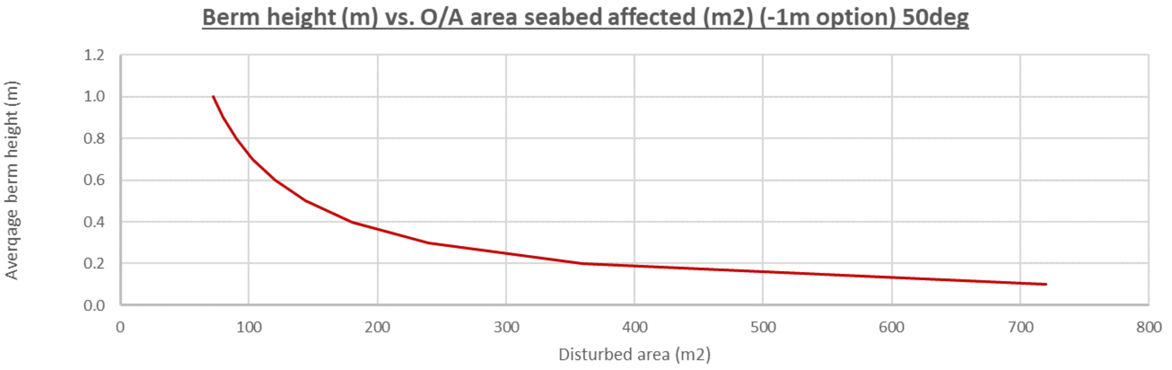
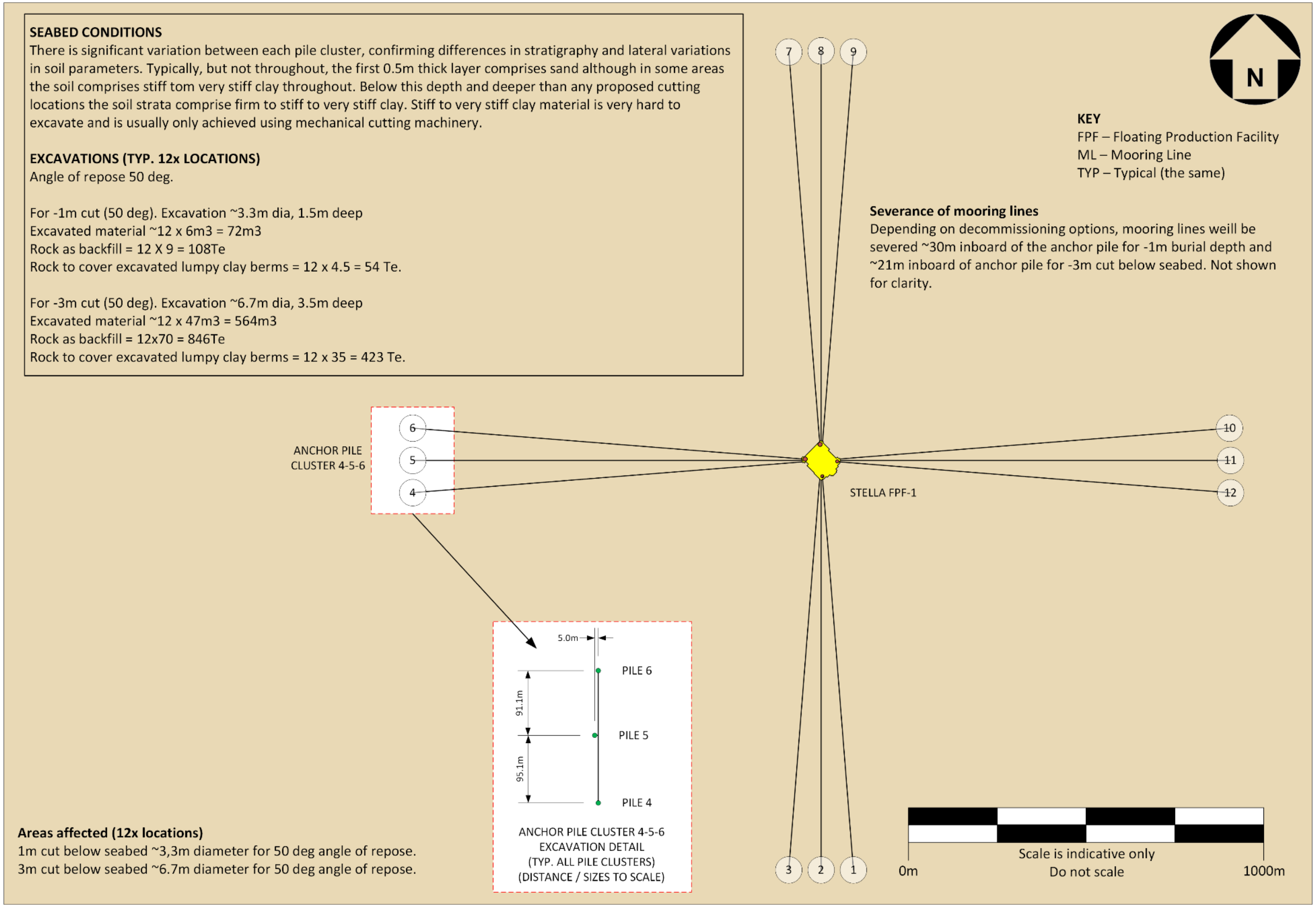


Figure 2.3.5: Mooring line recovery berm height vs. O/A area affected (-1 m option, 50 deg)

A summary of excavation requirement for both the removal options is presented in Figure 2.3.6 below.



SEABED CONDITIONS
There is significant variation between each pile cluster, confirming differences in stratigraphy and lateral variations in soil parameters. Typically, but not throughout, the first 0.5m thick layer comprises sand although in some areas the soil comprises stiff tom very stiff clay throughout. Below this depth and deeper than any proposed cutting locations the soil strata comprise firm to stiff to very stiff clay. Stiff to very stiff clay material is very hard to excavate and is usually only achieved using mechanical cutting machinery.

EXCAVATIONS (TYP. 12x LOCATIONS)
Angle of repose 50 deg.

For -1m cut (50 deg). Excavation ~3.3m dia, 1.5m deep
Excavated material ~12 x 6m3 = 72m3
Rock as backfill = 12 X 9 = 108Te
Rock to cover excavated lumpy clay berms = 12 x 4.5 = 54 Te.

For -3m cut (50 deg). Excavation ~6.7m dia, 3.5m deep
Excavated material ~12 x 47m3 = 564m3
Rock as backfill = 12x70 = 846Te
Rock to cover excavated lumpy clay berms = 12 x 35 = 423 Te.

KEY
FPF – Floating Production Facility
ML – Mooring Line
TYP – Typical (the same)

Severance of mooring lines
Depending on decommissioning options, mooring lines weill be severed ~30m inboard of the anchor pile for -1m burial depth and ~21m inboard of anchor pile for -3m cut below seabed. Not shown for clarity.

Areas affected (12x locations)
1m cut below seabed ~3,3m diameter for 50 deg angle of repose.
3m cut below seabed ~6.7m diameter for 50 deg angle of repose.

Figure 2.3.6: Mooring line recovery - excavation and remediation

2.4 Assumptions, limitations, and gaps in knowledge

The most significant assumptions, limitations and knowledge gaps relating to the comparative assessment are listed below. In addition, it should be noted that the presentation of the different categories of risks for comparison has required a degree of engineering judgement, which includes the following technical assumptions:

- A purely qualitative approach has been taken requiring a degree of judgement. Since most impacts are related to area of seabed impacted, duration of works and vessel time, this is deemed appropriate.
- The profile of the catenary has been estimated.
- Note that due to the rudimentary nature of the excavation operations, sea currents, etc, the impacted area calculations should be treated as indicative only but sufficient to compare the impacts of the options on the seabed.
- Ithaca is not aware of any fishing gear snagging reports. Any potential snag hazards or snagging incidents are recorded via Kingfisher Information Services on FishSAFE (www.fishsafe.eu).

The following legacy assumptions have also been made:

- ‘As-built’, debris and environmental surveys would be required following completion of decommissioning activities. These activities would be common to both options.
- The cut ends of a mooring chain (part of the overall mooring ‘line’) being left *in situ* and buried to less than 3 m below the seabed would be subject to at least three legacy burial surveys, although in practical terms taking this approach would need to be agreed with OPRED.
- The cut ends of a mooring chain being left *in situ* and buried to a depth of 3 m or more below the seabed would not be subject to legacy burial surveys, although in practical terms taking this approach would need to be agreed with OPRED.
- The seabed sediment type would be such that any spoil heaps created during any decommissioning operations could present a snagging hazard should remediation not be completed satisfactorily. This would need to be verified by a trawl sweep.
- In the long term, assuming the size and profile or the resulting rock berm is suitable, deposited rock remaining *in situ* used to backfill the excavations and for covering the lumpy clay berms would not present a snagging hazard.
- The impact of the procurement of any new materials such as fabricated items or mining of new rock is ignored.
- Impact on commercial activities (fishing in particular) is proportional to the duration of vessel activity. The impact would be negligible while the decommissioning works are being carried out.
- Societal benefits and vessel associated environmental impacts and risks are assumed to be proportional to vessel duration.
- Only a high-level comparison of what differentiates the costs is used.

3. COMPARATIVE ASSESSMENT METHOD

3.1 Method

The assessment is qualitative, and considers five criteria for both the short-term decommissioning activities and the longer-term for ‘legacy’ related activities. The criteria were: technical feasibility with three sub-criteria, safety related risks with three sub-criteria, environmental with five sub-criteria, societal effects with three sub-criteria and cost.

No scores have been determined. However, risk matrices have been used to determine if the planned and unplanned impacts would be for example broadly acceptable, possibly acceptable, unlikely to be acceptable or not acceptable. Cells coloured red indicate high risk, high impact, and less desirable outcomes. Green coloured cells indicate less risk, less impact, and more desirable outcomes. Cells coloured orange sit in-between red and green and may or may not be less, or more, desirable. It should be noted that societal assessment looked at beneficial outcomes as well as detrimental outcomes. Where a comparison of options varies by shades of green rather than by red or orange it means there is little to choose between the options.

High costs also attract a ‘less desirable outcome’; the cost of implementing a decommissioning option is compared against the others. A relatively high cost therefore would be coloured red or orange whereas a relatively low cost would be coloured green. Costs are assessed in relation to the cheapest cost. A red coloured cell would indicate that the incremental increase in cost would be an order of magnitude greater (i.e. more than 10x greater) than the cheapest cost.

Table 3.1.1: Comparative Assessment method – criteria & sub-criteria

Criteria	Definition	Criteria - short-term & legacy, UNO	Comments
Technical	A technical evaluation of the complexity of a job that can be expected to proceed without major consequence or failure if it is adequately planned and executed.	Risk of project failure. Technological challenge. Technical challenge	The risk of project failure given the technical and technological challenges. The technical challenge considers the viability of a task should the technology be available. The technological challenge concerns the availability of specific technologies to perform a task and the extent of research & development that may be required. The technical aspects of replenishing excavated material and the deposition of rock could be a consideration.
Safety	An assessment of the potential health and safety risk to people directly or indirectly involved in the programme of work offshore and onshore, or who may be exposed to risk as the work is carried out.	Health and safety risks for project personnel carrying out decommissioning activities offshore. Residual risks to marine users on successful completion of decommissioning. Safety risks for project personnel engaged in carrying out decommissioning activities onshore.	Typical offshore hazards might include loss of dynamic positioning, sudden movements during decommissioning works, dropped objects, collision between vessels, dealing with residual quantities of hazardous materials. Typical diving hazards might include, loss of heat or air supply, trapped cables and hoses, trapped limbs. After decommissioning has been completed typical hazards could relate to exposed mooring chains leading to a possibility of snagged fishing nets. Consider effects of a change in scour patterns due to the deposition of rock (more relevant to SNS than CNS). Typical onshore hazards might include dealing with residual hazardous materials, onshore cutting, sudden movements or dropped objects.
Environmental	An assessment of the significance of the risks / impacts to the environmental receptors because of operational activities or the legacy aspects.	Energy and emissions to atmosphere. Effect on seabed: Seabed disturbance and area affected. Permanent disturbance more significant than temporary disturbance. Effect on water column: Liquid discharges to sea Liquid discharges to surface water Noise. Waste creation and use of resources such as landfill. Recycling and replacement of materials.	The assets are located outside of environmentally sensitive areas, so the dominant environmental criteria would likely be the effect on the seabed, the amount and type of waste recovered, or replacement materials needing to be manufactured to compensate for materials left *in situ*. The mooring system(s) are not within a SAC or an MPA.
Societal	Assesses the significance of the work on societal activities, including offshore and	Effects on commercial activities e.g., fishing. Employment.	Decommissioning projects involve work that is generally temporary in nature. On its own this type of work might typically lead to an extension

Table 3.1.1: Comparative Assessment method – criteria & sub-criteria

Criteria	Definition	Criteria - short-term & legacy, UNO	Comments
	onshore activities associated with the complete programme of work for each option and the associated legacy impact. This includes all the “direct” societal effects (e.g., employment on vessels undertaking the work) as well as “indirect” societal effects (e.g., employment associated with services in the locality to onshore work, accommodation, etc.).	Communities or impact on amenities.	of employment rather than new employment. Any impact on commercial fishing offshore is temporary and of relatively short duration.
Economics or cost	Difference in cost.	Difference in cost compared for like-for-like activities.	In the short-term it is cheaper to do nothing, but this needs to be compared with the need for future surveys and potential remedial work.

4. COMPARATIVE ASSESSMENT DISCUSSION

4.1 Technical considerations

The risk of outright failure for either option is low but increasing for the -3 m option because the local seabed conditions would likely render remediation of the excavated material more problematic due to the increased volume of material being excavated.

Although tracked seabed cutting/excavating equipment and MFE are a proven technologies, the backfilling of excavations has only really been used for the installation of pipelines when backfilling during trenching operations where the seabed comprises mostly of sandy or silty material. Where excavations would be needed in areas of stiff to very stiff clays the pipelines are not trenched but would be laid on the surface of the seabed and buried under rock. This means that the only viable option would be to deposit rock into the excavated area. When excavating firm to stiff to very stiff clay to access and cut the mooring chain, the excavated material would be cut and removed as solid lumps of material deposited into the seabed using tracked cutting/excavation equipment. As the volume of excavated material increases (564 m^3 for the -3 m option and 72 m^3 for the -1 m option) it becomes increasingly unlikely that full remediation would be successful without an intervention, and deposited rock would be required to remediate the affected area, both within the excavation and outside where the excavated material has landed on the seabed. A smaller and less extensive berm height would be easier to remediate. Therefore, the approach should be to reduce the volume of excavation to the bare minimum. It is also worth noting that tracking devices become less accurate with depth. This means that for the -3 m option there is the possibility that the position of the mooring chain is not located accurately within the seabed, leading to a larger volume of seabed material being excavated than would otherwise be necessary. This needs to be carried out twelve times, once for each of the lower mooring chains.

For those locations where the sandy silty soils can be slurrified to allow the chain to sink and become buried no excavations would be required for the -1 m burial option. For situations where the final section of mooring line (i.e. the 120mm end chain) is buried in firm to stiff to very stiff clay the seabed will need to be physically cut, leading to lumps of excavated material being deposited on the seabed.

Post-decommissioning surveys will be required. Legacy surveys will be required to confirm extent of burial for the -1 m option but would unlikely be required for the -3 m option.

4.2 Safety considerations

During decommissioning operations there would be no discernible difference to the safety of mariners as the work would be executed using standard processes and procedures for vessel movements.

Both options would be executed using remotely operated equipment. The risk to Potential Loss of Life for the -3 m option would be slightly higher due to the increased vessel use and threat of collisions at sea, but standard procedures, procedures and protocols would be used to manage vessel movements. Therefore, in this regard the difference between the options is negligible. All equipment would be remotely operated and deployed using standard processes and procedures, but the vessels would be operating for longer for a cut at -3 m.

Any material recovered to shore would we dealt with using existing procedures and protocols. The difference in the quantities of material being handled would be relatively small (30 Te more for the -3 m option c.f. 3,047 Te overall, refer Table 2.3.1) so there is no discernible difference between the options from a safety perspective when considering the management of materials onshore.

As both options would result in the ends of the mooring chains being buried, there would be no residual snagging risk from the ends of the chains for either option. There may be small snagging risk associated with any berm material being left on the seabed but once this had been remediated – most likely with rock where stiff lumps of clay remain on the seabed, trawl sweeps would be conducted to confirm that the remedial work had been completed successfully.

4.3 Environmental considerations

Typically mooring lines would only be recovered using an AHV. In firm to stiff to very stiff soil conditions the -1 m option would involve the deployment of additional vessels (a CSV, estimated 10 days, and FPV, estimated 10 days). The -3 m option would also involve the deployment of such vessels (a CSV, estimated 13 days, and FPV, estimated 10 days) for slightly longer. In both cases the additional vessels would need to be mobilised specifically for the decommissioning works - to excavate to the required cutting depth, to replenish the excavation with deposited rock and to remediate those areas where lump clay berms have been deposited on the seabed. The -3 m option would result in slightly more energy and emissions.

The -3 m option would have much more of an impact on the seabed, both in terms of quantity of excavated material as well as area of seabed covered by lumps of the excavated material. As it depends on the dispersal of the excavated material, the area of seabed covered by excavated material is more difficult to quantify but in any event it would be significantly more than the area affected by the -1 m option. Please refer section 2.3 for an indication of the differences. Furthermore, in areas where firm to stiff to very stiff clay is present, both options would require the excavations to be back filled, and the local (lumpy clay) seabed would need to be remediated using a hard substrate (rock) that is not native to the area.

4.4 Societal considerations

Both options would involve working in the field, with the -3 m option requiring slightly more vessel time. However, vessel movement procedures and protocols would be used, and so there should be minimal disturbance to mariners transiting or working in the area.

With more vessel time, the -3 m option would impact slightly more positively on employment but the effect on employment would result in the continuation of existing jobs rather than lead to the creation of new jobs. For either option the significance of a positive impact on employment is low.

The port and the disposal site have yet to be established. However, they would be existing sites which are used for oil and gas activities and they would hold the permits necessary for waste management. The communities around the port and the waste disposal sites will have adapted to the types of activities required and the decommissioning activities associated with this project would be an extension of the existing situation. Therefore, the effect on communities is not considered a significant differentiator between options.

4.5 Cost considerations

Ordinarily it can be expected that mooring lines would be recovered using only an AHV. However, if firm to stiff to very stiff clays are to be encountered, both options will require the deployment of a CSV and FPV in addition to the AHV. These vessels would be mobilised specifically to address the need to excavate to the required depth of cut, replenish the excavation, and remediate the resulting lumpy clay berms with deposited rock.

On this basis, it is estimated that the incremental cost for the -3 m option would be ~£4,155,000. The reason for this is that as a standalone scope the CSV (13 days) and FPV (10 days) would need to be mobilised specifically for the excavation, cutting and backfill works. For situations where stiff to very stiff clays are expected the -1 m option would also be executed as a standalone scope with CSV (10 day) and FPV (10 days). Slightly less time for the CSV because the -1 m option would require less excavation and remediation work. There is little difference in FPV time because rock dumping capacity per hour far exceeds the volumes required at each location. The incremental increase for the -1 m option which would be ~£2,750,000. The incremental increase in cost will depend on the vessel rates committed to at the time, but on the basis of the foregoing the incremental cost of the -1 m option would be ~66.2% of the incremental increase for the -3 m option. This means that the incremental increase in cost for the -3 m option would be more than the cost of the -1 m option, but less than twice as much.

It is likely that any future burial surveys would be conducted as part of a wider survey campaign, in which case the incremental legacy costs associated with the -1 m option would not be significant.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

There is a significant difference between the options from a technical and environmental perspective. The volume of excavation and requirement for backfill material is significantly greater for the cutting at -3 m option; but both options would require remediation in the form of deposited rock – as backfill to the excavation as well as to remediate the local seabed where lumps of clay from the excavation had been deposited. More vessel time and energy would be required for the -3 m option compared to the -1 m option although the difference is not significant. Disturbance to the seabed for the -1 m option would generally be of just less than an order of magnitude lower (i.e. slightly less than 10x lower).

From a health and safety perspective there is little to differentiate the options. The decommissioning works for both options would be conducted using remotely operated equipment. There would be a marginally higher threat posed by PLL for the -3 m option simply due to the slightly longer vessel time and a slightly increased possibility of a vessel collision. Mitigations involve use of standard procedures and protocols and these would probably render the difference between the options as being insignificant. The nature of the seabed material (stiff to very stiff clay) is such that before remedial works had been completed, a potential snagging risk could remain from any excavated material remaining on the seabed. However, once remedial works - involving deposition of rock in the excavated areas and to cover the lumpy clay berms had been completed no snagging risk would arise from the lumpy soil berms or the severed mooring chains for either option.

The difference[3] between the -3 m and -1 m options in material being brought to shore for recycling is minimal, so there would be little to choose from a waste perspective.

There is little to choose between the options from a commercial and employment perspective. Any associated work would be extension of existing workloads rather than a creation of new and sustainable employment.

Finally, the cost of the -3 m option would be higher than the -1 m option, but less than twice as much. Both options would involve the deployment of CSV and FPV in addition to a AHV to execute the work. The -3 m option would need slightly more CSV time because of the higher volume of work. There is little to choose in FPV time because of the large dumping capacity of the such vessels in relation to the amount of rock required. Future burial surveys for the -1 m option would be conducted as part of a wider survey campaign and so would not be significant.

5.2 Recommendations

Excavate and cut the lower chain section of the mooring line such that it will be cut 1 m below the seabed on the basis that no snagging risk would remain, and the environmental impact – particularly to the seabed, would be minimised.

Proposals for monitoring and remediation of any potentially exposed sections of the cut chain ends will be explained in the decommissioning Close Out Report following completion of decommissioning activities and a post-decommissioning survey.

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[3] 30 Te vs. 3,047 Te overall. The -3 m option would result in the recovery of slightly more material than the -1 m option

6. REFERENCES

[1] Ithaca (2024) Decommissioning Programmes for Stella FPF-1, Moorings and Riser Systems, STE-LLA-LAPT-DE-PGS-0001.

[2] OPRED (2018) Decommissioning of Offshore Oil and Gas Installations and Pipelines, November 2018.

APPENDIX A MOORING LINE CA TABLES

Table A.1: CA operational summary table

Main criteria (operational)		Mooring lines cut -3 m	Mooring lines cut -1 m
Technical feasibility	Technical feasibility of offshore activities; risk of project failure	It would be technically feasible to excavate the seabed to cut the mooring line at 3 m below seabed without the risk of project failure; this type of work has been done before albeit to a shallower depth of burial. Risk of project failure is low, as contingency planning could be put in place.	It would be technically feasible to excavate the seabed to cut the mooring line at 1 m below seabed without the risk of project failure; this type of work has been done before. The -1 m option is preferred on the basis of significantly smaller volumes of material involved.
	Technological challenge (is there technology available)	Subsea mechanical cutting excavators are a proven technology but backfill has only really been used as part of a pipeline trenching process in sandy or silty soil conditions. Although backfilling of lumpy clay material is unlikely to be successful, the area of seabed with lump clay berms could be remediated using deposited rock. The deposition of rock would be conducted using a FPV that is a proven technology.	Subsea mechanical cutting excavators are a proven technology. Although backfilling of lumpy clay material is unlikely to be successful, the area of seabed with lump clay berms could be remediated using deposited rock. The deposition of rock would be conducted using a FPV that is a proven technology. The -1 m option is preferred on the basis of smaller volumes of material involved.
	Technical challenge (can the work be done?)	It would be technically feasible to mechanically dredge the seabed, but not straightforward to backfill with original clay material. Lumpy clay berms would need to be remediated with rock. Difficulty increases with volume (564 m^3 firm to stiff to very stiff clay, using angle of repose 50 deg.	It would be technically feasible to mechanically dredge the seabed, but not straightforward to backfill with original clay material. Lumpy clay berms would need to be remediated with rock. Difficulty increases with volume (72 m^3 firm to stiff to very stiff clay, using angle of repose 50 deg.
Health & safety risk	To offshore project personnel	Dredging and cutting of mooring lines -3 m would be done using remotely operated equipment. The equipment would be deployed using standard processes and procedures, but the vessel would be on location for slightly longer for a cut at -3 m.	Cut the chains at surface and bury the cut ends of the chains to -1 m. or excavate the seabed sufficient to cut the chains at 1 m below seabed. As for -3m option, this would be done using remotely operated equipment. The equipment would be deployed using standard processes and procedures. The vessel would be on location for marginally less time than for -3m.
	Onshore project personnel	Any material recovered to shore (13,576.1 m, 99.9%) would be recycled dealt with as part of existing procedures and protocols. No discernible difference.	Any material recovered to shore (13,471.4 m, 99.8%) would be recycled dealt with as part of existing procedures and protocols. No discernible difference.

Table A.2: CA operational summary table cont'd/…

Main Criteria (operational)		**Mooring lines cut -3 m**	**Mooring lines cut -1 m**
Environmental impact (planned)	Atmospheric emissions (E&E)	CSV (13 days) & FPV (10 days) required in addition to AHV time. Anchor Handling Vessels will be used to remove the mooring lines. In addition to an AHV, a construction support vessel (CSV) or similar and a fall pipe vessel (FPV) will be required. These would need to be mobilized specifically for the chain cutting operation and subsequent remedial works.	CSV (10 days) & FPV (10 days) required in addition to AHV time. Anchor Handling Vessels will be used to remove the mooring lines. In addition to an AHV, a construction support vessel (CSV) or similar and a fall pipe vessel (FPV) will be required. These would need to be mobilized specifically for the chain cutting operation and subsequent remedial works.
	Seabed	Difficulty increases with volume (564 m^3 in stiff to very stiff clay, using an angle of repose 50 deg). Note that accuracy of tracking devices decreases with depth below seabed leading to an uncertainty in the volume of excavation required. Rock – see legacy impact	Difficulty increases with volume (72 m^3) in firm to stiff to very stiff clay, using angle of repose 50 deg.
	Water column	The temporarily disturbed volume of seabed sediment will be significantly more than that associated with a -1 m cut. Disturbed sediment will initially be dispersed into the water column.	The temporarily disturbed volume of seabed sediment will be significantly less than that displaced for a -3 m cut will initially be dispersed into the water column.
	Waste	Mass of material recovered: 2,997 Te (99.9%) Mass of material left *in situ*: 50 Te. (0.1%) No discernible difference (30 Te) between options.	Mass of material recovered: 2,967 Te (99.8%) Mass of material left *in situ*: 80 Te (0.2%) No discernible difference (30 Te) between options.
	Affect on objectives of protected areas	INFORMATION ONLY The impact of the works associated with both mooring line decommissioning options will not affect any Special Protection Areas, Special Areas of Conservation or Marine Protected Area, as they are all too distant. The impact of the works on benthic fauna, including pennatulid sea pens, and habitats such as sea pens and burrowing megafauna, is considered in the DP. Note, however, that the scale of the works associated with the option to remove the moorings to 3 m below seabed could impact a wider area of seabed both directly, and indirectly through smothering and remediation.	

Table A.3: CA operational summary table cont'd/…

Main Criteria (operational)		Mooring lines cut -3 m	Mooring lines cut -1 m
Societal effect	Commercial activities	The impact of decommissioning vessel traffic on commercial activities such as fishing would be greatest for complete removal. The transit of work vessels and their presence in the field would be managed using existing procedures and protocol. Despite there being slightly more vessel traffic (AHV, CSV, FPV) for this option, the difference between the two options is not significant.	The impact of decommissioning vessel traffic on commercial activities such as fishing would be greatest for complete removal. The transit of work vessels and their presence in the field would be managed using existing procedures and protocol. Despite there being slightly less vessel traffic (AHV, CSV, FPV) for this option, the difference between the two options is not significant.
	Employment	Cutting the mooring lines 3 m below seabed will result in an extension to existing jobs rather than create new jobs.	Cutting the mooring lines 1 m below seabed will result in an extension to existing jobs rather than create new jobs.
	Communities	For any ports and disposal sites the any increase in work would be nominally larger for an increase in quantity of material recovered to shore for -3 m.	For any ports and disposal sites the any increase in work would be nominally less for the slightly smaller quantity of material recovered to shore for -1 m.
Cost	Incremental cost difference	The incremental cost for cutting the chains to -3 m would be more expensive than excavating and then cutting/burying the chains to 1 m below seabed.	Anchor Handling Vessels would be used to remove the mooring lines. The -3 m option would be less than 2x more expensive than the -1 m option.

Table A.4: CA legacy summary table

Main criteria (legacy)		Mooring lines cut -3 m	Mooring lines cut -1 m
Technical feasibility	Technical feasibility of offshore activities	Legacy surveys unlikely to be required.	Surveys may be required. If sufficiently buried, equipment may not be able to detect the cut ends.
Health & safety risk	To offshore project personnel	Legacy surveys unlikely to be required.	Seabed surveys may be required, but from an HSE perspective these are usually performed with no issues.
	To mariners, fishermen	Once the mooring chains have been cut and buried there would be no snagging hazards once the ends had been buried.	Once the mooring chains have been cut and buried there would be no snagging hazards once the ends had been buried.
		No remedial works are expected in future once the decommissioning works have been completed. The larger volume of excavated sediment material will be harder to remediate, although verification of a clear seabed will be done using a trawl sweep. The presence of the larger quantity of excavated material and rock on the seabed could be a factor when considering the potential for future snagging risk.	No remedial works are expected in future once the decommissioning works have been completed. The smaller quantity of excavated material and rock used for remediation on the seabed could be less of a factor when considering the potential for future snagging risk.
	Onshore project personnel	Legacy surveys unlikely to be required.	Legacy surveys may be required. To have to perform surveys at all means that vessel would need to be mobilised. From an HSE perspective such activities are (usually) performed without issue
Environmental impact (planned)	Atmospheric emissions (E&E)	Legacy surveys unlikely to be required.	Should seabed surveys be required, atmospheric emissions will arise.
	Seabed	Legacy surveys unlikely to be required. No difference.	Any seabed surveys would be non-intrusive. No difference.
		Backfill of excavated material not practical. Excavation will be backfilled using a hard substrate (rock): 12 x 70.5 = 846 Te. Berms will be remediated using 423 Te rock. Sub-total of rock required is 1,296 Te.	Backfill of excavated material not practical. Excavation will be backfilled using a hard substrate (rock): 12 x 9 = 108 Te. Berms will be remediated using 54 Te. Sub-total of rock required is 138 Te.
	Water column	Legacy surveys unlikely to be required.	Any disturbance to the water column would be minimal. No discernible difference between the options.
	Waste	N/A	N/A
Societal effect	Commercial activities	Legacy surveys unlikely to be required.	Minimal impact on commercial activities during transit and in the field. Managed by procedure and protocols. No discernible difference between the options.
	Employment	Legacy surveys unlikely to be required.	Any surveys would result in an extension to existing jobs rather than create new jobs. No discernible difference between the options.
	Communities	Legacy surveys unlikely to be required.	For any ports the any increase in vessel activity in the port would be nominal for survey related activities. No discernible difference between the options.
Cost	Incremental cost difference	Legacy surveys unlikely to be required.	Any future surveys will attract cost.