

Environmental Assessment of Options for the Management of the Murchison Drill Cuttings Pile



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GLOSSARY

Abbreviation	Meaning			
APE	Alkylphenol Ethoxylates			
BAC	Background assessment concentration			
BAT	Best Available Technique			
BEP	Best Environmental Practice			
CH ₄	Methane			
CNRI	Canadian Natural Resources International			
CO ₂	Carbon dioxide			
CoP	Cessation of Production			
DECC	Department of Energy and Climate Change			
DREAM	Dose-related Risk and Effect Assessment Model			
EAC	Environmental Assessment Criteria, below which adverse effects on organisms are not expected			
EIF	Environmental Impact Factor			
ERL	Effect Range Low, below which adverse effects on organisms are rarely observed			
ICES	International Council for the Exploration of the Seas			
loP	Institute of Petroleum			
LTOBM	Low-toxicity Oil Based Mud			
MBES	Multi-Beam Echo Sounder			
MUR Mean	Mean value for Murchison surrounding sediments (250m – 10,000m)			
NPD	Napthalene, phenanthrene, dibenzothiophene			
NLGP	Northern Leg Gas Pipeline			
NO _x	Mono-nitrogen oxides (nitric oxide and nitrogen dioxide)			
NSTF	North Sea Task Force, which is responsible for the OSPAR North Sea Quality Status Report			
OBM	Oil Based Mud			
OSPAR	Oslo Paris Convention			
P&A	Plug and Abandonment			
PAH	Polycyclic Aromatic Hydrocarbons			
ParTrack	Particle Tracking Model			
РСВ	Polychlorinated biphenyls			
Pers comm	Personal Communication			
ROV	Remotely Operated Vehicle			
SINTEF	Norwegian Independent research organisation (Stiftelsen for industriell og teknisk forskning)			
SO ₂	Sulphur dioxide			
ТВТ	Tributyltin			
THC	Total Hydrocarbon Concentration			
UCM	Unresolved Complex Material			
UKCS	United Kingdom Continental Shelf			
WBM	Water Based Mud			

EXECUTIVE SUMMARY

The Murchison platform has a historic drill cuttings pile located beneath the south-east edge of the platform, which was created by the discharge and subsequent accumulation of drill cuttings and drilling muds during its >20 year drilling programme. Between 1980 and 2000 oil based muds were used and oil-contaminated discharges were made in line with normal, permitted operations at the time. The cuttings pile has a measured height of 15.34 m and has been measured to cover an area of 6,840 m² and have a volume of 22,545 m³. Total hydrocarbon concentrations measured from the surface of the drill cuttings pile ranged from 1,310 μ gg⁻¹ to 10,100 μ gg⁻¹, compared to a range of 1.0 μ gg⁻¹ to 450 μ gg⁻¹ from background sediments.

OSPAR Recommendation 2006/5 sets out a regime for the management of historic oil-based mud cuttings piles. This is based on criteria thresholds against which the level of pollution attributable to a historic drill cuttings pile may be measured, to determine whether the level of pollution could be considered significant. The Murchison drill cuttings pile is predicted to be significantly below the OSPAR thresholds for both "total rate of oil release into the water column" and "persistence over the area of seabed contaminated" (Genesis, 2013a). As a result, OSPAR Recommendation 2006/5 indicates that natural degradation *in-situ* is considered to be the best environmental strategy.

However, if the Murchison jacket were to be removed completely, the entire drill cuttings pile would have to be excavated and removed or displaced to allow the jacket footings to be cut and the lower bracings to be released. Consequently, CNRI are examining options for the management of the Murchison drill cuttings pile, by means of a comprehensive Comparative Assessment as described in OSPAR Recommendation 2006/5. In addition, if the pile were to be left *in-situ* the eventual collapse of the derogated jacket footings could disturb the cuttings pile and consequently a Stage 2 assessment is required.

In addition to the option "leave *in situ*", four options for the removal or displacement of the Murchison cuttings pile have been considered:

Option 1: Recovery of the whole pile to the platform or a vessel; separation, treatment and discharge of liquids offshore; transportation and treatment of solids onshore.

Option 2: Recovery of the whole pile to a vessel; transportation of slurry to shore, separation and treatment of slurry onshore for disposal.

Option 3: Recovery of the whole pile to the platform, offshore injection of slurry into part of the Murchison rock formation.

Option 4: Dispersion / redistribution offshore, in the area immediately adjacent to the Murchison jacket.

Option 5: Leave *in-situ* for natural degradation.

This study assesses the potential environmental impacts associated with options for the management of the Murchison drill cuttings pile, for input into the comparative assessment process. The assessments of the safety risk, technical feasibility and cost of each management option have been conducted independently and are recorded separately in the comparative assessment report.

Energy use and atmospheric emissions resulting from the excavation, removal and treatment of the drill cuttings pile were very similar in all the different removal options. In all cases emissions were very low when compared to the emissions generated by Murchison during normal production operations in 2011 and as a result the impacts for all options were considered to be of low significance.

Modelling studies were conducted to give high level predictions of the nature, extent and duration of impacts to the seabed and water column as a result of physical disturbance to the drill cuttings pile associated with the four different options to remove the pile. Results of the modelling study were used to inform the impact assessment for each of the removal options.

In Option 4 "Re-distribution offshore", the drill cuttings pile would be significantly disturbed; the bulk of the cuttings would be re-suspended into the water column, where they would drift with local currents and settle on the adjacent seabed. It was predicted that this would lead to increased concentrations of contaminants in the water column for a prolonged period of time (estimated 394 days) and in seabed sediments, with potentially significant impacts to the water column, sediments and benthic organisms. Total hydrocarbon concentrations (THC) >50 mg/kg are predicted to impact an area of approximately 10 km² immediately post redistribution and reduce to 1 km² after 10 years. After 10 years post redistribution the contaminated area would be double the area of existing contamination from the historic cuttings pile discharge.

In Option 1 "Recovery with offshore treatment and onshore disposal"; Option 2 "Recovery with onshore treatment and disposal"; Option 3 "Recovery and re-injection"; and Option 4 "Re-distribution offshore"; offshore trials have indicated that the excavation system would be subject to frequent blockages that would require back-flush of the suction dredge and subsequent discharge of the cuttings material from the dredge system. Physical disturbance as a result of dredge back-flushing was considered to have a potentially moderate significant impact to the water column. It was estimated that there could be hundreds of back-flush operations required over the duration of the excavation operations (estimated 394 days) resulting in the discharge of 100's to 1,000's of cubic meters of cuttings material into the water column and over the surrounding sediments. It was predicted that this would lead to increased concentrations of contaminants in the water column for a prolonged period of time (> 1 year). Once the excavation operations are complete the contamination within the water column is expected to fall below risk levels within 24 hours. THC levels within the sediment

are predicted to impact an area smaller (0.19 km^2) than the existing THC 50 mg/kg extent from the historic cuttings pile discharge (0.57 km^2) .

There would be no operational disturbances to the drill cuttings pile associated with Option 5 "Leave *in-situ*". However, the eventual collapse of the derogated jacket footings could disturb the cuttings pile after 300-1000 years post-decommissioning as corrosion of the jacket members leads to a failure of structural integrity. An estimated 157 m³ of cuttings material could be re-suspended as the jacket footings collapse, leading to increased concentrations of contaminants in the water column and in seabed sediments. The impacts are predicted to be of low significance as the re-suspension into the water column would last for a very short duration (approximately 24 days) and be limited to a localised area. THC levels within the sediment are predicted to impact an area much smaller (0.04 km²) than the existing 50 mg/kg extent from the historic cuttings pile discharge (0.57 km²).

The potential for fishing gear to interact with the re-distributed drill cuttings pile, in Option 4, and lead to dispersion of cuttings and possible net fouling, was considered to be of low significance. Industry field trials have concluded that, whilst some anecdotal information records an oily taint to fishing nets when contacted with historic pile, trawling interactions are unlikely to result in a significant impact to the sediments or commercial fishing. In Option 5 "Leave *in-situ*" the drill cuttings pile would be left in its current location with the majority of the pile residing within the footprint of the jacket footings which would shield the pile from any fishing gear.

In both Option 1 "Recovery with offshore treatment and onshore disposal" and Option 2 "Recovery with onshore treatment and disposal" the requirement to dispose of 22,545 m³ of cuttings material to landfill would have the impact of reducing the capacity of onshore disposal facilities. This was considered to be of low significance given the relatively small volumes of material in comparison to UK landfill capacities.

If derogation for the jacket footings were granted Option 5 "Leave *in-situ*" was considered to be the best management option for the Murchison drill cuttings pile. This option would result in the lowest levels of physical disturbance to the contaminated cuttings material and would have the greatest potential for recovery of the wider contaminated sediments around the main deposition of the contaminated drill cuttings pile. The presence of the jacket footings would have the effect of shielding the pile from fishing activities, until the footings themselves collapse (within 300-1000 years) by which time the contaminated drill cuttings would be significantly weathered and degraded (Genesis, 2013c).

If derogation of the jacket footings were not granted and the cuttings had to be removed to access the jacket footings then Option 3 "Re-injection" could be considered an attractive management option from an environmental perspective. However, this option is currently not considered to be a viable management option for the Murchison drill cuttings pile as once recovered, the cuttings material would be classified as waste and injection into the seabed is not permissible under the OSPAR Convention and the London Protocol.

1. INTRODUCTION

The Murchison Field, in Block 211/19a of the United Kingdom Continental Shelf (UKCS), was discovered in 1975 and has been producing oil since 1980. It is now approaching the end of its economic life and decommissioning options are being reviewed.

The Murchison platform has an historic drill cuttings pile, located more or less directly beneath the jacket, which was created as a result of the drilling of 56 wells (excluding tiebacks and re-drills), 48 of which were drilled using OBM (ERT, 2008). This historic drill cuttings pile falls within the scope of the Murchison Field decommissioning programme and as such CNRI are conducting various studies on the cuttings pile to determine the appropriate management option for the decommissioning of the pile.

This purpose of this report is to assess the potential environmental impacts associated with the drill cuttings pile management options identified by CNRI.

1.1 Regulatory Framework

The OSPAR recommendation 2006/5 sets out the management regime for offshore cuttings piles, with the purpose of reducing the impacts of pollution by oil and other substances within the pile to a level that is not significant. The management regime sets out criteria thresholds against which the level of pollution attributable to a historic drill cuttings pile may be measured to determine whether the level of pollution could be considered significant. These thresholds, detailed below, form the basis of the screening assessment detailed in Stage 1 of the management regime to determine if the pile requires further investigation. The thresholds are:

- Rate of oil loss to the water column: 10 tonnes /yr
- Persistence over the area of seabed contaminated¹: 500 km²yr

Where a cuttings pile falls below both of these thresholds and no other discharges have contaminated the cuttings pile, no further action is required. If either of the thresholds is exceeded, however, the Stage 2 assessment for Best Environmental Practice (BEP) or Best Available Technique (BAT) for the pile must be initiated.

1.2 OSPAR Assessment of the Murchison drill cuttings pile

During the life of the platform, approximately 21,234 m³ of cuttings have been discharged to the sea (ERT, 2008). OBM was used and discharged with drill cuttings at 48 of the 56 wells drilled in this field (ERT, 2008). A proportion of this discharged material now exists as a mound on the seabed immediately below the jacket, covering the bottom bracing level of the jacket.

¹ Where area contaminated is the area of seabed where THC exceeds 50 mg/kg

MBES mapping of the drill cuttings mound (ISS, 2011) estimated that the pile has a volume of 22,545 m³, comprising both cuttings and drilling mud, and footprint area of 6,840 m². This figure excludes the platform legs but includes other general platform debris that may be present (e.g. dropped objects such as scaffold poles, welding rods, tools and gratings). The drill cuttings pile has a maximum height of 15.34 m and is located beneath the south-east edge of the platform (ISS, 2011; Figure 1). The edge of the pile extends approximately 40 m north-east and 75 m south-east, and has a clear north-west/south-east orientation which is aligned with the direction of the seabed current.

Results from a desk-top cuttings pile assessment (ERT, 2008) indicated that the Murchison cuttings pile falls below the OSPAR thresholds, and as such no further action would be required with regards to the OSPAR Recommendation 2006/5, and the cuttings pile may be left *in-situ* to degrade naturally (OSPAR, 2006). The volume of the drill cuttings pile used in the original assessment was based on industry average data rather than on site-specific measurement; these thresholds have therefore been recalculated using site-specific data and modelling techniques to re-evaluate the OSPAR thresholds (Sections 5.5 & 6.6).



Figure 1: MBES survey data of the Murchison drill cuttings pile (ISS, 2011).

1.3 Impacts of Full Removal of Murchison Jacket on Drill Cuttings Pile

The total weight of the Murchison jacket in air, excluding conductors, exceeds 10,000 tonnes, and as such the jacket falls within the category of steel structures for which

derogation may be sought from the general rule of "complete removal" under OSPAR 98/3. In such circumstances, OSPAR suggests that partial removal, leaving the "footings" of the jacket on the seabed, may be acceptable if it is demonstrated by a comparative assessment that this would provide significant safety or environmental benefits in comparison with total removal. Consequently, CNRI are considering two main options for the decommissioning of the jacket – full removal and partial removal.

The Murchison jacket footings are embedded within the historic drill cuttings pile, the majority of which is located within the base of the jacket structure (Figure 1 and Figure 2). Virtually all of the drill cuttings would have to be removed to ensure sufficient access to the jacket footings for cutting equipment to sever the piles to allow the jacket footings to be removed. Therefore it is necessary to consider different methods for removing the drill cuttings pile in order to access the jacket footings for full jacket removal. It is noted in the DECC Decommissioning Guidance Notes (v6 2011) that in some cases the 'footings' of the jacket may be embedded within a cuttings pile and any attempt to entirely remove the installation would be impossible without disturbance or removal of the drill cuttings pile.





2. OPTIONS FOR THE MANAGEMENT OF THE MURCHISON CUTTINGS PILE

2.1 Introduction

Contamination associated with the historic Murchison drilling discharges can be classified into two different components (i) the physical accumulation of contaminated cuttings material located primarily within the jacket footprint, (ii) the wider area of contaminated sediments surrounding the discharge site which do not form a physical accumulation but are nevertheless contaminated to a distance of approximately 500 m from the cuttings pile accumulation.

CNRI considered that, as the Murchison drill cuttings pile is below both of the OSPAR 2006/5 thresholds, management options for the pile would be limited to (i) the physical accumulation of contaminated cuttings material within the jacket footprint. The contaminated sediments over the wider area would not be considered within the management options. These sediments form a very thin layer over the background sediments and the benefit of removing this thin layer of sediment, which is currently undergoing natural recovery, would not outweigh the environmental, safety and cost impacts of removing such a large area of sediment.

The options that CNRI have identified and assessed for the management of the Murchison drill cuttings pile are (CNRI, 2012):

- 1. Recovery of the whole pile to the platform or a vessel; separation, treatment and discharge of liquids offshore; transportation and treatment of solids onshore.
- 2. Recovery of the whole pile to a vessel; transportation of slurry to shore, separation and treatment of slurry onshore for disposal.
- 3. Recovery of the whole pile to the platform, offshore injection of slurry into part of the Murchison rock formation.
- 4. Dispersion / redistribution offshore, in the area immediately adjacent to the Murchison jacket.
- 5. Leave *in-situ* for natural degradation.

A sixth option, that of covering the drill cuttings pile, was considered but rejected by CNRI. This option has primarily been considered in historical studies to prevent spreading of the drill cuttings pile material and associated contaminants over a wider area of seabed, and to inhibit the release of oil from the pile (UKOOA, 2002). The Murchison drill cuttings pile would only be left *in situ* if the Murchison jacket footings were left in place under an OSPAR derogation application. If the Murchison jacket were fully removed the drill cuttings pile would have to be removed in order to access the jacket footings (Section 1.3). CNRI consider that if the jacket footings were left in place the drill cuttings pile would be sufficiently protected by the footings structure from commercial fishing activities and that additional

protection by covering the pile would not be necessary to prevent pile disturbance. The Murchison drill cuttings pile is relatively steep-sided and therefore it is likely that it would have to be levelled out so that a cover could be effectively and evenly applied to the whole pile. This, in turn, would result in the disturbance of the pile and the subsequent resuspension of contaminated cuttings. In order to prevent oil gradually seeping through the covering, the coating material would need to remain impermeable. There are currently no suitable tried and tested materials available on the market to create an impermeable layer over a drill cuttings pile, and the long-term potential for the layer to remain impermeable would also be unknown. Consequently, CNRI have not taken this option forward for further assessment.

Table 1 outlines the activities that would be required for each of the management options.

Decommissioning	Disposal Operations		
Method			
	Excavation of the whole drill cuttings pile and recovery of cuttings to		
	surface		
Option 1: Separation,	Dewatering of the slurry		
treatment of liquids	Deoiling / decontamination of the separated water		
offshore, transportation	Disposal of treated water offshore		
and treatment of solids	Transportation of solids to shore		
onshore	Decontamination of the solids onshore		
	Disposal of contaminants (e.g. hydrocarbons)		
	Disposal of treated solids to landfill		
	Excavation of the whole drill cuttings pile and recovery of cuttings to		
	surface		
Option 2 ⁻ Transportation	Transportation of slurry to shore		
of slurry to shore,	Dewatering of the slurry		
separation and treatment	De-oiling / decontamination of the separated water		
onshore for disposal	Disposal of treated water to coastal waters		
	Disposal of contaminants (e.g. hydrocarbons)		
	Disposal of treated solids to landfill		
	Excavation of the whole drill cuttings pile and recovery of cuttings to		
	surface		
Option 3: Offshore	Maintenance of cuttings in a slurry prior to re-injection		
injection of slurry	Re-inject cuttings into nominated injection well(s)		
	Complete approved programme of work to plug and abandon the		
	well		
Option 4: Distribute	Excavation of whole drill cuttings pile		
cuttings over surrounding	Distribution of cuttings over surrounding sediments		
sediments			
Option 5: Leave in-situ	No remedial actions		
	Long-term monitoring		

 Table 1: Drill cuttings pile decommissioning management options and activity breakdown.

2.2 Description of operations in the various management options

2.2.1 Excavation of the Drill Cuttings Pile

An ROV-based suction dredge system is considered to be the most suitable method to remove the drilling cuttings given the limited access between the jacket footings. The ROV would be fitted with a suction hose head to recover cuttings and could be fitted with a cutting type dredge head to handle material of a cohesive nature. It is estimated that a dredge with a 6" diameter suction hose would be the largest tool that could be manoeuvred through the base of the jacket structure between the lower jacket members (CNRI, 2012a).

A number of factors will influence the duration of dredging operations required to excavate the entire Murchison drill cuttings pile, these include: volume of water recovered with the cuttings during dredging (trails on NW Hutton found that water recovery ranged between a water:solid ratio of 6:1 and 25:1 with an average of 15:1); removal rate capacity of the dredge (60-80 tonnes/hr for 6" diameter dredge CNRI, 2012a); and the number of operational hours dredging per day (16 hours dredging time per day out of a 24 hour working day (UKOOA 2002)). It has been estimated that excavation of the entire drill cuttings pile could take between 137 and 628 days with mid-duration of 394 days, based on the range of values of the factors influencing the dredging operations.

2.2.2 Recovery of Drill to Cuttings to the Surface

To recover the drill cuttings to the surface, a lift pipe would be lowered to the seabed from the platform or vessel. The lift pipe would be attached to the exhaust vent of the ROV suction dredge to create a closed dredging system. The ROV-based dredging system would excavate the drill cuttings as described in Section 2.2.1, and an additional pump placed on the seabed would be used to pump the cuttings up to the surface and into the vessel's storage tanks or to holding tanks on the platform. Based on the water:solid ratios (average of 15:1) experienced during the NW Hutton drill cuttings recovery trial it has been estimated that the total volume of slurry received to the surface could be 360,720 m³.

2.2.3 Dispersion / redistribution offshore

The drill cuttings would be excavated as described in Section 2.2.1 and the excavated drill cuttings material would be dispersed from an exhaust hose attached to the ROV suction dredge, and redistributed over the sediments surrounding the Murchison platform. The discharging end of the exhaust hose would be placed approximately 70 m away from the platform to ensure that the platform bottom brace members remained clear of the discharged cuttings (CNRI, 2012a). Whilst the end of the exhaust hose would generally remain static during dredging operations, as the discharged cuttings form a new pile the end of the hose would be moved several 10's metres as the pile height reached the height of the tethered exhaust hose to prevent it from blocking.

2.3 Disposal Operations

2.3.1 Separation and treatment of liquids offshore, transportation and treatment of solids onshore

Once on board the platform or the vessel, the cuttings would be held in storage tanks whilst being processed and cleaned. The slurry would be treated using a thermal desorption unit, where the recovered drill cuttings slurry is fed into a hopper before passing into either a Hammermill or Rotary Kiln unit in which the volatile components in the slurry are vaporised. Cleaned drill cuttings are returned to shore and the vapours are passed through condensers to recover the oil and water. Recovered seawater would be cleaned to regulatory standards for discharge overboard, and the recovered separated oil and rock cuttings would be transported to shore in containers for onshore disposal/reuse (CNRI, 2012a). At the treatment rates of 1.5-3.0 tonnes/hr achievable at these water/solid rates, it is estimated that it would take 10 years to treat the recovered slurry.

2.3.2 Transportation of slurry to shore, separation and treatment onshore for disposal

Once recovered to the surface, the slurry of drill cuttings (on average comprising an estimated 1 part cuttings to 15 parts entrained seawater) would be transported to shore for processing. Separation and treatment of the cuttings onshore would be carried out by a specialist contractor. Following treatment to remove the hydrocarbons from the cuttings, the inert material would be disposed of to landfill, the recovered oil would be reused, and the treated water discharged to sea under permit (CNRI, 2012a).

2.3.3 Offshore injection of slurry

Once on the platform, the cuttings may be further mixed with seawater and a suitable suspension agent and then slurrified by grinding the cuttings particles to a maximum diameter of 300 microns. The slurry would then be injected from the Murchison platform into a suitable formation through one of the existing platform wells, which would be converted into a disposal well. A temporary slurrification system, an injection system and four operators would be required on the Murchison platform to re-inject the recovered cuttings. It is expected that cuttings injection rates could equal the excavation/lifting rates for the pile material and as such injection would take the same amount of time as excavation/lifting (CNRI, 2012a).

3. IMPACT IDENTIFICATION

The first step in the risk assessment is to identify (i) the different activities or sources of potential environmental impact or risk associated with each of the proposed options for the management of the drill cuttings pile (Section 2), and (ii) the sensitivities of the receiving environment in which the Murchison facilities are located (Section 4).

Potential risks associated with the removal options for the Murchison drill cuttings pile were assessed using an environmental risk assessment matrix which combined two measures, the severity of an impact and the likelihood that it would occur. The likelihood that an impact would occur was assessed using the definitions specified in the CNRI Management of Aspects and Impacts Procedure (SHE-PRO-314) (Table 2).

Likelihood	Definition			
4 Mary Hullish	A freak combination of factors would be required for an incident to result.			
1. Very Officery	An incident has occurred within the UKCS in the past.			
2 Unlikoly	A rare combination of factors would be required for an incident to result.			
2. Unlikely	An incident has occurred on a CNRI platform in the past.			
2 Descible	Could happen if a number of additional factors are present, but otherwise unlikely to occur.			
3. FUSSIBLE	An incident has occurred within the named platform's lifetime.			
	Not certain, but incident could occur with only one normally-occurring additional factor.			
4. LIKEIY	An incident has occurred within the past year on the named platform.			
	Almost inevitable that an incident will occur under the circumstances.			
5. Very Likely	An incident has happened several times on the platform within the last year or the impact on the environment is part of a continuous operation.			

Table 2: Definition of likelihood	l of occurrence (SHE-PRO-314)
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The severity of any impact was assessed using the definitions specified in the UKOOA Offshore Environmental Statement Guidelines (1999) (Table 3). The definitions of severity outlined in the CNRI Management of Aspects and Impacts Procedure is specific to a process loss, therefore the UKOOA guidelines were used to support this definition for the assessment of impacts unrelated to process loss.

Severity	Definition (CNRI, SHE-PRO-314)	Definition (UKOOA Offshore Environmental Statement Guidelines (1999)
0. None	-	No interaction and hence no change expected.
Beneficial	-	Likely to cause some enhancement to the ecosystem or activity within the existing structure.
		May help local population.
	No loss to the external environment.	Change which is unlikely to be noticed or measurable against background activities.
		Negligible effects in terms of health or standard of living.
0 Oliaht	Potential loss to the external environment from a system or process	Change which is within the scope of existing variability, but can be monitored and / or noticed.
2. Slight	does not exceed 1 tonne.	May affect behaviour, but not a nuisance to users or public.
	Potential loss to the external environment from a system or process is between 1 and 25 tonnes.	Change in the ecosystem or activity in a localised area for a short time (< 2 years), with good recovery potential. Similar scale of effect
3. Moderate	There is a breach of consent and / or legislative conditions which is unlikely to	to existing variability, but may have cumulative implications.
	result in prosecution from Regulators.	Potential effect on health, but unlikely.
		May cause nuisance to some users.
4 High	Potential loss to the external environment from a system or process is between 25 and 100 tonnes.	Change in the ecosystem or activity over a wide area leading to medium-term (>2 years) damage, but with a likelihood of recovery within
4. mgn	There is a breach of consent and / or	10 years.
	prosecution from Regulators.	
	Potential loss to the external	Change in the approximation leading to long term
	environment from a system or process of greater than 100 tonnes.	(>10 years) damage and poor potential for recovery to a normal state.
5. Very high	There is a breach of consent and / or	Likely to affect human health.
	legislative conditions with a strong likelihood of prosecution from Regulators.	Long-term loss or change to users or public finance

Table	3:	Definition	of	severity	of	impact
1 4 5 1 0	•		•••	00101109	•••	mpaor

The likelihood and severity factors were combined using the risk assessment matrix (Table 4) to determine the level of risk that each aspect of each of the options could pose to the various environmental receptors that would or could be exposed to impact as a result of the proposed options. The overall significance of the impact of each aspect was determined by taking the highest severity of impact (Table 3) associated with the event against any one of the environmental receptors and combined with the likelihood of the event from Table 2. The definition of environmental risk is presented in Table 5.

	Environmental Risk Assessment Matrix					
		Severity				
		Negligible	Slight	Moderate	High	Very High
Likelihood	Very unlikely	1	2	3	4	5
	Unlikely	2	4	6	8	10
	Possible	3	6	9	12	15
	Likely	4	8	12	16	20
	Very likely	5	10	15	20	25

Table 4: Risk Potential Matrix Summary (SHE-PRO-314)

Table 5: Consequence and Probability Rating Guidelines (SHE-PRO-314)

Score	Level of significance	Environmental Risk Definition
1-6	Low significance	Risk acceptable: review annually and continue with current management controls
8-12	Moderate significance	Risk should be reduced: Identify opportunities for improvement through objectives and targets.
15-25	Significant	Risk unacceptable: Immediate action required to reduce risk to an acceptable level.

4. ENVIRONMENTAL BASELINE

The Murchison Field is located within United Kingdom Continental Shelf (UKCS) Block 211/19a and Norwegian Block 33/19b (61° 23' 48.78"N, 01° 44' 25.90"E) in the northern North Sea, approximately 150 km from the nearest UK coastline on the Shetland Islands and straddling the UK/Norwegian median line. This section provides a summary of the environmental conditions in the Murchison field. Further detailed descriptions are available in the following reports and references therein:

- Murchison Pre-Decommissioning Environmental Baseline Survey (Fugro ERT, 2013);
- Murchison Decommissioning EIA Environmental Description MURDECOM-BMT-EN-REP-00126 (BMT Cordah, 2011).

4.1 Environmental Baseline Survey

CNRI conducted a pre-decommissioning environmental baseline survey and drill cuttings pile assessment for the Murchison platform in April / May 2011 (ERT, 2012) with the objective of measuring the footprint, dimensions, topography and volume of the Murchison drill cuttings pile and characterising the physico-chemical and biological status of the pile and surrounding sediments. Prior to the 2011 survey, the Murchison Field had been surveyed on ten separate occasions, comprising 9 environmental surveys by Conoco UK between 1978 and 1993 (UK Benthos, 2004) and once by CNRI in 2006 (Hartley Anderson Ltd., 2007).

4.2 Description of the Murchison Drill Cuttings Pile

During the pre-decommissioning environmental baseline survey in 2011 the Murchison drill cuttings pile was surveyed using MBES (Multi-Beam Echo Sounder) to map the topography of the pile, and six ROV-operated push cores were collected to sample the cuttings pile material. Three cores were used for faunal analysis, and three were used to characterise the physical and chemical composition of the pile (Fugro ERT, 2013; ISS, 2011). Two of the three push core samples were taken at the edge of the Murchison jacket and drill cuttings pile and the third was taken in the centre of the jacket at the edge of the main pile volume. The push cores sampled the very surface of the pile, with one extending to a depth of 0.5 m. During this survey it was not possible to sample any deeper into the drill cuttings pile, to gain more representative samples throughout the different depth and discharge horizons, because of the location of the pile within the footprint of the jacket footings. However, CNRI are currently investigating potential sampling methods that could be used once the platform is no longer operational.

4.2.1 Location and dimensions

The results of the MBES survey indicate that the pile is located under, and to the south-east, of the Murchison platform extending in a south-easterly direction following the main residual current (Fugro ERT, 2013; ISS, 2011). The pile is located against and around the eastern leg of the Murchison jacket and covers the lower horizontal and vertical braces of the jacket (Figure 1). The seabed / base of the cuttings pile contour plane (i.e. the level taken to be where the cuttings pile and seabed level merge) was established as -154 m and the top of the cuttings pile was at a depth of -138.66 m, giving a maximum pile height of 15.34 m (Figure 2; ISS, 2011). The footprint area and volume of the Murchison cuttings pile were calculated as $6,840 \text{ m}^2$ and $22,545 \text{ m}^3$ respectively, based on the MBES topography mapping of the cuttings pile (ISS, 2011).





4.2.2 Physical and Chemical Analysis of the Drill Cuttings Core Samples

Three of the push cores taken from the Murchison drill cuttings pile were sub-sampled for chemical and physical analyses, and the results of the analyses are presented in Table 6 and below.

The silt/clay contents of the push core samples on the drill cuttings pile were 53.8%, 57.7% and 33.5% for stations 1, 2 and 3 respectively and the sediments were classified as coarse silt to fine sand on the Wentworth scale. The sediment samples taken from the wider Murchison area ranged in silt/clay contents from <0.1% to 8.5% and were classified as medium sand on the Wentworth scale, with the exception of one station 250m to the southeast (in the direction of prevailing current) which had 27.9% silt/clay content and was classified as very fine sand.

Analysis of the chemical properties of the Murchison drill cuttings pile material indicates that concentrations of Total Hydrocarbon Concentration (THC), Polycyclic aromatic hydrocarbons (PAH), Polychlorinated Biphenyls (PCBs), Alkylphenol Ethoxylates (APE), Tributyl tin (TBT) and heavy metals were elevated in the drill cuttings pile in comparison to mean concentrations from sediments in the wider Murchison area (Table 6 and Table 7). Concentrations of these contaminants in the drill cuttings pile were also found to exceed concentration levels typical of background marine sediments, and the concentration levels above which adverse effects on organisms may be observed. The chemical constituents recorded in elevated levels in the drill cuttings are consistent with those expected to be associated with drilling discharges, such as those that occurred during the development of the Murchison field (Fugro ERT, 2013). It should be noted that one station from the wider Murchison area, Station 4 - 250m SE Murchison, was found to have highly contaminated sediment almost comparable to levels found within the drill cuttings pile and two orders of magnitude greater than all other stations from the wider Murchison area. It is possible that at some point this station has been directly impacted by drill cuttings discharge.

Certain hydrocarbons (THC and PAH) are known for their toxic effects on marine organisms and are generally regarded as probable carcinogens and mutagens. The high proportion of petrogenically-derived aromatic hydrocarbons (NDP) to total aromatic material present in the drill cuttings pile (77%) indicates a predominantly petrogenic input to the material in these sediments. In comparison, the relatively low proportion of NDP (37%) present in the sediments in the wider Murchison area indicates a predominantly pyrogenic (i.e. arising from forest fires, etc.) input of aromatic material to the surrounding sediments, with some input from petrogenic hydrocarbons (Fugro ERT, 2013).

PCBs, APEs and TBT are known endocrine disrupters which have the potential to alter the function of the endocrine system and consequently cause adverse health effects to an organism or its progeny. Generally these compounds are toxic to marine organisms, may be

bioaccumulated and may cause the following effects; sex change in male fish, shell malformations in oysters, imposex in marine snails, reduced resistance to infection and effects on the human immune system (Fugro ERT, 2013). Concentrations of PCBs in the Murchison drill cuttings pile and the surrounding sediments were found to exceed background concentrations but were substantially lower than the ICES7 PCB ERL of 11.5 ng.g⁻¹ (Table 6).

There are no recognised assessment criteria against which to compare APE concentrations, however, Fugro ERT (2013) compared levels of octylphenol and nonylphenol with national monitoring datasets. The mean sediment octylphenol concentration (both raw data and following normalisation to 2.5% TOC) in the wider Murchison area, Station 4 and the drill cuttings material are lower than the background reference data suggesting that Murchison samples could be considered to be within background concentrations (Table 6) (Fugro ERT. 2013).. Normalised nonylphenol concentrations in sediment from the wider Murchison area (77.1 ng.g⁻¹) exceeded those found at the Swedish 'background' Baltic Sea reference site (20.0 ng.g⁻¹), and was a similar order of magnitude to nonylphenol concentrations observed in the Dutch North Sea (highest levels - 86 ng.g⁻¹, 10km offshore – 50 ng.g⁻¹) (Jonkers et al., 2005).. The measured and normalised levels of nonylphenol in the drill cuttings sediments and at Station 4 were higher than the background reference data and higher than levels recorded at a contaminated site in the Baltic Sea. Therefore the contaminated samples from the drill cuttings pile and Station 4 were considered to exceed background levels of APEs, whilst sediments from the wider Murchison area are considered to be within background concentrations.

Concentrations of TBT in drill cuttings samples exceeded the concentrations in the sediments in the wider Murchison area, and both exceeded the OSPAR EAC (Environmental Assessment Criteria) below which adverse effects on organisms are not expected (Table 6). The Murchison jacket was installed almost entirely uncoated, with the exception of the splash zone (upper 15 m of steel) which were primarily coated in glass-flake reinforced polymeric resin, with some sections of steel required to be galvanised coated in aluminium etch or inorganic zinc silicate primer, and coal tar epoxy top-coat. Therefore the source of the elevated TBT values in the drill cuttings pile is unknown.





Metals occur naturally in the marine environment; some are essential to marine life while others may be toxic to numerous organisms. Drilling discharges associated with the offshore oil and gas industry contain substantial quantities of barium sulphate, which contains measurable concentrations of heavy metals as impurities, including cadmium, chromium, copper, lead, mercury and zinc (NRC, 1983). Generally, concentrations of heavy metals in the drill cuttings exceeded concentrations in the sediments in the wider Murchison area, and those of background sediments and ERL (Table 7).

Table 6: Physical and chemical pro	operties of	f Murchiso	n drill cut	tings pile v	with backg	round dat	asets (Fug	gro ERT, 2	013)	
	Sediment type	TOC (%)	THC mg.g ⁻¹	2-6 Ring PAH µg.g ⁻¹	PCB ICES7 ng.g ⁻¹	NP ng.g ⁻¹	NPEO ng.g ⁻¹	OP ng.g ⁻¹	OPEO ng.g ⁻¹	TBT ng.g ⁻¹
Drill Cuttings Pile Core 1	Coarse Silt	1.31	1,310	14.1	0.44	773	414	0.8	888	1.7
Drill Cuttings Pile Core 2	Coarse Silt	5.29	10,100	65.8	0.73	196	97	<0.1	787	2.0
Drill Cuttings Pile Core 3	Fine sand	1.5	2,590	14.6	0.9	1510	166	3.8	209	5.0
St.4 - 250m SE Murchison	Very fine sand	1.13	450	2.41	0.56	315	451	1.9	5.5	1.5
Sediments (0-500m) (Mean ±StDev)	Medium Sand	0.24 ±0.05	23.63 ±20.56	0.16 ±0.13	<0.1 to 0.14	6.13 ±1.98	2.25 ±1.98	0.22 ±0.10	1.10 ±1.06	<0.4 to 0.5
Sediments (750-2000m) (Mean ±StDev)	Medium Sand	0.21 ±0.03	5.08 ±1.16	0.06 ±0.04	<0.1 to 0.14	3.66 ±0.82	1.22 ±0.82	0.12 ±0.04	0.44 ±0.45	<0.4
Sediments (5,000 – 10,000m) (Mean ±StDev)	Medium Sand	0.20 ±0.04	4.12 ±2.54	0.05 ±0.01	<0.1 to 0.16	4.93 ±2.21	0.91 ±2.21	0.20 ±0.15	0.39 ±0.30	<0.4 to 0.5
Comparative Data										1
NSTF (North Sea Quality Status Report, 1993)	-	-	5.0	-	-	-	-	-	-	-
BC (CEMP 2010) CEMP Assessment Criteria	-	-		0.19	0.20	-	-	-	-	-
BAC (Background Assessment Concentration) (CEMP 2010)	-	-	-	0.36	0.46	-	-	-	-	-
ERL (Effect-Range Low) (CEMP 2010)	-	-	-	3.34	11.50	-	-	-	-	-
OSPAR EAC (Environmental Assessment Criteria)	-	-	-	-	67.9	-	-	-	-	0.01
Dutch North Sea (Jonkers, 2005)	-	-	-	-	-	86.0	-	-	-	-
SSTMP Central Baltic (2003) 'Contaminated site'						360				
OSPAR Region II Irish Sea (2006)	-	-	-	-	-	-	-	170	-	-
OSPAR Region II Baltic Sea (2006)	-	-	-	-	-	-	-	81	-	-

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Table 7: Heavy metal concentrations with background datasets (Fugro ERT, 2013)

	Concentrations expressed as µg.g ⁻¹													
	AI	As	тВа	Cd	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Sr	v	Zn
Drill Cuttings Pile Core 1	18,890	24.6	173,000	5.74	41.1	237	41,110	1.73	686	50.4	3,043	666	33.6	753
Drill Cuttings Pile Core 2	14,760	10.1	231,000	0.99	41.7	59.8	26,580	3.89	860	25.3	279	221	42.8	523
Drill Cuttings Pile Core 3	12,030	23.5	195,000	2.30	36.0	96.7	30,540	2.86	397	24.6	1,037	2,018	44.4	610
St.4 - 250m SE Murchison	10,700	22.5	64,000	1.58	65.3	146.0	25,100	2.33	278	25.2	447	535	61.2	628
Sediments (0-500m) (Mean ±StDev)	2,911 ±224	5.25 ±1.15	3,333 ±3,382	0.06 ±0.02	12.85 ±2.28	14.71 ±8.64	10,456 ±987	0.35 ±0.01	95.0 ±11.9	4.8 ±0.7	19.4 ±6.5	303 ±89	16.8 ±2.8	132.7 ±94.3
Sediments (750-2000m) (Mean ±StDev)	2,641 ±284	5.39 ±1.35	1,412 ±508	0.05 ±0.02	9.23 ±0.99	3.67 ±1.75	9,067 ±1,032	0.28 ±0.25	82.5 ±9.3	4.1 ±0.4	8.7 ±2.9	319 ±112	16.0 ±3.3	18.3 ±7.0
Sediments (5,000 – 10,000m) (Mean ±StDev)	2,167 ±626	3.31 ±2.28	844 ±301	0.07 ±0.03	9.90 ±6.56	2.49 ±0.69	5,952 ±2,341	0.22 ±0.21	65.7 ±32.4	5.1 ±3.9	4.4 ±1.7	265 ±265	9.9 ±5.0	8.6 ±2.3
BC	-	15	-	0.20	60	20.0	-	0.05	-	30	25	-	-	90
BAC	-	25	-	0.31	81	27.0	-	0.07	-	36	38	-	-	122
ERL	-	-	-	1.20	81	34.0	-	0.15	-	-	47	-	-	150

4.2.3 Faunal Analysis of the Drill Cuttings Core Samples

The three cores obtained for faunal analysis were pooled to provide a qualitative assessment of faunal composition, due to the limited volume of material recovered by each core. A total of 32 species was recorded from the pooled core samples, compared to an average of 90 species from each of the grab samples from the surrounding sediments (Fugro ERT, 2013). One of the core samples was virtually abiotic, with only 5 individuals of the hydrocarbon-tolerant polychaete *Capitella capitata* present. The fauna in the other two core samples exhibited greater abundance and species diversity, but most species were present as single individuals. Species that were present in larger numbers were opportunistic and hydrocarbon-tolerant species e.g., *Cirratulus cirratus* (94 individuals), *Capitella capitata* (24 individuals) *Chaetozone setosa* (6 individuals) and *Ophryotrocha sp* (9 individuals).

4.3 Physical Environment within the Vicinity of the Murchison Platform

4.3.1 Seabed Sediments

The seabed in the vicinity of the Murchison platform is generally flat with water depths ranging from 152 m in the south-east to 162 m in the south-west. Sediment analysis throughout the Murchison area indicated low variation in sediment types which were generally classified as moderate to very poorly sorted, medium sand, with the exception of one station located 250 m to the south of the Murchison platform which comprised very fine sands (Fugro ERT, 2013; Hartley Anderson Limited, 2007).

Total carbonate and organic matter ranged from 6.4% to 44.7% and 0.5% to 8.7% respectively throughout the Murchison area. Total carbonate and organic matter in the drill cuttings pile were 18.7% and 4.9% respectively (Fugro ERT, 2013).

4.3.2 Seabed Chemistry

Results from the pre-decommissioning survey and other historical surveys indicate that at distances greater than 250 m from the Murchison platform total hydrocarbon concentrations (THC) are within the limits of typical background concentrations (9.41-40.10 μ g/g; UKOOA, 2001 referenced in Fugro ERT, 2013) for this area of the North Sea, and that at distances less than 250 m from the Murchison platform THC values were elevated above background levels (Fugro ERT, 2013; Hartley Anderson Limited, 2007; UK Benthos, 2004). Analysis indicated that the source of hydrocarbon contamination at the innermost sampling stations was likely to be drilling-related fluids (Fugro ERT, 2013; Hartley Anderson Limited, 2007).

Concentrations of metals were considered to be similar to natural background concentrations typical of the Northern North Sea (NNS), with the exception of the innermost

sampling station to the south where concentrations of metals were found to be elevated with respect to natural background concentrations. In general, a pattern of decreasing metal concentration with distance from the platform was observed (Fugro ERT, 2013).

The results from the 2011 survey of the Murchison field (Fugro ERT, 2013) concur with the estimates that the "effect footprint" of the Murchison cuttings pile, defined as the region within which sediment hydrocarbon concentrations are greater than the 50 mg/kg, extends to less than 500 m from the platform (ERT, 2008).

4.4 Biological Environment within the Vicinity of the Murchison Platform

4.4.1 Conservation Areas

There are no known Annex I habitats of the European Union Habitats Directive (92/43/EEC) in the vicinity of the Murchison Field. The only Annex II species sighted within the Murchison area is the harbour porpoise, sighted in very high numbers in February and July and in low numbers in May, June, August and September (Reid *et al.*, 1998; UKDMAP, 1998).

4.4.2 Seabed Fauna

Infauna and Epifauna

Analysis of samples taken during surveys between 1979 and 2011 has indicated that the macrofaunal community of the Murchison Field is typical of the wider northern North Sea but shows some indication of a moderately modified community within 500 m of the platform (Fugro ERT, 2013; Hartley Anderson Limited, 2007; UK Benthos, 2004).

Polychaete worms were the dominant group in all surveys in terms of both numbers of taxa and individuals (Fugro ERT, 2013; Hartley Anderson Limited, 2007; UK Benthos, 2004). Surveys in 1979 to 1980, at the start of the drilling period, found a community dominated by polychaetes such as *Amythasides macroglossus*, *Aonides paucibranchiata* and *Exogone* spp., nematoda and bivalve molluscs such as *Limatula subauriculata* and *Thyasari sarsi*. Surveys in 1985 and 1987 found an increase in opportunistic polychaete species such as capitellids and *Rhaphidrilus* spp. In 1990, 1993 and 2006, high abundances of opportunistic species, indicative of organic enrichment were recorded, including capitellids, cirratulids, *Raricirrus beryli* and *Paramphinome jeffreysii* (Hartley Anderson Limited, 2007; UK Benthos, 2004), as well as juveniles of brittle star *Ophiura* spp, which favour disturbed sediments, and *Thyasira sarsi*, which is associated with organically enriched sediments (MarLIN, 2011).

Common taxa recorded during the 2011 survey include the polychaetes *Galathowenia oculata*, *Spiophanes* cf *wigleyi*, *Aonides paucibranchiata*, *Amythasides macroglossus*, *Pteroeclysippe vanelli* and *Glyceralapidum*, the molluscs *Timoclea ovata* and species of *Thyasiridae* (Fugro ERT, 2013).

Stations closest to the platform exhibited highly modified benthic communities containing increased numbers of indicator species along with reduced numbers of hydrocarbon-intolerant polychaetes.

Communities between 500 m and 2,000 m from the platform on the transect parallel to the residual current were found to have increased values for numbers of taxa, individuals and diversity. Faunal assemblages were characterised by both high numbers of background species and increased numbers of mobile scavenger/predator carnivores, which are sometimes associated with areas of higher PAH levels. The outer reference grab stations had low numbers for both taxa and individuals.

Correlation of the environmental variables against the community structure indicated that Unresolved Complex Material (UCM), median diameter, silt, carbonate, arsenic and total barium were the main environmental variables influencing the benthic communities.

4.4.3 Summary of Historical Faunal Survey Data in the Murchison Field

The 1982 survey, which took place during the major drilling phase of the development wells, indicated the extent of the benthic macrofaunal disturbance was close to the platform at a distance of 100m and 250m. The results of the 1985 survey showed indications of some benthic recovery at these distances, approximately 16 months after the major oil based cuttings discharges had ceased. Benthic recovery observed close to the platform was due to decreased levels of contaminants, however, intermediate stations (500m and 1000m) showed slight alterations possibly caused by spreading out of the contaminants from the cuttings pile (IOE, 1986).

Following further discharges, primarily of low-toxicity oil based mud contaminated drill cuttings since 1985, the recovery of the benthos, evident at the two stations closest to the platform (100m and 250m), had deteriorated. The survey carried out during 1987 showed that the fauna at 1000m had recovered from the initial 'wave' of contaminant spread however the 1990 data indicated a subtle effect at 1000m extending the zone of effect to between 1000m and 2000m from the platform, possibly as the contaminants spread out on a second 'wave' (IOE, 1988). A slight recovery was seen during the survey conducted in 1990 at the 100m, 250m and 500m stations, when compared to data from 1987 (IOE, 1991).

To summarise, it could be suggested that the largest area of benthic perturbation was recorded during surveys carried out in 1987, 1990 and 1993. A highly modified community was found at 500m from the platform and the zone of impact was considered to extend to between 1000m and 2000m. It must also be noted however that during 1993 the severity of the effect within 250m had been reduced since 1990 (ERT, 1994).

During the most recent survey, 2011, a highly modified community is still recorded at 250m from the platform and subtle differences in species composition were also recorded at between 500m and 2000m (Fugro ERT, 2013).

Fluctuations at distances further from the platform could represent cycles of recovery and deterioration, but may also represent undefined temporal and spatial variability (ERT, pers comm).

4.4.4 Finfish and Shellfish

The main commercial fish species in the northern North Sea in the vicinity of Murchison are mackerel, herring, cod, haddock, whiting, ling, megrim, Pollack, monkfish, and saithe (SFF, 2012). The Murchison Field lies within spawning grounds for cod (*Gadus morhua;* January to April), whiting (*Merlangius merlangus;* February to June), saithe (*Pollachius virens;* January to April), haddock (*Melanogram musaeglefinus;* February to May) and Norway pout (*Trisopterus esmarkii;* January to April), and nursery grounds throughout the year for herring (*Clupea harengus*), ling (*Molva molva*), mackerel (*Scomber scombus*), spurdog (*Squalus acanthias*), and blue whiting (*Micromesistius poutassou*) (Coull *et al.*, 1998; Ellis *et al.*, 2010; Table 8).

Species / Life cycle	Adults	Eggs / larvae	Juveniles	Diet		
Cod Spawning	Demersal	Pelagic eggs and larvae present within top 30 m of the water column	Demersal juveniles from 6 months.	Benthic predator – crustaceans and fish.		
Whiting Spawning	Demersal – near bottom waters	Pelagic eggs	Pelagic juvenile phase	Benthic predator at night, and pelagic prey during daylight.		
Saithe Spawning	Semi-pelagic	Pelagic	Inshore habitats (0-3 yrs)	Benthic predator – fish and crustaceans		
Haddock Spawning	Demersal	Pelagic eggs and larvae present within top 40 m of the water column	Demersal juveniles from 7 months.	Sandeel, Norway pout, rough dab, gobies, sprat, herring		
Norway Pout Spawning	Bentho-pelagic, frequently living in mid-water off the bottom	Demersal at depths 50-200 m	Pelagic juvenile phase	Benthic predator – crustaceans, amphipods, fish		
Herring Nursery	Pelagic	Demersal at depths 15-40 m.	Shallow pelagic coastal waters	Pelagic diet - Copepods, small fish, euphausids, hyperiid amphipods, juvenile sandeels		
Ling Nursery	Demersal	Pelagic eggs.	Demersal in shallower waters	Fish, lobster and squid		
Mackerel* Nursery	Pelagic	Pelagic eggs and larvae within top 30 m of water	Pelagic	Pelagic crustaceans, small fish: herring, sprat, sandeel and Norway pout		
Spurdog Nursery	Throughout the v	vater column	Predominantly pelagic predator – fish, crustaceans, squid, ctenophores			
Blue whiting Nursery	Pelagic	Pelagic eggs and larvae	Pelagic juvenile phase within upper 100 m water depth	Plankton crustaceans and small fish		

Table 8: Characteristics of fish specie	s found within the Murchison area
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* References : ICES, 2012, Ellis *et al.* 2010, CEFAS, 2001.

4.4.5 Marine Mammals

Cetaceans

The main cetacean (whale and dolphin) species occurring in the Murchison area are minke whale (*Balaenoptera acutorostrata*), long-finned pilot whale (*Globicephala melas*), killer whale (*Orcinus orca*), white-beaked dolphin (*Lagenorhynchus albirostris*), white-sided dolphin (*Lagenorhynchus acutus*) and harbour porpoise (*Phocoena phocoena*); most

sightings occur in the summer months (Reid *et al.*, 2003; UKDMAP, 1998). In addition, sperm whales have occasionally been sighted in the vicinity of Block 211 between May and October (UKDMAP, 1998).

Pinnipeds

The grey seal (*Halichoerus grypus*) and the harbour or common seal (*Phoca vitulina*), are both resident in UK waters and occur regularly over large parts of the North Sea (SCOS, 2009). As the Murchison Field is 150 km from the nearest coastline it is unlikely that significant numbers of grey or common seals would be found in the vicinity of the field.

4.4.6 Seabirds

Seabirds found in offshore North Sea waters include fulmars, gannets, auks, gulls, kittiwake and terns (DTI, 2001). In general, offshore areas of the North Sea contain peak numbers of seabirds following the breeding season and through winter, with birds tending to forage closer to coastal breeding colonies in spring and early summer (DTI, 2001).

For the Murchison Field (UKCS Block 211/19 and surrounding blocks), the overall seabird vulnerability to surface pollution is "low" (JNCC, 1999). The most sensitive times of year are March, July, October and November when vulnerability to oil pollution is "high" in some of the area; vulnerability ranges from "moderate" to "low" for the remainder of the year.

4.4.7 Commercial Fisheries

Commercial fishing effort (days spent fishing) in the area around the Murchison Field (which is located in International Council for the Exploration of the Seas (ICES) Statistical Rectangles 51F1) is considered to be very low in comparison with other areas of the North Sea (Marine Scotland, 2010). The majority of fishing effort is associated with demersal fisheries operating single and pair bottom otter trawls to target haddock, cod and whiting stocks (SFF, 2012). UK vessels, and specifically Scottish vessels, account for the majority of demersal fishing effort in ICES Rectangle 51F1, although there are a number of non-UK vessels, such as Norwegian, French and Danish, which also operate in the area.

The relative value of the fishing catch originating from ICES Rectangle 51F1 is considered to be "moderate" in comparison with other areas of the North Sea (Marine Scotland, 2010). The Murchison platform is location within a region of an internationally important pelagic fishery, which is targeted by a number of countries including the UK, Norway, the Netherlands, Denmark and France (SFF, 2012). Pelagic fishing is a seasonal activity, and in a given area is restricted to a relatively short period of time as the fishing fleet targets migrating species, such as mackerel, which pass through the Murchison area during October, November and December. This is reflected in the high landings values but relatively low level of effort recorded. Mackerel represents the highest UK landings values in

Rectangle 51F1 (79% of the total), with the remainder comprising principally haddock (5%), cod (4%), saithe (3%), monkfish (3%) and whiting (2%) (SFF, 2012).

5. SUPPORTING MODELLING STUDIES

5.1 Introduction

CNRI commissioned Genesis Oil & Gas Consultants to conduct modelling studies to inform an assessment of the environmental impacts that may be associated with the different decommissioning options being considered for the Murchison drill cuttings pile. The modelling studies were specifically designed to:

- 1. Determine (i) the rate of oil loss and (ii) the persistence over the area of seabed contaminated for the Murchison drill cuttings pile, and compare the modelled values with the OSPAR Recommendation 2006/5 thresholds.
- 2. Provide data with which to assess the potential long-term impacts if the Murchison drill cuttings pile were decommissioned *in situ*. The modelling simulated changes over time in:
 - The area, volume, and height of the cuttings pile.
 - The concentrations of main contaminants in the surface layer of the pile (in particular hydrocarbons).
 - The area of seabed where sediment THC is greater than the OSPAR threshold.
 - The persistence over the area of seabed contaminated (in km².years).
 - THC loss rate (tonnes per year).
- 3. Assess the potential impacts from human disturbance of the drill cuttings pile during excavation of the pile to access the jacket footings, for both the recovery of the cuttings pile to the surface and the redistribution over an adjacent area of seabed.
- 4. Assess the effects of disturbance of the existing cuttings pile below the Murchison platform from the eventual collapse of the jacket bottle legs, should both the footings and the cuttings pile be left *in-situ*.

The methods and outputs of the modelling studies have been summarised in this chapter, and the full details are available in the following reports:

- MURDECOM-GEN-EN-REP-00133 Murchison drill cuttings pile modelling long-term cuttings pile characteristics;
- MURDECOM-GEN-EN-REP-00135 Murchison drill cuttings pile modelling the effects of human disturbance of the cuttings pile; and
- MURDECOM-GEN-EN-REP-00240 Murchison drill cuttings pile modelling disturbance of drill cuttings from the collapse of structural piles.
5.2 DREAM/ParTrack model (SINTEF)

The DREAM/ParTrack model (Dose-related Risk and Effect Assessment Model), developed by SINTEF, was used to model (i) the fate of drill cuttings and drilling mud discharged during the Murchison drilling programmes; (ii) the long-term impacts if the drill cuttings pile were left *in situ*; and (iii) the fate of any material discharged to the marine environment during drill cuttings excavation.

5.3 Modelling method

The first stage in the process of modelling the fate of the Murchison drill cuttings pile is to create the drill cuttings pile by simulating the original discharge of drill cuttings in the ParTrack model environment, rather than starting by inserting a description of an existing cuttings pile into the model. The Murchison cuttings pile has been built up in the model by simulating the order, size and characteristics of each phase of discharge.

5.3.1 Comparison of modelled pile with actual pile

The SINTEF model created a drill cuttings deposition pattern, which was close to the observed drill cuttings pile at the Murchison location; in terms of size and shape. A comparison of the two cross sections of the pile is shown in Figure 4 and Figure 5. Both the modelled and observed pile show an elongation towards the southeast, which reflects the predominant currents in the area.

The resulting modelled deposition pattern is close to the observed deposition pattern of the existing Murchison pile, with similar, albeit slightly smaller, volumes contained within the modelled cuttings pile (Genesis 2013a).

In addition to comparing the modelled size of the pile against the measured size of the existing pile, the extent and concentration of hydrocarbons in the surrounding sediments was compared to survey data from the pre-decommissioning environmental survey (Genesis 2013a; Fugro ERT, 2013). A number of model iterations were run to identify the optimum cuttings properties within the range of uncertainties present, and the model parameters were optimised to closely represent the total hydrocarbon content measured in the sediments (Genesis 2013a).



Figure 4: Modelled and actual profile of the Murchison drill cuttings pile to same scale: North-South

Figure 5: Modelled and actual profile of the Murchison drill cuttings pile to same scale: East-West



5.3.2 Model processes

The DREAM/ParTrack model calculates the dispersion and deposition of drilling muds and cuttings on the seabed and the dispersion of chemicals in the water column (Genesis, 2013a). The model calculates the time required for concentrations of contaminants in water column or sediment to return to previous levels once the discharges have ceased. Within the water column, the solids would settle out relatively quickly, but recovery of the sediment on the seabed would take substantially longer. The rates of ecosystem recovery are variable depending on the particular location, and the model predicts the subsequent physiochemical composition over time by taking into account processes such as mixing, resuspension and dilution due to currents, and sediment re-colonisation rates leading to bioturbation and biodegradation of the sediments. Figure 6 illustrates the processes computed by the model.

5.3.3 Calculation of environmental risk

The model output also calculates an estimate of risk to the environment using a metric known as the Environmental Impact factor (EIF), which is based on the PEC:PNEC ratios used to estimate environmental risks for chemicals in different marine environmental compartments. The PEC (Predicted Environmental Concentration) is an estimate of the concentration of a chemical to which the biota would be exposed during and after the discharge of the chemical. The PNEC (Predicted No Effect Concentration) is the concentration of the chemical in the environment below which it is unlikely that adverse effects on the biota inhabiting a particular environmental compartment would occur. The ratio of the PEC to the PNEC indicates the likelihood of the occurrence of adverse effects from drilling discharge chemicals in the water column and sediments.

The EIF for drill cuttings is based on the following identified stressors relating to drill cuttings and the PNEC values for each of the stressors, which were determined from scientific literature:

- Water Column: Toxicity of chemicals and oil, physical effects of suspended matter;
- Sediments: Toxicity of chemicals and oil, burial of organisms, change in sediment structure, oxygen depletion.

Oil-based drilling muds typically contain several organic chemical compounds which may be present in sufficient concentrations to cause toxic effects to marine organisms. These compounds have been incorporated in the modelling risk assessment and include aliphatic oil, BTEX, naphthalenes (NDP) and polycyclic aromatic hydrocarbons (PAH). Drilling muds typically contain Barite weighting agents, which also contain heavy metal impurities such as copper, chromium, lead, zinc, mercury and cadmium, all of which have also been accounted for within the model.

The model calculates an individual PEC:PNEC ratio for each of the stressors and applies a species sensitivity distribution to each stressor, which allows the model to combine and compare the contribution of different stressors to the overall risk, known as the potentially affected fraction (PAF) of species. The level of 5% PAF (corresponding to a PEC/PNEC ratio of 1) is a generally-accepted risk level representing the concentration below which unacceptable effects on organisms will most likely not occur (EC, 2003). As such the value of EIF is taken as the spatial extent over which the multi-stressor PAF exceeds 5%. An EIF of 1 in sediment occurs when an area of 100 m x 100 m is predicted to exceed a 5% risk.



Figure 6: Processes involved in DREAM/ParTrack model (Genesis, 2013a, b)

5.3.4 DREAM/ParTrack model uncertainties

There are a number of uncertainties associated with this modelling technique (Genesis, 2013a). The main uncertainties identified in the model are:

• The particle size distribution measured from the top of the pile during the predecommissioning survey (ERT, 2012) appears to be finer material than would normally be expected. It is possible that the surface layer is not representative of conditions deeper in the pile. Against this, agglomoration properties are used in the model, due to the presence of oil, which produce large pseudo-particles of combined mud/particles that act to mask the individual grain sizes. Overall since the modelled deposition pattern is close to the observed deposition pattern, and since grain size is not a dominant seabed stressor in the risk calculations, refining particle size distribution is believed to potentially affect results but not affect the overall conclusions.

- In constructing the cuttings pile, metocean data supplied by PhysE Metocean Services has been used. The data covers the years 1989-1992 and represents middepth current measurements for the Murchison location. Further data periods were available but this was the longest continuous data period available for the period of discharges. It is likely that different years of metocean data, or a longer range of actual metocean data would produce slightly different results.
- The precise oil composition of the mud discharged is unknown, therefore the mud composition modelled will inevitably be different to that actually used. The oil composition in the mud used has been assumed to comprise four main components, while in reality there may be more present. It is also acknowledged that the oil content actually discharged could be higher (or lower) than that modelled. The assumption of using the 4+ ring/alkylated PAH grouping to represent all PAHs (excluding NDP) is conservative from the viewpoint of toxicity. The oil content, which is 33% by weight in mud discharged, is a common industry estimate. Overall the assumption is that diesel oil types were used until the last year permitted, and similarly low-toxicity oils were used until the last year permitted. In practice this could be conservative if these oil types were replaced sooner. The majority of the OBM discharges modelled use diesel which is the most toxic oil type. It is expected that more detail on this issue would improve the quality of the results, but is unlikely to alter the conclusions around the OSPAR thresholds, since the predictions are well below the threshold levels.
- To make the model of manageable complexity, some sections of wells which were actually drilled with WBM have been assumed to have been drilled using OBM. Since OBM is more stressful to the seabed and increases the parameters of importance to OSPAR, this is a conservative assumption. The amount of WBM assumed to be OBM is small and is unlikely to make a significant difference to the results. Additionally, it has been assumed that drilling discharges have taken place towards the end of relevant periods for the use of diesel-based muds, LTOBM and SBM, when in reality the wells were spaced more evenly through the periods. This is conservative since it allows less time for degradation and recovery than has been the case in reality.
- SINTEFs expert panel considered inclusion of Alkylphenol Ethoxylates (APEs) during development of the DREAM approach to drilling discharges (Frost et al. 2006, drawing on Neff, 2002). However, on the basis of sampling results at the time it was considered that their concentrations, if present in drilling discharges, were expected

to be below toxic levels, and on this basis they were not included in the risk calculation for drilling discharges. Therefore the fate of APEs in the Murchison drill cuttings pile cannot be assessed using the DREAM model (See Section 4.2.2).

It is not believed that these uncertainties would alter the conclusions in relation to the OSPAR thresholds (Genesis, 2013a).

5.4 Human disturbance of the cuttings pile

5.4.1 Closed system recovery of drill cuttings – dispersion during blockage removal

Impacts associated with the excavation and recovery to surface of the Murchison drill cuttings pile using a closed recovery system are likely to be small and limited to (i) the resuspension of drill cuttings by placement of the suction dredge in the pile; and (ii) the likely requirement to back-flush the dredge in order to dislodge any debris (e.g. scaffold poles, grout bags) that becomes lodged within the suction hose. Back-flush of the suction dredge would be considered to be the worst case disturbance scenario, as it is expected that this would result in the discharge to sea of the entire contents of the closed system hose, from the suction dredge to the vessel on the surface, which is estimated to be 4.3 m³ (CNRI 2012a). Disturbance modelling was conducted to simulate a back-flush of drill cuttings from the suction dredge should a blockage occur.

Environmental impacts associated with back-flushing to remove blockages in the dredge were modelled for a single back-flush event (releasing 4.3 m³ of pile material). Offshore field trials conducted on the NW Hutton drill cuttings pile during 2001 reported that 20 dredge back-flushes were required during the 2 day dredging operations to recover 14 m³ of cuttings, although improvements in technique during the trial were found to reduce the number of back-flushes required (UKOOA, 2002). Therefore a single back-flush for the entire Murchison drill cuttings pile removal operation was not considered to be representative. Based on the UKOOA results it is likely that it will be necessary to back-flush the dredge on a more frequent basis at the start of the operation but that as the technique improves the requirement is likely to reduce. Therefore, in order to assess the potential extent of impacts from back-flushing operations to excavate the entire drill cuttings pile an average of one back-flush event per day for the 394 day pile removal scenario was modelled.

Sediment Impacts

After a back-flush, the majority of the relatively dense cuttings material would sink through the water column and settle onto the seabed, and a portion would remain suspended and move slowly due to the slow currents at that depth gradually settling out along the direction of the prevailing current. Modelling results indicate that the cuttings discharge from a single back-flush operation will settle along the prevailing current (towards the southeast) and hence deposit over a narrow area of seabed extending initially approximately 400-500 m from the discharge point, with a maximum width of approximately 30 m (Figure 7a).

In comparison, cuttings deposition in the multiple daily back-flush scenario occurs in all directions around the discharge location reflecting the varying current direction throughout the year (Figure 7b). Cuttings material deposition at the end of the multiple back-flushing scenario are predicted to have a maximum sedimentation thickness of 75 mm at the point of discharge, decreasing to less than 1 mm within 100 m of the discharge point (Figure 7). Sediment deposition is therefore considered to be relatively localised, with no thickness >0.1 mm predicted beyond 220 m of the release point (Genesis, 2013b).





For a single back-flush event it is predicted that total hydrocarbon concentration (THC) could be parts per thousand (ppt) within tens of meters of the discharge, dropping to around 50 mg/kg at approximately 75 m distance. THC levels are predicted to reduce below 50 mg/kg or 50 ppt within 5 years after the operation (Figure 8).





The deposition of cuttings material and hydrocarbons for multiple daily back-flushes over 394 days is considerably more extensive than for a single back-flush operation (Figure 7 to Figure 9). For the multiple back-flush scenario, THC are expected to exceed 50 mg/kg up to 450 m from the relase point and cover an area of approxmately 0.19 km^2 . THC are predicted to persist above 50 mg/kg after 10 years up to a distance of 100 m from the release point, and cover an area of 0.04 km^2 (Figure 9).





The environmental risk to the seabed (Section 5.3.3) for a single discharge suggests that a narrow area of risk above 5% develops, extending over the same area as the sediment

deposition and THC contamination (Figure 10). The area affected is initially close to, but less than, an EIF of 1, i.e. the area >5% risk is less than the equivalent of 100 m by 100 m square (10,000 m²). This area declines over time, initially rapidly, and by year 10 the area above a 5% risk is less than 1,000 m².





For multiple daily back-flushes, contamination of the sediments surrounding the Murchison platform above an environmental risk level of 5%, is initially predicted to extend up to 750 m from the release point, reducing to 500 m after one year and to 200 m after ten years.

Figure 11: Risk to the seabed (a) immediately after multiple daily back-flush operations, and (b) 10 years after operations (Genesis, 2013b).



The time development of the area at risk shown in Figure 12, indicates that the contributions to risk are initially from the toxic effects of the hydrocarbons (NPD, PAH) and oxygen depletion. NPD is predicted quickly to decay, with PAH decreasing significantly over several years, and some degree of oxygen depletion remaining in conjunction with the degradation of oil in a shrinking area (Genesis, 2013b).





Water Column Impacts

Figure 13 illustrates the environmental risk to the water column as a result of single and multiple back-flush operations. The irregular distribution of the single back-flush in Figure 13 is a result of two factors: the plot for a single discharge is highly influenced by instantaneous currents which can fluctuate widely over a period of hours; and secondly the wider scale bathymetry includes a depression to the southwest of the platform that can lead to elongation of the dense plume along a northwest-southeast line. The environmental risk contour plot in Figure 14 represents multiple back-flush discharges over a much longer period and is therefore more evenly distributed.

The plume from a single back-flush is not predicted to rise more than 30m from the seabed; whilst the upper water column would not be affected (Figure 13). Approximately 5 hours

after the discharge, risks to the water column are predicted to be less than 5% in any grid cell and no longer potentially significant. Overall, the environmental risk is only greater than 1 for a short period following discharge. The maximum EIF modelled in the water column is 25, which is equivalent to a water volume of 0.0025 km³ at >5% risk. The environmental risk >5% to the water column is predicted to have a maximum horizontal extent of 1.7 km.

The plume from multiple back-flush operations would rise a few tens of meters higher in the water column than from a single back-flush, however, the upper water column (<100 m depth) would not be affected (Figure 14). Multiple back-flushing operations are predicted to occur on a daily basis throughout the cuttings pile excavation operations and hence the environmental risk is predicted to be greater than 1 for 394 days. The maximum EIF modelled in the water column is 49, which is equivalent to a water volume of 0.0049 km³ at >5% risk. The environmental risk >5% to the water column is predicted to have a maximum horizontal extent of 2.2 km.

The time development of the risk to the water column is shown in Figure 15. Overall, the risk is relatively short lived and the EIF is only greater than 1 for around 24 hours following discharge, i.e. a volume of 105 m^3 of water put at risk >5%. The main contributions to toxic risk are predicted to be from barite solids and hydrocarbon toxicity (primarily aliphatic oils and PAH).









Figure 15: Time development of water column risk from back-flush operations over 1 day (Genesis, 2013b)



5.4.2 Dispersion / redistribution drill cuttings offshore

An ROV support vessel equipped with an ROV-based dredging spread would be required to gain access to the centre of the jacket structure to remove the drilling cuttings. As described in Section 2.2.1 it is anticipated that a dredge with a 6" diameter suction hose would be the maximum capacity that could be manoeuvred through the base of the jacket structure between the lower jacket members (CNRI, 2012a).

As the pile is dredged, drill cuttings material would be dispersed and redistributed over the sediments surrounding the Murchison platform directly from the exhaust hose attached to the ROV suction dredge. The discharging end of the exhaust hose would be placed some distance away from the platform to ensure that the platform bottom brace members remained clear of cuttings (CNRI, 2012a). Modelling has been conducted to predict the fate of the redistributed drill cutting material and associated contaminants over a new area of seabed located 70m from the centre of the Murchison platform.

The following assumptions and scenarios have been used for the inputs to the dispersion model; these assumptions were based on results of the drill cuttings removal trial on NW Hutton from the drill cuttings UKOOA JIP (UKOOA, 2002a, b).

Parameter	Values
Total Duration (Days)	394
Total Pile Volume (m ³) (ISS, 2011)	22,545
Total Pile Weight (tonnes)	39,679
Total Slurry Volume (Water and solids) removed (m ³)	360,720
Water : Solid (ratio) (UKOOA, 2002)	15:1
Density (t/m ³) (RF. 2004)	1.76
Discharge rate solids (tonnes per day)	101
Discharge rate slurry (tonnes water plus solids) (per day)	960
Work Hours/Day	16
Removal rate (GTO Subsea dredge) t/hr	60
The location of the discharge point	

Table 9: Assumptions relating to the excavation of the Murchison drill cuttings pile(CNRI, 2012b)

Scenario 1 – 4 locations in an arc from NE to SW of platform at a distance of 70 m from the centre of Murchison platform, 4.5 m discharge height above the seabed $\dot{}$

Scenario 2 - 10 locations in an arc from NE to SW of platform at a distance of 70 m from the centre of Murchison platform, 2 m discharge height above the seabed

^{*} The discharge height above the seabed is adjusted for Scenarios 1 and 2 to reflect the height required to accommodate either one quarter or one tenth of the pile volume, therefore a lower discharge height was used for Scenario 2: 10 discharge locations.

Sediment Impacts

Predicted drill cuttings material deposition thickness resulting from the two discharge location scenarios (4 and 10 locations) indicates that the majority of material is expected to settle within 400 m of each release point, resulting in a maximum thickness of approximately 1-2 m of sediment which would occur within 40 m of the discharge point (Figure 16). Only a small proportion of the solids are expected to be distributed over a wider area, and the resettlement of this material will form a much thinner layer; at distances of more than 1.15 km from the release point the new layer of cuttings is predicted to be less than 10 mm thick (Genesis, 2013a).

The sediment deposition contour predictions (Figure 16) reflect the dominant prevailing currents in the area that are towards the south and southeast. A secondary area of deposition/risk appears to the southwest and this reflects a low lying 'hollow' in the seabed contours where sediment is predicted to accumulate. The deposition thickness in this area is, however, very slight, being < 0.1 mm (Genesis, 2013b).

Modelling results for Scenario 1: 4 discharge locations, and Scenario 2: 10 discharge locations showed differences in the deposition thickness and in the overall extent of environmental risk to the sediment. The results indicate that the greater number of release points and greater discharge height above the seabed result in a lower maximum thickness at the centre of the redistributed cuttings pile and a slightly lower overall deposition thickness at a distance from the centre of the pile. This is the result of the drill cuttings material being spread more thinly over a larger seabed area. Additionally, where a greater number of release points were used, a smaller area of seabed appears to be at an environmental risk greater than 5%, which reflects the previous observation that the greater number of release points results in slightly lower deposition thicknesses at a distance. Overall the resemblance of the outputs for both scenarios suggests that the deposition is not particularly sensitive to quite large changes in the discharge conditions (Genesis 2013b). Consequently results are presented for Scenario 1: 4 discharge locations.





THC levels resulting from the redistribution of the cuttings pile could exceed 50 mg/kg up to 1.7 km from the discharge point and over an area of almost 10 km². Redistribution of the cuttings pile is predicted to reduce the THC within the redistributed pile by more than 70%. As cuttings are discharged from the suction dredge, hydrocarbons are liberated into the water column and much of the cuttings material would be distributed in thin layers over the wider area of seabed. These thinner layers have a good potential for relatively fast natural degradation, as indicated by the contour plots in Figure 17 which indicates that the area of seabed >50 mg/kg THC would reduced to less than 1 km² after 10 years. However, close to the discharge point the redistributed cuttings are deposited in thicker layers and the model indicates that these accumulations have a toxic, anoxic core that resists further degradation and are likely to persist for hundreds to thousands of years (Genesis, 2013b).





Environmental risk to the seabed as a result of stressors such as oxygen depletion from the presence of hydrocarbons, toxicity of contaminants, grain size change, and burial thickness indicates that the shape of the risk contours (Figure 18) reflect the depositional layers (Figure 16). The secondary area of deposition/risk to the southwest (Figure 18), reflects a low lying 'hollow' in the seabed, which is predicted to recover quickly and is therefore not considered further in detail.

The predicted environmental risk immediately after cuttings pile redistribution operations indicates that areas where the risk exceeds 5% extend more than 12 km from the discharge point. Figure 19 predicts the recovery potential over time and indicates that the affected area decreases significantly, particularly within the first 10 years after redistribution. Twenty years after redistribution an area of seabed with a radius of approximately 2 km from the discharge point would still be >5% environmental risk from the re-distributed cuttings.

The predicted effects footprint indicated by environmental risk (%) is a more sensitive measure of environmental disturbance than the 50 mg/kg threshold, with the distance to the 5% risk contour 2-3 times greater than the distance to the 50 mg/kg THC level. The two methods are based on different approaches; the measure of 5% risk represents a contaminant exposure level below which the 5% most sensitive species present would not be significantly affected (based on a range of field and laboratory analyses); whilst the 50 mg/kg represents the exposure level below which there are no discernable effects (based on field sampling of cuttings piles). Hence the model outputs for environmental risk show a greater potential risk area of 52.3 km^2 , than the area of seabed where THC >50 mg/kg, 9.76 km^2 .





Figure 19: Risk to the seabed (a) 10 years after the redistribution of drill cuttings, and (b) 20 years after redistribution (Genesis, 2013b)



The largest contributions to environmental risk are attributed to oxygen depletion (from the degradation of oil present) and hydrocarbon toxicity (PAH content of the cuttings material) (Figure 20). Other factors are predicted to be much less important, including heavy metals, burial thickness and grain size change (Genesis, 2013b).



Figure 20: Contributions to environmental risk to sediments from the redistribution of drill cuttings (Genesis, 2013b)

The maximum risk levels are plotted over time to indicate the development of environmental risk and the causing factors as the impacted area begins to recover (Figure 21). Environmental risk is expressed as an EIF value, where one EIF is equal to a risk >5% over an area of 104 m². As shown in Figure 20, the largest contributions to risk result from oxygen depletion (from the degradation of oil present) and the hydrocarbon toxicity (PAH content), given the relatively low concentration at which toxic effects are exhibited. Since the aliphatic oil and PAH are relatively persistent over time, the oxygen depletion and hydrocarbon risk factors are also persistent. Other risk factors such as heavy metals are relatively insignificant, and risks from naphthalene reduce quickly. A large reduction in area above 5% risk (93%) takes place in the two years post-discharge as oil content in the thinner deposited layers is naturally remediated, reaching 98% reduction in modelled area above 5% risk after 20 years (Genesis 2013b).



Figure 21: Time development of maximum risk to the seabed from redistribution of drill cuttings, expressed as EIF (Genesis, 2013b)

Water Column Impacts

Modelling the discharge of redistributed cuttings within the water column indicates a plume of drill cuttings generally extending to the southeast along the direction of the prevailing currents (Figure 22a), and laterally spreading to the northeast/southwest as a result of the local tidal currents. Areas of risk to the water column extend approximately 30 m above the seabed (Figure 22b), above which the upper water column would not be at risk (Genesis, 2013b). The water column within the modelled area is predicted to return to background conditions within 24 hours of the completion of drill cuttings redistribution operations (Genesis, 2013b). Cuttings material discharge as a result of redistribution operations are predicted to occur on a continuous basis throughout the cuttings pile excavation operations and hence the environmental risk is predicted to be greater than 1 for 394 days.

The maximum EIF modelled in the water column is 1,621 which is equivalent to a volume of water of 0.162 km³ at >5% risk. The environmental risk >5% to the water column is predicted to have a maximum horizontal extent of 15.9 km.

Figure 22: Risk to the water column from the redistribution of drill cuttings during operations (Scenario 1 - 4 discharge locations) (a) plan view of the sediment plume, (b) cross section through the centre of the plume (Genesis, 2013b)



The sources of risk to the water column are predicted to be a mixture of toxic risk from hydrocarbons (primarily aliphatics and PAH), but to a greater extent they result from the fine suspended solids (barite and bentonite) (Figure 23). This reflects the impact of non-natural fine particulates on plankton and zooplankton in the water column.





The time development profile of the water column risk fort he first 60 days of redistibution options is shown in Figure 24. The profile shows variation based on changes in the type of material being discharged. An important fraction of the risk contribution is from the fine suspended particulates barite and bentonite. Risks of this magnitude resulting from particulate stress in the water column are routine as a result of consented discharges of WBM and cuttings (Genesis, 2013b). The water column risks resulting from the toxicity of the oily discharges are predicted to be a similar magnitude as those from particulates (Genesis, 2013b).



Figure 24: Time development of maximum risk to the water column from redistribution of drill cuttings (first 60 days), expressed as EIF (Genesis, 2013b)

5.5 Long-term fate of the existing drill cuttings pile

5.5.1 Leaching of contaminants including hydrocarbons and metals into the water column

The OSPAR Recommendation 2006/5 states:

The rate of oil loss should be assessed on the basis of the quantity of oil lost from the cuttings pile to the water column over time. The unit used should be tonnes per year (tonnes/yr).

The DREAM model predicts the rate of oil loss from the drill cuttings pile by (i) estimating the mass of oil present per square metre on the seabed, (ii) calculating the total amount of oil in the modelled area, (ii) calculating the total loss of oil from the pile over time (per year) from both leaching and biodegradation. It is not currently possible within the model to separate the rate of oil leaching to the water column and rate of oil biodegradation from the calculated mass of oil lost from the pile over time, therefore the rate of oil leaching into the water column is predicted to be lower than the value calculated by the model.

The oil loss from the pile, i.e. from all the deposition within an 8 km² area around the discharge point, was predicted to start at a rate of 5 tonnes per year over the first year after drilling operations ceased, dropping rapidly over time to less than 1 tonnes oil per year at year 20 and beyond (Genesis, 2013a). A data point in 2012 has been selected (1st February 2012) and a total oil loss rate of 1.2 tonnes per year has been calculated as the average over the preceding two years (2010-2012). As this value is based on a decreasing trend it provides an over-estimate of the instantaneous rate of oil loss from the pile. The model therefore takes a precautionary approach to predicting the rate of oil loss to the water column given the limitations of the model.

As the total oil loss from the pile is currently predicted to be approximately **1.2 tonnes/yr**, which includes the loss of oil due to biodegradation and is an averaged value over the preceding two years, the loss of oil to water column is below the OSPAR 2006/5 threshold of **10 tonnes/yr**.

5.5.2 Long-term pile presence and contaminant persistence

The OSPAR Recommendation 2006/5 states:

The persistence should be assessed on the basis of the area of the seabed where the concentration of oil remains above 50 mg/kg and the duration that this contamination level remains. The unit used should be square kilometre years (km²yrs).

Modelling results predict that the area of seabed where THC exceeds 50 mg/kg would decrease to approximately 0.5 km^2 by 2019, from an initial area of more than 1 km² in 2000 (Figure 25).

The model predicted the area of seabed for which the concentration of oil exceeds 50 mg/kg (contaminated footprint) over the 40 year modelling period. Assuming that the OSPAR criterion can be taken as beginning in 2006 and is not retrospective, the contaminated area multiplied by the duration (footprint.persistence) has been calculated, beginning a minimum of 6 years after the last discharge of OBM which was in 2000. Thus, a cumulative footprint.persistence has been calculated. Taken to the end of the 40 year simulation period (extent of the model), the area of persistence is less than **11** km²years, which is well below

the OSPAR criterion of **500** km²years, below which no further action is necessary and the pile may be left to degrade naturally.

Analysis of survey data from the drill cuttings pile and surrounding sediments indicates that the Murchison cuttings pile falls below both OSPAR thresholds (Genesis, 2013a; ERT, 2008) and as such no further action is required with regards to the OSPAR Recommendation 2006/5; and the cuttings pile may be left *in situ* to degrade naturally (OSPAR, 2006).

Results of the long-term fate modelling of the existing drill cuttings pile left *in-situ* indicate that if left undisturbed, the core of the pile is expected to persist on the seabed physically for an indeterminate length of time. Its chemical and biological footprint is expected to diminish slowly and be detectable for many hundreds or possibly thousands of years (Genesis, 2013a).

Sediment Impacts

Figure 26 illustrates a series of contour plots which recreate a hydrocarbon footprint resulting from the initial deposition of the Murchison drill cuttings pile at the end of the Murchison Oil Based Mud (OBM) discharges in 1983, to the end of the Murchison drilling period in 2000, and the predicted concentrations of total hydrocarbons in the sediment at present day (in 2013) and after 20 years post-drilling (in 2019). The contours representing the greatest hydrocarbon concentrations also reflect the areas of thickest deposition of cuttings material; these contours extend slightly to the south-east of the discharge point reflecting the direction of residual seabed currents. The contour areas representing the lowest hydrocarbon concentrations reflect the areas of the finest cuttings material.

The contour plots in Figure 26 indicate a trend of decreasing hydrocarbon concentration in the sediments surrounding the Murchison platform where drill cuttings depositions are thinner than in the centre of the pile; THC concentrations in the surrounding sediments are predicted to be <0.001 mg/kg by 2019.

Model results predict that whilst BTEX and NDP hydrocarbon fractions remain in the core of the pile they are far less persistent than the aliphatic and PAH hydrocarbon fractions which are likely to persist within the active surface layer of the sediments.





Figure 26: Modelled distribution of total hydrocarbon concentration in sediments in the existing drill cuttings pile [50 ppm = 50 mg/kg], (a) during OBM discharges in 1983, (b) at end of 2000, (c) at end of 2013, (d) at the end of 2019 (Genesis, 2013a)



Figure 27 provides an illustration of the predicted recovery of the seabed in the form of environmental risk contour plots over time (starting at the end of the Murchison Oil Based Mud (OBM) discharges in 1983, present day (in 2013) and after 20 years post-drilling (in 2019)). The contour plots indicate a trend of decreasing environmental risk, such that by the end of 2019 areas where the risk to >5% PAF are predicted to be restricted to within approximately 2 km of the Murchison platform. Calculation of the EIF value also indicates a decreasing trend such that the EIF is predicted to have decreased from >3,900 following initial drilling discharges in 1983 to a value of 300 by the end of 2019, which equates to 3 km^2 of seabed above a risk level of 5%.

Figure 27: Estimation of environment risk resulting from the existing Murchison drill cuttings pile and in the event it is left *in-situ*, (a) during OBM discharges in 1983, (b) at end of 2013, (c) at the end of 2019 (Genesis, 2013a)



The profile of environmental risk over time is expressed as EIF (which is 104 m² area of seabed above a combined risk of 5%) and is shown in Figure 28, and the proportion of risk associated with oil toxicity, burial thickness, oxygen depletion, grain size and metals is shown in Figure 29. The time development graph (Figure 28) commences at year 0, which corresponds to the first drilling discharges of WBM in 1980. Oil toxicity is the main predicted source of risk and contribution to the EIF value, and this originates from PAH, BTEX, naphthalene and aliphatic components in the OBM, LTOBM and SBM. The WBM drilling discharges do not present a large contribution to the EIF value, as demonstrated by the low contribution of thickness to the EIF in Figure 29, and hence they do not contribute to the EIF on the time development graph. The overall risk and recovery of the pile are modelled as a complex interaction of all the risk elements. Risks from metals potentially present in the barite are not significant.

Figure 28: Time development of maximum risk to seabed expressed as EIF, demonstrating contribution of stressors to the overall EIF risk value as the Murchison drill cuttings pile was discharged and in the event it is left *in-situ* (Genesis, 2013a)



Figure 29: Predicted contributions to overall risk in sediments, demonstrating contribution of stressors to the overall EIF risk value from the existing Murchison drill cuttings pile and in the event it is left *in-situ* (Genesis, 2013a)



5.6 Disturbance of drill cuttings from the collapse of jacket footings

5.6.1 Murchison jacket footing collapse scenario

The rates of corrosion acting on the Murchison jacket footings have been predicted (Atkins, 2011) in order to indicate likely timescales for the life of the footings if left *in-situ*. The study assumed a corrosion rate of 0.1 mm steel/year and predicts that failure of the legs would be expected to occur in 300 – 1,000 years (Atkins, 2011), the range in duration reflecting corrosion occurring on one or both sides. The jacket corner legs comprise different components of varying steel thickness, which are consequently likely to experience different failure rates over the predicted window of leg failure (Table 10). Estimates of individual leg component corrosion rates suggest that the connecting members between the structural piles would fail before the structural piles, leading to their release and subsequent independent collapse.

The individual structural piles are likely to fail once the steel has corroded to an extent where it can no longer support the weight of the rest of the structural pile and as such the weight of each pile will be much reduced at the time of collapse. The collapse of each structural pile is expected to be gradual as the steel bends under the weight of the pile above it, rather than an instant collapse like a dropped object.

Bottle leg component	Original Steel thickness	Potential steel thickness (mm) (corrosion rate of 0.1mm/yr)	
		300 yrs	1000 yrs
Structural Pile (8 piles in total)	63 mm	33 mm*	0 mm*
Pile Sleeve	20 mm	0 mm	0 mm
Central leg	45 mm	15 mm	0 mm
Shear plate connectors	25 & 35 mm	5 mm	0 mm
Ring stiffeners	28 & 32 mm	2 mm	0 mm
Mud Mat	45 mm	15 mm	0 mm

Table 10: Corrosion rates of different Murchison jacket leg structural members

* Corrosion rates expected to be lower than these values owing to grout and limited water exchange within centre of pile.

Figure 30 illustrates the potential arc within which each leg may collapse into the jacket footprint, indicating that the structural piles from 2 of the legs have the potential to fall on to the drill cuttings pile, of which one may reach the centre of the pile (eastern leg) and the other may impact the edge of the pile (southern leg), it is possible that the tip of the northern leg may also contact the very edge of the pile. There are three main scenarios for the structural piles falling:

- Low risk pile weakens at the base and bends slowly over into the cuttings pile with no re-suspension;
- Intermediate risk the pile bends onto the pile surface then snaps, falling into the pile under its own weight; and

• High risk - pile snaps due to fatigue e.g. in a storm or from impact and falls onto the drill cuttings pile from an upright position.

For the latter two scenarios, it has been assumed that the structural pile falls horizontally.

A combination of calculation and modelling was undertaken to simulate:

(i) the velocity of the structural piles falling through the water – calculated using the Reynolds number equation;

(ii) the structural piles embedding themselves in the cuttings material - determined by calculating the velocity of the cylinder as it impacts with the sediment and modelled using a sediment impact model developed by the US Navy;

(iii) the re-suspension and deposition of drill cuttings – estimated on the basis of experimental and qualitative observations (Genesis, 2013c) which showed that 10% of material displaced by the impact would be re-suspended into the water column; and

(iv) the impacts and subsequent recovery of the seabed affected by the redistributed drill cuttings – modelled using the DREAM/ParTrack model.

It was assumed that the failure of the structural piles within each leg would be staggered at different times rather than a simultaneous collapse. To illustrate the potential impacts, the following scenarios were taken forward for dispersion modelling:

- 1. A single structural pile, with a maximum height of 44 m, falling from the east jacket leg directly into the pile (re-suspending the maximum amount of material, 4.08 m³, for a single pile).
- 2. All of the piles falling in a sequential manner over a period of 275 days. The disturbances are spaced out over a period of 275 days in order to model a representative set of regional current conditions, rather than concentrating all of the releases at the same time. A total of 157 m³ is assumed to be re-suspended in this scenario.

There are many uncertainties associated with this approach, and there is no available literature on previous assessments of the effects of collapsing piles or legs onto historic cuttings piles. The method used is expected to lead to an order of magnitude estimation of the potential effects, and as such conclusions are considered indicative (Genesis 2013c).

Figure 30: Murchison drill cuttings pile topography and indicative arcs of structural pile collapse



5.6.2 Modelling results of the jacket footing collapse scenario

Disturbance of the Murchison drill cuttings pile from the eventual collapse of the jacket footings, if left *in-situ*, is expected to occur over a number of years with varying degrees of impact as different leg components fail at different rates. The greatest disturbance events are expected to occur as the structural piles, which anchor the Murchison jacket legs to the seabed, eventually fail. The structural piles are expected to fall into the jacket footprint and onto the drill cuttings pile resulting in re-suspension of drill cuttings material into the water column which will subsequently settle onto adjacent sediments.

Modelling results of two collapse scenarios (Figure 31) (i) a single pile collapsing into the centre of the cuttings pile; and (ii) all structural piles collapsing into the cuttings pile, predict that deposition of re-suspended material would predominantly occur within 1 km of the release point, and that beyond 1 km thicknesses are predicted to be less than 0.1 mm in both scenarios. The majority of material is predicted to settle within 400 m of the release point. The maximum thicknesses of deposition are 3.5 mm for a single pile falling at a time, and 27.5 mm for all the piles falling within 275 days. Maximum thickness is predicted to occur within 40 m of the discharge point.

The deposition pattern for a single pile is predominantly along the direction of the prevailing current at the time of the release, which happens to be towards the southeast, and very little material is deposited to the northwest. In comparison, the scenario for all piles collapse the sediment deposition occurs in all directions around the drill cuttings pile. This reflects the collapse of the pile throughout the year and the varying current direction with time (Genesis 2013c.

Figure 31: Estimation of sediment deposition thickness resulting from the collapse of the jacket footings –structural piles (a) single pile collapse, (b) all piles collapse (Genesis, 2013c).



The deposition of cuttings material and hydrocarbons for the collapse of all the structural piles is considerably more extensive than for a single structural pile collapse (Figure 32 and Figure 33). For the scenario where all piles collapse, THC are expected to exceed 50 mg/kg up to 550 m from the relase point and cover an area of approxmately 0.04 km². THC are predicted to persist above 50 mg/kg after 10 years up to a distance of 150 m from the release point, and over an area of 0.004 km² (Figure 33).

Figure 32: Distribution of total hydrocarbon concentrations in sediments from the collapse of the jacket footings – single structural pile (a) immediately post collapse, (b) 1 year after collapse, (c) 10 years after collapse (Genesis, 2013c).



Figure 33: Distribution of total hydrocarbon concentrations in sediments from the collapse of the jacket footings – all structural piles (a) immediately post collapse, (b) 1 year after collapse, (c) 10 years after collapse (Genesis, 2013c).



The area of environmental risk resulting from the scenario of all piles collapsing sequentially (Figure 35) is larger than the area predicted for the single pile collapse scenario (Figure 34). The shape of the risk contours reflect the depositional pattern and areas where the risk is >5% extend up to 400 m from the discharge point in the single pile scenario and up to 1 km from the discharge point in the 'all piles' scenario (Genesis, 2013c).

The risk plots for the single pile and all structural pile collapse scenarios are different shapes because the wider area impacts from the single pile collapse scenario have almost completely remediated in the all pile scenario, and the periodic discharges in the all pile collapse scenario are affected by the variable current directions. Both scenarios predict that the recovery of thinner layers of deposition would be relatively rapid; within 5-10 years the area at >5% risk is expected to shrink back to a 'core' of oil-contaminated sediments less

than 100-200 m from the discharge point, the 'core' would persist beyond the 10 years modelled period.

Figure 34: Estimation of overall environmental risk to the seabed from the collapse of the jacket footings – single structural piles (a) immediately post collapse, (b) 1 year after collapse, (c) 10 years after collapse (Genesis, 2013c).



Figure 35: Estimation of overall environmental risk to the seabed from the collapse of the jacket footings – all structural piles (a) immediately post collapse, (b) 1 year after collapse, (c) 10 years after collapse (Genesis, 2013c).



The contributions to environmental risk from the various stressors are shown in Figure 36. Oxygen depletion accounts for the greatest contribution towards environmental risk followed by toxic risk from the hydrocarbons.

Figure 36: Predicted contributions to overall risk in sediments, demonstrating contribution of stressors to the overall EIF risk value for the collapse of the jacket footings (Genesis, 2013c).



The maximum risk levels can be plotted over time as shown in Figure 37, expressed as EIF, where one EIF is equal to a risk >5% over an area of 10^4 m^2 . The largest contributions to environmental risk arise from the hydrocarbon toxicity (PAH), given the relatively low concentration at which toxic effects are exhibited, and oxygen depletion (from the degradation of oil liberated). Since the aliphatic oil and PAH are relatively persistent over time, the oxygen depletion and PAH risk factors are also persistent. Other risk factors such as heavy metals are relatively insignificant. A large reduction in area above 5% risk takes place within 5-10 years post-discharge as oil content in the thinner deposited layers is naturally remediated.




Water Column Impacts

Modelling results for the single pile collapse scenario indicated that the majority of sediment re-suspended into the water column from a collapsing pile would remain within 20 m of the seabed, with a small amount of material reaching 60 m above the seabed (Figure 38). As the majority of material remains within 20 m of the seabed the plume is predicted to travel towards the south-east following the direction of the prevailing seabed currents. The majority of material would be re-deposited near the cuttings pile. Overall, the environmental risk is only greater than 1 for a short period following the single pile collapse.

Figure 38 shows the same plot but for the case of all the piles falling sequentially over time. The results indicate that some sediment re-suspension would extend nearly 100 m above the seabed, with a small amount of material predicted to reach the upper water column. The majority of material has re-deposited near the cuttings pile and the remaining suspended material has travelled at least 250 m from the cuttings pile. Contamination associated with the cuttings material is predicted to remain in the lower water column (Genesis, 2013c).

Re-suspension of drill cuttings is predicted to occur periodically as a result of all 24 piles collapsing sequentially over a 275 day period, hence environmental risk is predicted to be greater than 1 on 24 different occasions during that period.

The maximum EIF modelled in the water column is 88 for both the single and multiple pile scenario, which is equivalent to a volume of water of 0.008 km³ at >5% risk for each pile collapse. The environmental risk >5% to the water column is predicted to have a maximum horizontal extent of 2 km (Genesis, 2013c).





The sources of risk to the water column, shown in Figure 39 and Figure 40, are predicted to be a mixture of toxic risk from hydrocarbons (particularly aliphatics and PAH), but to a greater extent they result from the fine suspended solids, barites, which reflects the impact of non-natural fine particulates on plankton and filter feeders. The risk to the water column is predicted to last for a period of approximately 16 hours for each pile collapse (Figure 40).

Figure 39: Predicted contributions to overall risk to the water column, demonstrating contribution of stressors to the overall EIF risk value for the collapse of the jacket footings (Genesis, 2013c).



Figure 40: Time development of maximum risk to the water column from the collapse of the jacket footings (Genesis, 2013c).



5.7 Comparison of modelling results for the management options of the Murchison drill cutting pile

Management options for the physical accumulation of contaminated cuttings material located primarily within the jacket footprint, result in one of the following disturbances to the cuttings pile material:

- Excavation of the entire cuttings up to the sea surface discharge of cuttings during clearance of blockages in the excavating dredge;
- Redistribution of the entire pile to an adjacent area of seabed; and
- Leave the pile *in-situ* to degrade naturally disturbance of cuttings as a result of the future collapse of the derogated Murchison jacket footings.

It should be noted that the wider area of contaminated sediments surrounding the cuttings discharge site, which do not form a physical accumulation but are contaminated by a thin layer of cuttings material, would not be artificially remediated as part of any of the management options, and hence will remain *in-situ* for all management options.

Modelling results for the disturbance mechanisms of the Murchison drill cuttings pile predict that the majority of cuttings material would re-settle within:

- 400 m of the existing pile for the redistribution scenario;
- 125 m for the multiple back-flush scenario; and
- 40 m for the leg collapse scenario (Table 11).

The extent of total hydrocarbon concentrations (THC) which exceed the OSPAR 50 mg/kg no effect exposure concentration in the sediments are predicted to range from 0.044 km² as a result of the jacket footings collapse, to 9.76 km² as a result of the total redistribution of the cuttings pile (Table 11).

The leg collapse scenario predicts that approximately 0.6% of the total drill cuttings pile volume would be disturbed as a result of the collapse of all of the structural piles onto the drill cuttings pile. The model predicts that as the structural piles collapse onto the drill cuttings pile the impact would result in a plume of drill cuttings material being ejected approximately 60-100 m up into the water column (Genesis, 2013c), and a second plume of material travelling closer to the seabed, with the majority of material remaining within the vicinity of the seabed. The majority of the disturbed material is predicted to deposit within 40 m of the existing pile. Sediment deposition patterns from the existing pile from the collapse scenario is slightly thicker at distance than the back-flush scenario, despite the smaller volume of disturbed material resulting from the leg collapse. This is most likely a result of the greater height in the water column to which the material is re-suspended from the collapse scenario, allowing this material to travel a greater distance from the disturbance location. The environmental risk to the water column is expected to affect a maximum instantaneous volume of approximately 0.0088 km³, with impacts occurring on 24 days (Table 12).

In terms of the total volume of sediment disturbed, the multiple back-flush scenario of 1 discharge per day for 394 days is predicted to result in the re-suspension of approximately 7% of the total drill cuttings pile volume. The majority of sediment is expected to deposit within 125 m distance from the pile with only a very thin layer (<0.01mm) of sediment deposited at 1 km distance from the pile (Genesis, 2013b). The area of sediment contaminated with THC >50 mg/kg, as a result of the back-flush operations, is expected to fall entirely within the existing >50 mg/kg contour of existing background contamination. The environmental risk to the sediment is expected to exceed 5% at distances up to 0.75 km, and environmental risk to the water column is expected to affect a maximum instantaneous volume of approximately 0.0049 km³, with impacts lasting for a period of 394 days (Table 12).

On a comparative basis redistribution of the drill cuttings pile has the greatest environmental impact to the sediment and water column habitats, both in terms of spatial extent and overall duration (Table 11 and Table 12). Redistribution of the drill cuttings pile would require 100% of the existing cuttings pile material to be excavated and deposited over a new area of seabed. The area of seabed where the initial environmental risk >5% resulting from redistribution of the whole cuttings pile is approximately 52 km^2 (Genesis 2013c). The environmental risk to the water column is expected to affect a maximum instantaneous volume of approximately 0.16 km^3 , with impacts lasting for a period of 394 days.

Long-term risks of management options for the drill cuttings pile must be contrasted with the shorter-term risks identified above, Table 13 summarises the long-term risks predicted for each of the proposed management options.

If the drill cuttings pile were left *in-situ* to degrade naturally it was determined that the pile would persist for a sufficient length of time that the eventual collapse of the jacket footings (if also left in place) would fall onto the pile and cause disturbance of pile material. The model predicts that the long-term environmental effects as a result of disturbance from falling jacket footings would cover a very small area entirely within the existing background contaminated area. The collapse of the jacket footings is predicted to occur in several hundred years' time, at which point the existing drill cuttings pile would be significantly weathered and degraded, and hence modelling predictions are likely to represent a conservative outcome. Contamination associated with the collapse of the jacket footings would be expected to recover within tens of years, and the existing background contaminated area and core accumulation of cuttings pile material is predicted to degrade very slowly over hundreds to thousands of years.

Back-flush operations resulting from the excavation of the drill cuttings pile to the sea surface, are predicted to have a relatively small environmental effects footprint, which remains within the existing background contaminated area. Contamination associated with the back-flushing operations is predicted to recover within tens of years, and the existing background contaminated area is predicted to degrade slowly. However, the core accumulation of contaminated cuttings pile material, that is predicted to take hundreds to thousands of years to degrade, has been removed.

Table 13 illustrates that 10 years post discharge the redistribution of the pile retains the largest environmental effect footprint, which exceeds the existing background contaminated area from the original cuttings discharge. Whilst the original accumulation of pile material no longer exists after redistribution operations, the pile material now exists in a number of smaller accumulations, which are predicted to degrade very slowly over similar timescales to the original cuttings pile, of hundreds to thousands of years.

Table 11: Summary of predicted short-term impacts to the drill cuttings pile (Genesis, 2013b & 2013c, Genesis pers com)



See also Note to Table 13

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Table 12: Summary of predicted short-term impacts to the drill cuttings pile (Genesis, 2013b & 2013c, Genesis pers com)

	SHORT-TERM RISKS to the Water Column				
Model Scenario	Cumulative duration of >5% environmen tal risk in the water column.	1) Maximum instantaneous volume of water >5% environmental risk (km ³); and 2) Maximum instantaneous EIF value	Environmental risk to the water column during cuttings disturbance (EIF value) (all figures are on the same scale).	Vertical profile of environmental risk to the water column from the pile left <i>in-situ</i> and during cuttings disturbance (EIF value)	
Existing pile footprint / Undisturbed pile / Leave <i>In</i> <i>situ</i>	0	0	1'30E 1'40E 1'50E 2'10E 2'10E 20 km Risk % 2 85 % 01'0' 01'0' 100 01'0' 01'0' 01'0' 01'0' 01'0' Note 1'0' 01'0' 01'0' 01'0' 01'0' Note 1'0' 01'0' 01'0' 01'0' 01'0' Note 00'0' 00'0' 00'0' 00'0' 00'0' Note 00'0' 00'0' 00'0' 00'0' 00'0' Note 00'0'' 00''' 00''''' 00'''''' 00'''''''' Note 1''''''''' 1''''''''''''''''''''''''''''''''''''	Distance (km) 0 9 18 27 36 40 Risk (0-100%) 42 54 0.001 - 0.1 56 68 0.1 - 1 74 1 - 5 106 20 - 40 154 10 - 20 138 10 - 20 138 10 - 70 122 10 - 100 154 10 - 70 100 124 70 - 100 124 70 - 100 138 152 166 10 - 20 10 154 180 Depth (m)	
Leave <i>in situ</i> leg collapse – all structural piles	16 days	1) 0.0088 km ³ 2) 88 EIF	1°30'E 1°45'E 2°00'E 2°15'E 20 km 1°45'E 2°00'E 2°15'E Risk % 0°1°1° 1°0° 1°	Distance (km) 40 Risk (0-100%) 54 0.001 - 0.1 68 1 - 5 82 5 - 10 96 10 - 20 20 - 40 10 10 20 - 40 10 20 - 100 10 20 - 100 10 10 10 10 10 10 10 10 10	
Back-flush Scenario – 1 discharge per day for 394 d	394 days	1) 0.0049 km ³ 2) 49 EIF	1°30°E 1°40°E 1°50°E 2°00°E Risk % Image: State of the state of th	Distance (km) 40 40 Risk (0-100%) 54 0.001 - 0.1 68 0.1 - 1 1 - 5 82 5 - 10 96 10 - 20 20 - 40 10 40 70 - 100 20 - 40 10 20 - 40 10 20 - 40 10 20 - 100 10 20 - 100 10 10 20 - 100 10 20 - 100 10 10 10 10 10 10 10 10 10	
Podictribution	304 days	1) 0.1621 km ³	11'30'E 11'40'E 11'50'E 2'40'E 20 km North 1 10'-1 1.5 5.10 10.20 20.40 40.70 70.100 10'20'	Distance (km) 0 9 18 27 36 40 Risk (0-100%) 54 0.001 - 0.1 68 0.1 - 1 55 - 10 96 10 - 20 96 20 40	



See also Note to Table 13

Table 13: Summary of predicted long-term impacts to the drill cuttings pile (Genesis, 2013b & 2012c, Genesis pers. comm.)



NOTE: Contamination associated with the historic Murchison drilling discharges can be classified in two ways (i) the physical accumulation of contaminated cuttings material located within the jacket footprint, (ii) the wider area of background contaminated sediments which do not form a physical accumulation.

CNRI considered that, as the Murchison drill cuttings pile is below both of the OSPAR 2006/5 thresholds, management options for the pile would be limited to (i) the physical accumulation of contaminated cuttings material within the jacket footprint. The contaminated sediments over the wider area are not considered within the management options. These sediments form a very thin layer over the background sediments and the benefit of removing this thin layer of sediment, which is currently undergoing natural recovery, would not outweigh the environmental, safety and cost impacts of removing such a large area of sediment.

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6. ASSESSMENT OF THE IMPACTS OF METHODS FOR THE REMOVAL OR MANAGEMENT OF THE MURCHISON DRILL CUTTINGS PILE

6.1 Introduction

Table 14 identifies those activities associated with the different options for the management of the drill cuttings which have the potential to result in an environmental or societal impact. These impacts can be summarised under the following headings:

- Power generation during offshore operations to remove the drill cuttings pile leading to energy use and generation of atmospheric emissions.
- Physical disturbance to the drill cuttings pile, potentially releasing contaminants to the water column and seabed, resulting from:
 - o back-flush of suction dredging equipment to remove blockage;
 - o redistribution of the drill cuttings pile to another area of seabed;
 - o collapse of the jacket footings onto the cuttings pile.
- Fishing gear interaction with re-distributed cuttings pile leading to dispersion of drill cuttings pile and fouling of nets.
- Discharge of treated seawater to the offshore or onshore environment.
- Landfill disposal of residual solids resulting in reduced capacity of such disposal facilities.

This section discusses these potential environmental impacts and provides an assessment of the potential environmental risk associated with them.

Method	Aspect	Potential Impact	Receptors
Option 1: Separation, treatment of liquids offshore, transportation and	Power generation	Energy use leading to atmospheric emissions of CO_2 and VOC which may contribute to climate change; emissions of NOx and SOx which may contribute to acid rain.	Use of resources, atmosphere, cumulative impacts, transboundary impacts
	Excavation of drill cuttings pile and recovery to surface.	Blockage of suction dredging equipment leading to the release of drill cuttings potentially releasing contaminants to the water column and seabed.	Sediments, water column, benthos, fish, cumulative impacts
treatment of solids onshore	Landfill disposal of residual solids.	Reduced capacity of disposal facilities.	Landfill sites
onshore	Discharge of treated seawater.	Planned release of treated seawater resulting in release of contaminants (e.g. hydrocarbons, cleaning chemicals).	Water column

Table 14: Summary of potential in	mpacts associated with each c	ption for the
management of drill cuttings.		

Table 14 Continued: Su	mmary of	potential	impacts	associated	with	each	option	for
the management of drill	cuttings.							

Method	Aspect	Potential Impact	Receptors
Option 2:	Power generation.	Energy use leading to atmospheric emissions of CO_2 and VOC which may contribute to climate change; emissions of NOx and SOx which may contribute to acid rain.	Use of resources, atmosphere, cumulative impacts, transboundary impacts
I ransportation of slurry to shore, separation and treatment	Excavation of drill cuttings pile and recovery to surface.Blockage of suction dredging equipm leading to the release of drill cuttings potentially releasing contaminants to water column and seabed.		Sediments, water column, benthos, fish, cumulative impacts
onshore for disposal	Landfill disposal of residual solids.	Reduced capacity of disposal facilities.	Landfill sites
	Discharge of treated seawater.	Planned release of treated seawater resulting in release of contaminants (e.g. hydrocarbons, cleaning chemicals).	Water column
Option 3: Offshore injection of slurry	Power generation.	Energy use leading to atmospheric emissions	Use of resources, atmosphere, cumulative impacts, transboundary impacts
	Excavation of drill cuttings pile and recovery to surface.	Blockage of suction dredging equipment leading to the release of drill cuttings potentially releasing contaminants to the water column and seabed.	Sediments, water column, benthos, fish, cumulative impacts
Option 4: Distribute cuttings over surrounding sediments	Power generation for: excavation of the drill cuttings pile to another area of seabed.	Energy use leading to atmospheric emissions of CO_2 and VOC which may contribute to climate change; emissions of NOx and SOx which may contribute to acid rain.	Use of resources, atmosphere, cumulative impacts, transboundary impacts
	Excavation of the drill cuttings pile and redistribution to another area of seabed.	Physical disturbance to the drill cuttings pile potentially releasing contaminants to the water column and seabed. Deposition of dispersed cuttings material onto adjacent seabed.	Sediments, water column, benthos, fish, plankton, commercial fishing, cumulative impacts
	Fishing gear interaction with cuttings pile	Dispersion of drill cuttings pile and fouling of nets.	Sediments, commercial fishing
Option 5: Leave <i>in-situ</i> to degrade naturally	No remedial actions	Continued leaching of oil into the water column and persistence of contaminants on the seabed.	Sediments, water column, benthos
	Long term degradation of footings leading to falling jacket members and structures	Physical disturbance to the drill cuttings pile potentially releasing contaminants to the water column and seabed, which may impact pelagic and demersal species.	Sediments, water column, benthos, fish, plankton.

6.2 Power generation for vessel and helicopter use to remove the drill cuttings pile leading to energy use and generation of atmospheric emissions

6.2.1 Drill cuttings pile removal method

Power generation resulting in energy use and atmospheric emissions will arise from the following operations:

- excavation of the drill cuttings
- separation, treatment of liquids offshore, transportation and treatment of solids onshore
- transportation of slurry to shore, separation and treatment onshore for disposal
- offshore injection of slurry
- relocation to another area of seabed

6.2.2 Impact Assessment

The energy use and associated gaseous emissions would arise as a result of the following activities:

- The fuel used by marine vessels while excavating and redistributing the cuttings. Any dredging equipment would be powered by the vessels, therefore no additional allowance is made for the dredging equipment.
- The fuel used by the Murchison topsides to power cuttings re-injection.
- The fuel used by helicopters to transfer personnel to and from the site.
- The fuel used to power the onshore treatment plant.
- The fuel used to transport treated solids to a landfill site for disposal.

Table 15 to Table 18 summarises the energy use and gaseous emissions associated with each of the options and show the relative contributions from the various activities undertaken (BMT Cordah, 2012). For some of the decommissioning operations there was no information on the gaseous emission conversion factors and these are denoted in the table as "No data". The total CO_2 emissions resulting from each option is also expressed as a percentage of the total CO_2 emissions that were generated by Murchison during normal production operations in 2011.

The estimates for energy use and CO_2 emissions are very similar for all options; total energy use ranges from 255,109 GJ to 341,409 GJ, and total CO_2 emissions range from 18,941 tonnes to 24,370 tonnes. The estimated total CO_2 emissions from the drill cuttings options therefore equate to between 9.5% and 12.3% of the total CO_2 emissions arising from oil and gas production operations on the Murchison platform during 2011 (198,510 tonnes; CNRI, 2012c) (Table 15).

Table 15: Predicted energy use and emissions for removal of the drill cuttings pile –
Option 1, offshore treatment and onshore disposal. (BMT Cordah, 2012)

Decommissioning Aspect	Energy (GJ)	CO ₂ (t)	NO _x (t)	SO ₂ (t)	CH ₄ (t)	
Vessel and helicopter use						
Dredge equipment (estimated 364 day)	268,470	19,056	351	24	1.6	
Offshore treatment						
Onshore transportation and disposal	5,378	389	5	0.12	ND	
Total	273,848	19,445	356	24	1.6	
Total CO ₂ emissions generated by Murchison during normal operations in 2011 (t)						
CO ₂ from cuttings management express	ed as % of Muro	chison opera	ations in 2	011	9.8%	

Table 16: Predicted energy use and emissions for removal of the drill cuttings pile – Option 2, onshore treatment and onshore disposal. (BMT Cordah, 2012)

Decommissioning Aspect	Energy (GJ)	CO ₂ (t)	NO _x (t)	SO ₂ (t)	CH ₄ (t)	
Vessel and helicopter use	220 202	20,660	201	25.04	1 74	
Dredge equipment (estimated 364 day)	270,303	20,009	301	20.04	1.74	
Onshore transportation	51,217	3,702	46.56	1.16	ND	
Onshore treatment and disposal	11,809	ND	ND	ND	ND	
Total	341,409	24,370	428	27.00	1.74	
Total CO ₂ emissions generated by Murchison during normal operations in 2011 (t)						
CO ₂ from cuttings management express	ed as % of Muro	chison opera	tions in 20	11	12.3%	

Table 17: Predicted energy use and emissions for removal of the drill cuttings pile – Option 3, offshore reinjection. (BMT Cordah, 2012)

Decommissioning Aspect	Energy (GJ)	CO ₂ (t)	NO _x (t)	SO ₂ (t)	CH ₄ (t)
Vessel and helicopter use					
Dredge equipment (estimated 364 day)	270,223	18,941	349	23.68	1.60
Reinjection of recovered material					
Total	270,223	18,941	349	23.68	1.60
Total CO ₂ emissions generated by Murchison during normal operations in 2011 (t)					
CO ₂ from cuttings management express	ed as % of Muro	chison opera	tions in 20	11	9.5%

Table 18: Predicted energy use and emissions for removal of the drill cuttings pile –Option 4, offshore re-distribution. (BMT Cordah, 2012)

Decommissioning Aspect	Energy (GJ)	CO ₂ (t)	NO _x (t)	SO ₂ (t)	CH ₄ (t)
Vessel and helicopter use;					
Dredge equipment (estimated 364 day)	255,109	18,941	349	23.68	1.60
Offshore re-distribution					
Total	255,109	18,941	349	23.68	1.60
Total CO ₂ emissions generated by Murchison during normal operations in 2011 (t)					
CO ₂ from cuttings management express	ed as % of Muro	chison opera	tions in 20	11	9.5%

Impact on sensitive receptors and proposed or designated sites

The main environmental effects of the emission of gases to atmosphere are:

- Contribution to global warming (CO₂, CH₄)
- Contribution to formation of photochemical pollutants (NO_X, SO_X, VOCs)

The direct effect of CO_2 , CH_4 and VOCs is their implication in global climate change (CH_4 has 21 times the global climate change potential of the main greenhouse gas CO_2 (IPPC, 2007)) and contribution to regional level air quality deterioration through low-level ozone production. The indirect effects of these emissions are low level ozone, deleterious health effects, and damage to vegetation, crops and ecosystems.

The direct effect of NO_X , SO_X and VOC emissions is the formation of photochemical pollution in the presence of sunlight. Low-level ozone is the main chemical pollutant formed, with byproducts that include nitric and sulphuric acid and nitrate particulates. The effects of acid formation include contribution to acid rain formation and dry deposition of particulates.

The main environmental effect resulting from the emission of SO_2 as a consequence of vessel power generation is the potential to contribute to the occurrence of acid rain. The emissions of SO_2 predicted to arise from the options for the Murchison drill cuttings pile are very low (23.68 – 27.00 tonnes) in comparison to 107.43 tonnes SO_2 emitted during Murchison operations in 2011 (EEMS, 2011).

Emissions arising from the vessel activity associated with the removal of the Murchison drill cuttings pile could result in a very short-term deterioration of local air quality within a few metres of the point of emission. The exposed offshore conditions would promote the rapid dispersion and dilution of these emissions. Therefore outside the immediate vicinity of the Murchison area all released gases would only be present in low concentrations. The atmospheric emissions from the management options for the drill cuttings pile are unlikely to have any effect on sensitive receptors.

Annex II species

Harbour porpoise is the only Annex II species which has been sighted in the vicinity of Murchison (Section 4.4.1).

In the open conditions that prevail offshore, the atmospheric emissions generated during the Murchison drill cuttings removal activities would be readily dispersed. This would ensure that, outside the immediate vicinity of the Murchison platform, all released gases would only be present in low concentrations. The atmospheric emissions from Murchison drill cuttings options are therefore extremely unlikely to have any effect on marine mammals.

Contribution to Transboundary, Cumulative or Global Impacts

The Murchison Platform is located 2 km west of the UK/Norway median line. The open conditions that prevail offshore would be expected to readily disperse atmospheric emissions generated from the vessel activities associated with the management of the Murchison cuttings pile.

Under these offshore conditions, the small amount of additional air emissions that would be produced is unlikely to be sufficient to have a significant or measurable transboundary effect.

The potential cumulative effects associated with atmospheric emissions produced by the drill cuttings pile operations include global climate change (greenhouse gases), acidification (acid rain) and local air pollution. The temporary emissions resulting from the proposed activities are very much lower than the emissions from existing Murchison production operations and this small, short-term addition would not be significant in relation to the total annual offshore emissions from the UKCS.

6.3 Release of contaminants from the drill cuttings pile to the water column and seabed

6.3.1 Drill cuttings pile management option

In the five options for the management of the Murchison drill cuttings pile there are two mechanisms whereby the cuttings could be physically disturbed and re-suspended into the water column, which result of options 1-4:

- disturbance of the whole drill cuttings pile (Option 4 only); and
- disturbance of a small amount of material caused by back-flush of the suction dredge to remove a blockage of debris from the hose (Options 1 to 4).

The fifth management option to leave the Murchison drill cuttings in-situ to naturally degrade beneath the Murchison jacket footings, could give rise to the following impacts resulting from the long-term presence of the pile:

- long term degradation of the jacket footings leading to falling jacket members and structures on the drill cuttings pile left *in-situ* (Option 5).
- Leaching of contaminants including hydrocarbons and metals into the water column from an undisturbed pile (Option 5);
- Long-term pile presence and contaminant persistence leading to continued impact on sediment quality and benthic communities from an undisturbed pile (Option 5).

6.3.2 Impact Assessment

In all management options, the wider area of contaminated sediments or the historic "effect footprint" of the Murchison cuttings pile would remain following field decommissioning as it does not form part of the scope for the drill cuttings pile management options, which focuses on the physical accumulation of contaminated cuttings.

Relocation of the Murchison drill cuttings pile by redistribution to another area of seabed would result in the re-suspension in the water column and subsequent re-settlement on the adjacent seabed of the entire drill cuttings pile (22,545 m³). The proposed location for redistributed cuttings is approximately 70 m to the south east of the Murchison platform.

Back-flush of the suction dredge to remove a blockage of debris from the hose would result in the re-suspension in the water column and subsequent re-settlement on the adjacent seabed of approximately 4.3 m³ of cuttings for a single blockage, or up to 1,694 m³ for one blockage per day over the intermediate predicted removal duration of 394 days (Genesis, 2013b). Blockages in the suction hose would be removed at the source and modelling predicts that the material would be deposited over the existing drill cutting pile and surrounding area.

The potential volume of drill cuttings re-suspended as a result of falling jacket members has been estimated at 157 m³, which is significantly less (<1%) than the full volume of the pile. Although it is greater than the volume of material discharged as a result of a single backflush of the suction dredge, it is significantly less than the potential total discharge which may be experienced over the duration of total pile removal from cumulative back-flushing events.

If the drill cuttings pile were left *in-situ*, loss of oil from the pile, i.e. from all the deposition within an 8 km² area around the discharge point, was predicted to start at a rate of 5 tonnes per year over the first year after drilling operations ceased, dropping rapidly over time to less than 1 tonne oil per year at year 20 and beyond (Genesis, 2013a). The total oil loss from the pile is currently predicted (in 2013) to be approximately **1.2 tonnes/yr**, which includes the loss of oil due to biodegradation and is an averaged value over the preceding two years, consequently the loss of oil to the water column is below the OSPAR 2006/5 threshold of **10 tonnes/yr**.

The area of seabed for which the concentration of oil exceeds 50 mg/kg (contaminated footprint) was predicted over the 40 year modelling period. Assuming that the OSPAR criterion can be taken as beginning in 2006 and is not retrospective, the contaminated area multiplied by the duration (footprint.persistence) has been calculated, beginning a minimum of 6 years after the last discharge of OBM which was in 2000. Thus, a cumulative footprint.persistence has been calculated. Taken to the end of the 40 year simulation period (extent of the model), the area of persistence is less than **11 km²years**, which is well below

the OSPAR criterion of **500** km²years, below which no further action is necessary and the pile may be left to degrade naturally.

Seabed sediment

The deposition thickness of the wider area of contaminated sediments or the historic "effect footprint" of the Murchison cuttings pile is relatively thin. This area would therefore be expected to recover through natural biodegradation processes over time, as demonstrated by the shrinking of this area of contaminated sediments during its recovery since the end of OBM discharges in 1983.

If the cuttings accumulation were relocated onto the adjacent seabed it would be deposited within 70 m of the existing drill cuttings pile. The percentage of fines material in the receiving sediments would therefore increase but as the immediate receiving area already has elevated % fines (from the original drilling operations), impacts associated with any change in sediment grain size may be smaller than if the cuttings were distributed on previously undisturbed sediments further away from the Murchison platform. Modelling indicates that the majority of material would settle within 500 m of the discharge point, and that beyond 2 km the new layer of resettled cuttings would be less than 0.1 mm thick. Impacts associated with change in grain size are therefore likely to be experienced over a large area and are expected to contribute a small proportion of the overall environmental risk to sediments from the redistribution (Genesis, 2013b).

The hydrocarbon concentrations within the wider Murchison area are generally within expected background levels for the northern North Sea, but hydrocarbon concentrations within 250-500 m of the Murchison platform are elevated above background concentrations as a result of the historic drilling discharges (Fugro ERT, 2013; Hartley Anderson Limited, 2007). Cuttings dispersion modelling indicates that immediately after redistribution of the cuttings pile the area where THC >50 mg/kg in sediment would be approximately 10 km² and that oxygen depletion would contribute approximately 65% of the overall environmental risk, and hydrocarbon toxicity (primarily PAH) contributing 34%. The proposed activities therefore have the potential to cause contamination of seabed sediments from hydrocarbons and heavy metals over a relatively large area from the discharge operations. The majority of cuttings material is expected to settle within 500 m of the discharge location, with a thinner layer (0.01 m) of material resettling beyond 2 km of the discharge point. The thinner layer of contaminated material settling around the periphery of the discharge location will degrade more quickly than the bulk of material discharged close to the discharge point, as the thinner layer will be re-colonised by benthic fauna relatively quickly and biodegradation will occur in the thin oxygenated surface layer. The thicker deposition of cuttings material within 500 m of the discharge would take much longer to become re-colonised by benthic fauna, and the deposition would be characterised by a thin oxic surface layer covering a thick anoxic layer. Modelling predicts that the contaminated area would decrease in size significantly over a period of 10 years, such that after 10 years the area where THC >50 mg/kg would be less than 1 km² (Genesis, 2013b); the cuttings here would be thicker than the depth of the surface oxic layer and this would prevent degradation of contaminants deeper within the cuttings deposition.

The environmental risk (EIF) is primarily driven by oxygen depletion (as a result of organic carbon enrichment, from the presence of degraded oil) and toxicity of the PAH content (Figure 23). A large reduction in the EIF takes place during the ten years after redistribution as the oil content in the thinner layers is naturally degraded As aliphatic oil and PAH are relatively persistent over time these risk factors are also persistent particularly within the area of thicker deposition. PAH persisting in the sediment may have toxic effects on benthic organisms within the area of the thickest deposit for many hundreds of years (Genesis, 2013a).

Given the large volume of material that would be redistributed during the operations to relocate the entire drill cuttings pile it is predicted that the re-suspended material would travel beyond the existing "effect footprint" of the Murchison cutting pile and settle on "relatively" clean sediment. It is therefore considered that there is a high likelihood of previously uncontaminated sediment becoming contaminated by re-suspension of material during the operations.

In contrast, the relatively small volumes of cuttings material discharged to clear a blockage in the suction dredge or as a result of the jacket legs collapse, would only travel several hundreds of meters from the discharge point and sediment hydrocarbon levels exceeding 50 mg/kg would only be found, temporarily, over an area of <0.195 km² and 0.044 km² respectively (Table 11). The impacts associated with this discharge are predicted to remain within the historic "effect footprint" of the Murchison cuttings pile which is 0.566 km².

The long-term environmental risk to the seabed resulting from leaving the accumulation of the drill cuttings pile *in-situ* is predicted to be predominantly a result of oxygen depletion in sediments and elevated PAH concentrations (Genesis, 2013a). Alkylphenol Ethoxylates (APEs) were not assessed within the drill cuttings pile modelling, however, results from the pre-decommissioning environmental survey (Section 4.2.2) indicated that elevated levels of APEs were present in the drill cuttings pile accumulation and at one station 250m SE of Murchison. APEs are listed by OSPAR as chemicals for priority action due to being toxic to marine organisms, bioaccumulative and persistent in the environment. Nonylphenol, octylphenol and their derivates (ethoxylates) are suspected endocrine disruptors which induce sex change in male fish. Therefore, it is likely that APEs will contribute towards the overall environmental risk to benthic and demersal feeding organisms such as fish.

Oil and associated contaminants (such as APEs) will continue to leach through the layers of the cuttings pile continually re-contaminating the surface layers of the pile as they start to biodegrade. The core accumulation of the pile, if left *in-situ*, therefore has the potential to cause toxic effects to demersal organisms through continued leaching of hydrocarbons. The

area of sediment impacted would be limited to the small footprint area of the existing pile accumulation (<0.01 km²). Sessile demersal species would be at the greatest risk, with other benthic deposit feeding organisms at risk of bioaccumulation through the food chain. The chemical and biological extent of the pile is expected to diminish gradually over time and be limited to small releases spatially contained within the footprint of the bulk of the pile material.

Water quality

The re-suspension of drill cuttings is expected to result in a local reduction in water quality as a result of the release of contaminants and an increase in turbidity. Although the re-suspended contaminants would be diluted by currents, and the cuttings particles would rapidly re-settle onto the seabed, the continued re-suspension of material over the predicted 394 day operation would result in a prolonged period of water column contamination (CNRI, 2012b; Genesis, 2013b).

In both the pile redistribution and back-flushing operations, modelling shows that a plume of contaminated water would extend nearly 16 km kilometres down-current from the cuttings pile. Contamination in the water column is not expected to extend more than a few tens of metres above the seabed during redistribution operations and approximately 100 m from the seabed in the footing collapse scenario (Genesis, 2013b). During the operations that relate to the whole pile, these impacts would exist for over 1 year. Once the operations cease the quality of water in the affected area would recovery rapidly (within 24 hours) (Genesis, 2013b). It is therefore concluded that there would be a "moderate" impact to the water column from redistribution operations and a "low" impact from back-flushing operations and the footings collapse scenario (Table 4).

Impacts to the water column as a result of the jacket leg collapse would be very short lived, with the impacts from each of the 24 structural piles within the footings lasting for 16 hours, equivalent to 384 hours or 16 days. The majority of material is predicted to remain within 20 meters of the seabed. Although a small proportion of material will extend over 50 m into the water column, it would not exceed 5% environmental risk and consequently is considered to be a low environmental impact.

Oil loss from the existing historic drill cuttings pile accumulation into the overlaying water column is currently (2012) predicted to be of the order of 1.2 tonnes / year from a pile footprint area of 6,800 m², which equates to a release of 2.5 g / m² / day. The rate of oil loss from the pile includes biodegradation mechanisms (which are not separated out within the model) and is therefore conservative, with the rate of oil leaching predicted to be lower than this figure (Genesis, 2013a). The rate of oil loss is predicted to continue steadily decreasing over time to less than 1 tonne / year by 2019 and beyond (Genesis, 2013a). Environmental risk to the water column from the higher leaching rate of 1.2 tonnes / year is predicted to be

below the 5% risk value such that it is not considered to pose a significant risk to pelagic organisms.

Phytoplankton and zooplankton

The increase in water column turbidity, suspended fine particulates and toxic contamination is expected to be localised to within several tens of metres from the seabed and it is therefore not anticipated to have any significant impact on planktonic organisms, which are widely distributed throughout the water column and over the North Sea.

Benthic fauna

Redistribution of the drill cuttings pile to another area of seabed is likely to physically disturb benthic fauna in the area around the discharge location and to smother benthic fauna in the immediate discharge area. In the short term, this would kill benthic organisms in the area of the cuttings discharge and create a contaminated area of habitat up to approximately 10 km² from the discharge point. Studies have shown that re-colonisation of cuttings pile sediments may commence 1-2 years after the cessation of cuttings discharges (UKOOA, 1999). Resettlement of contaminated sediment onto the seabed would also have the potential to be toxic to benthic organisms. As a result re-colonisation is generally characterised by the appearance of opportunistic species such as Capitella capitata, which are tolerant to hydrocarbons and physical disturbance, and consequently have been found to dominate cuttings piles communities during the first 5 years; it is one of the dominant species present on the Murchison drill cuttings pile (Fugro ERT, 2013). Studies of the effects of cuttings piles in the Norwegian Sector of the North Sea have indicated that heavily contaminated sediment prevented macrofaunal re-colonisation during the first 5 years; the layer of contaminated cuttings forms a barrier to burrowing organisms and consequently recovery may be extremely slow (Bakke et al. 1989 cited in UKOOA, 1999).

Re-colonisation of the contaminated sediments would gradually result in the biodegradation of contaminants within the surface layer of redistributed sediments, and therefore in a gradual reduction in the overall contaminated area, especially in the area of thinly deposited material (Genesis, 2013b). Areas where sediment is deposited in a thicker layer would persist for a much longer period (tens of years) as only the upper oxygenated layers of deposited sediments would experience biodegradation. Faunal samples collected from the existing Murchison cuttings pile indicate that whilst re-colonisation of the contaminated sediments has occurred, samples exhibit low species diversity and abundance, and pollution-tolerant species still dominate approximately 20 years after drilling discharges ceased (Fugro ERT, 2013). Therefore redistribution of the drill cuttings pile over a new area of seabed is likely to affect faunal communities for decades.

Redistribution of the drill cuttings pile is very likely to result in a very high impact to the benthic faunal communities in the immediate and surrounding area of the discharge location,

leading to long-term damage and very slow recovery rates (>10 yrs), and is therefore considered to pose a "significant" risk (Table 4).

Dispersion of drill cuttings as a result of the back-flushing operations is expected to affect a very small area of seabed within the existing 'effect footprint' of the Murchison drill cuttings pile. The affected sediments are expected to show good recovery rates within the first year and total hydrocarbon concentrations will have dropped below 50 mg/kg after 10 years. The number of back-flushing operations that would be required to complete the removal of the Murchison drill cuttings pile is not known, but back-flushing is expected to occur intermittently throughout the operations (which could be over 1 yr). Back-flushing operations are likely (Table 2) to result in a moderate impact (Table 3) to the benthic faunal communities in the immediate and surrounding area of the discharge location leading to short-term damage with good recovery rates (<2 yrs), and are therefore considered to pose a "moderate" risk (Table 4).

Disturbance of drill cuttings as a result of the jacket leg collapse is predicted to have a low significance to benthic organisms (Table 4), as the initial impact area would not significantly exceed the area of the current pile accumulation and would be well within the existing background effects footprint of 50 mg/kg. Within 1 year post collapse the impact area is predicted to have receded to within the footprint of the existing pile accumulation.

Fish and shellfish

Fish are highly mobile organisms and are likely to avoid the areas of re-suspended sediments and turbulence during the operations to redistribute the drill cuttings pile. The operations at the Murchison platform will be undertaken continuously for more than 1 year, and would therefore coincide at various times with the spawning periods for cod, whiting, Norway pout, haddock and saithe. As noted previously, the platform is located in an area which forms part of the nursery grounds for herring, ling, mackerel, spurdog, and blue whiting (Coull *et al.*, 1998; Ellis *et al.*, 2010). Therefore it is likely that there could be localised disturbance to demersal spawning fish during the drill cuttings redistribution operations.

Of the fish spawning areas which coincide with the Murchison area, Norway pout is the only species which spawn onto the seabed (Table 8). All the other species spawn pelagic eggs and larvae and are therefore not likely to be affected by the re-suspended material from the drill cuttings pile since this is predicted to remain within tens of metres from the seabed (Section 5.4.1). The Murchison area is not located within an area of high spawning intensity for Norway pout, (which is approximately 60 km to the south of Murchison (Coull *et al.*, 1998)), and the size of the potentially affected area is relatively small (<10 km²) in comparison to the spawning area used by Norway pout in the northern North Sea (>10 Quadrants, each 250 km²).

Of the fish nursery areas which coincide with the Murchison area, ling is the only species which has a demersal juvenile phase. All the other species have pelagic juvenile phases (Table 8) and as such would not be affected by the re-suspension of the drill cuttings. Ling nursery grounds are spread across the northern North Sea and off north-western Scotland, with the greatest concentrations in deeper waters (Ellis *et al.*, 2010). The Murchison area lies on the north-eastern edge of the ling nursery grounds and accounts for a small percentage of available nursery area.

In addition to impacts associated with spawning and nursery areas, other potential direct impacts of the hydrocarbons in drill cuttings on fish include tainting of fish for human consumption, disease in adult fish such as abnormal tissue growths and other lesions, and physiological impacts such as repression of the immune system in adult fish CEFAS (1999). Of the species recorded within the Murchison area cod, whiting, saithe, haddock, Norway pout and ling all have a demersal existence as adults and generally feed on benthic organisms (Table 8).

Historical studies have recorded taint in fish caught close to oil and gas platforms (<1,000 m), mostly in demersal species (CEFAS, 1999). It is thought that taint contamination of benthic species could be due to ingestion of contaminated sediment (Cordah, 1998). Hydrocarbons, especially PAHs such as those found in OBM drill cuttings, have long been known to cause teratogenicity, mutagenicity and carcinogenicity in fish (References in CEFAS 1999) through chronic and acute effects on tissues. The main mechanism of toxicity of PAH in fish is through interference with cell membranes and thus disruption of cellular processes that depend on membranes; for example, PAHs bond to cellular proteins resulting in mutagenesis, teratogenesis and cancer.

The incidence of such impacts on adult fish has not been extensively studied in relation to contamination from drill cuttings piles (CEFAS 1999), partly because fish are highly mobile. In addition, many of these impacts have a long development time and are likely to have multiple causes. Exposure to drill cuttings contamination is likely to be a contributory factor rather than the sole cause in the incidence of disease, but its relative contribution is difficult to establish (CEFAS 1999).

Additionally, APEs which have been recorded in elevated levels within the drill cuttings pile are toxic to marine organisms and suspected endocrine disruptors which induce sex change in male fish (OSPAR 2009a, b, c).

Redistribution of the Murchison drill cuttings pile may result in disruption to a localised area (<10 km² area exceeding 50 mg/kg) of spawning ground for Norway pout and nursery ground for ling, for the duration of redistribution operations (> 1yr) and potentially over the duration of long-term impacts to the seabed sediments at the discharge location (tens of years). A maximum instantaneous volume of water of 0.1621 km³, would be at >5% environmental risk during the redistribution operations. This may also contribute towards

potential physiological impacts to demersal fish species living within the immediate vicinity of the redistributed drill cuttings pile. Redistribution of the drill cuttings pile and associated contaminants is likely to result in an impact to fish of high severity due to its long-term nature (>10 years) and therefore is considered to be a "significant" risk (Table 4).

Impacts associated with back-flushing operations, jacket leg collapse and the pile being left *in-situ* are predicted to be very localised (<1 km² of seabed and <0.009 km³ water volume). Back-flushing operations are considered to be of moderate impact (Table 4) as there would be a continuous >5% risk to the water column for the duration of operations (>1yr) with good potential for recovery (Table 3). Jacket leg collapse is considered to be of low impact (Table 4) as impact to the water column from the leg collapse would be of very short duration (<16 days) (Table 3). Persistence and leaching of THC within the pile if left *in-situ* does not exceed 5% environmental risk to the water column and whilst THC within the pile sediments would have the potential to cause toxic and endocrine responses in fish the area of seabed impacted is very small (<0.01 km²) such that it is unlikely to result in population level or ecosystem changes to mobile species within the wider area.

6.4 Fishing gear interaction with cuttings pile leading to dispersion of drill cuttings pile and net fouling

6.4.1 Drill cuttings pile management option

The Murchison drill cuttings pile is currently located within the footprint of the jacket footings and is therefore protected by the footings from potential interactions with fishing gear. Fishing gear interaction with the drill cuttings pile could only occur in Option 4, where the pile is redistributed over an adjacent area of seabed. All other management options result in the complete removal of the drill cuttings pile from the marine environment.

6.4.2 Impact Assessment

Redistribution of the Murchison drill cuttings pile from beneath the jacket to an area of seabed approximately 70 m to the south-east of the Murchison jacket would expose the drill cuttings pile to potential disturbance impacts from other activities, such as further redistribution by demersal trawling over the pile and potential fouling of fishing nets. Field studies designed to trawl over a known cuttings pile and measure the dispersion of cuttings resulting from the trawling activities were conducted by the Fisheries Research Services in 2000. The results indicated that trawling activity disturbed relatively little material to a significant height into the water column. Contamination would be spread by trawling activities, but not in amounts or at rates that are likely to pose serious wider contamination or toxicological threats to the marine environment (referenced within OSPAR, 1999). Therefore, fishing gear interactions with the redistributed cuttings pile would be unlikely to

result in an impact to the sediments and commercial fishing (Table 2), the severity of which would only be slight (Table 3), and therefore would present an "in-significant" risk (Table 4).

6.5 Landfill disposal of residual solids resulting in reduced capacity of disposal facilities

6.5.1 Drill cuttings pile management option

Two of the four management options involve the transportation of the recovered drill cuttings to shore for treatment and ultimate disposal in a landfill site, whereas in the other two options the cuttings are disposed of offshore. The impacts associated with the landfill disposal of residual solids apply to:

- Option 1: Separation, treatment of liquids offshore, transport and treatment of solids onshore; and
- Option 2: Transport slurry to shore, separation and treatment onshore for disposal.

6.5.2 Impact Assessment

Treatment of drill cuttings

The water entrained in the slurry would be separated from the solids and oil would be removed so that the water could then be discharged under licence to controlled waters. If the treatment method yields a final effluent which cannot be discharged to controlled waters, then additional treatment stages may be required.

The recovered solids would be treated to remove the hydrocarbons, and the most likely method that would be used is thermal desorption. Thermal desorption is an energy-intensive process which is widely used onshore for processing OBM cuttings prior to landfilling. It uses temperatures of 250-350°C to volatilise low molecular hydrocarbons within the drill cuttings, and the final product is a fine residue containing less than 5% water which can subsequently be disposed of as inert waste in landfill. The oil recovered from the cuttings and from the entrained seawater is recycled.

Thermal desorption has the advantages of significantly reducing the volume of material that must ultimately be disposed of to landfill, and reducing the hazard level of the waste. It would remove organic substances but not inorganic chemicals such as metals and salts. The presence of these contaminants may mean that the residual solids from this process would be classified as 'hazardous'. PCBs could be removed if the reaction temperature is high enough (>600°C) to cause volatilisation. This method has been used to successfully treat PCB-contaminated soils.

Although these treatment processes would take place at licensed sites with all necessary permits and consents for discharge, they could give rise to small-scale, localised and short-

lived effects including emissions of gases, generation of noise, production of odour, and increased levels of road traffic; none of these effects, however, are considered to be significant.

Landfill disposal of residual solids

Following treatment, the residual solids would be classified as hazardous waste because of the heavy metals and other inorganic contaminants that would remain after thermal desorption. Data from 2009 indicates that there is one landfill site in Scotland and a further 17 landfill sites in England that are licensed to accept commercial hazardous waste (SEPA, 2010; Environmental Agency (EA), 2012). In order to obtain a licence to landfill hazardous waste, potential landfill sites are assessed for all of the relevant factors, including type of ground, groundwater systems, proposed liner system, types of waste proposed and input rates, by SEPA or the EA. As such any drill cuttings materials disposed of to landfill would comply with the licensing requirements of the chosen landfill site. Final disposal is likely to involve transportation by road, with associated local impacts to infrastructure and communities through increased traffic levels.

The ultimate impact from a new source of waste being disposed of to landfills is that available capacity is used more quickly, and thus new landfill sites have to be developed sooner than expected (DNV, 1999). The development of new landfill sites would have impacts on society and the environment, the type and scale of which would depend on the local conditions and quality of landfill being developed. However, these impacts are considered to be out with the scope of this assessment as a new landfill facility would not be developed by CNRI or for CNRI's sole use.

6.6 Discharge of treated seawater

It is estimated that if an average water to solid recovery ratio of 15:1 (CNRI, 2012a and 2012b) could be achieved, the excavation operations to remove the Murchison drill cuttings pile would result in the recovery of approximately 360,720 m³ of seawater along with the Murchison drill cuttings pile.

Once recovered to the surface the seawater would be separated from the solids and treated using hydrocyclones and chemicals to reach an acceptable condition for discharge. Once the treated seawater has achieved or exceeded relevant permitted levels it would be discharged to sea offshore. Seawater would be discharged continuously over the predicted 394 day drill cuttings recovery period. To put this into context, the discharge of approximately 360,720 m³ of treated seawater would be equivalent to 12 days produced water discharge from Murchison platform (30,500 m³ per day in 2011).

Release of relatively small amounts of treated seawater to the marine environment would result in a short-term and localised impact immediately around the discharge point. The

organisms that would be at risk include planktonic organisms (i.e. those drifting in the nearseabed currents), epibenthic organisms (e.g. demersal fish and shellfish), sediment-dwelling filter feeders (e.g. polychaete worms, bivalve molluscs and amphipods) and spawning and juvenile fish.

Plankton is widely distributed in the water masses that flow over large areas of the North Sea (BMT Cordah, 2011). Planktonic species have the capacity to recover quickly due to the continual exchange of individuals with surrounding waters and any impacts associated with the proposed operations are likely to be small in comparison with the natural variations. Consequently, a relatively short-term permitted discharge of treated seawater will not present a significant risk to the viability of the plankton community in the discharge area for the treated seawater.

The discharge of treated seawater is unlikely to impact seabed chemistry as the seawater will be discharged in surface waters and would dissipate rapidly with the local surface currents. The benthic community in the Murchison area is therefore unlikely to be impacted by the short-term permitted discharge of treated seawater.

Fish are mobile organisms that would be able to move away from the immediate vicinity of the discharge point. The operations at the Murchison platform will be undertaken continuously for more than 1 year, and would therefore coincide at various times with the spawning periods for cod, whiting, Norway pout, haddock and saithe; the platform is located in an area which forms part of the nursery grounds for herring, ling, mackerel, spurdog, and blue whiting (Coull *et al.*, 1998; Ellis *et al.*, 2010). Therefore it is likely that there could be small localised disturbance to pelagic spawning fish during the discharge of treated seawater. The volume of water discharged is equivalent to 12 days produced water discharge from Murchison platform, but would be discharged over a much longer time period and therefore daily discharge volumes would be much smaller. All treatment chemicals would be risk-assessed and covered by the relevant discharge permit under the Offshore Chemical Regulations 2002. The fish and shellfish in the Murchison area are therefore unlikely to be impacted by the short-term permitted discharge of treated seawater.

If the recovered drill cuttings from the Murchison platform were transported to shore as a slurry, dewatering and de-oiling would be undertaken at an onshore processing site rather than in the Murchison area offshore, and treated seawater would be discharged to the marine environment from an existing onshore processing site. The potential onshore processing site is not known at this time, but CNRI would use an existing site and water treatment and disposal would be conducted under the site's existing permits. All chemicals used for treatment would be covered by the relevant permit for the site and would be risk-assessed accordingly. It is therefore considered that fish and shellfish in the vicinity of the onshore processing plant discharge location are unlikely to be impacted by the short-term permitted discharge of treated seawater.

7. CONCLUSIONS

This study examines and assesses the environmental impacts that could arise from different management options for the accumulation of Murchison drill cuttings pile material. The study does not make any assessment of the safety risk, technical feasibility or cost of the different options; these have been independently assessed and will be compared within the comparative assessment process. The environmental impacts associated with the management options for the Murchison drill cuttings pile comprise both short-term operational impacts associated with disturbance to the drill cuttings pile and long-term legacy impacts associated with leaving the contaminated sediments in place.

Short-term Impacts

Potential short-term operational impacts have been identified as energy use and generation of atmospheric emissions; disturbance of cuttings material during back-flush events and redistribution of the whole of the cuttings pile releasing contaminants to the water column and sediments; and discharges of treated seawater which will be recovered by the suction dredge.

Of these short-term impacts, energy use, generation of atmospheric emissions and discharge of treated seawater for all management options were considered to be of low significance when compared with the annual emissions and discharges arising from oil and gas production operations on the Murchison Platform during 2011. These activities would result in relatively short-term (approximately 1-3 years) deterioration of local air and water quality within the vicinity of the point of emission. The exposed offshore conditions would promote the rapid dispersion and dilution of these emissions.

Disturbance to the drill cuttings material as a result of back-flushing operations to remove debris from the suction dredge is considered to have a moderately significant impact on the benthic environment.

The redistribution of the whole drill cuttings pile over a new area of seabed is likely to result in a highly significant impact to the benthic environment. Redistribution of the drill cuttings pile over a new area of seabed has significant risks associated with the re-suspension of contaminants to the water column and subsequent settling to the seabed. This is likely to result in a potential short-term high impact to fish in the water column within the area, a high impact to demersal fish, and a very high impact to benthic fauna which have relatively low mobility and would be unable to avoid the affected area during operations. Long-term changes would be experienced within the local ecosystem.

Long-term Impacts

Long-term legacy impacts associated with the drill cuttings pile management options have been identified as contamination of new areas of seabed from pile redistribution, reduction in landfill capacity from recovered solids and the persistence and leaching of contamination from a pile that is left *in-situ*. Additionally, if the drill cuttings pile were left *in-situ* there could be future disturbance of the degraded pile as a result of fisheries trawling activities or by impact from the eventual collapse of the derogated Murchison jacket footings.

Impacts associated with the landfill of recovered solids are considered to be of low significance owing to the present annual capacity of existing landfill sites for hazardous waste. The potential for disturbance of the drill cuttings pile left *in-situ* from fishing gear interactions is considered to be of low significance as the majority of the pile would be protected by the presence of the derogated jacket footings and field trials have indicated that there is little disturbance from fishing gear. Modelling studies of the impact from the eventual jacket collapse predict that the cuttings would be significantly weathered and degraded by the time of collapse (300-1,000 years), and that impacts to the sediment would be localised with good recovery potential such that the long-term impacts might not represent a significant change to the underlying conditions.

Comparison of Short-term and Long-term Impacts

In order to determine the best management option for the drill cuttings pile it is necessary to balance the short-term impacts from operations with the long-term legacy impacts. The key impacts have been identified above as those which are generally above or out with impacts resulting from normal Murchison operations and as such involve the release of contaminants from the drill cuttings pile. The short-term and long-term impacts resulting from contamination release associated with the different drill cuttings pile management options are summarised in Table 19 below, and the impacts assessed in Table 20. Low environmental impacts that would persist for a very long time have been compared against high environmental impacts that would persist for much shorter timescales.

From an environmental perspective, management options 1-3, which involve complete removal of the pile, are the only options that effectively remove long-term contamination liability issues associated with the accumulation of cuttings pile material. However, there is uncertainty associated with the amount of material that could be released to the environment during the removal process, and the acknowledgement that an existing background contaminated area from the original drilling discharges will remain. Assessment of the predicted area and scale of impact from one back-flush event and consideration of the potential total number of back-flush events that may occur during removal of the whole pile suggests that the impact would be of moderate significance and that elevated hydrocarbons would be measurable for several decades.

Redistribution of the pile would result in high operational impacts during sediment redistribution and high long-term impacts from the redistributed contaminated sediments.

Worst case predictions of the impact from the eventual collapse of the jacket footings suggest that a relatively small proportion of the pile would be disturbed (7%) and resuspended and that much of the material would re-settle on the existing accumulation of drill cuttings pile material and currently contaminated sediments. The Murchison drill cuttings pile falls below the OSPAR 2005/6 threshold criteria, and is therefore considered to present a low or insignificant environmental impact and in this context natural degradation is considered the Best Environmental Strategy (OSPAR 2005/6; UKOOA, 2002a).

Excavation of the drill cuttings pile to the surface and reinjection of the cuttings material into a disposal well, gives a favourable balance between the moderate short-term environmental risks to the water column during excavation operations and low long-term environmental risks from removal of the accumulation of cuttings pile material. However, the recovered historic cuttings are considered waste, and as such injection back into the formation would not be permissible under the OSPAR Convention and the London Protocol, which prohibits the disposal of industrial wastes in such a manner.

	Short-term Impact	Long-term Impact
Option 1: Separation, treatment of liquids offshore, transportation and treatment of solids onshore Option 2: Transportation of slurry to shore, separation and treatment onshore for disposal Option 3: Offshore injection of slurry	 Blockage of suction dredge leading to the release of drill cuttings and associated contaminants to the water column and seabed. Moderately significant impact: Smothering and contamination of localised area of sediments, within 500m of discharge; Cuttings rapidly sink to seabed and water column impacts will be short-lived (<24 hrs); Unknown number of blockages and back-flush operations required to lift 	 Long-term contamination of a previously uncontaminated area of seabed. Unknown number of blockages and back-flush operations required to lift entire pile, long-term ecological impact unknown. High number of back-flush events could give rise to moderately significant long-term impact. Localised contaminant persistence likely for 10's years.
Option 4: Distribute cuttings over surrounding sediments	 entire pile, ecological impact unknown. Physical disturbance of the entire drill cuttings pile releasing contaminants to the water column. Highly significant impact: 70% of hydrocarbons liberated Smothering and contamination of previously uncontaminated sediments within a 6km radius of the discharge; Cuttings will rapidly sink to seabed (<24 hrs), but water column impacts will last for duration of excavation operations (estimated 137-628 days). 	 Long-term contamination of a previously uncontaminated area of seabed. High significant impact: Area of THC >50 mg/kg in sediments approx. 10 km² reducing to a <1 km² area within 10 yrs; Main volume of contaminated sediments will persist for 100-1000's yrs.
Option 5: Leave <i>in-situ</i> and leave to naturally degrade	No operational activities.	 Leaching of hydrocarbons and contaminants into the water column from undisturbed pile Low significant impact: Occur continuously for several 100's yrs Low level of hydrocarbon release (< 1 t/yr 2020 onwards) Long-term pile presence and contaminant persistence leading to continued impact on sediment quality and benthic communities from an undisturbed pile Low significant impact: Occur continuously for several 100's yrs Decreasing hydrocarbon concentrations in surface sediment and continued community recovery Long-term degradation of footings resulting in jacket members falling onto the drill cuttings pile and re-suspension of contaminants to the water column and seabed. Low significant impact: Occurs in 300-1000 yrs Localised contaminant release over existing contaminated sediment

Method	Aspect	Potential Impact	Receptor	L	S	Sig
Option 1: Separation, treatment of liquids offshore, transportation and treatment of solids onshore	Power generation	Energy use leading to atmospheric emissions of CO ₂ and VOC which may contribute to climate change; emissions of NOx and SOx which may contribute to acid rain.	Use of resources, atmosphere, cumulative impacts, transboundary impacts	5	1	L
	Excavation of drill cuttings pile and recovery to surface.	Blockage of suction dredging equipment leading to the release of drill cuttings potentially releasing contaminants to the water column and seabed.	Sediments, water column, benthos, fish, cumulative impacts	4	3	М
	Landfill disposal of residual solids.	Reduced capacity of disposal facilities.	Use of landfill capacity	1	1	L
	Discharge of treated seawater.	Planned release of treated seawater resulting in release of contaminants (e.g. hydrocarbons, chemical solutions).	Water column	1	1	L
Option 2: Transportation of slurry to shore, separation and treatment onshore for disposal	Power generation.	Energy use leading to atmospheric emissions of CO ₂ and VOC which may contribute to climate change; emissions of NOx and SOx which may contribute to acid rain.	Use of resources, atmosphere, cumulative impacts, transboundary impacts	5	1	L
	Excavation of drill cuttings pile and recovery to surface.	Blockage of suction dredging equipment leading to the release of drill cuttings potentially releasing contaminants to the water column and seabed.	Sediments, water column, benthos, fish, cumulative impacts	4	3	М
	Landfill disposal of residual solids.	Reduced capacity of disposal facilities.	Use of landfill capacity	1	1	L
	Discharge of treated seawater.	Planned release of treated seawater resulting in release of contaminants (e.g. hydrocarbons, chemical solutions).	Water column	1	1	L
Option 3: Offshore injection of slurry	Power generation.	Energy use leading to atmospheric emissions	Use of resources, atmosphere, cumulative impacts, transboundary impacts	5	1	L
	Excavation of drill cuttings pile and recovery to surface.	Blockage of suction dredging equipment leading to the release of drill cuttings potentially releasing contaminants to the water column and seabed.	Sediments, water column, benthos, fish, cumulative impacts	4	3	М

Table 20: Summary of environmental risks of options for the management of the Murchison drill cuttings pile

* L – Likelihood (Table 2), S – Severity (Table 3), Sig – Significance (Table 4)

Table 20: Continued: Summary of en	vironmental risks of options for the management
of the Murchison drill cuttings pile	

Method	Aspect	Potential Impact	Receptor	L	S	Sig
Option 4: Distribute cuttings over surrounding sediments	Power generation for: excavation of the drill cuttings pile to another area of seabed.	Energy use leading to atmospheric emissions of CO ₂ and VOC which may contribute to climate change; emissions of NOx and SOx which may contribute to acid rain.	Use of resources, atmosphere, cumulative impacts, transboundary impacts	5	1	
	Excavation of the drill cuttings pile and redistribution to another area of seabed.	Physical disturbance of the entire drill cuttings pile releasing contaminants to the water column and seabed.	Sediments, water column, benthos, fish, plankton, commercial fishing, stakeholders, cumulative impacts	5	5	н
	Fishing gear interaction with cuttings pile	Dispersion of drill cuttings pile and net fouling.	Sediments, stakeholders, commercial fishing	2	2	L
Option 5: Leave <i>in-situ</i> and leave to naturally degrade	No remedial action	Leaching of contaminants including hydrocarbons and metals into the water column from an undisturbed pile	Sediments, water column, benthos, fish, plankton, stakeholders, cumulative impacts	3	2	L
		Long-term pile presence and contaminant persistence leading to continued impact on sediment quality and benthic communities from an undisturbed pile	Sediments, benthos, benthos, fish, plankton, stakeholder, cumulative impacts	5	1	L
	Long term degradation of footings leading to falling jacket members and structures	Physical disturbance to the drill cuttings pile potentially releasing contaminants to the water column and seabed, which may impact pelagic and demersal species.	Sediments, water column, benthos, fish, plankton, stakeholders.	3	2	L

* L – Likelihood (Table 2), S – Severity (Table 3), Sig – Significance (Table 4)

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