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Dunlin Alpha Substructure Decommissioning Environmental Appraisal Report

APPROVAL STATUS (To be completed by FEL)		**SIGNED**	**DATE**
1	Not Approved		
2	Approved Subject To Comments		
3	Approved	Peter Lee	24 September 2021
4	For Information Only		

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A03	30/09/2019	Issued for Use	HB	KM	KM
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This Dunlin Alpha Substructure Decommissioning Environmental Appraisal Report is a supporting document to the Dunlin Alpha Substructure Decommissioning Programme alongside the Comparative Assessment Report and other documentation, available on Fairfield Energy Limited's website (http://www.fairfield-energy.com).

Contents

Acronyms

AIS	Automatic Identification System
ALARP	As Low as Reasonably Practicable
ANDOC	Anglo Dutch Offshore Concrete
AORP	Attic Oil Recovery Project
AtoN	Aid to Navigation
BAOAC	Bonn Agreement Oil Appearance Code
BEIS	Department for Business, Energy and Industrial Strategy
BODC	British Oceanographic Data Centre
BTEX	Benzene, Toluene, Ethylbenzene and Xylene
CCTR	Cell Contents Technical Report
CGBS	Concrete Gravity Base Substructure
CO_2	Carbon Dioxide
DECC	Department of Energy and Climate Change (now BEIS)
DFGI	Dunlin Fuel Gas Import
DP	Decommissioning Programme
DPI	Dunlin Power Import
DSV	Dive Support Vessel
EA	Environmental Appraisal
EBS	Environmental Baseline Survey
EIA	Environmental Impact Assessment
EIF	Environmental Impact Factor
EMS	Environmental Management System
EPS	European Protected Species
EU	European Union
EUNIS	European Nature Information System
FEL	Fairfield Energy Limited
Helideck	Helicopter deck
HLV	Heavy Lift Vessel
HRA	Habitats Regulations Assessment
HSE	Health and Safety Executive
ICES	International Council for the Exploration of the Sea
IMO	International Maritime Organisation
IOEM	Invert Oil Emulsion Mud
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organisation for Standardisation
ITOPF	International Tanker Owners Pollution Federation
IUCN	International Union for Conservation of Nature
JNCC	Joint Nature Conservation Committee
KGA	Key Geodiversity Area
LAT	Lowest Astronomical Tide
LoD	Limit of Detection
LSA	Low Specific Activity
LTOBM	Low Toxicity Oil Based Mud
MCDA	Multi Criteria Decision Analysis
MCZ	Marine Conservation Zone
MEMW	Marine Environmental Modelling Workbench

MMO	The Marine Management Organisation
MPA	Marine Protected Area
MSF	Module Support Frame
MSH	Make Safe and Handover
Navaid	Navigational Aid
NCMPA	Nature Conservation Marine Protected Area
NCS	Norwegian Continental Shelf
NLB	Northern Lighthouse Board
NORM	Naturally Occurring Radioactive Material
OGA	UK Oil and Gas Authority
OGUK	Oil and Gas UK
OPEP	Oil Pollution and Emergency Plan
OPF	Organic Phase Fluids
OPRED	Offshore Petroleum Regulator for Environment and Decommissioning
OSPAR	Oslo Paris Convention
PAH	Polycyclic Aromatic Hydrocarbons
P&A	Plug and Abandonment
PEC	Predicted Effect Concentration
pH	Potential hydrogen
PMF	Priority Marine Feature
PNEC	Predicted No-effect Concentration
SAC	Special Area of Conservation
SAHFOS	Sir Alister Hardy Foundation for Ocean Science
SCOS	Special Committee on Seals
SEA	Strategic Environmental Assessment
SEPA	Scottish Environmental Protection Agency
SIMOPs	Simultaneous operations
SMRU	Sea Mammal Research Unit
SNH	Scottish Natural Heritage
SOSI	Seabird Oil Sensitivity Index
SPA	Special Protection Area
THC	Total Hydrocarbon Content
TOC	Total Organic Carbon
TOM	Total Organic Matter
UK	United Kingdom
UKBAP	United Kingdom Biodiversity Action Plan
UKCS	United Kingdom Continental Shelf
UKOOA	United Kingdom Offshore Operators Association
UNESCO	United Nations Educational, Scientific and Cultural Organization
VMS	Vessel Monitoring System
WMB	Water Based Mud

Units of Measure

%	Percent
£	Pound sterling
°	Degrees
°C	Degrees Celsius
Am^3	Actual cubic meter
cm	Centimetre
ft	Feet
ft^3	Cubic feet
g/m^2	Grams per square metre
g/m^3	Grams per cubic metre
kg	Kilogram
km	Kilometre
km^2	Square kilometre
km^3	Cubic kilometre
μgg^{-1}	Microgram per gram
µm	Micrometre
m	Metre
m/s	Metres per second
m^2	Square metre
m^3	Cubic metre
NM	Nautical Miles
t	tonnes
vol%	Percentage by volume

Non-Technical Summary

Introduction

Fairfield Betula Limited and Fairfield Fagus Limited (collectively termed Fairfield), wholly owned subsidiaries of Fairfield Energy Limited, are the operators of the Dunlin, Merlin and Osprey fields (the 'Greater Dunlin Area'), located in United Kingdom Continental Shelf (UKCS) Block 211/23 of the northern North Sea. The Dunlin field lies approximately 137 km from the nearest landfall point, 197 km north east of Lerwick and 11 km from the United Kingdom (UK)/Norway median line (Figure i).

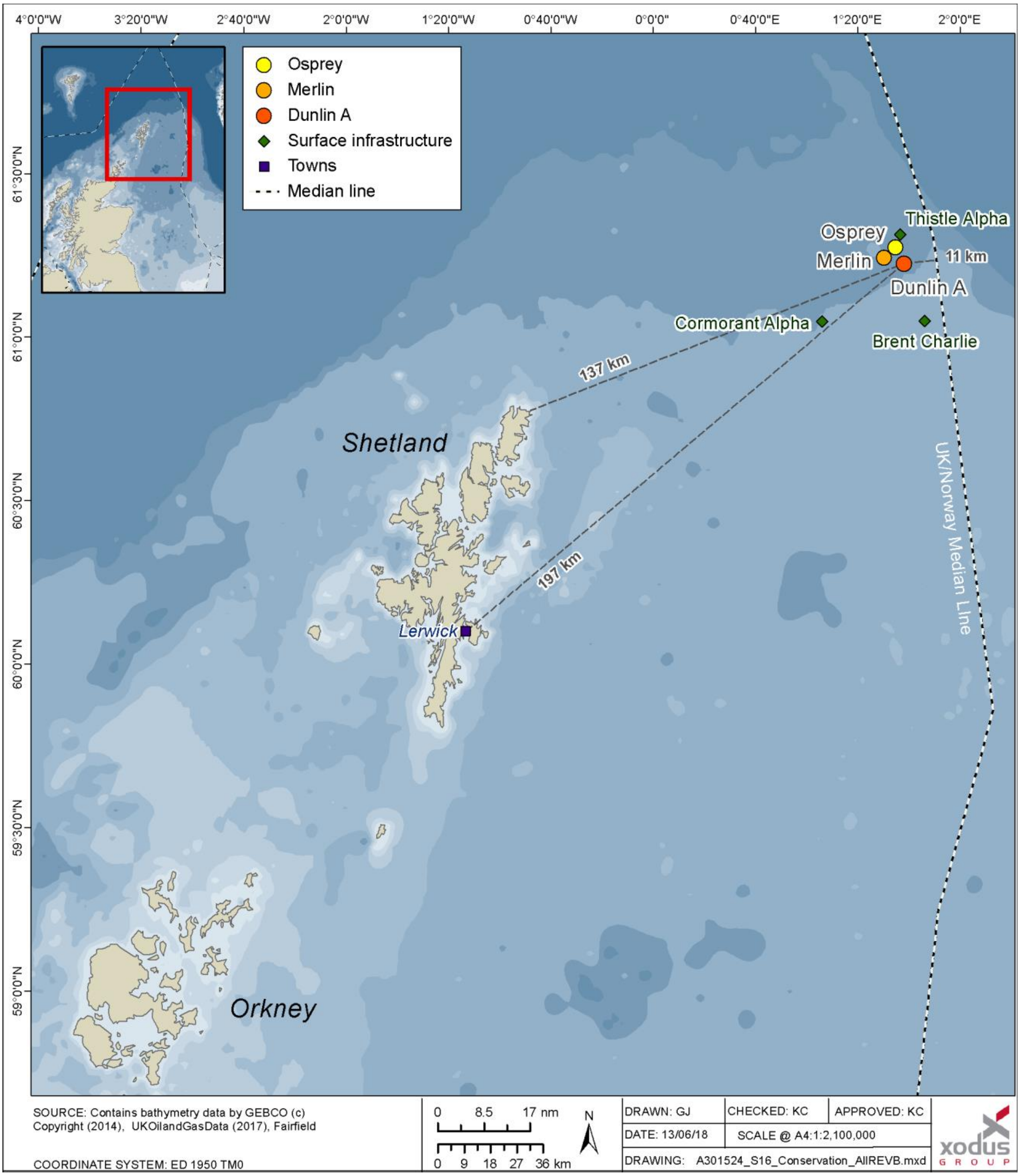


Figure i Location of the Dunlin, Merlin and Osprey fields

The Dunlin Alpha installation consists of a four-legged concrete gravity base substructure (CGBS), with modular topsides facilities supported by a steel box girder Module Support Frame (MSF). Four steel transition columns (transitions) rise above the sea surface, connecting the tops of the concrete legs to the bottom of the MSF. The installation is located in 151 m of water and is approximately 240 m high from the seabed to the top of the drilling derrick.

Production from the Dunlin, Merlin and Osprey fields ceased in June 2015, and Fairfield is now in the process of decommissioning all infrastructure associated with the Greater Dunlin Area. The decommissioning of the Dunlin, Merlin and Osprey subsea infrastructure has been considered separately from the Dunlin Alpha installation activities, and approval of the Decommissioning Programmes for that infrastructure has been approved. In addition, approval for the decommissioning of the Dunlin Alpha to Cormorant Alpha Pipeline (PL5) has also been received.

Proposals for the decommissioning of the Dunlin Alpha installation were submitted to the Department of Business, Energy and Industrial Strategy (BEIS) and subjected to formal consultation in Q3-2018. Following this consultation period, and in agreement with the Offshore Petroleum Regulator for Environment and Decommissioning (OPRED), a decision was made to split the Dunlin Alpha Decommissioning Programme (FBL-DUN-DUNA-HSE-01-PLN-0001) into two separate programmes. These are:

- Dunlin Alpha Topsides Decommissioning Programme (FBL-DUN-DUNA-HSE-01-PLN-00001-01); and
- Dunlin Alpha Substructure Decommissioning Programme (FBL-DUN-DUNA-HSE-01-PLN-00001-02).

This Environmental Appraisal (EA) report relates specifically to the activities associated with the proposed Dunlin Alpha Substructure Decommissioning Programme. This Non-Technical Summary provides an overview of the Environmental Appraisal report that has been prepared specifically for the proposed decommissioning of the Dunlin Alpha substructure. Figure ii provides an overview of the scope of the Dunlin Alpha Substructure Decommissioning Programme, which covers the following infrastructure and discharges:

- Concrete Gravity Base Substructure (CGBS):
  - Transitions;
  - Concrete legs;
  - Base caisson;
  - Conductors (lower sections);
  - Lower conductor guide frame;
- Residual materials contained within the CGBS storage cells (cell contents); and
- Drill cuttings.

Options for decommissioning the Dunlin Alpha substructure

The Dunlin Alpha installation supported production from the Dunlin, Merlin and Osprey fields. Options to reuse the infrastructure *in situ* for future hydrocarbon developments were assessed but did not yield any viable commercial opportunity. There are a number of reasons for this, including the absence of remaining hydrocarbon reserves in the Dunlin Alpha vicinity. It is considered highly unlikely that any opportunity to reuse the infrastructure would be viable. As such, there is no reason to delay decommissioning of the Dunlin Alpha installation.

As a Contracting Party to the Convention for the Protection of the Marine Environment of the North-East Atlantic, the UK is required to consider OSPAR Decision 98/3 on the Disposal of Disused Offshore Installations when reviewing decommissioning applications. In accordance with the requirements of OSPAR Decision 98/3, Fairfield has formally submitted proposals for the full recovery of the Dunlin Alpha topsides to shore. Details of the topsides decommissioning strategy and removal methodology can be found in the Dunlin Alpha Topsides Decommissioning Programme, available on the Fairfield website.

OSPAR Decision 98/3 also states that the dumping or leaving in place of disused offshore installations within the maritime area is prohibited but recognises that there may be difficulty in removing the 'footings' of large, steel jackets weighing more than 10,000 tonnes, and in removing concrete installations. The Dunlin Alpha substructure is a concrete gravity based installation, meeting the criteria set out in OSPAR Decision 98/3 as a potential candidate for derogation where 'an alternative decommissioning solution is preferable to full removal for the purpose of reuse or recycling or final disposal on land'.

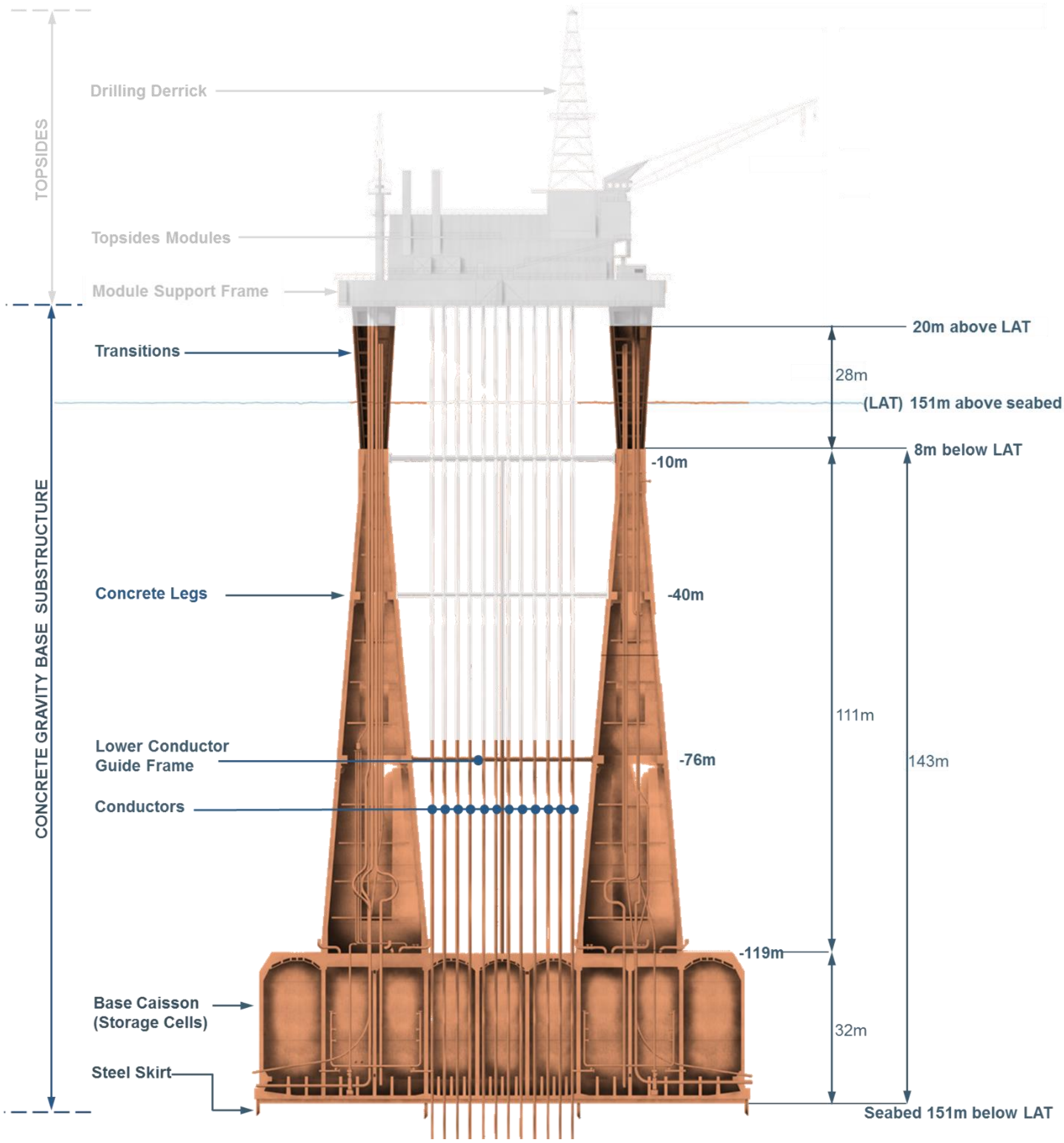


Figure ii Dunlin Alpha concrete gravity base substructure

Fairfield has complied with the requirements of OSPAR Decision 98/3 and undertaken a formal process called Comparative Assessment (CA), in accordance with decommissioning guidance notes issued by the Offshore Petroleum Regulator for Environment and Decommissioning (OPRED). This has allowed for the development of a preferred decommissioning methodology, based on the consideration of safety risk, environmental impact, technical feasibility, societal impacts and economic factors.

Alternative decommissioning options were assessed and a screening exercise was performed in order to identify viable options to be carried forward for formal evaluation. The option to refloat the Dunlin Alpha substructure, for either reuse at another location or deconstruction in a dry dock, was concluded to be unfeasible due to pipework and structural integrity issues, and substantial technical challenges required to free the substructure from the seabed and control buoyancy.

Consideration was also given to collapsing the concrete legs at their base. However, the controlled collapse of concrete legs on this scale at this depth is unprecedented. The use of either diamond wire cutting techniques and/or explosive charges would result in uncertain consequences, and present overwhelming recovery challenges. In addition, 'toppling' of the concrete legs was not viewed as consistent with UK governmental policy in this area.

A description of the substructure decommissioning options taken forward to the evaluation phase of the CA are provided in Table i.

Table i Substructure decommissioning options subjected to CA evaluation

Option	Description
Full removal (Option 4)	Full removal of the substructure through deconstruction *in situ*.
Shallow cut (Option 5)	Cut and remove the steel transitions and installation of a support tower to carry a navigational aid.
IMO cut (Option 6)	Cut and remove the steel transitions and upper concrete leg sections to 55 m below mean sea level, in compliance with International Maritime Organisation (IMO) specifications.
Transitions up (Option 9)	Following removal of topsides, installation of a cap at the top of each of the steel transitions and installation of a navigational aid.

The CGBS base caisson is divided into 81 storage cells, of which 75 were historically used for oil and water separation prior to export. Operations to recover mobile oil from the 75 storage cells were successfully completed in 2008, leaving a relatively thin layer of residual oil within each cell. Some mobile oil also remains trapped in ten triangular sub-compartments formed by the leg foundations.

Topsides based cell survey and sampling operations, completed in 2020, have confirmed that recovery of this residual oil cannot be achieved from the Dunlin Alpha topsides. Any further recovery would need to be undertaken from a vessel using new external subsea penetrations.

An extensive review of the storage cell contents has concluded that complete removal of all of the residual cell contents would require full removal of the substructure. A CA was therefore undertaken to assess alternative options for the long-term management of the residual contents within the CGBS storage cells. The options carried forward for formal evaluation focussed on recovery of the mobile oil and sediment using new subsea penetrations, and considered a targeted approach that would increase efficiency of recovery but also limit disturbance of the Dunlin Alpha drill cuttings pile. A description of the cell contents management options taken forward to the evaluation phase of the CA is provided in Table ii.

Table ii Cell contents decommissioning options subjected to CA evaluation

Option	Description
High-case oil and sediment removal (Option 1)	Allows access to up to 74 cells for removal of residual oil and sediment. Requires complete recovery of all cell top drill cuttings and 31 cell penetrations.
Mid-case oil and Sediment Removal (Option 2)	Allows access to up to 41 cells for removal of residual oil and sediment. Requires limited recovery of cell top drill cuttings and 18 cell penetrations.
Mid-case Oil Removal (Option 3)	Allows access to up to 5 triangle cells for removal of residual oil only. Requires limited recovery of cell top drill cuttings and 5 triangle cell penetrations.
Leave *in situ* (Option 4)	Leave *in situ* to degrade naturally over time, no further recovery.

Fairfield utilised a Multi Criteria Decision Analysis (MCDA) tool to evaluate each of the options against the other, in order to recommend a preferred decommissioning option. The MCDA tool allows an assembled team to review the available data for each option and determine, using terms such as 'neutral', 'stronger', 'much stronger' and so on, how each option compares to the other. This comparison was undertaken using the five criteria described in the OPRED decommissioning guidelines of safety, environmental, technical, societal and economic. The recommended options resulting from the CA process are summarised in Table iii.

Fairfield has also undertaken an assessment of the Dunlin Alpha drill cuttings pile, in according with OSPAR Recommendation 2006/5 on the Management Regime for Offshore Cuttings Piles. The purpose of the Recommendation is to reduce to a level that is not significant, the impacts of pollution by oil and/or other substances from cuttings piles. It describes thresholds for leaching and persistence against which cuttings piles can be compared in order to assess potential environmental impacts. The Dunlin Alpha cuttings pile has been assessed in detail and found not to exceed these thresholds.

Table iii Description of Dunlin Alpha decommissioning activities

Infrastructure type	Subject of Comparative Assessment	Decommissioning recommendation
Topsides	No	Full Removal
CGBS	Yes	Leave *in situ*, including transitions – install navigational aid
Cell Contents	Yes	Leave *in situ* to degrade naturally over time, no further recovery
Drill Cuttings	No	Leave *in situ*, drill cuttings to degrade naturally over time

Project description

It is proposed that the Dunlin Alpha substructure is decommissioned *in situ* with the four transitions remaining in place and the concrete legs flooded to reduce the differential pressure across the storage cell groups. The transitions will be sealed with concrete caps, and a navigational aid will be installed on top of one of the transitions. The conductors will be cut just above the lower guide frame and returned to shore along with the upper and middle conductor guide frames. The lower guide frame will be left attached to the concrete legs.

It is proposed that the cell contents are decommissioned *in situ* with no further recovery or remediation. No intervention work is required to facilitate this decommissioning option.

As it is proposed to decommission the substructure *in situ* and as the cuttings pile has been assessed to be below the OSPAR Recommendation 2006/5 thresholds for leaching and persistence, it is the intention of Fairfield to leave the drill cuttings pile *in situ* with minimal disturbance. No intervention work is required to facilitate this decommissioning option.

Fairfield anticipates executing the Dunlin Alpha Substructure Decommissioning Programme activities in 2022, following the OSPAR consultation process. However, the timing of decommissioning activities will be discussed with OPRED and the Health and Safety Executive, and applications for all relevant permits and consents will be submitted and approval sought prior to activities taking place.

Environment Description

Based on previous experience, technical studies (including Fairfield-commissioned surveys), review of scientific data and stakeholder consultation, it has been possible to identify the current key environmental sensitivities in the project area; these are summarised in Table iv and Figure iii.

Table iv Summary of the key environmental sensitivities of the Dunlin area

Environmental receptor	Description
Conservation interests	
OSPAR (2008) List of Threatened and/or Declining Habitats and Species	
Ocean quahog *Arctica islandica*	The presence of ocean quahog *A. islandica* has been confirmed in most of the survey datasets available around Dunlin. All occurrences of *A. islandica* in these records tend to be of small juvenile specimens in low numbers. However, it is relatively well distributed in the North Sea and the project area is not considered a particularly important area for ocean quahog.
Cold water coral *Lophelia pertusa*	A marine growth study carried out in 2017 indicated that *Lophelia pertusa* (a cold-water coral) was present on the platform legs, conductors and conductor guide frames at approximately 48 m below LAT and deeper. The worst-case estimate of marine growth on the structures being removed is 83 tonnes, some of which may be *L. pertusa*.
Conservation sites (within 150 km; see Figure iii)	
Special Areas of Conservation (SACs)	There is only one SAC located within 100 km of the decommissioning project area, the Pobie Bank Reef SAC. The stony and bedrock reefs of the site provide a habitat to an extensive community of encrusting and robust sponges and bryozoans and in the shallowest areas the bedrock and boulders also support encrusting coralline algae. The site is located 98 km to the south-west of the project area.
Special Protection Areas (SPAs)	The nearest SPA to the project area is Hermaness, Saxa Vord and Valla Field SPA, located 137 km to the south-west. It protects a population of European importance including red-throated diver (Annex I species), common guillemot, black-legged kittiwake, European shag, northern fulmar, Atlantic puffin, great skua and northern gannet. The Fetlar SPA is approximately 143 km from Dunlin Alpha and comprises a range of habitats including species-rich heathland, marshes and lochan, cliffs and rocky shores. During the breeding season this site supports a population of European importance of Arctic Tern *Sterna paradisaea* and red-necked phalarope *Phalaropus lobatus*. Additionally, it also supports populations of European importance of the following migratory species during the breeding season: dunlin *Calidris alpina schinzii*, great skua and whimbrel *Numenius phaeopus*, and at least 20,000 seabirds. During the breeding season, the area regularly supports 22,000 individual seabirds including Arctic skua, northern fulmar, great skua, Arctic tern and red-necked phalarope.
Nature Conservation Marine Protected Areas (MPAs)	There are two NCMPAs within 150 km of the installation. These are the North East Faroe Shetland Channel NCMPA (117 km) and the Fetlar to Haroldswick NCMPA (141 km). The North East Faroe Shetland Channel is the largest MPA in Europe and the protected features are deep sea sponge aggregations, offshore deep-sea muds, offshore subtidal sands and gravel, continental slope features and a wide range of features associated with Key Geodiversity Areas including West Shetland Margin Palaeo-depositional, Miller Slide and Pilot Whale Diapirs. The Fetlar to Haroldswick NCMPA supports a range of high energy habitats and species including horse mussel beds, kelp and seaweed communities and maerl beds. It also encompasses over 200 km^2 of important black guillemot *Cepphus grylle* feeding grounds. It also includes shallow tide-swept coarse sands with burrowing bivalves and marine geomorphology of the Scottish shelf seabed.

Environmental receptor	Description
Coastal and Offshore Annex II species most likely to be present in the project area	
Harbour porpoise	Harbour porpoise are frequently found throughout the UK waters. They usually occur in groups of one to three individuals in shallow waters, although they have been sighted in larger groups and in deep water. It is not thought that the species migrate.
Killer whale	Widely distributed with sightings across the North Sea all year round; seen in both inshore waters (April to October) and the deeper continental shelf waters (November to March). May move inshore to target seals seasonally.
Minke whale	Minke whales usually occur in water depths of 200 m or less and occur throughout the northern and central North Sea. They are usually sighted in pairs or in solitude; however, groups of up to 15 individuals can be sighted feeding. It appears that animals return to the same seasonal feeding grounds.
Atlantic white-sided dolphin	White-sided dolphins show both season and inter-annual variability. They have been sighted in large groups of 10 - 100 individuals. They have been sighted in waters ranging from 100 m to very deep waters, but also enter continental shelf waters. They can be sighted in the deep waters around the north of Scotland throughout the year and enter the North Sea in search of food.
White-beaked dolphin	White-beaked dolphins are usually found in water depths of between 50 and 100 m in groups of around 10 individuals, although large groups of up to 500 animals have been seen. They are present in the UK waters throughout the year, however more sightings have been made between June and October.
Grey and Harbour seal	As the project area is located approximately 137 km offshore, these species may be encountered in the vicinity from time to time, but the project area is not of specific importance for these species. The presence of grey and harbour seals in the project area is between 0 – 1 individual per 25 km^2.
Benthic environment	
Bathymetry	The Dunlin Alpha installation stands in 151 metres of water.
Seabed sediments	Sediment types around the Dunlin Alpha platform, as revealed by site surveys at Dunlin Alpha, Osprey, Merlin, Skye, and Murchison, are predominantly fine to medium sand with a silt/clay (i.e. 'mud') content mostly <20%. In all areas surveyed, sands contain admixtures of shell gravel and pebbles, and occasional small boulders were observed.
Benthic fauna	Species consistently appearing in the lists of most abundant taxa centre around the polychaetes *Galathowenia oculata, Euchone incolor, Aonides paucibranchiata, Paradoneis lyra,* and the bivalve molluscs *Adontorhina similis* and *Axinulus croulinensis.* The epifauna included hermit crabs (usually *Pagurus* spp.), various seastars including *Asterias rubens*, *Porania pulvillus,* and *Luidia sarsi,* and sea urchins such as *Echinus acutus.* Low numbers of juvenile ocean quahog *A. islandica* were observed in the survey areas. This species is on the OSPAR (2008) List of Threatened and/or Declining Habitats and Species however it is well distributed in the North Sea and the project area is not considered a particularly important area for ocean quahog.
Fish – spawning and nursery grounds	
Spawning grounds	The project area is located within the spawning grounds of haddock (*Melanogrammus aeglefinus*) (February to May, [peak spawning February – April]), saithe (*Pollachius virens*) (January to April, [peak spawning January – February]), Norway pout (*Trisopterus esmarkii*) (January to April, [peak spawning February – March]), cod (*Gadus morhua*) (January to April, [peak spawning February – March]) and whiting (*Merlangius merlangus*) (February to June).
Nursery grounds	The following species have nursery grounds in the vicinity of the project: anglerfish (*Lophiiformes spp.*), cod, haddock, horse mackerel (*Trachurus trachurus*), plaice (*Pleuronectes platessa*), sandeel (*Ammodytes tobianus*), saithe, sprat (*Sprattus sprattus*), Norway pout, mackerel (*Scomber scombrus*), blue whiting (*Micromesistius poutassou*), spurdog (*Squalus acanthias*), herring (*Clupea harengus*) and ling (*Molva molva*).

Environmental receptor	Description
Seabirds	

The project area is important for northern fulmar (*Fulmarus glacialis*), northern gannet (*Morus bassanus*), great black-backed gull (*Larus marinus*), Atlantic puffin (*Fratercula arctica*), black-legged kittiwake (*Rissa tridactyla*), and common guillemot (*Uria aalge*) for the majority of the year.

Of these species, northern fulmar and black-legged kittiwake have suffered significant population declines in the last two decades (i.e. -36% and -50%, respectively; JNCC, 2020).

In Block 211/23 the sensitivity of seabirds to oil pollution, reflected by the Seabird Oil Sensitivity Index (SOSI), is considered low for all months except November and December, when seabird oiling sensitivity is considered high. The assessment of SOSI values being high in November have been based on worst-case estimates for adjacent months and adjacent blocks. No data was available for Block 211/23 or the surrounding blocks during the month of May and, consequently, indirect assessment was required for the months of April and June for all of these blocks.

Seabed Oil Sensitivity Index (SOSI)

Block	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
211/17	3*	5	5	5*	N	5*	5	5	5*	N	3*	3
211/18	3*	5	5	5*	N	5*	5	5	5*	N	3*	3
211/19	3*	5	5	5*	N	5*	5	5*	5*	N	3*	3
211/22	5	5	5	5*	N	5*	5	5	4	4*	4*	4
211/23	5	5	5	5*	N	5*	5	5	5	5*	3*	3
211/24	5	5	5	5*	N	5*	5	5	5	5*	3*	3
211/27	5	5	5	5*	N	5	5	5	4	4*	5*	5
211/28	5	5	5	5*	N	5*	5	5	4	4*	5*	5
211/29	5	5	5	5*	N	5*	5	5	5	5*	5*	5

Key						
	* in light of coverage gaps, an indirect assessment of SOSI has been made					
	1 = Extremely high	2 = Very high	3 = High	4 = Medium	5 = Low	N = No data

Commercial fishing

The project area sits within International Council for Exploration of the Sea (ICES) rectangle 51F1, which predominantly supports demersal fisheries targeting saithe and cod. Mackerel, whiting, haddock, ling, megrim, monkfish and anglers are also fished in the area by demersal and pelagic trawl vessels. Some shellfish species are landed from ICES rectangle 51F1, but both value and tonnage of landings are very low. During the most recent five-year period in which published commercial fishing data is available (i.e. 2014 – 2018), demersal fishing effort was low, and the live weight and value of demersal landings was moderate compared to other areas in the North Sea (Scottish Government, 2019).

Other users

Environmental receptor	Description
Shipping activity	There is very little shipping activity in the project area, and no sites of renewable or archaeological interest. There is also limited infrastructure related to other oil and gas developments.
Oil and Gas	Several active offshore platforms and surface infrastructure are located within 30 km of the Dunlin Alpha installation: Thistle A (9.9 km NW; decommissioning planning underway), Statfjord B (14.6 km SE), Brent C (21 km SE; topsides Decommissioning Programme approved August 2018), Cormorant North (24.3 km SW), Northern Producer FPU (24.7 km NW); Eider A (25 .1 km NW; Decommissioning Programme approved May 2020), Brent B (25.2 km SE; topsides Decommissioning Programme approved August 2018), and Brent A (27.4 km SE; topsides Decommissioning Programme approved August 2018).
Telecommunications	There are no cables in the vicinity of the project area other than the decommissioned Dunlin Power Import cable (running from the Dunlin Alpha platform to the Brent Charlie platform).
Military activities	There are no charted military Practice and Exercise Areas and Unexploded Ordnance in the vicinity of the project area.
Renewables	There is no renewable energy activity in the vicinity of the project area; the closest potential renewable site is a Draft Plan Option for tidal energy, at Muckle Flugga (north of Shetland), located approximately 120 km south-west of Block 211/23.
Wrecks	There are no designated wreck sites in the vicinity of the project area. There is a non-designated wreck record to the north of Block 211/23, where the Dunlin Alpha platform is located.

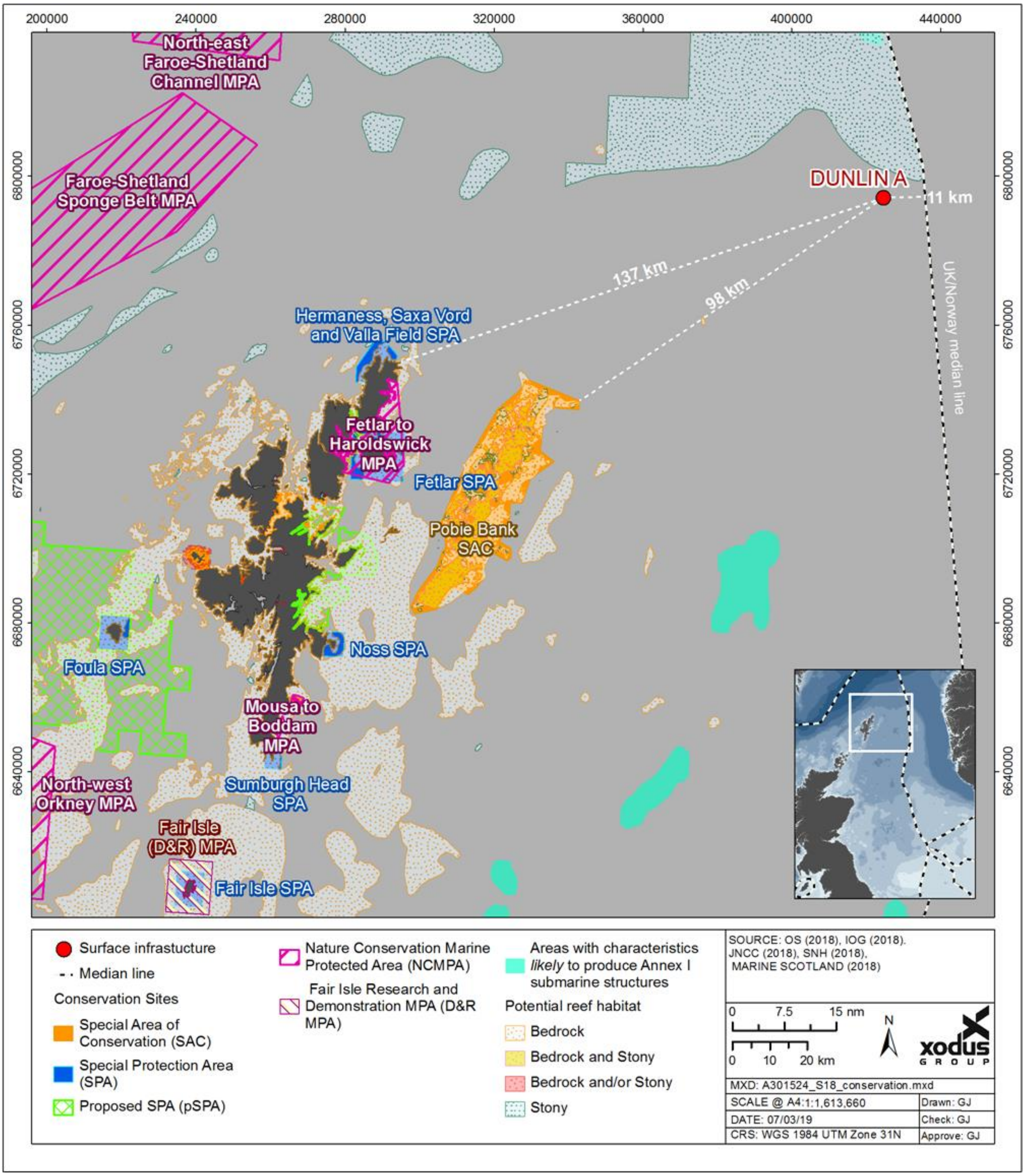


Figure iii Conservation areas in proximity to Dunlin Alpha installation

Impact Assessment

Environmental impact assessment undertaken in support of the Dunlin Alpha substructure decommissioning programme has been informed by a series of different processes, including scoping with the Regulators and their statutory advisors, workshops with specialists, and the comparative assessment process. Where impacts were identified during this process as having a potentially significant consequence, mitigation measures have been considered and detailed impact assessment has been undertaken and presented within this EA. Those impacts that were not assessed as key environmental sensitivities were scoped out. The decision on which issues required further study and assessment was based on the specific proposed activities and environmental sensitivities around the Dunlin Alpha installation, on a review of industry experience of decommissioning impact assessment, and on an assessment of wider stakeholder interest informed in part by stakeholder engagement. This was captured during the ENVID process.

Table v presents the findings of the environmental impact assessment for the potentially significant impacts identified for the project. The potential for cumulative and transboundary impacts is also considered.

Table v Details of the potential environmental impacts of the proposed activities

Key potential impacts assessed	Significance
Physical presence	
Physical presence of infrastructure decommissioned in situ	
Impact assessment: The Dunlin Alpha substructure decommissioning activities have the potential to impact upon other users of the sea. This may happen during the decommissioning activities themselves, when vessels working in the field and transiting to shore occupy space, and after decommissioning should any infrastructure decommissioned *in situ* interact with activities such as fishing. The main long-term interaction with other users of the sea will be as a result of a 500 m safety zone that will remain around the Dunlin Alpha CGBS, which is proposed to be decommissioned *in situ*. The 500 m safety zone will see the continued exclusion of commercial fishing effort from the immediate area around the CGBS. The exclusion zone corresponds to approximately 0.03% of the total area available for fishing within the host ICES rectangle, which is itself characterised by low commercial fishing effort and value. Based on the short-term nature of the impact during decommissioning operations, and the small area affected by the long-term presence of the exclusion zone, the impact is expected to be not significant. **Cumulative:** The small area of sea that would remain out of bounds to fisheries, especially in the context of the limited fishing effort in the Greater Dunlin Area, as a result of the Dunlin Alpha installation remaining *in situ* is not likely to present a significant cumulative impact. **Transboundary:** The vessel presence is regarded as relatively low, and there is no mechanism by which significant transboundary impacts could occur.	Not significant
Discharges to Sea	
Cell contents – gradual release over time	
Impact assessment: The most credible scenario for release of cell contents is one occurring over a prolonged period of time due to cracks in the concrete and communication paths opening up at existing pipework penetrations. This could result in small intermittent releases of mobile oil, water, chemicals, sediment and waxy residue. It is expected that up to a maximum of approximately 1,100 m^3 of mobile oil, 1,248 m^3 of sediment and 227,385 m^3 of cell water could be gradually released from the storage cells over time. This could have a potential impact on plankton, fish, seabirds, cetaceans and benthos and result in bioaccumulation. Assessment of these potential impacts was undertaken and concluded that, due to the low concentrations of contaminants present, the small volumes expected to be involved in any one release event, and the limited area impacted, gradual releases from the CGBS are not expected to result in any significant impact. **Cumulative:** Although gradual releases from other CGBS in the area are likely to be different, due to different construction of the substructures, it is possible that releases from other assets could occur in a similar time period. However, as a result of the water depth (151 m) and the release of relatively small volumes over an extended duration (up to hundreds of years as the structure degrades), any discharge of mobile oil is expected to dissipate and degrade relatively rapidly and have no significant capacity to act cumulatively with other potential discharges. Cumulative impacts with instantaneous releases from drill cuttings disturbance are addressed in the Unplanned Events chapter. **Transboundary:** The gradual release of mobile oil and other contents of the cells will be over a prolonged period of time and will be of a relatively small volume and duration at any one time. With the small volumes, there is expected to be no transboundary impact.	Not significant

Key potential impacts assessed	Significance
Effects on protected sites: Dispersal of any released contaminants will be such that should they reach any protected site their concentration will be very low and likely to be below the limits of detection of current analytical methodologies. There is not anticipated to be any detectable interaction with any protected sites as a result of the very low concentrations anticipated. As such, there is considered to be no Likely Significant Effect on SACs and SPAs and no impact on their conservation objectives or on-site integrity through a release of contaminants from the cells.	
Unplanned Events	
Cell contents – instantaneous release	
Impact assessment: The worst-case scenario of an instantaneous release associated with the Dunlin Alpha storage cell contents is an early failure of a transition falling from the top of a CGBS leg. Although highly unlikely, this could see a steel transition falling through the water column onto the roof of the CGBS base caisson. To understand the extent of any potential impact, oil spill modelling was undertaken which showed that the area over which the hydrocarbons might disperse would be limited. Given the limited release (50 – 100 m^3), there is expected to be no significant impact on the environment as the conditions in the offshore environment would also mean that any release would disperse relatively quickly. **Cumulative:** Potential failure mechanisms of other CGBSs in the area are likely to be different due to the different constructions of the other substructures. Any hydrocarbon release in the Dunlin Alpha decommissioning project area is expected to dissipate within days. It is considered very unlikely that additional releases from other sources would occur in the same timeframe and produce a cumulative impact. Additionally, the potential for cumulative impacts internal to the project were considered for both instantaneous release of cell contents and disturbance of the drill cuttings. The potential for these impacts to act cumulatively is considered limited as the drill cuttings on the CGBS roof provides considerable potential for energy absorption, protecting the reinforced concrete underneath, thus reducing the likelihood that a breach would occur where the cuttings are disturbed. Therefore, it is considered that there is limited potential for interaction between these two impact pathways to generate cumulative impacts. **Transboundary:** Depending on prevailing wind conditions at the time of any release, it is possible that any cell contents that are released could cross into the Norwegian sector. However, the realtively small volumes and the distance to the transboundary line (11 km) mean that the release would be widely dispersed to very low levels and it is unlikely there will be significant transboundary effects associated with an instantaneous release. **Effects on protected sites:** Modelling of an instantaneous release of mobile oil from the cells has shown that it would be very unlikely for this inventory to reach the shoreline; at worst, the very north-east coast of Shetland could receive a very small volume of oil depositing on the shoreline. As such, there is expected to be no mechanism for impacting protected sites.	Not significant
Disturbance of drill cuttings deposits	
Impact assessment: The Dunlin Alpha drill cuttings have been assessed and found not exceed the thresholds stated in OSPAR Recommendation 2006/5. However, as the CGBS begins to degrade over time, there is the possibility that the drill cuttings on the roof of the base caisson and around the base of the CGBS could be disturbed by falling objects. The subsequent possible re-distribution and re-settling of the cuttings has the potential to impact upon the benthos in the vicinity of the Dunlin Alpha installation. To understand the extent of any potential impact, cuttings disturbance modelling was undertaken, assuming disturbance of 10% of the existing cuttings pile as a worst case. The results indicated that an area of approximately 0.12 km^2 of seabed would be exposed to a degree of impact at the time of disturbance, reducing to an area of 0.08 km^2 after one year and gradually reducing further over time. Some of this impact would however be expected to occur on the estimated 0.671 km^2 of seabed around the CGBS that is already impacted by historical cuttings accumulations, thus reducing the area of previously undisturbed seabed impacted. A volume of up to 2 km^3 of water was also predicted to be impacted by the worst case cuttings disturbance, but the impact was predicted to be short term, returning to zero within 14 days. Observations from previous instances of cuttings pile disturbance indicated that the majority of disturbed material would re-settle rapidly and close to its previous position and cause limited	Not significant

Key potential impacts assessed	Significance
environmental impact, and as such the impact from cuttings disturbance was expected to be limited to relatively minor increases in the thickness of cuttings deposition around the fringes of the already impacted area. The benthos in the vicinity of the CGBS was expected to have some tolerance of the existing drilling contaminants in the area and are therefore likely to be resilient to the impact of cuttings disturbance. The small amount of material likely to be moved outside the existing cuttings accumulation area, the tolerance of the fauna to low levels of toxicity, and the limited potential for smothering and anoxia suggested that impacts on the benthos would not be significant. **Cumulative:** Any hydrocarbon or chemical release in the project area is expected to dissipate within days. It is considered very unlikely that additional releases from other sources would occur in the same timeframe and produce a cumulative impact. Gradual cell contents release was also considered for cumulative impacts with unplanned drill cuttings disturbance. The modelling results demonstrated that neither the disturbance of drill cuttings nor the release of cell water would increase the quantity of surface oil resulting from a worst-case impact. Therefore, no cumulative impacts on shoreline oiling, beaching, or impacts to designated site is expected. **Transboundary:** Seabed impacts will not cross the transboundary line (11 km to the east). Water column impacts are expected to be focused to the South of the disturbance area. In addition, plankton, fish and marine mammals are expected to have low sensitivity to drill cuttings and therefore no significant transboundary impact is expected. **Effects on protected sites**: Disturbance of the drill cuttings will result in spatially limited potential impacts and, given the location of the Dunlin Alpha installation, no impact on protected sites is expected.	

Environmental Management

The main focus of environmental performance management for the project is to ensure that activities taking place during the preparation period of decommissioning happen in a manner acceptable to Fairfield (and their stakeholders). The primary mechanism by which this will occur is through Fairfield's Environmental Management Policy, and specifically through the Environmental Management System that it requires to be operational. Beyond the main period of preparation for decommissioning *in situ*, the project has limited activity associated with it, other than the undertaking of post-decommissioning surveys. Fairfield has also developed a waste management strategy for the project to outline the processes and procedures necessary to support the Decommissioning Programme for the Dunlin Alpha. The waste management strategy details the measures in place to ensure that the principles of the waste management hierarchy are followed during all decommissioning (as shown in Figure iv).

Figure iv Waste hierarchy

Conclusions

Options for decommissioning the Dunlin Alpha substructure have been assessed through the CA process, in accordance with OSPAR Decision 98/3 and the OPRED decommissioning guidelines. Associated study work has revealed that there are significant technical and safety challenges associated with cutting the concrete legs. Full removal of the substructure is anticipated to require up to 40 years of subsea cutting and removal activities, with associated atmospheric emissions, underwater noise, and unavoidable marine discharges. The CA process has recommended that decommissioning the substructure *in situ* with legs up and installation of a navigational aid is the preferred alternative decommissioning option.

As a result of low solids loading rates in the production fluids, low wax deposition rates, and successful operations to recover over 97% of the mobile oil from the storage cells, the residual hydrocarbon inventory is considered small. Environmental impacts associated with both a gradual and instantaneous release of the residual cell contents have been assessed using conservative assumptions and worst-case scenarios to ensure impacts are not underestimated. It has been concluded that any future release of cell contents will not result in a significant environmental impact.

Fairfield has undertaken an extensive review of the cell contents and identified options for further recovery or treatment of the residual materials. It has been concluded that due to the physical properties of the cell contents and complex design of the substructure, any recovery or treatment option would have limited efficiency, and that the only option to remove the residual contents completely would require the full removal of the substructure itself. While some further recovery may be possible, it is considered highly unlikely that this would result in any net environmental benefit. Further recovery would result in additional atmospheric emissions and unavoidable marine discharges associated with cell contents and drill cuttings recovery operations, as well as increase the likelihood of an instantaneous release which would offset any marginal environmental gain from reductions in the residual content in the event of a release. As such, leaving the cell contents *in situ* is deemed to be the preferred option in terms of reducing net environmental impacts, and the CA process has recommended that decommissioning the cell contents *in situ*, with no further recovery, is the preferred decommissioning option.

Fairfield has identified potential environmental impacts resulting from the proposed decommissioning option and acknowledge that legacy impacts associated with decommissioning the residual storage cell contents and drill cuttings *in situ* are key stakeholder concerns. In accordance with OPRED decommissioning guidance, Fairfield has undertaken an EA on the proposed decommissioning operations, including legacy impacts associated with decommissioning the residual storage cell contents and drill cuttings *in situ*. The information used to undertake environmental impact assessments is based on evidence gathered from operational records, analysis of historical records, analogous data and/or the application of proven scientific principles. Conservative assumptions and worst-case release scenarios have been considered and it has been concluded that impacts associated with the proposed decommissioning strategies will not result in any significant environmental impacts.

1. Introduction

1.1. The Greater Dunlin Area

Fairfield Betula Limited and Fairfield Fagus Limited (collectively termed Fairfield), wholly owned subsidiaries of Fairfield Energy Limited, are the operators of the Dunlin, Merlin and Osprey fields (the 'Greater Dunlin Area'), located in United Kingdom Continental Shelf (UKCS) Block 211/23 of the northern North Sea. The Dunlin field lies approximately 137 km from the nearest landfall point, 197 km north east of Lerwick and 508 km north east of Aberdeen. The field sits 11 km from the United Kingdom (UK)/Norway median line and in a water depth of approximately 151 m (Figure 1.1). A layout of the infrastructure associated with these fields, in the context of the wider area, is shown in Figure 1.2.

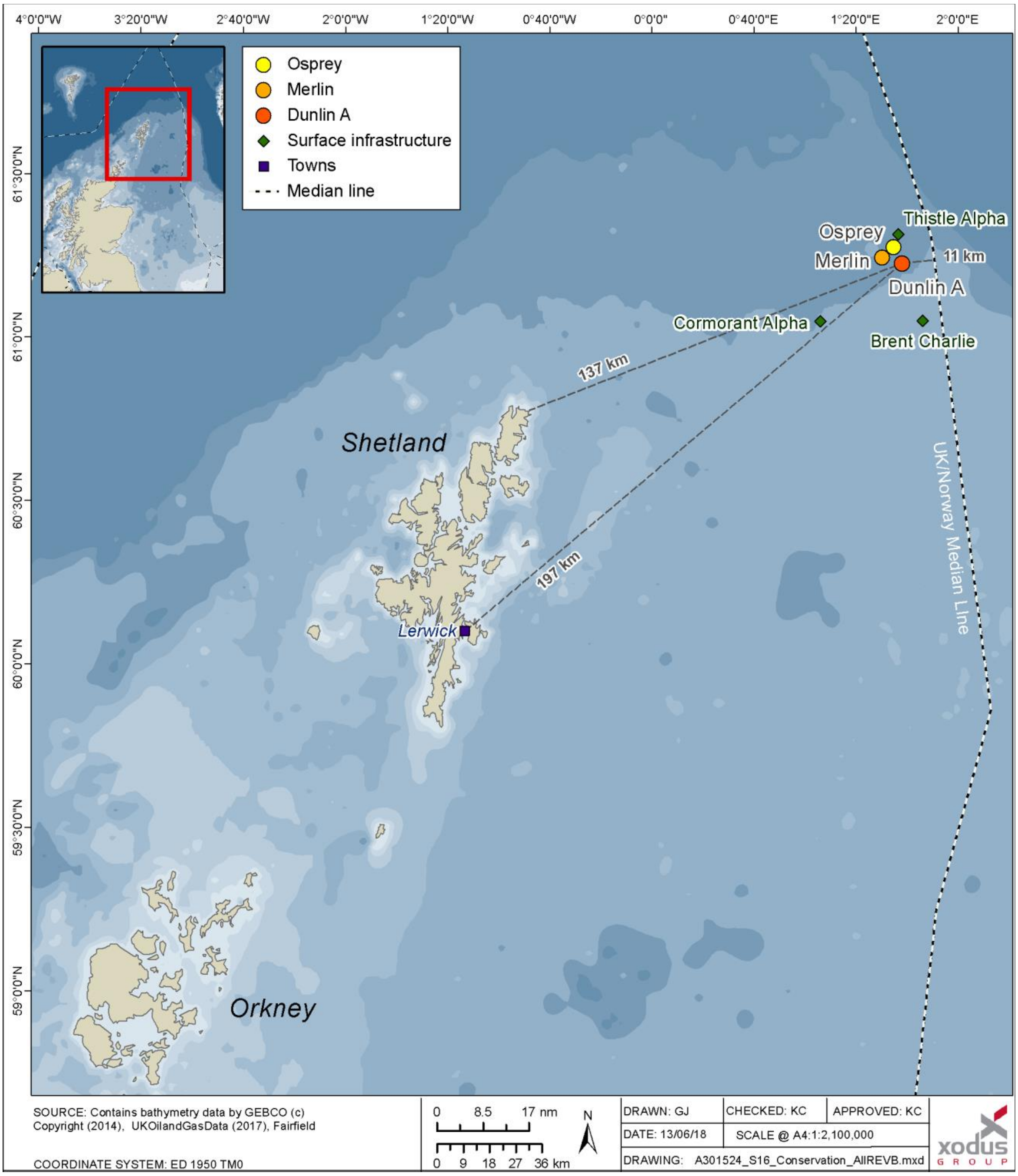


Figure 1.1 Location of the Greater Dunlin Area

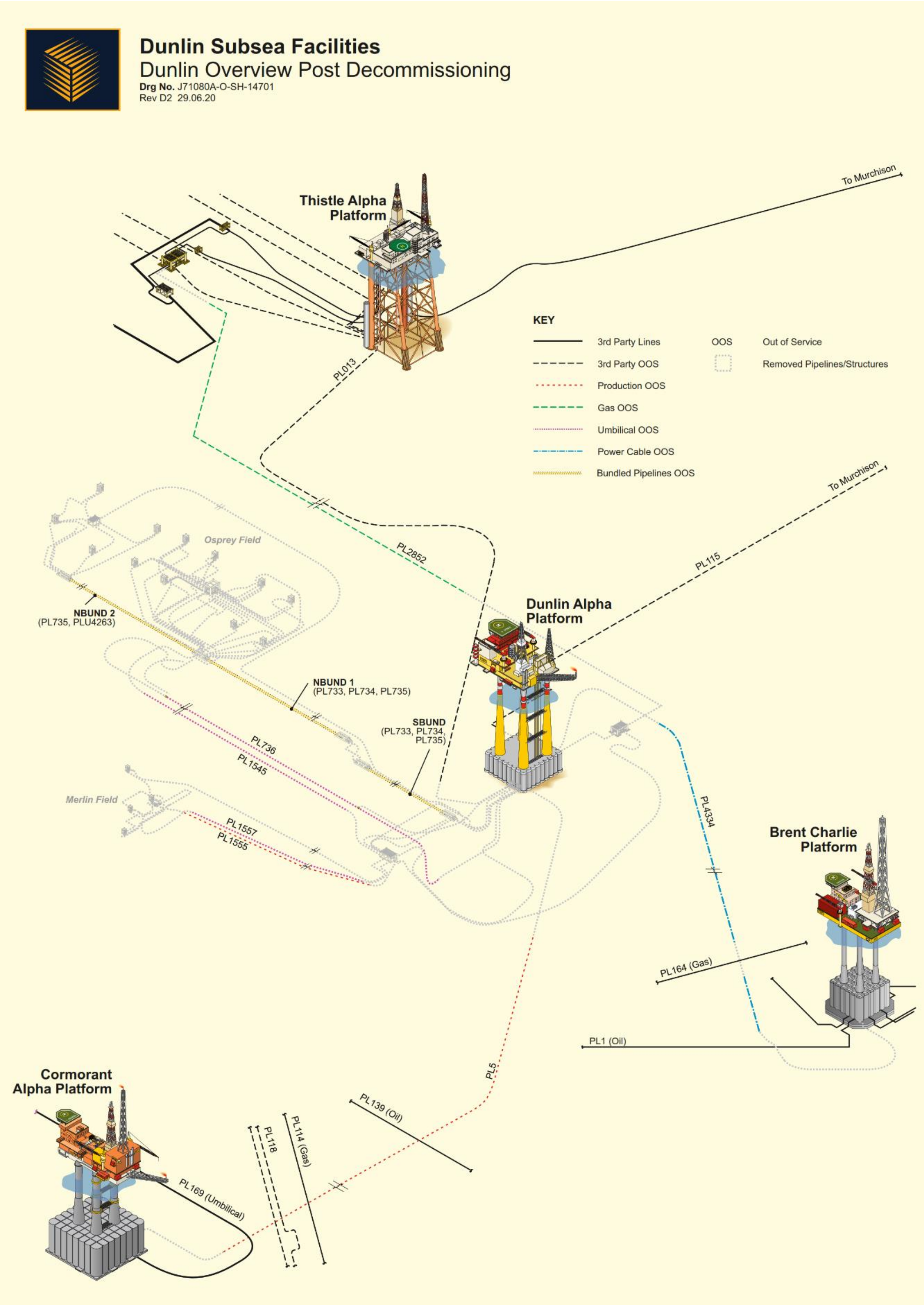


Figure 1.2 Dunlin Alpha installation in the context of the wider area

Production at the Dunlin, Merlin and Osprey fields ceased in June 2015 and Fairfield is now in the process of decommissioning all infrastructure associated with the Greater Dunlin Area. The decommissioning of the Dunlin, Merlin and Osprey subsea infrastructure has been considered separately from the Dunlin Alpha facilities decommissioning activities. The decommissioning of the Dunlin Alpha installation has been split into two separate scopes: the Dunlin Alpha Substructure Decommissioning Project (which is supported by this EA), and the Dunlin Alpha Topsides Decommissioning Project (details provided in Section 1.2). Approval for the Decommissioning Programme associated with the Dunlin Alpha Topsides was granted by Offshore Petroleum Regulator for Environment and Decommissioning (OPRED) in May 2019.

1.2. The Dunlin Alpha Substructure Decommissioning Project

Proposals for the decommissioning of the Dunlin Alpha installation were submitted to the Department of Business, Energy and Industrial Strategy (BEIS) and subjected to formal consultation in Q3-2018. Following consultation, and in agreement with OPRED, a decision was made to split the Dunlin Alpha Decommissioning Programme (FBL-DUN-DUNA-HSE-01-PLN-0001) (Fairfield, 2018) into two separate programmes; these are:

- Dunlin Alpha Topsides Decommissioning Programme (FBL-DUN-DUNA-HSE-01-PLN-00001-01) (Fairfield, 2019a); and
- Dunlin Alpha Substructure Decommissioning Programme (FBL-DUN-DUNA-HSE-01-PLN-00001-02) (Fairfield, 2020).

Figure 1.3 illustrates the scope of the Dunlin Alpha Substructure Decommissioning Programme, which covers the following infrastructure and discharges:

- Concrete Gravity Base Substructure (CGBS):
    - Transitions
    - Concrete legs
    - Base caisson
    - Conductors (lower sections)
    - Lower conductor guide frame
- Residual materials contained within the CGBS storage cells (cell contents)
- Drill cuttings

This Environmental Appraisal (EA) report relates specifically to the activities associated with the proposed Dunlin Alpha Substructure Decommissioning Programme. Consultation feedback relating to the environmental impacts associated with decommissioning the CGBS, residual storage cell contents and drill cuttings has been considered and is addressed, where applicable, in this document.

Consultation feedback relating to environmental impacts associated with the removal of the Dunlin Alpha topsides has been addressed and incorporated within the Dunlin Alpha Topsides Environmental Appraisal, available on the Fairfield website.

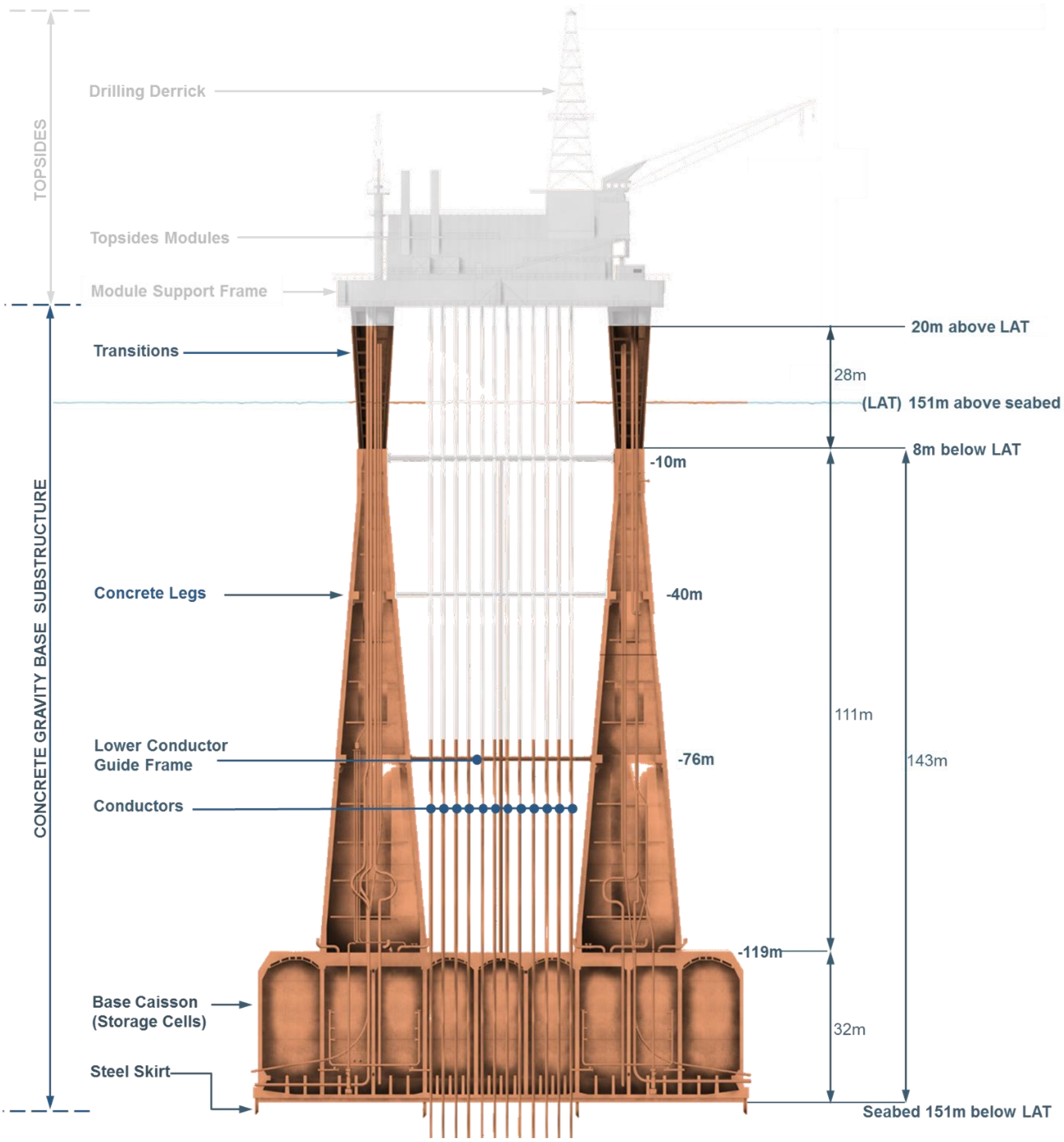


Figure 1.3 Scope of the Dunlin Alpha Substructure Decommissioning Project

1.3. Regulatory Context

1.3.1. Decommissioning Overview

The decommissioning of offshore oil and gas installations and pipelines on the UKCS is controlled through the Petroleum Act 1998 (as amended[1]). Decommissioning activities are also regulated under the Marine and Coastal Access Act 2009. The UK's international obligations on decommissioning are primarily governed by

[1] The most recent amendment to the Petroleum Act 1998 was by the Energy Act 2016, which amongst others, requires relevant persons to consult the UK Oil and Gas Authority (OGA) before submitting an abandonment programme to the Secretary of State, and to require the Secretary of State to consider representations from the OGA when deciding whether to approve a programme.

the 1992 Convention for the Protection of the Marine Environment of the North East Atlantic (the Oslo Paris (OSPAR) Convention).

Responsibility for ensuring compliance with the Petroleum Act 1998 rests with Department of Business, Energy and Industrial Strategy (BEIS), and is managed through the Offshore Petroleum Regulator for Environment and Decommissioning (OPRED). OPRED is also the Competent Authority on decommissioning in the UK for OSPAR purposes.

The Petroleum Act 1998 (as amended) governs the decommissioning of offshore oil and gas infrastructure on the UKCS. The Act requires the operator of an offshore installation or pipeline to submit a draft Decommissioning Programme (DP) for statutory and public consultation, and to obtain approval of the DP from OPRED before initiating decommissioning work. The DP must outline in detail, the infrastructure to be decommissioned and the method by which the decommissioning will take place.

The OPRED (2018) Guidance Notes on the Decommissioning of Offshore Oil and Gas Installations and Pipelines details the need for an EA to be submitted in support of the DP. The guidance notes set out a framework for the required environmental inputs and deliverables throughout the approval process. The guidance also outlines that an EA should be a document providing necessary content in proportion to the complexity and magnitude of a project. Decom North Sea's Environmental Appraisal Guidelines for Offshore Oil and Gas Decommissioning (Decom North Sea, 2018) provides further definition on the requirements of EA reports.

In terms of activities in the northern North Sea, the National Marine Plan (NMP) has been adopted by the Scottish Government to help ensure sustainable development of the marine area (Scottish Government, 2015). The NMP has been developed in line with UK, European Union (EU) and OSPAR legislation, directives and guidance. As part of the conclusions to this assessment (Section 6), Fairfield has given due consideration to the NMP during project decision making and the interactions between the project and the NMP.

1.3.2. OSPAR Decision 98/3

As a Contracting Party of the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR), the UK signed up to obligations laid out within OSPAR Decision 98/3 (OSPAR, 1998). OSPAR Decision 98/3 states that the topsides of all installations should be returned to shore. The Decision recognises that there may be difficulty in removing gravity based concrete installations and the 'footings' of large steel jackets that weigh more than 10,000 tonnes. Derogation from OSPAR Decision 98/3 may be considered where the installation falls into one of these categories and 'an alternative decommissioning solution is preferable to full removal for the purpose of reuse or recycling or final disposal on land'. Where a case for derogation is made, it must be supported by an assessment of disposal options conducted in accordance with the framework set out in Annex 2 of OSPAR Decision 98/3.

The OPRED guidance notes on decommissioning (OPRED, 2018) outline the requirements for undertaking a comparative assessment (CA) which should assess a project against five main criteria (environmental, safety, technical, societal and economic). Additional guidance on undertaking a CA was prepared in 2015 by Oil and Gas UK (OGUK, 2015), in which seven steps to the CA process are recommended. The Dunlin Alpha concrete gravity base substructure qualifies as a candidate for derogation, and Fairfield has undertaken a CA in accordance with the OSPAR and OPRED requirements, following the steps as recommended by OGUK. Further details of the CA process are provided in Section 2.2.2 and the Dunlin Alpha Comparative Assessment Report (Fairfield, 2018a).

1.3.3. OSPAR Recommendation 2006/5

OSPAR Recommendation 2006/5 governs the Management Regime for Offshore Cuttings Piles. This establishes a two-stage management regime: Stage 1 provided for initial screening of all cuttings piles, to identify any piles that require further investigation based on the thresholds set out in the Recommendation. Industry's subsequent report assessing UK cuttings piles in line with the Recommendation established that they were all below the specified thresholds. As a result, there is no need for immediate remediation of UK drill cuttings. However, at the time of decommissioning, the characteristics of the relevant cuttings piles must be assessed in detail and the need for further action (in line with Stage 2 of the Recommendation) should be reviewed. Where either threshold in Recommendation 2006/5 is exceeded, Stage 2 will apply and will require a study, including a CA, to determine the best option for handling the cuttings pile.

The associated guidance (OSPAR, 2009a) describes two thresholds against which cuttings piles can be compared; persistence to be below the 500 km^2/year threshold and oil loss to be below the 10 tonnes per year threshold. The cuttings pile at the Dunlin Alpha installation has been assessed and found not to exceed the OSPAR 2006/5 thresholds, as discussed above (Xodus, 2018).

1.4. Environmental Management

Fairfield's commitment to managing environment impacts underpins all proposed activities associated with decommissioning covered in this Environmental Appraisal. Continuous improvement in environmental performance is sought through effective project planning and implementation, emissions reduction, waste minimisation, waste management, noise reduction and energy conservation; this core philosophy has fed into the development of the mitigation measures for the project (and detailed in Section 5); these include both industry standard and project-specific measures. A summary of Fairfield's Environmental Management Policy is presented in Figure 1.4.

1.5. Scope and Structure of the Environmental Appraisal Report

This EA report sets out to describe in a proportionate manner, the potential environmental impacts of the proposed activities associated with decommissioning of the Dunlin Alpha installation and to demonstrate the extent to which these can be mitigated and controlled to an acceptable level. This is achieved in the following sections, which cover:

- A description of the infrastructure and materials to be decommissioned (Section 2.1);
- The process by which Fairfield has arrived at the selected decommissioning strategy (Section 2.2);
- A description of the proposed decommissioning activities (Section 2.3);
- A review of the potential impacts from the proposed decommissioning activities and justification for the assessments (Section 3);
- A summary of the baseline sensitivities relevant to the assessments (Section 4);
- Assessment of key issues (Section 5); and
- Conclusions (Section 6).

This report has been prepared in line with Fairfield's environmental assessment requirements and has given due consideration to the regulatory guidelines (OPRED, 2018) and to Decom North Sea's Environmental Appraisal Guidelines for Offshore Oil and Gas Decommissioning (2018).

Environmental Management Policy

It is the policy of Fairfield Energy Limited (Fairfield) to seek to conduct its business in a responsible manner that prevents pollution and promotes the preservation of the environment. Fairfield appreciates that our activities can interact with the natural environment in many ways. We recognise that sustained development of Fairfield and our long-term success depends upon achieving high standards of environmental performance. We are therefore committed to conducting our undertakings in an environmentally responsible manner. This means that we will:

- Integrate environmental considerations within our business and ensure that we treat these considerations with at least equal importance to those of productivity and profitability;
- Incorporate environmental risk assessment in our business management processes, and seek opportunities to reduce the environmental impact of our activities;
- Continually improve our environmental management performance;
- Comply with all environmental laws, regulations and standards applicable to our undertakings;
- Allocate necessary resources to implement this policy; and
- Communicate openly in matters of the environment with government authorities, industry partners and through public statements.

In particular, we will:

- Maintain an environmental management system in accordance with international best practice and with the BS-EN-ISO 14001:2015 standard, including arrangements for the regular review and audit of our environmental performance;
- Conduct environmental analyses and risk assessments in our areas of operation, in order to ensure that we understand the potential environmental impacts of our activities and that we identify the necessary means for addressing those impacts;
- Manage our emissions according to the principles of Best Available Techniques;
- Publish an annual statement on our public web site, providing a description of our environmental goals and performance; and
- Maintain incident and emergency systems in order to provide assessment, response and control of environmental impacts.

Ultimate responsibility for the effective environmental management of our activities rests with the Managing Director and the Board. This policy shall be implemented by line management through the development and implementation of working practices and procedures that assign clear responsibilities for specific environmental activities with our employees and contractors. In addition, each of our employees has a personal responsibility to conduct themselves in a manner that enables us to implement this policy and our environmental management system.

Figure 1.4 Environmental Management Policy

2. Project Description

2.1. Description of Facilities to be Decommissioned

Note: This section summarises the infrastructure that is subject of this Environmental Appraisal; further details of topsides infrastructure, including tabulated items and weights, is provided in the Dunlin Alpha Topsides Environmental Appraisal (Fairfield, 2019b).

2.1.1. Overview of the Dunlin Alpha Installation

The Dunlin Alpha installation consists of a four-legged concrete gravity-base substructure (CGBS), with modular topsides facilities supported by a steel box girder module support frame (MSF). A schematic of the Dunlin Alpha installation is provided in Figure 2.1.

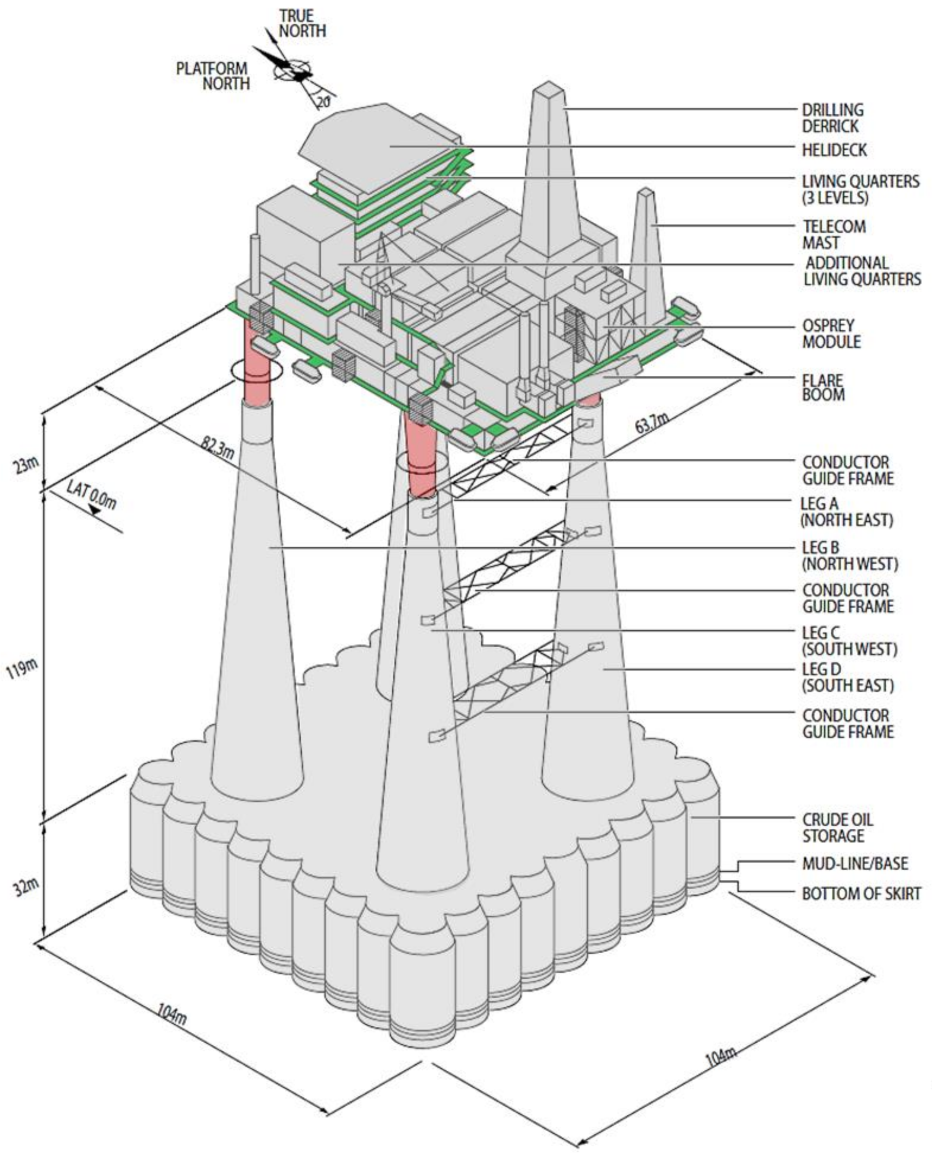


Figure 2.1 Schematic of the Dunlin Alpha installation

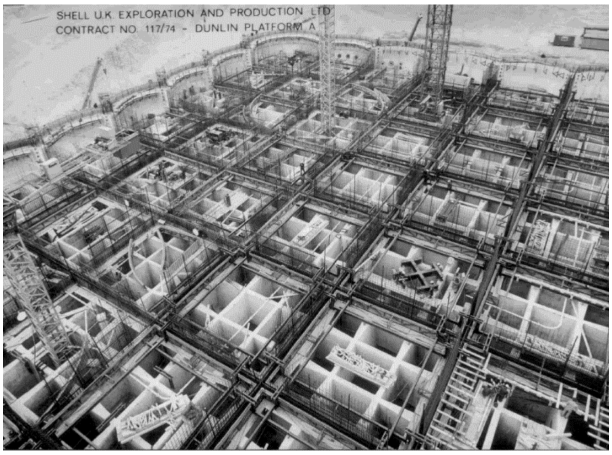
The base of the installation is 104 m square and the installation is over 240 m high from the seabed to the top of the drilling derrick. The installation was designed to accommodate 48 wells, with fluids from the wells passing from the reservoir to the topsides within steel pipes, one per well, the top section of which is known as a conductor. The conductors are contained within three steel conductor guide frames (CGFs) located between Legs C and D (leg labels are shown on Figure 2.1).

The installation was designed to:

- Serve as a production facility for the Dunlin and Dunlin South West fields, and subsequently for additional production from the Osprey and Merlin fields;
- Serve as a drilling facility for the Dunlin fields;
- Provide separation of oil and water within the CGBS (continuous use of the storage cells for separation ceased in mid-1995); and
- Accept oil imported from the Thistle Alpha and Murchison platforms, prior to onward export to the Cormorant Alpha platform via pipeline.

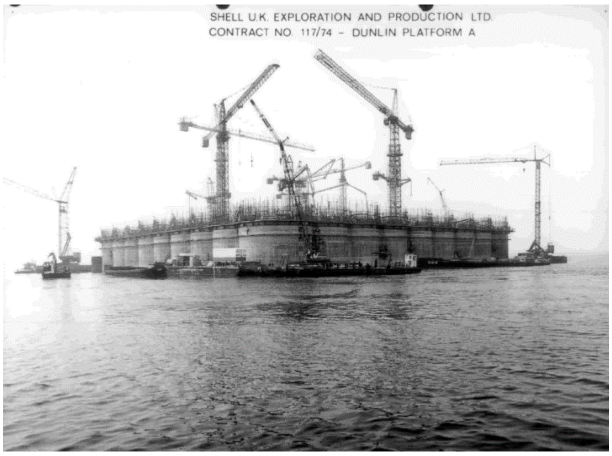
Design and construction of the Dunlin Alpha CGBS, on which the topsides facilities sit, was carried out by the Anglo Dutch Offshore Concrete (ANDOC) contractors' consortium in the Netherlands during the 1970s. The CGBS was floated from its construction site to the Dunlin field where it was ballasted down to rest on the seabed. The CGBS was not designed to be re-floated and the ballasting pipework was filled with grout to prevent communication between the legs and the storage cells.

The Dunlin Alpha installation was installed in 1977, and oil production began in 1978 after the drilling of initial wells. Figure 2.2 shows the CGBS base and concrete legs during construction in the 1970s.

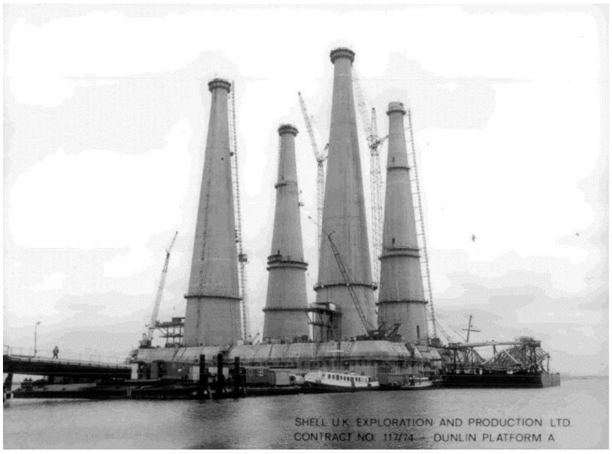


3m x 3m compartments for ballast material


Construction of the storage cell side walls



Construction of the full storage structure, prior to addition of the cell tops



Completed structure ready for deployment

Figure 2.2 CGBS base and concrete legs during construction (Shell UK)

2.1.1.1. Concrete Gravity Base Structure

The CGBS extends from the seabed to the tops of the steel transition columns (transitions), as shown in Figure 2.3. The transitions rise above the sea surface, connecting the top of the concrete legs (at LAT -8 m) to the bottom of the topsides module support frame (at LAT +23 m). The CGBS weighs approximately 342,000 tonnes, comprising 236,500 tonnes of steel reinforced concrete with the remainder of the weight being attributable to the four steel transitions, conductors, conductor guide frames, internal equipment in the legs, solid granular iron ore ballast at the bottom of the base caisson, and steel seabed skirt.

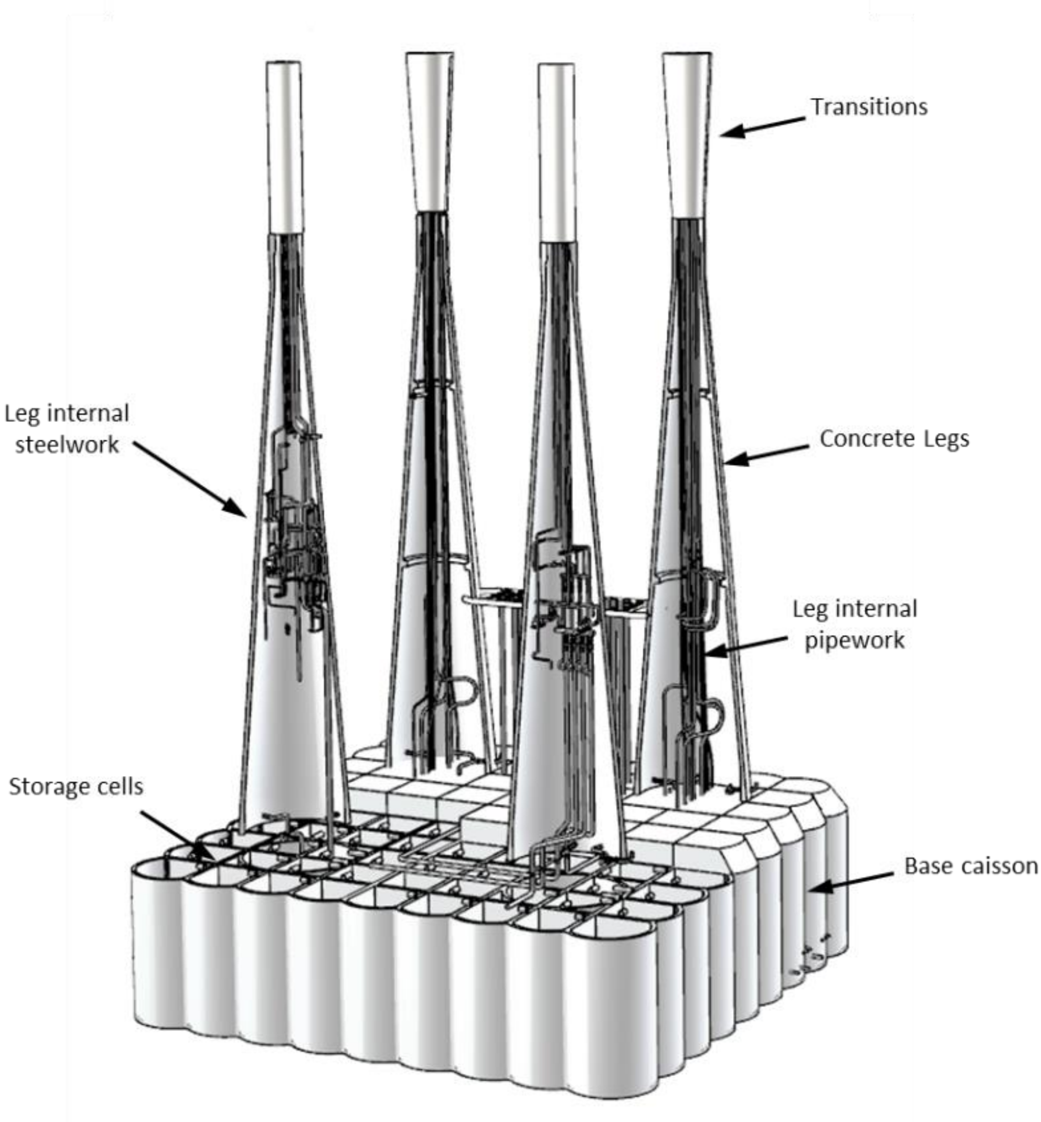


Figure 2.3 CGBS base and concrete legs (topsides and conductors not shown)

Four concrete legs, each 111 m high, rise up from the roof of the base caisson. These reduce in outside diameter from 22.65 m at the bottom to 6.7 m at the top, where they join the transitions at 8 m below sea level. The bolted connections are grouted in place. The legs are designed as hollow shafts, with concrete walls generally being 700 mm thick but increasing to 1,200 mm at the top and the bottom. Each of the concrete legs weighs approximately 8,625 tonnes.

Equipment and pipework are distributed within the legs, in order to provide a range of different functions:

- Leg A contains the header tank and standpipe which connects to the water ringmain within the storage cells, required to control the drawdown (system operating) pressure. Pumps associated with storage water, service water, firewater and conductor cooling water systems are also located in Leg A;
- Leg B contains the oil import/export pipework (otherwise known as rundown lines) which access the storage cells;
- Leg C contains the import risers (pipelines which run from the seabed to the topsides) which formerly brought in oil from the Thistle and Murchison fields, and the export riser which sent the same oil on to Cormorant Alpha and the Sullom Voe terminal on Shetland; and
- Leg D contains spare riser facilities.

The four transitions are constructed from stiffened steel plates, which rise above the sea surface to the underside of the topsides (where they meet the MSF). The steel transitions are bolted and grouted into the top of the concrete legs. The transitions on Legs C and D are conical in construction, weighing approximately 500 tonnes each, and change in cross section from approximately 6 m diameter at the top of the concrete legs to approximately 8.7 m square at the underside of the MSF. The other two steel transitions (on Legs A and B) are cylindrical in construction, weighing approximately 295 tonnes each and are 5.4 m in diameter changing to a 5.4 m square section at the deck underside. This is represented graphically in Figure 2.4.

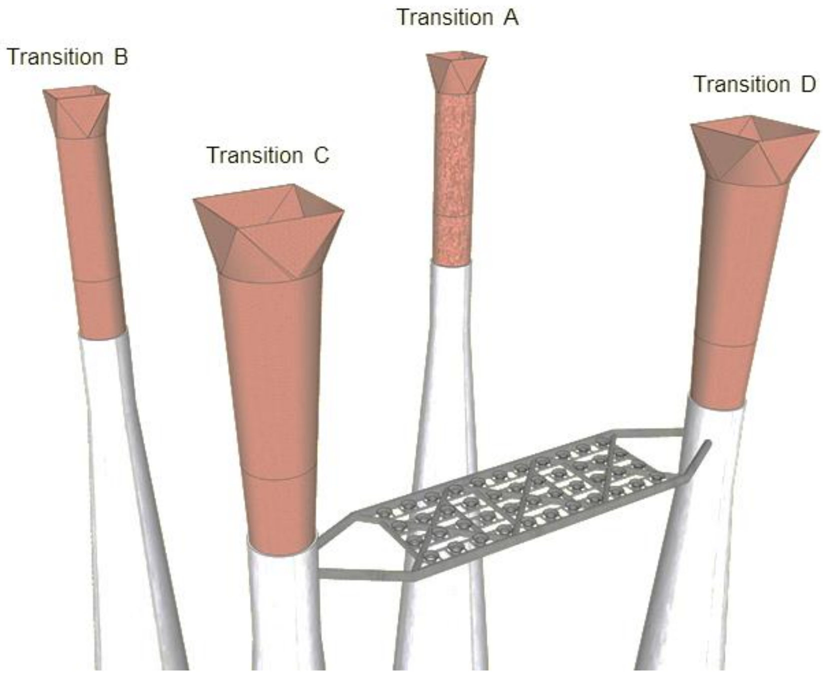


Figure 2.4 Transitions at the tops of the concrete legs (topsides and conductors not shown)

The Leg A and Leg B transitions are connected to the concrete legs with one external row of 40 bolts, plus two internal rows of 40 bolts of the same size (120 bolts in total per leg). The Leg C and Leg D transitions are connected to the concrete towers with two external and two internal rows of bolts totalling 160 bolts per leg.

Spanning between Legs C and D are three horizontal steel guide frames, which contain the well conductors in a 12 x 4 matrix. The function of these frames is to provide horizontal support to the 48 well conductors against wave action forces. Each of the three frames weighs approximately 200 tonnes.

The CGBS base caisson, which is 32 m high, is divided into 81 compartments, referred to as cells. Each cell is 11 m square and arranged in a 9 x 9 matrix as shown in Figure 2.5.

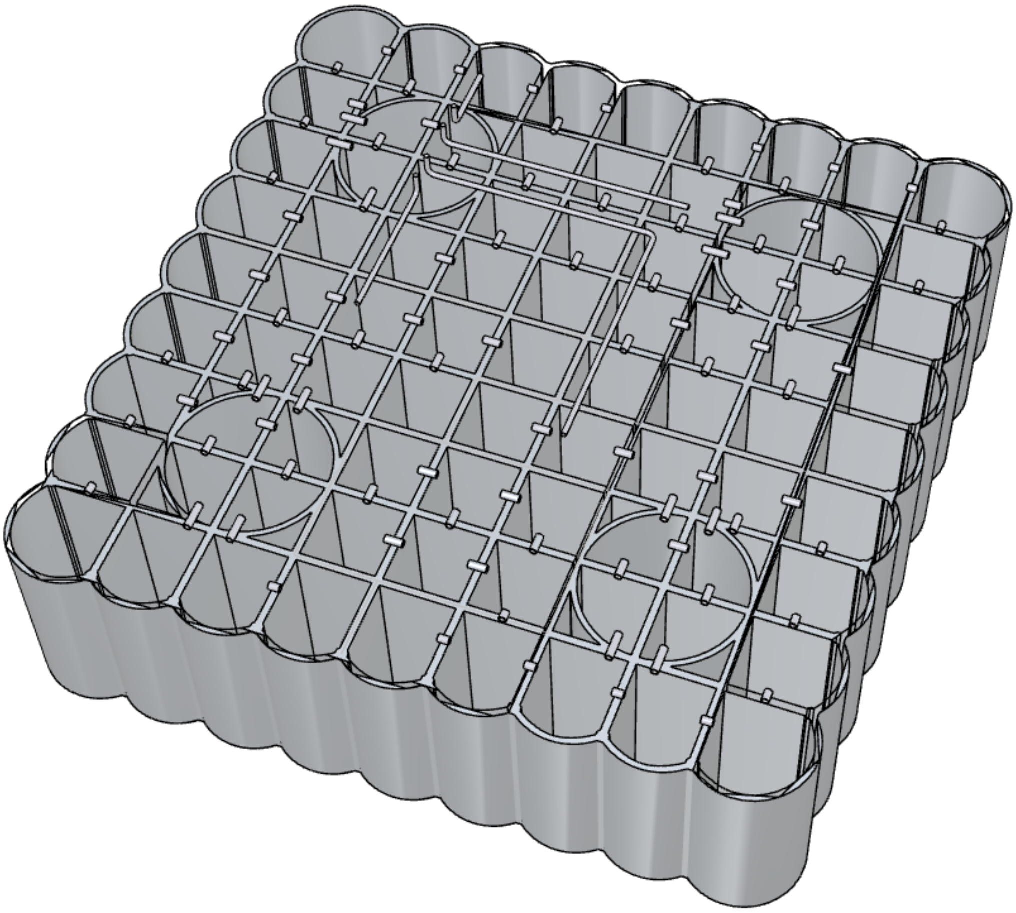


Figure 2.5 Cells in the CGBS (cutaway view)

Of the 81 cells, the original purpose of 75 of these was to provide additional separation of oil and water prior to oil export; this meant that fluids from the reservoir were pumped into a group of cells to allow the water and hydrocarbons to separate so that the hydrocarbons could be transported onshore for processing. Figure 2.5 shows the upper interconnecting ports within each cell, which allow the free movement of oil within individual cell groups.

Figure 2.6 provides an overview of how the CGBS storage cells are grouped and the location of the rundown lines (import/export pipework) to each cell group. A combination of the water distribution ringmain and lower interconnecting ports allow movement of water between the cells. The location of the lower ports is shown on Figure 2.6.

The remaining six cells, located between Legs C and D, were not used for oil and water separation and are filled with seawater. The 48 well conductors pass through these six cells, each conductor being protected by an outer carbon steel sleeve throughout the height of the base caisson. The six cells were designed to allow seawater to be pumped around the conductors to keep them cool.

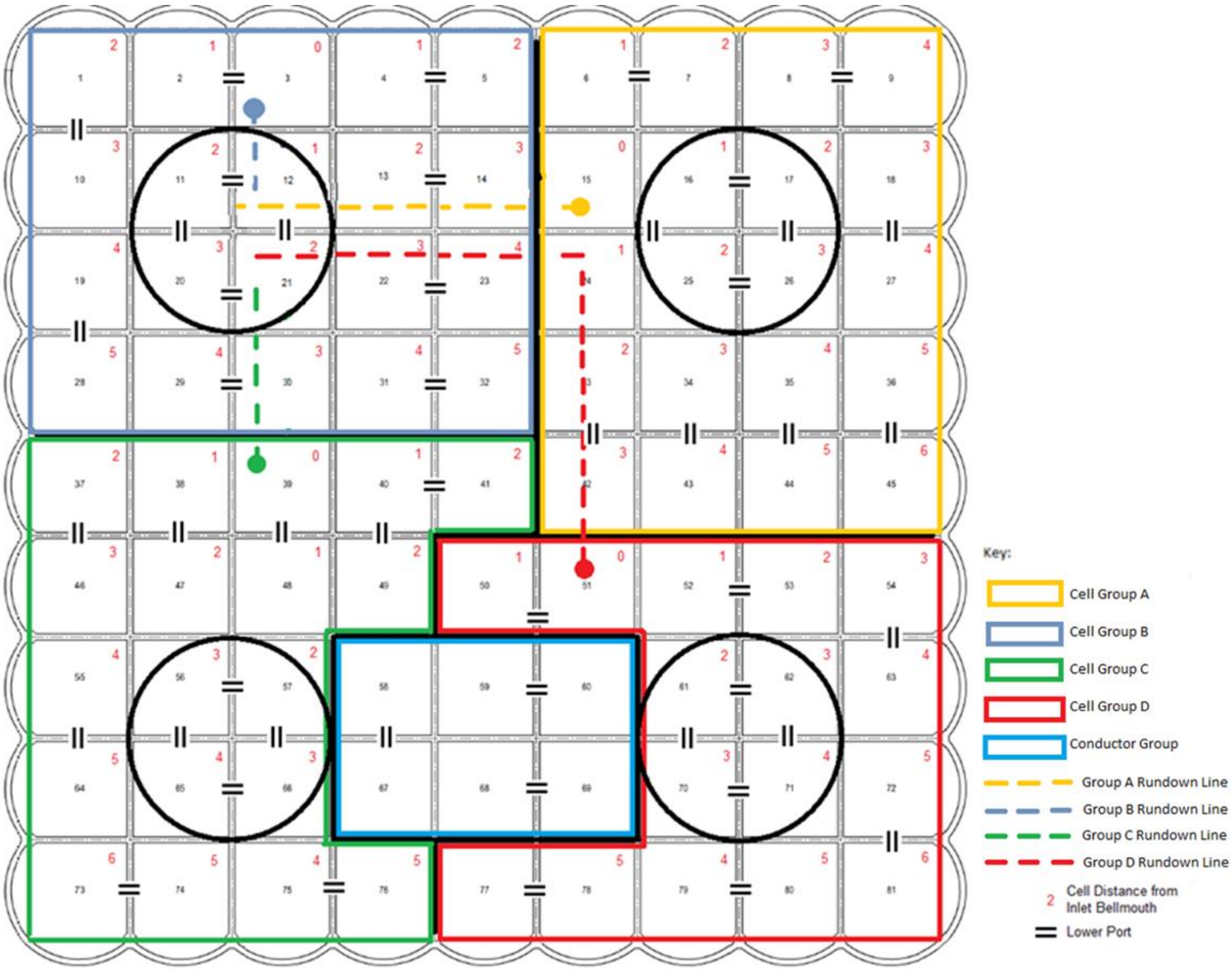


Figure 2.6 Configuration of the CGBS cell groups

There are four flat-topped cells underneath each platform leg. The foundations of the leg structures have created sixteen ‘triangle’ sections within these cells, which are open at the bottom. Figure 2.7 illustrates the stepped arrangement of the foundations and the sub-compartments created within these cells. Only six of these triangle cell sections have a communication port at the top to allow the free movement of oil between cells.

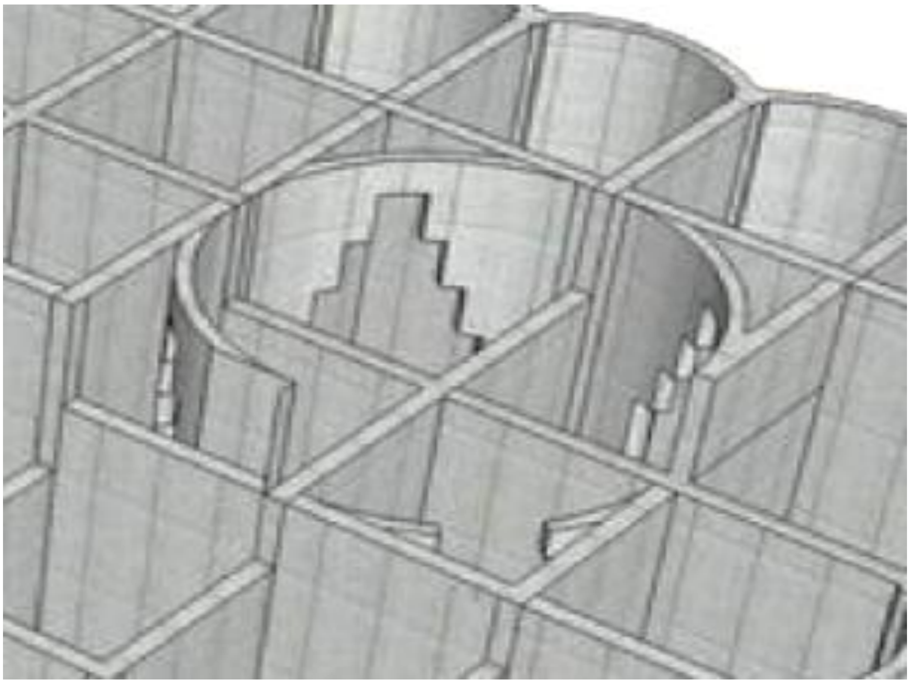


Figure 2.7 Triangle cells below CGBS leg structure

All of the other cells have dome roofs constructed of 0.8 – 2.5 m thick concrete. Figure 2.8 shows formwork within the internal structure of the cell tops that was used to support the construction of the concrete domed roofs. The formwork is a 6 x 6 lattice structure that effectively creates 36 further sub-compartments in the top of each individual domed roof.

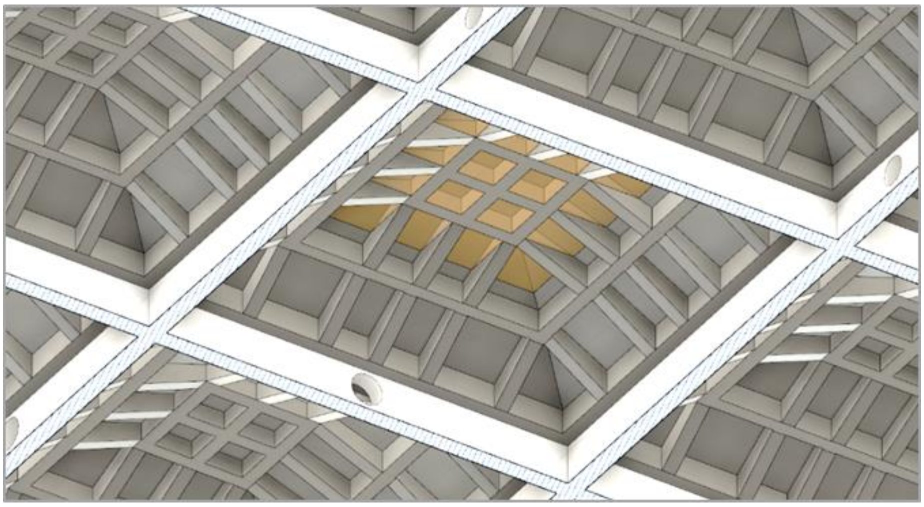


Figure 2.8 Formwork within the cell tops

Inside the bottom of each cell, secondary 4 m high concrete walls reinforce the base and sub-divide the bottom of each cell into nine compartments. These sub-compartments are filled with granular iron ore to act as ballast and are sealed with cement grouting. A stiffened steel plate wall runs around the outside perimeter of the base caisson to form a skirt, and penetrates the seabed to a depth of 4 m.

2.1.2. Cell Contents

2.1.2.1. Overview

The CGBS storage cells were historically used to provide additional separation and storage of reservoir fluids prior to oil export. During the early years of production, typically three of the four cell groups were used at any one time, allowing import to the first cell group, export from a second cell group and an extended period of settling in the third cell group. In the early years of platform operation, Cell Group D was used less frequently than the other three groups as it had a hydrogen sulphide (H_2S) contamination issue, which meant that use was restricted until the mid-nineties when the problem was resolved. All use of Cell Group A ceased in 1999 due to integrity issues.

The majority of material present within the cells (excluding seawater) will have originated from the reservoir, brought in as components of the produced fluids. These components include hydrocarbons (gas, oil and wax), inert particulate material (sand and clay) and scale. There will also have been limited contributions to the storage cells from the use of production chemicals and intermittent discharge of platform drains.

Continuous usage of the cells ceased in 1995 and all usage of the storage cells ceased in 2004. In 2007, a project was undertaken to recover the mobile oil remaining in the cells. The objective of the project was to recover both the residual stored oil from when the cells were taken out of operation, and the oil inaccessible by the existing platform pumps due to the position of the export pipework below the ceiling of the cells. This oil was termed 'attic oil' as the oil was sitting in the upper sections of the cell compartments.

As illustrated in Figure 2.9, the Attic Oil Recovery Project (AORP) was successfully able to generate carbon dioxide (CO_2) gas within the roof space of each cell group in order to push down the attic oil, thereby making it accessible. This was achieved by pumping Sodium Bicarbonate and Hydrochloric Acid into the cells in order to produce the required CO_2 gas.

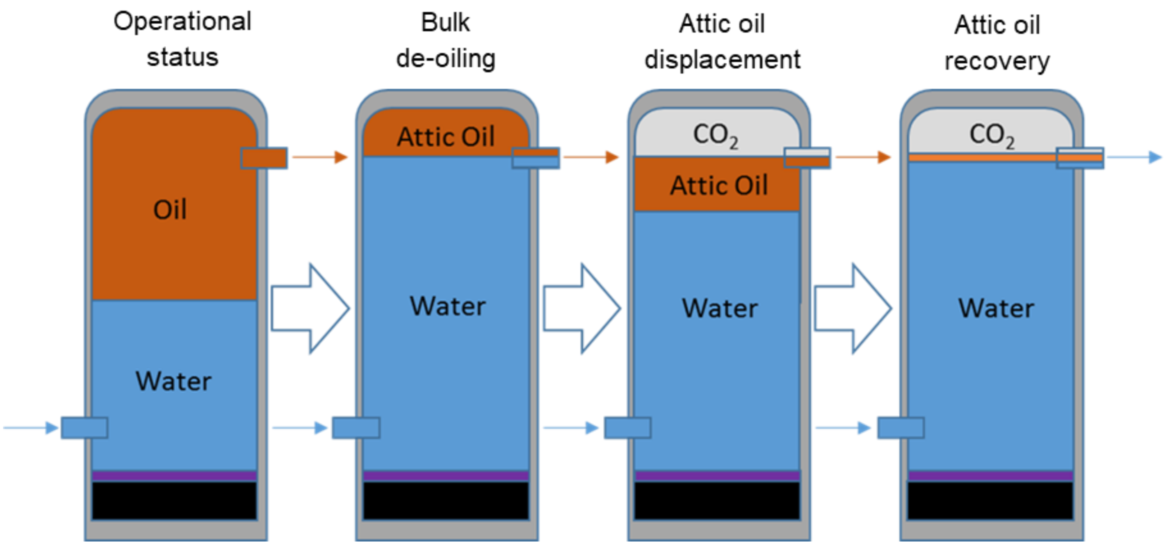


Figure 2.9 Overview of the Attic Oil Recovery Project

Removal of the oil was completed using a new set of temporary pumps that were able to draw off the oil at significantly reduced flow rates, in order to reduce coning effects. Coning describes the curvature of the oil-water interface into a 'cone' shape during export pumping, and is due to the different physical properties of the fluids and the velocity created by the pump suction; the higher the velocity the more pronounced the curvature (Figure 2.10). Coning will have resulted in the water at the water-oil interface being drawn into the export pipework, displacing the oil and leaving a relatively thin layer of residual oil in the cells. 'Cusping' is a phenomenon similar to coning whereby gas at the gas-oil interface is drawn into the export line, displacing the oil.

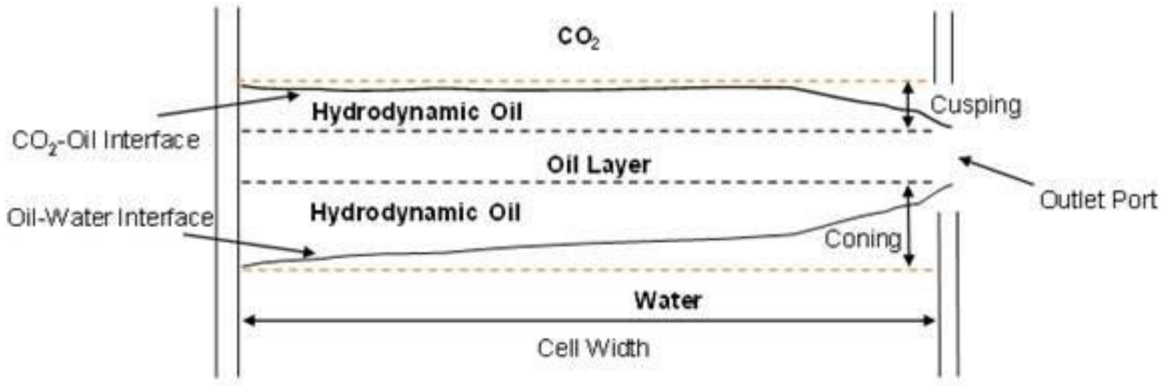


Figure 2.10 Schematic of oil, water and CO_2 interfaces upon completion of AORP

Pumping was performed until no further oil could be recovered, with physical detection of the CO_2 gas above the oil and the water layer below the oil. It should also be noted that there were no reported issues with emulsions during the pumping operations. Upon completion of the oil recovery, Ammonium Chloride, Methanol, and Potassium Hydroxide were injected into the storage cells in order to scavenge the excess CO_2.

Particulate material (sand and clay) within the reservoir fluids will have settled at the base of the cells, while scale and hydrocarbons will have deposited on the cell walls, roof and floors through physical and chemical processes. Other materials associated with these main component groups include organic and inorganic compounds, metals and naturally occurring radioactive material (NORM).

Fairfield has undertaken a comprehensive assessment of the residual materials contained within the CGBS storage cells. The Dunlin Alpha Cell Contents Technical Report (CCTR) (Fairfield, 2021a) provides a detailed analysis of the cell contents in order to quantify and characterise the residual materials within the storage cells. This information has been used to evaluate further recovery options, as well as assess potential environmental impacts associated with a release to the marine environment during, or after, the completion of decommissioning activities.

Table 2.1 summarises the base case estimated quantities of each phase across the entire CGBS storage cells (i.e. all production and conductor group cells).

Table 2.1 Summary of CGBS storage cell inventory

Phase	Quantity		Vol %
	Volume (m^3)	Tonnes	
Water Phase	227,385	233,069	96.0
Free Gas	6,825	45	2.9
Mobile Oil	1,100	954	0.4
Wall & Floor Deposits (Oil, Wax, Sand/Clay, Scale & Water)	1,610	2,494	0.7
Total	236,920	235,552	100

As Table 2.1 shows, the residual materials contained within the CGBS storage cells primarily consists of water (circa 96%) and free gas (circa 3%). Residual oil, wax, sand and clay make up approximately 1% of the overall volume. This is illustrated in Figure 2.11.

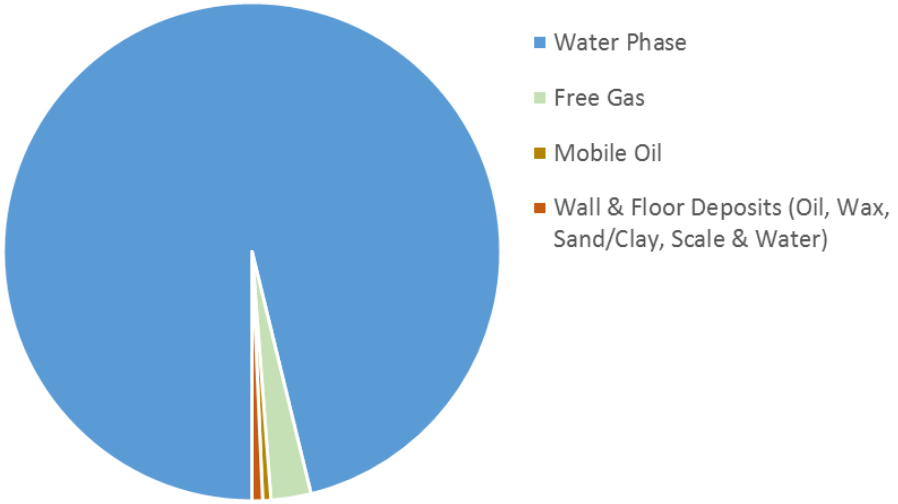


Figure 2.11 Summary of CGBS storage cell inventory

2.1.2.2. Cell Contents Survey and Sampling Programme

Between 2018 and 2020, topsides based survey and sampling operations were undertaken in order to attain further cell contents data and validate the base case inventory estimates used to inform management options. Initial investigation of the connecting pipework to the cells (referred to as rundown lines) revealed that there were significant volumes of free gas still contained within the cells. Observations from subsequent venting activities showed that the gas resided as a distinct gas cap within the tops of the cells, although an appreciable volume of gas would also be dissolved in solution in both the oil and the water phase. Figure 2.12 provides a representation of the residual cell contents.

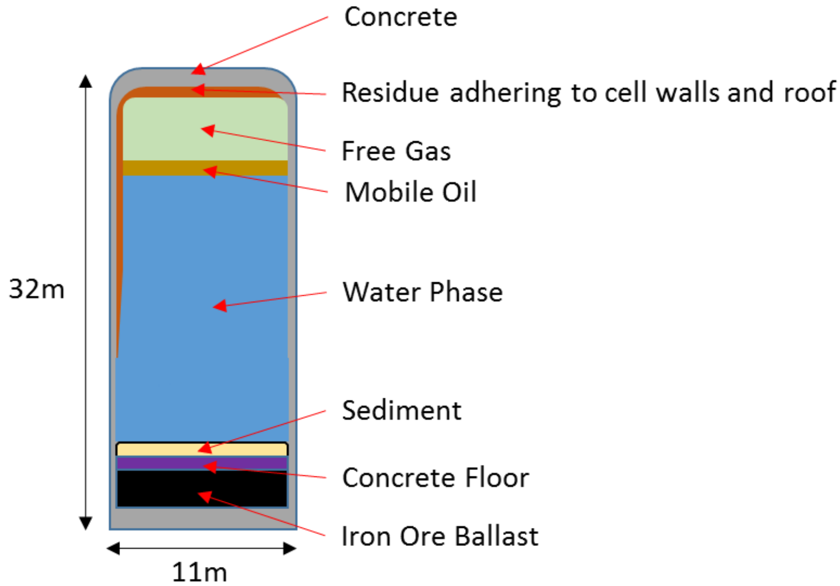


Figure 2.12 Representative schematic of a cell and residual contents (not to scale)

The gases were found to contain high concentrations of both Hydrogen Sulphide (H_2S) and Carbon Dioxide (CO_2), which presented a considerable safety hazard to personnel working within the leg. It is believed these gases are due to a combination of the residual CO_2 from the AORP and biological activity breaking down the remaining hydrocarbons.

The presence of gas in the cell groups has posed a significant challenge for completing the topsides based survey and sampling programme, mainly due to system integrity and challenges encountered in managing the residual gases within the storage cells and rundown lines. However, the presence of gas has also provided useful data on the status of the cells as well as enabling some further recovery of residual oil. In 2019 and 2020, gas venting and liquid pumping operations were successfully carried out on all of the rundown lines to check their contents and obtain a range of samples. A summary is provided in the sections below.

Cell Group A

Venting of the free gas was initially performed in 2018, with a further short venting operation in 2019 to reduce the pressure building up in the rundown line. The large volumes of gas extracted during the venting operations demonstrate that a free gas cap exists in line with interconnecting ports, positioned at the upper elevation of the horizontal rundown line pipework.

Throughout these operations there was no evidence of hydrocarbon contamination. If there was an appreciable oil inventory within the cells, this would have migrated up the rundown line and be evident physically and also through the pressure characteristics. In 2020 a suite of water samples were taken, further indicating that there is no appreciable oil layer. Any residual 'hydrodynamic' oil layer would be less than 3cm thick.

Cell Group B

There is a mechanical plug umbilical in rundown line B which reduces the pipework diameter to two inches. Initial pumping operations commenced in 2018 but were ceased after a high gas pressure developed in the line and prevented further liquid flow. Gas venting was undertaken in 2018 and 2019, and observations of liquid carryover indicated that there was a thin layer of residual hydrocarbons within the cells.

The position of the gas cap in cell group B meant that the residual oil layer was potentially recoverable, but would require a liquid handling system capable of managing the fluids and associated gas. A bespoke engineered system was designed and commissioned in early 2020, and approximately 45 m^3 of oil was successfully recovered before operations were forced to cease due to the global Covid-19 pandemic.

When operations recommenced, it was discovered that the line had completely blocked during the three month period that the system was shut-in. As a result, only two of the intended batches of oil samples were able to be taken and the water sampling operations were unable to be performed due to the blockage of the umbilical line. However, evidence of both the gas phase above the oil layer and water phase below indicates that the oil layer is no thicker than the diameter of the 3" valve at the end of the umbilical.

Cell Group C

Cell Group C operations involved venting off the cell gas cap and then recovering the residual chemicals and hydrocarbons from the rundown line to allow sampling of the oil and water. In total, approximately 33 m^3 of oil, 3 m^3 of chemicals and 6 m^3 of water were recovered. To aid recovery, the level of the standpipe in Leg A was raised to increase the system pressure. This also allowed the residual oil layer thickness to be measured by the water breakthrough that was observed when the standpipe was at an elevation of approximately 71.6 m. Evidence of both the gas phase above the oil layer and water phase below means that the oil layer is no thicker than 5 cm.

Cell Group D

Initial pumping operations commenced in 2018 but were ceased due to safety concerns when higher than expected concentrations of H_2S were detected. Pumping recommenced in 2020 after installation of the newly engineered temporary processing system.

During the pumping operations, nearly 19 m^3 of oil was recovered and approximately 3 m^3 of water was recovered and sampled. The oil is understood to have migrated along the horizontal section of the rundown line pipework within the cells as changes were made to the system operating pressure.

The topsides based survey and sampling scopes successfully retrieved physical samples of both oil and water fluids but were unable to obtaining samples of the sediment or wall residue materials, and no additional survey data from within the storage cells was obtained to validate the inventory basis. However, the pressure characteristics, the presence of water, and data on the volume of gases within the cells has provided supporting evidence about the amount of residual oil within the rundown lines and therefore cells. It has also been concluded that no further oil can be recovered via the A, B, C & D rundown lines.

2.1.2.3. Characterisation of Cell Contents

The following sections provide a summary of the base case estimates for the quantity, physical and chemical properties, and distribution of the residual cell contents. The information has been derived from evidence gathered from operational records, analysis of historical samples, analogous data, and the application of proven scientific principles.

Uncertainty in the base case estimates has been addressed by incorporating conservative, worst case assumptions where applicable. The methodologies used to determine the estimates and uncertainties associated with the input data, including how these have been addressed, are provided in Appendix A. Further details of the Dunlin Alpha cell contents are provided in the Dunlin Alpha Cell Contents Technical Report (CCTR) (Fairfield, 2021a).

2.1.2.4. Free Gas

Free gas within the CGBS storage cells is made up of the following:

- Residual carbon dioxide left behind upon completion of the AORP;
- Gases created through biological breakdown of the residual hydrocarbons under both aerobic and anaerobic conditions, predominantly carbon dioxide and hydrogen sulphide;
- Light end hydrocarbons from the historically processed oil that was transferred to storage could exist if the oil was not properly stabilised to reduce the oil vapour pressure; and
- Hydrocarbons, which have weathered over time, and diffused light ends from the residual oil layer and the floor or wall deposits.

Whilst it is anticipated that the gas is fairly evenly distributed within a cell group, there are some cells that contain more gas than others. The variation in the gas quantities can be explained in a number of ways:

- The cells with domed tops will have a larger free gas volume than those underneath the legs, which have flat tops; and
- The outer edge and corner cells physically have smaller attic volumes and therefore will have a smaller free gas volume.

As well as a distinct gas cap within the tops of the cells, there will also be appreciable volumes of gas dissolved in solution in both the residual oil and water phases. The free gas phase and the gas in the liquid phases are in equilibrium with one another.

Further details of the composition, quantity and distribution of free gas within the CGBS storage cells are provided in Appendix A.1. A summary of the cell-to-cell variation of gas characteristics is given in Table 2.2.

Table 2.2 Summary of gas characteristic variation from cell to cell

Parameter	Units	Minimum	Maximum
Free Gas Volume (@ approx. 4 bar·g)	Am^3	30	138
Maximum depth of Gas in Attic Space	m	1.0	2.6
Carbon Dioxide (CO_2) Concentration	Vol%	2	95
Light End Hydrocarbon Concentration	Vol%	4	96
Hydrogen Sulphide (H_2S) Concentration	ppm	91	>10,000

2.1.2.5. Mobile Oil

The mobile oil phase is assumed to be made up from the following:

- Residual oil left behind upon completion of the AORP executed in 2007.
    - Residual oil could also contain:
        - Fluids from the topsides drain system such as solvents and effluents from cleaning, lubricating and hydraulic fluids, cooling fluids, etc.
        - Trace quantities of chemicals such as demulsifiers injected into the topsides processing system.
        - Heavy metals.
- Hydrocarbons which have diffused over time from the sediment layer on the floor.

Upon completion of the AORP there will have been only a relatively thin layer of residual oil within each cell. An estimate of the mobile oil volumes has been made for each storage cell. While it is expected that the oil will be evenly distributed within a storage group, there are some cells that may be more contaminated with mobile oil than others. The variation in the oil quantities can be explained in a number of ways:

- Cells with higher sediment accumulation will have more oil trapped, which will diffuse and travel into the mobile oil phase slowly over time. Where the free gas cap above the oil layer holds it in communication with the interconnecting port, the oil will evenly redistribute across the cell group. If the gas cap has been released or diminished, then the oil will migrate to the cell tops into the pockets created by the formwork.
- The orientation and configuration of the rundown line pipework hinders effective oil recovery in some of the cell groups. With Cell Group B being limited by the narrow umbilical where the fluids and Cell Group D limited by the slope in the pipework created by the platform tilt, i.e. the platform does not sit perfectly horizontally.
- Cells underneath the leg with the triangle sections without the connecting upper port have approximately 45 m^3 of trapped oil per cell.

Further details of the composition, quantity and distribution of mobile oil within the CGBS storage cells are provided in A.2. A summary of the cell-to-cell variation of mobile oil characteristics is given in Table 2.3.

Table 2.3 Summary of oil characteristic variation from cell to cell

Parameter	Units	Minimum	Maximum
Mobile Oil Volume	m^3	2.45	57.24 Note 1
Depth of Oil in Attic Space	m	0.02	0.12
BTEX	kg	31.3	730.5
PAH	kg	1.8	41.7
Heavy Metals	kg	0.01	0.22
Chemicals	Kg	0.09	1.98

Note 1. Includes 45m^3 trapped in inaccessible triangle sub-compartments

Emulsions

Based on the knowledge of the topsides process, historic production chemical requirements and recent observations of the nature of the fluids within the cells, there is no appreciable oil-water emulsion build-up within the cells.

There was no evidence of emulsions during AORP in 2007, and during the most recent cell sampling operations only one sample from rundown line C showed any emulsion. The emulsion in this sample was less than 0.15vol% and is likely to be due to the residual mothballing gel chemicals present rather than anything inherent in the mobile oil. It should be noted that oil and water can only form a stable emulsion where there are impurities in the form of particulates or other chemical species. It is likely that the main reason that there are no emulsions is because Dunlin fluids don’t have high solids loading.

2.1.2.6. Material Adhered to Walls and Ceiling (Wax)

As produced fluids entered the storage cells, they mixed with the cooler water phase within the cells. This mixing resulted in a temperature reduction of the produced fluids and, if the resulting temperature was below the wax appearance temperature, solid wax formed within the fluid. Residual wax contents within the cells are most likely due to the temperature drop between the bulk fluid within the cells and the external cell walls, which would drive deposition of wax onto the cell roof and walls. Other mechanisms would have resulted in the wax being discharged from the cells during operational use or drawn down to the base of the cells by heavier sand/clay particles.

A base case estimate of the wall residue volumes has been made for each storage cell. It is expected that the wall residue deposition will be most concentrated on the inside of the external perimeter cell walls. There will also be additional wax inventory in Cell Groups B and D because of the wax pellets injected into the cells during the AORP.

Further details of the composition, quantity and distribution of wall residues within the CGBS storage cells are provided in Appendix A.3. A summary of the cell-to-cell variation of wall residue characteristics is given in Table 2.4.

Table 2.4 Wall residue characteristic variation from cell to cell

Parameter	Units	Minimum	Maximum
Deposited Wax Volume	m^3	1.40	5.73
Thickness of Residue Layer	mm	0.0056	0.0231
Heavy Metals	kg	1.40	5.73

2.1.2.7. Water

The water in the CGBS storage cells consists predominately of seawater. Dissolved contaminants will also be present in the water phase as a result of:

- Chemical reactions within the cells altering major components of the water phase;
- Chemical reactions within the cells causing precipitated materials to go into solution;
- Unaltered components in the residual material dissolving into the water;
- Water soluble chemicals being introduced during platform operations from the processing system including those introduced to the drainage system; and
- Chemicals added during the AORP.

Further details of the composition, quantity and distribution of the water content within the CGBS storage cells are provided in Appendix A.4. A summary of the cell-to-cell variation of water content characteristics is given in Table 2.5.

Table 2.5 Summary of water content variation from cell to cell

Parameter	Units	Minimum	Maximum
Water Phase Volume	m^3	2,567	3,406
THC	kg	52.3	289.5
BTEX	kg	6.88	9.13
Heavy Metals	kg	0.168	0.223
Chemicals	kg	2.11	2.80

2.1.2.8. Sediment

The sediment phase is considered to be composed of the following materials:

- Sand and clays;
- Hydrocarbons in the form of oils and waxes;
- Small quantities of naturally occurring contaminants such as heavy metals and low specific activity (LSA) scale or naturally occurring radioactive materials (NORM); and
- Water;
  - The water could contain fluids from the topsides drain system such as lubricating oils, solvents/cleaning compounds and cooling fluids, etc.; and
  - Residual quantities of production chemicals may be present.

The movement of fluids within the storage cells, the settling velocity of sediments, and buoyancy (as a result of being coated in oil) will have influenced how the solids entering the system will have distributed over time. Information on sediment particle size was obtained from analysis of sediment samples taken from topsides separators during cleaning operations, and used to determine how the particles would be deposited across the cells. This is strongly influenced by how the cells are interconnected and the distance (>10m) between cells, meaning that the majority of the particles would settle in the first cell, with some particles pulled through to the second cell via a lower interconnecting port

Further details of the composition, quantity and distribution of sediment within the CGBS storage cells are provided in Appendix A.5. A summary of the cell-to-cell variation of sediment characteristics is given in Table 2.6.

Table 2.6 Sediment characteristics variation from cell to cell

Parameter	Units	Minimum	Maximum
Sand/Clay Volume	m^3	1.0	32.7
Scale Volume	m^3	0.6	2.8
Hydrocarbon Volume	m^3	1.0	32.7
Water Volume	m^3	1.0	32.7
Depth of Sediment	m	0.04	0.9
Heavy Metals	kg	26.6	53.8
NP/NPE	kg	<0.003	<1.13

2.1.2.9. Summary

The CGBS storage cell inventory has been further broken down in Table 2.7 to summarise the base case inventory estimate within each individual cell group.

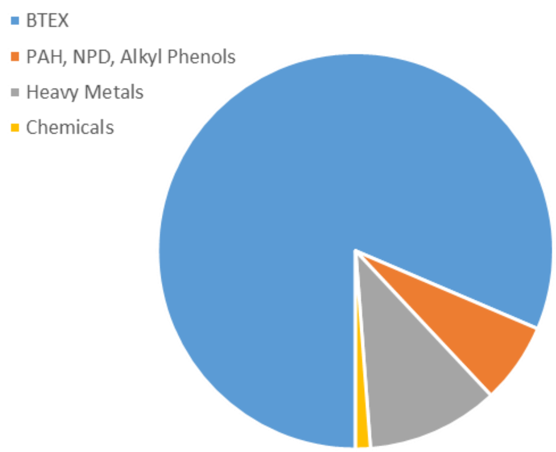
Table 2.7 Summary of base case cell contents for each group

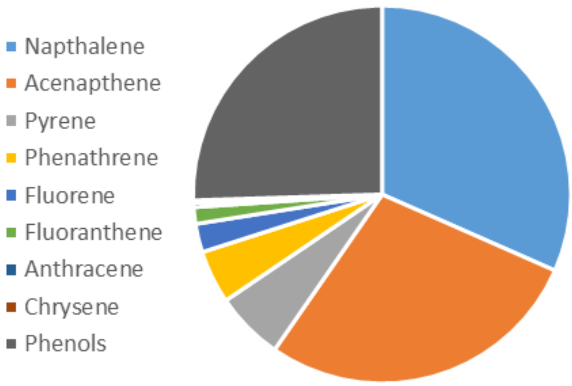
Cell Group	No of Cells	Free Gas Volume (Am^3 @ approx. 4 bar·g)	Mobile Oil Volume (m^3)	Sediment Volume (m^3)	Wall Deposits Volume (m^3)	Water Volume (m^3)
A	20	1,642	138	284	131	56,402
B	20	2,352	314	378	129	55,424
C	19	1,571	291	378	52	53,613
D	16	1,261	358	208	49	45,579
Conductor	6	0	0	0	0	16,475
Total	81	6,825	1,100	1,248	361	227,493

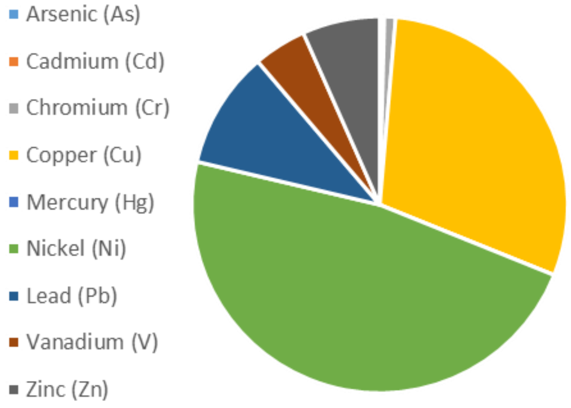
Within each of the phases, there will be quantities of PAH, BTEX, heavy metal and chemical components. Table 2.8 summarises the total mass of contaminants within the structure and Figure 2.13 illustrates the relative distribution of hydrocarbon contamination within the CGBS storage cells

Table 2.8 Summary of PAH, NPD, Alkyl Phenols, BTEX, Heavy Metal and Chemical Component Inventory

Component	Mass (tonnes)	%
Benzene	2.339	8.640
Toluene	5.608	20.700
Ethylbenzene	4.405	16.200
Xylenes (o,p,m)	9.771	36.100
Total BTEX	22.12	81.74
Napthalene	0.5654	2.090
Acenapthene	0.5017	1.850
Pyrene	0.1050	0.388
Phenathrene	0.0815	0.301
Fluorene	0.0437	0.161
Fluoranthene	0.0253	0.093
Anthracene	0.0065	0.024
Chrysene	0.0038	0.014
Phenols	0.4562	1.680
Total PAH, NPD and Alkyl Phenols	1.789	6.60
Arsenic (As)	0.0079	0.029
Cadmium (Cd)	0.0038	0.014
Chromium (Cr)	0.0281	0.104
Copper (Cu)	0.8717	3.220
Mercury (Hg)	0.0002	0.001
Nickel (Ni)	1.395	5.150
Lead (Pb)	0.2957	1.090
Vanadium (V)	0.1336	0.493
Zinc (Zn)	0.1957	0.723
Total Heavy Metals	2.932	10.82
O_2 Scav, Scale Inh. & Demuls	0.2235	0.825
NP/NPE	0.0121	0.045
Total Chemicals	0.236	0.87
Total Mass	27.1	100







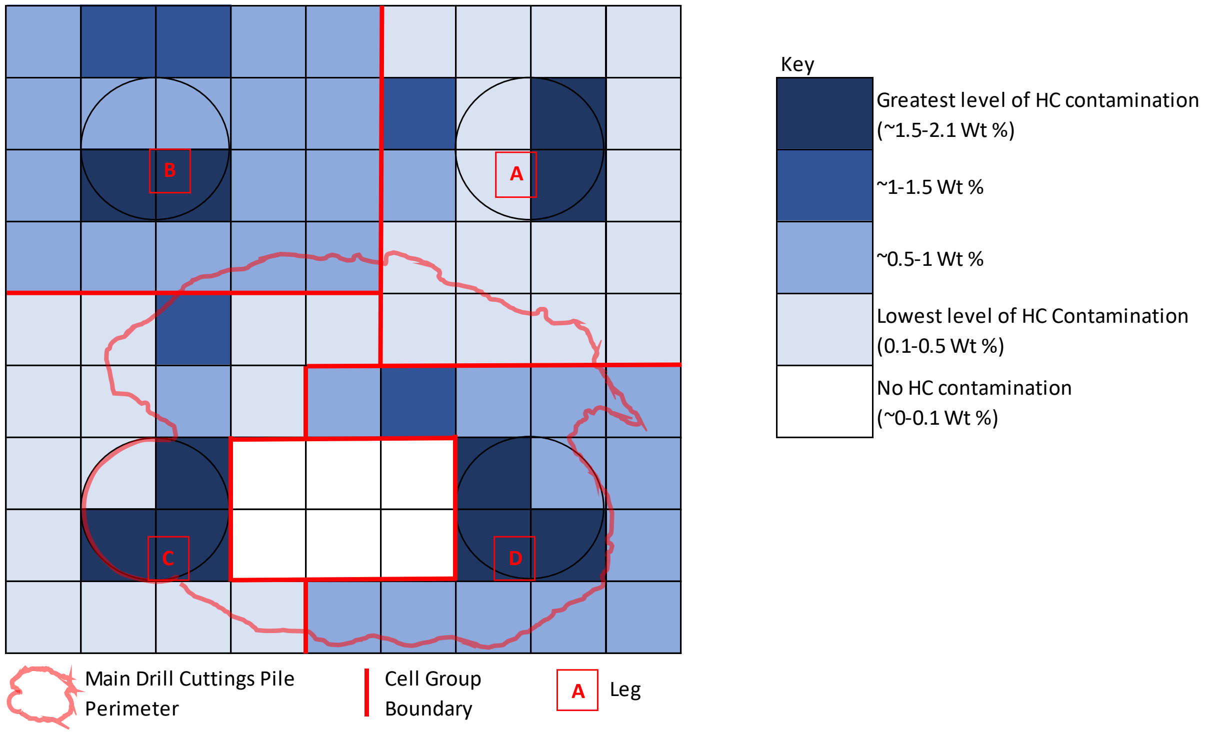


Figure 2.13 Distribution of hydrocarbon contamination with the CGBS storage cells

2.1.3. Drill Cuttings

During the drilling of a well, drill cuttings are generated by a drill bit which break formations into small pieces. These cuttings are then lifted and transported by the drilling fluid, which is pumped through the drill bit nozzles, circulating them to surface. If not directly discharged, the mixture of cuttings and drilling fluids are processed at surface via the solids control system, whereby the fluid is separated from the cuttings to be reused and the cuttings disposed of. In total, 733,126 ft (223.45 km) of formation was drilled from the Dunlin Alpha platform, equating to an estimated 75,949 tonnes of drill cuttings, of which over 99% were discharged on site.

Shortly after the Dunlin Alpha platform was installed, drilling commenced in August 1977 with the 30" conductors drill-driven into the seabed using spud mud[2] and occasional Hi-Vis sweeps[3]. The 26" hole sections were also drilled with the same fluid and, in order to protect the formation from fracturing with the circulating pressure, the cuttings were discharged through slots in the 30" conductor above the CGBS. A number of the top hole (30" conductor and 26") sections were drilled as part of a series of batch setting campaigns, generating approximately 19,265 tonnes of drill cuttings (25% of the total discharged).

Drill cuttings from the 17½" hole sections onwards, were returned to the platform via the circulating system to the shale shakers on the platform topsides. Here, the drilling mud and cuttings were separated, with the mud recovered for reconditioning and reuse, whilst the cuttings were routed to the cuttings chute following limited cleaning. The cuttings chute on Dunlin Alpha was hooked up to an unused conductor in Slot 41, which fed through the three conductor guide frames, terminating at 80 m below LAT. From here, cuttings fell 38 m to the top of the CGBS, eventually spilling over the south side of the CGBS and down to the seabed a further 32 m below.

[2] A simple fluid of seawater, natural formation solids
[3] Containing carboxylmethyl cellulose

The 17½" hole sections onwards were drilled with four fluid systems. Invert Oil Emulsion Mud (IOEM) was used as the main drilling fluid and accounted for around, 44,093 tonnes of discharged cuttings (58% of the total). Two main Water Based Mud (WBM) systems were also utilised, namely, a potassium chloride or gypsum lignosulfate polymer. During the drilling activity, these had accounted for approximately 12,592 tonnes of cuttings generated (17% of the total volume discharged). The final mud system used was a Low Toxicity Oil Based Mud (LTOBM), although the 669 tonnes of cuttings generated with this fluid were not discharged. This was due to the enforcement of the OSPAR Decision 2000/3, on the Use of Organic-phase Drilling Fluids (OPF) and the Discharge of OPF-contaminated cuttings, prohibiting the discharge of drill cuttings contaminated with more than 1% oil by weight of oil-based fluids on dry cuttings. After this regulation was implemented in 2001, only limited drilling was undertaken on the Dunlin Alpha, accounting for less than 1% of the total volume of cuttings generated from drilling activity.

In 2016, Fairfield undertook a pre-decommissioning drill cuttings survey to assess the status of the drill cuttings pile at Dunlin Alpha . The purpose of the drill cuttings assessment was to determine the most appropriate course of action with regards to the long-term management of the cuttings pile. Key to this assessment was consideration of OSPAR Recommendation 2006/5 on Management Regime for Offshore Cuttings Piles. This Recommendation describes two thresholds against which cuttings piles can be compared; one relates to the length of time and the size of the area over which the cuttings pile will remain (known as 'persistence') and the other is the rate at which oil comes out of the cuttings pile over time (known as 'leaching') (OSPAR, 2006).

A drill cuttings sampling strategy was developed collaboratively by Fairfield, Fugro and Xodus Group, in consultation with OPRED. The strategy was developed in accordance with the OLF 'Guidelines for Characterisation of Offshore Drill Cuttings Piles' (OLF, 2003) and, although the survey and sampling campaign was undertaken prior to its publication, the sampling strategy is also compliant with the 2017-03 guidelines on survey/sampling of cuttings piles from OSPAR.

Multi-beam echo sounder (MBES) surveys were undertaken to determine the area, topography and volume of the pile. Figure 2.14 shows that the cuttings are located on the south-east part of the CGBS and on the seabed against the south-eastern side of the CGBS. The average depth of cover within the entire Dunlin drill cuttings deposition area is 2.48 m, whilst the maximum thicknesses of the CGBS and seabed cuttings piles are 12.9 m and 12.8 m, respectively. The estimated total volume of cuttings for the Dunlin Alpha cuttings pile across the CGBS and seabed is 19,555 m^3 (48,888 tonnes).

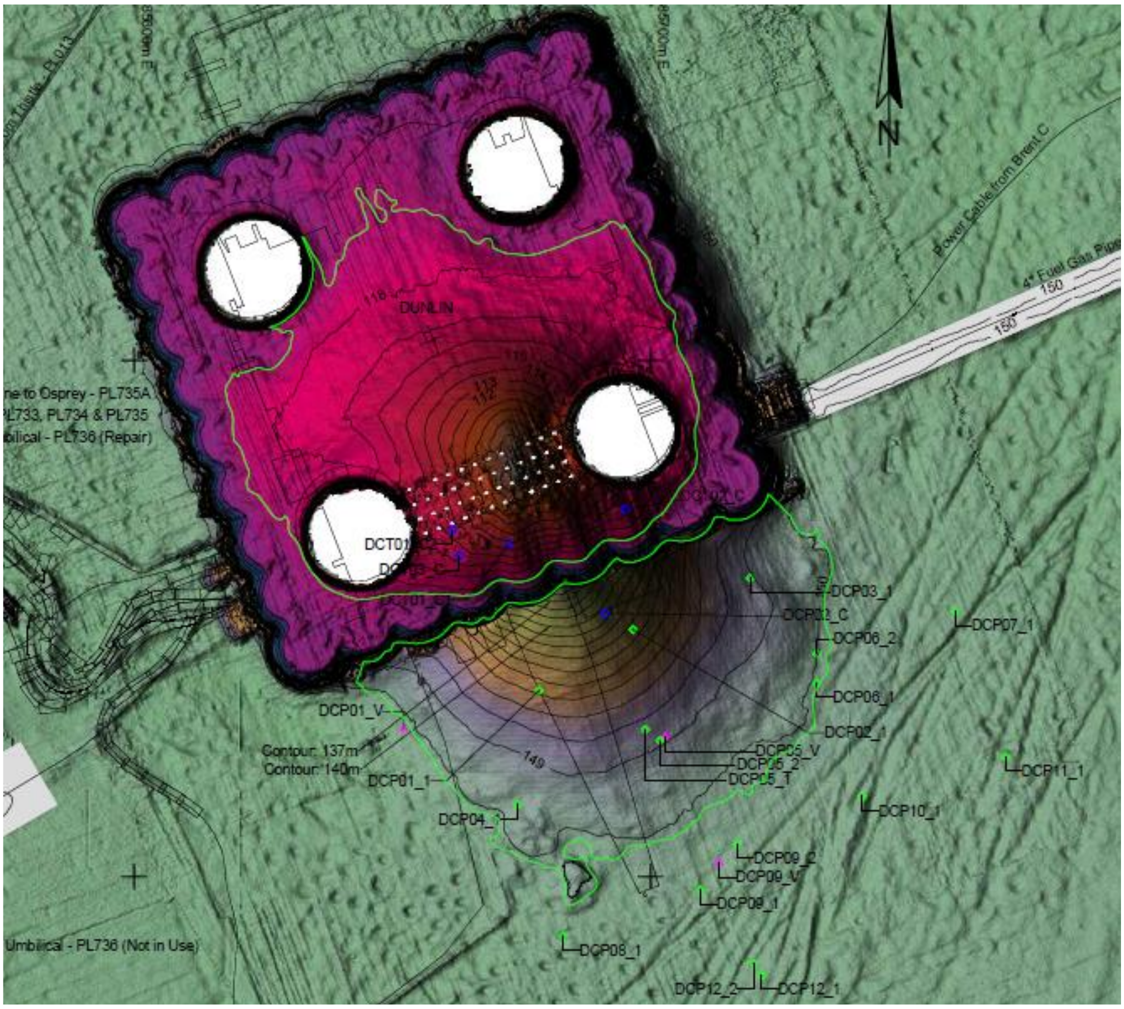


Figure 2.14 Drill cuttings profile at the Dunlin Alpha platform

The MBES data were used to select locations for the collection of grab samples and core samples (up to 4 m in depth). The aim was to collect a range of samples from different parts of the cuttings pile and from different sediment depth horizons to generate a dataset that describes the physical and chemical characteristics of the cuttings deposits around Dunlin Alpha. The collected samples were analysed for physio-chemical characteristics, a range of chemical components (heavy metals, PAHs, hydrocarbons, PCBs, AP, APE, and organotins) and macrofauna. Further details of the sampling strategy and results of sample analysis are provided in Section 4.2.3.

Modelling and detailed assessment of the Dunlin Alpha cuttings pile was undertaken in 2018 by Fairfield and summarised in a technical report (Xodus, 2018). The report concluded that the cuttings pile does not exceed the OSPAR Recommendation 2006/5 thresholds regarding the expected persistence and rate of loss of oil. The results of the assessment, given in Table 2.9, show persistence (47.4 km^2.year) to be below the 500 km^2.year threshold and oil loss (0.78 – 1.75 tonnes) to be below the 10 tonnes per year threshold specified by OSPAR (2009a). Further information on these values, and of the potential environmental impact of future potential disturbance of these piles, is given in Section 5.3.2.

Table 2.9 Estimates of Dunlin cuttings piles in the context of the OSPAR 2006/5 thresholds

Site	Persistence (km^2.year)	Yearly oil loss (tonnes)
Total area of cuttings	47.4	0.78 – 1.75
OSPAR threshold	500	10

2.1.4. Summary of Facilities

Table 2.10 provides a summary of the substructure and the weight of material associated with the facilities to be decommissioned, as described in the previous sections.

Table 2.10 Approximate weights of the Dunlin Alpha substructure

Section	Weight (tonnes)
Transitions	1,590 Note 1
Conductors (x 48)	4,030
Conductor guide frames (x 3)	570
Concrete legs	34,500 Note 1
Leg internals	1,250
Base caisson	202,000 Note 1
Storage cell contents	235,552 Note 2
Iron ore ballast	96,800 Note 1
Seabed skirt	1,450 Note 1
Drill cuttings	48,888
Total	**626,630**

Note 1: Structural weights include a 5% contingency.
Note 2: Figure includes total weight of free gas, mobile oil, wall residue, water, and sediment phases. See Section 2.1.3.

2.2. Consideration of Alternatives and Selected Approach

Note: This section summarises the Comparative Assessment undertaken for the Dunlin Alpha substructure; full details of the process and data used to inform decision-making is available in the Dunlin Alpha Comparative Assessment Report (Xodus, 2021).

2.2.1. Alternatives to Decommissioning

The Dunlin Alpha installation supported production from the Dunlin, Merlin and Osprey fields. Options to reuse the infrastructure *in situ* for future hydrocarbon developments and for carbon sequestration opportunities were assessed but did not yield any viable commercial or environmental opportunity. There are a number of reasons for this, including the absence of remaining hydrocarbon reserves in the vicinity of the Greater Dunlin Area, and the age and integrity of the infrastructure, and its distance to the mainland, introducing various prohibitive technical, environmental and safety risks. It is now considered unlikely that any opportunity to reuse the Dunlin Alpha installation will be feasible. As such, there is no reason to delay decommissioning of the Dunlin Alpha installation in a way that is safe and environmentally and socio-economically acceptable.

2.2.2. Options for Decommissioning of the Concrete Gravity Based Substructure (CGBS)

OSPAR Decision 98/3 states that the dumping or leaving in place of disused offshore installations within the maritime area is prohibited. However, the Dunlin Alpha substructure is a concrete gravity based installation, meeting the criteria set out in OSPAR Decision 98/3 as a potential candidate for derogation where 'an alternative decommissioning solution is preferable to full removal for the purpose of reuse or recycling or final disposal on land'.

In accordance with the UKs obligations described within OSPAR Decision 98/3 and the OPRED decommissioning guidelines, Fairfield has followed a formal process of CA to allow for the development of a preferred decommissioning methodology, based on consideration of safety risk, environmental impact, technical feasibility, societal impacts and economic factors.

An initial screening of feasible decommissioning options was undertaken in order to identify options to be carried forward for formal evaluation. This process screened the initial nine options identified down to four, illustrated in Figure 2.15, which were carried forward to the evaluation phase of the CA. The screening performed is detailed fully in the Dunlin Alpha Decommissioning Option Screening for Comparative Assessment Report (Fairfield, 2016).

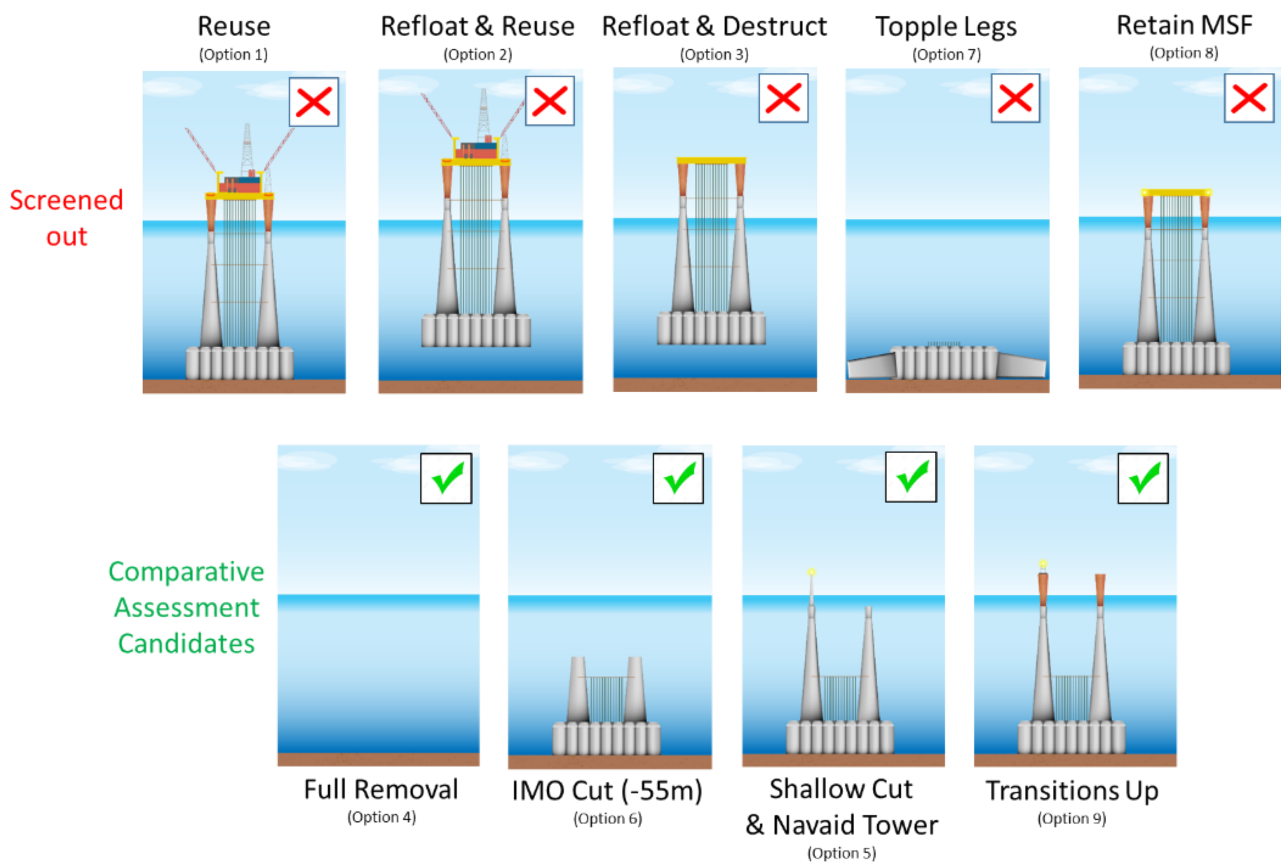


Figure 2.15 Option screening for the substructure

The option screening process concluded that there are no valid reuse opportunities for Dunlin Alpha (Option 1). Options to refloat the Dunlin Alpha substructure, for either reuse at another location (Option 2) or destruction in a dry dock (Option 3) were concluded to be unfeasible due to pipework and structural integrity issues, and the substantial technical challenges required to free the substructure from the seabed and control buoyancy.

Consideration was given to collapsing the four legs at their base (Option 7), through either diamond wire cutting techniques and/or explosive charges. The controlled collapse of concrete legs on this scale at this depth is unprecedented. The steel tendons in the concrete legs are pre-stressed and cutting would release this energy with uncertain consequences. The alternative, explosive charges, would be uncertain in its outcome and present overwhelming recovery challenges. In either case, extensive saturation diving, with associated risks, would be required to support the remedial operations such as the removal of snag hazards. In addition to these profound technical and safety challenges, 'toppling' of the concrete legs was not viewed as consistent with UK governmental policy in this area.

The option to decommission the substructure with the module support frame (MSF) *in situ* (Option 8) was screened out as retaining the MSF would entail significant legacy maintenance but would not materially increase the longevity of the legs..

The remaining four options were taken through to the evaluation phase of the CA, where further detailed study work was undertaken. These four options are described further below.

2.2.2.1. Option 9: Transitions Up

Option 9 involves leaving the substructure *in situ* up to its current elevation of LAT+23 m. The topsides would be removed and the transitions would be sealed to reduce the potential for a wet/dry cycle created by tidal influence, which would increase corrosion activity and reduce the longevity of the structures. One of the legs would be used to support an aid to navigation (AtoN) unit. Ongoing monitoring of the substructure would be required, including regular maintenance and change out of the AtoN unit.

The steel transitions will eventually succumb to corrosion activity, resulting in a gradual reduction of the steel plate wall thickness. Failure is likely to occur in approximately 200 years' time, although the mass of the transitions would be significantly reduced and it is very unlikely that a falling transition would breach the storage cells.

There would be no planned drill cuttings disturbance for Option 9, and the residual cell contents would be left *in situ*. Legacy environmental impacts would therefore be associated with the gradual release of cell contents over time and potential release resulting from dropped objects as the substructure degrades.

2.2.2.2. Option 5: Shallow Cut and Installation of Navaid Tower

Option 5 would involve removing the top of the legs, including transitions, at somewhere between - 8 m and -20.3 m LAT. The subsea cuts would be completed using a diamond wire cutting machine (DWCM), and a heavy lift vessel (HLV) would be utilised to support the structure during cutting and lifting operations. The cut section would then be lifted to a DSV / barge for transport to shore. Offshore works would be completed by a single HLV within 1 – 2 seasons.

As the remaining substructure would present a shallow hazard, a prefabricated concrete tower would be installed subsea, conceptually by a large grouted sleeve type assembly, onto the stub of one of the cut concrete legs. This concrete tower would rise through the splash zone to an appropriate elevation for supporting an AtoN unit. Ongoing monitoring of the substructure would be required, including regular maintenance and change out of the AtoN unit.

The AtoN supporting structure will be subjected to a number of potential future degradation mechanisms. These include degradation of the reinforced, pre-stressed concrete, fatigue damage and the probability of very extreme events occurring on the structure. Failure is predicted to occur in approximately 200 years or more and would result in the toppling of the upper leg, potentially impacting on the substructure below.

There would be no planned drill cuttings disturbance for Option 5, and the residual cell contents would be left *in situ*. Legacy environmental impacts would therefore be associated with the gradual release of cell contents and potential release resulting from dropped objects as the substructure degrades.

2.2.2.3. Option 6: -55m Cut

Option 6 would involve removing the steel transitions and upper concrete leg sections to -55 m below LAT. This would achieve the IMO standard of 55 m of clear, freely navigable water above the remaining substructure. There would be no requirement for navigational aids, however monitoring of the substructure would be required.

Study work concluded that the best option for cutting the legs at -55 m was to use a diamond wire cutting technique. However, the leg diameter at -55 m is greater than any current diamond wire cutting machine. An orbital cutting method would therefore be adopted as the preferred technique.

The subsea cuts would be completed using an HLV to support the leg during both cutting and lifting operations. When the cutting is complete the severed leg would be lifted vertically onto the deck of the HLV and transported to shore for recycling and disposal.

Failure to cut the leg at -55 m within a single weather window during the summer season could result in a leg failure during a significant summer storm. This is likely to cause major damage to the cell group leading to release from the cells. There would also be disturbance to the drill cuttings and the adjacent seabed.

Offshore works would be completed by a single HLV over a number of seasons. There would be no planned drill cuttings disturbance for Option 6, and the residual cell contents would be left *in situ*. Legacy environmental impacts would therefore be associated with the gradual release of cell contents as the substructure degrades over time.

2.2.2.4. Option 4: Full Removal by *in situ* deconstruction

Full removal of the Dunlin Alpha substructure would involve complex *in situ* deconstruction operations using a HLV to cut and lift the transitions, concrete leg sections, and lower conductor guide frame. The subsea cutting of concrete structures of this size has not been completed to date. As such, there is high risk of technical failure that could result in a number of high consequence events.

All drill cuttings would be removed and transported to shore for treatment and disposal. Assessment of recovery options concluded that disturbance of the cuttings pile and / or back-flushing of the suction system is likely to result in resuspension of 10% of the cuttings material, as a worst case.

The base caisson would then be deconstructed by remotely operated vehicle (ROV) on a cell-by-cell basis, including the removal of residual cell contents, iron ore ballast, conductors and steel skirt. In order to minimise environmental impacts resulting from the release of residual hydrocarbons and other contaminants within the storage cells, an access window would be cut in the side of each cell and the cell would be flushed as the worked progressed. Flushing operations are anticipated to include:

- Removal of sediment; sediment would be fluidised and pumped to a tanker for onshore treatment and disposal. A loss of some sediment can be expected due to back-flushing of suction equipment, and potential loss of containment.
- Recovery of mobile oil; mobile oil would be comingled with seawater and would be pumped to a tanker for onshore disposal. Chemicals are likely to be required for managing H_2S and CO_2 content.
- Flushing of cell water with seawater; up to 4x cell water volume (>1,000,000 m^3) would be treated on site and discharged to sea. Alternatively, flush water would be pumped to a tanker and shipped to shore for treatment/disposal.

Once flushing operations have completed, each cell would be cut up using diamond wire and the concrete lifted to the surface. The process would be repeated another 74 times for the remaining oil storage cells.

Operations would then be required to cut and lift the iron ore ballast, base slab and steel skirt. All cutting would be undertaken using diamond wire. A significant challenge with respect to removing the base caisson is the release of the suction that will exist between the base slab and the sea bed, and the releasing of the steel skirts from clay soils. As a result, the floor slab would also be removed on a cell-by-cell basis.

Once removal of the substructure is complete, operations would be undertaken to recover any debris and remediate the seabed. Due to the extent of deconstruction operations required, full removal of the Dunlin Alpha substructure by a single HLV is anticipated to take over 40 years to complete:

- Removal of upper leg sections (1 season)
- Removal of lower leg sections (1 season)
- Removal of the upper cell sections (27 seasons)
- Removal of the base slab (14 seasons)
- Seabed clear up (1 season)

Approximately 390,000 tonnes of materials (excluding cell water) would be recovered and transported to shore for processing, including over 230,000 tonnes of reinforced concrete. It is assumed that 5% of the concrete would be contaminated. Together with the drill cuttings and cell sediment, it is estimated that over 60,000 tonnes of hazardous material would require treatment before disposal at a hazardous landfill site.

2.2.2.5. Evaluation of Selected Decommissioning Options

To compare each option against the others and arrive at a decision, Fairfield utilised a Multi Criteria Decision Analysis (MCDA) tool. This tool uses pairwise comparison to consider difference between options – essentially, the assembled team reviews the relevant data compiled for each option and determines, using terms such as 'neutral', 'stronger', 'much stronger' (and so on), how each option compares to the other. This comparison was undertaken using the five criteria described in the OPRED decommissioning guidelines (OPRED, 2018):

- Safety;
- Environmental;
- Technical;
- Societal; and
- Economic.

The CA demonstrated that the option to decommission the substructure *in situ* with 'Transitions Up' (Option 9) was the most preferred of the derogation options against Safety, Environmental, Technical, and Economic Criteria. The assessment highlighted that there are considerable technical risks associated with all of the subsea concrete cutting and lifting operations which have significant potential to result in a number of high consequence events.

When evaluated against the Full Removal option (Option 4), Option 9 was also the most preferred option when assessed against Safety, Environmental, Technical, and Economic Criteria. Full details of the CA process and evaluation outcomes are detailed in Dunlin Alpha Comparative Assessment Report (Xodus, 2021).

Full Removal of the substructure was the preferred option with regards to 'legacy marine environmental impacts' as its removal would eliminate potential future impacts. However, it is projected that full removal would involve approximately 40 years of subsea cutting and concrete removal activities, with associated noise, atmospheric emissions and unavoidable marine discharges. As a result, Option 9 was the preferred option when assessed against 'operational marine environmental impacts' and 'atmospheric emissions' sub-criteria. In addition, potential legacy environmental impacts associated with both a gradual release and an unplanned instantaneous release of cell contents were assessed to inform the CA process. For both scenarios, environmental impacts were assessed to be not significant, as described in Section 5.

The recommendation from the CGBS CA is to decommission the substructure *in situ* with 'Transitions Up' and install a navigational aid on top of one of the transitions.

2.2.3. Options for Decommissioning of the CGBS Cell Contents

As discussed in Section 2.1.3, Fairfield conducted an extensive study to better understand and characterise the contents of the cells (Fairfield, 2021a). The study then progressed on using this inventory as the base case to evaluate potential management options. The study also demonstrated that, due to the complex construction of the base caisson and creation of sub-compartments, full removal of the residual cell contents is only technically feasible should the whole CGBS be removed and in doing so there would be inevitable release of some of the contents.

The residual cell contents are very widely distributed across the structure in very thin layers. The surface area of the cell floor across the 75 cells historically used for oil storage is approximately 9,000 m^2 and the surface area of the concrete walls of these cells is 97,000 m^2. Recovery of the contents presents some significant challenges because of these large areas, the compartmentalisation of the structure, and lack of access points.

It is not possible to recover 100% of the residual materials, only reduce their quantity, noting that of the 237,000 m^3 system volume, only just over 1% of this is the residual mobile oil, wall and floor deposits. As a basis, recovering 90% of what is there takes the final volume to 0.1%.

The cell contents management options and full removal option for the structure define a basis for how the cell contents could be recovered. It should be noted that while further oil could be recovered, it is more difficult to recover the sediment and then another degree of difficulty to clean the cell walls with the structure *in situ*. For example:

- Further recovery of the oil could be carried out via a relatively small access point.
- Recovery of the sediment would require a much larger access point for the tooling. Disturbing the sediment will cause it to fluidise and contaminate the cell water. The fluidisation makes recovery of all of the sediment very difficult to achieve.
- If the materials deposited onto the cell walls were to be cleaned, this would move a lot of the contamination into the cell water, where it would then be much more difficult to extract. Therefore, while concepts were defined for how this could be undertaken, if the aim is to recover the waxy wall residues this is really only going to be effective in the scenario where the structure was being dismantled. The wax is very stable and immobile and therefore would stay adhered to the concrete sections as they were removed.
- With the walls removed this provides much better access for recovery of the sediment, but inherently some particulates would fluidise into the water column. This would be minimised by working one cell at a time, and only creating an opening big enough to deploy the sediment recovery tool and carrying out this activity first followed by recovery of any mobile oil layer and flushing of the cell water prior to moving onto dismantling of the cell.

Considering the above, alternative options for the management of residual cell contents considered three possible management mechanisms:

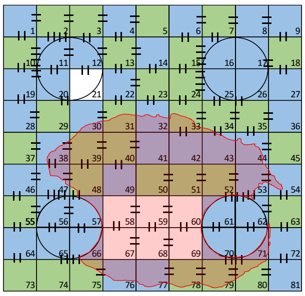
- Contents Removal - Accessing one or more cells with the intention of removing some/all of the contents. This could be achieved through direct access by penetration of the cell dome or indirectly using a directly penetrated cell to access an adjacent cell via the existing communication ports;
- Bioremediation - Actively enhancing the natural breakdown of crude oil components by biological organisms; and
- Capping - Covering the contents with suitable materials to act as a physical barrier.

Both the actively managed bioremediation and the capping based options were screened out as being less favourable than the contents removal options. This is largely because in all options the cells have to be accessed to deliver materials and / or deploy tooling. There is more certainty of the improvement achieved in the removal options than the other two management options. Enhancing the biological breakdown of the residual hydrocarbons requires the correct blend of microorganisms, nutrients and reactants. The rate of reaction is largely unknown as are the intermediate products that will be formed as the hydrocarbon chains are ultimately converted into gaseous products. There would also be a requirement to revisit the facilities over time to check progress of the reaction and replenish chemicals.

The fundamental aim of capping is to provide a suitable barrier between the sediments left *in situ* and the environment, however the Dunlin Alpha CGBS already provides an effective barrier. The main benefit that capping provides is in extending the time until the sediments exposure / release scenario occurs and it would occur at a slower rate, with contaminants having to travel through the capping material, however the overall quantity of material will remain the same.

Options for the management of the water and wall residue materials were also considered. Currently, no technology exists to recover the wall residue left on the structure. The large surface area of the storage cells also means that, even if technology were to be developed, it would take a disproportionate amount of time to complete cleaning operations for minimal benefit; this would result in further contamination of the water phase by converting a product which is largely immobile into the mobile fluid phase. In addition, the volume of water in the cells is significant (in the order of 230,000 m^3), and an operation of this nature would likely only provide a dilution effect, creating very large quantities of wastewater that would require treatment prior to being discharged overboard.

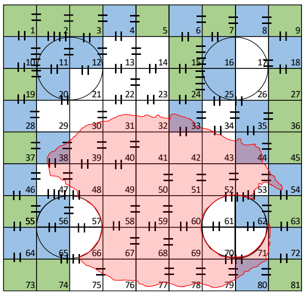
Following the CA recommendation to decommission the substructure *in situ*, a further evaluation was undertaken to assess options for the long-term management of the cell contents. The long-term management options taken into the detailed evaluation focussed on recovery of the mobile oil and sediment phases and looked at the potential to take a targeted approach which would increase efficiency of recovery but also limit the extent of disturbance to the drill cuttings on the cell tops. Potential treatment options were identified and screened (as reported in Fairfield, 2021a) and four viable options were taken forward for further study work – these are shown overleaf (Figure 2.16).



Option 1 – High Case – Oil and Sediment Removal

This would require 31 cell penetrations. Mobile oil would be recovered from 74 cells (31 cells accessed directly, and 43 cells accessed indirectly). Sediment would be recovered from 8 cells. This option would require removal of all cell top drill cuttings.

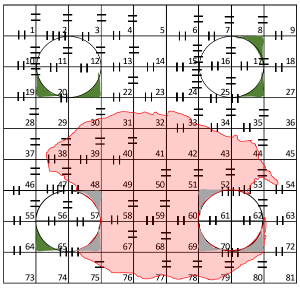
Mobile oil recovery = 648 m^3 (59% of total)/Sediment recovery = 270 m^3 (22% of total).



Option 2 – Mid-case – Oil and Sediment Removal

This would require 18 cell penetrations. Mobile oil would be recovered from 41 cells (18 cells accessed directly, and 23 cells accessed indirectly). Sediment would be recovered from 4 cells. This option would require limited removal of cell top drill cuttings.

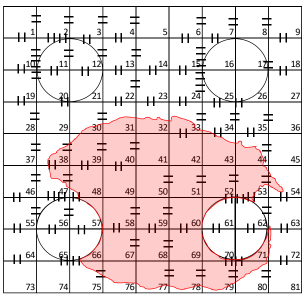
Mobile oil recovery = 269 m^3 (24% of total)/Sediment recovery = 147 m^3 (12% of total).



Option 3 – Mid-case – Oil Removal

This would require 5 triangle cell penetrations. Mobile oil would be recovered from 5 triangle cells. Sediment would not be recovered from any cells. This option would require limited removal of cell top drill cuttings.

Mobile oil recovery = 213 m^3 (19% of total)/Sediment recovery = 0 m^3.



Option 4 – Leave *In situ*

All cell contents left *in situ* with no removal or remediation.

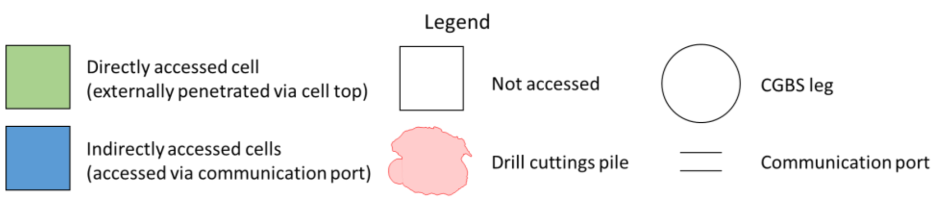


Figure 2.16 Summary of cell contents management options carried forward to evaluation

The assessment evaluated the options using the key criteria of safety, environmental, technical, societal and economic aspects. Further details of the CA process can be found in the Dunlin Alpha Comparative Assessment Report (Xodus, 2021).

Legacy environmental impacts associated with leaving the cell contents *in situ* were assessed to inform the CA process. These included both the gradual release of cell contents and a worst-case instantaneous release caused by a high-energy impact, although it should be noted that likelihood of a high impact instantaneous released is considered to be extremely low due to a number of limiting factors. For both scenarios, the environmental impact was assessed to be not significant. A detailed assessment of the environmental impacts associated with leaving the cell contents *in situ* is provided in Section 5.

The assessment of the cell contents management options identified that technical challenges associated with the removal options would limit the quantity of cell contents material that could be recovered. This is due to the physical restrictions of the cell compartments, the ability to adapt and upscale technology to locate and extract the contents, and the physical properties of the materials to be recovered. As a result, while further recovery of cell contents may reduce the quantity of contents released to the marine environment, the overall reduction in environmental impact would be indiscernible.

Potential environmental impacts associated with further cell contents removal operations would include:

- Resuspension of drill cuttings result from the removal of up to 10,000 m^3 of drill cuttings.
- Operational discharges associated with potential offshore treatment of cell water, including use and discharge of chemicals
- Accidental release of cell contents materials as a result of:
  - Loss of containment when accessing cells via roof penetrations
  - Hose failure while recovering mobile oil or sediment.
- Energy use and atmospheric emissions associated with vessel usage
- Onshore impacts associated with the management of hazardous waste materials

Individually the environmental impacts described above are not considered to be significant. However, they must be considered when evaluating the overall net environmental benefit of undertaking any further removal operations. Figure 2.17 illustrates the overall net environmental impact associated with all cell contents recovery efforts, including AORP and potential further contents removal. The dotted line indicates the current status.

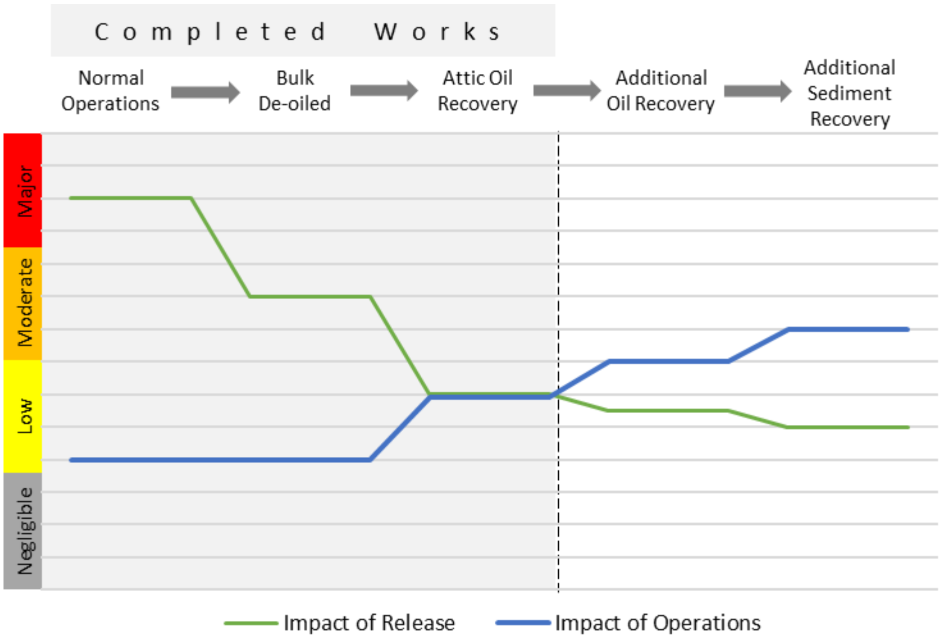


Figure 2.17 Summary of net environmental impact from all cell contents removal operations

The CA demonstrated that decommissioning the cell contents *in situ* was the most preferred management option when considering Safety, Environmental, Technical, Societal, and Economic Criteria. The recommendation from the Cell Contents CA process is therefore to leave the cell contents *in situ*, with no further removal or remediation.

Following formal consultation on the draft Decommissioning Programme in 2018, the project undertook a review of the option definitions (i.e. the proposed execution scopes), base assumptions, and input data used to evaluate the decommissioning options in order to confirm that the recommendations from the comparative assessment process remain valid. A suite of physical samples and process measurements of the residual cell contents have also been retrieved and the results reviewed in the context of the comparative assessment.

Stakeholder feedback received throughout the comparative assessment process was also considered during this review. Where applicable, base assumptions and input data have been updated to address issues raised, and are reflected in the option descriptions described above. A review of the option evaluation for both the Dunlin Alpha substructure and cell contents was subsequently undertaken to determine whether these changes would result in a material change to the recommended options from the comparative assessment process. The conclusion from the review is that the CA recommendation for both the substructure and cell contents remain valid. Further details of the comparative assessment process are available in the Dunlin Alpha Comparative Assessment Report (Xodus 2021).

2.2.4. Proposed Decommissioning Strategy

The proposed decommissioning strategy for the Dunlin Alpha substructure is summarised in Table 2.11. The CA process has been informed by extensive specialist study work and independently reviewed. The Dunlin Alpha Comparative Assessment Report outlines the decision-making process and procedures for the CGBS and cell contents in more detail.

Table 2.11 Recommendations for Dunlin Alpha substructure decommissioning

Infrastructure type	Subject of Comparative Assessment?	Decommissioning recommendation
CGBS	Yes	Leave *in situ*, including transitions. Install navigational aid.
Cell Contents	Yes	Leave *in situ*, no further recovery.
Drill Cuttings	No	Leave *in situ* to degrade naturally over time.

2.3. Decommissioning Activities

2.3.1. Preparation for Decommissioning

2.3.1.1. Topsides Removal

In accordance with OSPAR Decision 98/3, the Dunlin Alpha topsides will be fully removed by means of “optimised reversed installation”, which means that the modules will generally be removed in the same way they were installed but optimised within the capabilities of current equipment and considering structural limitations of the platform itself. Further details of the topsides decommissioning strategy and removal methodology are described within the Dunlin Alpha Topsides Decommissioning Programme (Fairfield, 2019a).

2.3.1.2. Removal of Well Conductors

The upper sections of the 30-inch well conductors will be removed as part of the Dunlin well Decommissioning Programme and/or during topside removal activities. These operations involve cutting each conductor at a depth just above the lower conductor guide frame, approximately 74 m below LAT, and removing them to shore for recycling or disposal. Any discharges from these operations will be managed in accordance with approved environmental permits as required.

2.3.1.3. Removal of Conductor Guide Frames

The upper and middle conductor guide frames (CGF) will be cut and removed as part of the Dunlin Alpha Topsides Decommissioning Programme. Marine growth remaining on the CGFs after the removal process will be disposed of onshore, and Fairfield will ensure that the selected decommissioning yard has the appropriate licences to manage any remaining marine growth. The lower guide frame, located at approximately 76 m below LAT, will be left attached to the concrete legs.

2.3.1.4. Preparation of CGBS Legs

Pipework within the concrete legs has been de-oiled, and operations to remove hazardous materials and substances from within the legs have been completed. Process pipework has been vented to remove residual gas, and left positively isolated to mitigate potential communication between the legs and the base caisson storage cells. All activities were undertaken under an approved regulatory permit and in accordance with Fairfield's waste management strategy.

A comprehensive sampling programme of the leg ponds has been completed, confirming that residual hazardous substances are as low as reasonably practicable. Each of the legs were then flooded using untreated seawater in order to reduce the differential pressure across the CGBS cell groups, protecting the integrity of the cell roofs.

The top of each transition has been sealed with a reinforced cap to reduce the potential for a wet/dry cycle created by tidal influence, which would increase corrosion activity and reduce the longevity of the structures. A concrete platform will be installed at the top of the transitions. One of these caps will support an AtoN unit.

2.3.1.5. Preparation of CGBS Cell Contents

As described in Section 2.1.2, the Attic Oil Recovery Project was successfully completed in 2007, taking over 18 months to complete. At its peak, over 200 personnel were involved in the execution of the project and over 27,000 tonnes of bulk chemicals were transported, blended, stored, shipped offshore and pumped into the storage cells. This required over 700 road tanker movements and nine round trip sailings by the dedicated supply vessel. Relative to the overall volume of the cells, the oil inventory was reduced from an oil layer that was estimated to be between 4 to 9 m (dependent on the cell group), to only a relatively thin layer of mobile oil within each cell (2 to 12 cm).

2.3.1.6. Drill Cuttings

As described in Section 2.1.3, an assessment of the Dunlin Alpha cuttings pile has been completed to determine the status of the drill cuttings. A pre-decommissioning survey was undertaken in 2016, successfully retrieving both surface samples and core samples from the cuttings pile. The samples and MBES data have been analysed in order to assess the persistence and leaching rate, in accordance with OSPAR Recommendation 2006/5. For both criteria, assessment of the Dunlin Alpha drill cuttings pile has concluded that it is well below the OSPAR thresholds.

2.3.2. Decommissioning Activities

2.3.2.1. CGBS

It is proposed that the Dunlin Alpha CGBS is decommissioned *in situ*, with the four transitions remaining in place. In addition, the lower sections of the 30-inch well conductors and the lower conductor guide frame will also be decommissioned *in situ*, as these are integrated within the substructure.

As described above, pipework within the legs has been de-oiled and hazardous materials and substances have been removed. The legs have been flooded to reduce the differential pressure across the cell groups, and the top of each transition has beensealed to protect against corrosion activity. A navigational aid will be installed at the top of one of the transition pieces.

2.3.2.2. Navigational Aids

Upon completion of topsides removal activities, the heavy lift vessel (HLV) will install an AtoN unit on top of one of the CGBS legs using the vessel crane.

Fairfield has consulted with the Northern Lighthouse Board to ensure that the design of the AtoN unit meets all regulatory requirements. It is anticipated that the unit will be of a self-contained offshore lighthouse (SCOL) design and will be helicopter portable to facilitate maintenance and replacement as required (Figure 2.18). Fairfield proposes to undertake monitoring and maintenance of the AtoN through a service contract with a specialist contractor, including real time status and analysis. Arrangements will also be made to ensure an emergency replacement service is in place in the event of a failure.

Figure 2.18 AtoN unit deployment by helicopter (Maritime Journal, 2015)

2.3.2.3. Cell Contents

The Attic Oil Recovery Project successfully reduced the inventory of mobile oil within the CGBS storage cells to as low as reasonably practical. Fairfield has undertaken an extensive review of these operations, assessed the status of the rundown lines, and identified alternative options for further recovery of the residual contents through new cell access points.

During work performed to validate the inventory estimate it was found that the residual mobile oil within Cell Group B was still accessible via the rundown line pipework. This was due to the inventory of free gas present holding the oil in place at the opening to the pipework. Operations were undertaken to extract approximately 46 m^3 of oil, but significant challenges were experienced with managing the high H_2S gases and high wax pellet volume which eventually completely blocked the line. Similarly around 33 m^3 of oil was able to be recovered from Cell Group C that had migrated up the rundown line, and almost 19 m^3 of oil was recovered from the top of rundown line D.

All reasonable endeavours have been used to recover the cell contents via the existing topsides. Any further recovery would not result in a discernible reduction in environmental impact. The Comparative Assessment evaluation has shown that the environmental impacts associated with further recovery operations is likely to result in an increase in the overall environmental impact of the project. As a result, Fairfield proposes to leave the cell contents *in situ*, with no further recovery.

2.3.2.4. Drill Cuttings

As it is proposed to decommission the CGBS *in situ*, and as the drill cuttings are below the OSPAR 2006/5 thresholds for leaching and persistence, Fairfield proposes to leave the drill cuttings pile *in situ* to degrade naturally over time. No intervention work is required on the drill cuttings to facilitate this decommissioning scenario.

2.3.3. Post-Decommissioning Activities

The following subsections describe the proposed post-decommissioning activities. These will include debris recovery, post-decommissioning surveys and periodic observations of the infrastructure decommissioned *in situ.* A programme will also be in place for maintaining any navigational aids on the site.

2.3.3.1. Initial Post-Decommissioning Survey and Debris Clearance

Following completion of decommissioning activities, Fairfield will make best endeavours to recover dropped objects subject to outstanding Petroleum Operations Notices (PONs), and any other oilfield related debris within the Dunlin Alpha 500m safety zone. Where possible, debris that is partially embedded in the drill cuttings will be severed as close to the drill cuttings as possible without causing disturbance to the drill cuttings and recovered. Items completely buried will be left *in situ.* All recovered seabed debris will be returned for onshore disposal or recycling in line with existing disposal methods.

A post decommissioning site survey will be carried out around a 500 m radius of the substructure. This will be followed by independent verification and a statement of seabed clearance to all relevant authorities. Fairfield plan to use geophysical survey methods, including ROV and Side Scan Sonar (SSS), to demonstrate debris clearance. A seabed clearance assessment will be submitted to OPRED for determining any requirement for further offshore works, and used to form the basis of the future monitoring strategy.

2.3.3.2. Monitoring

Fairfield will develop a post-decommissioning monitoring and survey strategy in consultation with the regulator. The agreed strategy may require multiple surveys, with the first being part of the close-out report process and further surveys scheduled for some time after the initial post-decommissioning sampling. The frequency of the monitoring is likely to be determined through a risk-based approach based on the findings from each subsequent survey. In addition, planned inspection and replacement of the navigational aid and a visual inspection of the CGBS will be undertaken.

2.3.3.3. Future Degradation of the CGBS

Decommissioned *is situ*, the substructure will slowly degrade over the next few centuries with the transition shell walls thinning due to corrosion and the concrete legs spalling from corrosion in the rebar. The substructure will succumb in a series of small failures during hostile weather events due to extreme environmental loading on partially degraded structural elements.

With regards to the potential for legacy environmental impacts, the degradation of substructure can be summarised in three key events:

1. Failure of steel transitions

   The steel transitions will eventually succumb to corrosion activity, resulting in a gradual reduction of the steel plate wall thicknesses. Detailed assessment of this process has indicated that buckling of a transition could occur as a result of severe environmental loading after wall thicknesses have been reduced to below 50% of their original values (Atkins, 2018). Corrosion rate calculations suggest this is likely to occur in approximately 200 years. At some point after this, the buckled transition piece will sever and fall.

Experience with tubular objects (such as well tubulars) suggests that within a depth of three times the length of the tubular, the object is falling in a horizontal rather than a vertical orientation, and with a significant horizontal motion which exceeds the vertical motion (Atkins, 2018). This means that a falling transition is much more likely to impact the seabed rather than the substructure below.

In the unlikely event that a falling transition does land on the base caisson, a reduction of 50% wall thickness would significantly reduce the mass of the transition piece, and therefore the potential impact energy (Atkins, 2017b). The result is that a falling transition piece is very unlikely to cause a breach of the storage cells.

There is also a significant amount of drill cuttings located on the top of the base caisson. The cuttings would provide a considerable amount of energy absorption, protecting the reinforced concrete underneath. Findings from a dropped object assessment (Atkins (2017b) indicate that there is little risk of the cell roofs being breached where there are drill cuttings. However, some drill cuttings may be re-suspended.

2. Concrete degradation

Fairfield commissioned a technical review (Atkins, 2017b) of the life expectancy of the CGBS, and how the substructure will degrade over time. Degradation of the concrete substructure can be expected to occur due to the following mechanisms, which are illustrated in Figure 2.19:

- Carbonation and chloride attack penetrating the concrete to reach the layers of steel reinforcement (rebar).
- Loss of rebar cross-section caused by corrosion mechanisms.
- Spalling of the concrete due to volumetric expansion caused by the generation of corrosion products around the steel.
- Accumulated fatigue damage to the concrete and reinforcement due to the above degradation mechanisms, and due to pitting of the steel caused by corrosion.

Figure 2.19 Corrosion expansion and spalling of reinforced concrete (not Dunlin Alpha)

Degradation of the substructure would be expected to vary with depth due to the availability of dissolved oxygen and the likely expansion of the resulting corrosion products. The availability of dissolved oxygen would directly influence the time taken for carbonation and chloride attack to penetrate down to the concrete reinforcement and therefore the generation of corrosion products and subsequent spalling of the concrete.

The result is that the corrosion/expansion/spalling cycle will continue to progressively crumble the concrete substructure over a prolonged period of time (Figure 2.20). Degradation of the upper sections of the substructure is estimated to occur within a 200 – 300 year period; the lower section, including base caisson and storage cells, is predicted to degrade at a much slower rate (1,200+ years).

3. Loss of containment of the substructure storage cells

The most credible scenario for the release of cell contents over time is one occurring due to cracks in the concrete, and communication paths opening up at existing pipework penetrations. Predicting the time to eventual failure of the structure is difficult given the lack of available cases for study. However, it is estimated that gradual releases are likely to occur over a period of 150 to 1,200 years or more into the future due to eventual corrosion of the steel transitions and degradation of the concrete structure. As a result, the gradual release of cell contents will occur as a series of small events that will occur hundreds of years into the future. Legacy impacts resulting from the gradual discharge or release of residual cell contents are discussed in Sections 5.2 and 5.3.

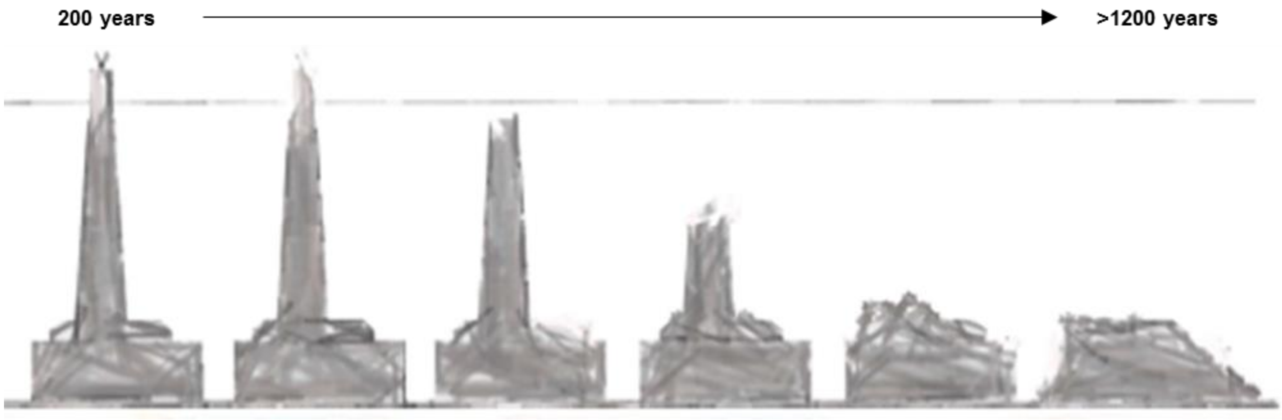


Figure 2.20 Long term degradation of the Dunlin Alpha substructure over time.

2.4. Waste Management

2.4.1. Overview

The main waste management challenges associated with decommissioning the Dunlin Alpha installation are largely associated with the removal of the Topsides facilities and operations required to prepare the substructure to be decommissioned *in situ*.

2.4.2. Regulatory Control

The Waste Framework Directive (Directive 2008/98/EC) defines waste as “any substance or object in the categories set out in Annex 1 of the Directive which the holder discards or intends or is required to discard”.

The Waste (Scotland) Regulations 2012 control the generation, transportation and disposal of waste within the European Union and the shipment of waste into and out of the EU. It covers controlled waste, duty of care, registration of carriers and brokers, waste management licencing, landfill, hazardous waste, producer responsibility, packaging waste, end-of-life vehicles, waste electrical and electronic equipment and the trans-frontier shipment of waste. Materials disposed of onshore must also comply with the relevant health and safety, pollution prevention, waste requirements and relevant sections of the Environmental Protection Act 1990.

The duty of care with regards to appropriate handling and disposal of waste from all decommissioning activities rests with Fairfield.

2.4.3. Management of Waste

Environmental management of the Dunlin Alpha decommissioning activities will include waste management as a key factor in limiting potential environmental impact. Management of waste will therefore be dealt with in accordance with Fairfield’s EMS, certified to the international standard ISO 14001:2015.

As operator of the Dunlin Alpha installation, Fairfield recognises its duty of care for waste materials generated from the all decommissioning activities and has considered the complete life cycle of all decommissioning waste including; waste generation, treatment, storage, shipment, processing and final recycling/disposal. To this end, Fairfield has developed a waste management strategy for the project in order to outline the processes and procedures necessary to ensure that waste is managed in a manner that complies with legislative requirements and prevents harm to people and the environment (Fairfield, 2017a).

The waste management strategy is underpinned by the waste hierarchy, shown in Figure 2.21. The hierarchy is based on the principle of waste disposal only where reuse, recycling and waste recovery cannot be feasibly undertaken.

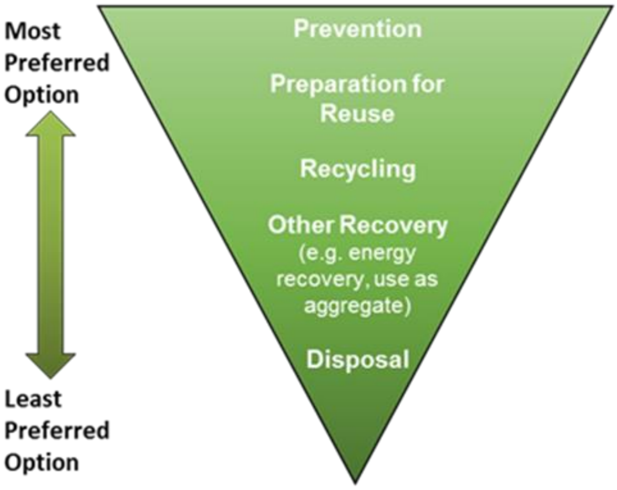


Figure 2.21 Waste hierarchy

Preparation and removal of Dunlin Alpha infrastructure may also result in the generation of special waste streams as equipment is flushed and isolated. Such wastes will be disposed of under an approved regulatory permit, as required, and in accordance with Dunlin Alpha safe operating procedures and the Fairfield waste management strategy, with consideration of specific sampling, classification, containment, and consignment conditions. It is likely that there will be small volumes of residual hydrocarbons, chemicals and naturally occurring radioactive material in some equipment recovered to shore. Any special wastes remaining in recovered infrastructure will be disposed of under an appropriate licence or permit.

As stated in Section 2.3.1.3, the majority of marine growth will be removed offshore. Any marine growth that is transferred to shore will be managed by an appropriately licensed dismantling facility. Options for the disposal of marine growth include composting, land spreading or landfill.

An Active Waste Management Plan will detail the measures in place to ensure all permits and licenses are in place for the handling and disposal of the waste types identified, and that all waste is transferred by an appropriately licensed carrier. The plan will be kept under constant review and appropriately updated throughout execution of the decommissioning project.

3. Environmental Appraisal Methodology

3.1. Overview of the Environmental Appraisal Process

This section provides detail on how the Environmental Appraisal (EA) process has been applied to the Dunlin Alpha decommissioning project and describes the key components that have fed into the assessment. Figure 3.1 below presents an overview flow diagram of the process.

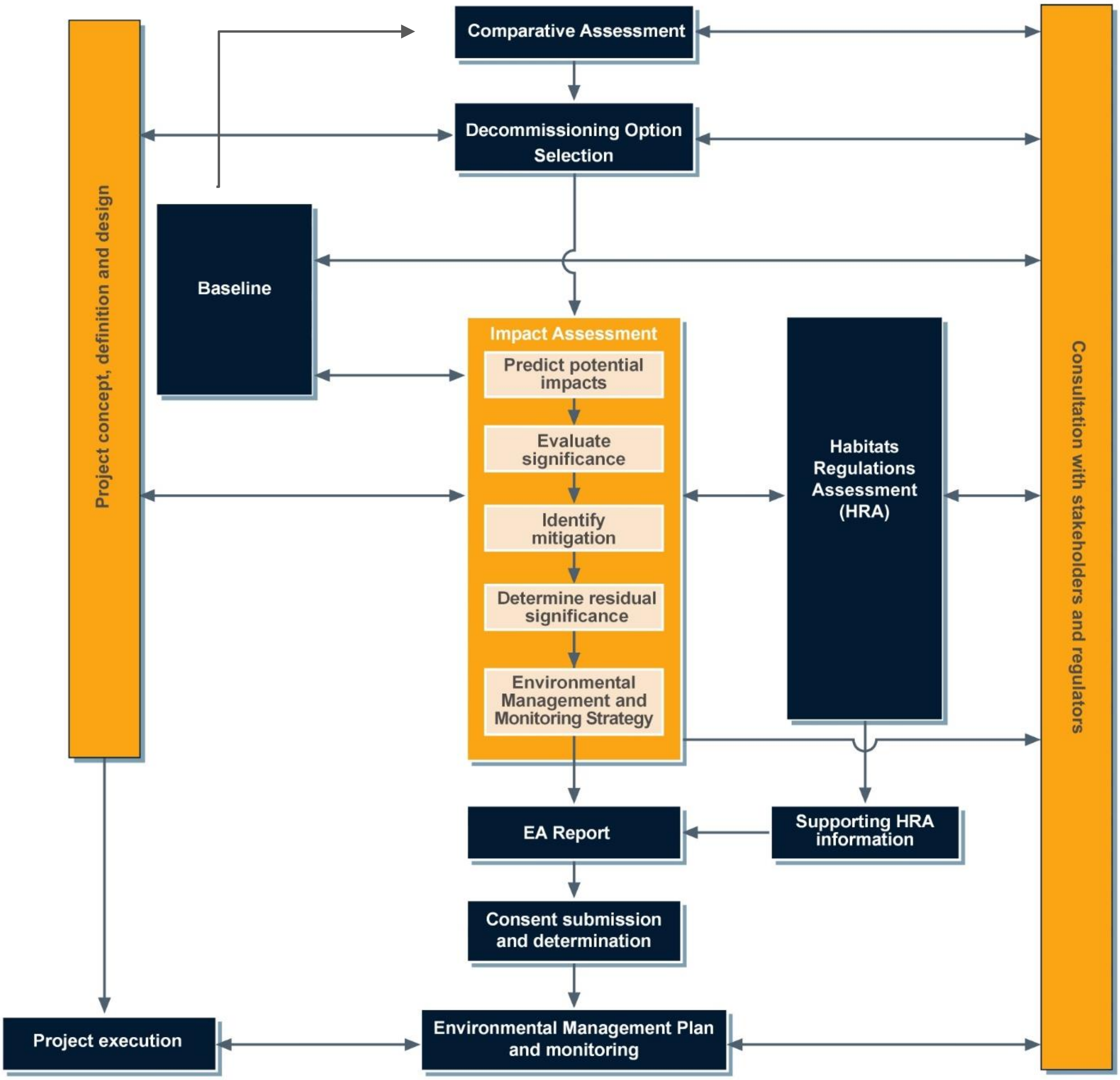


Figure 3.1 The Environmental Appraisal process

3.2. Stakeholder Engagement

Fairfield recognises that early and ongoing engagement with stakeholders is a critical part of the development of robust, respectful programmes for the decommissioning of North Sea installations. Key activities have included issue of an environmental scoping report, open information events and CA workshops with attendance from regulators and stakeholders. Further detail is provided in the Stakeholder Report (Fairfield, 2021b).

As well as working with key regulatory and environmental stakeholders, Fairfield has sought to understand the lessons that other UKCS operators have learned during their decommissioning activities to date. In addition, Fairfield makes information available to the general public via a dedicated decommissioning website.

As a detailed log of areas of interest raised during consultation is presented in the Stakeholder Report, it is not repeated here. However, the key environmental items identified by stakeholders, and how they have been assessed in the EA, are as follows:

- Loss of access to commercial fishing grounds from the permanent presence of the CGBS decommissioned *in situ*.
  - The presence of infrastructure decommissioned *in situ* is recognised by Fairfield as a key stakeholder concern in terms of societal impact. In addition, the decommissioning *in situ* of infrastructure is seen to be of key regulatory interest. As such, this impact mechanism is discussed further in Section 5.1.
- Gradual release of cell contents over time.
  - The novel nature of this impact mechanism means that it has been raised as a concern by stakeholders. Degradation of the substructure over time, along with the resultant water ingress, may gradually displace cell contents to the surrounding marine environment. Fairfield recognises the potential impact related to such a release over a prolonged period of time, and further assessment has been undertaken and is presented in Section 5.2.
- Instantaneous release of cell contents after decommissioning.
  - The outcome of the CA for the cell contents concluded that the contents should be left *in situ* with no further recovery. An unplanned event resulting in an instantaneous release of some of the cell contents at some future point is understood to be possible for the fluid- or gas-phase materials which comprise the majority of the cell contents. Given the novel nature of such a potential impact, this is assessed further in Section 5.3.1.
- Disturbance of the drill cuttings pile after decommissioning.
  - As described in Section 2.1.3, the drill cuttings present at the foot of the installation are below the relevant OSPAR Recommendation 2006/5 thresholds. Since it is proposed that the CGBS will be decommissioned *in situ*, the drill cuttings are not intended to be disturbed during decommissioning activities. It is possible, however, that the cuttings could be disturbed due to an unplanned event, such as a fallen object or commercial fishing gears making contact with the cuttings deposits. Disturbance of drill cuttings from unplanned events have been assessed in Section 5.3.2.
- The management of waste associated with all decommissioning activities.
  - The management of waste will be limited for the leave *in situ* decommissioning of the Dunlin Alpha CGBS. Regardless, Fairfield considers waste management to be an important environmental issue which requires thorough consideration. As such, Fairfield's waste management strategy is provided in Section 2.4.
- Legacy Management
  - Fairfield will be working collaboratively with relavent stakeholders to develop a legacy management plan, which manages ongoing monitoring and legacy of the infrastructure remaining *in situ*.

3.3. Identification of Environmental Issues

An EA in support of a Decommissioning Programme should be focused on the key issues related to the specific activities proposed; the impact assessment write-up should be proportionate to the scale of the project and to the environmental sensitivities of the project area. This does not mean, however, that the impact assessment process should be any less robust than for a statutory impact assessment or consider any fewer impact mechanisms. To this end, Fairfield undertook an environmental impact identification (ENVID) workshop exercise early in the EA process which sought to identify key environmental sensitivities, discuss sources of potential impacts and ascertain which sources required further assessment. The output of the ENVID is summarised in Table B1 in Appendix B, including explanations on why some topics were scoped in for further assessment and why some were considered sufficiently well-understood to render detailed assessment unnecessary. This section provides a summary of the ENVID results and indicates where further assessment takes place within the EA.

3.3.1. Summary of ENVID Scoping Justification

Energy Use and Atmospheric Emissions

The use of fuel to execute the proposed decommissioning programme will result in emissions of gases to air that could potentially result in impacts at a local, regional, and global scale. Potential sources of energy use and atmospheric emissions for the Project are limited to vessel use and the replacement of materials (predominately steel) decommissioned *in situ*. A summary is provided in Table 3.1.

Table 3.1 Energy use and atmospheric emissions from the proposed decommissioning programme

Project activity	Energy use (Gigajoules)	Atmospheric emissions (tonnes)		
		CO_2	NO_x	SO_2
Vessel movements	18,920	1,395	26	5
Replacement of materials (steel) decommissioned *in situ*	378,000	34,238	63	100
Total	396,920	35,633	89	105

The majority of the decommissioning activities are too remote from other human receptors (including other offshore oil and gas activity) for there to be any impact on local air quality (the dispersive offshore environment will limit the potential further). Vessel movement nearshore as they transit to the field will be limited to a matter of days. As such, local air quality issues have not been considered further.

The expected CO_2 emissions generated from the replacement of recyclable materials remaining *in situ* have been calculated to be 34,238 tonnes, resulting in a total of 35,633 tonnes of CO_2 for the Project. This is approximately 0.27% of the total atmospheric emissions associated with 2018 UKCS oil and gas activities (the latest year for which figures are available (OGUK 2019)). Emissions generated as result of the proposed decommissioning operations will be in the context of cessation of Dunlin Alpha operational and maintenance activities. As such, almost all future emissions from Project operations and vessels will cease. For these reasons, impacts associated with the energy use and atmospheric emissions resulting from the proposed decommissioning operations have not been further assessed.

As the substructure degrades, a total of 45 tonnes of free gas (consisting of CO_2, H_2S and light-end hydrocarbons) contained within the tops of the substructure storage cells will be gradually released. In addition, CO_2 and H_2S are also likely to be generated within the cells over time as a result of natural biodegradation processes. However, the total quantity of gas expected to be released from the substructure over time is low (<100 tonnes). Due to the relatively low quantity of gases considered and the gradual nature of any release, no further assessment has been undertaken.

Physical Presence

As vessels will be limited in number and in space and time, the *in situ* decommissioning of the Dunlin Alpha CGBS will not generate an important increased vessel presence across the project area, and vessel activities will be similar to baseline levels for the northern North Sea. Moreover, the long-term presence of structures remaining *in situ* will not exclude or alter significant extents of seabed or sensitive habitats which would generate local or regional impacts to benthic flora or fauna. Consequently, these impacts have been screened out from further assessment when addressing impacts from physical presence during decommissioning activities. The assessment of physical presence of infrastructure decommissioned *in situ* has been framed around impacts to other sea users, namely commercial fisheries.

Disturbance to the Seabed

There are no plans to disturb the seabed or cuttings piles during the proposed project activities. Any such disturbance will be either the result of potential debris clearance (to be determined during the seabed clearance verification survey) or as an unplanned event. As there is no planned mechanism in which impacts could result from these pathways, they have been screened out from further assessment. However, given the potential significance of environmental impacts which may result from cuttings disturbance, this mechanism has been assessed in detail in the context of unplanned events.

Discharges to Sea

Vessels are a potential source from which significant operational planned discharges to sea could transpire, but as there are no planned releases and all vessel activities are well controlled by national and international law, there is no impact mechanism within the project scope requiring further consideration. Any operational discharge(s) resulting from the preparation of the Dunlin Alpha substructure for decommissioning will be assessed under relevant environmental permitting and will adhere to the conditions specified therein.

Operations to de-oil the CGBS legs have been completed, successfully recovering over 99.9% of the hydrocarbons from the leg ponds. A comprehensive sampling programme of the leg ponds has been undertaken, and confirmed that hazardous substances have been reduced to as low as reasonably practicable.

The sampling results indicate that the total hydrocarbon content across the four CGBS legs is now <250 kg, and that the toxicity characteristics of the leg ponds is largely attributable to the salinity of sea water. As a result, the gradual release of the leg contents is unlikely to generate any significant impacts to the surrounding environment and has been screened out from further assessment.

As the substructure degrades over time, the residual cell contents have the potential to be gradually released or become exposed to the marine environment. The gradual release of cell contents has been identified as a potentially significant impact on the marine environment and has been carried forward for further assessment.

Assessment of the cuttings piles on both the cell tops and seabed indicates that neither OSPAR thresholds for leaching (10 tonnes of oil leaching to the water per annum) and persistence (500 km^2.yr) are breached. Consequently, leaving the cuttings piles *in situ* without disturbance is considered to be an environmentally acceptable solution and is anticipated to be of negligible impact. However, further assessment of gradual hydrocarbon release from undisturbed drill cuttings has been undertaken to inform the detailed assessment of unplanned events associated with drill cuttings disturbance by modelling baseline discharges from the cuttings. In turn, all of these impact pathways have been screened out from further assessment within the context of discharges to sea.

Underwater Noise

In terms of impacts relating to underwater noise, there will be no new activities which have not been previously assessed as 'acceptable' through the consenting process undertaken within the area. Moreover, the Dunlin Alpha CGBS is not located within an area protected for marine mammals and cumulative vessel-related impacts are unlikely as vessel activity is limited to a very small number of vessels (e.g. up to three vessels) for the majority of project activities, and subsurface cutting activities will be limited and controlled. For decommissioning projects outside of protected marine mammal habitats which do not include important sources of underwater noise (e.g. piling, explosives or seismic survey activities), the potential to introduce significant impacts to hearing sensitive species from the proposed activities is considered negligible and has therefore been screened out from further assessment.

Resource Use

Based on guidance from OPRED (2018) and Decom North Sea (2018), consideration of resource use has been constrained to offshore impacts. Resource use from the proposed activities will require limited raw materials and will be largely restricted to fuel use over the period of the decommissioning schedule and materials returned to shore for recycling and/or disposal. Following completion of decommissioning, nearly all future fuel use (from project operations and vessels) is expected to cease and the use of fuel resources is not typically an issue of concern in offshore oil and gas, an energy sector which generates fuels. Accordingly, fuel use is not considered to form an important environmental impact mechanism and has not been assessed further.

As the leave *in situ* option has been proposed for the Dunlin Alpha substructure, only small amounts of material are expected to be generated which would require onshore processing. The waste management strategy is to recycle all materials returned to shore, though there may be instances where infrastructure returned to shore is contaminated and cannot be recycled. However, the weight and volume of such material is not expected to result in substantial landfill use, and thus the use of landfill space is not considered to have the potential for significant environmental impact and has been screened out from further assessment.

Waste Management

As noted above, waste generation from the decommissioning of the Dunlin Alpha substructure is expected to be minimal, thus the emphasis when considering waste management and generation impacts will be on waste management. Fairfield will put in place a robust Waste Management Plan which covers non-hazardous, hazardous, radioactive (including NORM and LSA), and marine growth wastes, as detailed in Section 2.4, to ensure no potential mechanism for environmental impact is introduced through waste management practices. The Waste Management Plan also details how the overarching strategy and guiding principles will be applied to manage the Decommissioning Programme. In view of the waste management strategy currently in place and the limited waste to be generated by the *in situ* decommissioning of the Dunlin Alpha substructure, waste has been scoped out from further assessment.

Unplanned Events

There are a variety of circumstances in which unplanned events relating to the project may cause environmental or socio-economic impacts; however, they are largely limited to unplanned interactions with the cuttings piles and accidental instantaneous releases from vessels, or from the breach of cell storage structures.

Vessel releases are carefully managed under Ship Oil Pollution Emergency Plans (SOPEPs) developed by the vessel contractors under guidance and standards from the International Maritime Organisation. SOPEPs are management plans aimed at minimising the potential for oil pollution from instantaneous release and defining mitigations to limit release volumes during an accidental event. Even in the worst case scenario of a full release of one of the fuel tanks on the HLV (which has the largest fuel inventory volume of the proposed vessels), beaching is unlikely to occur under the dominant oceanographic conditions during 6 months of the year. Should the conditions arise such that beaching occurs, a maximum volume of 20 m^3 (1%) is expected to reach protected sites, based on available modelling data. When considering the hydrographic effects of wave action and mixing in nearshore environments, this volume would be highly dispersed and would have negligible effects on the conservation or functioning of such receptors. With such limited probabilities of a fuel release, beaching or interaction with protected sites, no further assessment is proposed for accidental vessel releases.

Another unplanned event which has been carefully considered for further assessment is that in relation to dropped objects. A breach of the cell storage structure caused by dropped objects which results in an instantaneous release has been considered for the mobile oil, water, and sediment cell contents. Of these, cell sediments have not been carried forward for detailed assessment as they occur in relativey low volumes (0.7% of total volume) at the bottom of the 13 m cells, with no feasible mechanism for an instantaneous release to the surrounding environment. Any breach of the storage cell(s) is not expected to activate a plume of sediment such that it would be ejected from a compromised cell. Rather, the residual cell sediments are expected to be further encased under concrete debris as the substructure degrades over time.

Other Environmental Impacts

The ENVID process considered several other potential environmental impact mechanisms in addition to those commonly considered above; they include: light, aesthetics and employment.

The potential long-term introduction of light-generating objects on site will be limited to a single navaid, and there will be an overall reduction in light-emitting activities due to the decrease in vessel presence following decommissioning. As such, impacts from offshore light emissions are deemed negligible.

As the project area is far from shore (137 km), aesthetic impacts are only pertinent to activities in which vessel movements take place close to shore, such as during vessel to vessel transfers. However, these are planned to take place 6 miles (or approximately 9.7 km) from shore and would be very temporary. Moreover, disposal will take place at a predefined, dedicated disposal yard. For these reasons impacts relating to aesthetics are also considered to be negligible.

Finally, employment impacts have been considered in the context of cessation of production. Whilst it is recognised that there could be a negative effect resulting from cessation of production, there will be a countering benefit in the additional work required to affect the decommissioning activities. It is expected that any potential socio-economic effects would occur through potential interaction with commercial fisheries, which is addressed as a part of the detailed assessment of physical presence of infrastructure remaining *in situ*.

3.3.2. Aspects considered for further assessment

The following summarises the potential impacts or mechanisms screened in for further assessment and where they are addressed within the EA:

- Physical Presence (Section 5.1):
    - Physical presence of infrastructure decommissioned *in situ* in relation to other sea users (Section 5.1.2);
- Discharges to sea (Section 5.2):
    - Gradual release of cell contents over time – residual mobile oil, cell water, and cell sediments (Section 5.2.2);
- Unplanned events (Section 5.3):
    - Instantaneous release of residual mobile oil and cell water through breach of cell storage structure from dropped object (Section 5.3.1); and
    - Disturbance of drill cuttings through collapse of concrete structure, or objects falling during structure collapse or from unplanned overtrawling (Section 5.3.2). It should be noted that, while impacts from the 'gradual release of hydrocarbons entrained in the drill cuttings over time' have been screened out for further assessment, they have been characterised in detail within this section to form a baseline of the planned activities against which to address the impacts of unplanned disturbance to the cuttings piles.

The modelling which has been undertaken to address both instantaneous and gradual releases, including those from disturbance events, has been summarised in Section 5.2.1, and is detailed in full in Appendix D.

3.4. Environmental Significance

3.4.1. Overview

The assessment method presented here has been developed by reference to the Institute of Ecology and Environmental Management (IEEM) guidelines for marine impact assessment (IEEM, 2010), the Marine Life Information Network (MarLIN) species and ecosystem sensitivities guidelines (Tyler-Walters et al., 2004), guidance provided by Scottish Natural Heritage (SNH) in their handbook on environmental impact assessment (SNH, 2013), and by the Institute of Environmental Management and Assessment (IEMA) in their guidelines for environmental impact assessment (IEMA, 2015, 2016).

Environmental impact assessment provides an assessment of the environmental and societal effects that may result from a project's impact on the receiving environment. The terms impact and effect have different definitions in environmental impact assessment and one drives the other. Impacts are defined as the changes resulting from an action, and effects are defined as the consequences of those impacts.

In general, impacts are specific, measurable changes in the receiving environment (volume, time and/or area); for example, were a number of marine mammals to be disturbed following exposure to vessel noise emissions. Effects (the consequences of those impacts) consider the response of a receptor to an impact; for example, the effect of the marine mammal/noise impact example given above might be exclusion from an area caused by disturbance, leading to a population decline. The relationship between impacts and effects is not always so straightforward; for example, a secondary effect may result in both a direct and indirect impact on a single receptor. There may also be circumstances where a receptor is not sensitive to a particular impact and thus there will be no significant effects/consequences.

For each impact, the assessment identifies a receptor's sensitivity and vulnerability to that effect and implements a systematic approach to understand the level of impact. The process considers the following:

- Identification of receptor and impact (including duration, timing and nature of impact);
- Definition of sensitivity, vulnerability and value of receptor;
- Definition of magnitude and likelihood of impact; and
- Assessment of consequence of the impact on the receptor, considering the probability that it will occur, the spatial and temporal extent and the importance of the impact. If the assessment of consequence of impact is determined as moderate or major, it is considered a significant impact.

Once the consequence of a potential impact has been assessed, it is possible to identify measures that can be taken to mitigate impacts through engineering decisions or execution of the project. This process also identifies aspects of the project that may require monitoring, such as a post-decommissioning survey at the completion of the works to inform inspection reports.

For some impacts, significance criteria are standard or numerically based. For others, for which no applicable limits, standards or guideline values exist, a qualitative approach is required. This involves assessing significance using professional judgement.

Despite the assessment of impact significance being a subjective process, a defined methodology has been used to make the assessment as objective as possible and consistent across different topics. The assessment process is summarised below. The terms and criteria associated with the impact assessment process are described and defined, and details on how these are combined to assess consequence and impact significance are provided in Appendix C.

3.4.2. Baseline Characterisation and Receptor Identification

In order to make an assessment of potential impacts on the environment it was necessary to firstly characterise the different aspects of the environment that could potentially be affected (the baseline environment). As part of preparation for the Dunlin Alpha decommissioning project, and as part of earlier operation of the Greater Dunlin Area, the following surveys have been undertaken in recent years:

- Surveys at the Dunlin Alpha platform and cuttings pile:
  - Dunlin Field Pre-Decommissioning Habitat Survey and Environmental Baseline Survey (EBS) (Fugro, 2016a, Fugro 2017b);
  - Dunlin Alpha Pre-Decommissioning Cuttings Assessment Survey (Fugro, 2015); and
  - Dunlin Development Debris Clearance, 'Mud Mound' and EBS (Gardline, 2009);
- Surveys in the Greater Dunlin Area:
  - Dunlin Fuel Gas Import Route Survey (Gardline, 2011);
  - Dunlin Fuel Gas Import Pre-Decommissioning Habitat Survey and EBS (Fugro 2016b; Fugro 2016c);
  - Dunlin to Northern Leg Gas Pipeline Route Survey (Gardline, 2010a);
  - Dunlin Power Import Cable Pre-Decommissioning Habitat Survey and EBS (Fugro 2016d; Fugro 2016e); and
  - Quad 211 Infield Environmental Survey (Gardline, 2010b).

The surveys undertaken closest to the Dunlin Alpha platform are reported in Gardline (2009), Fugro (2016a), Fugro (2017a) and Fugro (2017b). The locations of stations sampled during these surveys are presented in Figure 4.3. The description of bathymetry, seabed conditions and benthos in the project area draws on these surveys. Sample stations from the wider area surveys listed above are also presented in Figure 4.2. The results of these surveys were used to provide a baseline with which to compare the survey stations close to Dunlin Alpha. Information obtained through consultation with key stakeholders was also used to help characterise specific aspects of the environment in more detail.

The environmental impact assessment process requires identification of the potential receptors that could be affected by the project (e.g. marine mammals, seabed species and habitats). High-level receptors are identified within the Environmental Baseline chapter (Section 4).

3.4.3. Impact Definition

3.4.3.1. Impact magnitude

Determination of impact magnitude requires consideration of a range of key impact criteria including:

- Nature of impact, whether it be beneficial or adverse;
- Type of impact, be it direct or indirect etc.;
- Size and scale of impact, i.e. the geographical area;
- Duration over which the impact is likely to occur, i.e. days, weeks;
- Seasonality of impact, i.e. is the impact expected to occur all year or during specific times; and
- Frequency of impact, i.e. how often the impact is expected to occur.

Each of these variables is expanded upon in Appendix C, to provide consistent definitions across all EA topics. In each impact assessment, these terms are used in the assessment summary table to summarise the impact and are enlarged upon as necessary in any supporting text. With respect to the nature of the impact, it should be noted that all impacts discussed in this EA report are adverse unless explicitly stated otherwise.

3.4.3.2. Impact Magnitude Criteria

Overall impact magnitude requires consideration of all impact parameters described above. Based on these parameters, magnitude can be assigned following the criteria outlined in Appendix C, Table C6. The resulting effect on the receptor is considered under vulnerability and is an evaluation based on scientific judgement.

3.4.3.3. Impact Likelihood for Unplanned and Accidental Events

The likelihood of an impact occurring for unplanned/accidental events is another factor that is considered in this impact assessment. This captures the probability that the impact will occur and the probability that the receptor will be present, and is based on knowledge of the receptor and experienced professional judgement. Consideration of likelihood is described in the impact characterisation text and used to provide context to the specific impact being assessed in topic specific chapters as required.

3.4.4. Receptor Definition

3.4.4.1. Overview

As part of the assessment of impact significance, it is necessary to differentiate between receptor sensitivity, vulnerability and value. The sensitivity of a receptor is defined as 'the degree to which a receptor is affected by an impact' and is a generic assessment based on factual information. By contrast, an assessment of vulnerability, which is defined as 'the degree to which a receptor can or cannot cope with an adverse impact' is based on professional judgement taking into account an number of factors, including the previously assigned receptor sensitivity and impact magnitude, as well as other factors such as known population status or condition, distribution and abundance.

3.4.4.2. Receptor Sensitivity

These range from negligible to very high and definitions for assessing the sensitivity of a receptor are provided in Appendix C, Table C7.

3.4.4.3. Receptor Vulnerability

Information on both receptor sensitivity and impact magnitude is required to be able to determine receptor vulnerability as per Appendix C, Table C8. It is important to note that this approach to assessing sensitivity/vulnerability is not appropriate in all circumstances and in some instances professional judgement has been used in determining sensitivity. In some instances, it has also been necessary to take a precautionary approach where stakeholder concern exists with regard to a particular receptor. Where this is the case, this is detailed in the relevant impact assessment in Section 5.

3.4.4.4. Receptor value

The value or importance of a receptor is based on a pre-defined judgement based on legislative requirements, guidance or policy. Where these are absent, it is necessary to make an informed judgement on receptor value based on perceived views of key stakeholders and specialists. Examples of receptor value definitions are provided in Appendix C, Table C9.

3.4.5. Consequence and Significance of Potential Impact

3.4.5.1. Overview

Having determined impact magnitude and the sensitivity, vulnerability and value of the receptor, it is then necessary to evaluate impact significance. This involves:

- Determination of impact consequence based on a consideration of sensitivity, vulnerability and value of the receptor and impact magnitude;
- Assessment of impact significance based on assessment consequence;
- Mitigation; and
- Residual impacts.

3.4.5.2. Assessment of Consequence and Impact Significance

The sensitivity, vulnerability and value of the receptor are combined with magnitude (and likelihood, where appropriate) of impact using informed judgement to arrive at a consequence for each impact, as shown in Appendix C, Table C10. The significance of impact is derived directly from the assigned consequence ranking. The assessment of consequence considers mitigation measures that are embedded within the proposed activities.

3.5. Cumulative Impact Assessment

Although the scope of this impact assessment is restricted to the decommissioning of the Dunlin Alpha installation facilities as outlined in Section 1.5, it is recognised that the decommissioning workscope may also occur in the context of the subsea decommissioning at Dunlin, and other oil and gas and non-oil and gas activities, with which there is the potential to interact. To this end, the impact assessments presented in Section 5 specifically consider the potential for cumulative impact within the definition of significance.

3.6. Transboundary Impact Assessment

The impact assessments presented in Section 5 contain sections which identify the potential for and, where appropriate, assessment of transboundary impacts. For the Dunlin Alpha Decommissioning Project, this needs to be considered given the proximity to the UK/Norway median line (11 km).

3.7. Habitats Regulations Assessment (HRA) and Nature Conservation Marine Protected Area Assessment

Under Article 6.3 of the Habitats Directive, it is the responsibility of the Competent Authority (in this case, OPRED) to undertake an Appropriate Assessment, if necessary, of the potential impacts of a plan, programme or project, alone or in combination, on a Natura site (Special Area of Conservation (SAC), or Special Protection Area (SPA)) in view of the site's conservation objectives and the overall integrity of that site. In a similar but separate process of assessing impact on protected sites, there is also a requirement under the Marine and Coastal Access Act for the Competent Authority to consider the potential for the proposed activities to impact upon Nature Conservation Marine Protected Areas (NCMPAs). Where relevant, the impact assessments presented in Section 5 provide information on the potential for the proposed activities to affect the protected features of SPAs, SACs and NCMPAs, or to affect ecological or geomorphological processes on which the SPAs, SACs and NCMPAs are dependent.

4. Environment Baseline

The Environmental Baseline characterisation describes the current conditions of the receiving environment with the study area and is considered sufficient to allow the potential activity/receptor interactions and environmental sensitivities to be appropriately evaluated.

4.1. Weather and Sea Conditions

4.1.1. Wind

Wind speed in the vicinity of the Dunlin Alpha installation is generally described as being either a calm to gentle breeze in the range 0 – 6 m/s or a moderate to fresh breeze in the range 6 – 10 m/s. Calm winds occur for approximately 31% of the year and moderate winds for 34.5% of the year. Gale conditions occur most frequently during the winter months (October to March) with the percentage of winds at or above 14 m/s in January being greater than 30% (BODC, 1998). The 1-year maximum wind speed over 1 hour is 31.1 m/s (PhysE, 2012). Figure 4.1 shows a wind rose for the project area.

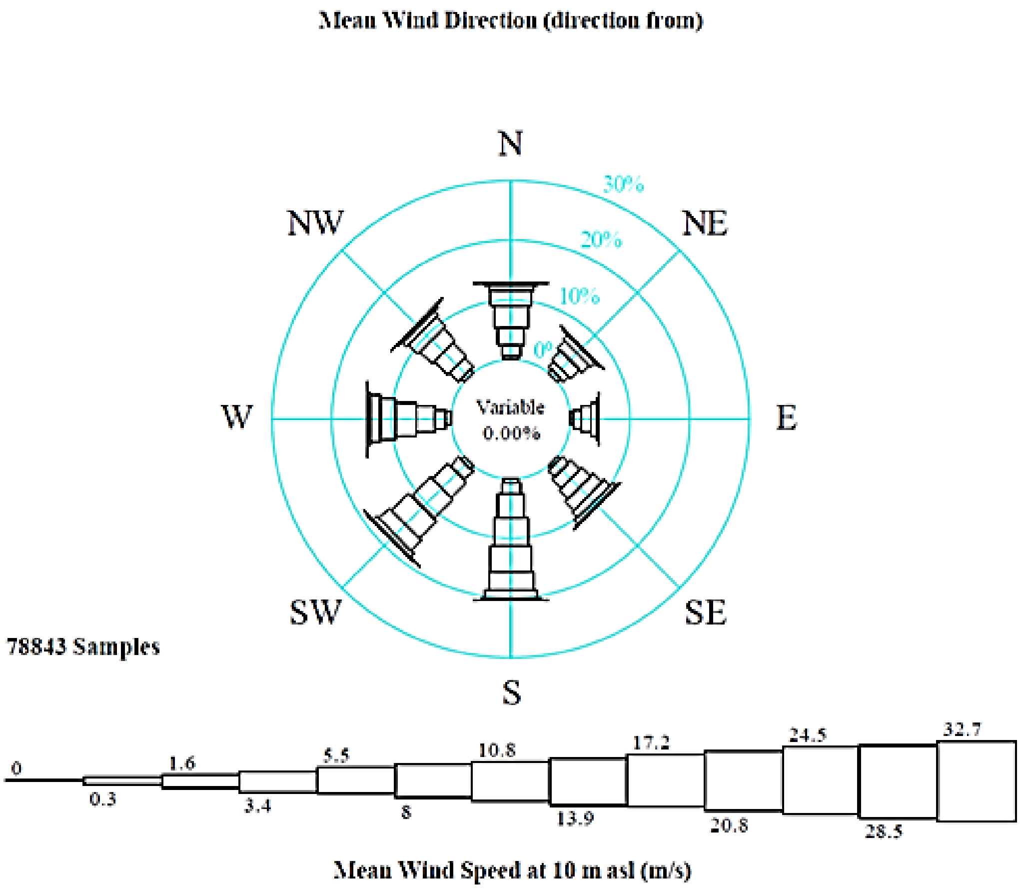


Figure 4.1 Wind rose for project area (Fugro, 2001)

4.1.2. Sea Conditions

Wave height in the vicinity of the project area ranges from a 1-year significant wave height of 11.5 m to a 1-year maximum wave height of 20.9 m. The maximum 100-year wave height is estimated to be 28.4 m (PhysE, 2012).

Average current velocities in the project area are 0.5 m/s at the surface, decreasing to 0.2 m/s near the seabed (PhysE, 2012), with an average current speed through the water column of 0.46 m/s. The prevailing surface current in the area is in a northerly direction (Scottish Government, 2011).

Distinct density stratification occurs in the northern North Sea in the summer months at a depth of around 50 m and the thermocline becomes increasingly distinct towards deeper water in the north. This stratification breaks down in September as the frequency and severity of storms increases, causing mixing in the water column (DECC, 2016). The average sea surface water temperature in the project area varies seasonally between approximately 4°C in winter to around 17°C in summer. Sea bottom temperatures vary between 5°C in winter to 12°C in summer (PhysE, 2012).

4.2. Bathymetry and Seabed Conditions

4.2.1. Overview and Surveys

As part of preparation for the Dunlin Alpha Decommissioning Project, and as part of earlier operation of the Greater Dunlin Area, the following surveys have been undertaken in recent years:

- Surveys in the Greater Dunlin Area:
  - Dunlin Fuel Gas Import Route Survey (Gardline, 2011);
  - Dunlin Fuel Gas Import Pre-decommissioning Habitat Survey and EBS (Fugro 2016b; Fugro 2016c);
  - Dunlin to Northern Leg Gas Pipeline Route Survey (Gardline, 2010a);
  - Dunlin Power Import Cable Pre-decommissioning Habitat Survey and EBS (Fugro 2016d; Fugro 2016e); and
  - Quad 211 Infield Environmental Survey (Gardline, 2010b).
- Surveys at the Dunlin Alpha platform and cuttings pile:
  - Dunlin Field Pre-decommissioning Habitat Survey and Environmental Baseline Survey (EBS) (Fugro, 2016a, Fugro 2017b);
  - Dunlin Alpha Pre-decommissioning Cuttings Assessment Survey (Fugro, 2017a); and
  - Dunlin Development Debris Clearance, ‘Mud Mound’ and EBS (Gardline, 2009);

Sampling stations for the Greater Dunlin Area surveys listed above are presented in Figure 4.2. The results of these surveys were used to provide a baseline with which to compare the survey stations close to Dunlin Alpha.

The surveys undertaken closest to the Dunlin Alpha platform are reported in Gardline (2009), Fugro (2016a), Fugro (2017a) and Fugro (2017b). The locations of stations sampled during these surveys are presented in Figure 4.3. It should be noted that the Fugro (2016a), Fugro (2017a) and Fugro (2017b) reports all refer to stations that were sampled during a single survey, and these stations are therefore presented as a single survey in Figure 4.3. The stations with a “DFC” prefix are reported in Fugro (2016a) and Fugro (2017b) (the Dunlin Field Pre-Decommissioning Habitat Survey and EBS). The stations with a “DCP” prefix were located on the cuttings pile, and are reported in the Dunlin Field Habitat Survey Report (Fugro, 2016a) and the Dunlin Alpha Pre-Decommissioning Cuttings Assessment Survey Report (Fugro, 2017a), but not the Dunlin Field EBS Report (Fugro, 2017b). The stations with a “CT” prefix were located on the Dunlin Alpha CGBS cell tops and are only reported in the Dunlin Alpha Pre-Decommissioning Cuttings Assessment Survey Report (Fugro, 2017a). The descriptions of bathymetry, seabed conditions and benthos in the project area (Section 4.2 and 4.3), draw on these four survey reports.

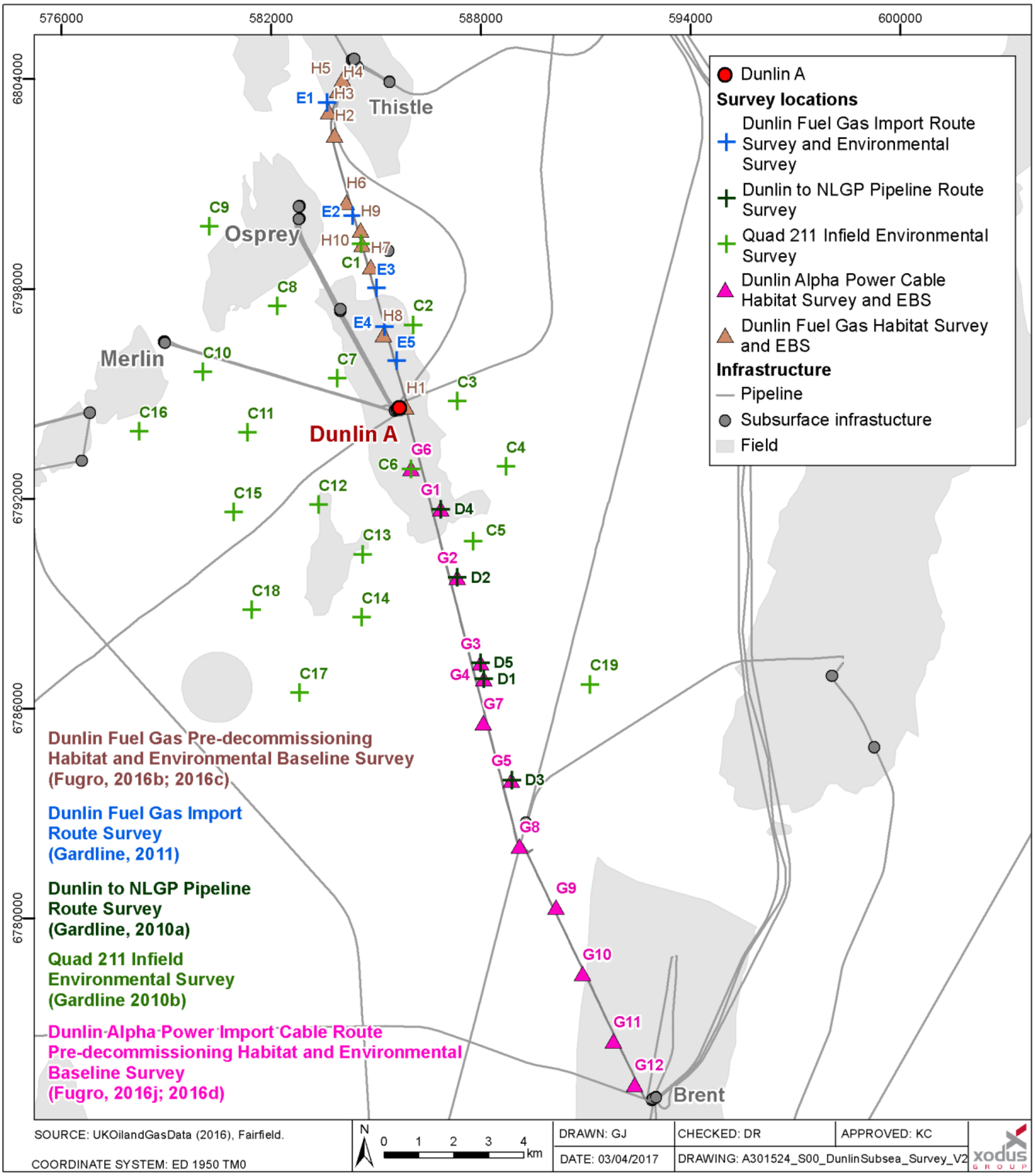


Figure 4.2 Wider area survey station sampling locations (Gardline, 2011; Fugro, 2016b; Fugro, 2016c; Gardline, 2010a; Fugro, 2016d; Fugro, 2016e; Gardline, 2010b)

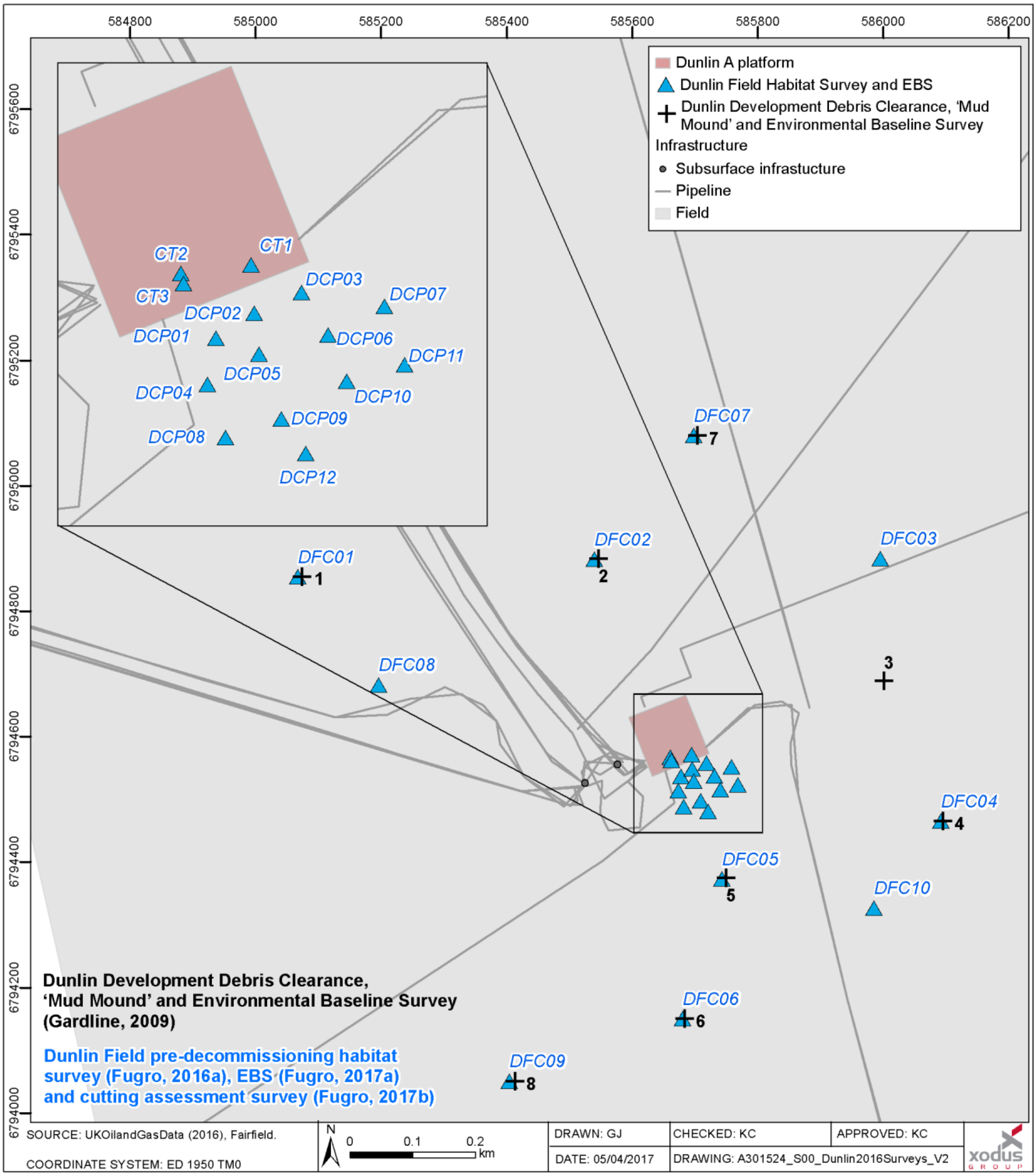


Figure 4.3 Environmental survey station locations close to the Dunlin Alpha installation and cuttings pile (Gardline, 2009; Fugro, 2016a; Fugro, 2017b; Fugro, 2018)

4.2.1.1. Dunlin Alpha Cuttings Pile Sampling Survey

Much of this section is based on the Dunlin Alpha Pre-Decommissioning Cuttings Assessment Survey (Fugro, 2017a). This survey was designed to generate environmental data which would be used to inform on the state of the seabed prior to the decommissioning process with regards to the potential disturbance of habitats and contaminated sediments. The sampling and analysis strategy for assessing the status of the Dunlin Alpha drill cuttings pile was developed in accordance with the OLF 'Guidelines for Characterisation of Offshore Drill Cuttings Piles' (OLF, 2003) to ensure sufficient data were collected and results were comparable with other cuttings data. It should also be noted that while this work was completed prior to the issue of OSPAR 2017-03 Guidelines for the Sampling and Analysis of Cuttings Piles, the methodologies employed were based upon the wide range of work conducted on cuttings piles by OLF, UKOOA and OSPAR. As those studies form the basis for the new OSPAR guidelines, the Dunlin survey work is considered compliant with the new guidance.

Multi-beam echo sounder (MBES) surveys were performed across a 1 km grid of the Dunlin Alpha platform and around the area of cuttings on the seabed against the platform. The MBES data were analysed to estimate the volume and footprint of the cuttings deposits, and used to select locations for the collection of grab and core samples (Figure 4.4) (Fugro, 2017a).

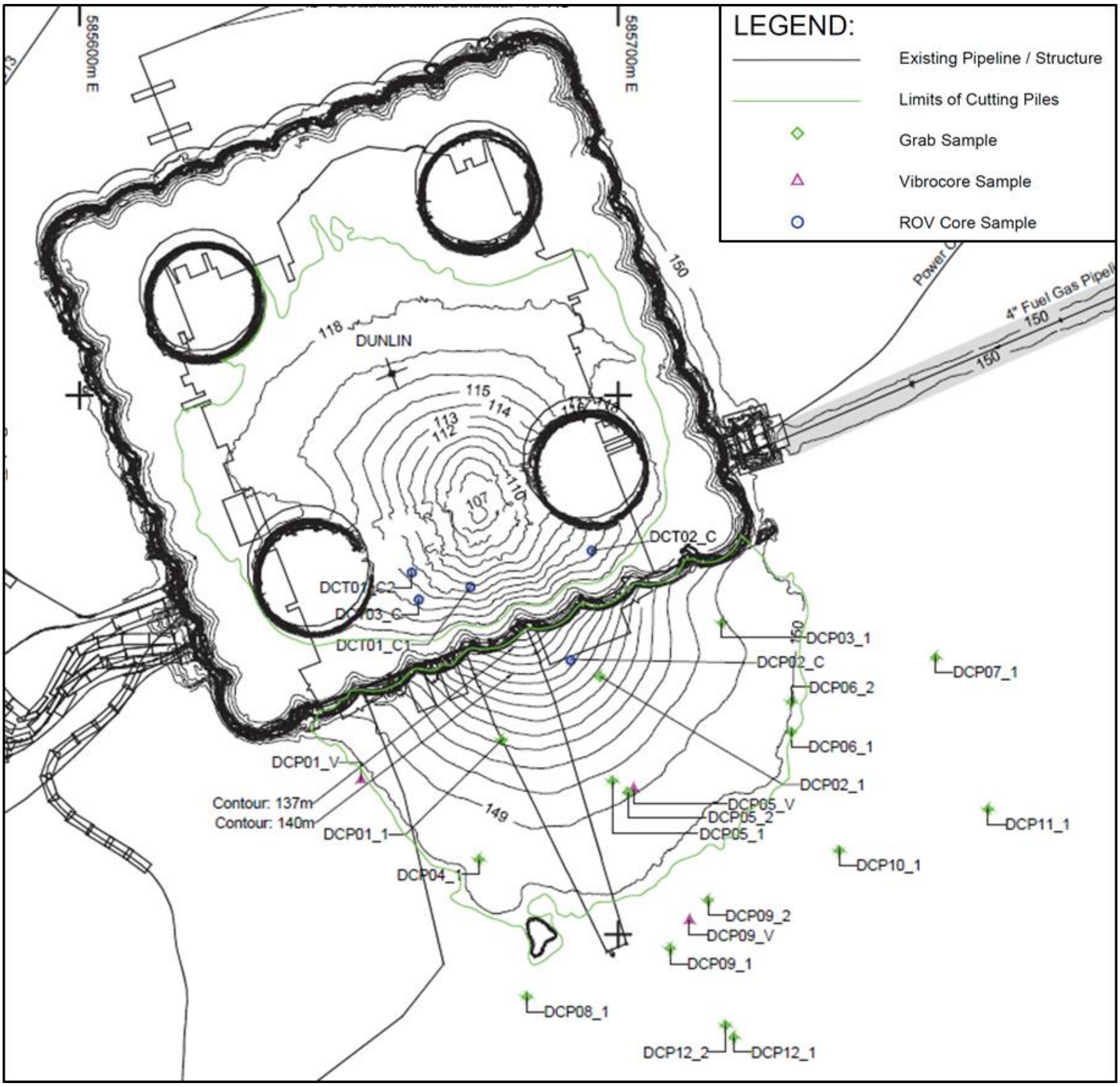


Figure 4.4 Dunlin Alpha cuttings pile sample locations

The aim was to collect a range of samples from different parts of the cuttings pile and from different sediment depth horizons to generate a dataset that describes the physical and chemical characteristics of the cuttings deposits around Dunlin Alpha.

Twelve seabed sampling stations were selected and sampled within the footprint of the Dunlin Alpha cuttings pile. Additionally, 4 m deep vibrocores were collected at three of the stations (DCP01, DCP05 and DCP09) and shallow (70 cm) cores collected from one station (DCP02) using a remotely operated vehicle (ROV), as the slope of the cuttings pile prevented the deployment of the vibrocore. As it was not physically possible to deploy the vibrocore on top of the CGBS, ROV cores were also collected from the locations on the top of the CGBS storage cells (CT 1 to CT 3) (Fugro, 2017a).

4.2.2. Bathymetry and Sediment Type

The natural seabed depth near the Dunlin Alpha installation is approximately LAT -151 m and varies very little (Gardline, 2009b, Fugro, 2016a). The top of the cuttings pile is at approximately LAT –134.5 m (Gardline, 2009b).

Sediment particle size data and the results of basic hydrocarbon analysis for three surveys close to the Dunlin Alpha installation are presented in Table 4.1. Fugro (2017) and Gardline (2009) investigated stations close to, but not on the cuttings pile (see Figure 4.3). Fugro (2018) investigated stations located on the cuttings pile and on the top of the CGBS in areas covered by drilling mud and cuttings.

Sediments collected away from the cuttings pile were classified as fine to medium sand under the Wentworth classification (Fugro, 2017a, Gardline, 2009). This was consistent with sediments collected from along the Dunlin Fuel Gas Import (DFGI) pipeline and Dunlin Power Import (DPI) cable route and in the wider Quadrant 211 area (Fugro, 2016c, 2016e; Gardline, 2010b). Sediment type close to the installation did not appear to be correlated with water depth; this was corroborated by the pipeline and cable route surveys, where no clear gradient was identified (Fugro, 2016c, 2016e).

Sediments in the cuttings pile and on top of the CGBS were generally finer, with coarse silt recorded at most stations, although coarse sand, medium sand and very fine sand were also recorded (Fugro, 2018). The generally finer sediment at the cuttings pile is consistent with the presence of drilling mud.

4.2.3. Sediment Hydrocarbon and Metal Content

Sediment Total Organic Carbon (TOC) at stations away from the cuttings pile was low, ranging from <0.2% to 0.5% along the DFGI pipeline route (Fugro, 2016c), from <0.2% to 0.45% along the DPI cable route (Fugro, 2016e) and from 0.5% to 1% in the wider Quadrant 211 area (Gardline, 2010b). Results were similar in the vicinity of the Dunlin Alpha installation, ranging from <0.2% to 0.8% (Fugro, 2017a; Gardline, 2009;Table 4.1).

Around the cuttings pile and on the cell tops TOC in surface samples was clearly elevated; of the 15 stations sampled in Fugro (2018) all surface samples but one had TOC >1% with a maximum of 3.11% recorded at Station DCP05 (Table 4.1). Core samples from within the cuttings were collected at Stations DCP01, DCP02, DCP05 and DCP09 on the cuttings pile and at Stations Cell Top 1, Cell Top 2 and Cell Top 3 (Table 4.2).

TOC in the sub-surface samples was inconsistent; at some stations TOC decreased with increasing core depth and at some stations it increased. At Station DCP01 TOC was elevated at 50 cm depth compared to the surface sample, but had reduced to below the limit of detection (LoD) at 100 cm. At Station DCP05 TOC was lower at 50 cm than at the surface, but then increased again at 100 cm depth. Below 150 cm depth, TOC was at background levels in all the cuttings pile cores. In the Cell Top 1 and Cell Top 2 cores TOC was high at all depths, and higher at 37 cm core depth than at the surface. In Cell Top 3 however, TOC fell to background levels at 17.5 cm core depth. The maximum TOC in the core samples was 8.52%, recorded from Cell Top 1 at 35 cm depth. This result was much higher than any of the surface sample results. There is a clear increase in TOC with increased proximity to the cuttings pile, but the core samples are difficult to interpret, as TOC appears to vary widely and inconsistently with core sample depth.

THC showed a similar pattern to TOC, with THC along the DFGI pipeline and DPI cable routes mostly falling between 8.0 μgg^{-1} to 22.9 μgg^{-1} with one outlying result of 170 μgg^{-1} close to the Dunlin Alpha installation

(Gardline, 2010a, 2011; Fugro, 2016c, 2016e). THC in the wider Quadrant 211 area ranged from 10.4 μgg^{-1} to 20.4 μgg^{-1} (Gardline, 2010b).

THC at stations close to but not on the cuttings pile ranged from 14.7 μgg^{-1} to 317 μgg^{-1} (Fugro, 2017a; Gardline, 2009) (Table 4.1), with higher results recorded at stations to the east and south-southeast of the cuttings pile.

THC in sediments taken from the cuttings pile and the cell tops was elevated, ranging from 300 μgg^{-1} at Station DCP08 at the periphery of the pile to 146,000 μgg^{-1} at Station DCP05 located halfway between the edge of the CGBS and the edge of the cuttings pile (Fugro, 2018) (Table 4.1). The result at Station DCP05 was unusually high; THC at the majority of cuttings pile stations was between 1,260 μgg^{-1} and 6,120 μgg^{-1}. THC in the cell top samples was consistently high, ranging from 16,100 μgg^{-1} to 73,400 μgg^{-1}. THC in the cuttings pile core samples generally reduced with depth, although the extent of the reduction varied. At Station DCP01 THC was 38,500 μgg^{-1} at 50 cm depth, much higher than the 1,440 μgg^{-1} recorded at the surface. It then reduced again to 13.7 μgg^{-1} at 100 cm depth. At Station DCP05 THC at 50 cm was 20,600 μgg^{-1}, much lower than the recorded surface concentration of 146,000 μgg^{-1}. At 150 cm however, the concentration rose again to 114,000 μgg^{-1} before reducing to 4,720 μgg^{-1} at 150 cm and 152 μgg^{-1} at 200 cm. In the Cell Top samples, THC was elevated at all depths, although once again there was no clear gradient.

Table 4.1 Surface sediment particle size and hydrocarbon data from site surveys (Fugro, 2017a, 2018; Gardline, 2009)

Survey	Station	Sorting	Mean particle size			Total organic carbon (%)	Total hydrocarbon content (μgg^{-1})
			Phi	μm	Wentworth class		
Fugro (2017) located close to the cuttings pile	DFC01	Very poor	2.16	223	Fine sand	0.33	14.7
	DFC02	Very poor	2.15	226	Fine sand	0.30	30.9
	DFC03	Poor	2.20	218	Fine sand	0.26	20.2
	DFC04	Very poor	1.66	316	Medium sand	0.35	102
	DFC05	Poor	1.98	254	Medium sand	<0.20	317
	DFC06	Poor	2.41	189	Fine sand	0.27	18.3
	DFC07	Very poor	2.10	233	Fine sand	0.34	16.4
	DFC08	Very poor	1.88	272	Medium sand	0.27	18.8
	DFC09	Poor	2.15	225	Fine sand	0.27	13.8
	DFC10	Very poor	2.35	196	Fine sand	0.33	73.8
Gardline (2009) located close to the cuttings pile	B1	Poor	1.93	262	Medium sand	0.8	26.8
	B2	Poor	2.03	244	Fine sand	0.8	62.6
	B3	Poor	2.57	168	Fine sand	0.8	136.1
	B4	Very poor	1.97	255	Medium sand	0.8	97.2
	B5	Poor	1.86	276	Medium sand	0.7	104.8
	B6	Very poor	1.89	270	Medium sand	0.7	48.5
	B7	Poor	2.12	230	Fine sand	0.7	43.8
	B8	Poor	2.46	182	Fine sand	0.8	33.3

Survey	Station	Sorting	Mean particle size			Total organic carbon (%)	Total hydrocarbon content ($\mu g g^{-1}$)
			Phi	µm	Wentworth class		
Fugro (2018) located on the cuttings pile	DCP01	Extremely poor	5.1	29	Medium sand	2.07	1,440
	DCP02	Extremely poor	3.1	117	Very fine sand	2.05	2,930
	DCP03	Extremely poor	4.83	35	Coarse silt	1.49	3,400
	DCP04	Extremely poor	5.04	30	Medium silt	1.70	2,610
	DCP05	Extremely poor	4.85	35	Coarse silt	3.11	146,000
	DCP06	Extremely poor	4.32	50	Coarse silt	1.49	2,170
	DCP07	Extremely poor	4.55	43	Coarse silt	1.33	1,990
	DCP08	Very poor	0.13	912	Coarse sand	<0.20	300
	DCP09	Extremely poor	4.37	48	Coarse silt	1.19	1,820
	DCP10	Very poor	4.25	53	Coarse silt	1.07	2,850
	DCP11	Very poor	4.87	34	Coarse silt	1.74	1,260
	DCP12	Extremely poor	4.26	52	Coarse silt	1.85	6,120
	Cell Top 1	Extremely poor	4.96	32	Coarse silt	2.64	73,400
	Cell Top 2	Very poor	4.76	37	Coarse silt	1.30	37,600
	Cell Top 3	Extremely poor	4.71	38	Coarse silt	1.58	16,100

Table 4.2 Cuttings pile and cell top core sample hydrocarbon analysis (Fugro, 2018)

Station	Core depth (cm)	Total organic carbon (%)	Total hydrocarbon content (µgg-1)	Station	Core depth (cm)	Total organic carbon (%)	Total hydrocarbon content (µgg-1)
DCP01	50	2.40	38,500	DCP09	50	1.53	24,500
	100	<0.20	13.7		100	0.23	54.2
	150	<0.20	6.7		150	0.23	60.7
	200	0.33	14.6		200	<0.20	6.3
	250	0.29	14.3		250	0.45	19.5
	300	0.33	11.9		300	0.45	44.7
	380	0.49	28.1	Cell Top 1	0	1.66	73,400
DCP02	23.5	1.46	37,400		35	8.52	24,800
	47	7.59	46,700		70	2.45	35,100
DCP05	50	1.41	20,600	Cell Top 2	0	2.32	37,600
	100	5.11	114,000		35	4.99	73,400
	150	0.26	4,720		72.5	2.15	49,200
	200	0.37	152	Cell Top 3	0	1.53	16,100
	250	0.26	79.6		17.5	0.23	48,400
	300	0.46	31.5		35	0.23	31,100
	350	0.44	18.0	-			

Table 4.3 presents the mean concentrations of THC and several heavy metals recorded in the three Dunlin surveys discussed above, as well as the Quad 211 infield survey which sampled the wider Quadrant 211 area (Gardline, 2010b), the OSPAR (2005) background concentrations, the United Kingdom Offshore Operators Association (UKOOA) (2001) mean, and 95th percentile concentrations for stations >5 km from an active platform and stations within 500 m of an active platform in the northern North Sea.

The mean THC from the Quad 211 infield survey (Gardline, 2010b) was between the UKOOA (2001) mean and 95th percentile values for stations more than 5 km from an active installation, indicating the background THC in Quad 211 is similar to other undisturbed areas of the northern North Sea. The THC recorded is likely to be a combination of naturally occurring and highly weathered anthropogenic hydrocarbons from distant diffuse sources (Gardline, 2010b).

Compared to the Gardline (2010b) result, the mean THC from the two surveys near the cuttings pile (but not actually on it) showed slightly elevated THC, though mean THC was still within one order of magnitude of the UKOOA (2001) values. The slightly elevated THC levels recorded in these two surveys are likely due to small amounts of diesel from the diesel based drilling fluids historically used at the Dunlin Alpha installation.

On the cuttings pile and the cell tops, THC was clearly and consistently elevated well above UKOOA (2001) 95th percentile levels for the northern North Sea and in line with the average concentration for sediments within 500 m of active platforms in the wider North Sea (11,049 µgg^{-1}; data specific to the northern North Sea was unavailable for this parameter). The elevated THC levels recorded are consistent with legacy contamination with non-aqueous drilling fluids, and Fugro (2018) identifies signatures of four separate drilling fluids within the sediment samples.

Heavy metal concentrations were consistent with the THC results. The mean heavy metal concentrations from Gardline (2010b) were in line with UKOOA (2001) mean concentrations for stations more than 5 km from an active installation, and were below the OSPAR (2005) background concentrations. Heavy metals at stations close to the cuttings pile were present at close to OSPAR (2005) and UKOOA (2001) background concentrations, although most were slightly elevated, notably barium, which is indicative of the presence of drilling mud.

On the cuttings pile concentrations of most heavy metals were much higher than background concentrations. Barium in the form of barium sulphite (barite) is a common weighting agent in drilling muds and often contains other trace elements as impurities, including cadmium, chromium, copper, lead, mercury and zinc. The elevated concentrations in the cuttings pile sediments are therefore consistent with the presence of drilling mud, while the slightly elevated levels in the surrounding sediments likely represent settling and re-settling of small quantities of drilling mud and cuttings away from the main pile.

Table 4.3 Comparison of contaminants from Dunlin surveys with background North Sea concentrations

Surveys/Standards and their description	Average concentration (μgg^{-1} dry sediment)							
	THC	Barium	Chromium	Copper	Cadmium	Nickel	Lead	Zinc
Fugro (2017a) *near cuttings pile*	62.6	2,043	18	17.3	0.083	6.87	20.3	97.1
Gardline (2009b) *near cuttings pile*	69.1	3,975	18	10.7	0.12	6.7	21	68
Fugro (2018) *on cuttings pile / cell tops*	14,400	34,412	82.8	155	1.78	41.3	79.1	1,565
Gardline (2010b) *Quad 211 infield survey*	16.9	478	14	3.2	0.06	6.4	8.8	8
OSPAR (2005) *background concentrations*	-	-	60	20	0.2	30	25	90
UKOOA (2001) Note 1 *mean concentration for stations >5 km from an active platform*	10.82	332	17.1	3.6	-	10.9	7	12.1
UKOOA (2001) *95th percentile concentrations for stations >5 km from an active platform*	20.32	637	36.5	5.4	-	12.4	8.6	13
UKOOA (2001) Note 2 *mean concentrations for stations 0 - 500 m from an active platform*	-	29,600	55.1	-	0.53	-	36.4	-

Notes:
1. Mean concentrations for metals in sediments >5 km from nearest platform for the northern North Sea.
2. Mean concentrations for metals in sediments 0 – 500 m from nearest platform for the northern North Sea.

Organotin compounds, principally tributyltin (TBT), were historically used in marine antifouling products. TBT accounted for almost all of the organotin compounds present in the surface samples collected from the Dunlin Alpha cuttings pile. Where measurable quantities were recorded, the values were higher than the EAC thresholds set by OSPAR. Dibutlytin (DBT) was the principle organotin compound recorded in the subsurface 'core' samples. This may indicate that microbial degradation of the TBT is occurring in the Dunlin Alpha drill cuttings pile. TBT levels ranged from a minimum of <0.4 ngg^{-1} at Station DCP02 and DCP05 to a maximum of 20.1 ngg^{-1} at Station DCP07. The mean across survey stations was 4.8 ngg^{-1}. Total organotins ranged from < 0.4 ngg^{-1} to a maximum of 20.1 ngg^{-1}, averaging 5.0 ngg^{-1} across stations (Fugro, 2018).

4.3. Biological Environment

4.3.1. Benthos

4.3.1.1. Around the Dunlin Alpha Installation

The area surrounding the cuttings pile has been investigated by recent surveys by Gardline (2009) and Fugro (2017b). In both surveys the macrofauna was dominated by annelids, and the most common taxon was the polychaete, *Galathowenia oculata*, which accounted for 5% of individuals identified in Gardline (2009) and 18% in Fugro (2017). *G. oculata* is considered to be a hydrocarbon intolerant species, as is *Euchone incolor*, another polychaete that was abundant in Fugro (2017), although *G. oculata* has been found at increased densities in disturbed or organically enriched environments (Gardline, 2009). *Paramphinome jeffreysii*, considered to be a hydrocarbon tolerant species, was common but not dominant in Fugro (2017), the moderate dominance of *G. oculata*, reported in Fugro (2017) (but not in Gardline, 2009) may indicate the slightly elevated TOC in the vicinity of the Dunlin Alpha installation is having a slight effect on community structure, although the survey area was found overall to be species rich, diverse and homogenous (Gardline, 2009, Fugro, 2017b). Six of the ten most dominant taxa reported in Gardline (2009) were also reported in comparison surveys from the surrounding area, indicating the abundances recorded in Gardline (2009) are not unusual for the region.

Observed epifauna was sparse and included seastars (Asteroidea), sea anemones (Actiniaria including *Cerianthus lloydii*), sea urchins (Echinoidea), sponges (Porifera) and gastropods (Gastropoda) (Fugro, 2016a).

Fugro (2017) reported that a previous habitat assessment (Fugro, 2016a) had identified the area around the Dunlin Alpha installation as the EUNIS biotope complex 'Circalittoral muddy sand' (A.26), but that the macrofauna present did not match any of the classifications within this complex. Fugro (2017) suggested the habitat in the area was a variation on European Nature Information System (EUNIS) habitat A5.253 (medium to very fine sand, 100 m to 120 m, with polychaetes (i.e. *Spiophanes kroyeri*, *Amphictene auricoma*, *Myriochele* sp., *Galathowenia* sp., *Aricidea wassi*) and amphipods (i.e. *Harpinia antennaria)*. A still taken at Station DFC01 is presented in Figure 4.5.

Figure 4.5 Seabed near the Dunlin Alpha installation showing fine sand (Fugro, 2016a)

No evidence of Annex I habitats or species was reported in Gardline (2009). Fugro (2017) reported small numbers of juvenile ocean quahog (*Arctica islandica)*, a bivalve that is on the OSPAR (2008) 'List of threatened and declining habitats and species' and is a Priority Marine Feature for which Scottish marine protected areas (MPAs) may be selected. The small numbers of juveniles reported are not expected to qualify the area as a potential protected site.

Surveys in the wider area, DFGI pipeline route (Fugro, 2016b, Fugro, 2016c, Gardline 2011), DPI cable route (Fugro, 2016d, Fugro, 2016e, Gardline, 2010a) and Quad 211 infield survey (Gardline, 2010b) indicated the macrofauna was not affected by anthropogenic disturbance. Macrofauna was broadly uniform with some small-scale variability (Fugro, 2016c). The number of taxa was high, and stations were not strongly dominated by single taxa. Many taxa were found at low abundances which, combined with a high overall taxa count, indicates a well-balanced, undisturbed community.

4.3.1.2. Cuttings Pile

The benthos on the cuttings pile was investigated by Fugro (2018). In contrast to Gardline (2009) and Fugro (2017), the macrofauna on the cuttings pile was found to be dominated by hydrocarbon tolerant taxa including *Capitella* sp. and *Thyasira sarsi*, and secondary colonisers including *Chaetozone setosa* and *Cirratulus cerratus*. The cuttings pile supported fewer taxa than the surrounding area, but higher numbers of individuals, suggesting super-abundance of disturbance tolerant taxa. The single most common taxon at each station accounted for between 33.5% and 84.2% of individuals at each station, indicating a high degree of numerical dominance (Fugro, 2018). Several taxa that were abundant in the surrounding area, including *G. oculata*, *E. incolor*, *Paradoneis lyra*, *P. jeffreysii*, *Amythasides macroglossus*, *Pterolysippe vanelli* and the bivalve, *Axinulus croulinensis*, were noted to be absent from the survey area or present in low numbers (Fugro 2018). Diversity and evenness values were low to moderate, reflecting the low number of taxa and the high abundance of the dominant taxa.

Statistical analysis showed that increased distance from the Dunlin Alpha installation correlated negatively with number of individuals and positively with number of taxa and diversity and evenness indices. This indicates that the community is more heavily modified closer to the Dunlin Alpha installation.

The predominant biotope identified across the cuttings is broadly similar to EUNIS habitat A5.374 '*Capitella* sp. and *Thyasira* spp. in organically enriched offshore circalittoral mud and sandy mud' (Fugro, 2018). A still taken at Station DCP05 is presented in Figure 4.6.

While the infauna on the cuttings pile was impoverished, the various sediment types and the anthropogenic debris present on the surface afforded a variety of habitats for epifauna. The sediment was interspersed with mussel shell fragments and possible bacterial mats of *Beggiatoa* spp (Fugro, 2018). The reef forming cold water coral *Lophelia pertusa* was also observed, as well as the IUCN listed ling (*Molva molva*) and possibly listed redfish (*Sebastes* sp.) (Fugro, 2018). Potentially sensitive habitats were limited to *Beggiatoa* spp. mats on anoxic sublittoral sediment (Fugro, 2018). Given that these habitats are present due to the artificial conditions on the cuttings pile, they are not expected to qualify for protected status.

Figure 4.6 Dunlin cuttings pile seabed photograph showing muddy sand with mussel shells and a seastar (*Asteroidea* sp.) (Fugro, 2016a)

Overall, the fauna close to but not on the cuttings piles was similar to that observed at undisturbed locations remote from the Dunlin Alpha installation. There was a possibility of slight community modification due to organic enrichment, but the community was found to be species rich, diverse and homogenous (Gardline, 2009b, Fugro, 2018). The benthic community on the cuttings pile itself was highly modified and dominated by hydrocarbon tolerant species. The community was species poor, with less diversity and less evenness (Fugro, 2018). The observed diversity of epifauna was higher on the cuttings pile due to the increased number of habitats available (higher variety of sediment grain sizes compared to undisturbed seabed and anthropogenic debris providing hard surfaces for attaching species).

4.3.2. Fish and Shellfish

DECC (2016) report that species diversity within the fish community is not as great in the central and northern North Sea as in the southern North Sea. DECC (2016) also report that the fish community between 100 and 200 m (i.e. within the depth bounds of the project area) is characterised by long rough dab (*Hippoglossoides platessoides*), hagfish (*Myxine glutinosa*) and Norway pout (*Trisopterus esmarkii*). Basking shark (*Cetorhinus maximus*), tope (*Galeorhinus galeus*) and porbeagle (*Lamna nasus*) are all also likely to occur in small numbers throughout the North Sea, and the common skate (*Dipturus batis*) occurs at low density throughout the northern North Sea. However, these species are considered to be rare in the waters surrounding the project area (DECC, 2016).

The fish populations in the project area are characterised by species typical of the northern North Sea. There are a number of spawning and nursery regions for commercially important fish and shellfish species that occur in the vicinity of the project area (Coull *et al.*, 1998, Ellis *et al.*, 2012). The project area is located within the spawning grounds of haddock (*Melanogrammus aeglefinus*), saithe (*Pollachius virens*), Norway pout (*Trisopterus esmarkii*), cod (*Gadus morhua*) and whiting (*Merlangius merlangus*) and the nursery grounds of haddock, Norway pout, mackerel (*Scomber scombrus*), blue whiting (*Micromesistius poutassou*), spurdog (*Squalus acanthias*), herring (*Clupea harengus*) and ling (*Molva molva*). Information on spawning and nursery seasonality for the different species is detailed in Table 4.4 and the extent of the areas is illustrated in Figure 4.7 and Figure 4.8 .

Table 4.4 Fish spawning and nursery timings in the project area (Coull *et al.*, 1998; Ellis *et al.*, 2012)

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Haddock	N	SN	SN	SN	SN	N	N	N	N	N	N	N
Saithe	S	S	S	S								
Norway pout	SN	SN	SN	SN	N	N	N	N	N	N	N	N
Mackerel	N	N	N	N	N	N	N	N	N	N	N	N
Blue whiting	N	N	N	N	N	N	N	N	N	N	N	N
Spurdog	N	N	N	N	N	N	N	N	N	N	N	N
Herring	N	N	N	N	N	N	N	N	N	N	N	N
Cod	S	S	S	S								
Whiting		S	S	S	S	S						
Ling	N	N	N	N	N	N	N	N	N	N	N	N
Key			S = Peak spawning			S = Spawning			N = Nursery			

Fisheries sensitivity maps produced by Aires *et al.* (2014), indicate that there is a low probability of aggregations of Group 0 fish (fish in their first year of life) occurring in the project area for all species investigated.

The pre-decommissioning habitat assessment survey of the Dunlin field recorded ling, redfish (*Sebastes* sp.), unidentified cod-like fish (*Gadiformes* sp.), saithe and haddock (Fugro, 2016a).

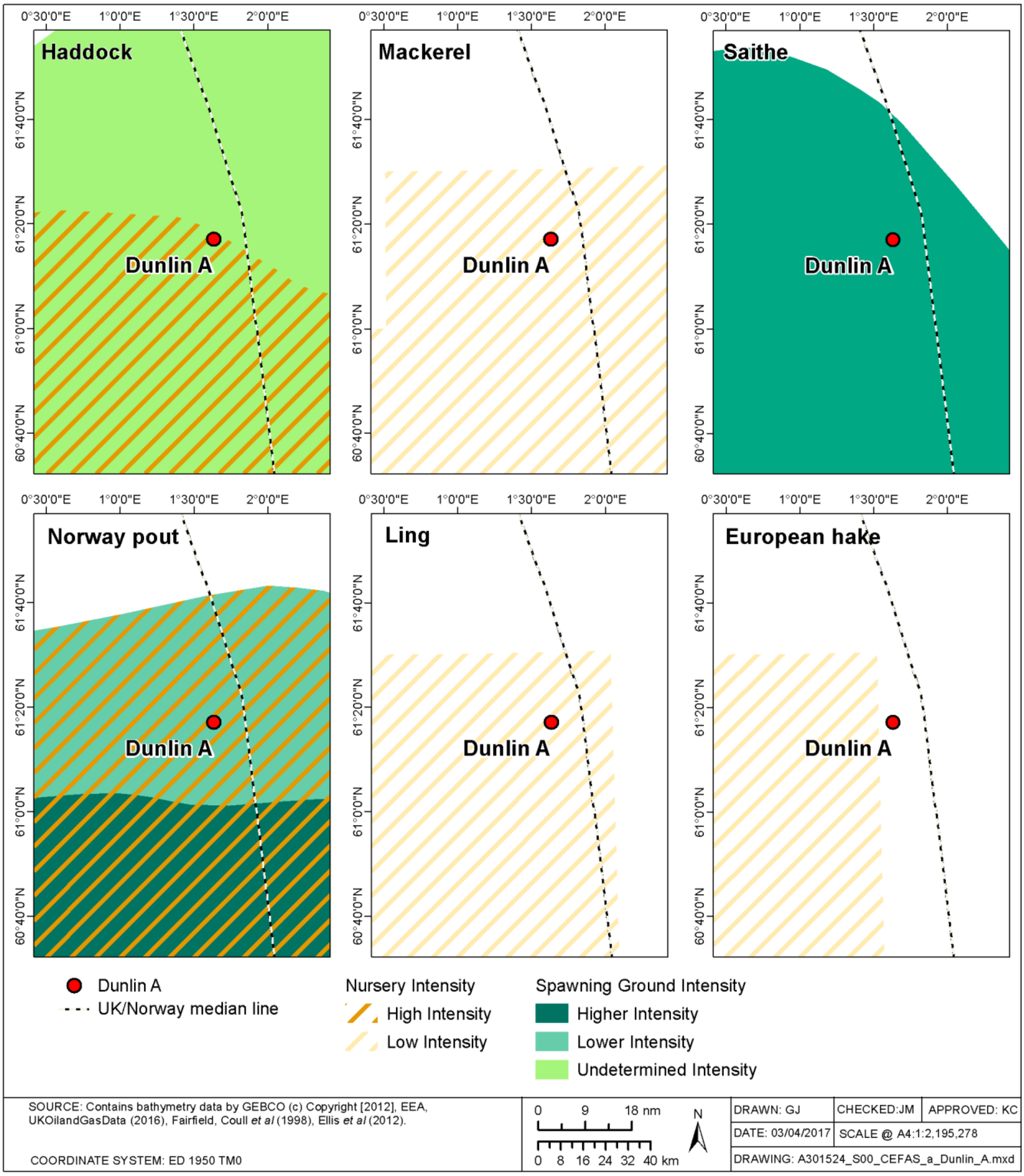


Figure 4.7 Fish spawning and nursery grounds around the project area (Coull *et al.*, 1998; Ellis *et al.*, 2012)

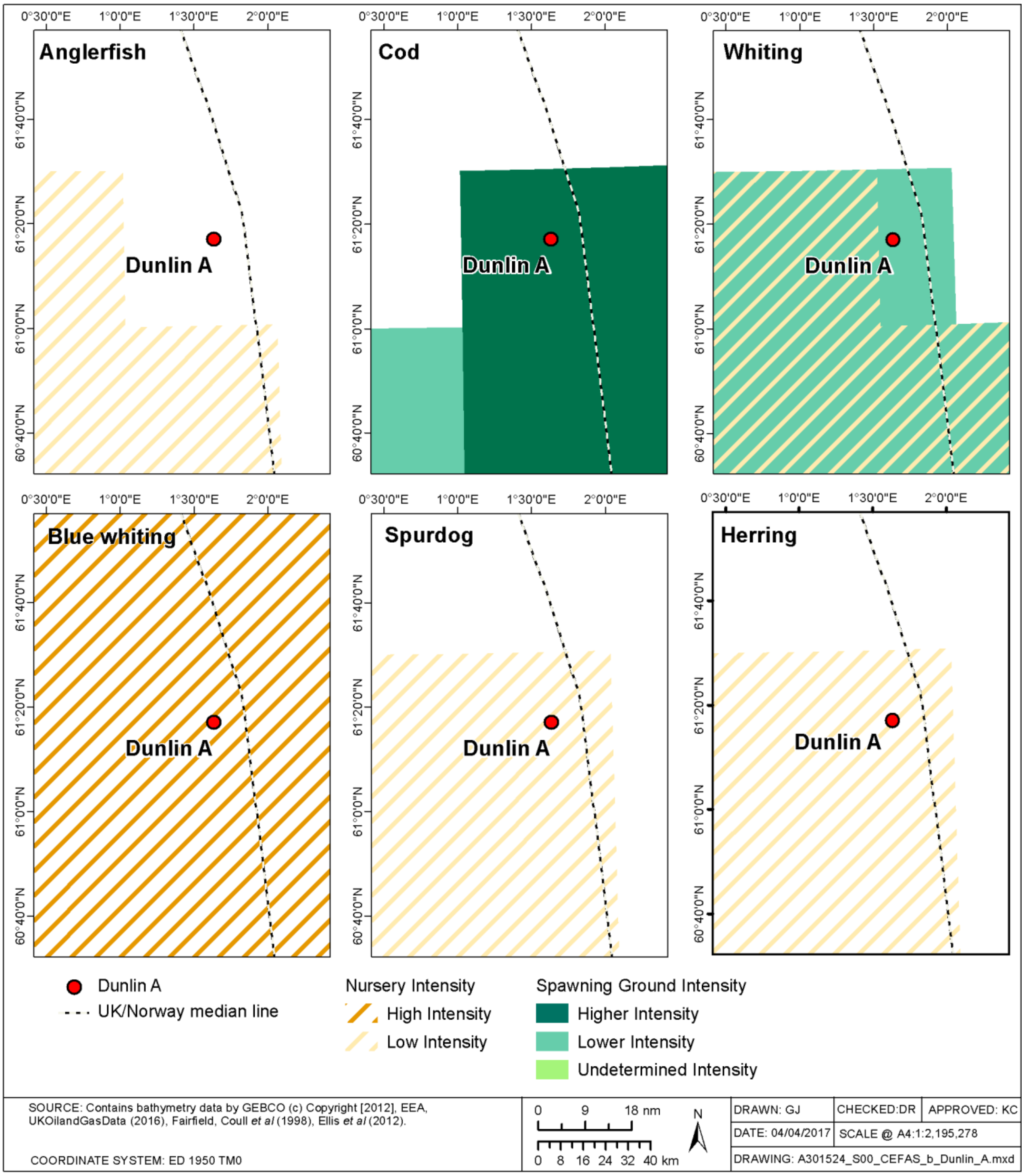


Figure 4.8 Fish spawning and nursery grounds around the project area (Coull *et al.*, 1998; Ellis *et al.*, 2012)

4.3.3. Seabirds

The project area is important for northern fulmar (*Fulmarus glacialis*), northern gannet (*Morus bassanus*), great black-backed gull (*Larus marinus*), Atlantic puffin (*Fratercula arctica*), black-legged kittiwake (*Rissa tridactyla*), and common guillemot (*Uria aalge*) for the majority of the year (DECC, 2016). Manx shearwaters (*Puffinus puffinus*) are present in the vicinity of the project area between spring and autumn months. European storm petrels (*Hydrobates pelagicus*) are present during September and November. Great skua (*Stercorarius skua*), glaucous gull (*Larus hyperboreus*), Arctic skua (*Stercorarius parasiticus*) and little auk (*Alle alle*) are generally present in the northern North Sea in low densities for the majority of the year. Of the species most likely to be seen in the project area throughout the year, northern fulmar and black-legged kittiwake have suffered significant population declines in the last two decades (i.e. -36% and -50%, respectively; JNCC, 2020).

The seasonal sensitivity of seabirds to oil pollution in the immediate vicinity of the project area has been derived from the JNCC Seabird Oil Sensitivity Index (SOSI) (Webb *et al.*, 2016), and is presented in Table 4.5, Figure 4.8 and Figure 4.9.

Table 4.5 Seabird sensitivity to oil pollution in the project Area (Webb *et al.*, 2016)

Block	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
211/17	3*	5	5	5*	N	5*	5	5	5*	N	3*	3
211/18	3*	5	5	5*	N	5*	5	5	5*	N	3*	3
211/19	3*	5	5	5*	N	5*	5	5*	5*	N	3*	3
211/22	5	5	5	5*	N	5*	5	5	4	4*	4*	4
211/23	5	5	5	5*	N	5*	5	5	5	5*	3*	3
211/24	5	5	5	5*	N	5*	5	5	5	5*	3*	3
211/27	5	5	5	5*	N	5	5	5	4	4*	5*	5
211/28	5	5	5	5*	N	5*	5	5	4	4*	5*	5
211/29	5	5	5	5*	N	5*	5	5	5	5*	5*	5
Key	* in light of coverage gaps, an indirect assessment of SOSI has been made											
	1 = Extremely high		2 = Very high		3 = High		4 = Medium		5 = Low		N = No data	

In Block 211/23 the sensitivity of seabirds to oil pollution, reflected by the Seabird Oil Sensitivity Index (SOSI), is considered low for all months except November and December, when seabird oiling sensitivity is considered high. The assessment of SOSI values being high in November have been based on worst-case estimates for adjacent months and adjacent blocks. No data was available for Block 211/23 or the surrounding blocks during the month of May and, consequently, indirect assessment was required for the months of April and June for all of these blocks.

There are significant data gaps at times of the year for the project area (Webb *et al.*, 2016), with data missing for some blocks for seven months out of the year. The JNCC (1999) seabird vulnerability index presents older data, but has more comprehensive coverage of the project area. Seabird vulnerability according to JNCC (1999) is presented in Figure 4.10 and Figure 4.11. The months of March, July, October and November are those when seabird species across the project area are considered most vulnerable to surface pollution, which does not correlate well with the Webb *et al.* (2016) data, except for the period of presumed elevated sensitivity in November.

Overall annual seabird vulnerability according to JNCC (1999) is predicted to be slightly higher than that predicted in Webb *et al.* (2016), with moderate, high or very high vulnerability reported in eight out of twelve months in JNCC (1999), compared to two months (including one month where proxy data is recorded) in Webb *et al.* (2016).

Figure 4.8 Seabird sensitivity to oiling in the vicinity of the project area (Webb *et al.*, 2016)

Figure 4.9 Seabird sensitivity to oiling in the vicinity of the project area (Webb *et al.*, 2016)

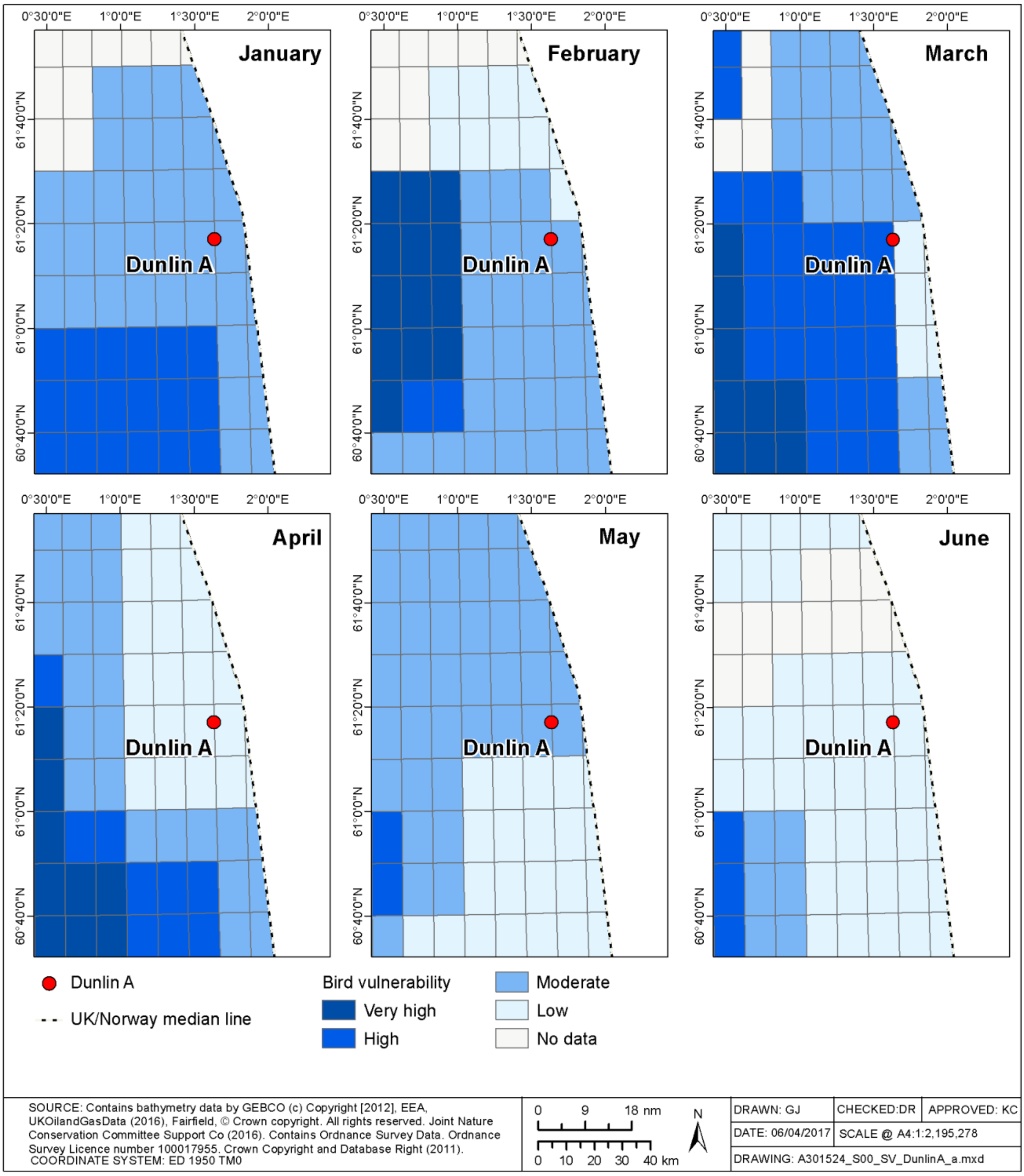


Figure 4.10 Seabird vulnerability in the vicinity of the project area (JNCC, 1999)

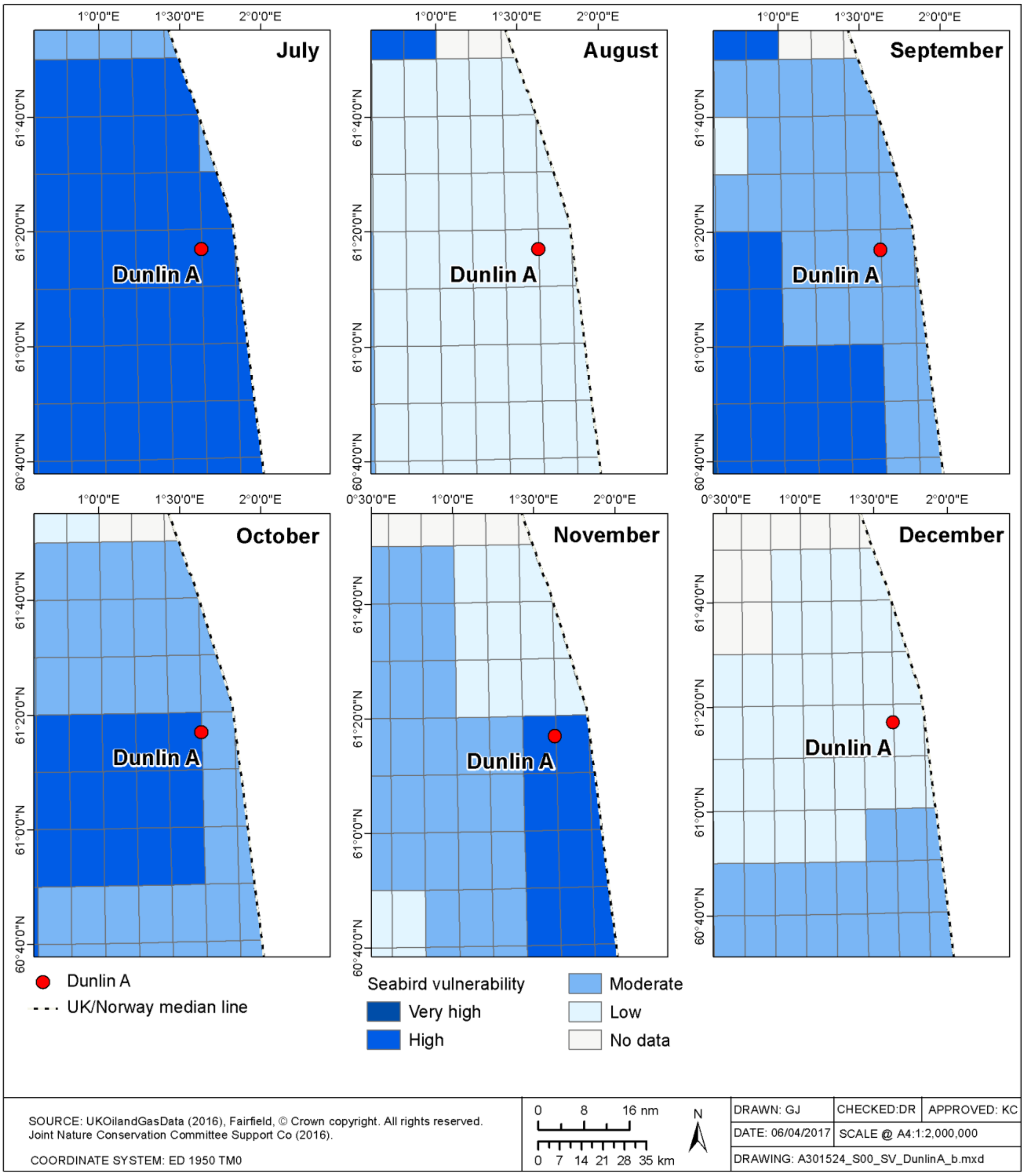


Figure 4.11 Seabird vulnerability in the vicinity of the project area (JNCC, 1999)

4.3.4. Cetaceans

Twenty-eight cetacean species have been recorded in UK waters from sightings and strandings. Of these, eleven species are known to occur regularly in the UKCS, while seventeen are considered rare or vagrant (DECC, 2016). Cetaceans regularly recorded in the northern North Sea include: white-sided dolphin (*Lagenorhynchus acutus*), bottlenose dolphin (*Tursiops truncatus)* (primarily in inshore waters), harbour porpoise (*Phocoena phocoena*), killer whale (*Orcinus orca*), minke whale (*Balaenoptera acutorostrata*), pilot whale (*Globicephala melas*), common dolphin (*Delphinus delphis*) and white-beaked dolphin (*Lagenorhynchus* *albirostris*) (Reid *et al.*, 2003). Risso's dolphin (*Grampus griseus*) and some large baleen whales are also occasionally sighted. Spatially and temporally, harbour porpoise, white-beaked dolphins, minke whales, killer whales and Atlantic white-sided dolphins are the most regularly sighted cetacean species in the offshore environment in the northern North Sea (Hammond *et al.*, 2001, Reid *et al.*, 2003). Bottlenose dolphins are largely coastal in this region and are unlikely to be sighted in the vicinity of the project area with any regularity.

Occurrence of the most frequently recorded species is detailed in Table 4.6; the project area is not considered to be particularly important for any cetacean species.

Table 4.6 Occurrence of the most regularly observed cetacean species across the project area (Hammond *et al.*, 2001; Reid *et al.*, 2003; Hammond *et al.*, 2017)

Species	Description of occurrence
Harbour porpoise	Harbour porpoise are frequently found throughout UK waters year round. They primarily occur in groups of one to three individuals in shallow waters, although they have been sighted in larger groups and in deeper waters on occasion. Based on available density estimates, this species is likely to be encountered within the project area.
Killer whale	Widely distributed with sightings across the North Sea all year round; seen in both inshore waters (April to October) and the deeper continental shelf waters (November to March). May move inshore to target seals seasonally. However, density and abundance remains very low across the project area and surrounding waters.
Minke whale	Minke whales usually occur in water depths of 200 m or less and occur throughout the northern and central North Sea. They are usually sighted in pairs or in solitude; however, groups of up to 15 individuals can be sighted feeding. It appears that animals return to the same seasonal feeding grounds. Based on available density estimates, this species may be encountered within the project area.
Atlantic white-sided dolphin	White-sided dolphins show both season and inter-annual variability. They have been sighted in large groups of 10 - 100 individuals. They have been sighted in waters ranging from 100 m to very deep waters, but also enter continental shelf waters. They can be sighted in the deep waters around the north of Scotland throughout the year and enter the North Sea in search of food.
White-beaked dolphin	White-beaked dolphins are usually found in water depths of between 50 and 100 m in groups of around 10 individuals, although large groups of up to 500 animals have been seen. They are present in the UK waters throughout the year, however more sightings have been made between June and October.

4.3.5. Seals

Grey (*Halichoerus grypus*) and harbour (*Phoca vitulina*) seals will feed both in inshore and offshore waters depending on the distribution of their prey, which changes both seasonally and yearly. Both species tend to be concentrated close to shore, particularly during the pupping and moulting season. Seal tracking studies from the Moray Firth have indicated that the foraging movements of harbour seals are generally restricted to within a 40 – 50 km range of their haul-out sites (Special Committee on Seals (SCOS), 2014). The movements of grey seals can involve larger distances than those of the harbour seal, and trips of several hundred kilometres from one haul-out to another have been recorded (Sea Mammal Research Unit (SMRU), 2011). As the project area is located approximately 137 km offshore, these species may be encountered in the wider area from time to time, but the project area is not considered to be particularly important for seals. This is confirmed by the latest grey and harbour seal density maps commissioned by the Scottish Government which report the presence of grey and harbour seals in the project area as between zero and one individual per 25 km^2 (Russell *et al.*, 2017).

4.4. Conservation

There are no designated or proposed sites of conservation interest in the project area. The closest designated site, the Pobie Bank Reef Special Area of Conservation (SAC), lies 98 km to the south west of the Dunlin Alpha installation, off the east coast of Shetland. The site has been designated for its stony and bedrock rocky reefs (JNCC, 2013a). The closest SPA is Hermaness, Saxa Vord and Valla Field, designated for protection of breeding northern gannet, great skua, and Atlantic puffin, which lies 137.5 km south west of Dunlin Alpha.

Marine Scotland has put forward areas with Priority Marine Features (PMF) for designation as MPAs under the Marine (Scotland) Act (2010). The Marine Management Organisation (MMO) has put forward areas with features of conservation importance (FOCI) for designation as MCZs under the UK Marine and Coastal Access Act (2009). The closest MPA to the project area is the North-east Faroe Shetland Channel Nature Conservation MPA (NCMPA). The site is approximately 116.5 km from the project area and is the largest designated MPA in Europe. The site is designated for deep-sea sponge aggregations, offshore deep-sea muds, offshore subtidal sands and gravels, and continental slope (JNCC, 2017). Details of the conservation sites in the vicinity of the project area are given in Table 4.7 and their locations are provided in Figure 4.12.

Table 4.7 Conservation sites in the vicinity of the project area

Description	Distance to Project area (km)
Pobie Bank SAC	
Reefs are the primary reason for selection of this site. The stony and bedrock reefs of the site provide a habitat to an extensive community of encrusting and robust sponges and bryozoans and in the shallowest areas the bedrock and boulders also support encrusting coralline algae (JNCC, 2013a).	98
Hermaness, Saxa Vord and Valla Field SPA	
This site supports the following populations of European importance: breeding red throated diver (*Gavia stellata*), northern gannet, great skua and Atlantic puffin; and "at least 20,000 seabirds". During the breeding season, the area regularly supports 152,000 individual seabirds including common guillemot, black-legged kittiwake, European shag (*Phalacrocorax aristotelis*), northern fulmar, Atlantic puffin, great skua and northern gannet (JNCC, 2005a).	137
North East Faroe Shetland Channel NCMPA	
This is the largest designated MPA in Europe and the protected features are deep sea sponge aggregations, offshore deep sea muds, offshore subtidal sands and gravel, continental slope and a wide range of features from the West Shetland Margin Palaeo-depositional, Miller Slide and Pilot Whale Diapirs that are considered to be 'Key Geodiversity Areas' (KGAs)(JNCC, 2017).	116
Faroe-Shetland Sponge Belt NCMPA	
The protected features of this NCMPA are deep sea sponge and ocean quahog aggregations, offshore subtidal sands and gravels, continental slope and slope channels, iceberg plough marks, prograding wedges and slide deposits representative of the West Shetland Margin paleo-depositional system KGA and sand and sediment wave fields and sediment representative of the West Shetland Margin contourite deposits KGA (JNCC, 2016).	169
Fetlar to Haroldswick NCMPA	
This MPA supports a range of high energy habitats and species and it covers over 200 km^2 of important seabird feeding ground. The protected features of the site are: black guillemot (*Cepphus grylle*); 'circalittoral sand and coarse sediment communities'; horse mussel and maerl beds; 'kelp and seaweed communities on sublittoral sediment'; 'shallow tide-swept coarse sands with burrowing bivalves'; and 'marine geomorphology of the Scottish shelf seabed' (SNH, 2016).	140
Fetlar SPA	
The SPA comprises a range of habitats including species-rich heathland, marshes and lochans, cliffs and rocky shores. The principal areas of importance for birds are the northernmost part of the island and the south-western peninsula of Lamb Hoga. This site supports the following populations of European importance: breeding Arctic tern (*Sterna paradisaea*), red-necked phalarope *(Phalaropus lobatus)*, dunlin (*Calidris alpina schinzii*), great skua, and whimbrel (*Numenius phaeopus*); and "at least 20,000 seabirds" (JNCC, 2005b).	143

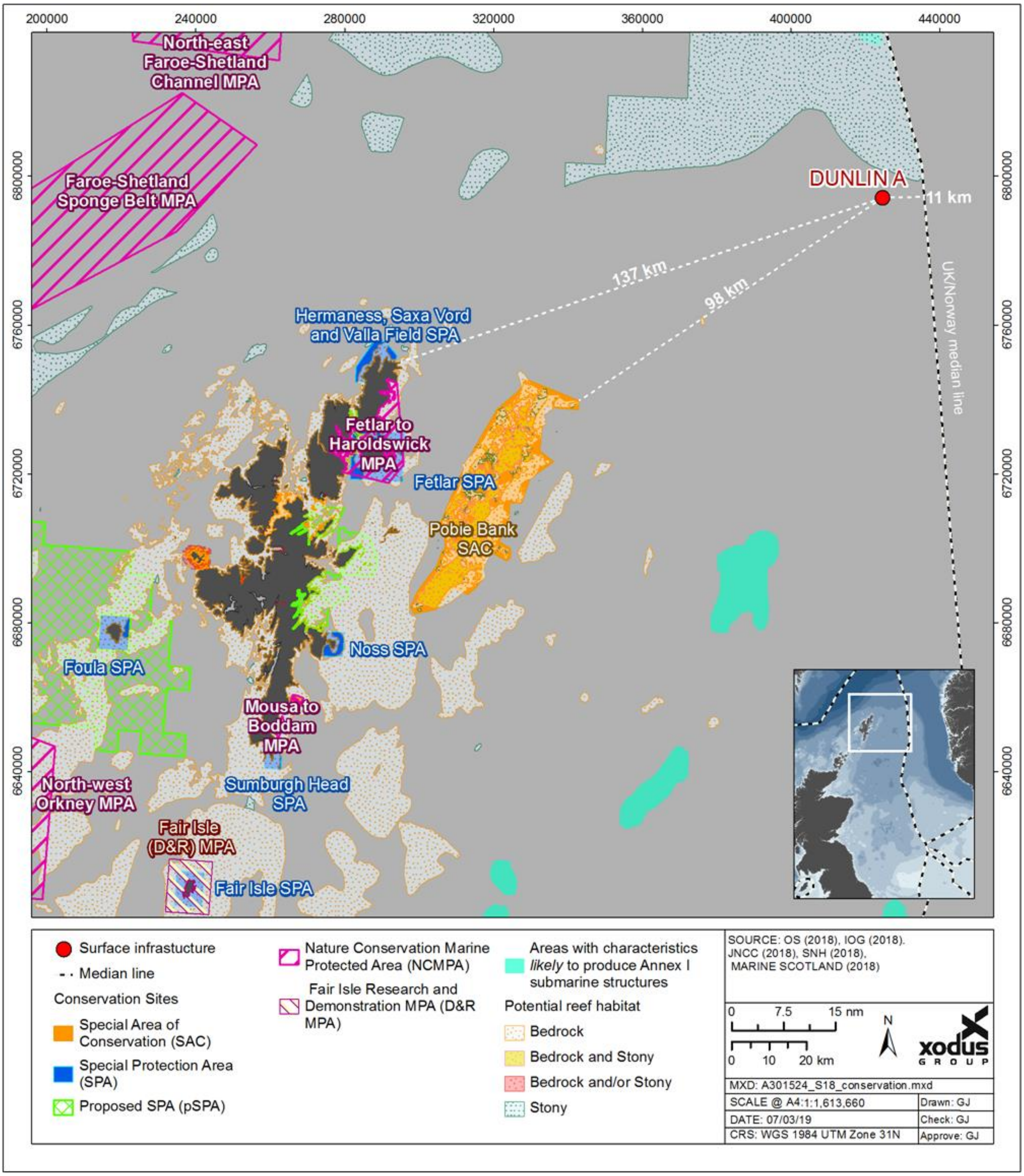


Figure 4.12 Sites of conservation importance

Survey work undertaken in the project area has identified several species and habitats of conservation interest, including juvenile *Arctica islandica* (Fugro, 2017b), mussel beds and *Beggiatoa* spp. on anoxic sediment, *Lophelia pertusa*, ling and *Sebastes* spp. (which may be protected depending on the species) (Fugro, 2017b). As the juvenile *Arctica islandica* were found in small numbers they are not expected to qualify the area as a potential protected site (Fugro, 2017b). The other species and habitats of conservation concern were deemed to be present in the area due to the artificial conditions on the cuttings pile and the substructure associated with the development, and are not therefore expected to qualify for protected status (Fugro, 2018).

Lophelia pertusa is known to be present on some of the Dunlin Alpha substructure, including the conductors and the CGBS (e.g. Fugro, 2016a). *Lophelia pertusa* is a reef-building cold water coral that provides habitats for other epifaunal and fish species, and is a UK habitat of principal importance and a Scottish Priority Marine Feature; it is also highlighted in Annex I of the European Habitats Directive, and is on the OSPAR List of Threatened and/or Declining Species and Habitats. This species is normally restricted to deep water in depth ranges of 200 – 2,000 m on the continental slope and the extent of *Lophelia pertusa* reefs is undergoing an overall decline due to mechanical damage by demersal fishing gear in all OSPAR areas (OSPAR, 2009b). However, the species has also been recognised in the scientific literature as one which grows opportunistically on oil and gas subsea infrastructure (e.g. Gass & Roberts, 2006) and which has been recorded from many offshore installations in the northern North Sea at depths between 59 m and 132 m.

The Dunlin Alpha was included in a study by the University of Edinburgh. The ANChor project (https://www.insitenorthsea.org/projects/anchor/), funded under the INSITE (INfluence of man-made Structures In The Ecosystem programme), established whether structures can connect species, populations and North Sea ecosystems. The findings showed that platform ecosystems have evolved to mimic those found in the wild and have the potential to contribute to natural ecosystems downstream (Henry, *et al.*, 2017). Larval trajectories for the protected coral species *Lophelia pertusa* showed the capacity for ecosystems on man-made structures to benefit ecosystems downstream that have been degraded by human impacts and climate change. This capacity was robust across climate states proxied by the North Atlantic Oscillation (NAO), with the furthest most dense connections happening in a year when current strength would have been strongest. Even in low-flow conditions, trajectories carried larvae into areas with known naturally-occurring coral ecosystems. By 2012 under what was assumed to be the strongest current strength, larvae reached a range of coral ecosystems in the Norwegian Exclusive Economic Zone (EEZ) including those in the deep-sea, on the continental shelf and slope, and in coastal fjords. Most notable was the direct supply of larvae in just a single generation into a Norwegian coral marine protected area from the Murchison and Thistle A platforms. Corals on both platforms have been verified. The Aktivneset coral MPA was designated to protect coral ecosystems from further fisheries degradation, the wider region also being impacted by climate change. The partial removal of Murchison (as an OSPAR derogation case) is unlikely to have impacted this role, with corals located on the structure that remains, and that was still within the range of ANChor's experiments (Henry *et al.*, 2017).

European Protected Species (EPS) are a group of animals and plants protected by law throughout the EU by virtue of being listed in Annexes II and IV of the Habitats Directive 92/43/EEC. Cetaceans are the EPS most likely to be recorded in the region, even if only in low numbers. The European sturgeon (*Acipenser sturio*) and leatherback turtle (*Dermochelys coriacea*) are also classed as EPS and occur in UK waters, although the project area is located at the furthest extent of their ranges and their occurrence in any numbers is unlikely.

The European Union meets its obligations for the conservation of bird species under the Bern Convention and the Bonn Convention, by means of the Directive 2009/147/EC (Birds Directive). It provides a framework for the conservation of wild birds in Europe, and includes provisions for the identification of SPAs for rare and vulnerable species listed in Annex I of the Directive, as well as for all regularly occurring migratory species, with particular attention to the protection of wetlands of international importance. Several species of seabird are considered to use the project area, though their occupancy varies between months (see Section 4.3.3).

Annex II species are protected under the EU Habitats Directive, which mandates that core areas of habitat these species rely upon must be protected under the Natura 2000 Network. The only species listed on Annex II of the EC Habitats Directive that is likely to occur in the vicinity of the project area with any regularity is the harbour porpoise. The harbour porpoise is the most common cetacean in UK waters, being widely distributed and abundant throughout the majority of UK shelf seas, both inshore and offshore. Due to the species' wide geographical distribution and the lack of knowledge with regards to their feeding and breeding habitats, there has been difficulty in selecting sites essential for their life and reproduction, as required under the Habitats Directive. Although potential calving grounds have been identified in the German North Sea (Sonntag *et al.*, 1999), no such areas are currently recognised in UK waters; a number of sites have been designated as candidate SACs for presence of harbour porpoise but none of these sites are located within the northern North Sea. Grey and harbour seals are also Annex II species but due to the distance from shore they are unlikely to be present in any significant numbers in the area.

Basking sharks, spurdog and blue shark (*Prionace glauca*) are listed on the IUCN red list and may be encountered in the project area, but the area is not of specific importance for any of these species. The basking shark and spiny dogfish are classed as vulnerable under the IUCN red list. The blue shark is classed as near threatened. In addition, basking sharks are protected under the Wildlife and Countryside Act 1981 (as amended).

4.5. Socio-Economic Environment

4.5.1. Commercial Fisheries

Fishing intensity in the project area is low in comparison to other areas in the North Sea. This section describes the types of fishing occurring in the project area and characterises commercial fish landings and fishing effort.

4.5.1.1. Baseline Fishing Activity Analysis

Fairfield commissioned Xodus (2016) to complete a fishing risk assessment, which included an analysis of the potential impact of the subsea infrastructure decommissioning options on fisheries. As part of this, the baseline fishing activity in the vicinity of the Greater Dunlin Area was reviewed (Xodus, 2016). The study area considered to be relevant for the decommissioning activities is shown in relation to the International Council for the Exploration of the Sea (ICES) rectangle 51F1 in Figure 4.2.

A commercial fisheries risk assessment was commissioned to investigate which nationalities actively fish around the Dunlin Alpha infrastructure (Anatec, 2017) using Automatic Identification System (AIS) satellite vessel tracking data. The distribution of AIS data recorded between June 2016 and July 2017 revealed that Norwegian vessels were the dominant fleet in the project area (45%), followed by the UK (28%) and France (21%), with Germany, Faroe Islands, Ireland, Netherland and Denmark as minority fleets (Figure 4.3).

Whilst trawl gear use forms the predominant fishing type undertaken by UK vessels across the project area, this comprises mostly of demersal UK gears such as bottom trawls. Pelagic trawl gear is associated with a small number of UK vessels but its use is more prolific with international vessels. Of the actively fishing national and international vessels, demersal gears contributed to 63% of the total activity, with static gear contributing 20% (mainly from Norway) and the remainder of the total active fishing coming from pelagic gears (Anatec, 2017; Figure 4.14 through Figure 4.17). Pelagic species are often caught as a bycatch species by the demersal fisheries, thereby contributing to the revenue generated by such vessels. However, pelagic species, such as mackerel targeted by the UK fleet, while high in value, are still relatively low in terms of volume compared to other regions of the UKCS and are not considered the target fisheries within this area for the UK fleet. The landings in the last five years for mackerel are equivalent to only a small number of trips, as an individual pelagic vessel can regularly land 1,000 – 2,000 tonnes of mackerel per trip. The primary fisheries in this area for the UK fleet would be demersal finfish and shellfish.

Across the project area, UK fishing effort using mobile gears is considered low compared to other areas in the North Sea, averaging between 0 – 1 days of fishing effort per year for the period 2012 – 2016. Published VMS data from the UK fishing fleet show that the number of fishing tracks recorded between 2012 - 2016 is low at the installation compared to other regions of the North Sea (Scottish Government, 2017; Figure 4.17).

To further inform this assessment, Scottish Fisherman's Federation (SFF) Services were contracted to carry out a consultation with relevant members of the fishing industry. SFF Services collected primary data by interviewing fishermen who utilise the waters around the Dunlin Alpha area. The vessel representatives interviewed provided output from their Global Positioning System (GPS) plotters to highlight the fishing areas they used within the study area.

Fishing activity in the offshore areas was widely influenced by the Cod Recovery Plan (CRP) and the Scottish Conservation Credit Scheme (SCCS). Through the duration of the CRP and SCCS, the number of days at sea for fishing vessels was considerably reduced. This often resulted in vessels changing their working practice so as not to waste valuable days at sea on steaming to offshore grounds. As a result, steaming time was accounted for as fishing time, which therefore impacted on the grounds that vessels operated on. Coincidentally, at the ICES Benchmark Workshop on North Sea Stocks (WKNSEA 2015), presentations demonstrated that the largest biomass of adult cod in the North Sea was found in the Viking area (which encompasses the area relating to the Greater Dunlin Area).

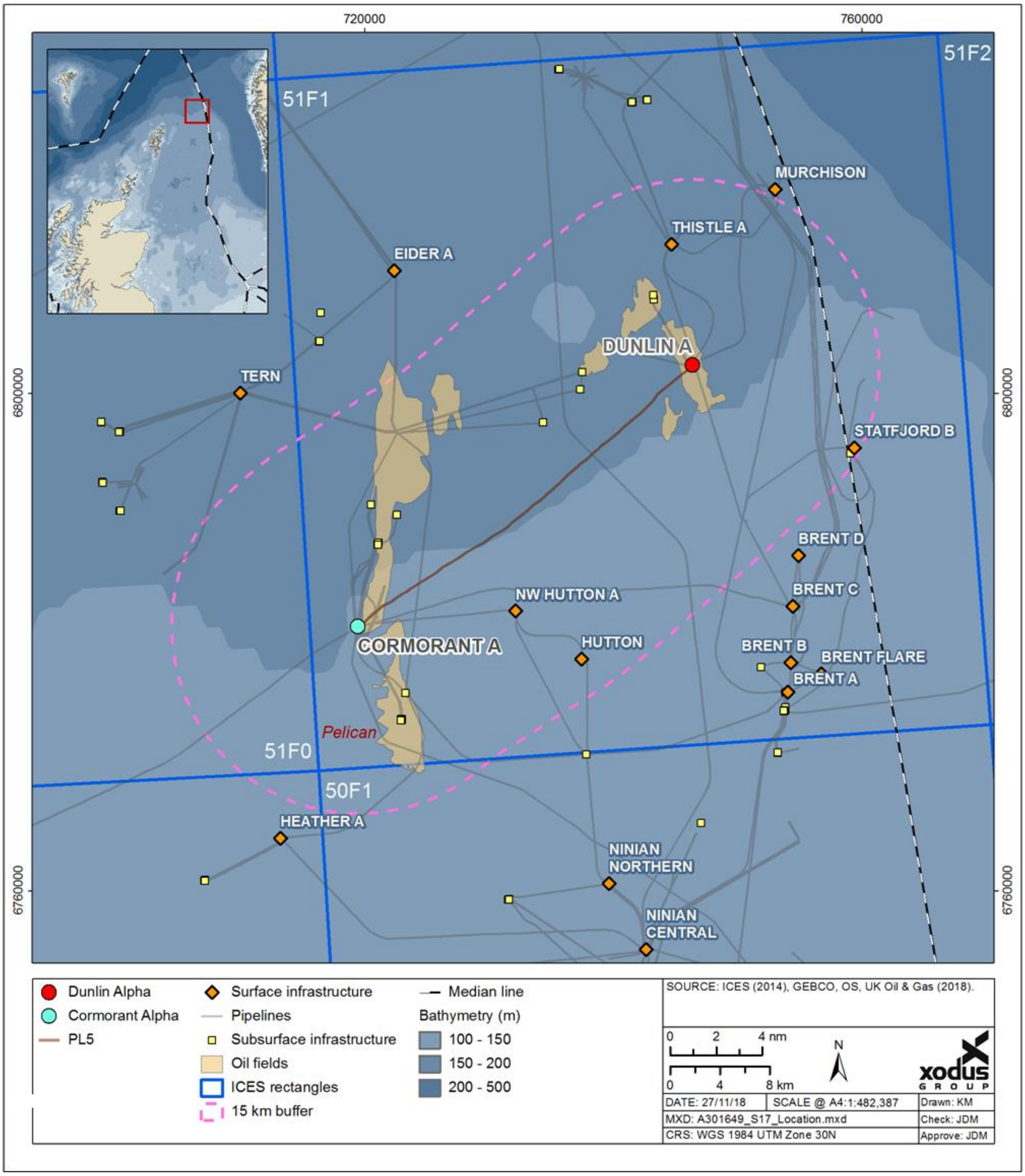


Figure 4.13 Baseline fishing activity study area relevant to Dunlin Alpha substructure

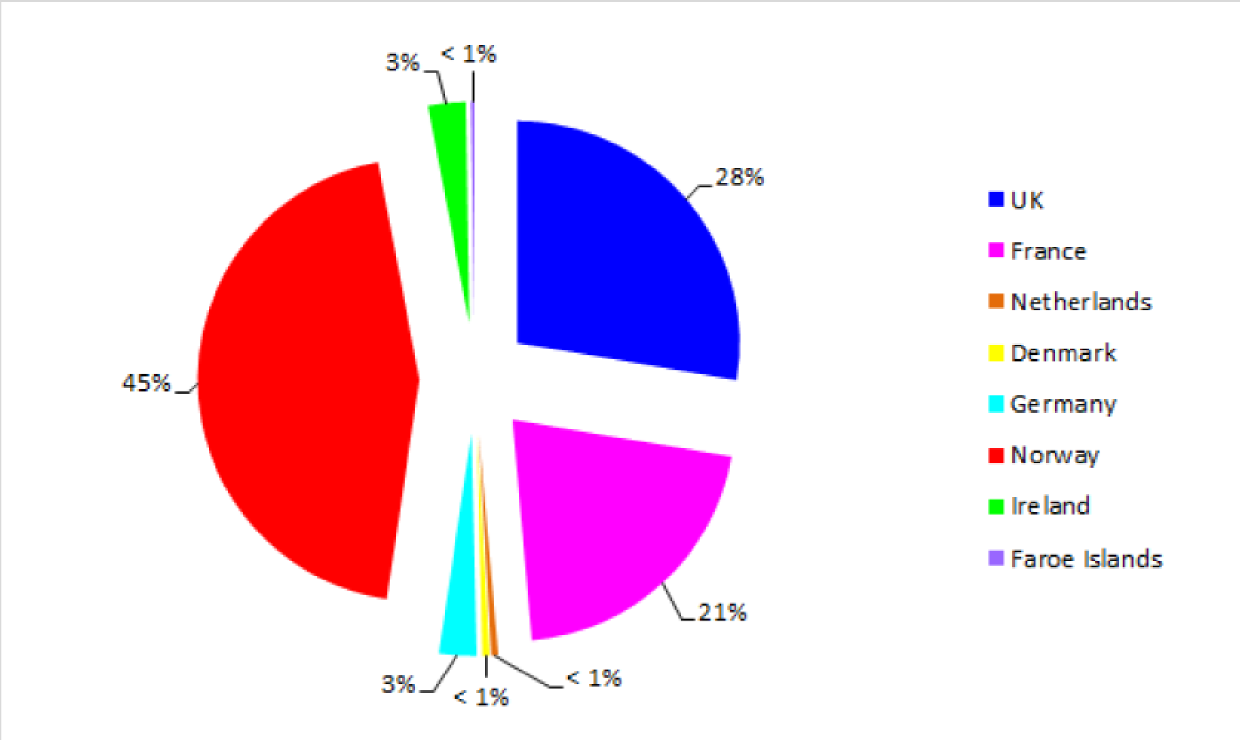


Figure 4.14 Proportion of AIS-identified nationalities recorded within the project area (June 2016 – July 2017) (Anatec, 2017)

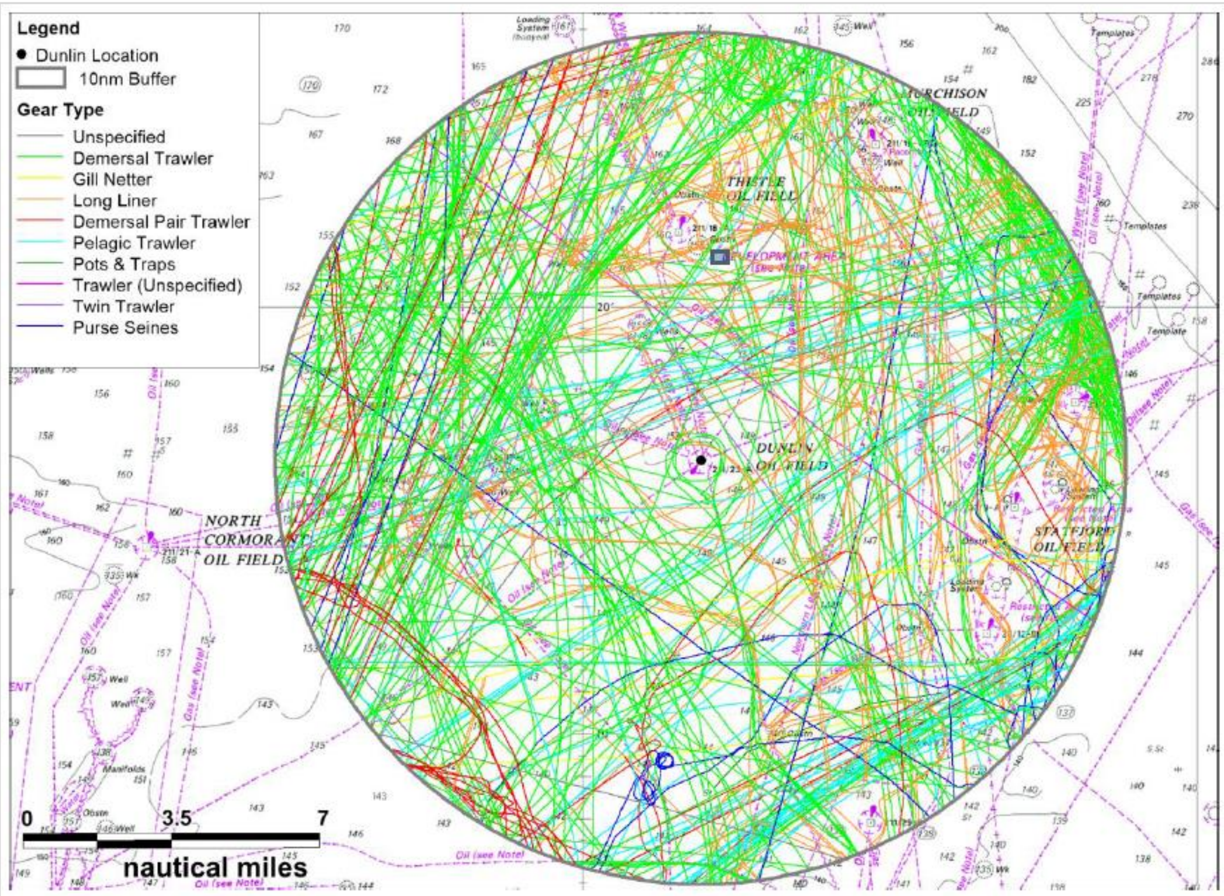


Figure 4.15 Fishing vessel activity over the period July 2016 - June 2017 (Anatec, 2017)

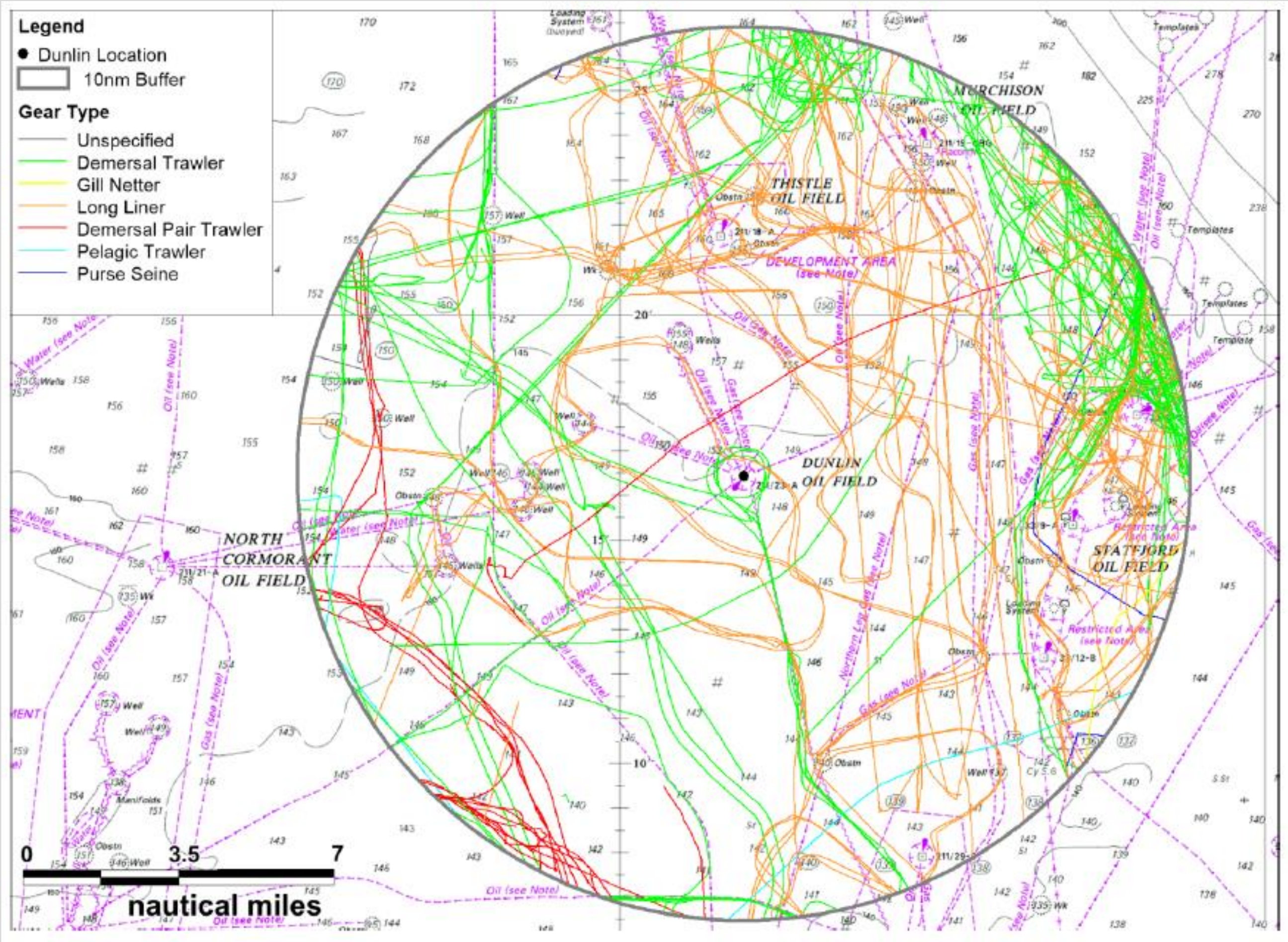


Figure 4.16 Vessels actively engaged in fishing (July 2016 – June 2017) (Anatec, 2017)

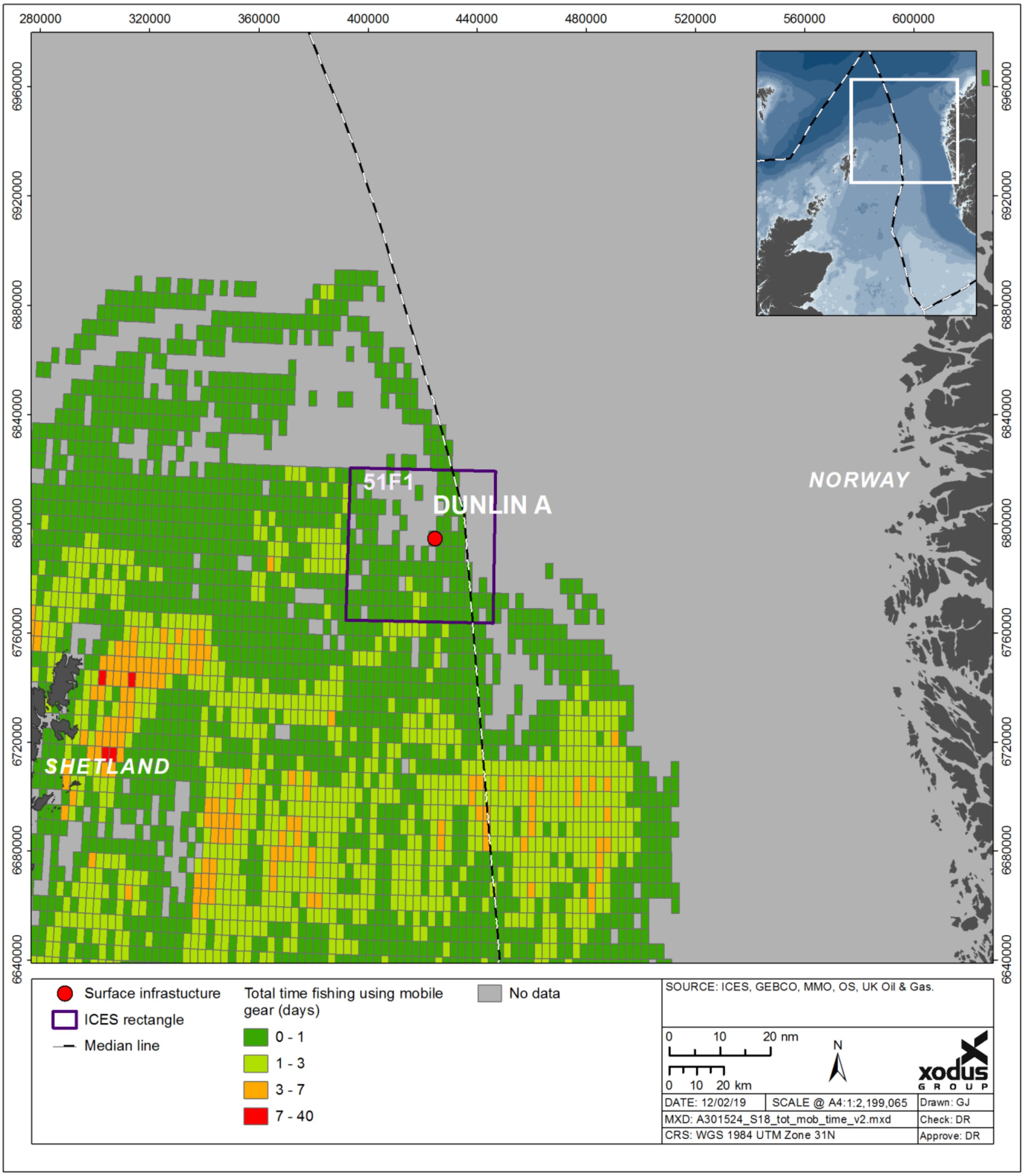


Figure 4.17 Relative distribution of fishing effort (time in days) of vessels using mobile gear (averaged across 2012 – 2016) (MMO, 2017)

4.5.1.2. Types of Fishery

Commercial fishing is excluded within the 500 m safety exclusion zone surrounding the Dunlin Alpha installation. Within the surrounding ICES rectangle 51F1 there are two types of commercial fisheries which indicate important levels of fishing activity: demersal and pelagic. There is additionally some shellfish fishing activity in the vicinity of the project area, but landings data suggests that this is very low compared to the wider region.

Kafas *et al.* (2012) report the Greater Dunlin Area as being at the northern extent of a large band of higher value demersal fishing effort, which stretches from the Outer Hebrides in the west, across the Northern Isles and southward to the southern North Sea. Kafas *et al.* (2012) additionally show the project area as situated within the eastern-most extent of a large band of higher value pelagic fishing that runs from the northern North Sea to the west of the Outer Hebrides.

Table 4.8 shows the value and liveweight tonnage of fish landed by demersal, pelagic and shellfish fisheries in ICES rectangle 51F1 between 2014 – 2018 based on available published data (Scottish Government, 2019). It is clear from this data that demersal fishing activity has been the predominant type of fishing in this region in recent years, as it comprised over 99% of landings between 2016 – 2018. Conversely, pelagic landings were of greater importance in the two prior fishing years, wherein they comprised roughly half of the landings.

When comparing the tonnage of the landings to their value during the years when both demersal and pelagic fishing activity was greater, there is an apparent discrepancy between the two fishing types. In both 2014 and 2015, the value of demersal landings contributed approximately 20% more to the total value than did the proportion of demersal liveweight tonnage. Whereas pelagic landings followed the converse pattern, with the value of the landings contributing roughly 20% less to the totals than the liveweight of the landings did. These observations indicate that demersal fished species have a higher value by weight and therefore may be more important to the fishing industry within this region.

Table 4.8 Annual economic value and live weight tonnage of three fishery types from ICES rectangle 51F1 for the five most recent published fishing years (Scottish Government, 2019)

Species Type	2018		2017		2016		2015		2014	
	Live weight (Te)	Value (£)	Live weight (Te)	Value (£)	Live weight (Te)	Value (£)	Live weight (Te)	Value (£)	Live weight (Te)	Value (£)
Demersal	846	1,381,095	545	824,054	482	709,207	525	724,269	753	948,798
Pelagic	1	637	*NA*	*NA*	<1	12	1,404	830,843	1,314	799,329
Shellfish	1	3,272	<1	1,711	<1	765	3	7,819	<1	220
Total	**848**	**1,385,004**	**546**	**825,765**	**484**	**709,984**	**1,932**	**1,562,931**	**2,068**	**1,748,347**

4.5.1.3. Fishery Value

Data from the Scottish Government (2019) offer insights into the value of landings within ICES Rectangle 51F1 relative to the wider UKCS. The key commercial species landed from ICES rectangle 51F1 based on value and weight are: mackerel, saithe, cod, haddock, monks/anglers, whiting, megrim, and ling (Scottish Government, 2019). Data published for the 2014-2018 fishing years show that these species vary dramatically in their individual contributions to landings between years. However, it is evident that when mackerel are available within this area, they are landed in large quantities and represent a significant proportion of both the value (26% based on the five-year average) and tonnage (57% based on the five-year average) of catches in ICES rectangle 51F1. When compared to the total landings of mackerel from across the UKCS, the five-year average of landings from the waters surrounding the Greater Dunlin Alpha area only contribute 0.17% to the total landings of this species (Scottish Government, 2019). Similarly, the total landings of all species from ICES rectangle 51F1 accounted for approximately 0.18% of the total UKCS landings value, when averaged across the five most recent fishing years (Scottish Government, 2019). Overall, the value of landings across the Greater Dunlin Area are considered low in comparison to the wider UKCS, though demersal landings were considered moderate on their own (i.e. landings value was between £500,000 - £2M annually; Scottish Government, 2019).

4.5.1.4. Gear and Fishing Effort

Trawl gear is the primary fishing gear type used in ICES rectangle 51F1 by UK vessels (Scottish Government, 2019). Trawls include demersal trawls (including seabed contact) and midwater trawls (i.e. pelagic) which operate within the water column. Baseline fishing activity analysis suggests that single demersal trawlers are the most common trawl type (Xodus, 2016). Gear used by vessels of other nationalities includes static gears, such as long lines and seine nets (Xodus, 2016) which are primarily deployed by Norwegian vessels (Anatec, 2017; Figure 4.18).

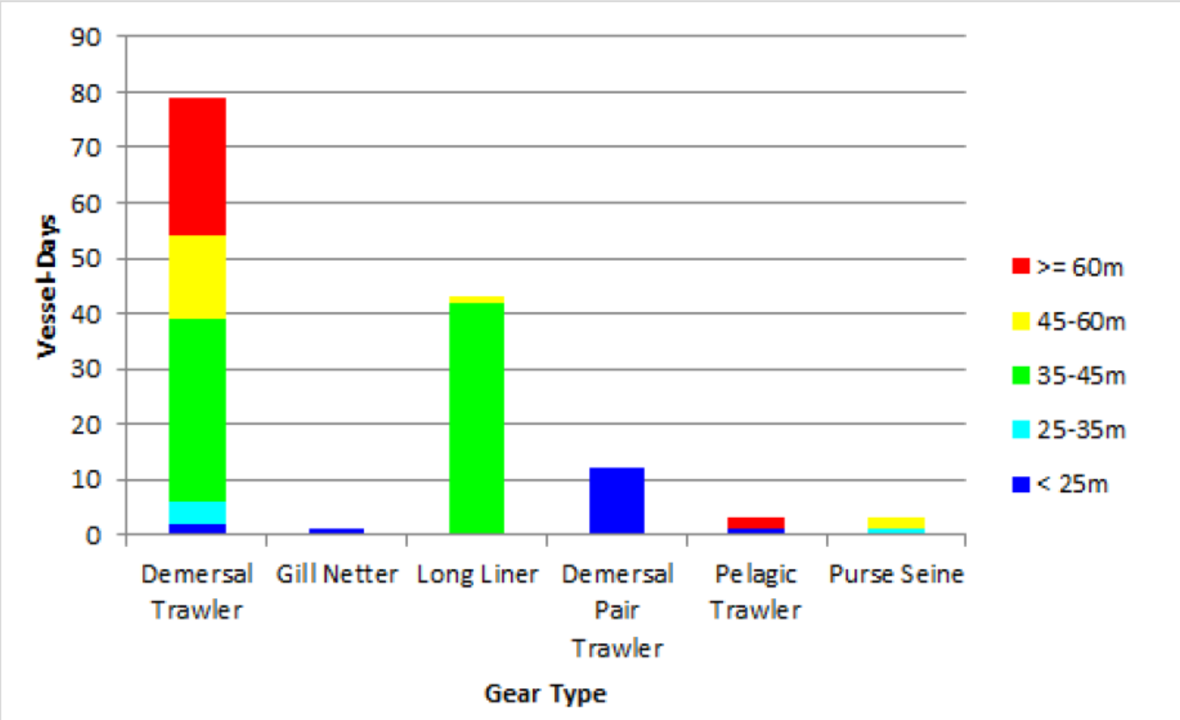


Figure 4.18 Vessel activity by gear type and vessel length over the period July 2016 – June 2017 (Anatec, 2017)

According to the Scottish Government (2019), a total of 132 days were spent fishing in ICES rectangle 51F1 in 2018, and effort was low in every month of fishing (Table 4.9). Whilst fishing effort in rectangle 51F1 was higher in 2018 than it was for the past five years, it was still only 21% of the average fishing effort for all ICES rectangles in the UKCS (mean = 619.2 effort days; Scottish Government, 2019). As such, commercial fishing effort in the Greater Dunlin Area is considerably lower than the average effort across the UK.

Table 4.9 Number of days fished per month (all gears) in ICES rectangle 51F1 in 2018-2014 (Scottish Government, 2019)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2018	D	10	D	27	14	D	7	17	19	19	D		**132**
2017	D	D	D	13	D	9	D	D	D	D	D	D	**75**
2016	D	D	D	D	14	D	20	D	D	D	D	D	**62**
2015	D	D	D	5	13	48	D	D	D	D	D	D	**103**
2014	D	D	13	21	26	14	D	D	D	D	D	D	**100**

Key: Blank = no data, D = Disclosive data (indicating very low effort), green = 0 – 100 days fished, yellow = 101 – 200, orange =201-300, red = ≥301

Notes:

1. Monthly fishing effort by UK vessels landing into Scotland.
2. The total for the year includes disclosive data, thus does not match the numbers in the table. It is possible to conclude that where disclosive data is given, effort is very low.

4.5.1.5. Seasonality

According to Scottish Government (2019), a total of 132 days were spent fishing in ICES rectangle 51F1 in 2018 (Table 4.9). Fishing generally peaks during the spring and summer months and falls during the autumn and winter as weather conditions worsen. Fishing effort in the Greater Dunlin Alpha area remained low for the majority of the 2018 fishing year, and was disclosive for the months of January, March, June and November, in which fishing effort could be considered very low (Table 4.9).

Mackerel landings, which are unpredictable on an annual scale for this region, are also likely to have an important influence on seasonal or monthly variance in commercial fisheries landings values, in the years when mackerel are targeted (Xodus, 2016). This assertion is based on evidence of seasonal changes to the marine environment (i.e. temperature, salinity and phytoplankton abundance) influencing mackerel larvae distributions (Bainbridge *et al.*, 1974) and the timing of migration for this species (Jansen and Gislason, 2011).

Data on monthly fishing effort were additionally obtained from the MMO for the time period 2010 – 2014 and analysed to establish seasonal trends. The Vessel Monitoring System (VMS) data show that most activity is concentrated in the spring and early summer months when five to twelve vessels have been recorded as active in the area, compared with fewer than four vessels per month during other seasons (Figure 4.19, MMO, 2016).

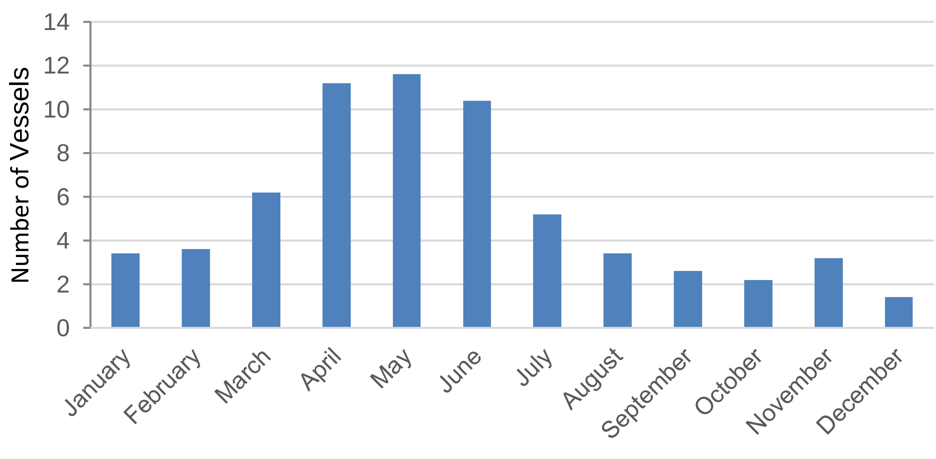


Figure 4.19 Seasonal distribution of vessel presence in ICES Rectangle 51F1 based on VMS data (average 2010 – 2014) (MMO, 2016)

4.5.2. Oil and Gas Activities

The planned decommissioning activities are located in an area of extensive oil and gas development, in a region of the UKCS experiencing rapidly progressing decommissioning activity. There are a number of installations located within the vicinity of the project area, as detailed in Figure 4.20, including: Thistle A (9.9 km NW; decommissioning planning underway), Statfjord B (14.6 km SE), Brent C (21 km SE; topsides Decommissioning Programme approved August 2018), Cormorant North (24.3 km SW), Northern Producer FPU (24.7 km NW); Eider A (25 .1 km NW; Decommissioning Programme approved May 2020), Brent B (25.2 km SE; topsides Decommissioning Programme approved August 2018), and Brent A (27.4 km SE; topsides Decommissioning Programme approved August 2018).

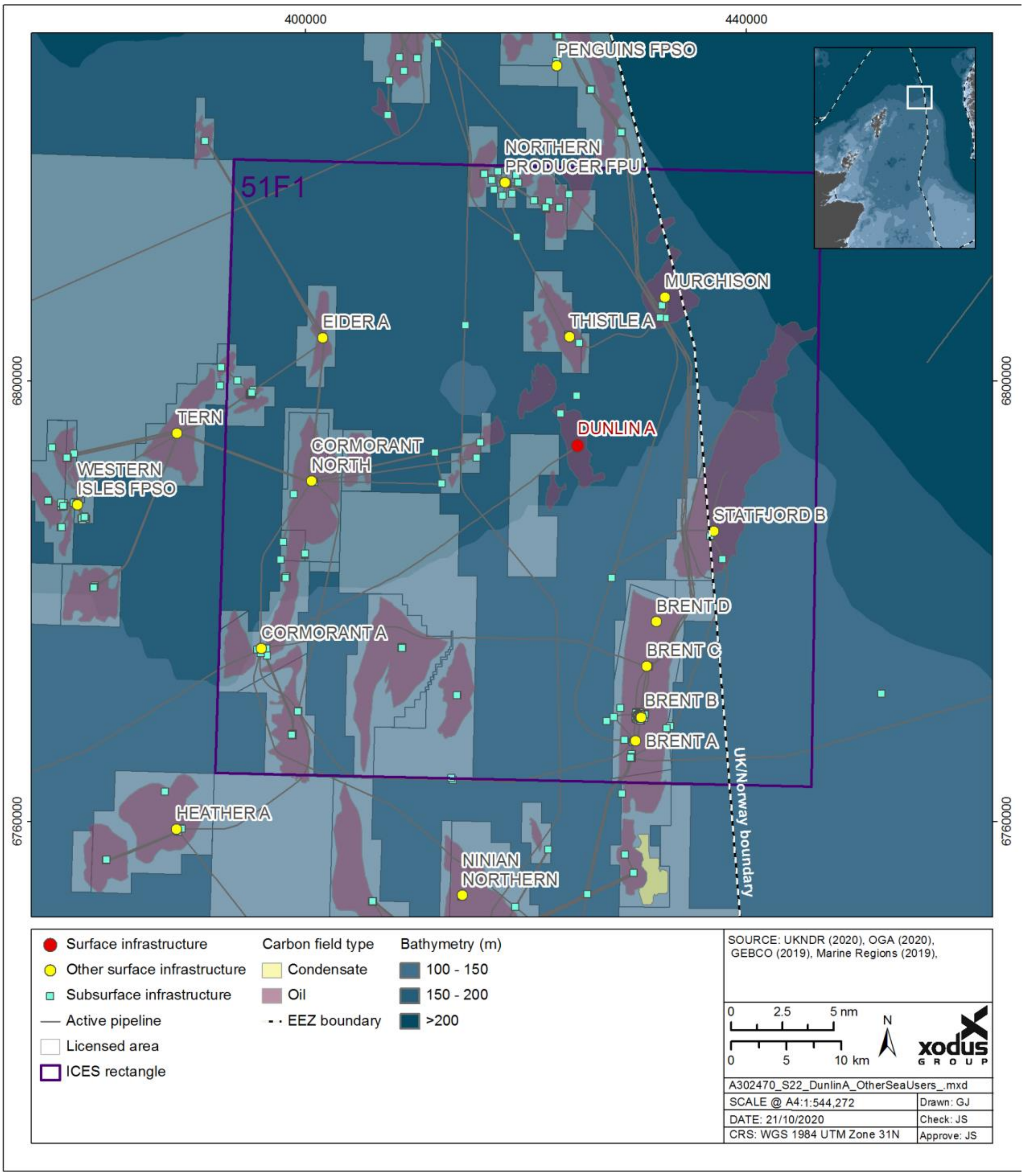


Figure 4.20 Other sea users in the vicinity of the Dunlin Alpha installation

4.5.3. Shipping Activity

The North Sea contains some of the world's busiest shipping routes, with significant traffic generated by vessels trading between ports at either side of the North Sea and the Baltic. North Sea oil and gas fields also generate moderate vessel traffic in the form of support vessels (DECC, 2016). Shipping activity is assessed to be low in Block 211/23 (DECC, 2016). An average of between 0.1 to 5 vessels per week pass the vicinity of the project area with the majority of traffic consisting of small to medium sized cargo ships and tankers (MMO, 2014). Other vessels that pass within the vicinity of the project area include dredging or underwater operation vessels and fishing vessels. A composite from AIS tracks of vessels using the project area in 2015 is presented in Figure 4.21.

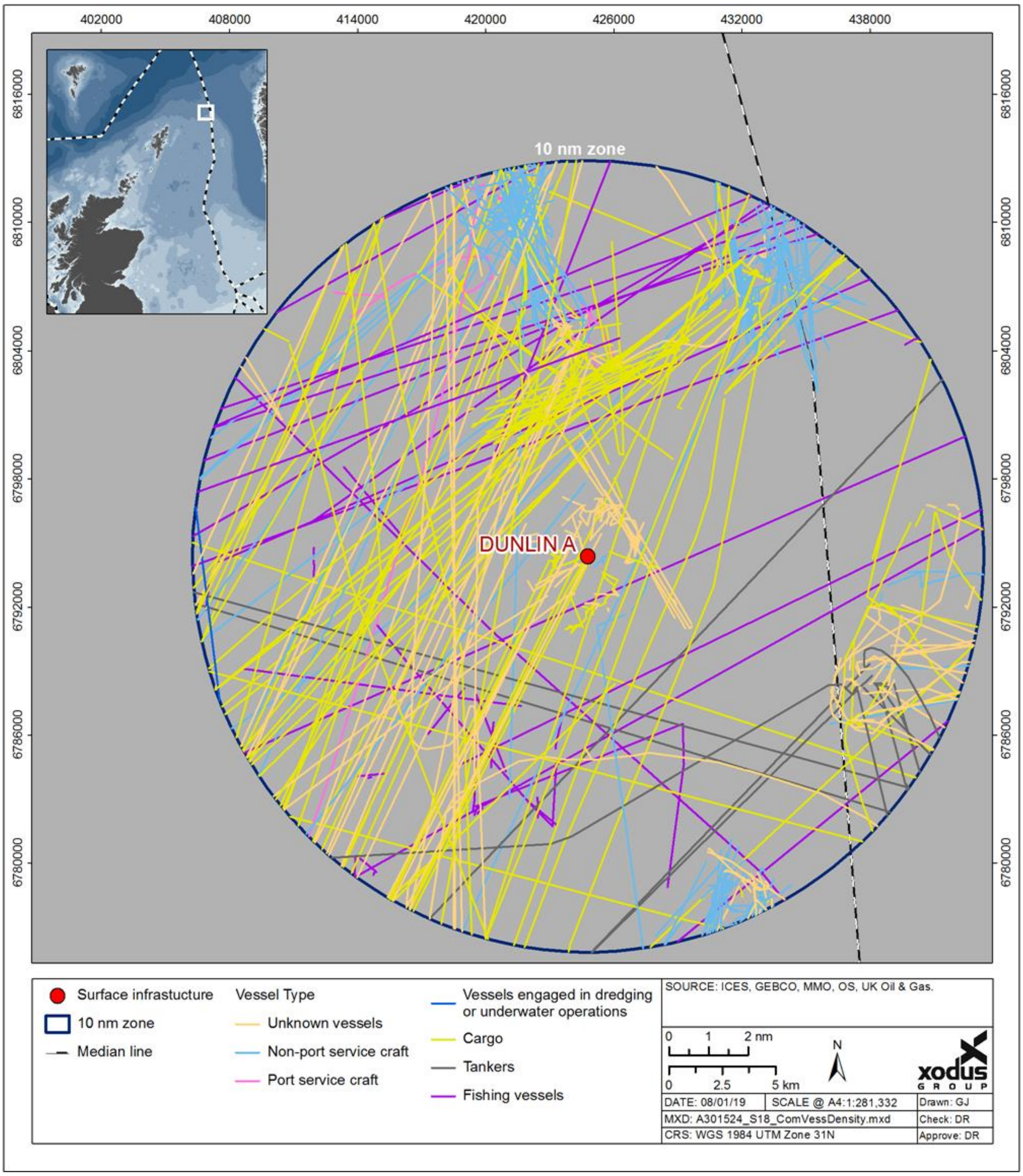


Figure 4.21 Shipping intensity

4.5.4. Cables and Pipelines

There are no cables other than the Dunlin Power Import cable (running from the Dunlin Alpha installation to the Brent Charlie platform which is due to be decommissioned) in the vicinity of the project area. There are several pipelines associated with the Greater Dunlin Area, including the Dunlin Fuel Gas Import Pipeline running from Thistle A to the Dunlin Alpha installation and pipelines connecting the Dunlin Alpha installation to the Merlin and Osprey tiebacks (now removed). In addition to these, other pipelines in the vicinity of the project area include the Dunlin Alpha installation to Cormorant Alpha pipeline (PL5) (decommissioned *in situ*), the Murchison oil export pipeline (decommissioned *in situ*), Magnus to Brent Alpha, Statfjord Bravo spur, Penguins to Brent Charlie, Brent Charlie to Cormorant Alpha and Thistle to Murchison.

5. Impact Assessment

The following section presents assessments of the impact factors that have been identified through stakeholder consultation and the ENVID process (Appendix B) as having the potential to be significant (as described in Section 3.4), they include:

- **Physical Presence** — presence of infrastructure decommissioned *in situ* in relation to other sea users (Section 5.1);
- **Discharges to sea** — gradual release of cell contents over time due to degradation (Section 5.2); and
- **Unplanned events** — (1) instantaneous release of cell contents (Section 5.3.1) and (2) disturbance of drill cuttings deposits due to unplanned events (Section 5.3.2).

The information used to undertake the following assessments is based on evidence gathered from operational records, analysis of historical samples, analogous data and/or the application of proven scientific principles. Uncertainties associated with the base data have been assessed and where appropriate, conservative (worst-case) assumptions have been applied to ensure environmental impact is not underestimated.

5.1. Physical Presence

5.1.1. Overview

The Dunlin Alpha substructure decommissioning activities have the potential to impact upon other users of the sea. This may happen during the decommissioning activities themselves, when vessels working in the field and transiting to shore occupy space, and after decommissioning should any infrastructure decommissioned *in situ* interact with activities such as fishing. The main long-term impact on other users of the sea will be as a result of a 500 m safety zone that will remain around the Dunlin Alpha CGBS, which is proposed to be decommissioned *in situ*. The presence of a 500 m safety zone will be marked on navigation charts to advise other users of the sea to avoid the area due to the presence of the CGBS and associated drill cuttings deposits.

5.1.2. Impacts to Other Sea Users from *in situ* Decommissioning

Fairfield expects that the existing 500 m safety zone around the CGBS will remain in place up to the point that the surface structures have degraded and fallen through the water column. As this is not likely to occur for the next 200 – 300 years, this will effectively mean continued exclusion of other users of the sea (shipping and fishing) from an area of approximately 0.8 km^2 for the foreseeable future. Should the surface structures collapse below the water line much earlier than anticipated, it is expected that the safety zone would be renewed on the basis of it being a subsea structure with potential safety concerns.

The maintenance of the 500 m safety zone will limit potential interactions between other sea users and the remaining structure and drill cuttings, effectively eliminating snag risk and possible tainting of catch, as well as disturbance to the cuttings pile. Regardless, the potential for unplanned disturbance to the cuttings pile through interactions with commercial fisheries has been assessed in detail in the Legacy Environmental Impact Modelling Report (Xodus, 2020a) and is addressed in Section 5.3.2 below.

Despite its crucial role in limiting detrimental interactions of fishing gears with the remaining structure and cuttings deposits, the 500 m safety zone also limits access to commercial fishing grounds, which may have socioeconomic implications within the fishing industry. The commercial fishing vessels operating near the Dunlin Alpha substructure decommissioning project area (as defined by ICES Rectangle 51F1) is dominated by demersal fishing activity, with bottom trawls mainly utilised by UK vessels and pelagic trawls by International vessels (Anatec, 2017). Demersal fisheries in the region target species such as saithe, cod, haddock, whiting and other groundfish species (Scottish Government, 2019). The data also suggests that pelagic fisheries operating in the vicinity of the project area target mackerel in the years when this species is available in the region. However, despite some years of elevated activity by both demersal and pelagic fisheries, the overall value of landings from ICES Rectangle 51F1 are considered low and fishing effort is low to very low throughout the year (Table 4.9).

Continued exclusion of commercial fisheries from 0.8 km^2 of fishing grounds within the 900 NM^2 (i.e. 3,087 km^2) ICES statistical rectangle area, equates to a displacement of approximately 0.03% of fishing activity within an area characterised by low effort and low value commercial fishing activity. Moreover, no change to the existing conditions, which have been in place since the Petroleum Act was passed in 1987, has been proposed by the leave *in situ* decommissioning option. For these reasons, socioeconomic impacts to commercial fisheries from the proposed decommissioning activities are deemed insignificant.

5.1.3. Mitigation Measures

There are several mitigation measures that Fairfield will have in place to limit the potential for interaction with fisheries and other users of the sea in the longer-term:

- Standard notifications and Notice to Mariners will detail the presence of the structure and the associated 500 m safety zone;
- Admiralty charts and the FishSafe system will show the permanent location of the Dunlin Alpha CGBS, and Kingfisher Bulletin and Notices to Mariners will be updated;
- A navigational aid will be installed on top of one of the steel transitions to visibly show the location of the structure and drill cuttings to other sea users.
- The top of each transition will be sealed to prevent the ingress of seawater, reducing corrosion activity and increasing the longevity of the structures;
- Annual visual assessment of navigational aid undertaken by the Northern Lighthouse Board (NLB);
- Replacement of the navigational aid will be undertaken on a 4-yearly basis; and
- Provisions will be made to the Fisheries Legacy Trust Fund Limited (FLTC) via monetary contributions to improve safety information available to fishers.

5.1.4. Cumulative Impact Assessment

In terms of the scale of leaving the 500 m safety zone in place with regards to fisheries, the area which will be lost to fisheries is minute in respect to the wider available fishing habitat. The estimated 457 safety zones within the UKCS are scattered across the central and northern North Sea (UKOilAndGasData, 2016), and 28 of these safety zones fall within ICES Rectangle 51F1 (OGA, 2019). This equates to approximately 360 km^2 of the fishing grounds within the entire UKCS and 22 km^2 or 0.7% of the fished area surrounding the Dunlin Alpha CGBS. When considered collectively, these areas of exclusion are still considered insignificant when compared to the fishing grounds which remain available both locally and across the wider region of the northern North Sea.

Additionally, some of the safety zones associated with offshore infrastructure outwith the Dunlin Field will be returned as navigable and fishable waters during decommissioning planning for those assets. This will assist in reducing the total area of the North Sea which is currently inaccessible to fisheries, thereby reducing the potential for cumulative impacts associated with the decommissioning of North Sea structures. The small area which would remain inaccessible to fisheries as a result of the Dunlin Alpha installation remaining *in situ* is not considered likely to present a significant cumulative socioeconomic impact to commercial fisheries, particularly in the context of the low fishing effort characterising the region comprising the Greater Dunlin Area.

5.1.5. Transboundary Impact Assessment

As the Dunlin Alpha installation is located beyond the UK's 12 nm limit, EU and non-EU vessels are also permitted to fish in the area[4], subject to management agreements including, for example, quota allocation and days at sea. Xodus (2016) report vessels of Norwegian origin to be present in the Greater Dunlin Area (up to 50% of vessels). Of the demersal trawlers actively fishing in the study area 38% were of Norwegian origin. It was also seen that the majority (64%) of vessels crossing the subsea infrastructure were of Norwegian origin with an average of 0.18 subsea infrastructure crossings occurring each day by Norwegian vessels (Xodus, 2016). Despite this, the vessel presence is still regarded as relatively low, and there is no mechanism by which significant transboundary impacts could occur.

5.1.6. Residual Impact

Receptor	Sensitivity	Vulnerability	Value	Magnitude
Other sea users	Negligible	Low	Low	Minor
Rationale				
The information in the Environment Description (Section 4) has been used to assign the sensitivity, vulnerability and value of the receptor as follows. There has been a safety zone around the Dunlin Alpha installation for over 40 years, and fishing in the much wider Greater Dunlin Area is not high (as discussed in Section 4.5.1). As a result, sensitivity is deemed negligible. The vulnerability has been ranked as Low as there is no change to the exclusion in the area. On the basis of the estimated catch values from the area around the Dunlin Alpha installation, the value is defined as Low. There will be continued localised exclusion from the area (approximately 0.8 km^2), thus the magnitude is considered to be Minor. Combining these rankings, the impact significance is defined as Negligible and thus not significant.				
Consequence		**Impact significance**		
Low		Not significant		

5.1.7. Positive Effects of Physical Presence

There is the potential for the decommissioning of infrastructure *in situ* resulting in an artificial reef which has the potential to be used as a sheltered area for fish species.

Installations of oil and gas platforms across the North Sea have introduced substantial amounts of hard substrate to the seafloor. These structures promote dense growth of hard-bottom marine organisms: including algae, mussels, tube-building worms, hydroids, anemones and reef-building corals, which colonise the platforms from the top of the platform substructure down to the footings resting at the depths of the seafloor. This results in the platforms functioning as "artificial reefs". The INSITE funded ANChor project, carried out by the University of Edinburgh (Henry *et al.*, 2017), has been undertaking research to establish the magnitude of effects these man-made structures have had in creating a larger inter-connected hard substrate reef system, current tests of this concept suggest connectivity varies across North Sea regions. According to ANChor modelling results, Dunlin Alpha was a potential larvae "donor" to seven other oil and gas structures and has a potential role in creating a network of coral ecosystems.

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[4] Note that arrangements may change post-Brexit.

5.2. Discharges to Sea

5.2.1. Modelling to Understand the Fate of a Release

The modelling described in the following sections was undertaken using the Marine Environmental Modelling Workbench (MEMW) interface, developed by Scandinavian Independent Research Organisation (SINTEF). This software interface provides access to the Oil Spill Contingency and Response (OSCAR) and Dose-related Risk and Effect Assessment Model (DREAM) models. An overview of these applications and a description of the modelling outputs is provided below.

Details of the modelling inputs used for each of the release scenarios are provided in Appendix D. Further information is detailed within the *Dunlin Alpha Decommissioning – Legacy Environmental Impact Modelling Report* (Xodus, 2020a).

A.1.1.1 Oil Spill Contingency and Response (OSCAR)

The Oil Spill Contingency and Response (OSCAR) model developed by SINTEF is a hydrocarbon spill model that predicts the fate of oil in the environment. OSCAR has been validated against controlled actual spills at sea and real spill events, supported with laboratory calibration. It has an in-built database of oils, condensates, synthetic oils and their properties.

Sets of both stochastic and deterministic simulations were run using the OSCAR model for this report:

- Stochastic modelling involves simulations that contain random elements. The result of stochastic modelling is determined by variable(s) which change randomly to provide a projection based on numerous model runs, each with a new set of random values of the variable(s). In stochastic oil spill modelling, currents and wind change throughout the year and are therefore the probabilistic elements to this particular type of modelling.
- Deterministic modelling contains no random elements. Instead of running multiple simulations, each with their own current and wind variables, one simulation is run using the worst-case conditions. To obtain these conditions, four years of current data is used to determine the least dispersive time period which will provide the highest proportion of oil which reaches the surface/shoreline.

5.2.1.1. Dose-related Risk and Effect Assessment Model (DREAM)

The Dose-related Risk and Effect Assessment Model (DREAM) was developed by SINTEF to predict the behaviour and environmental risk of produced water discharges. It was subsequently extended to include the ParTrack module to simulate the behaviour and environmental risk of drill cuttings and mud. The model predicts the fate of materials discharged to the marine environment, including their dispersion and physicochemical composition over time.

5.2.1.2. Calculation of Impact

Environmental risk to the water column and to the seabed are expressed in DREAM as an Environmental Impact Factor (EIF). EIFs are a relative measure of risk to the biota in the marine environment. They are calculated using the PEC/PNEC approach, in which the predicted environmental concentration (PEC) of a contaminant is divided by the predicted no effect concentration (PNEC; the highest concentration at which no environmental effect is predicted). A ratio of >1 indicates there is likely to be an environmental effect.

The PNEC values within the ParTrack model are estimated highest concentrations at which toxic effects are not expected. The PNEC values for each substance are defined by laboratory tests divided by an assessment factor to produce a value that is considered to be protective of all but the most sensitive 5% of species. This approach is internationally accepted in the regulatory assessment of chemicals. SINTEF have adapted this methodology by using experimental data to calculate pseudo-PNECs for non-toxic stressors such as burial, sediment grain size change and oxygen depletion.

The PEC for each contaminant is determined within the model using a number of calculations to simulate the behaviour of contaminants in the water column. Processes including dilution, partitioning, degradation and deposition into the sediment are simulated in order to generate a PEC for each contaminant over time. EIFs for the sediment compartment are more complex, incorporating toxicity of contaminants, but also processes such as oxygen depletion, change in median grain size and burial effects.

Within the model the entire water volume in the modelled area is split into compartments measuring 100 m x 100 m x 10 m (0.0001 km^3). Each compartment where the PEC/PNEC ratio is >1 contributes a value of 1 to the water EIF.

It should be noted that SINTEF, the developers of DREAM (ParTrack), clearly state that the EIF is not a measure of absolute impact, but a comparative tool to support environmental management decision making. As such, the absolute value of the EIF is not meaningful; however, comparison of EIF values for different discharge scenarios based on equivalent assumptions provides a powerful tool for understanding and comparing potential impacts of these scenarios.

5.2.2. Cell Contents – Gradual Release Over Time

5.2.2.1. Overview

As discussed in Section 2.1.3, the residual contents of the cells have been studied extensively by Fairfield in order to characterise the materials in sufficient detail to allow potential environmental impacts to be appropriately assessed. Further details required to inform these assessments are provided in the following sections.

Residual chemicals and hydrocarbons contained within the CGBS storage cells will gradually be released to sea as the infrastructure degrades. Such a release could occur as the concrete walls degrade, with small holes forming in the walls and water exchange occurring with the outside marine environment. This could see buoyant, mobile oil in the cells released slowly over time. Additionally, as the concrete degrades and crumbles, the waxy residues (deposited from the produced fluids) that are bound to the cell wall will eventually be exposed to the marine environment. There is also sediment at the base of the cells, but it is highly immobile and unlikely to be distributed beyond the proximity of the cells as part of the gradual degradation of the substructure.

5.2.2.2. Gradual Release of Mobile Oil

The mobile oil within the cells is made up from the following:

- Residual oil left behind upon completion of the Attic Oil Recovery Project (AORP) executed in 2007;
    - Residual oil could also contain:
        - Fluids from the topsides drain system such as solvents and effluents from cleaning, lubricating and hydraulic fluids, cooling fluids, etc.;
        - Trace quantities of chemicals such as demulsifiers injected into the topsides processing system; and
        - Heavy metals.
- Hydrocarbons which have diffused over time from the sediment layer on the floor or wall deposits.

Further details of the composition, quantity and distribution of residual contents within the CGBS storage cells are provided in Appendix A.

To assess the potential for environmental impact, modelling of a gradual release has been undertaken using the SINTEF OSCAR spill model. The mobile oil released in this scenario has been estimated based on there being 59 domed topped cells originally used for oil storage, each further sub-compartmentalised within the cell roof space by the construction formwork into 36 smaller compartments (Figure 2.6). As the structure slowly degrades it is reasonable to assume that a single sub compartment could fail and result in a leakage of the buoyant oil on any given day, which equates to a volume of approximately 0.2 - 0.8 m^3.

As a worst-case, it was assumed that cracks could allow releases from multiple sub-compartments within a cell, over a relatively short time frame. A hydrocarbon release of 24 m^3 over a 30-day period was therefore modelled to reflect the potential for consecutive releases of 0.8 m^3 / day. In addition, the model was run in deterministic mode, using environmental conditions that reflected the least dispersive time period to ensure surface oil thickness and distribution was not underestimated. The model inputs used in the deterministic model are presented in Appendix D, Section D.4.1.5.

The mass balance of the oil over a 60-day simulation period is shown in Figure 5.1. The majority of the oil is predicted to disperse in the water column, while the quantity of oil reaching the sea surface fluctuates overtime due to the effect of waves and sea state. The modelling predicts that surface oil will be gradually removed from the environment by evaporation or biodegradation. No oil is predicted to reach any shoreline.

The maximum quantity of oil expected to surface is 3.1 tonnes, which is spread over a 3 km^2 area. The modelling results have also indicated that the majority of surface oil is likely to be <50.0 µm thick, with virtually no thick oil predicted. The modelling results indicate that any impacts from surface oiling would be short-term and localised to the maximum surface oiling area (i.e. 3 km^2).

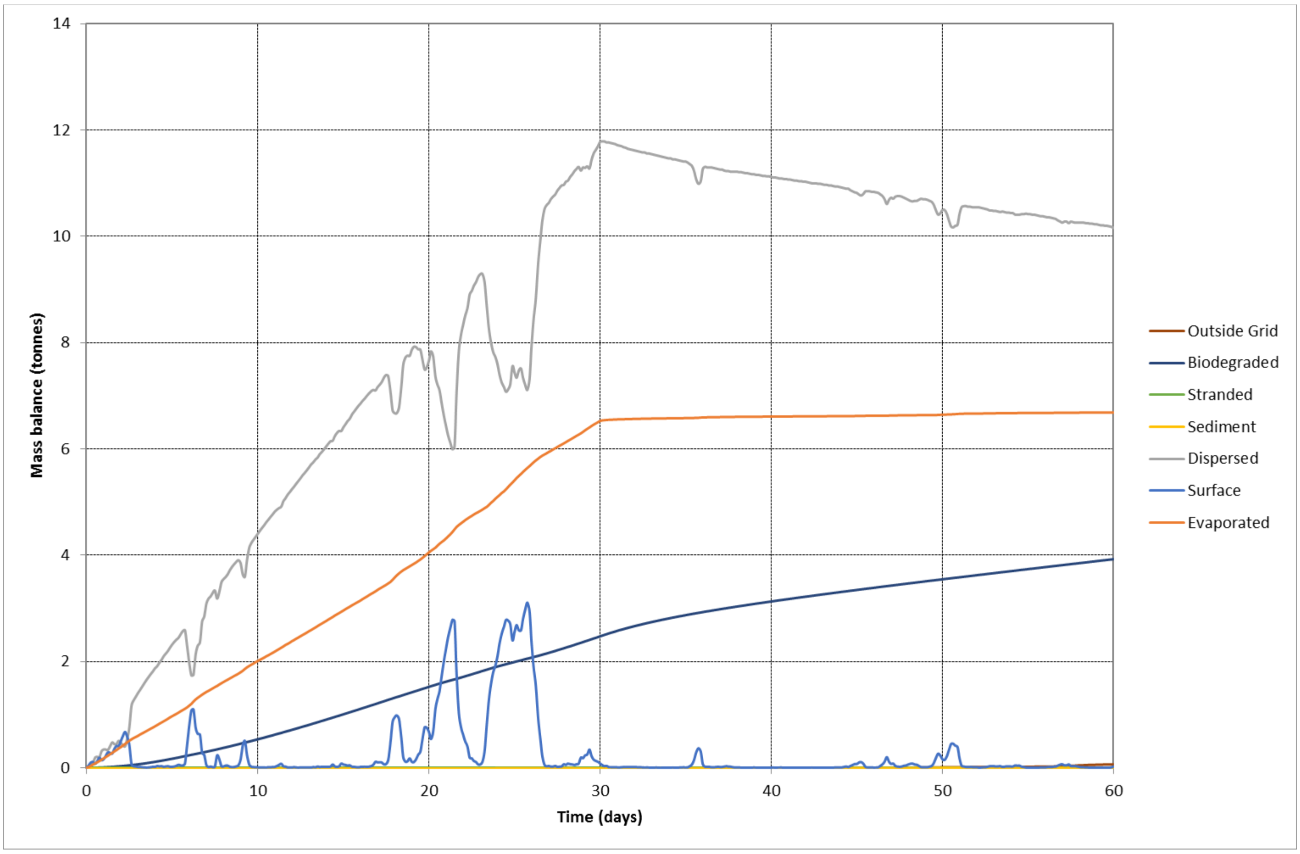

Figure 5.1 Fate of released hydrocarbons over 60-day period

5.2.2.3. Gradual Exchange of Cell Water

Loss of containment of a cell will also allow a slow interchange of the water phase with the seawater in the surrounding environment, which could result in release over a longer duration in the order of weeks to months following the loss of containment. The exchange of water will be at a low rate as there will be no significant pressure differential driving force between the internal and external of the cells; i.e. the cell contents are not sitting at a greater pressure than the outside seawater, and there will be no force to drive contents out in the event of a small breakthrough of the concrete structure.

Hydrocarbons present within the water phase may be released from the cell through any new communication path created as the structure degrades and disperse into the water column. Such a release of water would have an associated release of aromatics and heavy metals within the water phase. However, the release of oil within the water phase would be an order of magnitude smaller than the mobile oil release (Fairfield, 2021a); THC of the water phase will be between 20 and 100 mg/l, with an average of approximately 40 mg/l. Additionally, there is the potential for chemicals to be released from the water phase. As discussed in Section 2.1.3, the total weight of chemicals for the CGBS base caisson is expected to be approximately 174 kg and therefore, due to the low concentrations of residual chemicals within the CGBS water, there is very limited potential for significant environmental impact.

5.2.2.4. Gradual Exposure of Sediment

The sediment at the bottom of the cells is not mobile. However, upon exposure to the external marine environment, hydrocarbons and heavy metals within the sediment may slowly diffuse into the water column. This may occur due to water passing in and out of the cells or from small concrete pieces breaking off from the substructure disturbing the sediment layer, resulting in additional exposure of sediment.

In order to assess the potential for impact on water quality following diffusion of the solid phase material, a calculation based on the Osborne-Adams model has been used (OGP, 2005). The Osborne-Adams model is normally used to compare assessment criteria, based on toxicity, with calculated water column concentrations resulting from discharges of known quantities of dissolved products with known discharge rates. If the flushing time for the water column is less than the time taken to reach the assessment criteria a discharge is deemed “acceptable”.

For this assessment, the model has been adapted to yield the limiting time over which the quantity of the component estimated to be present within the CGBS could be released without exceeding a specified concentration threshold, the assessment criteria. If it is likely that the contents could be released at a faster rate, then the criteria could be exceeded.

The assessment criteria used for this assessment included:

- The Background Assessment Concentration (BAC) - concentrations of substances naturally present in the environment (OSPAR 2005).
- The Environmental Assessment Criteria (EAC) - recommended limiting concentrations for substances which are potentially toxic in the marine environment (OSPAR 2004).
- Predicted no effect concentrations (PNEC) for naturally occurring substances in produced water (OSPAR 2014).

Rather than setting the discharge rate, the model has been used to calculate the minimum discharge time, or Critical Release Time (CRT). If the entire component present is released over a time scale longer than the CRT, the water column concentration within 500 m of the CGBS is not expected to exceed the assessment criteria value for the estimated total quantities of individual components of the sediments. The residual current has been conservatively assumed to be 10% of the present estimated value of 0.2 ms^{-1}. This allows for long term changes in the North Sea circulation pattern, and effectively increases the CRT by a factor of 10. Table 5.1 presents the results of this modelling exercise.

Table 5.1 Results of the Osborne Adams calculations

Component	Modelled total in CGBS	Assessment criteria		Critical release time
	Q (kg)	C ($\mu g.l^{-1}$)	Source	CRT (years)
Metals				
Arsenic	3.3	0.6	PNEC	0.00007
Cadmium	2.4	0.008	BAC	0.0040
Chromium	25.8	0.6	PNEC	0.0006
Copper	868.0	0.005	EAC	2.3
Mercury	0.2	0.0002	BAC	0.013
Nickel	1,391.1	0.1	EAC	0.19
Lead	295.6	0.01	BAC	0.40
Vanadium	131.1	1.25	BAC	0.001
Zinc	194.4	0.25	BAC	0.010
Hydrocarbons – BTEX				
Benzene	928	8	PNEC	0.0016
Toluene	1,343	7.4	PNEC	0.0024
Ethylbenzene	991	10	PNEC	0.0013
Xylenes	2,205	8	PNEC	0.0037
PAH				
Napthalene	181.0	0.000280	BAC	9
Acenepthene	109.0	0.000160	BAC	9
Pyrene	23.0	0.000014	BAC	22
Fluorene	11.0	0.000074	BAC	2
Fluoranthene	6.0	0.000073	BAC	1
Anthracene	2.0	0.000001	BAC	27

Of the metals, copper has the longest CRT (2.3 years). This means that in order for the concentration within 500 m of the CGBS to exceed the EAC, which is below the northern North Sea background (see Table 4.3), all copper contained within the CGBS would have to be released in less than 2.3 years. This is considerably below the expected sediment lifetime following exposure. In addition, the majority of the metals in the CGBS, including approximately 98% of the copper, are expected to be contained in scales (Fairfield, 2020b) which are essentially insoluble. As a result, metals incorporated in the scales are not expected to be available for release to the water column. Hence it is unlikely that there will be a significant release of any metal over the time scales indicated in Table 5.1.

For the BTEX hydrocarbons, which are expected to be relatively mobile, the worst-case CRT is of the order of 1 to 2 days. If released over this time scale the concentration within 500m of the release could exceed the long term PNEC during the release period. However, the release time is considerably shorter than the expected lifetime of sediments within the CGBS following exposure. As a result, loss at the rate indicated in Table 5.1 is considered highly unlikely. Following release BTEX compounds are non-persistent in seawater (OGP 2005).

For the Polycyclic Aromatic Hydrocarbon (PAH) compounds the BACs and modelled quantities of individual compounds present in the CGBS (Table 5.1) vary widely. CRTs for these compounds range from 1 to 27 years, well below the estimated lifetime for sediments within the CGBS following exposure. In addition, PAHs are among the most refractory of naturally occurring organic compounds, as they are the residue of high temperature/pressure processes. They tend to partition strongly to particulate materials and hydrocarbons and are extremely unlikely to be released over the time scale suggested in Table 5.1.

The results of the water column assessment indicate that there is no potential for significant impacts on water quality as a result of the gradual exposure of the residual sediments within the CGBS to the wider environment. In the majority of cases this assessment has been based on the natural background levels expected in the northern North Sea, indicating that the risk of direct toxic impacts to water column species is negligible.

In addition to water column impacts, sediments could have the potential to be taken up by primary consumers (e.g. zooplankton, small fishes, etc.) and transmitted through the food chain in a process known as bioaccumulation (Intertek, 2020).

Chronic dose analyses of the substances of particular concern to marine biota (per various national and international guidance reports) have been undertaken to characterise unacceptable levels of contaminants intake from ingestion of cell sediments (METOC 2012; Intertek 2020). The study concluded that, due to the nature of the gradual release of the cell sediments as well as their expected chemical character, exposure rates of marine biota to bioavailable contaminants within the cells will be extremely low. Furthermore, the quantities of the individual contaminants within the sediments or other individual components of the cells are sufficiently low that transmission through the food chain could not cause significant impacts to marine biota. Further details on the potential impacts associated with bioaccumulation are provided in the Section 5.2.2.6.

5.2.2.5. Gradual Release of Waxy Residue

Waxy residues bound to the cell walls are not mobile but have the ability to slowly diffuse; the wax is spread over the surface area of the cells within the CGBS. Upon exposure to the external marine environment, either through water passing in and out of the cells or from small concrete pieces breaking off and being exposed to the external environment, the hydrocarbons and heavy metals within the waxy residues may slowly diffuse into the water column. Similar to cell sediments, waxy residues are considered to be bioavailable. However, the rate of transfer once wax-entrained hydrocarbons have entered the food chain is exceptionally low, as they are not readily metabolised once ingested (Intertek, 2020). As with the cell sediments analysis, the conclusions of the Intertek (2020) report found that there is no significant risk of harmful effects, either on the local environment or through the food chain, following eventual loss of containment of the CGBS cell contents.

5.2.2.6. *Environmental Vulnerability to a Release*

Potential impacts from the gradual release of cell contents to the surrounding environment include impacts to marine flora and fauna solid residues containing contaminants to enter the biotic environment through ingestion by primary consumers. The mechanisms and impact pathways associated with the gradual release of cell contents are described below.

Plankton

There may be impacts on plankton in the immediate area of the release until the release disperses, due to the dissolution of aromatic fractions into the water column (Brussaard *et al.*, 2016). However, given the small volume of material expected to undergo release in any single event, and the widely distributed and numerous plankton population, impacts are not expected to be significant.

Fish

Juveniles and eggs are the fish life-stages most vulnerable to chemical or hydrocarbon releases. However, given the small volume of material expected to undergo release in any single event, and the high numbers and wide distribution of fish eggs and juveniles expected in the area, impacts are not expected to be significant.

Seabirds

In a nature conservation context, seabirds are the group at greatest risk of harm due to surface oil pollution in the offshore environment (JNCC, 2011). The most familiar effect of oil pollution on seabirds is the contamination of plumage, resulting in the inability to fly and loss of insulation and waterproofing, which alone may cause death. Of the substances that could be gradually released from the CGBS, only mobile oil, which could float to the surface, would be expected to pose any risk to seabirds in the area. The volumes involved (estimated at 0.2 – 0.8 m^3 per release) are not expected to be sufficient to result in significant effects on the seabird population in the Dunlin area, which is located offshore far from vulnerable coastal colonies.

Cetaceans

Cetaceans are also present in the vicinity of the Dunlin Alpha installation (Section 4.3.4). The potential impact of a gradual release of cell contents will depend on the species and their feeding habits, the overall health of individuals before exposure, and the characteristics of the hydrocarbons. Given the small volumes of contaminants involved, significant impacts on cetaceans are not expected.

Benthos

Benthic organisms could be exposed through deposition of solids that have settled out of the water column. Epifauna and infauna could be exposed through direct toxicity of components that are attached to deposited sediment particles. The uptake would be through direct ingestion of particles, or possibly through contact with tissues. Sessile organisms are most likely to be in prolonged contact with contaminated sediments (mobile species can take avoidance action to varying degrees). Additionally, an indirect disruption pathway of benthic function may be caused by oxygen depletion resulting from organic enrichment of sediments by hydrocarbons. Due to the small release volumes involved in the gradual release scenario, as well as the likelihood that released mobile oil, water and waxy residue will remain in the water column rather than interacting with the sediment, significant impacts on the benthos are not expected.

Bioaccumulation

When the cell structure eventually degrades, there is potential for the residual cell contents to come into contact with and be ingested by bottom-feeding biota and thereby enter the food chain. This could be both from direct feeding on the residues and feeding on seabed sediments contaminated by dispersed residues. However, given the probable lack of mobility of both the wax on the cell walls and the compacted sediment on the cell floors it is likely that the majority of the materials will remain in the vicinity of the site, even under a high energy failure scenario.

A screening assessment was carried out by METOC 2012 and reviewed as part of the Cell Contents Technical Report (CCTR) (Fairfield, 2021a) to investigate whether contamination from the residual cell contents at the site could contribute to a significant proportion of a limiting acceptable dose to a distant receptor, as a result of bioaccumulation. The assessment considered a range of substances of potential concern, including heavy metals and OSPAR priority substances, and was scenario based, with species in the food chain selected to be representative of viable pathways to deliver dose to the receptor.

Humans and marine mammals were considered as ‘top-level’ predators in the quantitative assessment, however ‘lower’ trophic levels (fish, crustacea, sediment re-workers and bacteria, moulds and fungi) were also considered qualitatively. Of the higher-trophic species which may be encountered within the project area, harbour porpoise are considered to have the greatest potential to be affected by the accumulation of inorganic compounds (Fairfield, 2021a). This is due to their comparatively small size decreasing the thresholds for acute exposure compared to other species (Weijs and Zaccaroni, 2016), and their non-seasonal, continuous feeding requirements increasing the chance of exposure (Boothe, 2019). However, as harbour porpoise have a relatively short lifespan (15 years), humans were selected as the most vulnerable receptor, both on the basis of exposure as the ‘top level predator’ through potential consumption of food from the site, and because chemical specific dose limits are broadly available.

A potential pathway for environmental harm is through ingestion of the cell contents by biota and subsequent bio-accumulation through the food chain. This can take two forms: chronic impacts resulting from low dose levels over an extended period and acute impacts resulting from much higher doses over a short period.

From assessment of the potential chronic and acute impacts, the following conclusions were drawn:

- None of the components assessed could be delivered at sufficient rate, or for long enough duration, to lead to a significant (more than 1%) proportion of the chronic dose in humans.

- None of the components within the cells is capable of concentrating into the food chain in sufficient quantity to deliver an acute dose to humans.
- Only sessile, non-resistant species living on the outer boundary of the contaminated zone will be able to accumulate toxic levels of contaminants. These represent a very small portion of the regional population.

Species most likely to survive within any contaminated area are the lowest level forms, which are generally least susceptible to contaminants and are able to take advantage of increased nutrients in the contaminated area. The ecosystem within the contaminated area will therefore be highly modified. However, these low trophic level species will tend not to pass contamination up the food chain in a bio-accumulative manner. Furthermore, for migratory species, the uptake of food from the vicinity of the CGBS will be a small proportion both on an individual and on a species basis. It was therefore concluded that environmental impacts to lower trophic levels will be confined to the site location and will be minor. Overall, it was concluded that the CGBS cell contents do not represent an unacceptable risk to humans through the uptake by the food chain of substances in the sediments.

A further review of the METOC screening assessment was undertaken (Intertek, 2020) to ensure that any changes to assessment criteria (i.e. chemical specific dose limits) and/or updates to the cell contents inventory have been considered. The review included reassessment of potential chronic toxicity to humans resulting from biota feeding directly on the solid residues from the cells. To ensure that the assessment did not underestimate the potential for impact, it was assumed that all contaminants present within the CGBS could become available, with no restriction on transfer up the food chain. The assessment is therefore considered highly conservative as it does not take account of the bioavailability of individual contaminants or the release rate from the sediments.

The results of the evaluation demonstrate that the potential for a significant contribution to dietary contaminants from the CGBS contents is negligible, as quantities required to be able to increase dietary intake by one percent of the maximum tolerable intake are well in excess of those present in the CGBS. Overall, it was concluded that the CGBS cell contents do not represent an unacceptable risk to humans through the uptake by the food chain of substances in the sediments.

5.2.2.7. Mitigation Measures

The following mitigation measures have been identified to limit potential impact from gradual cell contents release:

- The Attic Oil Recovery Project, detailed in Section 2.1.3, removed the vast majority of the residual oil within the cells. Relative to the overall volume of the cell contents, there is now expected to be only a thin layer of mobile oil within each cell (2 to 12 cm). The Attic Oil Recovery Project is the key mitigation measure that has been implemented in terms of reducing the potential for long-term impact from release of the cell contents; and
- Retention of the 500 m safety zone. This will exist until the point that the surface structures have collapsed below the water line, at which point FEL will make an application to renew the safety zone for a subsea structure.

In addition, there are several other factors that will minimise the impacts of gradual releases from the cells:

- Waxy residues are strongly bonded to the walls so will not be released instantaneously;
- Cell contents are compartmentalised (as detailed in Section 2.1.2), limiting the circulation of hydrocarbons or sediments that could be released from any single ingress to the structure;
- The geometry of the cells makes it difficult for falling debris to physically pierce the cells; and
- Concrete legs are predicted to crumble rather than collapse (Section 2.3.3.3).

Bioremediation

Bioremediation was initially considered as a management option to treat the CGBS cell contents *in situ*, in order to mitigate against potential future impacts. A wide range of organisms, particularly bacteria, algae and yeasts, are able to utilise crude oil components as a source of energy, with carbon dioxide being the end product. However, the following conclusions were drawn when assessing this option further, resulting in significant uncertainty regarding the effectiveness of bioremediation as a management option:

- The bioremediation process requires an oxidant, normally oxygen, and the Dunlin Alpha storage cells are an anoxic environment. Other electron receptors, such as sulphate or nitrate can be used, although such processes tend to be less efficient;
- If algae are an important component of the biodegrading process, light will also be required. As natural sunlight will not be available within the Dunlin Alpha storage cells, algae will not be a suitable material.
- Nutrients, particularly phosphate and nitrate, would need to be repeatedly supplied over time. This would require individual access to each cell and involve numerous interventions to check progress and replenish chemicals;
- The rate at which biodegradation takes place is temperature dependant, increasing rapidly between 5° C and 30° C, although activity can occur within a temperature range from near 0° C to >40° C. The temperature within the Dunlin Alpha cell groups is approximately 5°C; and
- As well as temperature, another key factor in the effectiveness of the biological processes is the acidity or alkalinity of the environment, measured in potential Hydrogen (pH). The pH requirement will depend on the micro-organism selected. The existing environment within the CGBS cells is unknown[5] but would likely require frequent adjustment through the addition of chemicals to ensure a suitable range.

Although the technology has been used in other situations, bioremediation of crude components in a closed environment, where light and oxygen are minimal and the ambient temperature is low, has not been tested. The effectiveness of the process is therefore unknown. Research into micro-organisms which can react in low temperature and low light environments (as in the Dunlin Alpha CGBS) is being carried out. However, the work is in its infancy and is some years (decades) away from achieving significant breakthroughs (if any). As a result, bioremediation as an active management option was not considered further.

It is noted that there undoubtedly will be ongoing biological processes within the storage cells, evidence of which has been seen during venting operations of gases from within the cells. This will result in a natural attenuation and degradation of the mobile oil. However, the rate at which this process occurs will be very slow and it is uncertain as to whether the processes can be sustained in the cell conditions, as discussed above when considering a more managed approach to bioremediation.

5.2.2.8. Cumulative Impact Assessment

It is expected that up to a maximum of approximately 1,100 m^3 of mobile oil could be released from the Dunlin Alpha storage cells over a prolonged period of time. Although the gradual release mechanisms of other CGBS in the area are likely to be different, due to different construction of the substructures, it is possible that releases from other assets could also occur over this period. However, as a result of the water depth (151 m) and the release of such a volume occurring in small percentages over an extended duration (up to hundreds of years

[5] In any system the molecules will try to find an equilibrium, and each component has an influence on the other. Empirical data tends to look at systems with a fixed pressure, however the pressure within the cells varies by over 2barg from the top of the cells to the bottom. Data on how gases interact with water is available for pure water and single gas species but not for seawater and complex gas mixtures. The available data is insufficient to determine the molar balance of all the components to determine exactly how they will interact. This means determining the amount of dissolved gases or the physical properties like pH and conductivity for example is very difficult. All things that micro-organisms are likely to be very sensitive to.

as the structures degrade), any release of mobile oil is expected to dissipate relatively rapidly and the small amount of oil which has the potential to surface will be removed by evaporation and biodegradation.

The modelling results indicated that the short-term and localised impacts of gradual mobile oil release would only be discernible (i.e. between 0.3 - 50 µm thickness) over an area of 3 km^2. As the Dunlin Alpha CGBS is approximately 9.9 km from the nearest oil and gas installation (Thistle A), there is considered to be no potential for the gradual hydrocarbon release to act cumulatively with oil and gas activities taking place in surrounding waters.

For these reasons, no cumulative impacts from the gradual release of hydrocarbons are predicted for projects external to the Dunlin Alpha CGBS decommissioning activities. Cumulative impacts with instantaneous release from disturbance of the cuttings pile are assessed in Section 5.3.2.8 of the Unplanned Events chapter below.

5.2.2.9. Transboundary Impact Assessment

The gradual release of mobile oil and other contents of the cells will be over a prolonged period of time and will be of a relatively small volume at any one time. With the small volumes noted, there is expected to be no transboundary impact.

5.2.2.10. Protected Sites and Species

Gradual release of cell contents during the degradation of the Dunlin Alpha installation will not occur within any SAC, SPA or NCMPA. Dispersal of any released contaminants will be such that there will unlikely be detectable interaction with any protected sites. As such, there is considered to be no Likely Significant Effect on SACs and SPAs and no impact on their conservation objectives or on-site integrity through a release of contaminants from the cells. There will also be no interaction with any NCMPA, and no mechanism by which the sites could be compromised.

The video footage undertaken as part of the marine growth assessment (Xodus, 2017) showed that the only species of conservation significance identified as present is *Lopehlia pertusa*, the cold-water coral. This species is present on the deeper parts of all legs, below depths of approximately 48 m and on the CGBS (e.g. Fugro, 2017b). *Lophelia pertusa* is a reef-building cold water coral that provides habitats for other epifaunal and fish species and is a UK habitat of principle importance and a Scottish PMF; it is also listed in Annex I of the European Habitats Directive and is on the OSPAR List of Threatened and/or Declining Species and Habitats. This species naturally occurs in deep water, typically in depth ranges of 200 – 2,000 m, on the continental slope. The extent of *Lophelia pertusa* reefs is undergoing an overall decline due to mechanical damage by demersal fishing gear in all OSPAR areas (OSPAR, 2009b). However, the species has also been recognised in scientific literature, and evidenced in survey footage, to grow opportunistically on oil and gas subsea infrastructure (e.g. Gass and Roberts, 2006). The specimens of coral present on the structures are not likely to be affected by the slow and limited release of cell contents.

5.2.2.11. Residual Impact

Receptor	Sensitivity	Vulnerability	Value	Magnitude
Biological features	Low	Low	Low	Minor
Rationale				
The information in the Environment Description (Section 4) has been used to assign the sensitivity, vulnerability and value of the receptor as follows. Biological features around the Dunlin Alpha installation will have some tolerance to accommodate the particular effects that could result from discharges (as a result of depth and refreshing of water column) and sensitivity is low. Additionally, there is potential for the residual cell contents to come into contact with and be ingested by bottom-feeding biota and thereby enter the food chain. However, as potential impacts are not likely to affect the long-term function of a system or a population, there will be no noticeable long-term effects above the level of natural variation experienced in the area and vulnerability is low. The fish populations in the project area are characterised by species typical of the northern North Sea, with some spawning and nursery regions for commercially important fish and shellfish species occurring in the vicinity of the project area. There appear to be low densities of cetaceans and seals within the project area. There are no designated or proposed sites of conservation interest in the project area. None of the survey work undertaken in the project area has identified any benthic habitats or species that are of specific conservation significance (L. *pertusa* is not considered to be naturally present in the area). Value is therefore defined as low. The impact magnitude is Minor due to the anticipated release of a relatively small volume of residual chemicals and hydrocarbons over an extended period of time. There is expected to be limited potential for cumulative impacts from this anticipated release.				
Consequence		**Impact significance**		
Low		Not significant		

5.3. Unplanned Events

5.3.1. Cell Contents – Instantaneous Release

5.3.1.1. Overview

There is the possibility that residual chemicals and hydrocarbons contained within the cells will be released over a much shorter period of time than described in Section 5.1, in the event of a significant structural failure of the CGBS. This could see mobile oil, water, sediment and waxy residues distributed within the vicinity of the Dunlin Alpha installation in a relatively short timeframe.

5.3.1.2. Mechanism for Worst-case Instantaneous Release

The Atkins Leg Failure Study (Atkins, 2017b) provides an assessment of potential dropped objects from the CGBS as it degrades over time. The information from this study has been used to determine credible scenarios that could result in a future release or exposure of the residual cell contents.

The worst-case scenario resulting in an instantaneous release involves an early failure of a transition falling from the top of a CGBS leg. Although unlikely, this could see a transition falling side-on through the water column onto the roof of the CGBS base caisson. This could potentially cause significant damage to the base caisson roof slab should it land directly on it, but is not expected to cause collapse or implosion (Atkins, 2017b).

The impact energy from a complete transition falling has been estimated to be 10 – 15 MJ (Atkins, 2017b). Considering the size of a transition, it is possible that such an impact could result in the loss of containment of up to four storage cells. It is estimated that this could result in an instantaneous release of up to 64 m^3 of mobile oil. Table 5.2 summarises the release volumes modelled to inform the environmental impact assessment.

Table 5.2 Inventory basis for modelling an instantaneous loss of containment of the cells

Inventory	Volume (m^3)	Method of exposure to the marine environment
Mobile oil	50 – 100 (Note 1)	Release into the water column
Water	12,500	Interchange with the water column
Sediment	190	Exposure, remaining within the concrete substructure
Wall residue	40	Exposure, remaining adhered to the concrete substructure

Note 1. The worst-case potential release volume comprises of the residual mobile oil residing within four domed roof cells. Based on base case estimates, this would range from approximately 12 m^3 and 64 m^3. However, modelling of a 50 – 100 m^3 range has been undertaken to account for uncertainty in release volumes

It should be noted that the release scenario described above is considered worst-case, as it does not consider a number of factors that would limit the potential for such a release:

- Over time, the wall thickness of steel transitions will decrease due to corrosion activity. This will result in a reduction in mass and subsequently, a reduction in potential impact energy. In the future, the mass of steel will have significantly reduced and may not have sufficient impact energy to breach the cell roof structure.
- As described in Section 2.1.3, there is a significant amount of drill cuttings located on the CGBS roof. The cuttings provide a considerable amount of energy absorption, protecting the reinforced concrete underneath. Findings from the Atkins (2017b) study indicate that there is little risk of the cell roofs being breached where there are drill cuttings.
- As described in Section 2.1.1, formwork within the internal structure of the concrete domed roofs effectively creates thirty-six sub-compartments (Figure 2.5). In the unlikely event that a cell roof is breached, the sub-compartmentalisation of any residual oil would limit the extent of a release.
- A further limiting factor is that the orientation of the falling transition will determine the scale of the impact on the cell tops. If this is end on there will be more energy and a higher likelihood of penetration, however this will also be limited by the presence of the cuttings material as mentioned above. As a result, if there is no cover there is a potential for the impact energy whether end on or side on to breach the cell tops; however the chance of this happening is remote as a side on impact on an area with no cuttings deposits is unlikely. Nevertheless, in order to be conservative, the more likely scenario of a single cell breach has been increased to four to allow for an impact that falls across a cell dividing wall.

5.3.1.3. Instantaneous Release of Hydrocarbons

The potential impact of any instantaneous release will be determined by the chemical characteristics of the release (including weathering potential), the circumstances and volume of the release, the environmental conditions at the time, the direction of travel of the release and the presence of environmental sensitivities in the path of the release. These environmental sensitivities will have spatial and temporal variations. Therefore, the likelihood of any accidental release having a potential impact on the environment must take into account the likelihood of the release occurring against the probability of that hydrocarbon or chemical reaching a sensitive area and the timing of the presence of environmental sensitivities in that area at the time of release.

To assess the potential for environmental impact, modelling of 50 m^3 and 100 m^3 releases were undertaken using the SINTEF OSCAR release model and used to inform the CA process (described in Section 2.3.2.3). As the expected maximum release volume for mobile oil is 64 m^3, this range is considered appropriate to cover uncertainty in the released volume. Further details of the composition, quantity and distribution of residual contents within the CGBS storage cells are provided in Appendix A.

The model was run in both stochastic and deterministic modes, with a release of the mobile oil occurring over one hour. This is considered worst-case, as it models the effects of releasing the most mobile oil at a single point in time.

Stochastic modelling

The stochastic modelling results for the 100 m^3 release are provided in Table 5.3 and Table 5.4. Table 5.3 indicates that there is a low probability (15.2%) that hydrocarbons will cross the UK / Norway median line, and Table 5.4 indicates that there is a very low probability (6.7%) that any beaching will occur.

Table 5.3 Probability of 100 m^3 release crossing UK / Norway median line

Season	Median line(s) crossed	Probability of Contamination (%)
Winter	UK / Norway	1.0 % - 9.5 %
Spring	UK / Norway	1.0 % - 15.2 %
Summer	UK / Norway	1.0 % - 9.5 %
Autumn	UK / Norway	1.0 % - 12.4 %

Table 5.4 Probability of 100 m^3 release beaching

Aspect(s) considered		Winter	Spring	Summer	Autumn
Norway	Probability of contamination (%)	1.0 % - 1.9 %	1.0 % - 2.9 %	1.0 %	1.0 % - 4.8 %
Shetland	Probability of contamination (%)	1.0 % - 1.9 %	1.0 % - 3.8 %	1.0 % - 6.7 %	1.0 % - 2.9 %
Protected areas with beaching oil probability > 40%		None			
Maximum mass of beached oil in any single run (t)		0.04	0.06	0.23	0.07
Maximum mass of beached emulsion in any single run (t)		0.11	0.24	0.86	0.25
Maximum volume of beached emulsion in any single run (m^3)		0.12	0.24	0.87	0.26

Deterministic modelling

The modelling results for the 100 m^3 release scenario run in deterministic mode are shown in Figure 5.2. In order to ensure that any potential shoreline impact was not underestimated, the environmental conditions that predicted the largest mass of oil to reach the shore were used.

Figure 5.2 shows the predicted surface oiling and dispersion of a 100 m^3 release. From the release point, approximately 137 km north east of the nearest landfall point in the Shetland Islands, the metocean conditions (predominately the wind) result in the surface oil moving south west (Day 3) towards the east coast of Shetland, away from the UK / Norway median line. This results in the surface oil spreading parallel to the east coast of Shetland as the wind turns towards the west on Day 6, resulting in some beaching along most of the east coast of Shetland. While some of the remaining oil would be carried further south and east before dispersing (Day 30), most of the surface oil that did not beach would be carried north by Day 8 and would be naturally dispersed across a large area directly north of Shetland by Day 14. Eight protected sites are predicted to receive some surface oil. However, this is expected to all be of Bonn Agreement Oil Appearance Code (BAOAC) 2 (0.3 – 5.0 µm thick) or below (i.e. sheen / rainbow appearance).

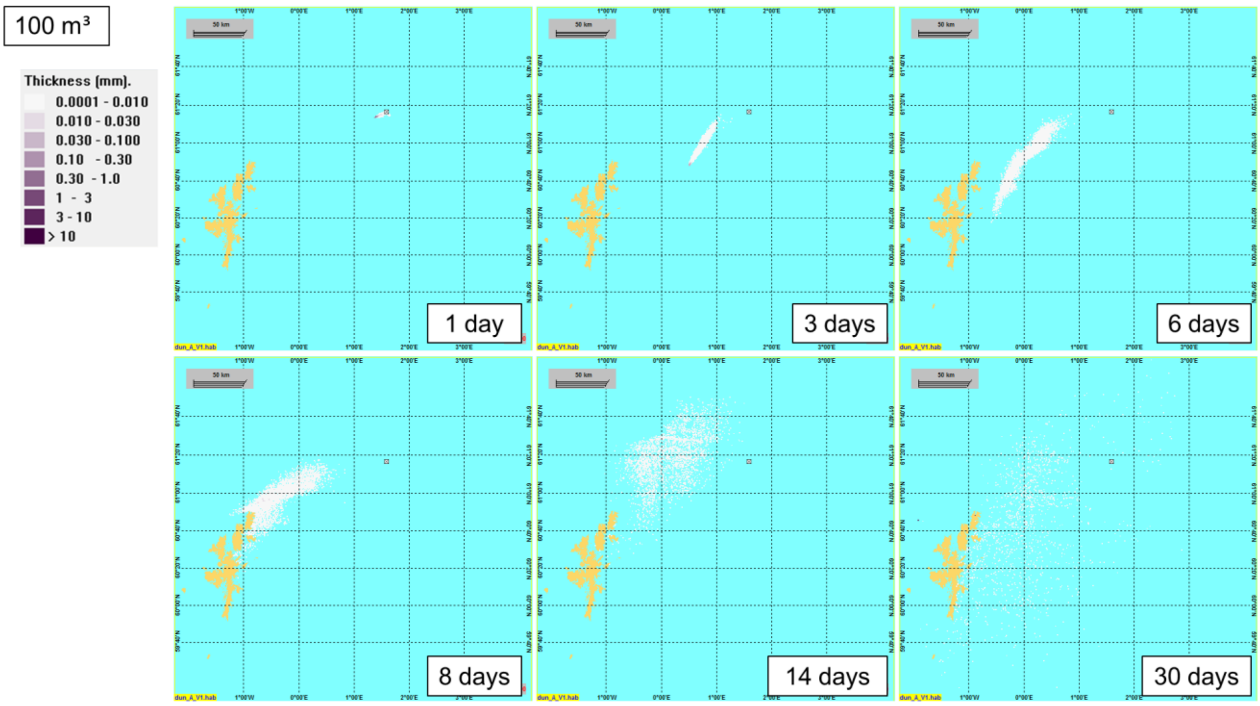

Figure 5.2 Surface oiling for 100 m^3 oil release

It should be noted that the release modelling is based on the worst-case release volumes and metocean conditions. It is expected in reality that any release would disperse at sea.

Modelling outputs from the 50 m^3 and 100 m^3 release scenarios have been provided in Table 5.5 - Table 5.7, summarising the potential for sea surface and shoreline oiling. As the UK has the nearest shoreline to Dunlin Alpha, the modelling focuses on the Shetland Isles and nearby sensitive areas for impact assessment. Information on protected sites is presented in the environmental baseline in Section 4.4.

Table 5.5 Surface oil thickness at protected sites

Protected site	Thickness (µm)			
	50 m^3 Release Scenario		100 m^3 Release Scenario	
	Max.	Min.	Max.	Min.
Central Fladen NCMPA	0.63	0.40	2.82	0.31
Fair Isle SPA	-	-	-	-
Hermaness, Saxa Vord and Valla Field SPA	-	-	-	-
Fetlar to Haroldswick NCMPA	0.86	0.30	3.30	0.32
Pobie Bank Reef SAC	1.26	0.31	2.56	0.33
Yell Sound Coast SAC	0.59	0.50	1.15	0.34
Fetlar SPA	0.63	0.30	1.89	0.32
Mousa SAC	-	-	0.94	0.94
Noss SPA	0.50	0.50	1.11	0.35
Mousa to Boddam NCMPA	-	-	1.04	0.33

Table 5.6 Shoreline oiling

Shore line oiling	50 m^3 Release Scenario	100 m^3 Release Scenario
Occurrence of first oil to shore	6 days 15 hours	6 days 18 hours
First appearance of oiling above 0.1 l/m^2 (87 g/m^2)	Does not occur	Does not occur
First appearance of oiling above 0.5 l/m^2 (430 g/m^2)	Does not occur	Does not occur
Maximum oiling (g/m^2)	5.9	51
Length of oiled shoreline (km)	172	268
Occurrence of max oiling	9 days 18 hours	9 days 18 hours
Maximum total stranded oil (tonnes)	0.19	1.85
Occurrence of max total stranded oil	10 days 18 hours	10 days 12 hours

Table 5.7 Shoreline oiling at protected sites

Protected site	Oil conc. (g/m^2)			
	50 m^3 Release Scenario		100 m^3 Release Scenario	
	Max.	Min.	Max.	Min.
Hermaness, Saxa Vord and Valla Field SPA	5.9	0.2	31.4	0.1
Fetlar to Haroldswick NCMPA	3.9	<0.1	50.3	<0.1
Yell Sound Coast SAC	0.3	<0.1	2.6	<0.1
Fetlar SPA	1.8	<0.1	10.7	<0.1

The mass balance of oil in the 100 m^3 release scenario over the 30 days following the release is presented in Figure 5.4, and shows the quantity of oil on the shoreline on each day over the release period (the "stranded" line shown in green). Evaporation, movement to sediment and biodegradation accounted for the removal of 36.6% (31.8 t), 4.8% (4.2 t) and 17.0% (14.8 t), respectively of the total amount of material released by Day 30. Beaching commences on Day 6 with a maximum of 1.85 t onshore on Day 10. This mass is spread out over a length of approximately 270 km. Sediment contamination was predominantly associated with the seabed around Shetland where beaching occurred. Sediment concentrations were generally predicted to be very low, with the maximum concentration at 30 days of less than 0.005 g/m^2.

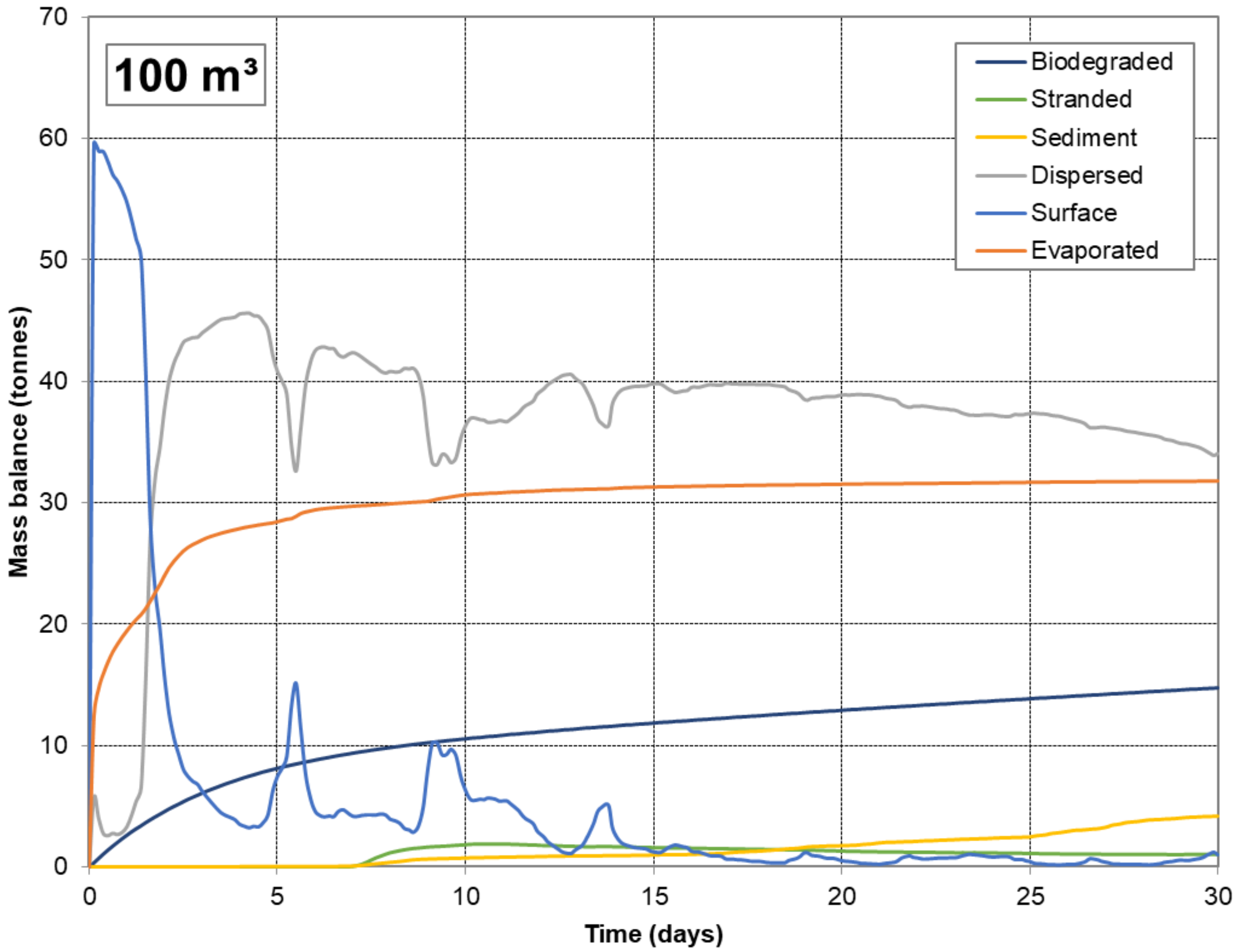

Figure 5.3 **Mass balance of Dunlin Alpha cell contents release (100 m^3)**

The area within which the predicted environmental concentration (PEC) of the released contaminants exceeded the predicted no effect concentration (PNEC) was calculated. Figure 5.4 shows that the maximum water column PEC / PNEC ratio predicted in each model cell during the 30 days following the release of 100 m^3 of oil. The greatest risk occurs to the south of the release point, but the area experiencing a PEC / PNEC ratio >1 at any time during the release scenario is very small and no designated conservation sites overlap with the area at risk of impact. Inspection of a vertical cross section through the water column (not shown) shows that the greatest risk is localised in mid-water, in close proximity to the release location.

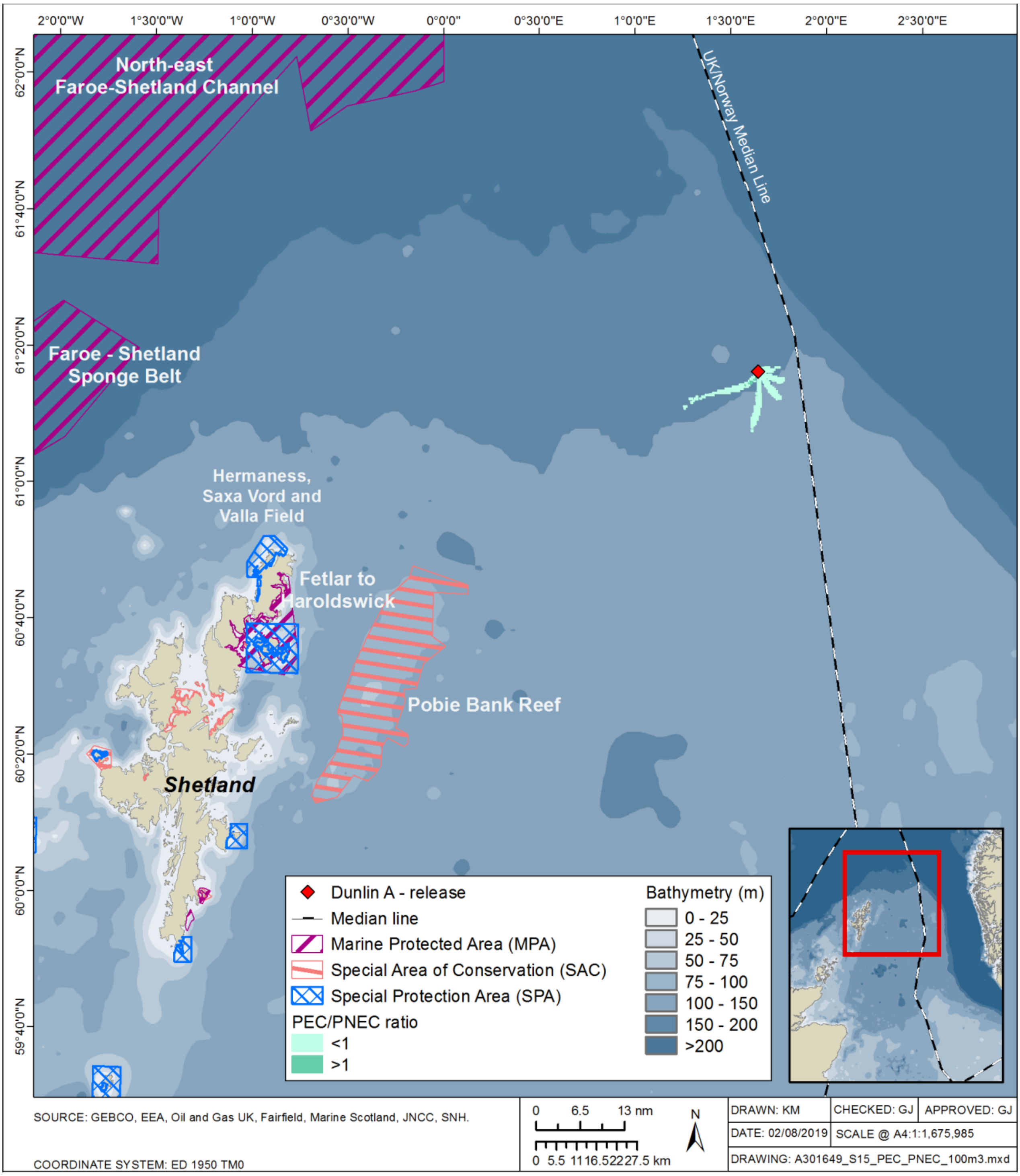

Figure 5.4 Maximum PEC / PNEC ratio occurring in each model cell during the first 30 days following release (100 m^3 scenario)

In addition to modelling undertaken to assess the worst-case potential impact from an instantaneous release of the CGBS storage cells, modelling of a 200 m^3 release was also undertaken to understand the sensitivity of the impact assessment to a larger release volume. The results of the modelling suggest that despite a minor increase in shoreline oiling, the characteristics of such an impact would be similar to that of the 100 m^3 release. Any such beaching would be rapidly dispersed in the rocky nearshore environment and unlikely to impact on individuals or populations.

5.3.1.4. Instantaneous Release of Cell Water

As described above, the impact energy from a falling transition could cause significant damage to the base caisson roof slab. While this is not expected to cause collapse or implosion, it could result in the loss of containment of up to four storage cells including displacement of cell water.

Modelling of a cell water release was undertaken using the SINTEF DREAM model. Cell water will be contaminated with various inorganic and organic components. Table 5.8 provides the input data that was used to model the release, including chemical concentrations. There is also the potential for residual chemicals to be released from the water phase. However, as discussed in Section 2.1.3, the total volume of chemicals within the CGBS base caisson is expected to be approximately 174 kg, therefore there are unlikely to be any significant effects and this is not discussed further.

Table 5.8 Concentration of components in cell water

Natural Substance	Concentration in Release (g/m^3)
Arsenic	0.02
Cadmium	0.006
Chromium	0.01
Copper	0.016
Lead	0.000125
Mercury	0.0001
Nickel	0.01
Zinc	0.0032
Naphthalene	0.25
Acenaphthene	0.001
Pyrene	0.001
Phenanthrene	0.013
Fluorene	0.008
Fluoranthene	0.0004
Anthracene	0.0004
Chrysene	0.0006
C0-C3 Phenols	2
Benzene	1.79
Toluene	0.54
Ethylbenzene	0.15
Xylene	0.2
THC	Maximum in inventory basis = 100 mg/l

Although there will be no significant pressure differential between the internal and external of the cells, required to drive cell water out of the cells, the release scenario has assumed that all of the cell water within four storage cells, approximately 12,500 m^3, would be released instantaneously. The modelling undertaken is therefore considered to be overly conservative. In order to ensure marine impacts are not underestimated, environmental conditions that reflected the least dispersive time period were also used.

A time series showing the risk to the water column after the release is shown in Figure 5.5. This shows that the water column risk, as described by EIF values, peaks at around 15 hours after the release and is very short term, returning to zero within 24 hours. The EIF is dominated by the contribution of the Total Hydrocarbon Content (THC) component, represented in Figure 5.5 as dispersed oil.

The area that is predicted to have a risk of greater than 5% is approximately 3.03 km^2 and is not expected to extend beyond 5 m above or below the release point. As such, there is no risk of impact on the sea surface or seabed.

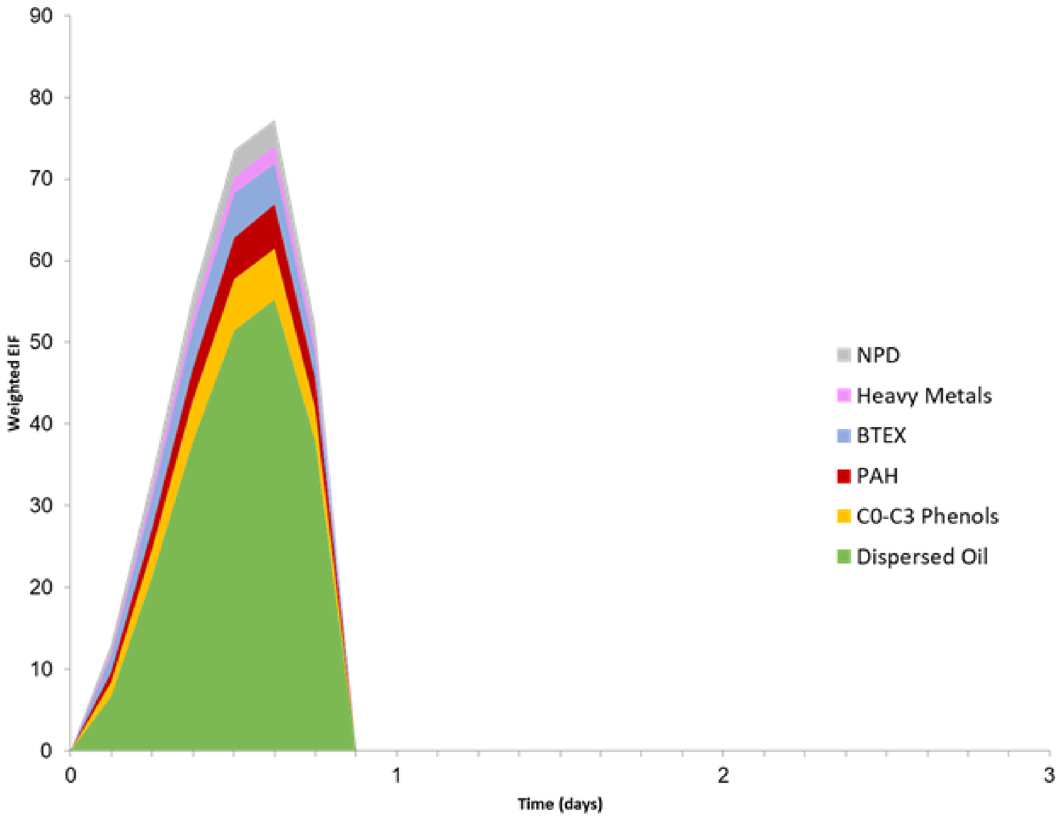

Figure 5.5 Water column impact in terms of EIF from cell water release

5.3.1.5. Environmental Vulnerability to a Release

The receptors which could potentially interact with the release of the cell contents are considered below.

Plankton

There may be impacts on plankton in the immediate area of the release until the release disperses, due to the dissolution of aromatic fractions into the water column (Brussaard *et al.*, 2016). Such effects will be greater during a period of plankton bloom and during fish spawning periods. Contamination of marine prey including plankton and small fish species may then lead to aromatic hydrocarbons accumulating in the food chain. These could have long-term chronic effects such as breeding failure in fish, bird and cetacean populations. This may also affect stocks of commercially fished species. However, the relatively small size of any release in comparison to the available habitat and the widespread populations of plankton and small fish is expected to limit the potential for these impacts to be realised.

Fish

Juveniles and eggs are the fish life-stages most vulnerable to chemical or hydrocarbon releases. As outlined in Section 4.3.2, a number of commercially important pelagic and demersal fish species are found in the vicinity of the Dunlin Alpha installation. Ten species are expected to use the project area for spawning and/or nursery grounds at various times of the year. However, any release is not expected to affect fish spawning or recruitment success as the maximum release volume is relatively small, will be rapidly dispersed and the available spawning and nursery areas are very large.

Seabirds

In a nature conservation context, seabirds are the group at greatest risk of harm due to surface oil pollution in the offshore environment (JNCC, 2011). The most familiar effect of oil pollution on seabirds is the contamination of plumage, resulting in the inability to fly and loss of insulation and waterproofing, which alone may cause death. Individuals surviving these primary impacts are prone to ingest toxins whilst preening in attempts to remove contamination; this may result in secondary toxic effects. The seasonal vulnerability of seabirds to surface pollutants in the immediate vicinity of the Dunlin field, derived from JNCC block-specific data, suggest that seabirds in this area have a low vulnerability to surface pollution, although some of the blocks exhibit high vulnerability at certain times of the year (see Section 4.3.3). The magnitude of any impact will depend on the number of birds present, the percentage of the population present, their vulnerability to hydrocarbons and their recovery rates from oil pollution. Modelling suggests that the area of sea surface contaminated by hydrocarbons in the event of a spill will be very small, with a low probability of a surface sheen exceeding 0.3 µm thickness extending outside of the project area. This means that even for the short periods of time when seabirds are present and spending time on the sea surface, there is little chance of interacting with surface oil.

Cetaceans

Cetaceans are also present in the vicinity of the Dunlin Alpha installation (Section 4.3.4). The potential impact of a release will depend on the species and their feeding habits, the overall health of individuals before exposure, and the characteristics of the hydrocarbons. Baleen whales are particularly vulnerable whilst feeding, as oil may adhere to the baleen if the whales feed near surface slicks (Gubbay and Earll, 2000). Cetaceans are pelagic (move freely in the oceans) and migrate. Their strong attraction to specific areas for breeding or feeding may override any tendency cetaceans have to avoid hydrocarbon contaminated areas (Gubbay and Earll, 2000). However, given the low density of cetaceans in the vicinity of the Dunlin Alpha installation and the rapid dispersal of an instantaneous release, there is not likely to be any impact on individuals or populations.

Benthos

With regard to the assessment of potential impacts from release or exposure of the solid material contents of the cells, the main parallels lie with cuttings piles contaminated with oil-based muds. Indeed, the most significant in-combination impact relates to the legacy of drill cuttings piles, specifically those that include oil-based mud residues from drilling operations. Surveys indicate that drill cuttings are present on the roof of the cells and extend down onto the seabed around the southern edge of the CGBS. Any disturbance to the roof of the CGBS cells would be accompanied by some disturbance of cuttings material on the roof. However, a release of the solids content of the CGBS (e.g. from a high-energy impact scenario) through the top of the CGBS or side walls is considered unlikely to occur.

As described in Section 3.3.1, the sediment contents of the cells sit 13 m below the cell roof, where a breach may occur. A breach of the storage cells is not expected to activate a plume of the small volume of sediment contained within the cells to a height of 13 m such that it would be ejected from the breached cell. While cell sediment may become exposed to the surrounding environment, it likely that the sediment will become entombed in the fallen debris as the substructure degrades overtime, limiting potential impacts to the benthic habitat characterising the CGBS.

Although considered unlikely, a disturbance-mediated instantanous release of sediment from the base of the cells or of the wall residue bound to the concrete could lead to the smothering of benthic species and habitats due to sediment suspension and re-settlement. This may particularly affect the epifaunal species described in Section 4.3.1, with the degree of impact related to individuals' ability to clear particles from their feeding and respiratory surfaces (e.g. Rogers, 1990). There is no smothering sensitivity assessment available for the 'Circalittoral Mixed Sediment' biotope complex. Sensitivity of the two biotopes within the 'Circalittoral Muddy Sand' complex is low, with medium to high resistance and high recovery (Tillin and Budd, 2016, De-Bastos, 2016). Species characterising these biotopes are expected to be exposed to, and tolerant of, short term increases in turbidity following sediment mobilisation by storms and other events. There may be an energetic cost expended by individuals to either re-establish burrow openings, to self-clean feeding apparatus or to move up through the sediment, though this is not likely to be significant. Most animals will be able to re-burrow or move up through the sediment within hours or days.

With regard to the settlement of any re-suspended sediments from the tops or base of cells, the infaunal community is adapted to fluctuations in sedimentation levels and not likely to be particularly sensitive to temporary and localised increases. Tillin and Budd (2016) report on the abilities of buried fauna to burrow back to the surface. Results indicate bivalve molluscs are able to burrow between 20 – 50 cm depending on species and substrate; results for some species range from 60 cm in mud to 90 cm in sand. The abilities of the fauna to recover to the sediment surface will depend on the species and the burial depth, but as the resuspension of any disturbed cell sediment is not expected to result in deep burial, success should generally be high.

Impacts upon benthic habitats and species from the above releases will be localised and are not expected to result in changes to the benthic community in the long-term. Ecological implications of a cell breach are discussed in terms of food chain impacts in the Section below.

Bioaccumulation

Should a high-energy impact breach the base caisson, there is the potential for some of the residual cell contents to be ingested by bottom-feeding biota and thereby enter the food chain. Further assessment on the potential for bioaccumulation has been previously discussed in Section 5.2.2.6.

A radiological impact assessment has also been undertaken by an independent specialist to consider the potential impacts resulting from a release of NORM contaminated sediment from the CGBS. The assessment considered a worst-case release scenario resulting in the greatest potential mass of NORM contaminated sediments being dispersed throughout an area capable of sustaining a small fishing vessel. The assessment concluded that no annual dose of any concern would arise as the result of even the worst case release scenario (ARPS, 2018), and that the exposure of fishermen to the potential NORM release was acceptable (ARPS, 2018).

Coastal Environment

The likelihood of a hydrocarbon release impacting the coastal environment is a function of the likelihood of such an event occurring and the probability of the hydrocarbon beaching. The level of impact is also directly related to the volume of the hydrocarbons released, the volume of hydrocarbon beaching, the composition of the beached hydrocarbons, and the type of beach and receptors present on the shore at the time of beaching. The results of the stochastic release modelling indicate that the probability of oil reaching the UK shoreline (Shetland) is low (1.0 % - 6.7 %). However, in the unlikelihood that mobile oil does reach the shoreline, the volume will be small and any such beaching oil would be rapidly dispersed in the rocky nearshore environment.

5.3.1.6. Mitigation Measures

The following mitigation measures have been identified to limit potential impact from instantaneous cell contents release:

- The Attic Oil Recovery Project, detailed in Section 2.1.3, removed the vast majority of the residual oil within the cells and there is now expected to be only a very thin layer of mobile oil, between 2 to 12 cm, within each cell. The Attic Oil Recovery Project is the key mitigation measure that has been implemented in terms of reducing the potential for long-term impact from release of the cell contents;
- The top of each transition will be sealed to prevent the ingress of seawater, reducing corrosion activity and increasing the longevity of the structures

In addition, there are several other factors that will minimise the impacts of instantaneous releases from the cells:

- Waxy residues are strongly bonded to the walls so will not be released instantaneously;
- Cell contents are compartmentalised (as detailed in Section 2.1.2), limiting the circulation of hydrocarbons or sediments that could be released from any single ingress to the structure;
- The geometry of the cells makes it difficult for falling debris to physically pierce the cells; and
- Concrete legs are predicted to crumble rather than collapse.

Bioremediation was considered but as discussed in Section 5.2.4 will not be used as an active management option.

5.3.1.7. Cumulative Impact Assessment

It is important to consider the potential for impacts to arise from instantaneous release of the cell contents in conjunction with similar releases from other installations in the wider area. In the North Sea, there are 12 CGBS facilities in the UK sector, 12 in the Norwegian sector, two in the Dutch sector and one in the Danish sector. Only two of these CGBS facilities are present within the same ICES rectangle as the Dunlin Alpha installation (Cormorant Alpha and Brent Delta), and each are located more than 20 km away.

The failure mechanisms of other CGBS in the area are likely to be different, due to different construction of the substructures (i.e. transitions). Since any instantaneous hydrocarbon or chemical release from the cells at the Dunlin Alpha installation is expected to dissipate within days, it is considered very unlikely that additional similar releases from other CGBS facilities would occur in the same timeframe to produce a cumulative impact. Cumulative impacts with other external projects are therefore considered unlikely, due to the relatively short duration of the release in comparison to the relatively large distances between structures which will experience gradual releases over an extended period.

Should a dropped object cause a breach to the cell structure, it is considered unlikely that this would also generate important disturbance to the cuttings piles causing cumulative impacts internal to the project (Xodus, 2020a). The potential for these impacts to act cumulatively is limited as the quantity of drill cuttings on the CGBS roof is significant, and provides considerable potential for energy absorption, protecting the reinforced concrete underneath. Findings from the Atkins (2017b) study indicate that there is a much lower risk of the cell roofs being breached where drill cuttings are located. Therefore, it is considered that there is limited potential for synergies between these two impact pathways to generate cumulative impacts.

5.3.1.8. Transboundary Impact Assessment

There is the potential for released cell contents to cross into the Norwegian sector. However, the small volumes and the distance to the transboundary line (11 km) mean it is likely that the contents would be diluted substantially into the wider marine environment and thus not detectable at any significant level within Norwegian waters. As such, there will be no significant transboundary impacts associated with an instantaneous release from the cells.

5.3.1.9. Protected Sites and Species

Overview

Modelling of an instantaneous release of mobile oil from the cells has shown that it would be unlikely for this inventory to reach the shoreline; at worst, the very north-east coast of Shetland could receive a very small volume of oil depositing on the shoreline. Review of the quantities against the International Tanker Owners Pollution Federation scale for shoreline oiling shows that any beaching would be classed as “less than light” and may not even be detectable.

This section considers the potential for such a release from the cells to impact upon the conservation objectives (and ultimately site integrity) of important protected sites, specifically SPAs, SACs and NCMPAs. The output of the modelling described in Section D has been compared against the location of SPAs, SACs and NCMPAs to determine where there is considered to be the potential for interaction.

Direct Interaction with Coastal Sites

As outlined in Section 5.3.2.2, a 100 m^3 worst-case release could result in a maximum of 1.85 tonnes of oil being dispersed over 268 km of shoreline, which is a very small proportion of that originally released. Considering the low likelihood of released oil reaching shore, and the very low volumes involved, direct interaction with any coastal or onshore protected sites is not expected. However, should some of the mobile oil reach the shore, the volumes would very small and of a light rainbow/sheen character. Any such beaching would be rapidly dispersed in the rocky nearshore environment.

Direct Interaction with Receptors from Coastal Sites Found Offshore

In addition to direct interaction with a site (i.e. mobile oil from the cells crossing the boundary of a site), it is necessary to acknowledge that qualifying features of some sites are mobile (e.g. seabirds and marine mammals) and that some individuals may forage or move through the area within which a release has occurred. In terms of marine mammals for which sites are designated, as outlined in Section 4.4, the Southern North Sea SAC, for which harbour porpoise is the qualifying feature, is located 640 km south of the Dunlin project area. Harbour porpoise are highly mobile, and records exist of individuals travelling over 1,000 km (JNCC, 2013b). It is not expected however that individuals associated with the Southern North Sea SAC will occur in the project area in sufficient numbers during any limited period over which a release would take to disperse to have a significant impact on the harbour porpoise population associated with the SAC.

Sites designated for bottlenose dolphin, harbour seal and grey seal are present along the east coast of Scotland. However, the distance of these sites from the Dunlin Alpha installation and the home and foraging ranges of these species suggests no individuals from these sites will occur in the project area and they are therefore excluded from further assessment.

It would be very difficult to assign seabirds identified within the vicinity of the Dunlin Alpha installation area to specific SPAs. For many species, once breeding is complete, individuals are no longer restricted to foraging within certain distances (i.e. foraging ranges) from their breeding colony as there is no longer any requirement to return to eggs or chicks. Furness (2015) defines biologically appropriate, species-specific, geographic non-breeding season population estimates for seabirds. For a number of key species there is strong evidence that once birds leave the breeding colony they become widely dispersed over large distances, often intermingling with birds from other breeding colonies (typically of the same species) and in some cases birds that have migrated from overseas breeding colonies (Furness, 2015). Consequently, the potential for a cell contents release to have population level impacts on birds from any single SPA is much reduced. Potential impacts on birds from protected sites during the non-breeding season (i.e. when they are offshore) are therefore expected to be negligible.

Direct Interaction with Offshore Sites

For direct interaction with offshore sites without a land component, surface occurrence of released hydrocarbon within the site is taken as an indication that the site has the potential to be impacted. The closest protected site to the project area is the Pobie Bank SAC, which is 98 km away at the closest approach. This site is designated for seabed features that would not be affected by a limited volume of oil being present on the surface. There will therefore be no significant impact on any offshore protected sites.

Protected Species

In addition to protected species that are associated with protected sites and which are discussed above (e.g. seabirds, cetaceans), there are several species that are expected to occur in the area that are protected but not associated with a site designation. For example, basking sharks, spurdog and blue shark are all on the IUCN Red List; basking sharks are also protected under the Wildlife and Countryside Act 1981 (as amended). All three species are expected to occur in the area, although not in numbers that are important in a population context, especially for the limited period over which a release would take to disperse. It is not expected that a release from the cells would have a significant impact on any of these three species.

Some benthic species, such as the ocean quahog, are protected. However, as discussed above, instantaneous release of the cell contents is not expected to result in substantial interaction with the seabed and there will therefore be no significant impact on protected benthic species. This also applies to *L. pertusa*, with further discussion on that species provided within the gradual release assessment in Section 5.2.2.10.

5.3.1.10. Residual Impact

Receptor	Sensitivity	Vulnerability	Value	Magnitude
Biological features	Low	Low	Low	Minor
Rationale				
The information in the Environment Description (Section 4) has been used to assign the sensitivity, vulnerability and value of the receptor as follows. Biological features around the Dunlin Alpha installation and along the potential route of mobile oil to shore will have some tolerance to accommodate the particular effects that could result from discharges (as a result of depth in the offshore area and of refreshing of water column along the route) and sensitivity is low. As potential impacts are not likely to affect the long-term function of a system or a population, there will be no noticeable long-term effects above the level of natural variation experienced in the area and vulnerability is low. The fish populations in the project area are characterised by species typical of the northern North Sea, with some spawning and nursery regions for commercially important fish and shellfish species occurring in the vicinity of the project area. There appear to be low densities of cetaceans and seals within the project area. There are no designated or proposed sites of conservation interest in the project area. None of the survey work undertaken in the project area has identified any benthic habitats or species that are of specific conservation significance (L. *pertusa* is not considered to be naturally present in the area). Value is therefore defined as low. Modelling of the instantaneous hydrocarbon releases has indicated that water column impacts are restricted to the mid-water, in relatively close proximity to the release location. Impacts associated with a cell water release would be of short-term (< 24 hours) and would be limited to the water column 5 m above and below the release point (Xodus, 2020a). The impact magnitude is Minor due to the anticipated release of a relatively small volume of residual chemicals, hydrocarbons and sediments. There is expected to be limited potential for cumulative impacts from this anticipated release.				

Consequence	Impact significance
Low	Not significant

5.3.2. Disturbance of Drill Cuttings Deposits

5.3.2.1. Overview

Drill cuttings that are left *in situ* are expected to remain relatively undisturbed by seabed currents, and the maintenance of the 500 m safety zone around the Dunlin Alpha platform will negate disturbance by commercial trawling. However, as the CGBS begins to degrade over time, there is the possibility that the drill cuttings on the roof of the cells and around the base of the CGBS could be disturbed by falling objects. The possible re-distribution and re-settling of the cuttings following such a disturbance event has the potential to impact the benthos in the vicinity of the Dunlin Alpha substructure. The following sections provide an assessment of the potential impacts associated with long term degradation and potential disturbance of the drill cuttings pile.

5.3.2.2. Characterisation of Deposits

In their current state and with natural degradation, the release rate of the drill cuttings is anticipated to be between 0.78 – 1.75 t/year (see Appendix D). These gradual release rates are well below the threshold considered to trigger a significant environmental impact (i.e. 10 t/year) under the OSPAR 2006/5 thresholds (UKOOA, 2005).

The cuttings pile, which sits at a depth of approximately LAT - 134.5 m, has been characterised by MBES survey and core sampling methods, as detailed in Section 4.2.1.1 (Fugro, 2017a). The sediments comprising the drill cuttings pile were found to be predominantly fine sands, with some coarse and medium sand included in the core samples taken further away from the cuttings pile (Fugro, 2018). The TOC levels recorded across the survey area ranged from <0.2% to 3.11%, with the highest values recorded on the cell tops. However, the noted decreasing contamination levels with distance from the cuttings pile was inconsistent and varied based on core sample depths in addition to location. THC recordings were highest at stations close to, but not on, the cuttings pile. These ranged from 14.7 μgg^{-1} to 317 μgg^{-1} (Table 4.1), with the greatest values recorded at stations to the east and south-southeast of the cuttings pile. These samples indicated that the THC levels were slightly above background levels, and were within one order of magnitude of the UKOOA (2001) values, reflecting the presence of diesel based drilling fluids. Heavy metal concentrations, which were dominated by barium and other trace metals, also showed evidence of drilling muds, but not exceeding background concentrations as defined by OSPAR (2005) and UKOOA (2001). The structure of the drill cuttings pile is described in detail in Section 4.2.3.

5.3.2.3. Degradation of the Drill Cuttings Pile

Drill cuttings that are left *in situ* are expected to remain relatively undisturbed by seabed currents, and the proposed maintenance of the 500 m safety zone around the Dunlin Alpha installation will negate disturbance by commercial trawling (Section 5.3.2.1 covers the potential impact on commercial fisheries of exclusion from the area).

To assist in estimating environmental impacts, OSPAR has defined an 'ecological effect' threshold for cuttings piles of 50 ppm (50 µg of hydrocarbons per gram of sediment by dry weight) (OSPAR, 2006). This means that using sufficiently robust survey data, it is possible to estimate the area of a given cuttings pile which may be considered as having an environmental impact (the areas where hydrocarbon content exceeds 50 ppm), and locate the boundary outside of which the environmental impact can be considered negligible. The Dunlin Alpha cuttings pile threshold was calculated using evidence attained from MBES and chemical survey results, which was assessed using an Eiva NaviModel and a gridding method (Fugro, 2018). The spatial extent of the cuttings pile above the ecological effects threshold was calculated to be 0.671 km^2 and is shown spatially in Figure 5.6.

The undisturbed cuttings pile will continue to have an impact on the benthic community living in the sediments that make up the pile, as indicated by the reduced number of taxa described in the cuttings pile survey (Fugro, 2018). The hydrocarbon content of the pile will also have a small impact on the area immediately surrounding the 'ecological effect' boundary, as hydrocarbons gradually leach out of the cuttings and into the water column, and contaminated sediments from the cuttings pile are redistributed to the surrounding seabed by natural processes. This impact is expected to be small as evidenced by the current presence of a benthic community close to the cuttings pile that is generally species rich, diverse, homogenous and representative of the wider region as discussed in Section 4.3.1. The worst-case hydrocarbon leaching rate has been calculated at 1.75 t/yr (Fugro, 2018). This is well below the OSPAR limit of environmental significance of 10 t/yr (UKOOA, 2005).

It is possible to estimate the persistence of a cuttings pile using the area of the pile that is above the ecological effect threshold and a conversion factor presented in UKOOA (2005). This gives a persistence value in "km^2 years". A persistence of 1 km^2 year would indicate a pile of 1 km^2 persisting for 1 year and equally a pile of 0.1 km^2 persisting for 10 years. The Dunlin Alpha installation cuttings pile is expected to have a persistence of 47.4 km^2 years. The area of the cuttings pile that is above the ecological effect threshold is currently 0.671 km^2, which at a constant rate of size reduction would suggest a persistence of 70.6 years. However, the initial rate of leaching will reduce over time in line with the gradual reduction in hydrocarbon content in the pile. The majority of the hydrocarbons would therefore leach out during the first part of the degradation period, which would tail off with a small remnant cuttings pile remaining in place for much longer than 70.6 years, but releasing smaller and smaller amounts of hydrocarbon.

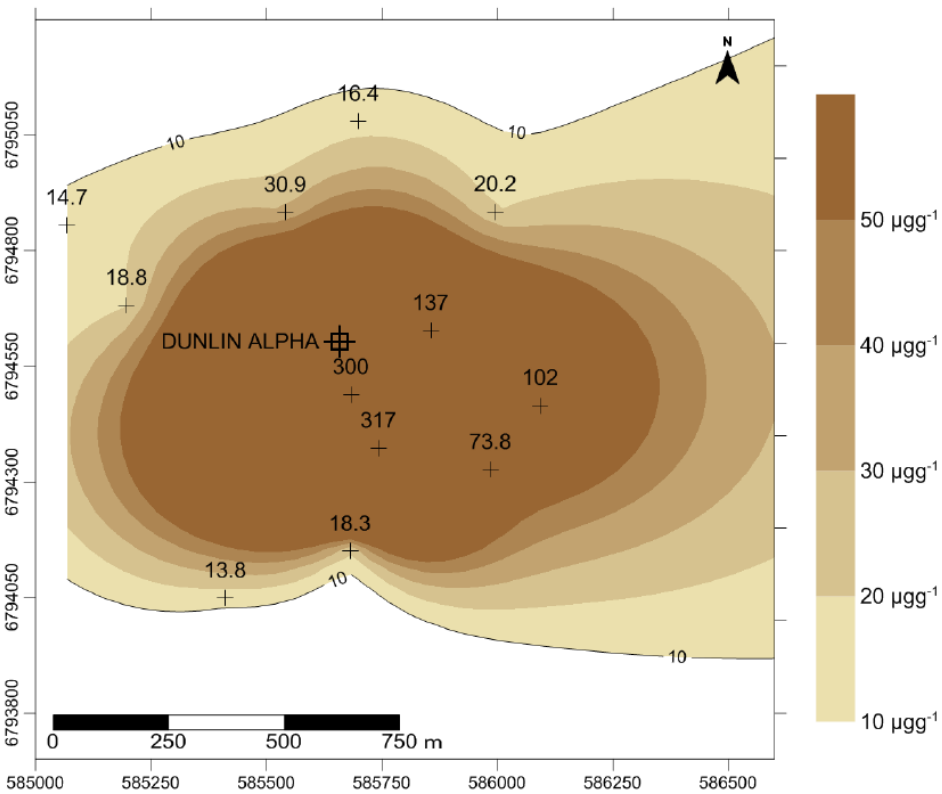

Figure 5.6 Spatial distribution of surface sediment total hydrocarbon concentrations showing 50 ppm hydrocarbon content boundary

5.3.2.4. Disturbance from Dropped Objects

Whilst the cuttings pile on the seabed and cell tops is not expected to exert a significant negative environmental impact when left *in situ*, it is possible that future disturbance of the cuttings pile on the cell tops could be caused as the CGBS begins to deteriorate and pieces fall onto the cuttings pile that remains on the top of the cells. As described in Section 2.3.3.3, the failure of a transition is considered to be worst-case in regard to a dropped object with an estimated impact energy of 10 – 15MJ (Atkins, 2017b), although it is likely that numerous smaller impacts will also disturb the drill cuttings pile over time. The roof of the CGBS base caisson is expected to degrade very gradually, taking in excess of 1,000 years before there is significant structural failure which could result in the disturbance of any drill cuttings that remain at that time (disturbance of the drill cuttings at this time would have extremely limited impact, given the calculated persistence of 70.6 years).

Each time a piece of infrastructure falls into the cuttings pile on top of the roof of the cells, cuttings material is likely to be re-suspended into the water column. The specific degree of re-suspension is not quantifiable without detailed analysis due to the large number of variables at play including: shape and orientation of falling objects; the energy that might be absorbed by deformation of the falling object on impact; and the degree of cementation of the cuttings pile and its consequent structural strength. In addition, the timing of materials falling onto the cuttings pile will determine the potential for impact from any redistribution, since the cuttings pile will degrade over time; the later that a dropped object lands on the cuttings pile, the further degraded will be the constituents of the cuttings pile.

Despite the uncertainties regarding the exact method and timing of interaction between a falling object and the cuttings pile, modelling has been undertaken to quantify the potential impact on the marine environment. Details of the modelling undertaken, including the software and input data, are provided in Appendix D. Although the results of modelling cannot be directly substituted for observed impacts occurring during an actual dropped object event, it is a useful tool to help assess the magnitude of risk that is posed.

To account for uncertainties, modelling was conducted under three scenarios, considering disturbance of 1%, 5% and 10% of the total cell top cuttings pile volume, as described in Appendix D. As a worst-case, the modelled thickness of the deposited drilling mud disturbed during the 10% cell top cuttings pile dropped objects scenario is presented in Figure 5.7. This represents the impact associated with a fallen transition piece, previously described in Section 5.3.1.2.

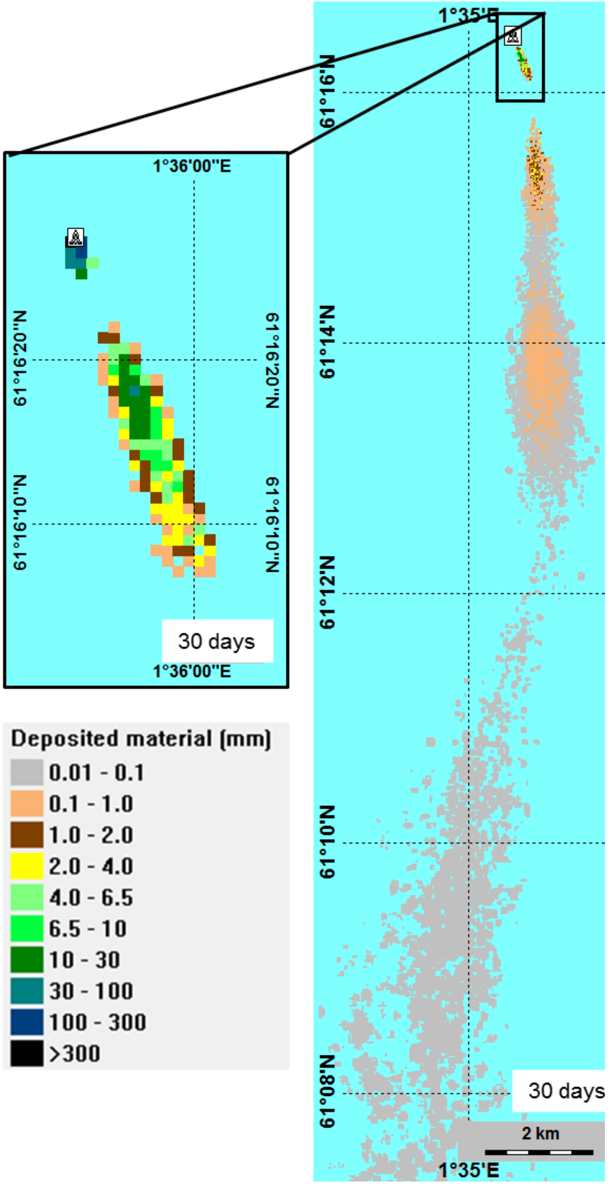

Figure 5.7 Accumulation of redistributed cuttings on the seabed

The result of the worst-case 10% disturbance scenario indicates that the predicted drill cuttings distribution immediately around the CGBS will be a maximum of approximately 100 – 300 mm in thickness. The cuttings pile thickness is predicted to decrease rapidly as the distance from the CGBS increases. At approximately 1 km from the CGBS the cuttings thickness decreases to a maximum of approximately 1 mm thick. Wider scale deposition of small amounts of finer material are also predicted by the modelling, but the amount of material deposited is likely to be very small (less than 0.1 mm thick) and distributed over a large area (several kilometres) such that it would not be readily detectable.

Further to the spatial extent of cuttings redistribution, the modelling also calculates an Environmental Impact Factor (EIF). EIFs are a relative measure of risk to the biota in the marine environment and are a common approach used in environmental modelling. They are calculated using the PEC / PNEC approach introduced in Section 5.3.2.2 and explained further in Appendix D.

Modelling of the worst-case release scenario predicted an EIF value of 12.4, corresponding to a seabed area of approximately 0.12 km^2 over which some degree of environmental impact is expected immediately following the release. The area subject to impact is predicted to decline to approximately 0.08 km^2 after one year and approximately 0.04 km^2 after 10 years. The area impacted will continue to decline over subsequent years (Appendix D).

The existing extent of the seabed and cell tops cuttings pile which exceeds the ecological effect threshold is 0.671 km^2. As such, the 0.12 km^2 predicted to be affected by cuttings disturbance does not represent a substantial additional impact. Some of the 0.12 km^2 area predicted to be affected by cuttings disturbance likely falls within the existing 0.671 km^2 impact area. Disturbed cuttings re-settling onto the existing cuttings pile are likely to impact the seabed to a lesser degree than those falling on seabed areas not previously contaminated with cuttings.

In addition to potential impact on the seabed, the model also provides estimates of interaction with the water column. As with sediment EIF, a water column EIF of >1 can be considered the threshold at which impact may begin to occur. Modelling of the worst-case release predicted that an EIF >1 will occur over an area that extends, at its peak, approximately 40 km from the Dunlin Alpha installation, but which is limited to depths of greater than 100 m. Although the spatial extent of the water column impact is greater than that for sediment, water column impacts typically persist for a shorter period. The modelling indicates that up to 2 km^3 of the water column will be impacted by the worst case release (Appendix D), but the water volume affected will decrease to zero within approximately 14 days of the disturbance event (Appendix D). No further impact on the water column is expected beyond this time.

5.3.2.5. Disturbance from Unplanned Overtrawling

The *in situ* decommissioning of the Dunlin Alpha substructure includes the maintenance of the 500 m facilities safety zone, which will limit potential interactions with the remaining drill cuttings which fall within the zone. However, there is some potential that commercial fisheries operating within the adjacent waters could have gear which enter the 500 m zone and disturb the cuttings piles, particularly if the safety zone is removed at a future point.

In order to investigate the potential environmental impacts associated with an unplanned disturbance of the cuttings pile, a Legacy Environmental Impact Modelling Report (Xodus, 2020a) was undertaken in which the Shell Model methodology used for Shell Brent decommissioning was adopted (Shell, 2017). The Shell Model is a technique for finding the volume of solids of revolutions by considering vertical slices of the region being integrated rather than horizontal ones, thereby greatly simplifying problems where the vertical slices are more easily described (Kahn *et al.*, 2019).

The size of the initial cuttings pile was taken from a recent drill cuttings pile survey, which found the area of coverage to be 4,084 m^2 on top and adjacent to the CGBS (Fugro, 2017b). The proportion of cuttings disturbed by trawling was assumed to be 10% of the total. This assumption is based on the methodology in Shell (2017) and results in a calculated cuttings release mass of 2,338.74 tonnes which, at a density of 2.4, equates to a volume of 954.5 m^3 (Xodus, 2020a).

Time-series modelling was then used to predict the water column and seabed impacts of an unplanned trawling event at the Dunlin Alpha cuttings pile. The modelling suggested that any impacts to the water column will be short term, with no discernible differences in water quality after 5 days (Xodus, 2020a). Furthermore, location-based sediment thickness modelling indicated that beyond 200 m from the release location, the thickness of the deposited material is not expected to exceed 10 mm and beyond 1.3 km from the release location, the thickness is not expected to exceed 1 mm (Xodus, 2020a). The time-averaged risk to benthic fauna was shown to be negligible, except potentially very close to the release point, based on remodelling using a finer-scale spatial resolution (Xodus, 2020a). In such a case, impacts to the wider benthic community would still be considered, negligible, however. Overall, the modelling predicted that overtrawling of the drill cuttings pile will result in small-scale, short term impacts on the water column, and negligible impacts on the seabed sediments.

Modelling conducted by DNV (reported in OSPAR, 2009a) estimated that of drill cuttings material disturbed by trawling events (an analogous impact mechanism to objects being dropped on the cuttings pile), 96.7% would immediately re-settle without becoming suspended in the water column. 3.3% of the disturbed drill cuttings would become suspended, with 2.47% re-settling within the existing accumulation area and only 0.83% re-settling outside of the existing accumulation area.

Assuming as a worst case that the entire volume of the cuttings pile was disturbed in a single event (and not taking into account any degradation of the cuttings pile between now and the disturbance event) this would represent a disturbance of 10,200 m^3 of cuttings. If the modelling assumptions for the DNV modelling are also representative of this scenario, approximately 9,863.4 m^3 of cuttings would re-settle immediately and 336.6 m^3 would become suspended, of which 251.94 m^3 would re-settle within the original accumulation area and 84.66 m^3 would re-settle outside the existing accumulation area. Such limited redistribution is also apparent in the modelling results presented above.

The limited extent of redistribution and impact predicted by the modelling is further corroborated by the observations of several instances of actual cuttings pile disturbance reported in OSPAR (2009a), which were as follows:

- High intensity overtrawling of a cuttings accumulation in 70 m water depth resulted in spread of contamination, but not at a rate likely to pose wider contamination or toxicological threats to the marine environment;
- Dredging of the North West Hutton platform cuttings pile (including repeated dredge backflushes resulting in significant re-suspension of cuttings material) showed:
  - Drifting of re-suspended material was low during operations;
  - Hydrocarbon concentrations on dredged cuttings were similar to those on undisturbed cuttings, and while levels of alkylphenol ethoxylates and barium were higher in the dredge-recovered water at the platform topsides, hydrocarbon levels in the water remained low, indicating that the majority of hydrocarbons remained bound to the cuttings and did not become free in the dredged water;
  - Corroborating the above, hydrocarbons were not increased significantly in the seawater samples from monitoring stations as a result of the dredging, and there was no detectable oil in the plumes generated during the trial; and
  - There were no visible indications of an oil sheen at the surface, and little discernible effect was seen in the water column more than 100 m from the dredging operations.
- Use of high-pressure water jets to clear oil-based mud cuttings from the Hutton Tension Leg platform, causing significant re-suspension of cuttings, had no major effect on the spatial distribution of cuttings contamination, or on biological communities located more than 100 m from the original platform location.

These observations indicate that extensive disturbance of North Sea cuttings piles has tended to result in limited spreading of contaminated material to the seabed surrounding the cuttings piles, and limited discernible environmental impacts. The investigations at North West Hutton and the Hutton Tension Leg platform suggest that release of hydrocarbons into the water column from disturbed drill cuttings is minimal, and the majority of hydrocarbons present would remain bound to the cuttings (OSPAR, 2009a). Based on these conclusions, the likely impact of disturbance to the Dunlin Alpha installation drill cuttings pile is assessed below.

5.3.2.6. Environmental Vulnerability to Drill Cuttings Disturbance

Fugro (2017; 2018) indicate that the drilling fluids present around the Dunlin Alpha installation are a mixture of diesel, low toxicity oil based fluids and synthetic fluids. Toxicity of synthetic-based mud to benthic organisms is, as summarised by Neff *et al.* (2000), generally low. Neff *et al.* (2000) conclude that a proportion of observed harmful effects are probably due to nutrient enrichment and subsequent anoxia in affected sediments. Hydrocarbon concentrations in the surface layer of the Dunlin cuttings pile range from average 300 $\mu g g^{-1}$ to 146,000 $\mu g g^{-1}$. These concentrations exceed the concentrations expected to cause toxic effects on the benthos (Neff *et al.*, 2000; OSPAR, 2006). The term 'total hydrocarbon content' incorporates all types of hydrocarbon material, and toxic effects vary widely within the hydrocarbon grouping. Groups that tend to cause toxicity include PAHs.

The OSPAR Coordinated Environmental Monitoring Programme (CEMP) identified nine PAHs of specific concern. Fugro (2018) reported that maximum concentrations of these nine PAHs across the cuttings at the Dunlin Alpha installation typically exceeded Effects Range Low (ERL) concentrations, indicating toxic effects may be expected. Trace element (heavy metal) concentrations were also generally elevated above ERL concentrations. These results from the surface of the cuttings accumulation were generally in line with those from other North Sea cuttings accumulations.

Benthos

The macrofaunal community of the cuttings pile at the Dunlin Alpha installation is considered to be impoverished, with reduced numbers of taxa and a high abundance of the hydrocarbon-tolerant *Capitella* sp. (Fugro, 2018). Statistical analysis indicated that proximity to the cuttings pile and variation in sediment particle size, sediment lithium content and total hydrocarbon content best explained the variation in the benthic community (Fugro, 2018). These results suggested that the cuttings have the potential to impart toxic impacts if spread outside the existing accumulations by decommissioning activities, and this is borne out by the modelling results (both the spatial distribution and the sediment EIF, which shows the majority of the risk is presented by the chemical constituents of the pile).

Outside of the actual cuttings accumulations, the macrofaunal community was similar to that found in the wider area, and the majority of the dominant species were considered to be hydrocarbon intolerant (Fugro, 2018). This suggests that the faunal community surrounding the cuttings pile is reasonably stable and tolerant of the contaminants in the area. It is therefore likely that re-settling of small amounts of cuttings around the fringes of the existing accumulation will not cause community level changes through toxicity. Again, this is reflected in the limited spatial extent of the predicted impact from cuttings redistribution.

As such, whilst disturbance of the accumulation is predicted by modelling to distribute contaminated material over a small additional area, it is deemed unlikely to result in significant toxic effects beyond that which will be experienced by individuals, especially when considering that large scale disturbance events (such as the Hutton Tension Leg platform operations described above) have been found to have no major effect on the spatial distribution of cuttings contamination, or on biological communities located more than 100 m from the disturbance location (OSPAR, 2009a).

IOGP (2016) reports a threshold drilling fluid/cuttings burial depth causing mortality of benthic organisms of 6.5 mm. Modelling suggested that disturbance of the Dunlin Alpha cuttings pile could cause burial of the benthos to depths greater than 6.5 mm within a few hundred metres of the Dunlin Alpha installation. There may be some impact on the benthos from burying if a sufficiently large disturbance event occurs, but this is expected to be local, and recovery is expected to be around a year following the disturbance event (as supported by the one off nature of the redistribution and of the rapidly declining sediment EIF). This is supported by the presence of a benthic community near to the Dunlin Alpha installation (but not on the cuttings pile itself) that is representative of the wider area, despite being routinely subjected to oil-based drill cuttings discharges up until 2001.

In addition to toxicity and burial, drill cuttings can impact the benthos through anoxia caused by a combination of organic enrichment (which increases the biochemical oxygen demand) and introduction of fine sediments (which restricts oxygen penetration into sediments). The survey field logs indicate the grab samples from the cuttings accumulation were anoxic below the surface, with a characteristic odour of hydrogen sulphide. Laboratory analysis showed that the Total Organic Matter (TOM) content of the samples taken from the surface of the cuttings accumulation was elevated compared to samples taken outside the cuttings accumulation.

Cuttings material that re-settles following a re-suspension by a disturbance event is likely to be fine, and unconsolidated (since coarser and/or consolidated material is unlikely to be re-suspended). It will settle gently and therefore there is likely to be oxygenated water in the pore spaces initially. It is not expected to form an effective barrier to oxygen penetration from the surrounding seawater. In addition, the act of re-suspension is likely to partially re-oxygenate the material. Outside of the deeper areas of cuttings re-settlement, the infauna is expected to burrow back to the surface and assist in re-working the sediment.

OSPAR (2009a) suggests that spreading of cuttings material will encourage aeration and degradation of cuttings material. Whilst there is potential for cuttings disturbance to promote organic enrichment in the surrounding sediments, the scale of this impact is expected to be limited and is not expected to cause anoxic conditions. The amount of material that will be re-distributed is unlikely to be sufficient to produce an effective oxygen barrier between the seabed and the surrounding seawater, or to prevent infauna from reaching the surface and re-working the sediment. The sediment EIF development (Appendix D) appears to corroborate this, showing almost no contribution to impact from lack of oxygen.

In conclusion, the small amount of material likely to be moved outside the existing cuttings accumulation area, the tolerance of the fauna to low levels of toxicity, and the limited potential for smothering and anoxia suggest there will be no significant impacts on the benthos from disturbance of the cuttings accumulation that is predicted by the modelling.

Plankton

IOGP (2016) cites a number of sources indicating the impacts of drill cuttings discharge on plankton are negligible. Recorded deleterious effects on phytoplankton are generally attributed to light attenuation due to suspended solids. The majority of the disturbed material is expected to re-settle almost immediately, and material disturbed at the seabed is predicted by the modelling to be unlikely to interact with the photic zone (Appendix D). No impact on plankton is therefore expected.

Fish

Neff *et al.* (2000) reports that synthetic-based fluids have very low toxicity to fish, and do not bioaccumulate meaning there is no risk of SBM being concentrated in the food chain. The diesel and LTOBM material may be toxic since many of the toxic components (such as aromatics) remain present at levels exceeding ERL concentrations. However, OSPAR (2009a) indicates that hydrocarbons are likely to remain bound to sediments rather than become free in the water column and therefore pathways for toxic components into fish are likely to be limited. The most significant effect on fish is interference with feeding behaviour due to increased sediment load in the water column. Impact from increased sediment load as a result of the proposed activities is predicted by the modelling to be short-term (likely to peak at a maximum of around 5 days after the disturbance event).

Seabirds

The most familiar effect of oil pollution on seabirds is the contamination of plumage, resulting in flightlessness and lack of insulation, compounded by ingestion of toxins through preening during attempts to remove contamination. The decommissioning of the Hutton Tension Leg platform and the large-scale disturbance of the cuttings accumulation resulted in no visible surface sheen. The modelling of Dunlin Alpha installation drill cuttings disturbance indicated that disturbed sediments and associated contaminants would remain within the lower portion of the water column (Section D 4.2.5) beyond the diving capability of most seabirds. No impact on seabirds is therefore expected.

Marine Mammals

There is little published data available on the impacts of synthetic-based fluids on marine mammals. The available data on other fauna suggests that synthetic-based fluids are low in toxicity and non-bioaccumulating. Fugro (2018) indicates toxic components of the diesel and LTOBM are still present at concentrations exceeding ERL. Since the majority of the drilling fluid disturbed by the proposed activities is expected to remain bound to the drill cuttings particles, which are expected to re-settle close to the original cuttings accumulation (as shown in Figure 5.7), marine mammals in the area will experience minimal exposure. Furthermore, suspended material is expected to remain in the lower portion of the water column and to settle quickly following disturbance (no further impact will be exerted to the water column after 14 days). Therefore, no impact on marine mammals is expected.

5.3.2.7. Mitigation Measures

The following mitigation measures have been identified to limit potential impact from drill cuttings disturbance:

- A navigational aid will be installed on top of one of the steel transitions to visibly show the location of the structure and drill cuttings to other sea users, reducing the potential for damage to occur;
- The top of each transition will be sealed to prevent the ingress of seawater, reducing corrosion activity and increasing the longevity of the structures;
- Standard notifications and notice to mariners will detail the presence of the drill cuttings and associated 500 m safety zone;
- Annual visual assessment of navigational aid and transition condition undertaken by the NLB;
- Admiralty charts and the FishSafe system will be updated to show the location of the drill cuttings; and
- Retention of the 500 m safety zone. This will exist until the point that the surface structures have collapsed below the water line, at which point it is expected that the safety zone would be renewed on the basis of it being a subsea structure.

In addition, the concrete legs are predicted to crumble rather than collapse, reducing the likely scale of individual cuttings disturbance events.

5.3.2.8. Cumulative Impact Assessment

It is important to consider the potential for impact to arise from unplanned disturbance of the drill cuttings in conjunction with similar events occurring as part of other projects or activities in the area. Given the limited spatial extent of the drill cuttings distribution and the extremely limited depth of deposition, settling of disturbed cuttings will not occur with sufficient depth to accumulate on existing cuttings piles from other assets. There will likely be disturbance of other drill cuttings in the wider northern North Sea in the coming years during which the Dunlin Alpha cuttings pile persists. Assuming redistribution of such cuttings occurred with a similar extent as predicted for Dunlin Alpha, sediment deposition would be unlikely to extend as far as the footprint of the Dunlin Alpha cuttings pile. It is therefore considered that cumulative impacts will not arise from concurrent or sequential disturbance of drill cuttings.

In addition, significant cumulative impacts resulting from the disturbance of drill cuttings and a release of cell contents, as a result of an early transition failure, are unlikely to occur. The drill cuttings pile provides protection for the CGBS cell contents, acting as a buffer to absorb the energy impact and prevent or limit the extent of a loss of containment. The potential for impacts resulting from disturbance of the drill cuttings pile will also be significantly reduced by the time of the anticipated transition failure.

Gradual cell contents release may also be considered for cumulative impacts with unplanned drill cuttings disturbance. The modelling results presented in Xodus (2020a) demonstrate that neither the disturbance of drill cuttings nor the release of cell water would increase the quantity of surface oil resulting from a worst-case impact. Consequently, there would be no cumulative impacts on shoreline oiling or beaching, or designated sites, due to concurrent gradual and instantaneous release scenarios.

Decommissioning of the Dunlin Alpha installation may overlap temporally and geographically with subsea decommissioning activities in the Dunlin area. The overlapping execution of these projects could result in higher than normal vessel densities in the area, increasing the risk of a dropped object hitting the drill cuttings. Mitigation measures, including identification and management of simultaneous operations (SIMOPS) and use of Automatic Identification System, are considered to reduce this additional risk to as low as reasonably practicable.

5.3.2.9. Transboundary Impact Assessment

Seabed impacts are not expected to reach the transboundary line (11 km to the east). Impacts on the water column are expected to be extend up to 40 km from the disturbance point, however the modelling indicates that the majority of the water column impact will occur to the south of the disturbance point, rather than approaching Norwegian waters to the east. In addition, plankton, fish and marine mammals are expected to have low sensitivity to drill cuttings disturbance, and there is no impact mechanism for seabirds as the cuttings will remain in the lower water column. As such, significant transboundary impacts are not expected.

5.3.2.10. Protected Sites and Species

Protected Sites
As outlined above, disturbance of the drill cuttings will result in spatially limited potential impacts and, given the location of the Dunlin Alpha installation, no impact on protected sites is expected.

Protected Species
The ocean quahog is on the OSPAR list of threatened or declining species and is a PMF. This species is known to occur in the area at low densities as detailed in Section 4, although the area is not thought to be particularly important for the species. Ocean quahog is a benthic species, and therefore there is the potential for slight impact in the event of a drill cuttings release. However, the volumes are small and as detailed in Section 4.3.1, there are found to be limited numbers of ocean quahog in the area, it is considered unlikely that any disturbance of the drill cuttings would have a significant impact on the ocean quahog population in the area.

5.3.2.11. Residual Impact

<table>
<tr><th>Receptor</th><th>Sensitivity</th><th>Vulnerability</th><th>Value</th><th>Magnitude</th></tr>
<tr><td>Benthos</td><td>Low</td><td>Low</td><td>Low</td><td>Minor</td></tr>
<tr><td>Other features of the seabed, water column and sea surface</td><td>Low</td><td>Low</td><td>Low</td><td>Minor</td></tr>
<tr><th colspan="5">Rationale</th></tr>
<tr><td colspan="5">Direct impacts may occur in the event of a release such as impacts to benthic species, those in the water column and oiling of seabirds at the surface. Impacts are expected to be short-term and local, although there is a low probability of a localised transboundary impact. The frequency of the impact is expected to be a one-off. The likelihood of an instantaneous release of drill cuttings through disturbance is considered very low.

The likelihood that the receptors (benthic species and seabirds) will be in the area in the event of a release is considered high, although the number of seabirds present is expected to be low during most months. Taking this into account, the impact magnitude for benthos and other marine receptors is minor.

Data on sensitivity of the dominant benthic species present in the area is sparse, but there is good data on the sensitivity of the biotope complexes present. Biotope tolerance (resistance) to direct disturbance ranges from medium to low and ability to recover or adapt ranges from high to medium. Tolerance is therefore characterised as low and ability to recover as medium, giving a receptor sensitivity of low.

The impact is not likely to affect long term function of the benthic system or the status of the benthic population. There will be no noticeable long-term effects above the level of natural variation experienced in the area. Receptor vulnerability is therefore deemed to be low.

The impact area contains small numbers of ocean quahog, which is listed on the OSPAR (2008) List of threatened and declining habitats and species. However, only three juvenile individuals were identified in</td></tr>
</table>

three of the 30 grab samples recovered from the area, indicating the area is not currently important for the species. Apart from ocean quahog there is no specific value or concern about the site, which supports biotopes that are abundant across the wider area. The value of the receptor is therefore deemed to be negligible.

Potential impacts on local seabed sediments would be predominantly due to the redistribution and resettlement of drill cuttings, with the majority of drill cuttings deposited on the existing cutting pile. Modelling results from hydrocarbon and cell water releases indicate that there would be no cumulative impacts on the local seabed sediments (Xodus, 2020a).

In addition, the modelling results have demonstrated that neither the disturbance of drill cuttings nor the release of cell water would increase the quantity of surface oil resulting from a worst-case impact. As a result, there would be no cumulative impacts on shoreline oiling or beaching and no cumulative impact on designated areas (Xodus, 2020a).

The impact is expected to be temporary, with recovery occurring relatively quickly. The seabed in the area is reasonably homogenous, and the available habitat is extensive, with any potential impact affecting a small proportion of the total available habitat. The geographical extent of the impact is therefore deemed to be local.

Consequence	**Impact significance**
Low	Not significant

6. Conclusions

Options for decommissioning the Dunlin Alpha substructure have been assessed through the CA process, in accordance with OSPAR Decision 98/3 and the OPRED decommissioning guidelines. Study work has revealed that there are significant technical and safety challenges associated with cutting the concrete legs, and full removal of the substructure is anticipated to require up to 40 years of subsea cutting and removal activities. The CA process has recommended that decommissioning the substructure *in situ* with legs up and installation of a navigational aid is the preferred decommissioning option.

As a result of low solids loading rates in the production fluids, low wax deposition rates, and successful operations to recover over 97% of the mobile oil from the storage cells, the residual hydrocarbon inventory is considered small. Fairfield has undertaken an extensive review of the cell contents and identified options for further recovery of the residual materials. The review has concluded that, due to the complex design of the substructure, any recovery option would have limited efficiency, and the only option to remove the residual contents completely would require the full removal of the substructure itself. While some further recovery may be possible, it is considered highly unlikely that this would reduce future environmental impacts. Further recovery would, however, result in additional atmospheric emissions and unavoidable marine discharges associated with recovery operations, as well as increase the likelihood of an instantaneous release. The CA process has recommended that decommissioning the cell contents *in situ*, with no further recovery, is the preferred decommissioning option.

Fairfield has identified potential environmental impacts resulting from the proposed decommissioning option and acknowledged that legacy impacts associated with decommissioning the residual storage cell contents and drill cuttings *in situ* are key stakeholder concerns. In accordance with OPRED decommissioning guidance, Fairfield has undertaken an EA on the proposed decommissioning operations, including legacy impacts. The following issues were identified as requiring further assessment and discussion within this environmental appraisal report.

- Loss of access by the permanent phyiscal presence of the CGBS decommissioned *in situ.*
- The gradual release of cell contents as the CGBS degrades over time;
- An event resulting in an instantaneous release of the cell contents; and
- An event resulting in disturbance of the drill cuttings pile

As there is a safety zone around the Dunlin Alpha installation which has been in place for over 40 years and fishing intensity in the area is low, there is not deemed to be a significant impact from the installations physical presence or its changing state. Releases of any residual contents were assessed under separate assessments. The following is a list of the proposed mitigation measures associated with minimising any potential impact form the physical presence of the substructure post decommissioning:

- Standard notifications and notice to mariners will detail the presence of the structure and the associated 500 m safety zone;
- Admiralty charts and the FishSafe system will show the permanent location of the Dunlin Alpha CGBS, and Kingfisher Bulletin and Notices to Mariners will be updated;
- A navigational aid will be installed on top of one of the steel transitions to visibly show the location of the structure and drill cuttings to other sea users. The top of each transition will be sealed to prevent the ingress of seawater, reducing corrosion activity and increasing the longevity of the structures;
- Annual visual assessment of navigational aid and transition condition undertaken by the NLB;
- Replacement of the navigational aid will be undertaken on a 4-yearly basis; and
- Provisions will be made to the Fisheries Legacy Trust Fund Limited (FLTC) via monetary contributions to improve safety information available to fishers.

The gradual release of residual material within the structure as it degrades may impact species in a highly localised manner. Releases are anticipated to be intermittent and discrete; unlikely to cause long-term impacts or result in any significant population level effects. There are no designated or proposed sites of conservation interest within the project area and no species or habitats of conservation significance were recorded further reducing the risk of any significant impact. The Attic Oil Recovery Project is the key mitigation measure that has been implemented in terms of reducing the potential for long-term impact from release of the cell contents.

In addition to this mitigation measure, there are inherent reasons why the potential impact is limited, such as: the waxy residues being strongly bonded to the walls thereby hindering instantaneous release; cell contents being highly compartmentalised, which limits circulation of the cell contents which have the potential of being released from any ingress to the structure; cell geometry reducing the likelihood of falling debris potentially piercing the cells; and the fact that the concrete legs supporting the structure are predicted to crumble rather than collapse (as detailed in Section 2.3.3.3). As such, Fairfield considers that implementation of further mitigation measures is not necessary.

As the substructure eventually degrades, any residual material will be released. However, the volumes of this material are not significantly large enough to cause impact to the environment far from the immediate vicinity of the substructure. As a result, any impact is expected to be localised and will dissipate over time. The majority of any material will be deposited within the 500 m safety zone radius. As discussed above, there are no species or habitats of conservation importance in the local vicinity so any impact will have negligible affects to species at the population level in this region of the North Sea.

Drill cuttings that are left *in situ* are expected to remain relatively undisturbed by seabed currents, and the proposed maintenance of the 500 m safety zone around the Dunlin Alpha installation will negate disturbance by commercial trawling. In their current state and with natural degradation, the release rate of the drill cuttings is anticipated to be between 0.78 – 1.75 t/year. These gradual release rates are well below the threshold considered to trigger a significant environmental impact (i.e. 10 t/year) under the OSPAR 2006/5 thresholds (UKOOA, 2005).

To minimise any potential for impact, Fairfield propose the following mitigation:

- The top of each transition will be sealed to prevent the ingress of seawater, reducing corrosion activity and increasing the longevity of the structures;
- A navigational aid will be installed on top of one of the steel transitions to visibly show the location of the structure and drill cuttings to other sea users.
- Standard notifications and notice to mariners will detail the presence of the drill cuttings and associated 500 m safety zone, and Admiralty charts and the FishSafe system will be updated;
- Annual visual assessment of navigational aid and transition condition undertaken by the NLB;
- Retention of the 500 m safety zone. This will exist until the point that the surface structures have collapsed below the water line, at which point it is expected that the safety zone would be renewed on the basis of it being a subsea structure.

A review of each of the potentially significant environmental interactions has been completed and, considering the extent of potential interaction with receptors, there is expected to be no significant impact on receptors. As part of this review, cumulative and transboundary impacts have also been assessed and determined to be not significant.

The Dunlin Alpha installation is located a substantial distance from designated sites; the closest is the Pobie Bank Reef SAC, designated due to the presence of reefs, which is 98 km to the southwest. Consideration of the potential impact on protected sites in the wider vicinity has been considered in the assessment. Having reviewed the project activities, there is not expected to be a significant impact on any protected sites.

Finally, this environmental appraisal has considered the objectives and marine planning policies of the National Marine Plan across the range of policy topics including biodiversity, natural heritage, cumulative impacts and oil and gas (Scottish Government, 2015). Fairfield considers that the proposed decommissioning activities are in broad alignment with such objectives and policies.

In summary, the proposed operations have been rigorously assessed through CA and environmental appraisal processes, resulting in a set of selected decommissioning options which are considered to present the least risk of environmental impact whilst satisfying safety risk, technical feasibility, societal impacts and economic requirements. The information used to undertake the assessments is based on evidence gathered from operational records, analysis of historical records, analogous data and/or the application of proven scientific principles. Conservative assumptions and worst-case release scenarios have been considered and it has been concluded that impacts associated with the proposed decommissioning option will not result in any significant environmental impacts.

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Appendix A – Characterisation of Cell Contents

This appendix describes the methodology and data used to characterise the composition, quantity and distribution of the residual contents within the CGBS storage cells. The methodologies were initially developed by METOC, in consultation with external stakeholders, and extensively reviewed and updated from 2017 - 2020. Full details of the cell contents characterisation and inventory basis can be seen in the Cell Contents Technical Report (Fairfield, 2021a).

Information regarding uncertainty associated with the input data and how these have been addressed is also provided. For consistency, the following terms are used to define certainty and the level of variation associated with that term.

Terminology	Description	% Variation in Inventory
Low	Estimate derived from data that is fairly accurate and using a methodology that is also well defined.	+/- 10%
Moderate	Data partially defined, but gaps filled with assumptions or analogous data that is assessed to be representative.	+/- 30%
High	Data is less well defined and broad assumptions or use of analogous information has been necessary in order to characterise the contents.	+/- 50%

A.1 Free Gas

A.1.1 Composition

The composition of free gas has been determined by use of manual sampling and an online analyser, and was found to vary across the four cell groups. Free gas within the CGBS storage cells is considered to made up of the following:

- Residual carbon dioxide left behind upon completion of the AORP;
- Gases created through biological breakdown of the residual hydrocarbons under both aerobic and anaerobic conditions, predominantly carbon dioxide and hydrogen sulphide;
- Light end hydrocarbons from the historically processed oil that was transferred to storage could exist if the oil was not properly stabilised to reduce the oil vapour pressure; and
- Hydrocarbons, which have weathered over time, and diffused light ends from the residual oil layer and the floor or wall deposits.

A.1.2 Quantification

Pressure build-up in the rundown lines required the gas within the cells to be vented safely; this involved the installation of flow metering, online gas analysers, and pressure transmitters for each cell group. As a result, the total volume of free gas within the cell groups has been determined based on physical evidence of the pressures within the system, the composition of the gases, and the actual geometry of the structure and pipework. The pressure in the cell tops is approximately 4 barg due to the hydrostatic pressure from the standpipe when it is at a level of +70m.

Table A1 Summary of free gas inventory

Cell Group	No of Cells	Free Gas Volume (Am^3 @approx. 4 barg)
A	20	1,642
B	20	2,352
C	19	1,571
D	16	1,261
Total	**75**	**6,825**

A.1.3 Distribution

Whilst it is expected that the gas is fairly evenly distributed within a cell group, there are some cells that contain more gas than others (Figure A1). The variation in the gas quantities can be explained in a number of ways:

- The cells with domed tops will have a larger free gas volume than those underneath the legs, which have flat tops; and
- The outer edge and corner cells physically have smaller attic volumes and therefore will have a smaller free gas volume.
- Cell Group B has a narrower outlet for the gas, due to the mechanical plug and umbilical set within the rundown line. Therefore the gas within these cells is deeper.
- There is no gas within the conductor cell group as these cells were not used for oil storage and the interconnections are near to the bottom of the cells meaning that the gas cannot migrate into these cells.

As well as a distinct gas cap within the tops of the cells, there will also be appreciable volumes of gas dissolved in solution in both the residual oil and water phases. The free gas phase and the gas in the liquid phases are in equilibrium with one another.

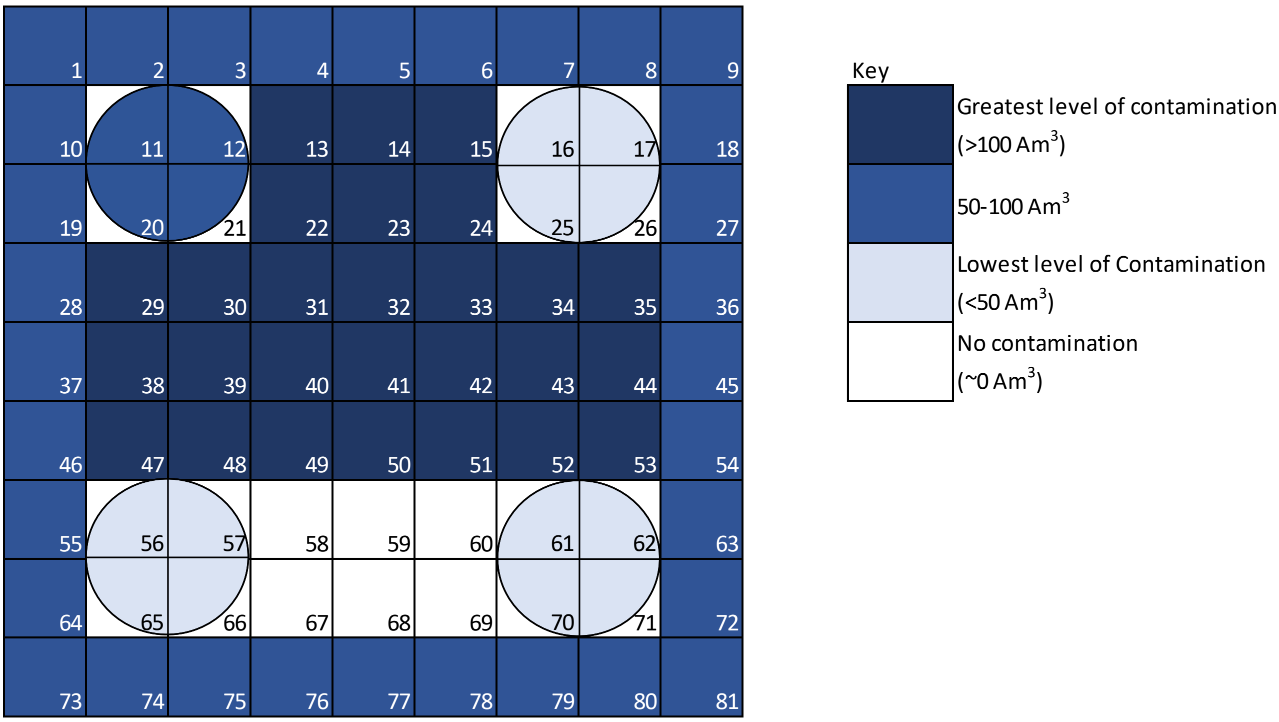

Figure A1 Distribution of gas contamination within the storage cells

A.1.4 Summary

Table A2 provides a summary of how the gas characteristics vary from cell to cell.

Table A2 Gas characteristic variation from cell to cell

Parameter	Units	Minimum	Maximum
Free Gas Volume (@ approx. 4barg)	Am^3	30	138
Maximum depth of Gas in Attic Space	m	1.0	2.6
Carbon Dioxide (CO_2) Concentration	Vol%	2	95
Light End Hydrocarbon Concentration	Vol%	4	96
Hydrogen Sulphide (H_2S) Concentration	ppm	91	>10,000

A.1.5 Uncertainty

Table A3 provides a summary of the input data used to characterise the free gas in the CGBS storage cells.

Table A3 Summary of input data used for free gas characterisation

<table>
<tr><th>Data Source</th><th>Relevance</th><th>Uncertainty</th><th>Environmental Consequence</th></tr>
<tr><td>Attic Oil Removal Project (AORP) Pumping and Cell Pressure Records</td><td rowspan="2">These data sets have been used to estimate the composition and volume of gas across the cells.</td><td rowspan="3">Low uncertainty with the distribution of free gas within the cells as there is evidence of the gasses migrating along the rundown lines filling the high point in the rundown line pipework. Large volumes of gas extracted suggest that the gas in the cell group is all in communication with each other via the upper ports in the cells.

Moderate uncertainty with the total volume of gaseous products within the cells (total free gas and gas dissolved in solution within the liquid phases). This is due to inconsistencies with the pumping records and accuracy of the metering systems during the original AORP operations.</td><td rowspan="3">Although there is some uncertainty on the total volume of gas present (free gas and dissolved). This should not pose a significant risk to the environment as any increase in emissions would dissipate rapidly and become almost unmeasurable outwith the immediate vicinity.</td></tr>
<tr><td>2018 – 2020 Topsides Based Survey and Sample Activities:
-Cell pressure records
-Venting operation records
-Manual and online gas analysis</td></tr>
<tr><td>Dunlin Alpha base caisson schematic diagrams</td><td>Schematics have been used to calculate volumes of free gas.</td></tr>
</table>

Although there is some uncertainty around the total volume of gas present (free gas and dissolved), this is not expected to pose a significant risk to the environment as any increase in emissions would dissipate rapidly and become almost unmeasurable outwith the immediate vicinity.

A.2 Mobile Oil

A.2.1 Composition

The mobile oil phase is assumed to be made up from the following:

- Residual oil left behind upon completion of the AORP executed in 2007.
  - Residual oil could also contain:
    - Fluids from the topsides drain system such as solvents and effluents from cleaning, lubricating and hydraulic fluids, cooling fluids, etc.
    - Trace quantities of chemicals such as demulsifiers injected into the topsides processing system.
    - Heavy metals.
- Hydrocarbons which have diffused over time from the sediment layer on the floor.

A Produced Fluids Characterisation Programme was undertaken by Fairfield in 2010. Offshore sampling withdrew a total of 89 samples from zones of the reservoir which had contributed to reservoir production in the earlier years of operation. The composition (Table A4) and heavy metal concentration (Table A5) of residual oil within the storage cells has been determined from the analysis of these samples.

Table A4 Oil composition

Component	Concentration %
Overall Fractions	
<C12	29
C13 – C19	23
>C20	48
Benzene, Toluene, Ethylbenzene and Xylene (BTEX) Compounds	
Benzene	0.092
Toluene	0.38
Ethylbenzene	0.31
Xylene (o,p,m)	0.69
Total BTEX	**1.5**
PAH Compounds	
Naphthalene	0.03
Acenapthene	0.036
Pyrene	0.0075
Phenanthrene	0.0053
Fluorene	0.0028
Fluoranthene	0.0018
Anthracene	0.00045
Chrysene	0.00025
Total PAH	**0.08**

Table A5 Heavy metal concentration in the oil phase

Heavy Metal	Concentration (mg/kg)
Arsenic (As)	0.0045
Cadmium (Cd)	0.011
Chromium (Cr)	0.0174
Copper (Cu)	0.0609
Mercury (Hg)	0.0055
Nickel (Ni)	1.5
Lead (Pb)	0.0454
Vanadium (V)	2.25
Zinc (Zn)	0.59

A.2.2 Quantification

Fairfield has performed an extensive review of the AORP operations performed by the previous operator, including project closeout report and pumping records. Dynamic modelling has been undertaken to validate the effectiveness of the operations with respect to the delivery and distribution of the CO_2 displacement gas and the extraction of the oil. This modelling has concluded that the CO_2 displacement technique would have been very effective, leaving only a relatively thin layer of residual oil within each cell group. There is no appreciable emulsions present as evidence during the AORP operations and recent sampling operations.

An assumption of 10 cm, plus a further 2-3 cm to account for coning and cusping effects (where the interfaces between the gas-oil and oil-water exhibit some curvature during pumping), was initially applied to calculate the base case estimate. This figure was based on the overall material balance of oil movements during the AORP, the pumping rates, and the design intent of the project to inject sufficient CO_2 to push the oil layer below the inlet of the pipework.

Observations made from the venting of the different cell groups, described in Section 2.1.2, have revealed that there are significant volumes of gas still contained within the cell tops. Originally it had been assumed that all of this gas was successfully scavenged by the addition of chemicals at the end of AORP or would have naturally gone into solution in the oil and water phases. Analysis of cell pressures, gas compositions and fluid samples from within the export pipework support the conclusion that there are minimal residual volumes of mobile oil remaining with the cell tops, and provide further information regarding the distribution of oil within each cell group. A summary of the observations is provided below:

- There is no appreciable hydrocarbon build up in the rundown line A, which indicates minimal mobile oil within the cells and the original 10 cm basis has been reduced to 2-3cm.
- Evidence of hydrocarbons in rundown line B indicates there is residual mobile oil within the cells, over 44 m^3 of oil was recovered before the umbilical line became blocked. The clear evidence of both the gas phase above the oil and water phase below means that the oil layer is no thicker than the diameter of the 3” valve at the end of the umbilical. The original 10 cm basis has been reduced to 7.6 cm.
- Evidence of hydrocarbons in rundown line C indicates there is residual mobile oil within the cells, around 33 m^3 of oil was recovered and the residual layer measured by raising the standpipe to displace the oil. The clear evidence of both the gas phase above the oil and water phase below means that the oil layer is no thicker than 5 cm, therefore the original 10 cm basis has been reduced.
- Evidence of hydrocarbons in the rundown line D indicates there is residual mobile oil within the cells, nearly 19 m^3 of oil was recovered. The horizontal section of rundown line between CGD and Leg B has a slight downward slope and then an upward slope before it runs vertically up into the leg. As the

system operating pressure was increased by increasing the standpipe level, it is believed that this swept some oil along the horizontal section of the line. The deviation from horizontal is in the region of 10 cm and therefore the inventory basis has not been reduced.

Table A.6 provides the base estimate of the residual mobile oil inventory with the storage cells.

Table A6 Quantification of mobile oil

Cell Group	Residual Attic Oil (m^3)	Trapped Oil (m^3) (Note 1)	Diffused Oil (m^3) (Note 2)	Total (m^3)
A	43.4	89.8	4.6	137.8
B	219.6	89.8	4.8	314.2
C	151.2	134.8	4.6	290.6
D	219.2	134.8	3.9	357.8
Total	**633**	**449**	**18**	**1,100**
Notes: 1. Oil within the ‘triangle’ compartments which is in accessible. 2. Oil migrated from the sediment phase.				

A.2.2.1 Emulsions

Based on the knowledge of the topsides process, historic production chemical requirements and recent observations of the nature of the fluids within the cells, there is no appreciable oil-water emulsion build-up within the cells.

There was no evidence of emulsions during AORP in 2007, and during the most recent cell sampling operations (2019 -2020) only one sample from rundown line C showed any emulsion. The emulsion in this sample was less than 0.15vol% and is likely to be due to the residual mothballing gel chemicals present rather than anything inherent in the mobile oil. It should be noted that oil and water can only form a stable emulsion where there are impurities in the form of particulates or other chemical species. It is likely that the main reason that there are no emulsions is because Dunlin fluids don’t have high solids loading.

A.2.3 Distribution

As described above, upon completion of the AORP there will have been only a thin layer of residual oil within each cell. An estimate of the mobile oil volumes has been made for each storage cell. While it is expected that the oil will be evenly distributed within a storage group, there are some cells that may be more contaminated with mobile oil than others.

The variation in the oil quantities can be explained in a number of ways:

- Cells with higher sediment accumulation will have more oil trapped, which will diffuse and travel into the mobile oil phase slowly over time. Where the free gas cap above the oil layer holds it in communication with the interconnecting port, the oil will evenly redistribute across the cell group. If the gas cap has been released or diminished, then the oil will migrate to the cell tops into the pockets created by the formwork.
- The orientation and configuration of the rundown line pipework hinders effective oil recovery in some of the cell groups. With Cell Group B being limited by the narrow umbilical where the fluids and Cell Group D limited by the slope in the pipework created by the platform tilt, i.e. the platform does not sit perfectly horizontally.
- Cells underneath the leg with the triangle sections without the connecting upper port have approximately 45 m^3 of trapped oil per cell in addition to the residual oil within the attic space.

Figure A2 depicts the worst affected cells in terms of oil contamination.

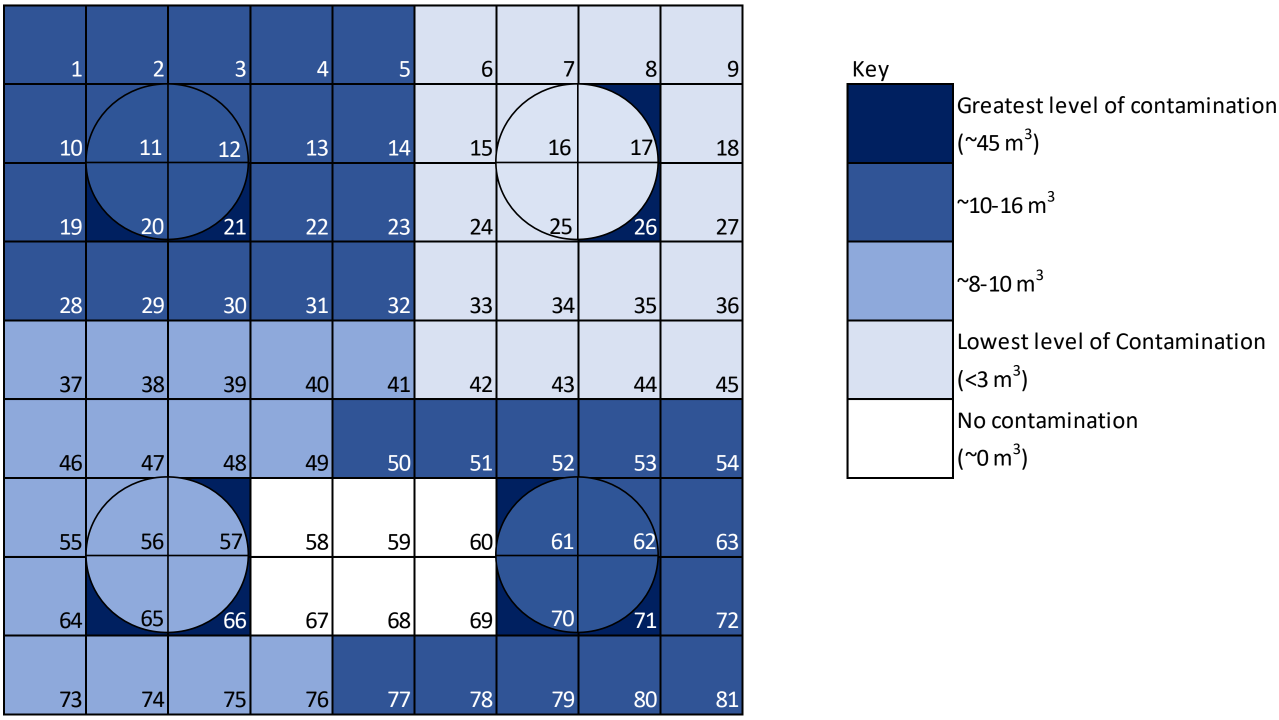

Figure A2 Distribution of oil contamination within the storage cells

A.2.4 Summary

Table A7 provides a summary of how the oil characteristics vary from cell to cell.

Table A7 Summary of oil characteristic variation from cell to cell

Parameter	Units	Minimum	Maximum
Mobile Oil Volume	m^3	2.45	57.24 (Note 1)
Depth of Oil Layer	m	0.02	0.12
BTEX	kg	31.3	730.5
PAH	kg	1.8	41.7
Heavy Metals	kg	0.01	0.22
Chemicals	kg	0.09	1.98
Notes 1. Includes 45 m^3 in triangle sub-compartments			

A.2.5 Uncertainty

Table A8 provides a summary of the input data used to characterise the residual mobile oil within the CGBS storage cells.

Table A8 Summary of input data used for mobile oil characterisation

<table>
<tr><th>Data Source</th><th>Relevance</th><th>Uncertainty</th><th>Environmental consequence</th></tr>
<tr><td>Dunlin historical production data</td><td>Fiscal records used to calculate production throughputs</td><td rowspan="6">Low uncertainty with the correlations to examine the coning and cusping tendencies of the fluids as the effect of these are far less pronounced at the low pumping rates during the attic oil export.

Moderate uncertainty about how the attic oil is distributed across the network of cells. This has been assumed to be evenly distributed but could vary depending on a number of factors during the AORP.

High uncertainty around the quantities of heavy metals within the oil although the overall concentrations are expected to be low based on physical sampling of production fluids

High uncertainty with how the hydrocarbons within the sediment phase will diffuse and migrate as free oil into the attic space. The rate of diffusion is likely to be overestimated, as the volume of oil able to diffuse is highly dependent on the thickness and composition of the sediment.</td><td rowspan="6">Although there is a moderate to high level of uncertainty around some of the characteristics associated with the mobile oil, the total mobile oil volume is relatively small, and the probability of the total volume being instantaneously released to the environment is extremely low

Any entrained oil volumes within the sediment are expected to be low and diffusion is very slow, therefore minimal additional impacts.</td></tr>
<tr><td>2010 Dunlin produced fluids sampling analysis (89 samples from different reservoir zones)</td><td>Laboratory analysis of well fluid samples taken from zones of the reservoir relevant to the earliest years of production. Used to determine oil composition.</td></tr>
<tr><td>AORP pumping and cell pressure records

2018 – 2020 Topsides Based Survey and Sample Activities</td><td>Used to estimate the quantity of mobile oil and validate the composition basis.</td></tr>
<tr><td>Sullom Voe samples for oil heavy metals content</td><td>Sample analysis used to supplement lack of data for nickel, vanadium and mercury</td></tr>
<tr><td>Cuttings pile oil loss rates</td><td>Used to estimate the movement of hydrocarbons from the sediment in to the mobile oil phase.</td></tr>
<tr><td>Dunlin Alpha base caisson schematic diagrams</td><td>Used to calculate oil volume</td></tr>
</table>

To address uncertainties in the mobile oil characterisation, which could have an influence on the selected management option and the residual environmental impact, conservative assumptions have been applied to determine the base case mobile oil inventory:

- It has been assumed that all the hydrocarbon content of the sediment could become mobile oil. In reality, some oil will be less mobile wax and diffusion rates will reduce as hydrocarbon concentration in the sediment is depleted.
- A minimum oil layer equivalent to approximately 2 cm thick has been presumed to be present across Cell Groups A despite there being little evidence of oil in the rundown lines.
- A maximum oil layer equivalent to approximately 12 cm deep has been assumed to be present across Cell Group D; the actual oil layer is likely to be smaller than this based on the results from dynamic modelling.

Although moderate to high levels of uncertainty exist around some of the characteristics associated with the mobile oil, the total mobile oil volume is relatively small and the probability of an instantaneously release to the environment is extremely low. As described in Section 5.3, the volume of oil that could be released from a breach in the cell structure would be limited due to the sub-compartmentalisation of the cell roof structures. It is therefore unlikely that additional sampling to reduce uncertainties with the characterisation of the mobile oil phase would result in a significant change to environmental impact assessments.

In addition, any entrained oil volumes within the sediment are expected to be small and diffusion will be very slow. Additional sampling to reduce uncertainties would therefore be of very little value.

A.3 Material Adhered to Walls and Ceiling (Wax)

As produced fluids entered the storage cells, they would have mixed with the cooler water phase within the cells. This mixing would have resulted in a temperature reduction of the produced fluids and, if the resulting temperature was below the wax appearance temperature, solid wax would have formed within the fluid. Residual wax contents within the cells are most likely due to the temperature drop between the bulk fluid within the cells and the external cell walls, which would drive deposition of wax onto the cell roof and walls. Other mechanisms would have resulted in the wax being discharged from the cells during operational use or drawn down to the base of the cells by heavier particles.

A.3.1 Composition

The concentration of heavy metals in the wall residues will be similar to those present in the mobile oil phase (Table A6), which has been determined from historical analysis of Dunlin oil samples.

A.3.2 Quantification

The temperature gradient through the cell walls was established using a one-dimensional transient finite difference heat and mass transfer model. The thick (generally 0.45 - 0.75 m) concrete walls of the Dunlin Alpha cells mean that heat transfer rates through the cells walls would be relatively low. The model provided average deposition rates of 0.0016 $mm.day^{-1}$. The volume of wax based on this deposition rate would have resulted in a maximum wax thickness of 12mm on the ceiling attic space and outer walls, tapering to zero at approximately EL+6.5m. No appreciable wax is expected to have been deposited on the inner walls of the cell matrix, as the temperature at the wall surface will have been close to that of the fluids within the cells (Table A9).

In addition to waxes precipitated from the crude oil, 70 tonnes of wax gel pellets were injected into Cell Group A during the AORP to seal a leak in the cell roof. Earlier in the operations, the same quantity of wax was injected into Cell Group B to trial the wax delivery method. Some of the wax pellets from Cell Group B were then transferred to Cell Group D during mothballing of the rundown lines during AORP. Significant evidence of the wax pellets has been seen in Cell Group B during 2010 pumping operations. Some evidence of these wax pellets was also observed in rundown line D, but to a much lesser extent.

Table A9 Quantification of wall residue within each cell group

Cell Group	Wall Residue Volume (m^3)		
	Hydrocarbon Deposits	AORP Wax	Total
A	79	78	157
B	79	76	155
C	77	0	77
D	70	2	72
Total	**306**	**156**	**462**

A.3.3 Distribution

A base case estimate of the wall residue volumes has been made for each storage cell. It is expected that the wall residue deposition will be most concentrated on the inside of the external perimeter cell walls. There will also be additional wax inventory in Cell Groups B and D because of the wax injected into the cells during the AORP.

Figure A3 illustrates the distribution of wall residues based on the known external wall surface area and the calculated average deposition rates, as described above.

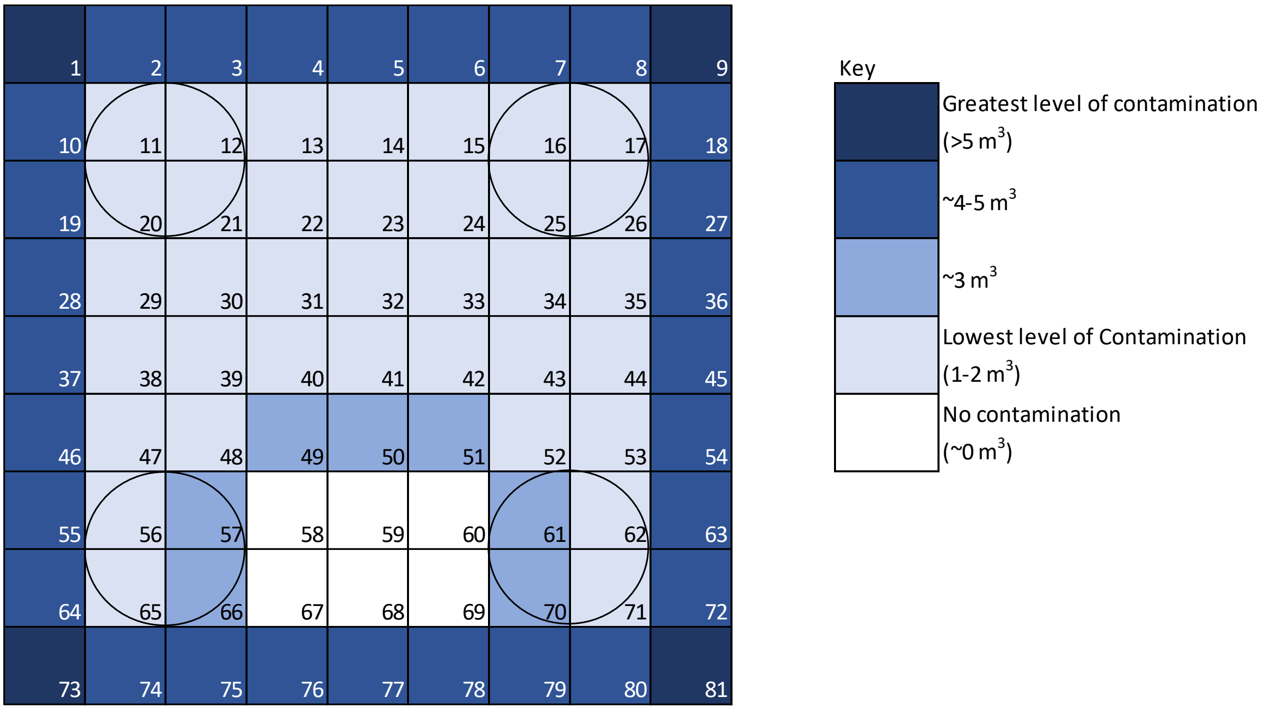

Figure A3 Distribution of wall residue (wax) contamination within the storage cells (not including AORP wax)

A.3.4 Summary

Table A10 provides a summary of how the wall residue characteristics vary from cell to cell.

Table A10 Wall residue characteristic variation from cell to cell

Parameter	Units	Minimum	Maximum
Deposited Wax Volume	m^3	1.40	5.73
Thickness of Residue Layer	mm	0	12
Heavy Metals	kg	0.0056	0.0231

A.3.5 Uncertainty

Table A11 provides a summary of the input data used to characterise the wax materials adhering to the walls and ceiling of the CGBS storage cells.

Table A11 Data inputs for wax characterisation including uncertainties

Data input	Relevance	Uncertainty	Environmental consequence
Dunlin historical production data	Fiscal records used to calculate production throughputs in order to quantify wax production	Low uncertainty as to the level of wax deposition within the cells, including the portion of lighter ends that this wax may contain that could diffuse and migrate into attic spaces as free oil in the future. High uncertainty regarding the amount of wax gel left within the cells following the AORP operations. Tracking of this material and accurate records of volumes used is limited.	Low consequence as the uncertainties in the wall residue quantity of hydrocarbons is small. If exposed, as the structure degrades, the majority will remain in relatively close proximity to the structure.
2010 Dunlin produced fluids sampling: -Hydrocarbon fluids characterisation -Wax precipitation curves for Dunlin fluids -Wax cold finger testing -Asphaltene formation tests	Laboratory analysis of well fluid samples taken from zones of the reservoir relevant to the earliest years of production. Used to determine wax composition, wax appearance temperature, and to confirm there are no asphaltenes present.		
AORP wax gel injection pumping records	Used to calculate additional wax material added into the cells.		
Dunlin Alpha base caisson schematic diagrams	Used to calculate wax deposition surface area		

To address uncertainties in the wall residue characterisation, which could have an influence on the selected management option and the residual environmental impact, the following conservative assumptions have been made:

- No account has been taken for the insulating effects of the drill cuttings accumulations on top of the roof and along the south face of the CGBS.
- There may be some wax accumulation on the walls of the cells adjoining the conductor cell group, this cooling effect has not been quantified, but is expected to contribute only a small proportion of the overall wax deposition.
- Calculations have assumed an external seawater temperature of 4’C. This is lower than the average ambient conditions.
- Heat transfer calculations have been based on natural convection and laminar flow. In reality, there would have been some turbulent mixing; the effect of which would reduce the wax deposition rates.

Uncertainties associated with the quantification of wall residue hydrocarbons is considered to be of low consequence. If exposed, as the structure degrades, the majority of wall residues will remain in relatively close proximity to the structure and diffusion rates will be very low. It is unlikely that any additional sampling to reduce these uncertainties will result in a significant change to environmental impact assessments.

A.4 Water Phase

A.4.1 Composition

Dissolved contaminants will be present in the water phase as a result of:

- Chemical reactions within the cells altering major components of the water phase;
- Chemical reactions within the cells causing precipitated materials to go into solution;
- Unaltered components in the residual material dissolving into the water;
- Water soluble chemicals being introduced during platform operations from the processing system including those introduced to the drainage system; and
- Chemicals added during the AORP.

Hydrocarbons will be present in the water phase at concentrations dictated by their solubility under the conditions within the cells. Since AORP, hydrocarbons will have migrated from the sediment and wall residues and it is likely that the composition of the water will vary slightly between cells. An average concentration of 40 mg/l has been applied, based on analogous data attained from similar projects. The composition of dissolved hydrocarbons has been determined from historical Dunlin produced water sample analysis.

Chemicals introduced into the wells and topsides processing systems, which partition with the water phase, may also be present within the storage cells. Prior to 1991, environmental reporting of the use of production chemicals was not required. As a result, there are no specific records for this period. It has been assumed that chemicals would have been used for:

- Injection water treatment (deoxygenation, biocides, corrosion inhibition, scale inhibition);
- Scale squeeze treatments; and
- Production fluids treatment (scale inhibition, corrosion inhibition, demulsifiers).

A number of chemicals were also introduced into the cells during AORP. However, during AORP the storage cells were flushed through with fresh seawater such that the residual quantities of chemicals would have been diluted by a ratio of approximately 60:1.

A.4.2 Quantification

The total volume of the water within the CGBS has been determined from the cell geometry, with water occupying the volume not taken up by free gas, mobile oil, wall residue and floor sediments, this is presented in Table A12.

Table A12 Volume of water within the cell groups

Cell Group	No of Cells	Volume of Water (m^3)
A	20	56,402
B	20	55,424
C	19	53,505
D	16	45,579
Conductor	6	16,475
Total	81	227,385

A.4.3 Distribution

Figure A4 provides an estimated distribution of contamination within the water phase of cells across the CGBS. The contamination variation is due to the variation in the other hydrocarbon containing materials; with the highest sediment and wall residue deposition anticipated to have higher levels of contaminants in the water phase.

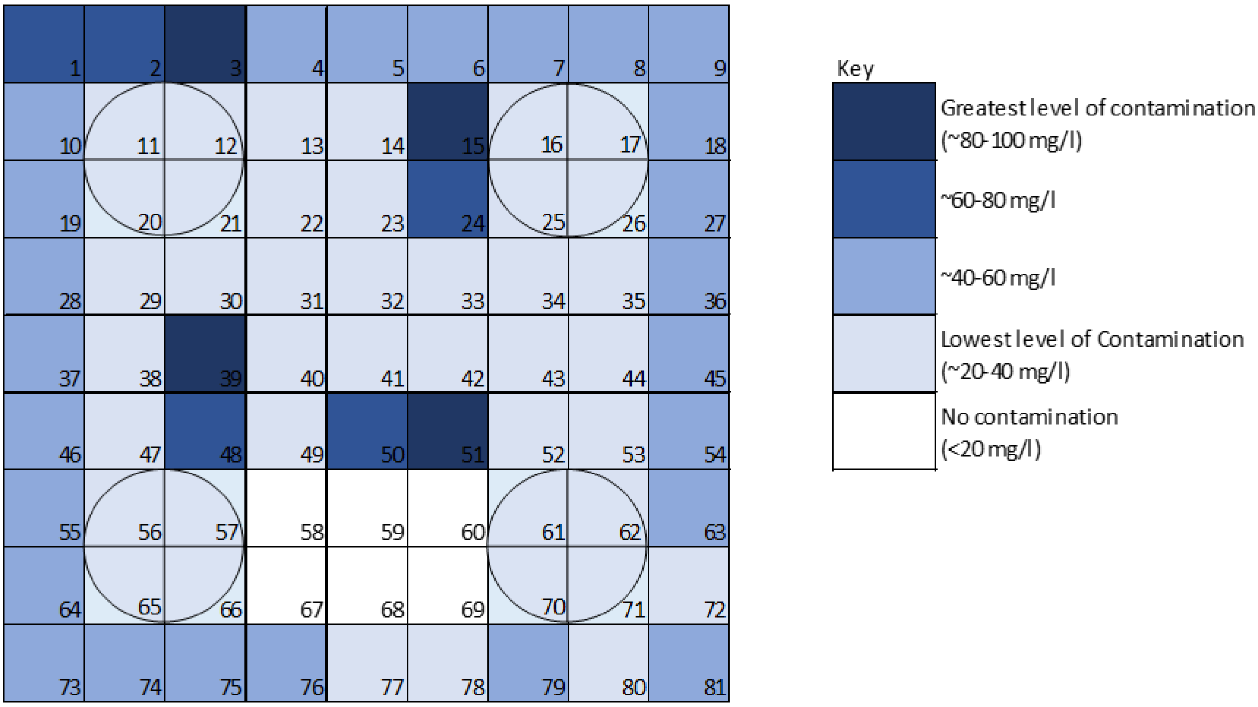

Figure A4 Distribution of water contamination within the storage cells

A.4.4 Summary

Table A13 Water content characteristic variation from cell to cell

Parameter	Units	Minimum	Maximum
Water Phase Volume	m^3	2,567	3,406
THC	kg	52.3	289.5
BTEX	kg	6.88	9.13
Heavy Metals	kg	0.168	0.223
Chemicals	kg	2.11	2.80

A.4.5 Uncertainty

Table A14 provides a summary of the input data used to characterise the water phase of the CGBS storage cells.

Table A14 Data inputs for water characterisation including uncertainty

<table>
<tr><th>Data Input</th><th>Relevance</th><th>Uncertainty</th><th>Environmental Consequence</th></tr>
<tr><td>Historical produced water discharge sampling analysis</td><td>Water chemistry data for dissolved constituents in the production water</td><td rowspan="6">Moderate uncertainty about exact chemicals used, formulations will have changed over time.

High uncertainty in the amount of dissolved hydrocarbons and heavy metals within the water phase.</td><td rowspan="6">During AORP, the cell contents were displaced with seawater and this will have diluted the chemical composition.

The hydrocarbon contamination in the sediment and wall residue is anticipated to be low, therefore water contamination should be limited.

Post decommissioning there will be no pressure differential between the internal cells and the external environment and therefore upon degradation of the structure there is no driving force for the water to be instantaneously released.</td></tr>
<tr><td>Data for dissolved metals at oxic/anoxic boundaries in seawater and sediments</td><td>Used to understand saturation levels of water components</td></tr>
<tr><td>Data for solubility of hydrocarbons in seawater</td><td>Used to understand equilibrium levels of water components</td></tr>
<tr><td>Chemical Hazard Assessment and Risk Management (CHARM) for Use and Discharge of Chemicals Offshore</td><td>Used to understand hazard potential of chemical components.</td></tr>
<tr><td>AORP pumping records</td><td>Used for chemical dosage information</td></tr>
<tr><td>Dunlin Alpha base caisson schematic diagrams</td><td>Used to calculate volume of water</td></tr>
</table>

To address uncertainties in the characterisation of the water phase, the following conservative assumptions have been made:

- Metals are present at the concentrations reported in the literature for dissolved metal enrichment at oxic/anoxic boundaries. This provides analogous data on the composition of seawater when exposed to similar conditions as those experienced within the storage cells.
- It has been assumed that the water phase is saturated with benzene, toluene, ethylbenzene and xylene (BTEX) compounds. However, other hydrocarbon components, such as polyaromatic hydrocarbons (PAHs) will be less concentrated due to their limited solubility. This is likely to over-estimate the amount of hydrocarbon contamination. Water samples retrieved from Cell Group A have been able to validate these assumptions

During AORP, the cell contents were displaced with seawater at a ratio of approximately 60:1, which will have significantly diluted the chemical composition of the water phase. In addition, the hydrocarbon contamination in the sediment and wall residue is anticipated to be low, and contamination of the water phase will therefore be limited.

The water within the storage cells has been settling for an extended period, this means that any hydrocarbon content will be as a result of dissolved hydrocarbon components rather than dispersed droplets. During historical operation of the storage cells, produced water from the cells achieved very low oil-in-water concentrations (less than 30 mg/l) due to the long residence time for the fluids (typically they were left to settle for at least a week). It is envisaged that the diffusion processes happening within the cells will be causing some of the hydrocarbon components to move into the water phase, resulting in some variation in the quality of the water from cell to cell. However, the amount of hydrocarbons in the water will be limited by both the solubility of the hydrocarbon components and the low volume of residual hydrocarbons within the mobile oil, wall residue and sediment phases. Further to this the diffusion processes are very slow acting, with similar characteristics to that of a drill cuttings pile.

Uncertainties associated with the characterisation of the water phase is considered to be of low consequence. If a communication path with the external environment opens up, as the structure degrades, the water inside will slowly interchange with the external sea as a result of currents, rather than any pressure or buoyancy effects. It is unlikely that any additional sampling to reduce these uncertainties will result in a significant change to environmental impact assessments.

A.5 Sediment

A.5.1 Composition

The sediment phase is considered to be composed of the following materials:

- Sand and clays;
- Hydrocarbons in the form of oils and waxes;
- Small quantities of naturally occurring contaminants such as heavy metals and low specific activity (LSA) scale or naturally occurring radioactive materials (NORM); and
- Water;
  - The water could contain fluids from the topsides drain system such as lubricating oils, solvents/cleaning compounds and cooling fluids, etc.; and
  - Residual quantities of production chemicals may be present.

The composition of the sediment layer is assumed to be one part solids, one part hydrocarbon to one part water by volume. This assumption is based upon sampling analysis from similar decommissioning projects such as Shell Brent Delta and ConocoPhillips Ecofisk.

There are two main potential forms of hydrocarbon deposition within the cell sediment layer: oils and waxes, which would have been transported on the surface of the sands and clays as they settled on the storage cell floors. The chemical composition for oil and waxes has been described in Section A.2 and A.3 respectively.

Similarly, the chemical composition of the water fraction has been described in Section 2.1.2.7.

Scale may have formed and deposited on the cell floor in the early years of production, when barium and strontium ions from the reservoir fluids came into contact with the sulphate ions in the seawater within the storage cells. Scale will also have been formed during AORP when chemicals were used to scavenge the residual CO_2. No scavenger chemicals were applied to Cell Group A, therefore this group will have a lower scale deposition.

The total quantity of heavy metals within the sediment phase has been calculated using the anticipated concentrations of heavy metals within each sediment fraction (i.e. sand/clay, hydrocarbon, water). This gives an overall basis for the heavy metal concentrations within the sediment (Table A15).

Table A15 Heavy metal concentration in the sediment phase

Heavy Metal	Concentration (mg/kg)
Arsenic (As)	2.25
Cadmium (Cd)	1.29
Chromium (Cr)	13.8
Copper (Cu)	464
Mercury (Hg)	0.100
Nickel (Ni)	744
Lead (Pb)	158
Vanadium (V)	70
Zinc (Zn)	104

A.5.2 Quantification

Reservoir fluids will have contained quantities of sediments (sands and clays), generated during the production phase of the asset. It is common for high amounts of sediment to be produced in young formations and when a reservoir experiences water breakthrough. For Dunlin Alpha, this high sediment production phase will have been predominantly in the early 1980's.

The evaluation of sands and clays within the storage cells is based on historical operational data for the solids content of the well streams. This data has been used to determine a mean solids loading rate of 7 g/m^3 (expressed as mass of sand per unit volume of total fluids produced), which has been applied to the total well production rates for the life of the field to determine the total quantity of sand entering the storage cells.

As the cell groups were used at different frequencies during the field life this total sand loading has been divided between the four groups (Table A16). As described earlier, use of Cell Groups A and D was restricted, therefore the calculation has been adjusted assuming a proportional split of 0.25:0.3:0.3:0.15 between the A:B:C:D cells.

Table A16 Summary of sand/clay inventory within the cell groups

Cell Group	No of Cells	Sand/Clay Volume (m^3)
A	20	90.8
B	20	108.9
C	19	108.9
D	16	54.5
Total	**75**	**363**

A.5.3 Distribution

The movement of fluids within the storage cells, the settling velocity of sediments and buoyancy (as a result of being coated in oil) will have influenced how the solids entering the system will have distributed over time. Information on sediment particle size was obtained from analysis of sediment samples taken from topsides separators during cleaning operations, and used to determine how the particles would be deposited across the cells. This is strongly influenced by how the cells are interconnected and the distance (>10m) between cells, meaning that the majority of the particles would settle in the first cell, with some particles pulled through to the second cell via a lower interconnecting port. Figure A5 illustrates the estimated sediment distribution across the CGBS storage cells.

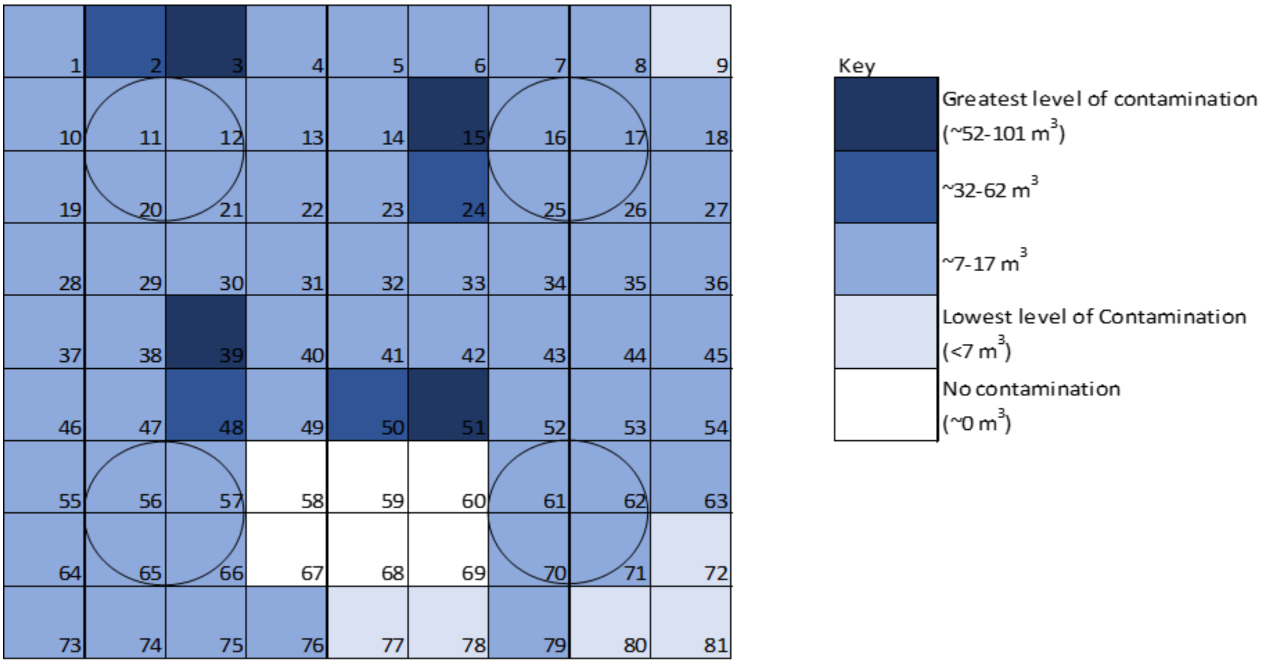

Figure A5 Distribution of sediment within the CGBS storage cells

A.5.4 Summary

Table A17 provides a summary of the expected worst-case sediment loading and composition in each cell grouping based on the highest deposition rates, which were recorded during the initial phases of operation. The depth of sediment within the cells varies from 0.04m to 0.9m, assuming that deposition is an even layer across the cell floor.

Table A17 Summary of sediment volumes and composition

Cell Group	Sediment volume (m^3)				
	Sand/clay	Scale	Hydrocarbon	Water	Total
A	90.8	12.0	90.8	90.8	284.4
B	108.9	51.3	108.9	108.9	378.2
C	108.9	51.3	108.9	108.9	378.2
D	54.5	44.1	54.5	54.5	207.5
Total	**363**	**159**	**363**	**363**	**1,248**

Table A18 provides a summary of how sediment volumes vary from cell to cell.

Table A18 Sediment characteristics variation from cell to cell

Parameter	Units	Minimum	Maximum
Sand/Clay Volume	m^3	1.0	32.7
Scale Volume	m^3	0.6	2.8
Hydrocarbon Volume	m^3	1.0	32.7
Water Volume	m^3	1.0	32.7
Depth of Sediment	m	0.04	0.9
Heavy Metals	kg	26.6	53.8
NP/NPE	kg	<0.003	<1.13

A.5.5 Uncertainty

Table A19 provides a summary of the input data used to characterise the sediment phase of the CGBS storage cells.

Table A19 Data inputs for sediment characterisation including uncertainty

Data Input	Relevance	Uncertainty	Environmental Consequence
Annual oil and water production rates for Dunlin Alpha	Used to calculate production throughputs for estimating sand production.	High uncertainty in the total sediment inventory and moderate uncertainty about how the sediment is distributed High uncertainty about the amount of scale that could have formed within the cells. Low uncertainty about the level of radioactivity associated with the sediment materials Low to moderate uncertainty about concentration of heavy metals, chemical and hydrocarbon components within the sediment.	Although there is high uncertainty around the total quantity of sediment, the volume is anticipated to be low due to the way the reservoir was operated. If exposed, as the structure degrades, the majority will remain in relatively close proximity to the structure.
Dunlin solids sampling records from early production years (1980 – 1982)	Used to baseline solids loading rate from early production phases		
2010 Dunlin fluids sampling Hydrocarbon fluids characterisation	Laboratory analysis of well fluid samples taken from zones of the reservoir relevant to the earliest years of production. Used to determine oil composition.		
2017 sediment samples from Dunlin Alpha production separators	Used to inform solids particle size and distribution.		
Chemical Hazard Assessment and Risk Management (CHARM) for Use and Discharge of Chemicals Offshore	Used to understand hazard potential of components.		
AORP pumping records	Used for chemical dosage information		
Dunlin Alpha base caisson schematic diagrams	Used to calculate sediment depth.		
Sullom Voe sediment samples for heavy metal content and particle size	Used to inform solids composition and distribution		
Seawater chemistry	Used to examine the scaling tendency of the production fluids		
Geochemical data for metal concentrations in scales and clays	Provides representative data on metal content of geologically derived clays		

To address uncertainties in the characterisation of the sediment phase, which can have an influence on the selected management options and the residual environmental impact, a conservative inventory basis has been used:

- It has been assumed that the mean sand loading rate experience during the early years of operation continued at this rate for the whole of field life. There were no changes to the operating regime that would have resulted in an increase to the sand production rates, i.e. blowdown of the reservoir was not undertaken. This will overestimate the overall sediment quantity as sand production will have been at its highest during the early years.
- Although the Dunlin processing system had three stages of separation before the production fluids were directed to the storage cells, it has been assumed that all of the sand/clay materials in the production fluids will have settled in the storage cells (i.e. no account for settling in the upstream topsides processing train). It is also assumed that none of the solids entering the cells were transported back out during oil export or produced water discharge. This will overestimate the sediment quantity.
- The hydrocarbon content of the sediment is assumed to be oil that can diffuse into the water phase and build-up in the mobile oil phase. However, much of the hydrocarbon material associated with the particles will be less mobile wax.
- An equal parts ratio is assumed to determine the hydrocarbon and water contents of the sediment (i.e. 1 part solid: 1 part oil: 1 part water). This is likely to overestimate the oil content of the sediment, as the sediment is unlikely to be highly compacted due to low deposition rates, allowing hydrocarbons to diffuse and voidage spaces to fill with water. The sediment composition may therefore be higher in water content, at up to 50% by volume.
- The ammonium chloride added to the storage cells during scavenging of the CO_2 at the end of AORP is assumed to have been ineffective and therefore magnesium and calcium carbonate scale would have formed.

Although there is high uncertainty around the total quantity of sediment, the total volume is anticipated to be low due to the way the reservoir was operated. If exposed, as the structure degrades, the majority will remain in relatively close proximity to the structure. It is therefore unlikely that any additional sampling to reduce uncertainties will result in a significant change to environmental impact assessments.

Appendix B – ENVID Summary

Table B1 Summary of the impact identification exercise, with the justification for the inclusion and exclusion of impact sources

Aspect	Potential impact or mechanism	Further assessment	Rationale
Energy Use and Emissions to Air	• Vessel use for undertaking offshore decommissioning activities; • Material Recycling and Replacement • Gradual release of gas from the substructure storage cells	No	Emissions and energy use during decommissioning activities are considered in the context of the cessation of production and will be limited to decommissioning vessels undertaking activities on-site and transiting to shore. As such, almost all future emissions from Project operations and vessels associated with O&M will cease. Historical European Union (EU) Emissions Trading Scheme data suggests that emissions are likely to be small relative to those during production. Indeed, CO_2 emissions generated from vessel use associated with Option 9 – leave *in situ* (Transitions up) – has been has been estimated to be 1,395 tonnes based on the emissions calculations undertaken in Xodus (2020b) using the IP (2000) *Guidelines for the Calculation of Estimates in Energy Use and Gaseous Emissions in the Decommissioning of Offshore Structures*. The expected CO_2 emissions generated from the replacement of recyclable materials remaining *in situ* have been calculated to be 34,238 tonnes, resulting in a total of 35,633 tonnes of CO_2 for the Project. This is approximately 0.27% of the total atmospheric emissions associated with 2018 UKCS oil and gas activities (OGUK 2019). Emissions generated as result of the proposed decommissioning programme are expected to be very small compared to the annual emissions associated with the operation and maintenance of the asset to date, which will almost all cease upon completion of decommissioning. For these reasons, impacts associated with energy use and atmospheric emissions have not been further assessed. As the substructure degrades, a total of 45 tonnes of free gas (consisting of CO_2, H_2S and light-end hydrocarbons) contained within the tops of the substructure storage cells will be gradually released. In addition, CO_2 and H_2S are also likely to be generated within the cells over time as a result of natural biodegradation processes. However, the total quantity of gas expected to be released from the substructure over time is low (<100 tonnes). Due to the relatively low quantity of gases considered and the gradual nature of any release, no further assessment has been undertaken.
Physical Presence	• Physical presence of vessels in relation to other sea users; • Exclusion to sedimentary infauna due to long-term presence of anthropogenic hard substrata in an otherwise sedimentary habitat encouraging fouling growth	No	Vessel presence during decommissioning activities will be relatively short term in the context of the life of the Dunlin Alpha platform. Activity will occur using similar vessels to those currently deployed for oil and gas across the northern North Sea. Vessel days required for decommissioning will be comparable to operational vessel requirements, and vessels will also generally be utilised around existing infrastructure and will not occupy 'new' areas. Other sea users will be notified in advance of activities occurring, meaning those stakeholders will have time to make any necessary alternative arrangements for the limited period of operations. A review of decommissioning Environmental Appraisals shows that some projects indicate a greater potential issue with short term vessel presence. However, these largely relate to project-specific sensitive locations, which is not the case for this project. Option 9 will result in structures remaining *in situ*, thereby altering the seabed habitat for significant period of time. However, the area is relatively small in relation to wider North Sea area and should not pose a significant impact on habitat availability, either on local or regional scales.

Aspect	Potential impact or mechanism	Further assessment	Rationale
	• Physical presence of infrastructure decommissioned in situ in relation to other sea users	Yes	It is proposed to decommission the CGBS *in situ*, with transitions in place. The OSPAR and UK Regulatory base case is for full removal of the structure where possible (taking into account safety, environmental, technical feasibility, societal and economic factors). Additionally, decommissioning infrastructure *in situ* has been raised as a key stakeholder concern in this and previous decommissioning projects. On this basis, further assessment of the long-term physical presence of the infrastructure in relation to other sea users has been undertaken and is presented in Section 5.1. Specifically, this assessment has focussed on the potential interaction with fisheries in the longer-term.
Disturbance to the Seabed	• Disturbance to the seabed; • Disturbance of cuttings piles during decommissioning activities; • Loss of habitat (long term habitat change) due to cuttings piles	No	The seabed footprint will be extremely limited, and related largely to potential recovery of debris by ROV. Additionally, the Dunlin Subsea Infrastructure Decommissioning Environmental Statement (Fairfield, 2017b) considered the impact on the seabed within the 500 m zone and beyond, concluding sensitivity was low and recoverability high, such that no significant impact was expected. On this basis, no further assessment is to be undertaken. Disturbance of the cuttings piles during decommissioning activities could, in theory, cause release of drill cuttings. However, such disturbance is only expected to be an issue as a result of intrusive works, and as there are no intrusive activities planned, there is no potential mechanism for this impact as a part of the proposed decommissioning activities. Cuttings disturbance has also been considered separately in the context of unplanned events. The benthic habitat across the Greater Dunlin Area has been characterised through several marine surveys as uniform, typical for the region, with sparse epifauna and no qualifying protected species present. The loss of habitat/long term habitat change due to the cuttings piles should be considered under the present conditions, in which the cuttings piles have been on the seabed for decades and have been colonised by a variety of benthic fauna. The cuttings piles are below the OSPAR thresholds for leaching and yearly oil loss, and therefore are considered environmentally acceptable based on international standards. Nonetheless, the taxa found on the cuttings pile are dominated by hydrocarbon tolerant species. The abundance of epifaunal organisms was found to be higher within the cuttings pile area than outside of it, but the infaunal abundance showed the opposite trend. Several species of importance were found within the cuttings piles, including cold water corals, bacterial mats, and two species of IUCN Red Listed fish. However, the artificial nature of the cuttings pile precludes it from gaining protections for the species it supports. It is apparent that the cuttings pile has introduced a modified seabed environment in which its benthic communities differ from the surrounding region, but have become well established over several decades, and which does not impact the quality or availability of habitat across the wider region, nor does it put pressures on protected sites or species. Given the small footprint of the cuttings pile remaining on the seabed relative to the wider available habitat, the leave *in situ* option will not cause important change to the benthic habitat characteristic of the Greater Dunlin Alpha project area. Whilst there is evidence of habitat change introduced from the long-term presence of the cuttings on the seabed, the proposed activities are not thought to add additional modification to the existing habitat beyond the long-term habitat change consented during the development stage. Therefore, there are no significant impacts expected from the continued presence of the cuttings piles on the seabed.

Aspect	Potential impact or mechanism	Further assessment	Rationale
Discharges to Sea	• Routine vessel (e.g. greywater, blackwater, ballast) and topsides facilities discharges; • Chemical, hydrocarbon and other discharges (not from legs, cells or drill cuttings); • Gradual release of leg contents during operations or once operations are complete; and • Gradual release of hydrocarbons entrained in the drill cuttings over time	No	Discharges from vessels are typically well-controlled activities subject to ongoing management. Routine discharges are not generally considered to be a major oil and gas issue, and a review of decommissioning Environmental Appraisals where assessments of routine discharges have been undertaken note that the potential impact of such limited discharges is not significant. There are no planned releases, and thus no impact mechanism for further consideration. Any operational discharge will be subject to risk assessment and undertaken under the conditions of an approved environmental permit (OCR/OPPC). Operations to de-oil the CGBS legs have been completed, successfully recovering over 99.9% of the hydrocarbons from the leg ponds. A comprehensive sampling programme of the leg ponds has been undertaken, and confirmed that hazardous substances have been reduced to as low as reasonably practicable. The sampling results indicate that the total hydrocarbon content across the four CGBS legs is now <250kg, and that the toxicity characteristics of the leg ponds is largely attributable to the salinity of sea water. Given the gradual nature of any future release of the leg water, it is considered very unlikely that such a release would result in any significant impacts to the surrounding environment. Assessment of the cuttings piles on both the cell tops and seabed indicates that neither OSPAR threshold for leaching (10 tonnes of oil leaching to the water per annum) and persistence (500 km^2/yr) are breached. Consequently, leaving the cuttings piles *in situ* without disturbance is considered to be an environmentally acceptable solution, based on current guidance and international standards. On this basis, the gradual release of hydrocarbons within the drill cuttings over time is anticipated to be of negligible impact and has been screened out from further assessment under impacts associated with discharges to sea. However, as a key stakeholder concern and important aspect to define the planned effects of the proposed decommissioning activities, gradual hydrocarbon release from the undisturbed drill cuttings has been considered within the EA. This has been done to inform the detailed assessment of associated with drill cuttings disturbance by modelling baseline discharges from the cuttings.
	• Gradual release of cell contents over time – residual mobile oil, cell water, and cell sediments;	Yes	As the structure degrades over time, communication paths between the cell internal and external environments will form. Due to the highly compartmentalised structure of the storage cells, an intermittent, gradual release of cell contents is likely to occur as a result of long term water ingress, rather than currents forcing contents out of the cells. Such a release would see mobile oil and water, containing heavy metals and aromatics, released to the water column, as well as the exposure of cell sediments. Given the potential for release, and that the issue has been raised as a key area of concern for stakeholders, and given the novel nature of the impact mechanism, further assessment has been undertaken and is presented in Section 5.2.
Underwater Noise	• Underwater noise from vessels causing injury or disturbance to marine species; • Underwater noise from other sources, such as	No	The project will not be using any new activities that have not previously been assessed as 'acceptable' through previous permit applications in the area. This project is not located within an area protected for marine mammals. Cumulative use from multiple vessels is unlikely as more than one vessel will not be present for much of the activity.

Aspect	Potential impact or mechanism	Further assessment	Rationale
	cutting of guide frames and conductors, causing injury or disturbance to marine species		There will be very limited cutting activity below the water line, and this will be restricted largely to cutting of the guide frames and conductors. Given the limited cutting activity, there will be very limited possibility for cumulative impacts from vessel noise emissions. With appropriate industry standard mitigation measures, Environmental Appraisals for offshore oil and gas decommissioning typically show no injury, or significant disturbance. For decommissioning projects outside of protected marine mammal habitats, this issue can often be scoped out.
Resource Use	• Use of raw materials and additives (incl. plastics, chemicals, steel); • Energy consumption (fuel use and power consumption by offshore and onshore plant/equipment); • Use of landfill space	No	The OPRED (2018) and Decom North Sea (2018) guidance advises scoping out onshore resource use related issues, therefore only offshore impacts were considered for this aspect. Generally, resource use from the proposed activities will require limited raw materials (and be largely restricted to fuel use). Such use of resources is not typically an issue of concern in offshore oil and gas. Fuel use during decommissioning activities is occurring in the context of the cessation of production. As such, almost all future fuel use (from project operations and vessels) will cease. Such use of resources is not typically an issue of concern in offshore oil and gas. Limited quantities of material will be returned to shore as a result of project activities (most that is returned is expected to be recycled). There may be instances where infrastructure returned to shore is contaminated and cannot be recycled, but the weight/volume of such material is not expected to result in substantial landfill use.
Onshore Dismantling Yard Activities	• Airborne noise, including traffic movements at onshore sites; • Emissions, such as release of chemicals, odour (e.g. from cutting, marine growth); • Light – onshore (including shadowing effects of any large structures); • Dust; • Aesthetics (onshore)	No	The OPRED (2018) and Decom North Sea (2018) guidance advises scoping out onshore related issues. All onshore yards in which decommissioned material will be handled already deal with potential environmental issues as part of their existing site management plans. There is anticipated to be no change in potential for impact as a result of any of the material proposed for recovery. Whilst the yard(s) remain to be selected, they will be in the UK or Europe. Fairfield procedures require suitably approved facilities, including site visits, review of permits and consideration of how new facility and construction and design has been developed to minimise impact.
Waste Management and Generation	• Non-hazardous waste; • Hazardous waste; • Radioactive waste (including naturally occurring radioactive	No	It is waste management, not generation, that is the issue across DPs, with capacity to handle waste within the UK often cited as a stakeholder concern. Environmental documentation prepared to support DPs usually recognises this. As waste management is understood to be a key stakeholder interest in decommissioning, Fairfield has detailed measures in place to manage waste in Section 2.4, which describes the Waste Management Plan and how the overarching strategy and guiding principles will be applied to manage the Decommissioning

Aspect	Potential impact or mechanism	Further assessment	Rationale
	material and low specific-activity material); • Marine growth		Programme. This section does not seek to replicate inventory data from the DP or quantify waste streams in detail, but instead discusses Fairfield's expectations with regards appropriate handling. In view of the waste management strategy currently in place and the limited waste to be generated by the *in situ* decommissioning of the Dunlin Alpha substructure, waste has been scoped out from further assessment.
Others	• Light (offshore); • Aesthetics (offshore/nearshore); • Livelihood/employment	No	There will be a reduction in long-term light emissions from the activities, and activities will see no more light emissions than during normal operations. Activities will occur in summer when days are longer and less artificial light is required. There will be one navaid, which will emit light. Highly limited movement of vessels through the nearshore, and distant location of the offshore activities. There could be transfer from vessel to vessel during transfer to shore, but this would happen approximately 6 miles offshore and would be highly limited temporally. The disposal yard will be an established location; therefore, the aesthetic impact is expected to be low. Whilst it is recognised that there could be a negative effect resulting from cessation of production, there will be a countering benefit in the additional work required to affect the decommissioning activities. It is expected that the key socio-economic effect would occur through potential interaction with commercial fisheries (assessed as part of Physical Presence).
Unplanned Events	• Accidental chemical/hydrocarbon release to sea from vessels (boats)	No	Vessel releases are carefully managed under Ship Oil Pollution Emergency Plans (SOPEPs) developed by the vessel contractors under guidance and standards from the International Maritime Organisation. The heavy lift vessel (HLV) will have the largest fuel inventory of the vessels involved in the decommissioning activities. However, the fuel inventory of such vessels are typically split between a number of separate fuel tanks, significantly reducing the likelihood of an instantaneous release of a full inventory of the vessel. Assuming a maximum inventory of approximately 18,000 m^3, split by approximately 10 tanks, a release of less than 2,000 m^3 is a credible scenario. Modelling undertaken for the Subsea Infrastructure EIAs indicated a release of approximately 3,500 m^3 would be unlikely to reach shore under most conditions, and with a probability of less than 5% even when modelling did indicate beaching. Interaction with protected sites would be limited to possibility in only six of 12 months, and with a maximum of 1% of inventory release. With such limited probability of a release, limited probability of beaching and interaction with protected sites, no further assessment is proposed.
	• Instantaneous release of residual mobile oil through breach of cell storage structure from dropped object; • Instantaneous release of cell water through breach of cell	Yes	The worst-case release scenario from the cells at any one point in time is considered to result from a steel transition falling and penetrating the cells. It is estimated that such an event could lead to a breach of a maximum of four cells, resulting in a release of between 50 -100 m^3 of mobile oil and 12,500 m^3 of contaminated cell water. As stated above, the Atkins study on the energy in any fall suggests it would not be sufficient to breach the cells. Despite the low probability of a release occurring (it is considered that the fall would not have sufficient energy to pierce the cells), this issue has been raised as a key area of concern for stakeholders. Given this interest, and the novel nature of the impact mechanism, further assessment has been undertaken and is presented in Section 5.3.1.

Aspect	Potential impact or mechanism	Further assessment	Rationale
	storage structure from dropped object		
	• Instantaneous exposure of cell sediments from breach of cell storage structure by dropped object	No	The sediments contained within the cells are in very low volumes (0.7% total volume) and sit directly on top of the cell floor (13 m from the ceiling of the cell). An unplanned breach of cell storage from dropped objects has the potential for instantaneous release of low density gas- and fluid-phase contents, but not an instantaneous release of its sediments, which would require a 13 m high plume internal to the cell to be activated. Rather, a cell breach is likely to cause the low volume cell sediments to become exposed to the surrounding environment (e.g. through water ingress, etc.), but those sediments will become entombed over the course of the degredation of the CGBS. Consequently, exposure of the surrounding water to residuals in the sediments left behind in the cell is not anticipated and therefore not considered representative of a change to baseline water quality conditions which would require an impact assessment on an instantaneous time scale. Rather, the impact pathway is more similar to cuttings disturbance and would be a gradual exchange between the receiving water and the sediments. As disturbance of the cell sediments in such a manner that they would be released to the surrounding seabed, requires extensive change to the cell structure beyond a dropped object (e.g. catastrophic breach from explosion or impact which ejects the solid contents of the cells), such a breach is not anticipated in any capacity and not assessed further within the EA.
	• Disturbance of drill cuttings through collapse of concrete structure, or objects falling during structure collapse; • Fishing interaction with drill cuttings pile	Yes	Although the cuttings pile does not exceed OSPAR 2006/5 thresholds to leave *in situ*, it is possible that the cuttings pile could be disturbed during decommissioning activities, should objects be dropped onto them, or in the longer-term as parts of the concrete structure begins to degrade and fall towards the seabed. Given this potential interaction and given that the issue has been raised as a key area of concern for stakeholders, this has been assessed further and is discussed in Section 5.3.2. The 500 m safety exclusion zone surrounding the Dunlin Alpha CGBS will remain in place as a part of the proposed Decommissioning Programme's activities to limit the potential for overtrawling interactions with the drill cuttings immediate to the CGBS. However, given the potentially important environmental implications of such an unplanned event, fishing interactions with the drill cuttings pile has been included as a part of the assessment of unplanned events within the EA.

Appendix C – Impact Assessment Methodology

C.1 Impact Definition

C.1.1 Impact Magnitude

Table C1 Nature of Impact

Nature of impact	Definition
Beneficial	Advantageous or positive effect to a receptor (i.e. an improvement).
Adverse	Detrimental or negative effect to a receptor.

Table C2 Type of impact

Type of impact	Definition
Direct	Impacts that result from a direct interaction between the project and the receptor. Impacts that are actually caused by the introduction of project activities into the receiving environment. E.g. The direct loss of benthic habitat.
Indirect	Reasonably foreseeable impacts that are caused by the interactions of the project but which occur later in time than the original, or at a further distance from the proposed project location. Indirect impacts include impacts that may be referred to as 'secondary', 'related' or 'induced'. E.g. The direct loss of benthic habitat could have an indirect or secondary impact on by-catch of non-target species due to displacement of these species caused by loss of habitat.
Cumulative	Impacts that act together with other impacts (including those from any concurrent or planned future third-party activities) to affect the same receptors as the proposed project. Definition encompasses "in-combination" impacts.

Table C3 Duration of impact

Duration	Definition
Short term	Impacts that are predicted to last for a short duration (e.g. less than one year).
Temporary	Impacts that are predicted to last a limited period (e.g. a few years). For example, impacts that occur during the decommissioning activities and which do not extend beyond the main activity period for the works or which, due to the timescale for mitigation, reinstatement or natural recovery, continue for only a limited time beyond completion of the anticipated activity
Prolonged	Impacts that may, although not necessarily, commence during the main phase of the decommissioning activity and which continue through the monitoring and maintenance, but which will eventually cease.
Permanent	Impacts that are predicted to cause a permanent, irreversible change.

Table C4 Geographical extent of impact

Geographical extent	Description
Local	Impacts that are limited to the area surrounding the proposed project footprint and associated working areas. Alternatively, where appropriate, impacts that are restricted to a single habitat or biotope or community.
Regional	Impacts that are experienced beyond the local area to the wider region, as determined by habitat/ecosystem extent.
National	Impacts that affect nationally important receptors or protected areas, or which have consequences at a national level. This extent may refer to either Scotland or the UK depending on the context.
Transboundary	Impacts that could be experienced by neighbouring national administrative areas.

Geographical extent	Description
International	Impacts that affect areas protected by international conventions, European / international designated areas or internationally important populations of key receptors (e.g. birds, marine mammals).

Table C5 Frequency of impact

Frequency	Description
Continuous	Impacts that occur continuously or frequently.
Intermittent	Impacts that are occasional or occur only under a specific set of circumstances that occurs several times during the course of the project. This definition also covers such impacts that occur on a planned or unplanned basis and those that may be described as 'periodic' impacts.

C.1.2 Impact Magnitude Criteria

Table C6 Impact magnitude criteria

Magnitude	Criteria
Major	Extent of change: Impact occurs over a large scale or spatial geographical extent and /or is long term or permanent in nature. Frequency/intensity of impact: high frequency (occurring repeatedly or continuously for a long period of time) and/or at high intensity.
Moderate	Extent of change: Impact occurs over a local to medium scale/spatial extent and/or has a prolonged duration. Frequency intensity of impact: medium to high frequency (occurring repeatedly or continuously for a moderate length of time) and/or at moderate intensity or occurring occasionally/intermittently for short periods of time but at a moderate to high intensity.
Minor	Extent of change: Impact occurs on-site or is localised in scale/spatial extent and is of a temporary or short-term duration. Frequency/intensity of impact: low frequency (occurring occasionally/intermittently for short periods of time) and/or at low intensity.
Negligible	Extent of change: Impact is highly localised and very short term in nature (e.g. days/few weeks only).
Positive	An enhancement of some ecosystem or population parameter.
Notes: Impact Magniture is based on a variety of parameters. Definitions provided above are for guidance only and may not be appropriate for all impacts. For example, an impact may occur in a very localised area (minor to moderate) but at very high frequency/intensity for a long period of time (major). In such cases informed judgement is used to determine the most appropriate magnitude ranking and this is explained through the narrative of the assessment.	

C.1.3 Receptor Sensitivity

Table C7 Sensitivity of receptor

Receptor sensitivity	Definition
Very high	Receptor with no capacity to accommodate a particular effect and no ability to recover or adapt.
High	Receptor with very low capacity to accommodate a particular effect with low ability to recover or adapt.
Medium	Receptor with low capacity to accommodate a particular effect with low ability to recover or adapt.
Low	Receptor has some tolerance to accommodate a particular effect or will be able to recover or adapt.
Negligible	Receptor is generally tolerant and can accommodate a particular effect without the need to recover or adapt.

C.1.4 Receptor Vulnerability

Table C8 Vulnerability of receptor

Receptor vulnerability	Definition
Very high	The impact will have a permanent effect on the behaviour or condition on a receptor such that the character, composition or attributes of the baseline, receptor population or functioning of a system will be permanently changed.
High	The impact will have a prolonged or extensive temporary effect on the behaviour or condition on a receptor resulting in long term or prolonged alteration in the character, composition or attributes of the baseline, receptor population or functioning of a system.
Medium	The impact will have a short-term effect on the behaviour or condition on a receptor such that the character, composition, or attributes of the baseline, receptor population or functioning of a system will either be partially changed post-development or experience extensive temporary change.
Low	Impact is not likely to affect long term function of system or status of population. There will be no noticeable long term effects above the level of natural variation experience in the area.
Negligible	Changes to baseline conditions, receptor population of functioning of a system will be imperceptible.

C.1.5 Receptor Value

Table C9 Value of receptor

Value of receptor	Definition
Very high	Receptor of international importance (e.g. United Nations Educational, Scientific and Cultural Organisation (UNESCO) World Heritage Site (WHS)). Receptor of very high importance or rarity, such as those designated under international legislation (e.g. EU Habitats Directive) or those that are internationally recognised as globally threatened (e.g. IUCN Red List). Receptor has little flexibility or capability to utilise alternative area. Best known or only example and/or significant potential to contribute to knowledge and understanding and/or outreach.
High	Receptor of national importance (e.g. NCMPA, SAC, SPA). Receptor of high importance or rarity, such as those which are designated under national legislation, and/or ecological receptors such as United Kingdom Biodiversity Action Plan (UKBAP) priority species with nationally important populations in the study area, and species that are near-threatened or vulnerable on the IUCN Red List. Receptor provides the majority of income from the project area. Above average example and/or high potential to contribute to knowledge and understanding and/or outreach.
Medium	Receptor of regional importance. Receptor of moderate value or regional importance, and/or ecological receptors listed as of least concern on the IUCN Red List but which form qualifying interests on internationally designated sites, or which are present in internationally important numbers. Any receptor which is active in the project area and utilises it for up to half of its annual income/activities. Average example and/or moderate potential to contribute to knowledge and understanding and/or outreach.

Value of receptor	Definition
Low	Receptor of local importance. Receptor of low local importance and/or ecological receptors such as species which contribute to a national site, are present in regionally. Any receptor which is active in the project area and reliant upon it for some income/activities. Below average example and/or low potential to contribute to knowledge and understanding and/or outreach.
Negligible	Receptor of very low importance, no specific value or concern. Receptor of very low importance, such as those which are generally abundant around the UK with no specific value or conservation concern. Receptor of very low importance and activity generally abundant in other areas/not typically present in the project area. Poor example and/or little or no potential to contribute to knowledge and understanding and/or outreach.

C.1.6 Assessment of Consequence and Impact Significance

Table C10 Assessment of consequence

Assessment consequence	Description (consideration of receptor sensitivity and value and impact magnitude)	Impact significance
Major	Impacts are likely to be highly noticeable and have long term effects, or permanently alter the character of the baseline and are likely to disrupt the function and status/value of the receptor population. They may have broader systemic consequences (e.g. to the wider ecosystem or industry). These impacts are a priority for mitigation in order to avoid or reduce the anticipated effects of the impact.	Significant
Moderate	Impacts are likely to be noticeable and result in prolonged changes to the character of the baseline and may cause hardship to, or degradation of, the receptor population, although the overall function and value of the baseline/receptor population is not disrupted. Such impacts are a priority for mitigation in order to avoid or reduce the anticipated effects of the impact.	Significant
Low	Impacts are expected to comprise noticeable changes to baseline conditions, beyond natural variation, but are not expected to cause long term degradation, hardship, or impair the function and value of the receptor. However, such impacts may be of interest to stakeholders and/or represent a contentious issue during the decision-making process, and should therefore be avoided or mitigated as far as reasonably practicable	Not significant
Negligible	Impacts are expected to be either indistinguishable from the baseline or within the natural level of variation. These impacts do not require mitigation and are not anticipated to be a stakeholder concern and/or a potentially contentious issue in the decision-making process.	Not significant
Positive	Impacts are expected to have a positive benefit or enhancement. These impacts do not require mitigation and are not anticipated to be a stakeholder concern and/or a potentially contentious issue in the decision-making process.	Not significant

Appendix D – Modelling Details

D.1 Overview

As outlined in Section 5, modelling has been undertaken to support both release of cell contents and disturbance of drill cuttings resulting from objects falling from above which have been compiled in the Xodus (2020a) *Legacy Environmental Impacts Modelling Report*. This appendix provides further technical detail on the modelling undertaken within this EA, as well as illustrations of selected modelling results.

D.2 Modelling Software

D.2.1 Cell Contents Release

The Scandinavian Independent Research Organisation (SINTEF) has developed a Marine Environmental Modelling Workbench (MEMW) interface to provide an interface for undertaking a range of modelling exercises. This interface provides an industry-standard mechanism for predicting the environmental fate of a user-defined release scenario. For the cell contents release, modelling was run in deterministic mode with a release of the mobile oil contained within the cells occurring over one hour. In doing this it was possible to understand the fate of the oil and to fully evaluate impacts on shoreline, sediment, water column and the sea surface over the duration of the release. It should be noted that deterministic modelling differs from stochastic modelling (commonly used for oil spill contingency planning) in two important aspects. Firstly, in a deterministic model the sediment compartment is considered, whereas in a stochastic oil spill model, oil that enters the sediment compartment is considered to have left the model domain in the same manner as oil leaving the edge of the model grid. This oil therefore cannot be assessed in a stochastic model. Secondly, oil may be removed from the beach after beaching. In a deterministic model, wave action and biodegradation may remove oil from the beach, with oil remobilised by wave action able to move under the influence of currents and wind and subsequently beach again. In stochastic modelling, oil only accumulates on the shoreline, and thus the location of first interaction receives the oil. Whilst this is not an issue when assessing oil accumulation from large volume releases, it does not allow for the detailed assessment of small volume releases such as the CGBS oil release considered here.

D.2.2 Drill Cuttings Disturbance

The cuttings discharges were modelled using DREAM (Dose-related Risk and Effect Assessment Model), Sintef, part of the Marine Environmental Modelling Workbench (MEMW) suite of models, Version 9.0.0, which incorporates the ParTrack sub-model used for modelling the dispersion and settlement of solids. The model predicts the fate of materials discharged to the marine environment (their dispersion and physico-chemical composition over time) and it can also calculate an estimate of risk to the environment using a metric known as the Environmental Impact Factor (EIF).

The model has been developed to calculate the dispersion and deposition on the seabed of drilling mud and cuttings as well as the dispersion of chemicals in the free water masses. The calculations are based on the particle approach, combined with a near field plume model and the application of external current fields for the horizontal advection of the particles. The model consists of a plume mode and far-field mode. The plume mode takes into account affects from water stratification on the near field mixing, ambient currents and geometry of the discharge port. Once plume advection ceases, particles fall out of the plume and deposit on the bottom. Downwards (or rise) velocity of the particles is dependent on size and particle density and also on agglomeration of solids in the presence of oil-related components. The far-field model includes the downstream transport and spreading of particles and dissolved matter, once the plume mode is terminated.

D.2.3 Calculation of impact

The modelling incorporates two difference but related metrics of impact calculation, the PEC / PNEC ratio and the EIF. These are explained in the sections below.

D.2.3.1 PEC / PNEC ratio

The PEC of each contaminant is divided by the PNEC. Where the result exceeds 1, an unacceptable effect on the biota is likely to occur.

The model calculates the PEC for each contaminant within each model grid cell for each time step of the simulation. The PEC is calculated by tracking the fate of each contaminant particle released based on the dilution, partitioning, degradation and deposition of the particles.

The PNEC value for each contaminant is the highest concentrations at which toxic effects are not expected. The PNEC values for each substance is calculated by laboratory tests and by an assessment factor to produce a value that is considered to be protective of all but the most sensitive 5% of species. This approach is internationally accepted in the regulatory assessment of chemicals.

D.2.3.2 Environmental Impact Factor (EIF)

EIFs are a relative measure of risk to the biota in the marine environment and can be calculated for the water column or the seabed. First, the entire modelled area is split into compartments. For the water column EIF each compartment measures 100 m x 100 m x 10 m (0.0001 km^3), and for the seabed EIF, this is 100 m x 100 m (0.01 km^2).

In each compartment, the PEC/PNEC approach is used, however in this case the model incorporates additional stressors (rather than just contaminant toxicity) to calculate the PEC values. For example, stress to the biota due to changes in seabed sediment particle size (resulting from settling of released particles onto the existing sediment) is incorporated. In each time step, every compartment exhibiting a PEC/PNEC ratio ≥1 contributes a value of 1 to the total EIF for that time step in the scenario.

SINTEF, the developers of the DREAM (ParTrack) model clearly state that the EIF is not a measure of absolute impact, but rather a comparative tool to support environmental management decision making. As such, the absolute value of the EIF is not meaningful alone; however, comparison of EIF values for different discharge scenarios based on equivalent assumptions provides a powerful tool for understanding and comparing potential impacts of these scenarios.

Further details of the model can be found at the Sintef Environmental Risk Management System Website (https://www.sintef.no/Projectweb/ERMS/Reports/).

D.3 Modelling Limitations

There are a number of limitations to consider when interpreting the outputs from any modelling exercise, in particular:

- Modelling results are to be used for guidance purposes only and response strategies should not be based solely on modelling results.
- The results are dependent on the quality of the environmental parameters and scenario inputs used.
- The resolution/quality of tidal and oceanic current data vary between regions and models.
- The properties of analogues in the model’s database may not precisely match those of the discharge predicted.

If the same scenarios were to be modelled in another modelling programme with identical parameters and inputs, the results may show a degree of variance. This is expected, as the different fate and weathering models have been developed and programmed independently.

D.4 Modelling Inputs

D.4.1 Cell Contents Release

D.4.1.1 Current Selection

The Oil and Gas UK shelf hourly current file which covers the period April 2011 until June 2014 and are freely available to all members to support MEMW modelling on the UKCS was used in this modelling. In the first instance the metocean data for the release location was reviewed to identify which metocean conditions led to interaction with the shore. The conditions that predicted the largest mass of oil on shore was then run as a standalone deterministic model (i.e. a release scenario under a defined set of environmental conditions) to allow the behaviour of the oil and dissolved components to be assessed in detail. A worst-case deterministic model was selected over a stochastic model as, based upon knowledge of oil spill modelling and major environmental incident assessment conducted in the general area of Dunlin, this would provide a much more detailed information on the likely worst impact of an oil release from the CGBS for such a small quantity of released oil.

D.4.1.2 Volume of the Discharge

Two modelled scenarios of 50 m^3 and 100 m^3 were undertaken to reflect the instantaneous release of cell contents. Whilst the engineering analysis of the likely failure and release of oil from the CGBS identified that the worst-case release scenario resulted from the breaching of the roof of 3 cells would result in a release of 50 m^3 of oil. It was considered that the modelling of 100 m^3 would give a further level of confidence in the modelling results. In both instances, the metocean conditions most likely to result in a release arriving at shore were selected. Effectively, these scenarios model a near-instantaneous release of contents in weather conditions that drive the released contents to shore (the likelihood of these sustained metocean condition and release scenario occurring simultaneously is remote). Modelling input for the 50 m^3 and 100 m^3 scenarios are described below.

Location						
Scenario description	Release of 50 / 100 m^3 of oil from the Dunlin Alpha CGBS					
Latitude (WGS84)		Longitude (WGS84)			Quad / block	
61° 16.45'		01° 35.75'			211/23	
Hydrocarbon blow-out parameters						
Hydrocarbon name	Attic Oil					
Release rate (m^3/d)	Release duration (d)	Total release volume (m^3)	Persistence time (d)	Total simulation time (d)	Depth (m) Relative to Seabed or Surface	Temperature of release (°C)
n/a	Instantaneous	50	30	30	32 m above the seabed	10
n/a	Instantaneous	100	30	30	32 m above the seabed	10

Hydrocarbon properties								
	Name	ITOPF category	Specific gravity	API	Pour point (°C)	Wax content (%)	Asphaltene content (%)	Viscosity (cP @ 15°C)
OSCAR analogue	Norne Blend 2010, 13°C	2	0.868	31.6	12	11.7	0.06	53

Metocean parameters				
Season	**Air temperature (°C)**	**Sea surface temperature (°C)**	**Wind data**	**Current data**
Winter	2	8	6 years' (2008 – 2014) 3-hourly European Centre for Medium-Range Weather Forecasts (ECMWF) wind data	5 years' (2008 – 2013) seasonal Hybrid Coordinate Ocean Model (HYCOM) daily current data
Spring	4	8		
Summer	10	13		
Autumn	7	11		

D.4.1.3 Composition of the Discharge

The contaminant concentrations within the cells are presented in Xodus (2018) and summarised in Section 2.1.2. These contaminants are used as direct input to the model to describe the composition of the discharge.

D.4.1.4 Rate of Discharge

Aspect	Instantaneous Release Input (50 m^3)	Instantaneous Release Input (100 m^3)
Number of cells	4	4
Release volume (m^3)		
Mobile oil	*50*	*100*
Water phase	*13,000*	*13,000*
Exposure volume (m3)		
Sediment	N/A	N/A
Wall residue	N/A	N/A
Release duration (hour)		
Mobile oil	0.5	0.5
Water phase	168	168
Sediment	N/A	N/A
Wall residue	N/A	N/A
Release rate (m^3/hour)		
Mobile oil	100	200
Water phase	77	77
Sediment	N/A	N/A
Wall residue	N/A	N/A

D.4.1.5 Gradual Hydrocarbon Release

As described in Section 5.2.2.2, the table below presents the inputs that were used in the deterministic modelling for the gradual hydrocarbon release.

<table>
<tr><th colspan="9">Location</th></tr>
<tr><td colspan="2">Scenario description</td><td colspan="7">Release of 0.8 m³/day of oil from the Dunlin Alpha CGBS sub-compartments</td></tr>
<tr><td colspan="3">Latitude (WGS84)</td><td colspan="3">Longitude (WGS84)</td><td colspan="3">Quad / block</td></tr>
<tr><td colspan="3">61° 16.45’</td><td colspan="3">01° 35.75’</td><td colspan="3">211/23</td></tr>
<tr><th colspan="9">Hydrocarbon blow-out parameters</th></tr>
<tr><td colspan="2">Hydrocarbon name</td><td colspan="7">Attic Oil</td></tr>
<tr><td>Release rate (m³/d)</td><td>Release duration (d)</td><td>Total release volume (m³)</td><td>Persistence time (d)</td><td>Total simulation time (d)</td><td colspan="2">Depth (m)
Relative to Seabed or Surface</td><td colspan="2">Temperature of release (°C)</td></tr>
<tr><td>0.8</td><td>30</td><td>24</td><td>30</td><td>60</td><td colspan="2">32 m above the seabed</td><td colspan="2">4</td></tr>
<tr><th colspan="9">Hydrocarbon properties</th></tr>
<tr><td></td><td>Name</td><td>ITOPF category</td><td>Specific gravity</td><td>API</td><td>Pour point (°C)</td><td>Wax content (%)</td><td>Asphaltene content (%)</td><td>Viscosity (cP @ 15°C)</td></tr>
<tr><td>OSCAR analogue</td><td>Norne Blend 2010, 13°C</td><td>2</td><td>0.868</td><td>31.6</td><td>12</td><td>11.7</td><td>0.06</td><td>53</td></tr>
</table>

<table>
<tr><th colspan="5">Metocean parameters</th></tr>
<tr><th>Season</th><th>Air temperature (°C)</th><th>Sea surface temperature (°C)</th><th>Wind data</th><th>Current data</th></tr>
<tr><td>Winter</td><td>2</td><td>8</td><td rowspan="4">6 years’ (2008 – 2014) 3-hourly European Centre for Medium-Range Weather Forecasts (ECMWF) wind data</td><td rowspan="4">5 years’ (2008 – 2013) seasonal Hybrid Coordinate Ocean Model (HYCOM) daily current data</td></tr>
<tr><td>Spring</td><td>4</td><td>8</td></tr>
<tr><td>Summer</td><td>10</td><td>13</td></tr>
<tr><td>Autumn</td><td>7</td><td>11</td></tr>
</table>

D.4.2 Drill Cuttings Disturbance

D.4.2.1 Current Selection

The Oil and Gas UK shelf hourly current file which covers the period April 2011 until June 2014 and are freely available to all members to support MEMW modelling on the UKCS was used in this modelling. These current files were analysed to determine the least dispersive period for the discharge location (i.e. at the Dunlin Alpha location near the seabed) and this was used for the subsequent modelling.

D.4.2.2 Volume of Cuttings

The cuttings pile volumes have been derived from the Fugro (2018) drill cuttings report. Based on the scenarios described above, the following volumes were utilised in the model:

- Scenario 5a: 10% discharge – 2,550 tonnes - equivalent to a cylinder with an 8.9 m radius penetrating approximately 3.5 m into the cuttings pile or a cylinder with a 5.4 m radius penetrating approximately 4.3 m into the cuttings pile;

- Scenario 5b: 5% discharge – 1,275 tonnes - equivalent to a cylinder with an 8.9 m radius penetrating approximately 2.1 m into the cuttings pile, or a cylinder with a 5.4 m radius penetrating approximately 2.6 m into the cuttings pile; and
- Scenario 5c: 1% discharge – 255 tonnes - equivalent to a cylinder with an 8.9 m radius penetrating approximately 0.7 m of into the cuttings pile, or a cylinder with a 5.4 m radius penetrating approximately 0.8 m into the cuttings pile.

Location	
Scenario description	Disturbance of cuttings pile at the Dunlin Alpha CGBS for 3 scenarios
Start Date	20th November 2010

Latitude (WGS84)	Longitude (WGS84)	Quad / block
61° 16.4572’	1° 35.7508’	211/23

Mass of material resuspended (te)			
Material	Scenario 5a (10%)	Scenario 5b (5%)	Scenario 5c (1%)
Cuttings	2,120	1,060	212
Barite	329	164	32.9
Bentonite	97.4	48.7	9.74
Total particulate material	426	213	42.6
Mass of organic contaminants (te)			
Contaminant	Scenario 5a (10%)	Scenario 5b (5%)	Scenario 5c (1%)
Dispersed oil	187	93.6	18.7
AP/APE	0.576	0.288	5.76 x 10-2
BPA	1.79 x 10-5	8.93 x 10-6	1.79 x 10-6

Concentrations of heavy metals (µg/g)					
Cadmium	Chromium	Copper	Mercury	Lead	Zinc
3.46	1.4	87.8	1.23	126	897

Metocean parameters				
Parameter	Value	Data Source	Wind data	Current data
Air temperature (°C)	7	UK MetOffice (2015)	6 years’ (2008 – 2014) 3-hourly European Centre for Medium-Range Weather Forecasts (ECMWF) wind data	5 years’ (2008 – 2013) seasonal Hybrid Coordinate Ocean Model (HYCOM) daily current data
Sea surface temperature (°C)	11	MyOcean (2014)		
Seabed temperature (°C)	10	MyOcean (2014)		
Salinity	35‰	Default value in DREAM		

D.4.2.3 Composition of the Discharge

The contaminant concentrations within the cuttings pile are presented in Fugro (2018) and summarised in Section 5.3.2. These contaminants are used as direct input to the model to describe the composition of the discharge.

D.4.2.4 Nature of the Discharge

To approximate the instantaneous disturbance that would occur from a dropped object, the model assumes a single release location and a rapid discharge from a single location above the point of assumed impact. The material is released in accordance with the following assumptions:

- Discharge time: 1 hour; and
- Height above seabed: 30 m.

Detailed results of the modelling undertaken to date can be found in the Xodus (2020a) *Dunlin Alpha Decommissioning* - *Legacy Environmental Impacts Modelling Report.*