Defence Infrastructure Organisation

Dalgety Bay

Outline Management Options Appraisal
Final Report
DIO Project No. 12920

13 January 2014

Prepared by AMEC Environment & Infrastructure UK Limited for the Ministry of Defence, under commission GPS/ELMG/063

Defence Infrastructure Organisation

Report for

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Executive Summary

AMEC Environment and Infrastructure UK Ltd (AMEC) was commissioned by the Defence Infrastructure Organisation (DIO) to undertake an Outline Management Options Appraisal of an area surrounding the Dalgety Bay Sailing Club, Dalgety Bay, Fife, KY11 9SJ (the 'Study Site'), in support of the Investigation Plan, dated February 2012, as agreed with SEPA.

The Investigation Plan and the Proposed Scope of Works are focussed on radium-226 only. The Outline Management Options Appraisal represents Stage 3b of The Dalgety Bay Inspection Investigation Plan.

The purpose of Stage 3b of the Investigation Plan is to undertake an Appraisal of Outline Management Options based on the findings of earlier stages of work undertaken by AMEC and the Scottish Environment Protection Agency (SEPA). This report presents the findings of the Appraisal of Outline Management Options. Further development and appraisal of the available options is dependent on the completion of ongoing work and the establishment of remediation criteria which is currently in discussion with Public Health England (PHE).

Contents

Glossary of Terms

Site Specific

DE	-	Defence Estates
DBSC	-	Dalgety Bay Sailing Club
DEFRA	-	Department for Environment Food and Rural Affairs
DIO	-	Defence Infrastructure Organisation
MOD	-	Ministry of Defence
RNAS	-	Royal Naval Air Station
SG	-	Scottish Government

Environmental

ACM	-	Asbestos Containing Material
AOD	-	Above Ordnance Datum
CEM	-	Conceptual Exposure Model
CSM	-	Conceptual Site Model
DQRA	-	Detailed Quantitative Risk Assessment
LQA	-	Land Quality Assessment
NGR	-	National Grid Reference
OS	-	Ordnance Survey
PHE	-	Public Health England
PPE	-	Personal Protective Equipment
SEPA	-	Scottish Environment Protection Agency
SPL	-	Significant Pollutant Linkage

1. Introduction

1.1 Terms of Reference

AMEC Environment and Infrastructure UK Ltd (AMEC), formerly Entec UK Ltd, was commissioned by the Defence Infrastructure Organisation (DIO) to undertake an Appraisal of Outline Management Options for an area surrounding the Dalgety Bay Sailing Club, Dalgety Bay, Fife, KY11 9SJ (the 'Study Site').

The Appraisal of Outline Management Options represents Stage 3b of the Dalgety Bay Inspection Investigation Plan, first published 29 February 2012, as subsequently amended following comment by the Scottish Environment Protection Agency (SEPA), and is available at:

http://www.mod.uk/DefenceInternet/MicroSite/DIO/OurPublications/TechnicalDocuments/MTP/DalgetyBayApril2012InvestigationPlan.htm

The Investigation Plan and the Proposed Scope of Works are focussed on radium-226 only. It should be noted that the progression of Stage 3b is in part dependent on the progress on other aspects of work currently being undertaken including the establishment of remediation criteria which is the subject of ongoing discussions with Public Health England (PHE).

The purpose of Stage 3b of the Investigation Plan is to undertake an Appraisal of Outline Management Options based on the findings of earlier stages of work, including the Stage 1 Conceptual Model produced by AMEC, and the Stage 2 Phase Two Land Quality Assessment comprising targeted intrusive and non-intrusive investigation. It should be noted that previous work at the site not undertaken by AMEC but used to inform the scope of work is not warranted by AMEC.

This document presents a preliminary Appraisal of Outline Management Options with the aim of providing an indication of the nature and scale of a range of possible risk management options whilst other aspects of work, including the further development of the conceptual site model and agreement of remediation and performance criteria, are ongoing. As such, there are several uncertainties associated with defining the scope of any risk management options and the initial appraisal of outline management options has been based on currently available information only. The nature of some of these uncertainties are discussed in Section 1.5. Further development and appraisal of the available options is dependent on the completion of ongoing work including the establishment of remediation criteria.

1.2 Background

The Study Site formed an area adjacent to the former Royal Naval Air Station (RNAS) Donibristle. A Site Location Plan is included as Figure 1 and a Site Layout Plan is included as Figure 2.

Radioactively contaminated materials, the source of which is radium-226, have been identified on and in the vicinity of the Study Site.

As part of Stage 1a of the Investigation Plan, AMEC issued a Phase One Land Quality Assessment Report[1] (May, 2013). The Conceptual Model (CSM) presented in the Phase One Land Quality Assessment report was used as the basis for the design of the subsequent site investigation.

AMEC's Stage 2 Investigation Proposed Scope of Works Final Report, dated 25 September 2012, presented in detail the proposed scope of works for the Stage 2 Investigation. AMEC's Factual Investigation Report dated 25 April 2013 presented the findings of the Stage 2 Intrusive Investigations.

A Radioactive Contaminated Land Risk Assessment report has been prepared by SEPA[2] (SEPA 2013), and is available at:

http://www.sepa.org.uk/radioactive_substances/publications/dalgety_bay_reports.aspx

1.3 Objectives

The objective of this report is to present an appraisal of outline management options, which may or may not include site remediation, in accordance with Stage 3b of the Investigation Plan. The Investigation Plan defines Stage 3b as follows:

STAGE 3b

Outline Management Options

Further to recent correspondence from SEPA, MOD will set out within the investigation report outline management options which may include remediation. These must be practical options to address the SPL (Significant Pollutant Linkages) such that the unacceptable risks associated with the radium contamination is addressed. The options should be distinct and range from the 'do minimum' to the 'maximum possible'. Whilst CLR 11 focuses on the identification of options to address individual pollutant linkages the more holistic approach advocated by CIRIA W28 may be preferable as this should produce a more integrated cost effective solution.

It may be appropriate to sift the outline options at this stage in order to whittle the number down to a manageable size (ordinarily 3 options would be envisaged). The criteria will include: technical feasibility and practicality. This stage is dependant on the progress of any required Detailed Quantitative Risk Assessment and the establishment of remediation criteria by SEPA.

In order to be effective the options need to be practical and address relevant pollutant linkages such that any unacceptable risks associated with the radium-226 contamination are adequately mitigated.

Consequently, the site-specific risk management objectives need to:

- Reduce/ control the risks associated with the Significant Pollutant Linkages identified in SEPA 2013 with respect to current and future human site users and the environment, to an extent such that the site is suitable for its current use and does not meet the requirements for determination as statutory Radioactively Contaminated Land under current provisions;

[1] AMEC. Dalgety Bay, Fife, Land Quality Assessment, Phase One Desk Study Final Conceptual Model Report, 15 May 2013.
[2] Scottish Environment Protection Agency. Dalgety Bay, Radioactive Contaminated Land Risk Assessment, 29 May 2013.

- Identify potential techniques which are practical to implement, technically effective and durable; and
- Identify potential management solutions which are capable of high stakeholder confidence, including regulators and the local community.

1.4 Scope of Work

This appraisal of outline management options has comprised the following scope of works:

- Define management objectives;
- Summarise the Potential Significant Pollutant Linkages (SPLs) identified by SEPA;
- Identify potential key constraints and considerations which influence the selection of management techniques;
- Identify potential management techniques to mitigate potential SPLs;
- Assess the suitability of potential management techniques;
- Preliminary discussion with experienced contractors to assess suitability and practicability of implementation of identified management options;
- Produce a draft report detailing outline management options based on a range of potentially suitable techniques.

1.5 Uncertainties

As stated in the Investigation Plan, Stage 3b is dependent on the progress of any required Detailed Quantitative Risk Assessment and the establishment of remediation criteria. The definition of appropriate remediation criteria is currently the subject of ongoing discussions with PHE. SEPA 2013 identifies three areas where potential SPLs have been identified within the boundary of the Study Site. However, at the present time, the boundaries of these areas or the thickness/depth of material representing a potential SPL have not been fully defined but will be further characterised following the updated CSM. Therefore, there is currently considerable uncertainly in terms of estimating the volume of material that may require removal and/or disposal should such work be required.

Additionally, whilst Outline Management Options can be developed to address the potential SPLs defined by SEPA, the foreshore is a dynamic environment and the ongoing monthly surveys continue to recover radioactive particles, albeit with activities that fall predominantly below the monitoring criteria set by SEPA's Advisory Group. An updated Conceptual Site Model describing possible ongoing migration pathways which are resulting in the continued presence of the radium contaminated materials (also referred to as particles) within the foreshore is in preparation. However, it has been assumed for the purpose of this appraisal of outline management options that the radioactive particles are located entirely within the boundary of the Study Site and the potential for cross-boundary migration has not been considered further.

Possible Management Options include remediation or removal of the material currently present within the foreshore. This document presents an Appraisal of Outline Management Options using currently available information only. Further, more detailed appraisal of the available options is dependent on the completion of other aspects of work currently being undertaken including the establishment of remediation and performance criteria.

2. Revised Conceptual Site Model

2.1 Development of the Conceptual Model

The Conceptual Model is developed initially at the Preliminary Risk Assessment (Tier 1) stage and reviewed and refined during the subsequent tiers (Tier 2 Generic and Tier 3 Detailed Quantitative Risk Assessment (DQRA)). In general terms, the Conceptual Model represents the characteristics of the Study Site and indicates the possible relations between a **contaminant**, a **pathway** (or pathways) and a **receptor**.

In the context of radioactive contaminants, the Statutory Guidance[3] to support the implementation of the Radioactive Contaminated Land Regulations, defines the following:

- A **radioactive contaminant** is a substance which is in, on, or under the land and which has the potential to cause harm or to cause pollution of the water environment;
- A **receptor** is a human being which is being, or could be, harmed by a radioactive contaminant; or a water environment which is being, or could be, polluted by a radioactive contaminant;
- A **pathway** is one or more routes or means by, or through, which a receptor is being exposed to, or affected by a radioactive contaminants, or could be so exposed or affected.

For a potential risk to exist at a site all three of the above elements must be present, and linked together so that a contaminant has been identified, a receptor is located on the site and there is an exposure pathway that links the contaminant to the receptor. The term **pollutant linkage** is used to describe a particular combination of contaminant-pathway-receptor relationship.

Due to the complex developmental history and dynamic processes that have resulted in the observed contamination at the Study Site, AMEC developed the overall initial Conceptual Model for Dalgety Bay in two distinct elements as part of the Phase One Land Quality Assessment:

- A **Conceptual Site Model** representing the physical, historical or ongoing processes that have resulted in the current distribution of contaminated materials at the Study Site; and
- A **Conceptual Exposure Model** which represents the means by which the current distribution of contaminated materials could present potential risks to the identified receptors.

The initial conceptual model for the study area is presented in full in AMEC's Phase One Land Quality Assessment Report[4].

[3] Scottish Government. Environmental Protection Act 1990: Part IIA, Contaminated Land. The Radioactive Contaminated Land (Scotland) Regulations 2007 Statutory Guidance, 28 May 2009. SG/2009/87.

2.2 Identified Potentially Significant Pollutant Linkages

Following completion of the Stage 2 Intrusive Investigation, potentially significant pollutant linkages (SPLs) were identified by SEPA associated with radium 226 in the Slipways Area, the Boat Park foreshore and the Demarcated Area of foreshore in SEPA 2013. These areas are shown as Areas C, D and E on Figure 14 in SEPA 2013 and are also shown on Figure 3.

It should be noted that the potential SPL areas identified by SEPA are present in only the three selected foreshore areas of the site. No potential SPLs were identified in the landward areas.

2.3 Revised Conceptual Site Model

In order to identify appropriate risk management options, it is necessary to understand the physical, historical or ongoing processes that have resulted in the current distribution of contaminated materials at the site. Such processes are identified in the Initial Conceptual Site Model presented within AMEC's Phase One LQA. Further development of a Revised Conceptual Site Model incorporating the findings of the intrusive investigation is currently in preparation. However a summary is presented below to provide context to the selection of Outline Management Options.

SEPA has identified potential SPLs associated with the presence of radium 226 on the beach. The Initial Conceptual Site Model has therefore been updated to focus only those source areas and activities which could have resulted in the presence of radium 226 on the beach. As no potential SPLs have been identified by SEPA in relation to exposure to radium 226 in the landward areas, these have been discounted and removed from the Conceptual Site Model.

This Summary Revised Conceptual Site Model identifies areas and activities which could give rise to the potential significant pollutant linkages identified by SEPA and is presented below. The Summary Revised Conceptual Site Model has been used to inform and develop the outline risk management options within this report.

Table 2.1 Summary of Revised Conceptual Site Model Areas and Activities of Potential Significant Pollutant Linkage

Source Definition - Area and Activity		Exposure Area	
2	East of New Harbour: Erosion or Disturbance of Material	1	Dalgety Bay Beach
5	'Headland': Erosion or Disturbance of Material	1	Dalgety Bay Beach
8	'Boat Park': Erosion or Disturbance of Material	1	Dalgety Bay Beach
9	'Slipways and Jetty' Development:	1	Dalgety Bay Beach
13	Ross Plantation Foreshore: Erosion and Disturbance of Material	1	Dalgety Bay Beach
16	Dalgety Bay Beach: Deposited Material	1	Dalgety Bay Beach
17	Dalgety Bay Beach: Erosion or Disturbance of Material.	1	Dalgety Bay Beach

[4] AMEC. Dalgety Bay, Fife, Land Quality Assessment, Phase One Desk Study Final Conceptual Model Report, 15 May 2013.

3. Identification of Site Constraints

In order to identify possible management techniques that may be practicable to implement at the site, it is first a requirement to understand the constraints present which will influence the techniques identified and the subsequent management options.

3.1 Physical Constraints

3.1.1 Location and Access

The Study Site is located on the eastern coastal margins of Dalgety Bay new town. The area to the west of the Study Site has been extensively developed to residential housing. The site is overlooked by adjacent residential properties along The Wynd and The Spinneys. There may be limitations to working hours, noise and other activities given the proximity of residential property.

Vehicular access to Dalgety Bay Sailing Club land is via The Wynd through residential housing. There is a rough unsurfaced access track to Ross Plantation from Moray Way South located to the north west of the Study Site. Vehicular access may be subject to restriction through residential areas, potentially via conditions to Local Authority planning approval for any management actions implemented.

3.1.2 Working Area

The Study Site extends to a total area of approximately 4.5 hectares (ha). However, much of this area lies within the inter-tidal zone, and the north western area of the site is densely vegetated in Ross Plantation. As such, the working area available for implementation of a management option is restricted. The working area could potentially be further restricted if site access and on-going site use are required by DBSC and other site users during implementation of any management actions.

3.1.3 On-Going Site Activities

The DBSC land is an active sailing club facility, comprising access roads, car parking, Boat Park, sailing clubhouse and grounds. Any risk management actions will need to consider the current operation of the site as a sailing club, and the need to minimise disruption the sailing club activities.

Ross Plantation, the Fife Coastal Path and the Dalgety Bay foreshore are currently used for a range of recreational activities (outwith the demarcated area) including dog walking, walking, running, cycling, bird watching and other activities. Again, risk management options are likely to be constrained by a need to minimise disruption to recreational site users during risk management works.

3.1.4 Structures

There are several structures present at the site, which are a consideration for the future management options. The sailing clubhouse, stores, jetties, slipways, services, sewer outfall and access roads are all constraints where co-incident with the location of radioactive materials which require management. In addition, the rock armour coastal defences present at the site are a further constraint, particularly for techniques which requires excavation or other works at or adjacent to these defences.

3.2 Remediation and Performance Criteria

SEPA 2013 identifies three areas where potential SPLs have been identified. At the present time, the boundaries of these areas or the thickness/depth of material representing a potential SPL have not been fully defined. The three potential SPL areas identified by SEPA (see Figure 3) are as follows:

- Area C – Demarcated Area foreshore;
- Area D – Boat Park foreshore; and
- Area E – Slipways foreshore.

Risk management techniques will be driven by the remediation and performance criteria that are to be adopted. Possible management options include remediation or removal of the material currently present within the foreshore. Remediation criteria have not yet been established but are the subject of ongoing discussions with PHE. The criteria will also be dependent upon the level of residual risk which will be acceptable to the project stakeholders. Remediation and performance criteria will need to be agreed before further appraisal of the available outline management options can be made.

In the absence of such criteria, together with the absence of the area and depth definition discussed above, there is currently considerable uncertainly in estimating the location and volume of material to be addressed by the available management options.

3.3 Health Protection during Implementation

The selected management techniques will be required to provide acceptable mitigation of the identified pollutant linkages, whilst providing adequate health protection to workers, site users and the public during implementation. The degree of protection required will depend upon the techniques selected, and the scale of the works implemented. A technique which gives rise to ground disturbance will require more extensive consideration to health protection than other non-intrusive techniques.

Every employer who undertakes work with ionising radiations is required by Regulation 4 of the Ionising Radiations Regulations (1999) to provide, in writing, Local Rules for the guidance of employees authorised to carry out this work. These Local Rules are therefore, made under Regulation 17(1) of The Ionising Radiations Regulations 1999 in order to identify key working instructions to restrict radiation exposure.

Local rules are general principles and descriptions of the means of complying with the Ionising Radiations Regulations (1999), its associated Approved Codes of Practice and site Health and Safety rules. The specific objectives of these Local Rules are to:

- Ensure that work with ionising radiations is controlled such that during normal working, doses to employees and other persons are 'As Low As Reasonably Practicable' (ALARP), and do not exceed the limits specified in the Regulations; and
- Ensure that precautions are taken to minimise the risk of accidental exposure, arising from whatever cause, to significant doses of radiation and to ensure that all work involving ionising radiation is performed safely.

Local Rules are specifically written in order to define the general radiological protection measures to be applied to employees working on sites potentially contaminated with radioactive materials, and how these apply to work at the specific site in question.

3.4 Other Contamination Constraints

The focus of investigations undertaken on a voluntary basis by DIO has been on contamination by radioactive radium-226. As a consequence, there is little information available regarding other potential contaminants present within materials at the Study Site. Other contaminants, if present, could potentially influence the management techniques identified and may also influence the suitability of the Study Site for its future on-going use. Notably, management techniques which involve ground disturbance will be required to consider the presence of asbestos containing materials (ACMs) which have been observed at the Study Site.

3.5 Coastal Processes

The Study Site partly comprises the inter-tidal zone in the Firth of Forth. As a consequence, the daily tidal inundation is likely to also affect the practicability of management options in this zone. The tidal cycle in the Inner Firth of Forth has a mean period of 12.1 hours with a mean spring tidal range that increases further up the estuary from 4.7 m at Burntisland (2.75 to -1.95 m AOD) to 5.00 m (2.85 to -2.15 m AOD) at Rosyth, immediately upstream of the Forth Bridge narrows. For intrusive management techniques, consideration and possible prevention of tidal inundation of the work area may be required to control tidal inundation and repopulation of the work area by radioactive materials.

Although Dalgety Bay is a relatively sheltered environment, there are wave dominated sediment movement mechanisms still present that will transport a significant range of particles locally north-eastwards along the coast. Minimisation of wave action in the work area during implementation of management action is therefore a further consideration to reduce re-population during works of an intrusive nature.

3.6 Geotechnical Constraints

Geotechnical issues are also likely to influence the practicability of management solutions, and issues which require consideration include the following:

- Stability of steep slopes, notably along the coastal profile where rock armour is present at the Headland and Boat Park;
- Stability of deep excavations where intrusive works form part of a management option;
- Potential interaction with existing structures in areas where management solutions include excavations adjacent to existing structures;
- Ground bearing capacity, settlement and foundation conditions where management options may involve surcharging the current surface or construction of new sea defences, for example;
- Groundwater ingress to excavations; and
- Use of construction techniques to minimise water ingress to excavations, notably in the inter-tidal zone, if intrusive techniques are considered practicable.

3.7 Environmental Protection

3.7.1 Ecological Constraints

The bay area of the Study Site is classified as a Ramsar site (a wetland of international importance), a Site of Special Scientific Interest (SSSI) and a Special Protection Area. Ecological sensitivity of the site is assessed as high. Management techniques will therefore be required to minimise the effect on the local highly sensitive ecological receptors.

3.7.2 Sustainability

A Framework for Assessing the Sustainability of Soil and Groundwater Remediation (CIRIA, 2010) sets out the link between the principles of sustainable development and the criteria (environmental, social and economic) for selecting the optimum land use design with sustainable remediation strategies and treatments. Assessment of sustainable remediation is defined as ‘the practice of demonstrating, in terms of environmental, economic and social indicators, that the benefit of undertaking remediation is greater than its impact and that the optimum remediation solution is selected through the use of balanced decision making processes’.

Sustainability is therefore a further constraint to the management of radioactive contamination at the Study Site, and requires consideration in the selection of management options.

3.8 Timescales

The Dalgety Bay Investigation Plan provides an indicative timescale for Stages 1-3 of the investigation. However, it does not provide a timescale for implementation of subsequent stages, notably Stage 4, the Detailed Management Options Development and Appraisal and Stage 5, Management Plan development and delivery. The required programme will influence the selection of appropriate management options. Where a prompt timeframe for implementation is required, the preferred option could be more intrusive and disruptive to site use and activities.

3.9 Future Site Use

It is anticipated that DBSC intend to operate at the Study Site for the foreseeable future following risk management implementation, and a change of land use is not envisaged. In addition, future use of the foreshore areas, Fife Coastal Path and Ross Plantation also require further consideration; it is anticipated that existing site users will require "normal access" to these areas in future for on-going use following implementation of management options.

3.10 Stakeholder Considerations

Stakeholders include, but are not limited to, SEPA, DBSC, DIO, Moray Estates, Fife Council, site users and the local community. Further discussion with these stakeholders will be essential for further development of the outline management options, particularly with regard to the results of any formal risk assessments, plus agreement of remediation and performance criteria and the acceptable level of residual risk which will remain following implementation of management options.

3.11 Other Regulatory Considerations

Liaison with Marine Scotland will also be required for any licensable activities to be carried out in the marine environment under the Marine (Scotland) Act 2010.

Any works below the high water mark may also require approval from the Forth Ports Authority in advance of implementation.

4. Identification of Management Techniques

4.1 Introduction

4.1.1 Background and Regulatory Guidance

The main objective of this study is to assess the relative feasibility of potential management options to reduce or control the health and environmental risks associated with the relevant pollutant linkages identified in Section 3.

To assess the feasibility of various management options, an options appraisal has been carried out following the guidance provided in Contaminated Land Report 11 – Model Procedures for the Management of Land Contamination[5].

CLR 11 recommends that each relevant pollutant linkage should be considered separately in the options appraisal and this approach has been followed. CLR 11 also recommends that site-specific remediation criteria (e.g. the permitted concentration of a particular contaminant in soil and/or groundwater) are established as part of the options appraisal. As noted in Section 3 remediation criteria have not yet been agreed so there is considerable uncertainty surrounding the overall objectives, and therefore the ability of some management options to achieve these.

Reference has also been made to the guidance given in Safegrounds Guide to the Comparison of Contaminated Land Management Options[6]. This document provides guidance on comparing contaminated land management options, and presents selected methods and discussion on how to choose the most appropriate option for a given contaminated land situation. The guide has a focus on comparing options for managing contaminated land on nuclear-licensed and defence sites. Radioactively contaminated land on defence or other sites regulated under the Part 2A regime should adhere to the regulatory guidance that recommends a broad comparison of management options is carried out and the identification of Best Practicable Environmental Option (BPEO).

4.1.2 Objective and Approach

The objective of management options appraisal is to establish, taking site-specific factors and constraints into account, which management (or remediation) option (either singly or in combination) offers the best overall approach to the management of the site, by removing, reducing or controlling unacceptable risks, in relation to land contamination.

[5] DEFRA & Environment Agency. Model Procedures for the Management of Land Contamination. Contaminated Land Report 11, 2004.

[6] CIRIA. Safegrounds Guide to the Comparison of Contaminated Land Management Options, May 2009.

Appraisal of Management Options involves a two-stage approach, as follows:

i) **Stage 1**: Identifying feasible management options for each relevant pollutant linkage (i.e. those techniques which are most likely to address the pollutant linkage). The assessment involves consideration of the broad capabilities of the techniques and their applicability to the contaminants and pathways under consideration. It focuses primarily on the 'practicability', 'effectiveness' and 'durability' of the techniques.

ii) **Stage 2**: Carrying out a detailed evaluation of feasible management options to identify the most appropriate option(s) for each pollutant linkage. The evaluation makes use of a set of ranking criteria against which to assess and compare the relative merits of each option. The 'reasonableness' of the techniques is also considered, having regard to costs and benefits.

4.1.3 Available Management Options

Overall Approach to Management Options

In line with current regulatory guidance, there are three main ways to reduce or control risks associated with land contamination, as follows:

i) To remove or modify the behaviour of the receptor(s);

ii) To remove, modify or control the pathway(s);

iii) To remove, modify or control the contaminants (source).

Source and pathway control measures may involve:

- Partial or complete removal of the contaminated material (source), for off-site treatment/ disposal;
- Treatment to reduce the concentration, toxicity or mobility of the contaminant;
- Blocking the pathway (between source and receptor);
- The destruction or removal of contaminants moving along the pathway.

Remove or Modify the Behaviour of the Receptor

There are currently recreational site users who frequently access Dalgety Bay foreshore. Routine access to an area of foreshore has been recently modified by SEPA. SEPA has placed warning signs and erected a fence to demarcate an area of restricted access to the foreshore adjacent to the north of the Boat Park and south of Ross Plantation (the 'demarcated area'). In addition, the Fife Coastal Path is also used by recreational site users, and Ross Plantation is also subject to recreational use.

The revised Conceptual Exposure Model indicates that for humans (site users) undertaking non-intrusive activities on the beach, there is a potential significant pollutant linkage due to the presence of radioactive material on the beach and a credible exposure pathway via dermal contact and ingestion pathways. In addition, the revised Conceptual Exposure Model indicates that for humans (site users) undertaking intrusive activities on the beach, there is also a potential significant pollutant linkage due to dermal contact and ingestion pathways. For Ross Plantation and Fife Coastal Path site users undertaking intrusive activities, such as maintenance works,

dermal contact and ingestion pathways could also give rise to encountering radioactive material at depth during intrusive activities.

Pathways associated with intrusive activity are not carried forward in the appraisal as they are not identified by SEPA as potential SPLs in the Appropriate Persons report.

The option of removing or modifying the behaviour of the receptor(s) can be used where the future site use or layout can be modified. Removing the receptor or preventing ground disturbance are potential management options.

Remove, Modify or Control the Pathway

Removal, modification or control of the pathway is a further technique that is used to reduce the risks associated with potential significant pollutant linkages.

Pathways could be prevented from operating by management options such as use of a cover system and/or in-ground barriers or by controlling the duration (and hence exposure time) of site users proximity to radioactively contaminated materials.

Remove, Modify or Control the Contamination

There are a considerable number of generic remediation techniques to address a wide range of contaminants and many more commercial variants of these available in the UK. These include techniques identified by the regulators as representative of techniques that the Agency considers to be applicable to contaminated land remediation (as set-out in CLR11 and Remedial Treatment Datasheets). These techniques fall under six main headings of technology types, although in practice, a number of the techniques are based on a combination of technologies.

Common remediation techniques are listed in Table 4.1, under the six remediation technology types, together with a brief description of technique.

Table 4.1 Remediation Techniques for Options Appraisal

Remediation Technique	Brief Description
1 Containment Systems and Civil Engineering Methods:	
• Cover systems (in situ) • Containment – in ground barriers/ cut-off walls (in situ) • Containment – hydraulic barrier (in situ) • Excavation, screening, segregation and disposal	**Cover systems** seek to isolate the source from direct contact by human receptors and/or to reduce the transfer of gases and/or the infiltration of water thereby reducing or eliminating contaminant migration. **Containment systems (barriers)** seek to break the pathway in a pollutant linkage by preventing the lateral migration of contaminants. **Excavation, screening, segregation and disposal** removes the source in a pollutant linkage.

Table 4.1 (continued) Remediation Techniques for Options Appraisal

Remediation Technique	Brief Description
2 Biological Processes: • Monitored Natural Attenuation (MNA) (in situ) • Ex-situ bioremediation (bio-piles, windrows, land-farming) • In-situ bioremediation (e.g. biosparging) • Bioventing (in situ)	Biological processes aim to eliminate, attenuate or transform contaminative substances through biological processes. **Monitored natural attenuation** is a monitored activity applied to groundwater, which requires sufficient evidence to demonstrate that the attenuation processes are occurring and will continue to occur so as to achieve the required remedial objectives within an acceptable time frame. **Ex-situ bioremediation** is a process whereby excavated soil is placed in an above ground treatment area and stimulated to enhance the biodegradation of contaminants present. **In-situ bioremediation** is the enhancement or stimulation of biological processes to degrade, transform or remove contaminants present in soils and/or groundwater. Bioremediation processes may be operated under aerobic and/or anaerobic conditions. **Bioventing** is an in-situ process whereby active aeration of contaminated soil stimulates and enhances biological transformation of organic compounds. Air flow within the unsaturated zone is enhanced by air injection, air extraction or a combination of the two through a network of injection and/or extraction well, pipes or trenches. It is sometimes used in combination with Soil Vapour Extraction (SVE) (see below) and this combined process is known as 'bio-slurping'.
3 Chemical Processes: • Soil flushing (in situ) • Solvent extraction (ex situ) • Transformation by chemical treatment (in situ), including: - Chemical oxidation - Chemical reduction (chemical dehalogenation) - Other	Chemical processes aim to transform, destroy or concentrate contaminants through use of chemical reagents. **Soil flushing** is an in-situ process that uses aqueous solutions (e.g. containing surfactants and co-solvents) to dissolve contaminants from soil into groundwater for recovery, e.g. by pump and treat (see below). **Solvent extraction** is normally an ex-situ based process whereby soils are mixed with a solvent in a reaction vessel in order to transfer the soil-bound contaminants into the solvent, which is then separated from the soil for further treatment. **Chemical treatment** is generally carried out in situ and may be applied alone or in combination with other remediation techniques. In addition to the aims noted above, it can also be used to increase the susceptibility of contaminants to other forms of treatment (e.g. biological).
4 Physical Methods and Processes: • Soil washing (ex situ) • Soil vapour extraction (SVE) (in situ) • Air sparging (in situ) • Permeable reactive barriers (PRB) (in situ) • Pump and treat	Most physical methods involve separation and /or concentration of contaminants by exploiting differences in physico-chemical properties of the contaminant and the contaminated soil or groundwater. **Soil washing** is an ex-situ process to mechanically separate contaminants from soil particles, yielding a recovered soil fraction with lower contamination levels than the source material and a concentrated soil fraction containing higher contamination levels. The method is similar to ex-situ solvent extraction, except that the soil washing process makes greater use of the soil's physical properties to separate fine-grained soils (which usually contain the highest portion of contaminants) from the larger-grained soil. **SVE** is an in-situ process used to physically remove volatile compounds from soil above the groundwater table. Air is injected into the subsurface, causing volatilisation of volatile contaminants. It is then abstracted under vacuum (through a series of extraction wells) and treated to remove the contaminants. Volatilisation of contaminants may be improved by injecting steam into soil and/or groundwater (see Thermal Methods, below). The process of removing a combination of free product, volatile organic compounds and contaminated groundwater is known as dual phase or multi-phase extraction.

Table 4.1 (continued) Remediation Techniques for Options Appraisal

Remediation Technique	Brief Description
4 Physical Methods and Processes (continued)	**Air sparging** is a form of SVE applicable to groundwater and/or soils beneath the groundwater table. Air is diffused through impacted groundwater at depth causing release of volatiles into the vapour phase and encouraging natural biodegradation. A permeable reactive barrier (PRB) comprises either: • A permeable in-ground barrier wall, which contains a reactive medium, which traps and/or degrades the contaminants as they pass through the wall, carried by groundwater, or; • An impermeable barrier wall (the 'funnel') with an opening (the 'gate'), which contains a reactive medium, which traps and/or degrades the contaminants, while allowing the carrier water and/or soil air to pass freely through the gate. **Pump and treat** involves abstracting groundwater and treating it ex situ, before returning it to groundwater or disposing of it by alternative means.
5 Stabilisation and Solidification Methods: • Hydraulic binders (cement, lime) (in situ and/or ex situ) • Vitrification (in situ or ex situ)	This technology involves fixation of contaminants and/ or physical encapsulation to reduce the availability and mobility of contaminated materials. **Vitrification** uses electric current to heat and melt contaminated soil (at temperatures typically 1 600 to 2,000ºC). Upon cooling, the product is a chemically stable, leach-resistant, glass/ crystalline rock material. The high temperature component of the process destroys or removes organic materials. Other contaminants are retained within the vitrified product.
6 Thermal Methods:	Thermal methods seek to destroy or concentrate contaminants by heating the soil or groundwater.
• Incineration (ex situ) • Thermal desorption (ex situ) • Thermal desorption (in situ)* including: - Steam enhanced extraction (SEE) - Electrical resistive heating (ERH) - Thermal conductive heating	**Incineration** is a high temperature combustion process, leaving no volatile/combustible contaminants or other materials. A residue of solid material is likely to remain. **Thermal desorption (ex situ)** involves heating of contaminated soils in order to desorb/volatilise volatile contaminants from the soil. The exhaust gas/vapour is collected and treated to remove the contaminants. The treated soil is cooled and stockpiled for reuse or further treatment, as necessary. **In situ thermal desorption** involves heating the subsurface to volatilise, mobilise and/or degrade contaminants, which are then extracted from the subsurface using a vapour (and in some cases liquid) extraction system. Available methods include: • SEE, in which steam is injected into the source zone; • ERH, in which electrical current is passed through the contaminated zone, increasing the subsurface temperature based on the electrical resistance of the soil and groundwater; and • thermal conductivity heating, in which surface or subsurface conductive heating elements are used to create a high-temperature zone.

4.2 Stage 1 Methodology

Stage 1 of the management options appraisal has involved 'screening' of the available management options to identify a short-list of feasible options applicable to each relevant potential significant pollutant linkage. This process has involved consideration of the following:

- The broad capabilities of the different techniques;
- The applicability of the different techniques to the particular contaminant type/ media-type combinations and/or the nature of the pathway;
- Any overarching considerations (e.g. unacceptable health and safety risks).

The exercise has been documented with an explanation of the basis for selection or rejection of each available remediation technique, focusing on the effectiveness, practicality and durability of the technique, and details of any assumptions made.

4.3 Stage 1 Assessment

The Stage 1 assessment is presented in Table 4.2 for the various management options considered, presented under the various technology groups.

Health and safety risks during implementation are assessed and mitigated through Occupational Health procedures, which consider acute exposure, adoption of safe working methods and use of PPE. Therefore, risks to construction workers are not considered as part of the appraisal.

Table 4.2 Management Options Appraisal - Stage 1 Assessment

Source	Receptor	Pathway	Technique	Targeted Element	Feasible Option?	Comment on Feasibility (including Effectiveness/Practicality/ Durability) and Caveats/ Assumptions
Management Technique:	**1 Remove or Modify Behaviour of Receptor**					
Radium 226 at Dalgety Bay Beach	Humans (Non-Intrusive Activities)	Direct Contact, Ingestion	Remove Receptor	Receptor	Yes	Future use of the beach would be restricted. Fully effective technique, and practicable. However, may not be acceptable to stakeholders (public and DBSC members) as future site use restricted. No action to reduce further migration and repopulation from beach and landward sources.
	Humans (Intrusive Activities)	Direct Contact, Ingestion	Modify Behaviour	Receptor	Yes	Behaviour of beach users modified to prevent ground disturbance. Technique not fully effective as radioactive particles could adhere to footwear and objects in contact with beach surface. Option practicable, but would require monitoring to ensure compliance. No action to reduce further migration and repopulation from beach and landward sources.
Management Technique:	**2 Containment Systems and Civil Engineering Methods – Cover System**					
Source	**Receptor**	**Pathway**	**Technique**	**Targeted Element**	**Feasible Option?**	**Comment on Feasibility (including Effectiveness/Practicality/Durability) and Caveats/ Assumptions**
Radium 226 at Dalgety Bay Beach	Humans (Non-Intrusive Activities)	Direct Contact, Ingestion	Cover systems (in situ)	Pathway	Yes	A cover system/capping layer over beach areas could be an effective management technique. It would modify the pathway, by preventing direct contact with contaminants of concern and prevent ingestion. Practicality of beach-wide capping likely to be limited, with potential effect on ecology. May not be acceptable to stakeholders, although localised capping (e.g. slipway enhancement) potentially acceptable solution for localised beach areas. No action to reduce further migration and repopulation from beach and landward sources. Capping system would be required to be durable (e.g. concrete) given coastal processes.
	Humans (Intrusive Activities)	Direct Contact, Ingestion	Cover systems (in situ)	Pathway	Yes	A cover system/capping layer over beach areas could be an effective management technique. It would modify the pathway, by preventing direct contact with contaminants of concern and prevent ingestion. Practicality of beach-wide capping likely to be limited, with potential effect on ecology. May not be acceptable to stakeholders, although localised capping (e.g. slipway enhancement) potentially acceptable solution for localised beach areas. No action to reduce further migration and repopulation from beach and landward sources. Capping system would be required to be durable (e.g. concrete) given coastal processes.

Table 4.2 (continued) Management Options Appraisal - Stage 1 Assessment

Source	Receptor	Pathway	Remediation Technique	Targeted Element	Feasible Option?	Comment on Feasibility (including Effectiveness/Practicality/Durability) and Caveats/ Assumptions
Management Technique:			**3 Containment Systems and Civil Engineering Methods –Excavation, Screening, Segregation and Disposal**			
Radium 226 at Dalgety Bay Beach	Humans (Non-Intrusive Activities)	Direct Contact, Ingestion	Excavation, Screening, Segregation and Disposal	Source	Possible	Excavation, screening, segregation and disposal in beach areas could be an effective management technique. It would remove the source of contamination and thereby prevent direct contact with contaminants of concern and prevent ingestion. Practicality of beach-wide implementation difficult given site constraints (e.g. tidal inundation) with potential effect on ecology. Limited landward working areas on site for materials processing. Long term durability dependent upon other actions taken to minimise potential for re-population of beach.
	Humans (Intrusive Activities)	Direct Contact, Ingestion	Excavation, Screening, Segregation and Disposal	Source	Possible	Excavation, screening, segregation and disposal in beach areas could be an effective management technique. It would remove the source of contamination and thereby prevent direct contact with contaminants of concern and prevent ingestion. Practicality of beach-wide implementation difficult given site constraints (e.g. tidal inundation) with potential effect on ecology. Limited landward working areas on site for materials processing. Long term durability dependent upon other actions taken to minimise potential for re-population of beach.
Management Technique:			**4 Biological Processes**			
Source	**Receptor**	**Pathway**	**Remediation Technique**	**Targeted Element**	**Feasible Option?**	**Comment on Feasibility (including Effectiveness/Practicality/Durability) and Caveats/ Assumptions**
Radium 226 at Dalgety Bay Beach	Humans (Non-Intrusive Activities)	Direct Contact, Ingestion	Biotreatment	Source	No	Technique unsuitable for treatment of radioactive materials.
	Humans (Intrusive Activities)	Direct Contact, Ingestion	Biotreatment	Source	No	Technique unsuitable for treatment of radioactive materials.

Table 4.2 (continued) Management Options Appraisal - Stage 1 Assessment

Source	Receptor	Pathway	Remediation Technique	Targeted Element	Feasible Option?	Comment on Feasibility (including Effectiveness/ Practicality/ Durability) and Caveats/ Assumptions
Management Technique:			**5 Chemical Processes**			
Radium 226 at Dalgety Bay Beach	Humans (Non-Intrusive Activities)	Direct Contact, Ingestion	Chemical process e.g. Transformation by chemical treatment (in situ)	Source	No	Technique unsuitable for treatment of radioactive materials.
	Humans (Intrusive Activities)	Direct Contact, Ingestion	Chemical process e.g. Transformation by chemical treatment (in situ)	Source	No	Technique unsuitable for treatment of radioactive materials.
Management Technique:			**6 Physical Methods**			
Source	**Receptor**	**Pathway**	**Remediation Technique**	**Targeted Element**	**Feasible Option?**	**Comment on Feasibility (including Effectiveness/ Practicality/ Durability) and Caveats/ Assumptions**
Radium 226 at Dalgety Bay Beach	Humans (Non-Intrusive Activities)	Direct Contact, Ingestion	Physical Technique e.g. Soil washing	Source	No	Technique unsuitable for treatment of radioactive materials. Radioactivity associated with a wide range of particle sizes, soil washing unlikely to be effective at segregation of radioactive materials.
	Humans (Intrusive Activities)	Direct Contact, Ingestion	Physical Technique e.g. Soil washing)	Source	No	Technique unsuitable for treatment of radioactive materials. Radioactivity associated with a wide range of particle sizes, soil washing unlikely to be effective at segregation of radioactive materials.

Table 4.2 (continued) Management Options Appraisal - Stage 1 Assessment

Management Technique:	7 Stabilisation and Solidification Methods					
Source	**Receptor**	**Pathway**	**Remediation Technique**	**Targeted Element**	**Feasible Option?**	**Comment on Feasibility (including Effectiveness/ Practicality/ Durability) and Caveats/ Assumptions**
Radium 226 at Dalgety Bay Beach	Humans (Non-Intrusive Activities)	Direct Contact, Ingestion	Cement Binders/ vitrification	Source and pathway	No	Stabilisation or verification could be a feasible technique, which could be effective at reducing ingestion and also repopulation from source areas, but radioactive materials would remain on site. Practicality may be limited in the beach area, and solution could potentially be durable given coastal processes. Soils potentially unsuitable due to high water content. Limited working area may restrict practicability of implementation.
	Humans (Intrusive Activities)	Direct Contact, Ingestion	Cement Binders/ vitrification	Source and pathway	No	Stabilisation or verification could be a feasible technique, which could be effective at reducing ingestion and also repopulation from source areas but radioactive materials would remain on site. Practicality may be limited in the beach area, and solution could potentially be durable given coastal processes. Solidification techniques would reduce potential for intrusive works and resultant exposure. Soils potentially unsuitable due to high water content. Limited working area may restrict practicability of implementation.
Management Technique:	**8 Thermal Methods**					
Source	**Receptor**	**Pathway**	**Remediation Technique**	**Targeted Element**	**Feasible Option?**	**Comment on Feasibility (including Effectiveness/ Practicality/ Durability) and Caveats/ Assumptions**
Radium 226 at Dalgety Bay Beach	Humans (Non-Intrusive Activities)	Direct Contact, Ingestion	Incineration (ex situ)	Source	No	Technique unsuitable for treatment of radioactive materials.
	Humans (Intrusive Activities)	Direct Contact, Ingestion	Incineration (ex situ)	Source	No	Technique unsuitable for treatment of radioactive materials.

4.3.1 Conclusions

Based on the Stage 1 Appraisal no single technique will be best suited to the management of the radium contamination at the site, especially given the wide range of constraints identified. Rather, a combination of techniques is likely to be required to fulfil the management objectives.

4.3.2 Techniques Carried Forward to Stage 2

Based on the Stage 1 appraisal, the shortlisted management techniques carried forward to the Stage 2 evaluation are as follows:

Management Technique	Short Description
Exclusion of Receptors	Permanent use of fencing and warning signs to demarcate the source zones and prevent public access.
Cover System/ Encapsulation	Construct a clean cover layer over the source zones to provide a barrier between the sources and receptors.
Excavation and Disposal	Excavation, screening, segregation and disposal of source material; reinstatement of excavated areas with suitable screened materials.
Optimised Approach	A suitable combination of the above techniques which is a balance between cost plus environmental and social benefits (sustainable).

The assessment is considered on a zone by zone basis (Areas C, D and E in Figure 3), as the constraints vary between the respective zones, and therefore the applicability of the techniques also vary.

4.4 Assessment of Management Options

4.4.1 Stage 2 Assessment

The Stage 2 assessment of each relevant pollutant linkage against each of the shortlisted management techniques which may be practicable is presented below.

Assessment Criteria and Evaluation

The assessment methodology outlined below has been adopted to allow consideration of the techniques with respect to the site conditions and constraints. Provisional criteria have been used to assess the relative suitability of each option in general accordance with CLR11, Input 2 (see Table 4.3).

Table 4.3 Assessment Criteria

1. Practicability	7. Regulatory confidence/acceptability	13. Timescale for implementation
2. Effectiveness	8. Stakeholder confidence	14. Suitability for phased approach (verification)
3. Durability (robustness)	9. Extent of residual risks/liabilities	15. Initial relative cost to confirm suitability
4. Health and safety risks	10. Environmental benefits	16. Flexibility during implementation
5. Potential for environmental/nuisance impacts	11. Technical risks (uncertainties)	17. Sustainability
6. Commercial availability and track record	12. Ability/practicality of verification	18. Long term obligations (monitoring; maintenance etc)

The associated merits and drawbacks of the shortlisted options are discussed below.

4.5 Option 1 – Exclusion of Receptors

The potential SPLs could be managed by exclusion of receptors from areas of concern. The degree of exclusion may be dependent upon the level of risk posed to potential site users.

Human exclusion could comprise active control through erection of suitable fencing to prevent access to the identified foreshore areas. The fence would be required to be of sufficient height and construction to form a robust barrier to human access. Further management and periodic inspection of the exclusion areas may also be necessary to confirm the effectiveness of the fencing and receptor exclusion.

Alternatively, a voluntary approach could be adopted whereby receptor exclusion could be achieved by provision of warning signs and information boards to provide advice requesting that potential foreshore users actively avoid the foreshore areas of potential SPLs. This approach would also require management to demonstrate that it is an effective technique to mitigate the risks associated with the potential SPLs.

Key Advantages

Key advantages of this management option are as follows:

- **Practicality** – Ease of practicability of implementation. Erection of signage, information boards and fencing may be easily carried out in a short time frame; Requirements for disruptive construction/ engineering works minimised;
- **Effectiveness** – Effective management technique as receptors are removed from areas of potential SPL, but management of the effectiveness will be required;
- **Health and safety during implementation** – Low risk with respect to health & safety during implementation;
- **Potential for environmental impact and/or nuisance during implementation** - Low potential for environmental impact or nuisance to local residents, and the SSSI/RAMSAR local ecology during implementation;

- **Commercial availability and track record** – Straightforward approach that has been implemented previously in UK to mitigate potential risks;
- **Risks associated with implementation** – Minimal risks during implementation;
- **Timescale of implementation** – Option could be quick to implement following decision to proceed;
- **Initial cost** – Low initial cost option which achieves effective management of SPLs;
- **Flexibility during implementation** – Receptor removal and behaviour modification could be combined with other techniques; and
- **Sustainability** – Limited waste materials generated, and limited natural resources required.

Key Disadvantages

Key disadvantages of this management option are as follows:

- **Durability and Robustness** – No action taken to reduce radioactive contamination in the SPL areas. No action taken to mitigate any potential ongoing release of radioactive materials from landward areas onto the foreshore. Future migration of radioactive material beyond fenced areas within the foreshore by coastal processes is possible;
- **Regulatory confidence/acceptability and authorisation** – Approach could potentially be an acceptable to the regulators as it effectively mitigates the risks from the identified SPLs and has been implemented by SEPA in the currently Demarcated Area of the foreshore (albeit as a temporary mitigation measure);
- **Stakeholder confidence/ acceptability** – The foreshore is used for recreational activity and site user exclusion from potential SPLs areas may be unacceptable;
- **Extent of residual risks and liabilities** – potential longer term liabilities given that the radioactive material will remain within the area and on-going management of the effectiveness of the option would be required;
- **Environmental benefits** – Limited significant benefit as radioactive contamination sources would remain in-situ in the areas of concern, and possible wider dispersal and weathering of particles by coastal processes;
- **Ability and practicality of verification** – Verification would comprise monitoring of compliant behaviour by receptors. Under a more passive approach, such as a voluntary exclusion from the foreshore, **the degree of reliance** upon the receptor group is higher than a fenced exclusion strategy, and additional verification effort would be required;
- **Long term obligations (monitoring and maintenance, etc.)** – The option may require on-going management in the long term to demonstrate that the technique remained an effective management approach.

4.6 Option 2 – Cover System/ Encapsulation

Under this option, coastal defences in key areas would be re-constructed or improved to form an appropriate barrier system. This would aim to prevent possible ongoing (but unproven) release of radioactive materials from landward areas behind armouring as a result of coastal processes. The coastal defence improvement works could potentially comprise a combination of the following actions:

- Improvement to existing stone armour slope by reconstruction using suitable geotextile filter, protective basal stone layer and armour stone layer. The reconstruction works would be required in areas of existing armour defences present around the Boat Park, Demarcated Area and Headland (Area F). Improvement works could include a further enhanced barrier system (e.g. concrete or grout barrier wall or sheet piled wall) along the crest and/or toe of existing coastal defences;
- Encapsulation of beach materials on the foreshore e.g. (i) construction of enhanced slipway structure in the Slipways Area – large concrete apron; (ii), construction of coastal defences seaward of existing armour location e.g. extend rock armour cover over Boat Park foreshore and Demarcated Area of foreshore and encapsulate with additional materials; and
- Ongoing monitoring and management of encapsulation/structures in foreshore areas.

Key Advantages
Key advantages of this management option are as follows:

- **Practicality** – This technique is practicable to implement and relies upon conventional construction techniques;
- **Effectiveness** – Fully effective at preventing possible (unproven) release of radioactive materials from landward areas behind existing defences, but also requires foreshore encapsulation/cover and/or receptor behaviour modification to be effective in reducing risks from the potential SPLs in the foreshore;
- **Regulatory confidence/acceptability and authorisation** – Possible regulatory confidence in prevention of possible but unproven particle release from landward areas and encapsulation to mitigate risks from exposure to material in the foreshore;
- **Health and safety during implementation** – Possible health and safety implications during construction phase but risks may be controlled and managed by competent contractor;
- **Commercial availability and track record** – Coastal defence works are widely commercially available and have an extensive track record in UK, although foreshore encapsulation not as well proven;
- **Flexibility during implementation** – Coastal defence improvement offers opportunity for integration with other techniques. The technique also offers

flexibility for inspection of materials directly under coastal defences and removal of high activity sources if present;

- **Durability and Robustness** – Improvement of coastal defences would be durable and robust solution to minimise potential particle release from landward areas and provide encapsulation;
- **Environmental benefits** – Placement of a cover system could raise ground levels, extend useable site area, and could provide minor benefit of additional coastal flooding protection. Construction of an enhanced slipway would encapsulate beach deposits and may provide enhancement to sailing club facilities at the site;
- **Sustainability** – Raw materials use may be partially mitigated by re-use of existing rock armour;
- **Ability and practicality of verification** – Monitoring practicable to implement post-construction to verify mitigation of potential SPLs.

Key Disadvantages

Key disadvantages of this management option are as follows:

- **Stakeholder confidence/ acceptability** - Possible stakeholder acceptability issues associated with this option, notably to the local community and regulator, given that radioactive materials would remain in-situ at the site on the foreshore and landward areas behind rock armour. Placement of rock armour cover throughout the wider foreshore could potentially be aesthetically unacceptable. Large scale construction activity potentially disruptive to local community and site users including Dalgety Bay Sailing Club and recreational site users. Vehicle movements through the adjacent residential area could give rise to stakeholder acceptability issues;
- **Regulatory confidence/ acceptability and authorisation** – Possible regulatory concern as the radioactive material will remain in the foreshore area;
- **Potential for environmental impact and/or nuisance during implementation** – Improved coastal defences and encapsulation of the foreshore may also give rise to impacts to sensitive ecological receptors in this area during and following construction activity, if unmanaged. Placement of cover materials such as additional rock armour on the foreshore, and construction of an enhanced slipway or cover system could significantly modify the foreshore environment and associated coastal processes;
- **Risks associated with implementation** – Potential risks during implementation including disturbance of unidentified high activity sources if present, and construction constraints such as storm events in a marine environment;
- **Timescale of implementation** – Requires moderate timescale for planning, design and implementation given likely scale of construction activity;
- **Durability and Robustness** – Encapsulation in tidal zone subject to coastal processes and durability and robustness a key consideration, potential to degrade over time;

- **Sustainability** – Potential sustainability issues, given that large quantities of materials would require import to the site for construction phase of coastal defence works/ encapsulation;
- **Long term obligations (monitoring and maintenance, etc.)** - Although the potential pathway for the possible ongoing particle release from landward areas would be prevented, the timescales for acceptable reduction in occurrence of radioactive particles in the wider foreshore beyond encapsulated areas would be uncertain. Long term monitoring and management of the effectiveness of barrier construction would be required, with associated long-term cost implications for appropriate monitoring and management action. Radioactive materials already present in foreshore beyond encapsulation could potentially continue to disperse by coastal processes where no encapsulation is constructed; and
- **Initial cost** – Moderately high initial cost is foreseeable for coastal defence improvement and encapsulation option.

4.7 Option 3 – Excavation and Disposal

Under Option 3, the strategy for management of the potentially significant SPLs would be source removal. Works under this option may include the following:

- Excavation of materials containing radioactive contamination in the areas of potential SPL on the foreshore as identified by SEPA (Slipways Area, Boat Park foreshore, Demarcated Area);
- Optional additional excavation of source areas in the Headland foreshore up-drift of areas of identified potentially significant SPL to prevent potential repopulation of radioactive materials into SPL areas, should this be supporting by further risk assessment;
- Screening of excavated materials for the presence of radioactive materials;
- Segregation of unsuitable radioactive materials and appropriate off-site disposal of radioactive materials;
- Re-use of suitable screened materials as backfill to foreshore areas.

Mass excavation of soils from the identified areas of the foreshore would be conducted under this option. It is anticipated that excavated materials would be transported from the foreshore to a landward materials processing area. The Sailing Club land, located immediately adjacent to the area of potential SPLs, is probably the only suitable operational area, although the space for establishment of processing plant is limited.

The criteria for unsuitable radioactive contaminated materials on the foreshore are not yet defined and therefore there is considerable uncertainty in the volume of material that would require off-site disposal.

Key Advantages

Key advantages of this management option are as follows:

- **Durability and Robustness** – Removal of the source of contamination from the foreshore provides a robust and durable solution to the risks from the identified potential SPLs, particularly if up-drift areas are also managed. This technique is a suitable approach to management of radioactive contaminants, which are difficult to manage by other means such as treatment;
- **Effectiveness** – Effective management technique as sources are removed from defined areas of potential SPLs on the foreshore. However this does not address any potential for future release from landward areas,(although this pathway has not currently been proven). Technique efficiency is unlikely to be 100% effective;
- **Timescale of implementation** – Likely to require significant programme for planning, design, regulatory and stakeholder approval, tendering and implementation;
- **Flexibility during implementation** – It has the advantage of being flexible, easily incorporated into a staged approach to management of SPLs and provides for a systematic verification process. Excavation and source removal from the foreshore may not be an effective management technique in isolation. Ongoing (albeit unproven) potential for release of radioactive materials from source areas behind rock armour which could repopulate foreshore. Flexible technique which could be combined with other techniques which reduce the potential for any repopulation of the foreshore from landward sources;
- **Stakeholder confidence/ acceptability** – Source removal from foreshore likely to meet stakeholder expectations, but consideration of future foreshore repopulation required. Likely to be highly disruptive to the on-going use of the site by DBSC and recreational site users. May require exclusion of site user/ public access from the site during works. Extensive stakeholder engagement required;
- **Regulatory confidence/ acceptability and authorisation** – Approach likely to meet with regulatory approval and high confidence;
- **Long term obligations (monitoring and maintenance, etc.)** – Potential for medium-term radiological monitoring to ensure that the technique remained an effective management approach. Requirement for longer term radiological monitoring and management is likely to be reduced following a source removal option, although short term post-implementation verification radiological monitoring is likely to be required;
- **Environmental benefits** – Significant benefit as radioactive contamination sources would be removed from the areas of concern;
- **Sustainability** – Screening of soil arisings offers potentially highly sustainable management option. Screening is likely to reduce the overall volume of materials requiring appropriate off-site disposal. Site-won materials could potentially be re-used for restoration of the foreshore.

Key Disadvantages

Key disadvantages of this management option are as follows:

- **Practicality** – Difficult to implement. Constrained by the tidal inundation of the foreshore areas, and would be limited to low tide conditions unless tidal ingress to work area prevented by temporary barrier or 'wet working' by pumping of beach deposits. Tidal inundation could potentially give rise to redistribution of radioactive materials into excavated areas, and would require monitoring, management or control. Appropriate working methods such as radiological monitoring of excavated areas and working away from up-drift areas may be effective management techniques. Other constraints limit practicability (e.g. working area available for materials processing, site establishment etc). Water ingress to excavations will therefore require management during the works. Excavations potentially unstable and stability would require appropriate management. Consideration of other contamination constraints required (e.g. asbestos) as they could limit the options for screening, disposal or reuse of the material. Effectiveness and efficiency of screening process is unknown and may require more than one process stage with double handling etc, pilot trials would be required;

- **Durability and Robustness** – Potential for repopulation from landward source areas. Screening may not be 100% effective;

- **Commercial availability and track record** – Limited commercial availability and track record in UK;

- **Extent of residual risks and liabilities** – Material within the foreshore removed, but this option would not address potential possible repopulation of foreshore from landward areas. Medium term monitoring of the effectiveness of the option would be required to assess potential repopulation;

- **Health and safety during implementation** – Health and Safety controls required during implementation to maintain worker exposure As Low as Reasonably Practicable. Strict controls also required to prevent potential public exposure during implementation; presence of asbestos in beach materials may be a significant constraint;

- **Potential for environmental impact and/or nuisance during implementation** - The option would comprise significant construction activity and disturbance to the foreshore; local sensitive ecological receptors could potentially be affected during construction activity. High potential for environmental nuisance or impact to local residents and SSSI/RAMSAR local ecology during implementation;

- **Risks associated with implementation** – High risks during implementation, efficiency of waste screening uncertain, trials required to demonstrate applicability and efficiency;

- **Ability and practicality of verification** – Verification of foreshore practicable following implementation; and

- **Initial cost** – Very high initial cost option which achieves effective management of the defined potential SPLs. Radioactively contaminated materials will require disposal/ storage at a specialist facility and will incur significant costs.

4.8 Option 4 – Optimised Approach

A further optimised approach option is also presented, which includes elements identified above in the previous management options. This option would also be based on a risk-management approach, and a robust assessment of risks to receptors is therefore integral to the selection of an appropriate management solution. Cost benefit analysis will also be an important influence, whereby the performance of options against the management objectives is assessed.

In assessing the management techniques, it is apparent that no single technique is best suited for the site in isolation. An integrated approach should therefore be considered to potentially provide the optimised solution, and could potentially comprise a combination of one or more of the previous three options to varying extents and dependant on the risk posed and agreed remediation criteria.

An example of the implementation of this option is described below, which combines elements of Option 2 (Cover System/ Encapsulation) and Option 3 (Excavation and Disposal) in selected areas. However, this is presented as an example only and an Optimised Approach could consider any combination of Option 2 and Option 3 together with Option 1 (Exclusion of Receptors) in selected areas.

Option 4, Part 1 – Excavation and Disposal (Source Removal)
Source removal in selected areas of the site, notably the areas of potential SPLs (Boat Park foreshore, Demarcated Area, Slipways) may be required in an integrated approach. The potential for repopulation from up-drift areas, i.e. the Headland foreshore, could also be addressed should the need for this be identified by risk assessment.

Option 4, Part 2 – Cover System/ Encapsulation (Landward Source Materials Only)
The pathway from sources to receptors could be modified where radioactively contaminated particles are potentially released from source areas behind the rock armour sea defences. The existing rock armour could require re-construction and/or replacement with suitable geotextile, basal stone layer and rock armour. This pathway modification does not address identified potential SPLs, but reduces the potential for future release of radioactive materials from possible landward source areas into areas of identified potential SPLs.

Key Advantages
Key advantages of this management option are as follows:

- **Durability and Robustness** – Optimised approach likely to provide durable and robust solution with due consideration to the costs incurred and associated benefits. Possible removal of the source of contamination from the foreshore coupled with pathway prevention may provide the most robust and durable solution, but other effective approaches achievable at lower cost may also form part of an optimised solution;

- **Effectiveness** – Optimised approach likely to be fully effective management technique, notably if solution includes source removal from areas of potential SPL on the foreshore, and mitigation of potential for future release from landward areas; technique efficiency is unlikely to be 100% effective;
- **Flexibility during implementation** – Option comprises combined technique with potential for flexibility to include additional measures such as selective removal of high-activity sources if encountered in landward materials behind armour;
- **Stakeholder confidence/ acceptability** – Any source removal and pathway mitigation measures are likely to be an acceptable solution to stakeholders;
- **Regulatory confidence/ acceptability and authorisation** – Approach likely to be an acceptable solution to regulators;
- **Long term obligations (monitoring and maintenance, etc.)** – Requirements for on-going monitoring could be reduced under optimised option;
- **Sustainability** – An optimised approach would aim to be the most sustainable approach;
- **Ability and practicality of verification** – Verification of foreshore practicable following implementation; and
- **Extent of residual risks and liabilities** – Option likely to give rise to lowest residual risk and liabilities, although residual potential risk and liability associated with any buried in-situ of landward materials.

Key Disadvantages

Key disadvantages of this management option are as follows:

- **Practicality** – Difficult to implement. Constrained by the tidal inundation, working area available, contamination constraints, site access and other factors. Effectiveness and efficiency of screening process is unknown and may require more than one process stage with double handling etc, pilot trials would be required;
- **Commercial availability and track record** – Limited commercial availability and track record for screening, but some aspects such as coastal defence construction widely available;
- **Health and safety during implementation** – Significant potential for health and safety risks during implementation, but risks may be controlled; presence of asbestos in beach materials may be a significant constraint;
- **Environmental benefits** –Radioactive contamination sources could be removed from the areas of concern and potential for repopulation minimised. Offers opportunity for environmental enhancement;
- **Potential for environmental impact and/or nuisance during implementation** – Significant construction activity and disturbance to the local residents, the foreshore and local sensitive ecology requires management;

- **Risks associated with implementation** – High risks during implementation, efficiency of soils screening uncertain, trials required to demonstrate applicability;
- **Timescale of implementation** – Significant programme required for planning, design, regulatory and stakeholder approval, tendering and implementation;
- **Long term obligations (monitoring and maintenance, etc.)** – Potential for medium or long-term radiological monitoring to ensure that the technique remained an effective management approach; and
- **Initial cost –** Optimised option potentially high cost approach, but requires consideration of cost and benefits in accordance with statutory guidance. Long term costs potentially much reduced.

4.9 Timescales

The timescales for each of the management options will be dependent upon several factors, including regulatory and stakeholder discussion, detailed design, option implemented and post-implementation monitoring. Initial estimates of timescales (in months) are as follows:

Work Element	Option 1 Exclusion of Receptors	Option 2 Cover System/ Encapsulation	Option 3 Excavation and Disposal	Option 4 Optimised Approach
Regulatory & Stakeholder Engagement	1-2	1-2	1-2	1-2
Detailed Options Appraisal	1-2	2-3	2-3	2-3
Detailed Design/ Trials	1	2-3	2-3	2-3
Regulatory Approvals	2-3	3-4	3-4	3-4
Contractor Tender & Award	1	2-3	2-3	2-3
Implementation	1	9-12	5-7	9-12
Subtotal	7-10	19-27	15-22	19-27
Post-Implementation Verification/ Management	12+	12	12	12

It should also be noted that the above programme assumes a timely straightforward planning approvals process. There is no allowance for environmental impact assessment preparation and submission, which may potentially add a further 3-12 months. Any additional planning appeal or public inquiry may further lengthen the programme.

4.10 Preferred Option

The preferred option will need to be selected following further detailed options appraisal, and consultation with various stakeholder groups and organisations. However, prior to this there needs to be agreement of achievable remediation and performance criteria. On the basis of this

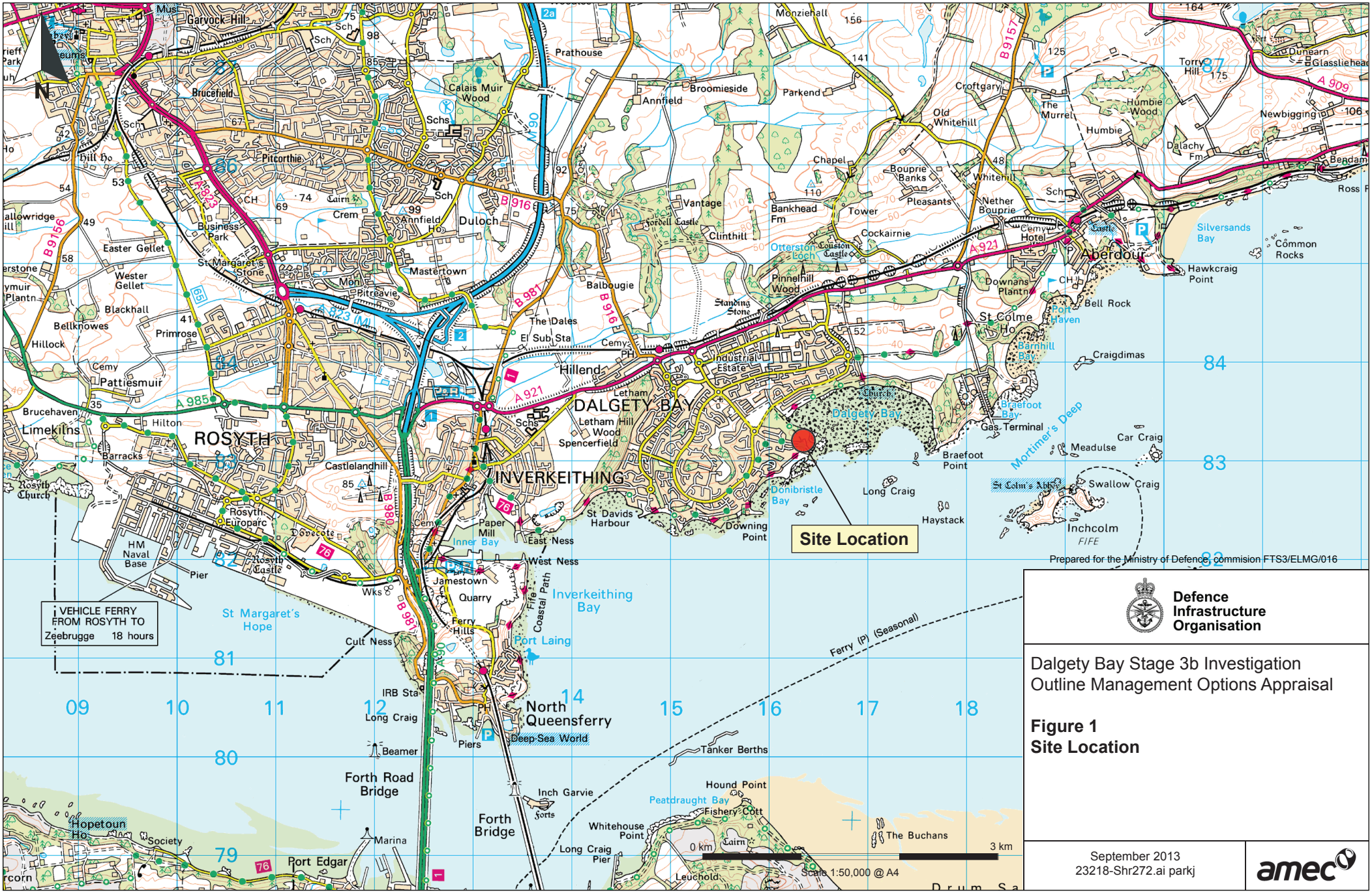
outline management options appraisal, it is likely that the preferred solution will be an optimised option and comprise a combination of techniques to address receptor behaviour, pathway modification and possible selected source removal.

5. Conclusion

5.1 Conclusion

An appraisal of outline management options for mitigation of potential SPLs at Dalgety Bay has identified a number of approaches including receptor removal, pathway modification and source removal. The appraisal has been undertaken prior to the completion of other ongoing work, including the revision of the conceptual model and the agreement of remediation and performance criteria. In addition to this uncertainty, there are various site-specific constraints which require careful consideration in order to assess the most suitable management option. Significant constraints include an inter-tidal setting, ecological sensitivity, site access and working area, proximity to residential areas and stakeholder considerations.

Figures



Prepared for the Ministry of Defence, commision FTS3/ELMG/016

Defence Infrastructure Organisation

Dalgety Bay Stage 3b Investigation
Outline Management Options Appraisal

Figure 1
Site Location

September 2013
23218-Shr272.ai parkj

amec

316000 316500

683500 683500

N

Coastal Path to Crow Hill & St Bride's Kirk

Sealstrand

Moray Way South

20/22

24

Sand and mud

Coastal Path

Un-named Burn

Sand and Mud

Area of Marsh / Bog

Sewage Outfall Pipe

Ross Plantation

Coastal Path

Dalgety Bay Beach

Ross Plantation

The Spinneys

Sand and mud

The Wynd

Sand, mud & rock outcrops

Dalgety Bay Sailing Club Boat Park

The Wynd

The Knowe

The Beeches

Slipway

Dalgety Bay Sailing Club Clubhouse

Jetty

Headland

Firth of Forth

Rocky Beach

New Harbour

Donibristle Gardens

Hopeward Mews

683000 683000

316000 316500

Key:

- Site boundary
- Fife coastal path
- Footpath
- High water level
- Low water level

0 50 100 150 Metres

Scale: 1:3,000 @ A3

\MOD Projects\23218 Dalgety Bay\Drawings\GIS Drawings\23218-Shr273

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Dalgety Bay Stage 3b Investigation
Outline Management Options Appraisal

Figure 2
Site Layout Plan

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316500

N

Coastal Path

Woodland

AREA C

Beach

AREA D

Sailing Club and Boat Park

AREA E

Slipways

AREA F

Beach

683000

683000

316500

Key:

Indicative Study Site Boundary

Site Uses

Beach

Sailing Club and Boat Park

Coastal Path

Woodland

Approximate extent of rock armour defences

0 50 100 Metres

Scale: 1:2000 @ A3

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Dalgety Bay Stage 3b Investigation
Outline Management Options Appraisal

Figure 3
Areas of Potential Significant Pollutant Linkages

September 2013
23218-Shr271 browj

amec