Defence Infrastructure Organisation

Dalgety Bay

Coastal Processes Review

March 2013

Prepared by AMEC Environment & Infrastructure UK Limited for the Ministry of Defence, under commission FTS3/ELMG/016

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Report for

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1	Draft	31 Jan 2013
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Executive Summary

Purpose of this Report

AMEC Environment and Infrastructure UK Ltd (AMEC) was commissioned by the Defence Infrastructure Organisation (DIO) to undertake Land Quality Assessment of an area surrounding the Dalgety Bay Sailing Club, Dalgety Bay, Fife, KY11 9SJ (the 'study site'). The works were carried out under commission FTS3/ELMG/016 Amendment 2.

The Land Quality Assessment is in support of DIO's Dalgety Bay Inspection Investigation Plan, first published 29 February 2012, as subsequently amended by DIO following SEPA comment, and available at:

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

DIO's Investigation Plan and the Proposed Scope of Works are focussed on radium-226 only.

This document has been produced for the purpose of assessing the coastal processes currently operating around the Dalgety Bay Sailing Club (DBSC) shoreline on the north coast of the Firth of Forth, based on site inspections on 8 May 2012, 14 November 2012, and site investigation work undertaken in November 2012. This document is aimed at assisting the establishment of a Conceptual Model, which may be revised, through defining the coastal processes that may affect the presence, mobility and dynamism of the radium-226 contaminant source. It comprises a review of potential wave and current energy levels in the vicinity based on wind and tidal data, combined with site observations made during the two visits to establish likely erosion, transport and deposition mechanisms for the full range of particles observed on the foreshore.

The report concludes that 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. There is also some evidence that although relatively stable, beach levels are still adjusting to the loss of sediment supply caused by the armour stone protection of Promontory 1 in c.1996, particularly around the DBSC jetty and slipway areas.

Contents

1. Introduction

1.1 Background

AMEC Environment and Infrastructure UK Ltd (AMEC) was commissioned by the Defence Infrastructure Organisation (DIO) to undertake Land Quality Assessment of an area surrounding the Dalgety Bay Sailing Club, Dalgety Bay, Fife, KY11 9SJ (the 'study site'). The works were carried out under commission FTS3/ELMG/016 Amendment 2.

The Land Quality Assessment is in support of DIO's Dalgety Bay Inspection Investigation Plan, first published 29 February 2012, as subsequently amended by DIO following SEPA comment. This document has been produced for the purpose of assessing the coastal processes currently operating around the Dalgety Bay Sailing Club shoreline on the north coast of the Firth of Forth., based on site inspections on 8 May/ 14 November 2012, and site investigation work undertaken in November 2012. This document is aimed at assisting the establishment of a Conceptual Site Model, which may be revised, through defining the coastal processes that may affect the presence, mobility and dynamism of the radium-226 contaminant source.

1.2 Objectives

Although prepared simultaneously with other AMEC site investigation factual and interpretive reports, the objectives of this report are to independently:-

i. collate data from two site inspections on 30 May/14 November 2012, site investigation work undertaken in November 2012 and generic local marine data for the Firth of Forth

ii. develop hypothetical mechanisms for movement, erosion and deposition of various particle sizes on the foreshore

iii. assess the validity of these mechanisms in the light of the field evidence obtained

iv. summarise the likely mechanisms for movement, erosion and deposition of the range of particles observed on the foreshore

v. consider how this may have changed with site development over time, and what effect this may have had on the transport of contaminated materials

It comprises a review of potential wave and current energy levels in the vicinity based on wind and tidal data, combined with site observations made during the two visits to establish likely erosion, transport and deposition mechanisms for the full range of particles observed on the foreshore.

1.3 Site Location & Setting

The Dalgety Bay study site is centred at approximate National Grid Reference (NGR) 316500 683200 (NT 165 832), on the north coast of the Firth of Forth as shown on Figure 1, approximately 5km downstream of the Forth road and rail bridges. The study site consists of the intertidal foreshore of Dalgety Bay, generally between the New Harbour to the west and the sewer outfall pipe to the north of Dalgety Bay Sailing Club, as defined on Defence

Estates (DE)'s Public Notice drawing together with the area of land occupied by the Dalgety Bay Sailing Club, and the area of Ross Plantation extending westwards to the coastal path link to The Spinneys residential road.

As this report concentrates on the marine coastal processes that are relevant to the study, it is only the intertidal foreshore and the surrounding marine environment that is of immediate interest, as shown on Drg. No. 23218-rr415 – 01. This drawing also defines a reference baseline along the 860m long coastline, giving reference chainages from west to east, commencing at the tip of the New Harbour stone quay. All chainage references in this report refer to this baseline to aid with locating various features.

For assessing coastal processes, the Scottish coast is divided into various discrete cells, of which the Firth of Forth sits within Coastal Cell 1 (St Abb's Head to Fife Ness) as defined by HR Wallingford (see Scottish Natural Heritage RSM143 "Coastal Cells in Scotland: Cell 1 – St Abb's Head to Fife Ness" Ramsay & Brampton 2000 – ref.1). Within this main cell, Dalgety Bay sits in Section 13 (St Davids Bay to Braefoot Point) of Sub Cell 1c.(Inner Firth of Forth to Elie Ness).

The site falls within Fife Council's powers as the coastal protection authority as defined by the 1949 Coastal Protection Act, under which Fife have developed a Shoreline Management Plan (SMP). This was first put forward and adopted in 1998 and was updated in 2011 as "Fife SMP2 Policy Unit 13 – St David's Bay to Braefoot Point" (Mouchel 2011- ref.2). This document confirms the following points relevant to the coast protection policy for Dalgety Bay:-

- The current proposed long term strategy for the coastal cell is to "Hold The Line"
- The current action plan indicates a short to medium term goal to renew / upgrade the sea defences along the western shore of Dalgety Bay north of the outfall going south to the Dalgety Bay Sailing Club (DBSC)
- The SEPA flood maps indicate that the land behind the foreshore falls within their Coastal Flood Area at two relevant locations:-
    - Boat storage area (Chainage 320-460m) currently protected by armour stone
    - Woodland (Chainage 720-850m) – behind salt marshes
- The 1998 SMP noted that "In the last 5 years work has been carried out at Dalgety Bay where as a result of the new housing estate a new esplanade with rock armour was constructed. The sailing club at Dalgety Bay has also benefited from 60m of riprap laid in the summer of 1996"
- The foreshore and tidal mudflats within the bay holds the following Natura 2000 and national environmental designations:-
    - Firth of Forth Special Protection Area (SPA)
    - Firth of Forth Ramsar
    - Firth of Forth SSSI

2. Site Observations

Site observations were made during two visits in 2012. The first visit, which concentrated on the coast protection structures, was on 30 May in warm but overcast conditions with minimal wind. The inspection lasted from 1500h to 1700h with a neap low tide due at 1632h at Leith of 1.5m ACD (chart datum is-2.90mAOD at Leith). Wave action was minimal, with waves breaking at <100mm height.

The second visit was from 0800h to 1100h on 14 Nov in overcast showery conditions again with no wind and minimal wave action, with a low spring tide of 0.6m ACD due at 0815h at Leith. This visit was undertaken during an ongoing programme of intrusive site investigation work which included topographic surveys and trial pits on both land and foreshore.

2.1 Coast Protection

The following observations were made travelling from south to north along the intertidal foreshore, with reference to baseline chainages along the coastline as shown on Drg. No. 23218-rr415 – 01.

2.1.1 New Harbour (Chainage 0-70m)

The study area commences at the extremity of the SW facing stone quay or breakwater that protects a small sandy bay with well graded shell particles giving a white appearance to the beach, visible to the north/ left in Fig.1. The quay is approximately 30m long and up to 5m tall, built using roughly dressed boulders typically of 0.5m diameter. There is little evidence of mortar between boulders, with gaps typically 0.5m deep suggesting the quay could be vulnerable to further storm damage.

Figure 1 New Harbour Quay (Chainage 0m)

The quay is founded on a large outcrop of bedrock folded into an anticline with a NE-SW axis, roughly parallel with the coast for Chainages 0-70m , visible to the right in Fig.1. This outcrop occupies the full foreshore down to MLWS mudflats for Chainages 0-50m, trapping a small raised beach against a modest block wall visible on Fig.2 at Chainage 60m before disappearing below the beach beyond Chainage 70m.

Figure 2 Rock foreshore & Raised Beach (chainage 40 to 50m)

2.1.2 Promontory 1/ Reclaim Area (Chainage 70-200m)

This area of open grassland, which is termed the ‘Headland’ in accompanying AMEC reports, is significantly higher than the surrounding coastline and extends further onto the intertidal foreshore. The reclaimed nature of this land is confirmed by the Fife SMP (ref.1) detailed maps, showing the seaward corner furthest from the previous coast forming Promontory 1 at Chainage 140m . The two faces of this promontory are protected with armour stone of various sizes and gradings, forming slopes varying from 1:1 to 1:2. Along the SE facing edge (Chainage 70 to 140 m), an armour stone revetment of up to 5m high has been formed with up to 1m boulders at MHWS level, reducing to smaller boulders near the crest and at the foot of the structure. There is no apparent geotextile nor toe detail and minimal evidence of a separate filter stone layer. Localised erosion is visible near the crest, notably at Chainage 140m (visible in Fig.5), but the stone generally appears to be tipped randomly rather than placed, with a significant variation in stone sizing.

The foreshore seaward of the armour stone comprises a steep (approximately 1 in 10) beach full of debris which appears to have been partially eroded from the armour stone; the evidence for which consists typically of 50-200mm size bricks/cobbles down to the mudflats just visible at MLWS, as shown on Fig.3. Such erosion could be linked to localised slumping of the armour stone, that would explain the variations in armour stone gradient observed.

Figure 3 Armour stone to Promontory 1 (Chainage 70-140m)

The return face of Promontory 1 (Chainage 140 to 200m) is of similar armour stone construction, but facing ENE approximately parallel with the DBSC jetty, as shown in Fig.4. It is consequently comparatively sheltered and shows a more uniform 1:1.6 gradient, and less crest erosion, but still plenty of typically 50-200mm size bricks/cobbles on the beach along the toe, suggesting reduced wave erosion is also occurring here.

Figure 4 NE Face of Promontory 1 (Chainage 60-80m)

2.1.3 DBSC Jetty and Slipways (Chainage 200-290m)

This section of coast comprises a low exposed sandstone bedrock cliff up to 2m high, with minimal vulnerability to erosion, with a wide foreshore dominated by the DBSC structures built to improve boating access over the years. There are three structures apparent:-

Figure 5 Promontory 1 Erosion (Chainage 170m) with Jetty beyond

- **Jetty** – this is the most substantial and westernmost structure approximately 4m wide and 130m long, extending down to MLWS, built with near vertical dressed masonry walls capped with an insitu slab and 150mm dia half pipe plastic rubbing strips along each edge above assumed rubble fill. The jetty is built onto a rock outcrop just above MLWS (see Figs. 5 & 10) beyond which it drops more steeply to the mud flats beyond MLWS, as shown in the long section 4 on Drg. No. 23218-rr415 – 03. Although clearly built well above the foreshore to enable boat loading/ unloading through most tidal states, the jetty reaches heights of 1m above foreshore to the SW (updrift) and 2m above foreshore to the NE (downdrift), suggesting the jetty acts as a groyne trapping NE littoral drift along this coast. These different beach levels each side of the jetty are visible in Figs 5 & 13 and Section 5 on Drg. No.. 23218-rr415 – 04). Records summarised in the AMEC Phase One Land Quality Assessment Conceptual Model Report indicate the jetty was built between 1988 and 1995.
- **Central Slipway** – this is an approximately 4m wide 50m long series of insitu concrete slabs laid directly onto the beach and now extensively cracked and no longer maintained. It extends from the shore end of the jetty down to c.0.5m above MLWS, , with no obvious current effect on sediment patterns. Records summarised in the AMEC Phase One Land Quality Assessment Conceptual Model Report indicate that this was built between 1973 and 1979, after the original east slipway.

- **East Slipway**– this is an approximately 10m wide 60m long slipway extending to MLWS, built with in-situ concrete slabs laid directly onto the beach with a central joint at beach level, although the eastern slabs appear to have been added later as a widening scheme. Although the slabs are at beach level to the west, the slab is protected along the east edge by more recently stacked precast blocks and posts, where the beach level is approached 1m below the slipway level. This again suggests the slipway acts as a groyne, trapping NE littoral drift along this coast. The different beach levels each side of the jetty are visible in Figs 6 &7 and Drg. No. 23218-rr415 – 04. Records summarised in the AMEC Phase One Land Quality Assessment Conceptual Model Report indicate that the west half of this slipway is visible in the 1973 aerial photograph although the subsequent widening date is unclear.

Figure 6 East Slipway showing precast block protection to east face (Chainage 280m)

2.1.4 Promontory 2 (Chainage 290-320m)

This promontory is built on a substantial bedrock outcrop that extends up to 50 m out into the bay, exhibiting N-S strata, and causing a local raising of beach levels. The boat storage area is protected by armour stone, placed variably on damaged filter cloth/no filter stone, topped up with ad-hoc precast blocks/smaller stone.

Beach sections from this promontory are shown in Sections 6, 7 and 8 on Drg. No. 23218-rr415 – 04.

Figure 7 **Showing Slipways and Promontory 2 (Chainage 300m) from Promontory 1 (Chainage 170m)**

2.1.5 Boatyard Bay South (Chainage 320-400m)

This section of the boat storage area is slightly higher and more exposed than further north, comprising a double layer of approximately 1m rock armour boulders on damaged filter cloth with no evidence of filter stone, bedding or toe details. There is evidence of localised wave erosion behind some boulders and ad-hoc filling/repairs with smaller stone. The typical beach profile is shown in Section 9 on Drg.No. 23218-rr415 – 04. Records summarised in the AMEC Phase One Land Quality Assessment Conceptual Model Report indicate the armour stone construction along the coastline has been added as repeated, minor extensions from the 1970s to the present day.

Figure 8 Boatyard Bay South (Chainage 320-400m)

2.1.6 Boatyard Bay North (Chainage 400-460m)

This bay extends in a single 140m long curve from Promontory 2 to Promontory 3, backed by the DBSC boat storage area which is protected by continuous rock armour. However the north half is slightly lower lying (hence its inclusion in the SEPA flood maps (ref.2)), requiring a single layer of approximately 1m rock armour boulder as a sea wall, but built on inadequate filter cloth, again with no apparent filter stone or toe detail. At Chainage 400m, there is a 100mm diameter flapped outfall pipe at the foot of armour that was not flowing on either visit, but is assumed to provide land drainage of some form from the low lying boat park behind. Again there is evidence of localised wave erosion behind some boulders and ad-hoc repairs using waste building materials.

Figure 9 Boatyard Bay North – showing strandlines and tide lag

2.1.7 Promontory 3 (Chainage 460-480m)

This promontory signifies the northern end of the armour stone protected plateau occupied by the Dalgety Bay Sailing Club boat storage area. It is formed by an outcrop of reddish sandstone bedrock that displays strata aligned in a N-S direction, extending approximately 30m out into the intertidal foreshore from the coastline. The rock armour reduces into a transition length of small approximately 0.3m boulders which has successfully avoided end erosion that often occurs around abrupt ends of armour stone structures.

A large approximately $1m^3$ mass of concrete was also noted on the foreshore at this location, assumed to be the historic washout of a concrete mixer fly tipping on the beach.

2.1.8 Ross Plantation (Chainage 480-720m)

This length of beach appears the most stable, comprising an approximately 5m wide shingle strip along the strand lines merging into the mud flats, with minimal evidence of erosion where the head of the shingle beach turns to grassland, footpath and the mature Ross Plantation. Ross Plantation features tall deciduous trees. The trees reach heights exceeding 10m within short distances of the beach, suggesting permeable soil allowing root development to significant depths.

Figure 10 Ross Plantation (Chainage 520m) – showing mature trees/ raised beach

2.1.9 Spinneys SPS (Chainage 720-750m)

This section comprises an approximately.30 m long concrete/coarsely dressed boulder constructed sea wall up to 1.5m high in poor condition, with undermining near 250mm diameter flapped emergency overflow from Spinneys sewage pumping station (SPS) which is located approximately 30m inland. The wall has collapsed and shows localised wave erosion at two separate locations. These and the leaking flap valve are a possible source of erosion and leaching onto the foreshore of deposited Made Ground materials from landward area.

A buried outfall is indicated on the Admiralty Chart (and reproduced on Drg No. 23218-rr415 – 06) running from this wall to the navigation post shown on Fig.16, which marks the end of this and a longer outfall from the north coast of Dalgety Bay. No further utility searches have been made, but it is assumed both outfalls are storm outfalls from Scottish Water SPSs, that are normally required by SEPA to reach MLWS or beyond. The backfilled trench construction that would have been used for both outfall pipes is routed away from the rock outcrops, and through an obvious gap in the Promontory 3 outcrop for the Spinneys SPS storm outfall, as shown on Drg. No. 23218-rr415 – 01.

Figure 11 Spinneys SPS Emergency Outfall (Chainage 740m) – showing scour under wall

2.1.10 Salt Marshes (Chainage 750-850m)

The northernmost section of the study area is the most sheltered, with small areas of salt marsh developing at the head of the mud flats, with a relatively narrow beach strip between. There is no sign of the long outfall shown on the Admiralty Chart, presumed now removed, but a small burn and two piped surface water discharges all flow onto the foreshore. Random boulders up to 600mm in diameter, presumably from occasional bedrock outcrops on the beach and mud flats suggest occasionally strong wave energy in the bay.

2.2 Intertidal Foreshore

2.2.1 Off Promontory 1

The mud flats are notably lower along this foreshore than elsewhere in the study area, possibly due to the increase in reflective wave energy that the steep armour stone clad reclaim area will have caused. They extend a considerable distance beyond MLWS at flat (1 in 100+) gradients, strewn with boulders notably off the New Harbour rock outcrop. The beach rises uniformly steeply at a typical 1 in 10 gradient up from these mud flats below MLWS to the foot of the armour stone between the New Harbour rock outcrop and the DBSC Jetty, as Sections 2 & 3 on Drg. No. 23218-rr415 – 03.

The beach comprises boulders, cobbles, bricks and construction debris typically in the 200-500mm range, with occasional rock outcrops as shown on Drg.No. 23218-rr415–01. It is understood that the armour stone revetment was built in 1996 to protect a previous tip, so it is likely that this beach material has been eroded from both the previous tip and the current armour stone revetment. Sediment sources further west are unlikely because of the "groyne effect" of the New Harbour quay and rock outcrop (as Section 1 on Drg.No. 23218-rr415–03).

The only variation from this pattern is the c.10m long coarse sandy beach trapped between the jetty and bedrock outcrop just above the mudflats at MLWS, as shown on Fig.12.

Figure 12 Coarse Sand Beach formed updrift of Jetty off Promontory 1 (Chainage 170m)

2.2.2 Off Jetty/Slipways

This foreshore area has no rock outcrops, so the beach has formed a classic concave profile from the low sandstone “cliff”, slowly flattening to seawards as it merges into the mud flats at MLWS. This is evident from Section 5 (Drg.No. 23218-rr415–04) drawn along the east slipway that was built with in-situ concrete slabs presumed to be laid flush with this pre-existing beach profile.

Both the jetty and the east slipway exhibit lower beach levels to the east, suggesting a clear littoral drift from west to east i.e. downstream along the Firth of Forth coast. Although the general drift is upstream for this coastal sub-cell, this local variation can be explained by the sheltering of Inchcolm and Haystack rock from the long fetch easterly waves that would otherwise push sediment upstream. Moored boats visible in Figs. 4, 5 and 6 confirm the sheltered nature of this area. This has left Dalgety Bay vulnerable to prevailing S/SW waves and refracted E waves/ swells that are pushing sediment N/NE locally and causing these differential levels of up to 1m across the jetty (as Fig.13) and 0.5m across the east slipway (as Fig.6). This “groyne effect” of the jetty is particularly noticeable in Sections 4 & 6 (Drg Nos. 23218-rr415–04 & 05) taken along and across the jetty respectively.

The beach comprises gravel/shingle, cobbles and a few boulders but no sand, merging into mudflats at the foot of the slipways as seen in Figs 6 & 7. The comparative lack of boulders compared with the beach SW of the slipway further points to this groyne effect, suggesting the jetty forms a terminal barrier to larger sediment movement as well as throttling the finer material.

Figure 13 Groyne Effect of Jetty on beach levels

2.2.3 Off Promontory 2

This foreshore area is dominated by outcrops of the sandstone bedrock just above MLWS and just below MHWS, the latter forming the promontory that the boat storage area is built on. Both outcrops follow parallel NNE/SSW strata alignments, with a c.30m wide silty/sandy channel formed between them. Various features were noted in this area at low tide as shown on Drg.No. 23218-rr415–01 and described as follows:-

- Roofing Debris – this silty beach area just west of the east slipway (as shown in Fig.14) was strewn with corrugated roofing panel debris, typically 100 to 800mm long and of a type that is often found to contain asbestos. The unusual concentration of this material here suggests a batch of this material being eroded or tipped and being sorted into groups of broadly similar aspect ratios that react similarly to storm wave movement at high tide.

Figure 14 Roofing Debris

- Beach Ripples – the surface of the silty channel between rock outcrops was marked by ripples typically 25mm high by 200mm long, aligned across the channel in a ENE/WSW direction, suggesting predominant wave action from the SSE direction immediately preceding the site visit. These ripples only form as the tide ebbs away, and the rock outcrops dominate wave directions more than at high tide, but it still gives an indication of prevailing wave activity, which aligns with the high tide wave crests shown on Fig.15.

Figure 15 Silt Ripples between Rock Outcrops

- Coarse sandbank / mussels – various discrete locations around the main rock outcrop were noted to attract deposits of coarse (0.5-2mm) pink coloured sand/shell fragments, together with banks of mussels. These are indicative of more sheltered areas where the comparative lack of wave action allows residual tidal currents to deposit sediment and provide a suitable environment for the mussels to feed. This coarse sand is shown in Fig. 16 and is the same sand accreting at the SW foot of the jetty (Fig 6).
- Of particular littoral significance however is the curving sandbank approximately 20 long and approximately 0.5m tall that extends from the northern end of the rock outcrop in an arc curving inland to the NE before fading into the silt, as shown on Fig 17. This suggests either prevailing SSE waves refracting clockwise into Dalgety Bay, or ESE waves becoming more dominant at the north end of the outcrop as SSE/S waves break and lose energy on the rock as the tides ebbs. Even if both are true, the evidence clearly points to sediment movement around Promontory 2 from the south and into Dalgety Bay.

Figure 16 Mussel Beach & Marker Post

- Leaning navigation marker post – there is a tubular steel marker post bolted to an insitu concrete base slab to mark the end of the surface water outfall just off the main rock outcrop, as shown on Drg. No. 23218-rr415 – 01. Normally this would have no significance, but it is clear from comparing Figs 16 & 17 that the post has a pronounced lean of 2-3^{o} in a NE direction. The age of this post is unknown, but this lean is very likely to be the result of fatigue loading caused by years of prevailing wave loadings that will obviously be greatest during high tides. The direction of this lean is therefore a stronger pointer to large wave /deep water conditions than the sandbanks and silt ripples, that are generally formed at lower ebbing tide levels.

Figure 17 Coarse Sandbank & Leaning Marker Post

2.2.4 Boatyard Bay

The bay formed between Promontories 2 and 3 forms the second section of armour stone sea wall at Dalgety Bay, built to protect the boat storage area. Although some of the land is reclaimed, the bay is a natural occurrence defined by the bedrock outcrops that form each promontory. The orientation of the bay, facing ENE gives dramatically more sheltered conditions than the foreshore further south, reflected in a higher, more pronounced shingle beach with clear strandlines indicating neap high tidelines away from the coastal structure. Sections 9 & 10 on Drg No. 23218-rr415 – 05 clearly show this higher profile when compared with Sections 1-5.

There is a coarse shingle/gravel upper beach that merges into silty seaweed strewn mudflats also at higher levels than south of Promontory 2. Both the beach and the mud flats are strewn with occasional boulders, cobbles, bricks etc that appear to have been eroded from the sea wall or carried around Promontory 2 from the deeper water. A discrete area was observed containing significant fragments of pottery as shown on Drg No. 23218-rr415 – 01, that as with the roofing material, suggests a discrete batch of this material being eroded or tipped in the past and being sorted into groups of broadly similar density and aspect ratios and thus mobility for any given storm waves.

Groundwater was noted to be weeping out of the beach just below the shingle, suggesting a considerable volume of granular material that fills and empties with saline groundwater on each tide. This phenomena, known as tide lag, was less obvious near the slipways where the sandstone cliff suggests a relatively small “reservoir” of granular material to fill and empty. However the very recent trial pitting on the foreshore had disturbed the beach material, which was clearly still settling back to equilibrium conditions during the November 2012 site visit, and could distort this observation.

Tide lag is not considered a serious potential mechanism for contaminated material to reach the foreshore from reclaimed land behind the armour stone, because the flows would never reach adequate velocities to mobilise significant size particles.

Figure 18 Debris & Tide Lag in Boatyard Bay

2.2.5 North of Promontory 1

This area of foreshore is the most sheltered, highest and flattest, with consequent reduced wave energy exposure and least evidence of erosion. The beach comprises a well defined shingle/gravel strip approximately10m wide, backed by grass/ low walls/ salt marshes as described in Sections 2.1.8 to 2.1.10. This merges into a wide expanse of mud flats strewn with seaweed and drained by meandering channels from the surface water discharges noted above, as Section 12 on Drg No. 23218-rr415 – 01.

There are occasional outcrops of sandstone bedrock and boulders up to 600mm dia that are assumed to come from these outcrops, but it is difficult to envisage wave conditions violent enough to move these boulders in such a sheltered environment.

2.3 Site Investigation / Surveys

Previous work undertaken by AMEC included topographic foreshore surveys to establish any fluctuations on foreshore levels. From these surveys, key profiles through structures critical to the local coastal processes could be obtained. These sections and their location plan are included as Drg Nos.23218-rr415 – 02 to 05 in Appendix A for the various key structures as follows:-

Table 1 List of Critical Cross Sections

Section No.	Drg. No. (23218-rr415...)	Structure	Comments
1	03	New Harbour Rock Outcrop (Chge 55m)	
2	03	Reclaim Armour Stone (Chge 90m)	steep beach gradient
3	03	Reclaim Promontory 1 (Chge 140m)	steep beach gradient
4	03	DBSC Jetty (Chge 205m)	
5	04	DBSC East Slipway	
6	04	Promontory 1/ Jetty / Rock Outcrop	beach level drop across jetty
7	04	Promontory 2 - SE	
8	04	Promontory 2 - NE	
9	05	Boatyard Bay South	raised beach profile
10	05	Boatyard Bay North	raised beach profile
11	05	Promontory 3 - East	
12	05	Promontory 3 - North	sheltered mudflat profile

3. Coastal Energy Data

3.1 Shore Management

From Ramsay & Brampton (ref.1), the beaches of Sub Cell 1c are self contained bays with "*little interaction between beach units*." The strong flood and ebb tidal currents in the Firth "*tend to be deflected further offshore by the rocky headlands*." (Braefoot Point in the case of Dalgety Bay). The main influence on local beaches is therefore wave activity from the North Sea, i.e. the east, which "*has the potential for causing a east to west net littoral drift but the beach areas have long since adapted to this influence*." Dalgety Bay is further protected from such waves by Inchcolm Island and the Meadulse Rocks, enabling the more prevailing SW wind driven waves to dominate littoral drift as observed on site.

The report also notes that "much of the backshore along this coastline is protected, which cuts off the input of fresh material released to the system by wave erosion." This would apply to well constructed coast protection structures, but less so to the poorly constructed armour stone structures and consequent beach debris noted on the foreshore at Dalgety.

From the Fife SMP2 Policy Unit 13 – St David's Bay to Braefoot Point (ref.2), the following comments on wind and wave climate have been noted:-

- Dalgety Bay is described as " …bays of stable sand and shingle where sediment appears to be in a balanced state with little evidence of significant erosion."
- South westerly winds with a short fetch (5 to 15km) are the major factor in the shoreline wave process. The wave heights are "typically around 0.3m though maximum heights of 1.0m have been encountered"
- Swell waves entering the Forth from the north or easterly direction but have limited effect due to the sheltered nature of the bay;
- The general sediment movement for the sub cell is believed to be in an upstream ie south west direction however it is restricted by the confined nature of the bays and head lands

This would appear to be the case in Dalgety Bay where evidence points to sediment movement in a downstream i.e. north east direction (see site observations).

It is clear that the only oceanic wave fetch for Dalgety Bay is from the North Sea, virtually due east (WCB 90^{o}). This produces significant waves and residual swells at Dalgety Bay that refract and shoal around Inchcolm Island, Haystack rock etc. to approach Dalgety Bay from the SE to S quadrants (i.e. WCB 135 to 180^{o}).

All other wave fetches at Dalgety Bay, notably from SE around to SW (i.e. 135 to 225^{o}), are limited by the geometry of the Firth of Forth.

3.2 Tidal Levels

From Ramsay & Brampton (ref.1), the tidal cycle in the Inner Firth of Forth sub-cell has a semi-diurnal mean period of 12.1 hours with a mean spring tidal range that increases further up the estuary from 4.7m at Burntisland (2.75 to -1.95mAOD) to 5.00m (2.85 to -2.15mAOD) at Rosyth, immediately upstream of the Forth Bridge narrows.

Representative predictive tide levels are therefore taken for Dalgety Bay, approximately 7km up the estuary from Burntisland but 6km down the estuary from Rosyth through the Forth Bridge narrows, as follows:-

Table 2 Tide Levels

Tide Level		Rosyth (mAOD)	Dalgety Bay (mAOD)	Burntisland (mAOD)
Highest Astronomic Tide	HAT	3.45		-
Mean High Water Spring Tide	MHWS	2.85	2.80	2.75
Mean High Water NeapTide	MHWN	1.75	1.70	1.65
Mean Sea Level	MSL	0.25	0.25	0.25
Mean Low Water Neap Tide	MLWN	-0.75	-0.70	-0.65
Mean Low Water Spring Tide	MLWS	-2.15	-2.05	-1.95
Lowest Astronomic Tide	LAT	-2.95	-	-

Chart Datum level is taken from Leith docks, approximately 10km across the Firth of Forth, as .-2.90m AOD.

3.3 Tidal Currents

From Ramsay & Brampton (ref.1), the strong flood and ebb tidal currents in the Firth tend to flow along the northern coastline. Peak currents in the main channel and Mortimer's Deep north of Inchcolm can exceed 1m/s on both flood and ebb tides, but "*tend to be deflected further offshore by the rocky headlands*." (Braefoot Point and Haystack rock in the case of Dalgety Bay).

The tidal stream data on the Admiralty Chart 736 confirms such currents, suggesting spring tide velocities of up to 1.2/1.3 knots (0.62/0.67m/sec) on flood/ebb tides respectively at diamond E, 500m SW of Oxcar and 1.5/1.7 knots (0.77/0.87m/sec) on flood/ebb tides respectively at diamond F,1.5km east of Inchcolm, both in the deep shipping lane approach to the Firth and both visible on Drg. No. 23218-rr415 – 01. In both cases the tidal vectors are aligned with the shipping channel, which clearly takes the bulk of the tidal flows in/out of the Forth Estuary upstream of the bridges.

It is therefore reasonable to assume tidal currents are of secondary importance to waves in considering the coastal processes affecting Dalgety Bay.

3.4 Wind Exposure

From BRE Digest 346, which is compatible with BS6399:Part 2, the hourly mean site wind speed can be calculated for any location in the UK, based on Meteorological Office hourly mean wind speeds and maximum gust speeds each hour at stations throughout the UK. . This is defined as having "an annual probability of exceedance of 0.02, irrespective of direction, and was previously referred to as the 50 year return period wind speed." With minor adjustments for altitude, direction and season, an hourly mean site wind speed can be assessed for Dalgety Bay as 23.5m/sec.(52.5mph or 46 knots).

There is a national Meteorological Office wind recording station at Turnhouse (Edinburgh Airport) approximately 10km south of Dalgety Bay, and approximately 20m above sea level, that could provide more detailed suitably local wind rose data if required, but for the purposes of this report, typical wind speeds up to this value can be anticipated particularly in the prevailing SSW to WSW sector.

Figure 19 Jetty high tide - Showing Prevailing S waves shoaling behind Inchcolm

3.5 Wave Fetches

It is clear that the only significant wave fetch for Dalgety Bay is from the North Sea, virtually due east (WCB 90^{o}). This produces significant waves and residual swells at Dalgety Bay that refract and shoal around Inchcolm Island, Haystack rock etc. to approach Dalgety Bay from the SE to S quadrants (i.e. WCB 135 to 180^{o}).

All other wave fetches at Dalgety Bay, notably from SE around to SW (ie 135 to 225^{o}), are limited by the geometry of the Firth of Forth, as shown on Drg No. 23218-rr415 – 01.

This drawing also confirms the bathymetric protection afforded to Dalgety Bay by a comparatively shallow area protected by an underwater "shelf" running along the north edge of Mortimer's Deep indicated in blue. The edge of the shelf even breaks low tide surface at Thank

Rock (700m south of DBSC jetty) and Long Craig (800m ESE of DBSC jetty), providing further “Reef” type protection to Dalgety Bay, but generally runs at around 0.7m depth below chart datum i.e. at -3.6mAOD.

The shelf provides significant protection for Dalgety Bay against waves, as summarised in Table 3 below, where the depths at various radii out from the DBSC jetty (taken as an arbitrary focus for the wave fetch rose in Drg no. 23218-rr415 – 06) are indicated for each relevant compass sector. Each depth is taken from the Admiralty Chart bathymetric data which is quoted as below chart datum(ACD), plus the depth of MHWS above i.e. by adding 2.8 + 2.9 = 5.7m to each chart reading. The increased depths (shown in bold) in Mortimers Deep can be seen grouped at 750 or 1000m off Dalgety Bay in Table 3.

Table 3 Depth Limited Wave Fetches

Compass Sector	WCB (°)	Wind Fetch (km)	Water Depth at MHWS Approach radius (m)				
			1000	750	500	250	100
N	0	0.6	-	-	1	3	3
NNE	22.5	0.7	-	-	2	3	3
NE	45	0.93	-	1.5	3	3	3
ENE	67.5	1.2	1.5	3.5	3.5	3	3
E	90	40	4.5	6	4.5	2.5	3
ESE	112	20	**20.5**	4.5	6	5	3
SE	135	7.9	**27.5**	**16**	6.5	5.5	3
SSE	157	6.4	**21**	**26**	6.5	6	3
S	180	4.2	**23**	**17**	6.5	6	3
SSW	202	4.8	**12.5**	6	6	6	3
SW	225	2?	**-**	1	2	2	1
WSW	247	0					

3.6 Wave Heights

Design wave heights for coastal structures are normally calculated as the significant wave height H_s which is defined as the average height of the highest one third of waves in a given sea state. Such sea states are often defined using real time recorded data that may be extrapolated for the required location. However the sheltered nature of Dalgety Bay would require significant analysis to enable meaningful extrapolation, potentially requiring mathematical modelling of the Firth of Forth. Although such models will already exist, their use for analysing the wave climate at Dalgety Bay would be time consuming and costly.

A more pragmatic approach has therefore been taken for the purposes of this report, in the use of the US Corps of Engineers “Shore Protection Manual”- 1984 (SPM)(ref.3) which although superseded by reports like the CIRIA “ Beach Management Manual”- 2010 and the CIRIA

"Rock Manual"- 2007, remains a well respected practical guide to assessing design wave heights.

As the SPM states, it is desirable to have a simplified method for estimating wave heights. This requires simplified assumptions including:-

- the waves being considered are formed purely by winds blowing at a constant speed and direction for the required duration
- there is no residual swell from previous wind events
- simplified bathymetry of water body i.e. constant depths across fetch

Wave conditions can then be regarded as either duration-limited or fetch/ depth-limited

For deep-water conditions, the wave heights are generally limited by the length of time the wind has blown, i.e. conditions are duration-limited. For shallow-water conditions, winds have blown constantly long enough for wave heights at the end of the fetch to reach equilibrium, and the depth or fetch effectively limits the wave development.

These two conditions represent asymptotic approximations to the consideration of wave growth, which inevitably is a combination of the two cases at any given site.

Certain built in assumptions should be emphasised in this simplified approach, including:-

- the waves being considered are formed purely by winds blowing at a constant speed and direction for the required duration
- there is no residual swell from previous wind events

The two approaches have therefore been taken from the SPM as follows:-

3.6.1 Deep Water Waves

SPM equation 3.33 for fetch limited deep water conditions gives :

$g\,H_s / U_a^{2} = 1.6.10^{-3}(g\,F/U^2)^{1/2}$

- .....where F = wave fetch, Ua = adjusted wind stress factor (= 0.71(Us)1.23= 34.5m/sec) and Hs = spectral significant wave height

At Dalgety Bay, for the design hourly maximum wind speed of 23.5m/sec as assessed in 3.3 above, this wave height can be assessed crudely for various critical compass sectors as follows :

- SE (WCB = 135^o)..... F = 7.89km thus H_s = **1.56m**
- SSE (WCB = 157.5^o)...F = 6.37km thus H_s = **1.41m**
- S (WCB = 180^o)...... F= 4.15km thus H_s = **1.13m**
- SSW (WCB 202.5^o)....F=4.75km thus H_s = **1.21m** generated across the Firth of Forth.

However this equation does not allow for the bottom friction/ shoaling effect of shallow water on such waves, which will inevitably reduce both wave heights and wave periods.

3.6.2 Shallow Water Waves

There is no single formula for determining the actual growth of waves generated by winds blowing over relatively shallow water. The SPM method presented in equations 3.39 and 3.40 and the associated wave forecasting curves (Figs.3-27 to 3.36) is an interim simplified forecasting technique based on successive approximations in which wave energy is:-

- added due to wind stress using deepwater forecasting techniques
- subtracted due to bottom friction and percolation using relationships developed by Bretschneider and Reid (1953)

Resultant wave heights and periods are obtained by combining the above relationships by numerical methods for various typical shallow-water depths in Figs. 3-27 to 3-36. Although subsequent research in the shallow–water forecasting has superseded these curves, they still provide a realistic pragmatic estimate for assessing design wave heights.

Thus for typical shallow water depth of 6m (taken from the approach depths identified in Table 3 above, where typical depths around 6m apply to the final 700m or so for virtually all fetch compass sectors) and using the consequent Fig.3.30.......

- fetch = 4 to 8km
- design surface wind speed Us= 23.5m/sec
- therefore wind-stress factor Ua = 0.71(Us)1.23= 34.5m/sec

and reading from Fig.3.30:-

- wave height H = 1 to1.25m
- wave period T = 3 to 3.7 sec
- with required wave duration t = 20 to 40min
- This equates to the deep water range for the same fetch range of 1.13 to 1.56m

It is therefore reasonable to assume design wave heights approaching Dalgety Bay should be anticipated in the range of 1.0 to 1.25m

4. Sediment Transport Mechanisms

4.1 Particle Qualities

It is understood that the contaminated particles recovered to date from the foreshore vary considerably in size, density and aspect ratio. There is thus little point in identifying critical particle qualities to assess the most relevant transport mechanisms. It is further understood that a possible source of contaminated particles is the tipped material forming the bulk of the reclaimed area forming and updrift of Promontory 1 before the armour stone protection was added in 1996. This tipped material would have been vulnerable to wave erosion and movement for a significant period before 1996, and residual debris from this source (notably pottery and potentially roofing material) is likely to still form much of the observed sediment on the foreshore even though the armour stone has effectively cut off this supply for approximately 16 years.

Although tidal currents are a factor, waves arriving at Dalgety Bay are clearly the primary mechanism for sediment transport on the foreshore. Obviously different waves have different effects on sediment depending on their direction, period, height and tide level. There are two fundamental extremes of sediment movement caused by waves on the intertidal foreshore, namely deep-water conditions where passing waves and currents can move considerable sediment volumes in one high tide storm event, and shallow-water conditions where breaking/plunging waves can momentarily move substantial particles within the surf zone. These conditions are discussed in further detail below.

4.2 Deep Water Conditions

From Section 3.3 above, it can be assumed that waves can approach from the SE to SW quadrants in deep water conditions with maximum significant wave heights of 1-1.25m. at approach depths of 4.5 to 6m. To establish the ability of these waves to mobilise sediment over the range of particle sizes observed on site, a review of the relevant littoral processes is required.

There are two recognised modes of sediment transport along the sea bed in deep water conditions:

- suspended sediment transport - where sediment particles are carried above the bottom by the turbulent eddies of the water
- bed-load sediment transport- where generally larger/denser sediment particles remain close to the bed and move by rolling and saltating

Although this distinction may be made conceptually, it is difficult to separately measure these two modes of transport. Despite these uncertainties, and the difficulties of combining longshore with onshore/offshore sediment transport mechanisms, some quantitative guidance has been established for deep water littoral processes as described in SPM Chapter 4.

In particular, SPM equation 4.27 provides a simplified method for assessing the wave energy needed to initiate granular particle motion. This states...

$U_{max} = [8(\gamma_s/\gamma\text{-}1)g.d_{50}]^{0.5}$

where U_{max} = peak fluid velocity at sediment bed

γ_s= specific gravity of the solid particles – say 1.4

γ= specific gravity of seawater – say 1.0

d_{50}= diameter of particle – say 2-10mm

This gives U_{max} = 0.25 to 0.56m/sec required to move particles of dia 2 to 10mm respectively

From the associated Fig.4-29, where wave periods below 5 sec approximate to the T = 5 sec curve,

A depth of 6m gives the dimensionless ratio $U_{max}.T / H = 2$

And therefore $H = U_{max} .T/ 2 =$ **0.625m to 1.4m**

This suggests that design wave heights of up to 1.25m would mobilise particles up to say 8mm i.e. silts/sands/ gravels but not cobbles/bricks/boulders in deep water conditions. It is unlikely that the larger particles observed on the foreshore, notably bricks, boulders and roofing material, would be moved by waves in deep water conditions.

It is possible with further data to predict longshore transport rates using methods in the more recent "Coastal Engineering Manual (CEM) Chapter III-2-3 - Predicting Potential Longshore Sediment Transport" (ref.5) but it is evident that this will not apply to the larger particles observed at Dalgety Bay.

4.3 Shallow Water Conditions

The movement of larger particles by the violent action of plunging/breaking waves is well observed during storm events but very difficult to quantify. The SPM equations do not cover boulders and brick size particles and still less particles with planar aspect ratios like the roofing material, that could be moved considerable distances by individual waves or storm events if presented to the relevant waves at the critical angle.

Table 5.19 in the CIRIA "Rock Manual" (ref.4) describes critical depth average velocities that can mobilise loose granular material. This covers typical particle sizes up to 200mm sieve size (i.e. typical bricks) which require depth-averaged velocities in 1m depth of 3.3 to 3.9m/sec. This could momentarily be achieved by breaking or plunging design waves, but would tend to move particles primarily up and down the beach with a secondary component along the beach.

In the absence of theoretical analysis for such size particles, it would be expected that the waves would tend to sort particles into similar size groups at similar locations, and to move them with the longshore drift. This accords with site observations, in that the larger debris is concentrated in areas nearer to their possible sources (i.e. the tip behind Promontory 1) and quantities reduce with distance downdrift of the sources.

The significant reduction in quantity of these relatively large particles across the jetty indicates the terminal groyne effect that the jetty creates for sediment movement.

5. Conclusions

This report has addressed the 5 objectives set out in Section 1.2 above as follows. Data and observations have been collated as set out in objective i. to develop assess and summarise the validity of various mechanisms for sediment erosion, transport and deposition (i.e. objectives ii., iii. and iv.) in Sections 5.1, 5.2, 5.3 and 5.4 below. Consequent consideration of the effect over time of coastal developments on these mechanisms (i.e. objective v.) are then discussed in Section 5.5.

5.1 Wave Climate

Dalgety Bay is clearly protected from the significant North Sea fetches (ENE to ESE) by the geometry of the Firth of Forth, notably Inchcolm island, Haystack Rock and Braefoot Point (all visible in Fig.8. and named on Drg. No. 23218-rr415 – 06). Consequently the local wave climate is dominated by direct fetch/depth limited waves from the prevailing S-SW compass sector (WCB 180-250^{o}), potentially augmented by refracted swells from previous North Sea storm events refracted within the Firth to approach Dalgety Bay from the south.

Combining a MHWS tide level of 2.80mAOD with the BS6399 design maximum wind speed for Dalgety Bay of 23.5m/sec and the relatively shallow sea bed level north of Mortimers Deep gives a tolerably accurate worst case using Shore Protection Manual (ref.3) formulae for a significant design wave of height 1- 1.25m and period 3 - 3.5 sec. approaching Dalgety Bay from the SSE to SSW sector.

5.2 Littoral Drift

Littoral drift is not a strong feature of this shoreline due to the sheltered nature of Dalgety Bay from both tidal currents and prevailing waves. Although the general drift is upstream (i.e. NE to SW) in the Firth of Forth north coastal sub-cell (ref 1), considerable local evidence points strongly to SW-NE drift across the site as follows:-

- Drop in beach levels approaching 1m from SW to NE sides of DBSC jetty and east slipway
- 30m long coarse sandbank formed in NE lee of rock outcrop
- Outfall marker post leaning 2-3^{o} to NE probably due to fatigue from SW wave forces

This drift can be explained by the protection from North Sea fetches that Inchcolm island, Haystack Rock and Braefoot Point provide, plus the shelf along the ENE flank of Mortimers Deep as shown on Drg.No. 23218-rr416-06. This shelf and its rock outcrops at Long Craig and Thank Rock retain the main tidal currents of up to 1m/sec in the deeper water, and provide a reef protection typically 500-700m off Dalgety Bay within which MHWS depths cannot exceed 6m and refracted waves combine with prevailing SW fetch driven waves to generate such littoral drift.

5.3 Sediment Qualities

There is no critical size, density or aspect ratio for the contaminated sediment particles recovered from the Dalgety Bay foreshore, so identifying critical wave sizes is of little significance. Under deep water conditions the significant design wave identified above would move typical density particles up to approximately 8mm in diameter i.e. sands and gravels but not cobbles or larger particles. These would only get moved by the momentary violent forces of breaking waves in shallow water conditions, which because of the prevailing S-SW fetch, will tend to move particles along the shore in the observed littoral drift direction. Over time these waves will also abrade and fracture larger particles until they are small enough to be moved in deepwater conditions as well.

Discrete areas of certain particles observed on the foreshore (e.g. roofing material and pottery) suggest discrete supply events in the past (e.g. tipping of roofing material at an updrift location) that only certain breaking storm waves have been able to move or fracture into a range of similar size/aspect ratio particles. The significant reduction on boulders, bricks and similar beach debris from W to E across the jetty indicates the terminal groyne effect that this jetty provides for larger particles, which can only pass the jetty once broken up to smaller more mobile particles.

5.4 Sediment Sources

The littoral drift has been established as a local sheltered downstream eddy (i.e. SW to NE) along the coast within a larger Firth of Forth upstream drift in the opposite direction. Sources of local foreshore sediment are therefore unlikely to be far up the coast, particularly when the New Harbour rock outcrop acts as an effective groyne, limiting sediment supply at the SW end of the study area. The Made Ground that the armour stone was built to protect at Promontory 1 is thus considered likely to have historically provided much of the larger (100-500mm dia.) particle debris seen on the foreshore.

5.5 Effect of Site Development

The natural coastline has been disrupted at four locations by human activity within the study area, with varying effect on the local coastal processes as follows:-

5.5.1 New Harbour Jetty

This jetty is understood to be at least 150 years old, and has been trapping sand and silts in the bay immediately to its north, restricting sediment movement further east since then. However the existing bedrock outcrop that the jetty is founded on has always provided this function and the addition of the jetty merely increases the efficiency of this barrier, notably for smaller i.e. sand particles, effectively starving Dalgety Bay of a plentiful sediment supply.

5.5.2 Promontory 1/ Armour Stone

This armour stone revetment was added in 1996 to protect the headland. The very need for the revetment suggests material was being eroded from this area, which is evidenced by the immediate debris strewn foreshore and supported by the sediment starved wave activity that would have been present.

The 1955 aerial photo in the DBSC archives clearly shows a large “spit” of debris curving around Promontory 2 into Boatyard Bay that could well result from unimpeded erosion of material at Promontory 1, and has since effectively shrunk to the remnant sandbank in the lee of the Promontory 2 outcrop, as photographed in Fig. 17.

The relative loss of this source created by the armour stone construction in 1996 has effectively cut off this supply and a net erosion of the downdrift foreshore might be expected. This would further explain the loss of beach level in the lee of the jetty and slipway, although no obvious erosion trends have been noted from the beach surveys monitored to date.

5.5.3 DBSC Jetty and Slipways

The slipway construction in 1973-79 and more significantly the jetty construction in 1988-95 precede the 1996 armour stone around Promontory 1. The comparatively recent placing of precast blocks along the leeward edge of the east slipway suggests the leeward erosion is an ongoing transient change rather than a state of equilibrium. This suggests the foreshore is still adapting to the armour stone revetment, some 16 years after its construction in 1996.

5.5.4 Boatyard Bay Reclaim/ Armour Stone

There has always been a higher sheltered foreshore here, protected from the prevailing waves by natural promontories 2 and 3, and the significant rock outcrop extending down to MLWS off Promontory 2. The beach has clearly been reclaimed as a boat storage area by the armour stone sea wall. Although such seawalls tend to increase wave reflection and thus energy levels immediately offshore, there is insufficient depth for this to erode the apparently stable beach levels, and the potential erosion observed around the slipways is far less likely to be repeated here.

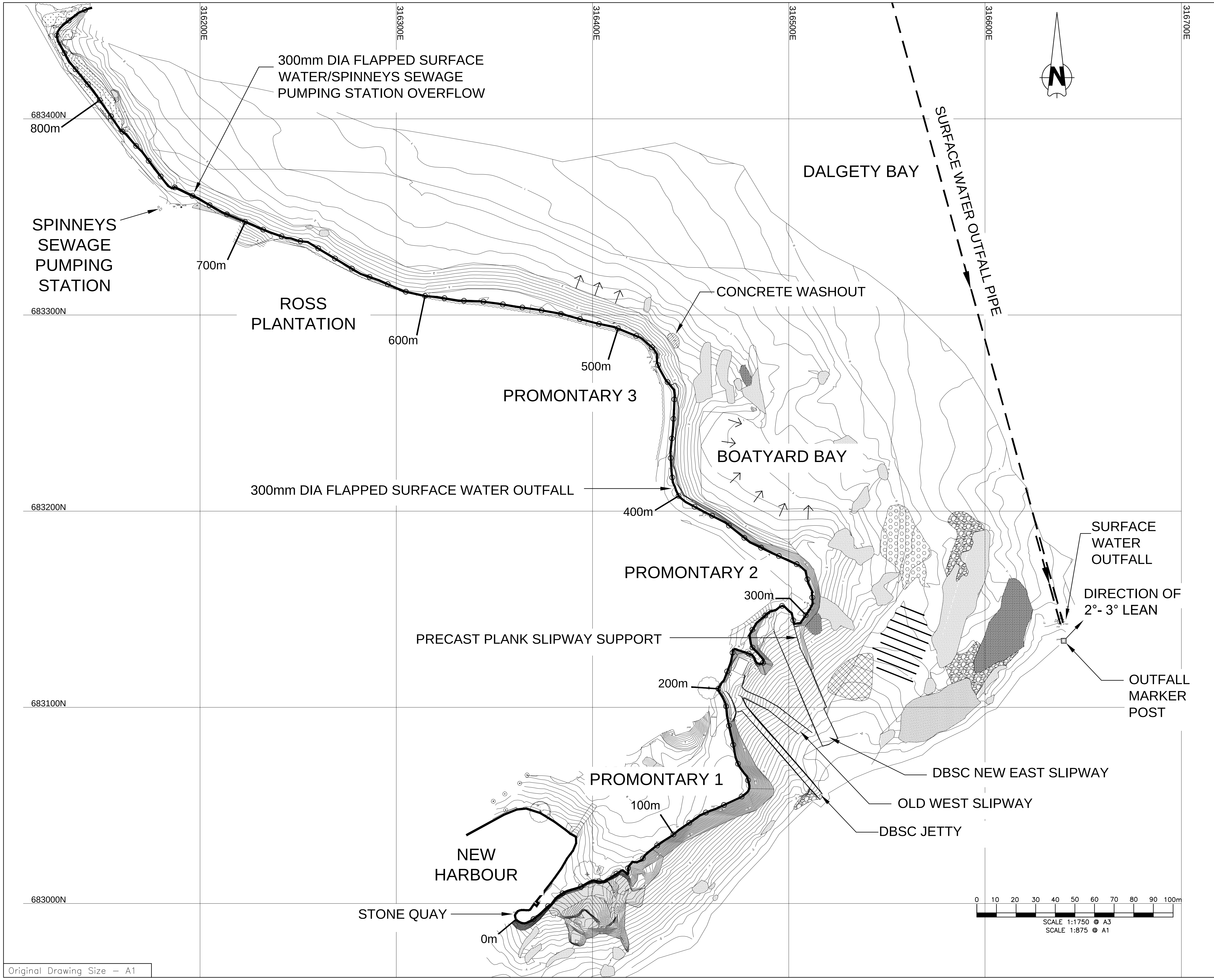
6. Recommendations

Based on the above conclusions, the following recommendations are made for further work at this stage:-

- Regular inspections should be introduced for the armour stone revetments, notably to each face of Promontory 1, to ensure no further damage or erosion of contaminated material can occur, and to monitor any further deterioration of the armour stone so that repairs can be programmed before further erosion can occur
- Beach levels should continue to be monitored and historical DBSC records examined to establish if the observed beach level drops across the jetty and east slipway are still increasing or have reached an equilibrium

Appendix A
Drawings

Drg No	Title
23218-rr415 – 01	Study Area
23218-rr415 – 02	Section Location Plan
23218-rr415 – 03	Sections 1-4
23218-rr415 – 04	Sections 5-8
23218-rr415 – 05	Sections 9-12
23218-rr415 – 06	Wave Fetch Rose – based on Admiralty Chart



DESCRIPTION

REV	DATE		DWN	CHK	APP
A	12.12 2012	FIRST ISSUE	LC	TL	TL

REVISIONS

REV	DATE		DWN	CHK	APP

NOTES:

- BED ROCK OUTCROPS
- ROOFING DEBRIS (100mm - 500mm)
- POTTERY DEBRIS (20mm - 100mm)
- COARSE SAND/ MUSSEL BEDS
- SILT RIPPLES
- GROUND WATER WEEPING "TIDELAG"

SCALES: AS SHOWN

PROJECT TITLE:
DALGETY BAY
COASTAL PROCESSES REVIEW

DRAWING TITLE:
FORESHORE PLAN

CLIENT:
Defence Infrastructure Organisation

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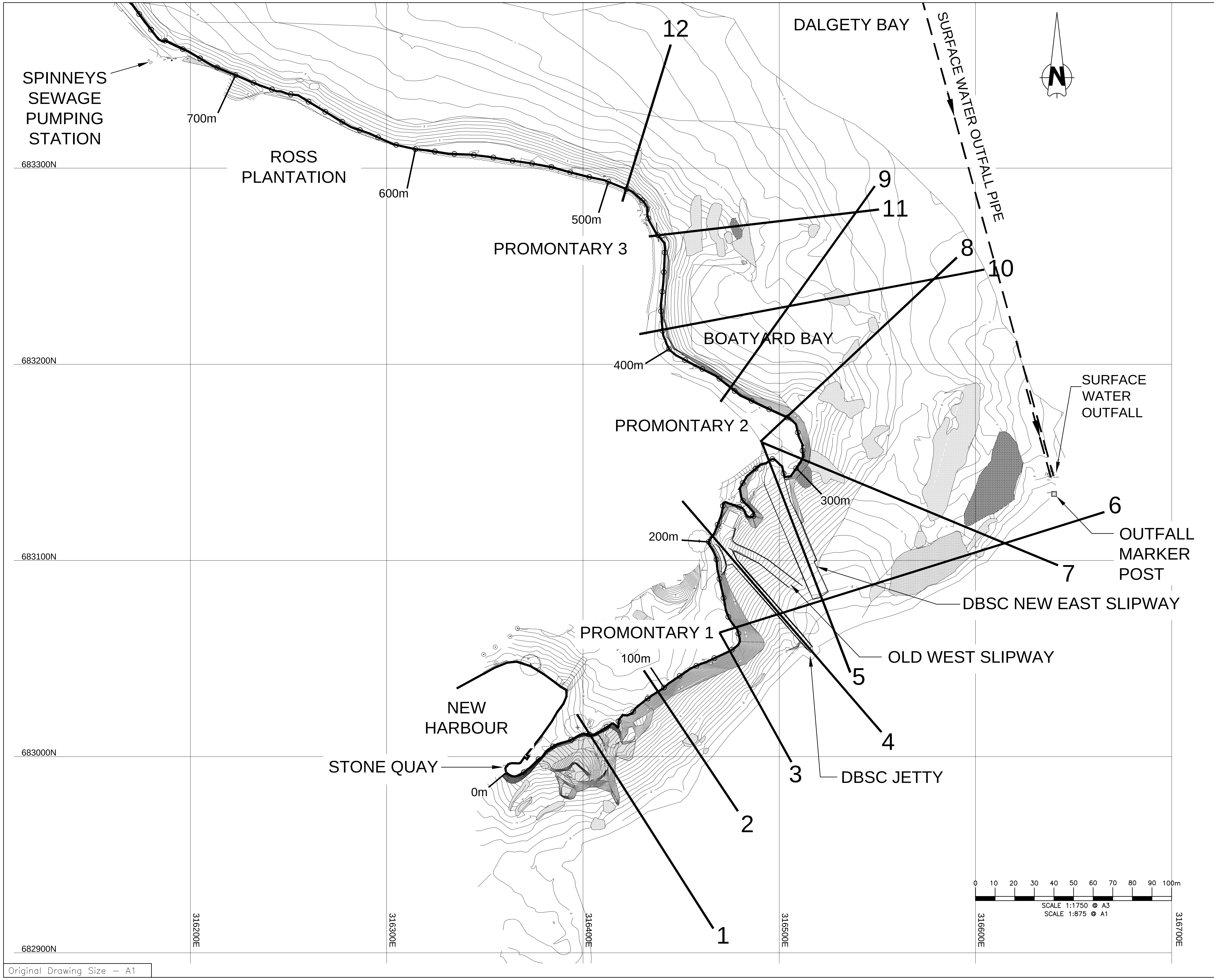
DRAWING No.
23218–rr415–01



DESCRIPTION					
REV	DATE		DWN	CHK	APP
A	12.12 2012	FIRST ISSUE	LC	TL	TL

REVISIONS

REV	DATE		DWN	CHK	APP

NOTES:

1. FOR SECTION DETAILS SEE DRG No 03, 04, 05

SCALES: AS SHOWN

PROJECT TITLE:
DALGETY BAY
COASTAL PROCESSES REVIEW

DRAWING TITLE:
COASTAL SECTIONS
LOCATION PLAN

CLIENT:
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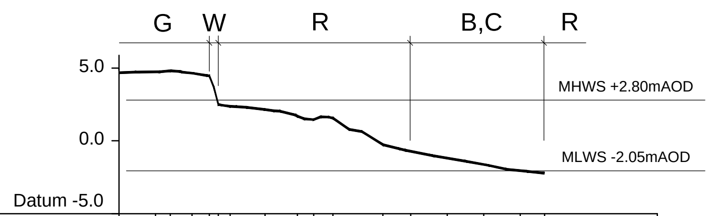
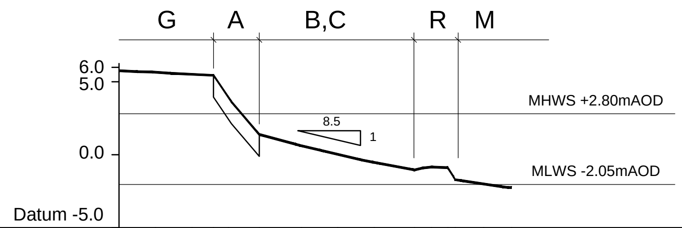
23218–rr415–02



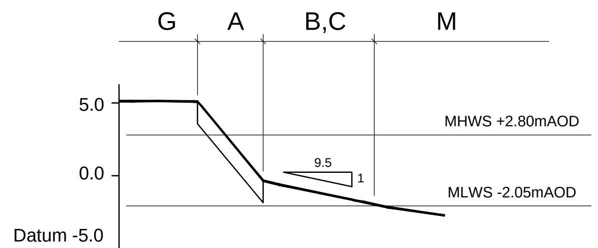
Existing Ground Levels (mAOD)	4.675, 4.748, 4.803, 4.651, 4.466, 2.501, 2.378, 2.152, 1.698, 1.460, 1.566, -0.271, -0.713, -1.181, -1.618, -2.037, -2.226
Chainage (m)	0.000, 5.000, 10.000, 15.000, 20.000, 25.000, 30.000, 35.000, 40.000, 45.000, 50.000, 55.000, 60.000, 65.000, 70.000

Section 1 - New Harbour Outcrop (Chainage 50m)



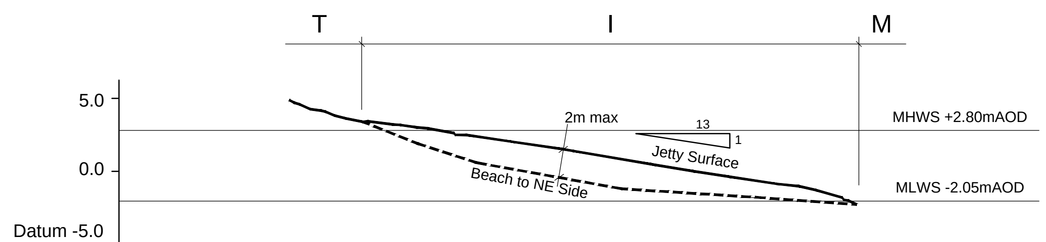
Existing Ground Levels (mAOD)	5.761, 5.656, 5.514, 5.447, 3.938, 1.393, 0.605, 0.025, -0.534, -1.052, -0.854, -0.891, -1.716, -2.008, -2.251
Chainage (m)	0.000, 5.000, 10.000, 15.000, 20.000, 25.000, 30.000, 35.000, 40.000, 45.000, 50.000, 55.000, 60.000, 65.000, 70.000, 75.000, 80.000, 85.000

Section 2 - Promontary 1 (Chainage 95m)



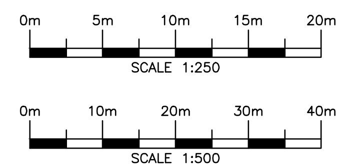
Existing Ground Levels (mAOD)	5.119, 5.128, 5.076, 2.543, -0.336, -0.914, -1.431, -1.950, -2.239
Chainage (m)	0.000, 5.000, 10.000, 15.000, 20.000, 25.000, 30.000, 35.000, 40.000, 45.000, 50.000

Section 3 - From Promontary 1 to South (Chainage 104m)



Existing Ground Levels (mAOD)	4.908, 4.867, 3.773, 3.395, 3.385, 3.084, 2.708, 2.327, 1.953, 1.590, 1.170, 0.740, 0.316, -0.091, -0.470, -0.841, -1.221, -1.796, -2.279
Chainage (m)	0.000, 5.000, 10.000, 15.000, 20.000, 25.000, 30.000, 35.000, 40.000, 45.000, 50.000, 55.000, 60.000, 65.000, 70.000, 75.000, 80.000, 85.000, 90.000, 95.000, 100.000, 105.000, 110.000

Section 4 - DBSC Jetty (Chainage 205m)



Original Drawing Size – A1

DESCRIPTION

REV	DATE		DWN	CHK	APP
A	12.12 2012	FIRST ISSUE	LC	TL	TL

REVISIONS

REV	DATE		DWN	CHK	APP

NOTES:

1. FOR SECTION LOCATIONS SEE DRG No 02

LEGEND

A – ARMOUR STONE
B – BOULDERS
C – COBBLES
G – GRASS
H – SHINGLE
I – INSITU CONCRETE SURFACE
M – MUD
R – ROCK OUTCROP
S – SAND
T – TRACK
W – STONE WALL

SCALES: HORIZ 1:500 VERT 1:250

PROJECT TITLE:
DALGETY BAY
COASTAL PROCESSES REVIEW

DRAWING TITLE:
COASTAL SECTIONS
SHEET 1 of 3

CLIENT:
Defence
Infrastructure
Organisation

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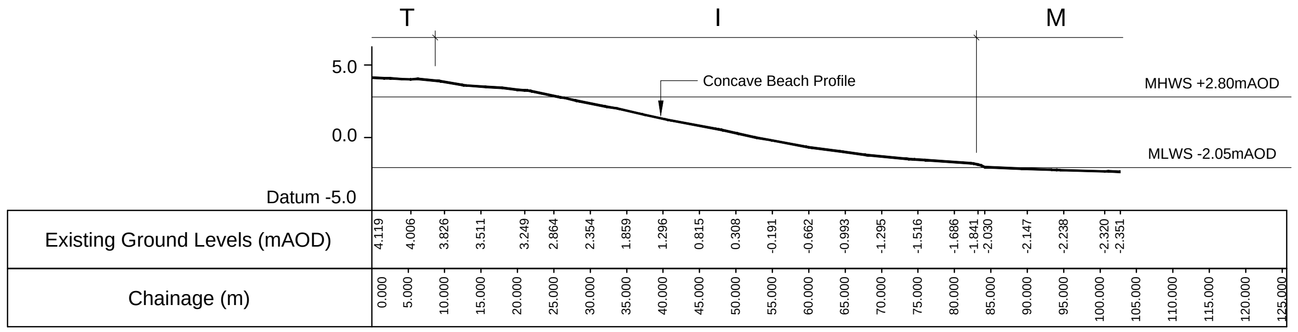
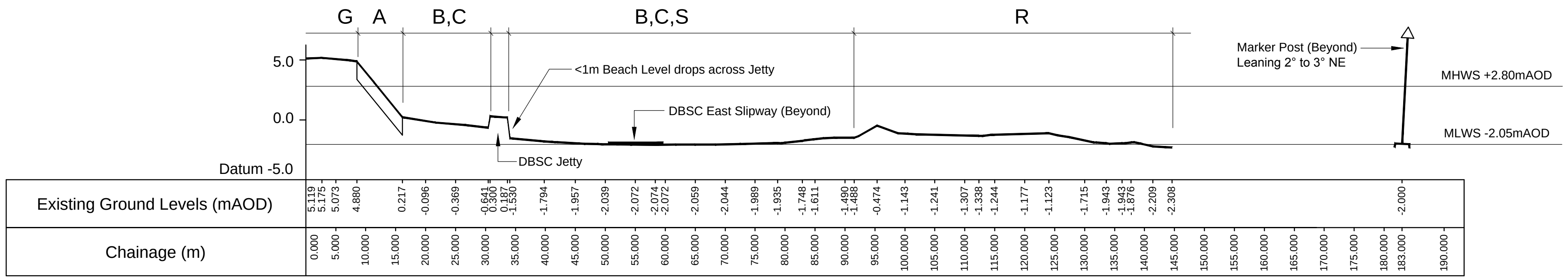
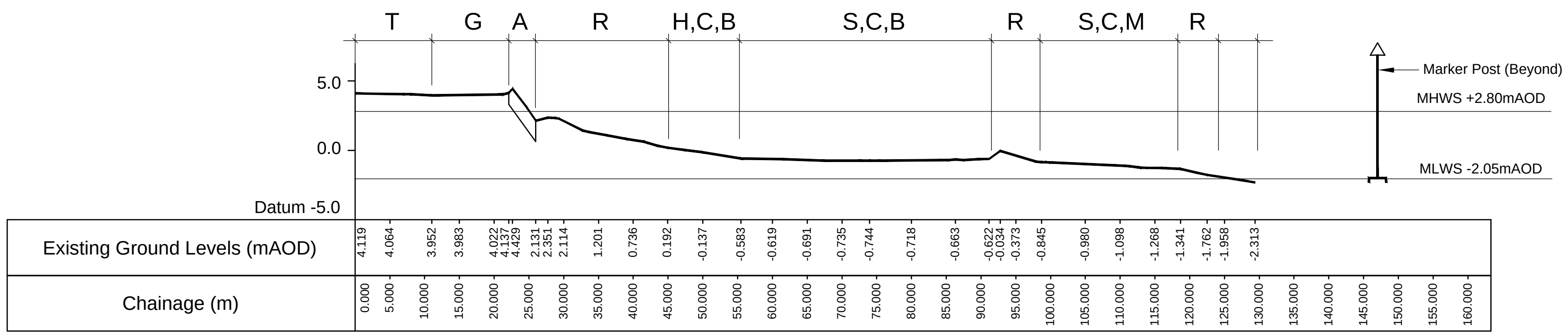
DRAWING No.
23218–rr415–03



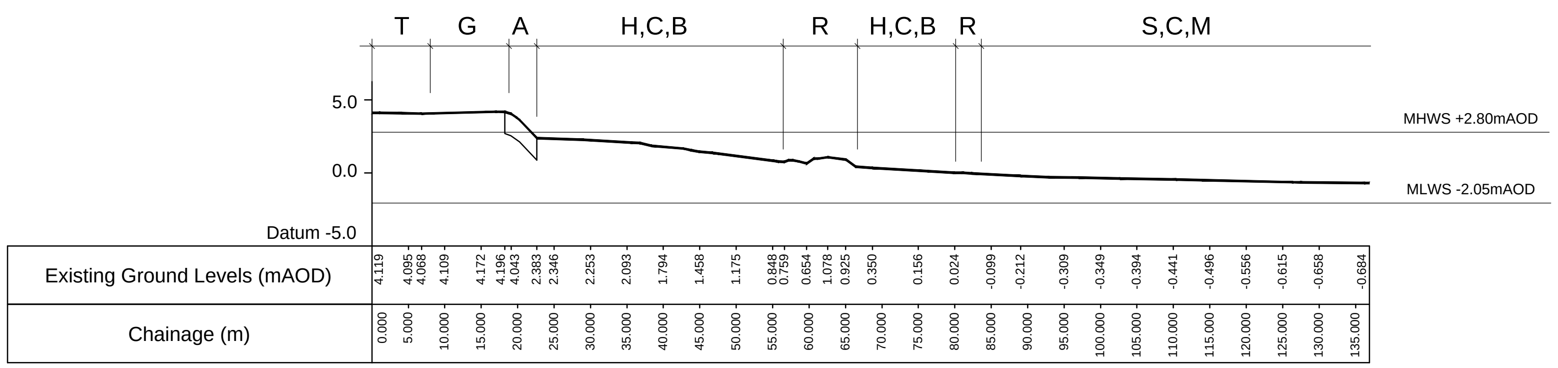
Section 5 - DBSC East Slipway (Chainage 280m)



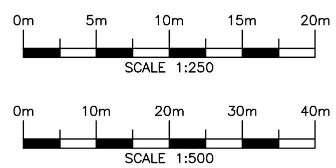
Section 6 - From Promontary 1 to North-East (Chainage 155m)



Section 7 - From Promontary 2 to South-East (Chainage 305m)



Section 8 - From Promontary 2 to North East (Chainage 330m)



Original Drawing Size – A1

DESCRIPTION

REV	DATE		DWN	CHK	APP
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REVISIONS

REV	DATE		DWN	CHK	APP

NOTES:

1. FOR SECTION LOCATIONS SEE DRG No 02

LEGEND

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- M – MUD
- R – ROCK OUTCROP
- S – SAND
- T – TRACK
- W – STONE WALL

SCALES: HORIZ 1:500 VERT 1:250

PROJECT TITLE:
DALGETY BAY
COASTAL PROCESSES REVIEW

DRAWING TITLE:
COASTAL SECTIONS
SHEET 2 of 3

CLIENT:
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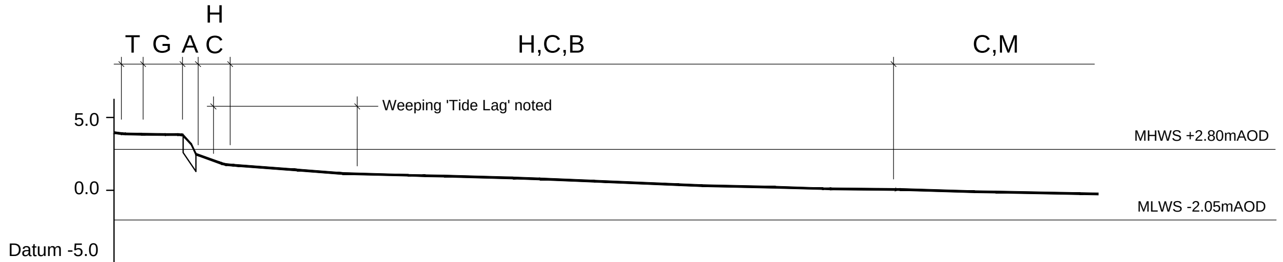
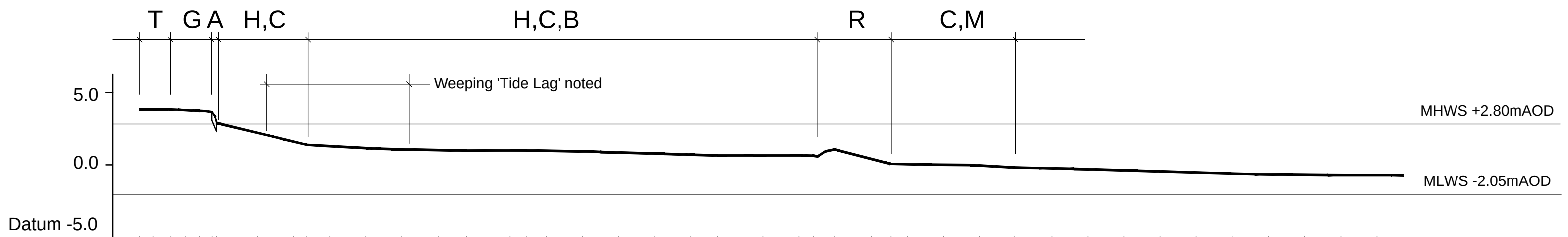
DRAWING No.
23218–rr415–04



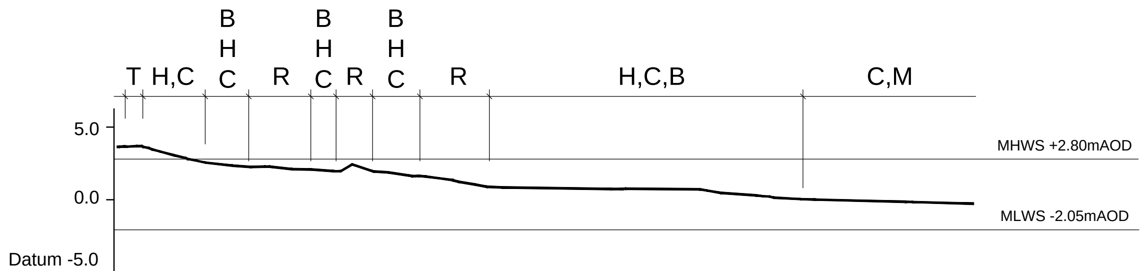
Existing Ground Levels (mAOD)	3.966, 3.849, 3.831, 3.778, 2.481, 1.754, 1.580, 1.389, 1.202, 1.101, 1.032, 0.972, 0.901, 0.828, 0.740, 0.642, 0.541, 0.440, 0.328, 0.261, 0.205, 0.138, 0.088, 0.064, 0.053, 0.016, -0.053, -0.111, -0.162, -0.216, -0.251
Chainage (m)	0.000, 5.000, 10.000, 15.000, 20.000, 25.000, 30.000, 35.000, 40.000, 45.000, 50.000, 55.000, 60.000, 65.000, 70.000, 75.000, 80.000, 85.000, 90.000, 95.000, 100.000, 105.000, 110.000, 115.000, 120.000, 125.000, 130.000, 135.000

Section 9 - From Boatyard Bay to North-East (Chainage 306m)



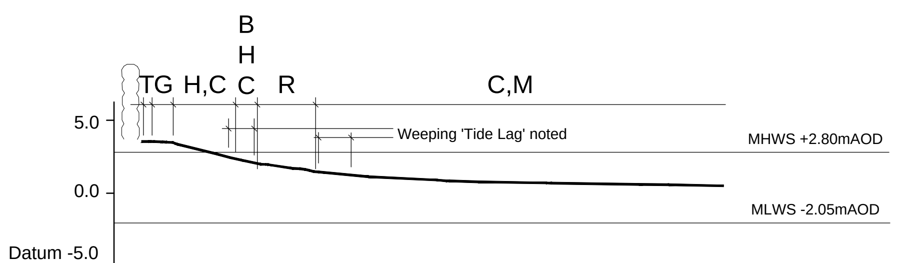
Existing Ground Levels (mAOD)	3.829, 3.826, 3.838, 3.795, 3.742, 3.662, 2.886, 2.201, 1.600, 1.381, 1.288, 1.159, 1.070, 1.021, 0.982, 0.996, 1.001, 0.971, 0.918, 0.852, 0.781, 0.696, 0.637, 0.643, 0.651, 0.618, 1.066, 0.412, 0.063, 0.044, 0.008, -0.049, -0.189, -0.245, -0.314, -0.388, -0.458, -0.528, -0.598, -0.648, -0.673, -0.691, -0.702, -0.720
Chainage (m)	0.000, 5.000, 10.000, 15.000, 20.000, 25.000, 30.000, 35.000, 40.000, 45.000, 50.000, 55.000, 60.000, 65.000, 70.000, 75.000, 80.000, 85.000, 90.000, 95.000, 100.000, 105.000, 110.000, 115.000, 120.000, 125.000, 130.000, 135.000, 140.000, 145.000, 150.000, 155.000, 160.000, 165.000, 170.000, 175.000

Section 10 - From Boatyard Bay to East (Chainage 410m)



Existing Ground Levels (mAOD)	3.649, 3.687, 2.834, 2.556, 2.420, 2.254, 2.280, 2.103, 2.084, 1.965, 2.444, 1.961, 1.713, 1.641, 1.361, 1.248, 1.055, 0.897, 0.837, 0.803, 0.769, 0.737, 0.741, 0.722, 0.421, 0.222, 0.053, -0.026, -0.086, -0.149, -0.224, -0.269
Chainage (m)	0.000, 5.000, 10.000, 15.000, 20.000, 25.000, 30.000, 35.000, 40.000, 45.000, 50.000, 55.000, 60.000, 65.000, 70.000, 75.000, 80.000, 85.000, 90.000, 95.000, 100.000, 105.000, 110.000, 115.000

Section 11 - From Promontary 3 to East (Chainage 460m)



Existing Ground Levels (mAOD)	3.541, 3.541, 3.531, 3.369, 2.571, 2.271, 1.976, 1.690, 1.573, 1.365, 1.131, 1.008, 0.848, 0.788, 0.743, 0.699, 0.659, 0.619, 0.588, 0.541, 0.503
Chainage (m)	0.000, 5.000, 10.000, 15.000, 20.000, 25.000, 30.000, 35.000, 40.000, 45.000, 50.000, 55.000, 60.000, 65.000, 70.000, 75.000, 80.000

Section 12 - From Promontary 3 to North (Chainage 490m)

0m 5m 10m 15m 20m
SCALE 1:250

0m 10m 20m 30m 40m
SCALE 1:500

Original Drawing Size – A1

DESCRIPTION

REV	DATE		DWN	CHK	APP
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NOTES:

1. FOR SECTION LOCATIONS SEE DRG No 02

LEGEND

- A – ARMOUR STONE
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- M – MUD
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- S – SAND
- T – TRACK
- W – STONE WALL

SCALES: HORIZ 1:500 VERT 1:250

PROJECT TITLE:
DALGETY BAY
COASTAL PROCESSES REVIEW

DRAWING TITLE:
SECTIONS
SHEET 3 of 3

CLIENT:
Defence Infrastructure Organisation

amec
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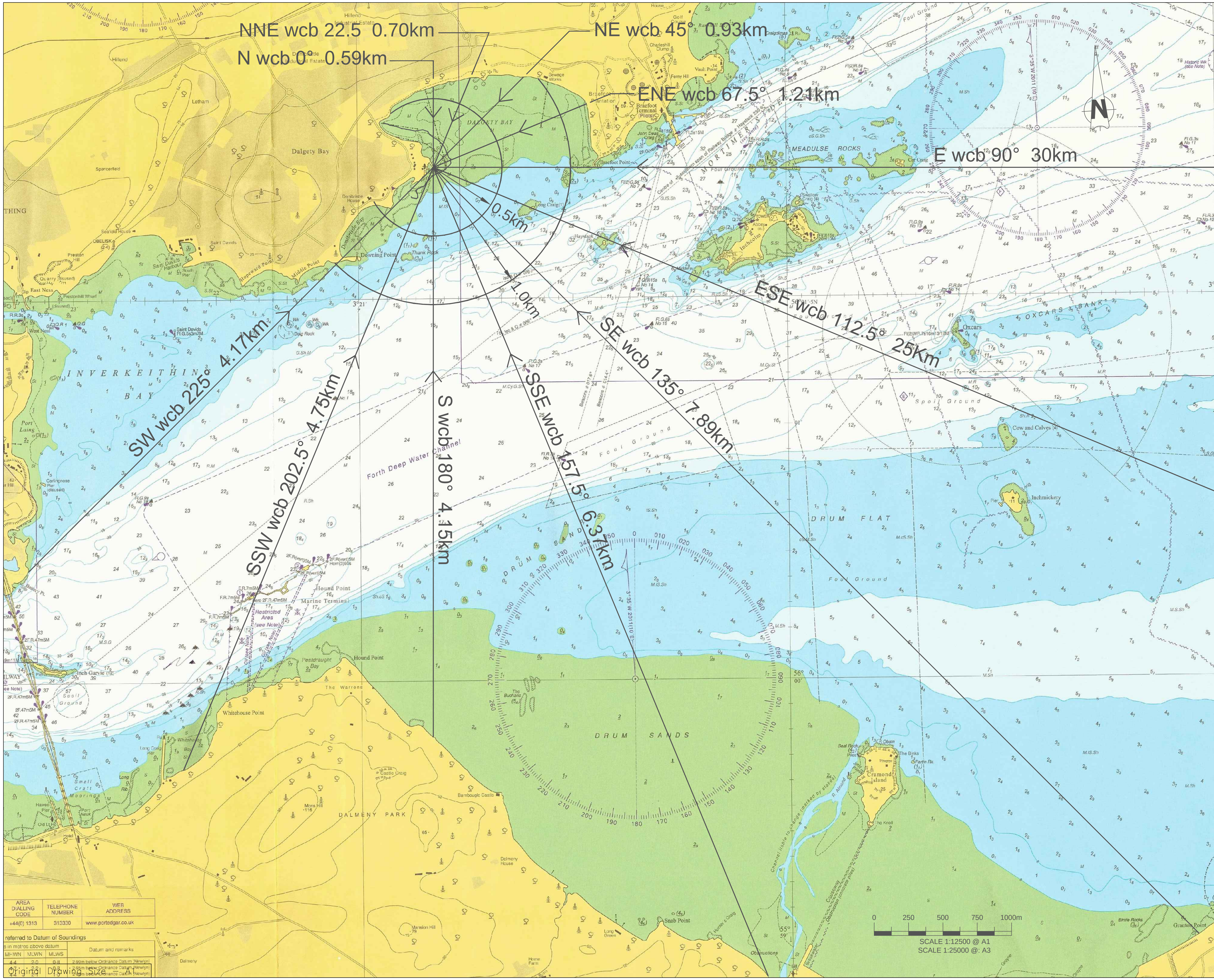

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REV	DATE		DWN	CHK	APP

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COASTAL PROCESSES REVIEW

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DRAWING No.

23218-rr415-06

Appendix B
References

Reference No.	Title	Year	Author
1	Scottish Natural Heritage RSM143 “Coastal Cells in Scotland: Cell 1 – St Abb’s Head to Fife Ness”	2000	Ramsay & Brampton
2	“Fife SMP2 Policy Unit 13 – St David’s Bay to Braefoot Point”	2011	Mouchel
3	“Shore Protection Manual” 4th edition	1984	US Corps of Engineers
4	“The Rock Manual”	2007	CIRIA et al
5	Coastal Engineering Manual	2002	CERC/ US Coastal & Hydraulics Laboratory