Malcolm Rose (Marine Licencing Group Leader) Marine Scotland Licencing Operations Team (MSLOT)	Our ref	171500j/cgf/001

By email only

8 November 2019

Dear Malcolm,

Hunterston Marine Construction Yard Redevelopment
Further Information to Inform Screening Decision

Further to the email of 19 July 2019 (from Kerry Bell to us) we have attached the two final pieces of information to assist you in reaching a screening opinion for the above site. These studies are as follows:

- Marine Mammal Protection Principles: A document describing the approach and principles of protection for marine mammals to avoid likely significant effects; and
- Coastal Hydrodynamic and Wave Assessment: This report presents the findings of pre and post-development hydrodynamic and spectral wave modelling studies, with an assessment of the potential impact of the proposed development on coastal processes, particularly in relation to the adjacent SSSI.

We trust the above two reports now allow you to consult and conclude your screening assessment. Should you wish to discuss these reports or any other aspects of the screening information supplied please contact the undersigned.

Yours sincerely
for EnviroCentre Ltd

(issued electronically)

Dr. Campbell Geo. Fleming **Director**	**Craig Potter** **Principal Environmental Consultant**

Enc: Two reports as described above.

CC: Kerry Bell – MSLOT
Anni Makela – MSLOT
Douglas Coleman – Peel Ports Group

Marine Mammal Protection Principles

Project Overview

The existing marine yard at Hunterston is a facility for constructing large marine structures. Designs have been developed to provide a more functional facility and to minimise/eliminate impacts on the site surrounds. The construction of a jetty will include the removal of the existing rock armour, the installation of a combi-wall via vibratory and impact piling, the installation of anchor walls, via vibratory and impact piling, and tie rods, to facilitate a heavy lifting area. The operation of Hunterston Construction Yard will include an oil decommissioning facility.

A consultation response relating to the proposals was received from Scottish Natural Heritage (SNH)[1] stating that: *There are resident populations of cetaceans (harbour porpoise and common dolphin) and seals in the vicinity of the construction operations. Potential impacts and mitigation proposals should be fully assessed. Potential areas of environmental impact could be assessed as standalone investigations or as part of a formal Environmental Impact Assessment.*

Underwater noise produced by the above construction and operation activities has the potential to cause lethal and sub-lethal effects, and disturbance to marine mammals. The Marine Scotland 'Guidance for Scottish Inshore Waters: The Protection of Marine European Protected Species from Injury and Disturbance' defines what disturbance means to cetaceans as:
'Changes in behaviour which may not appear detrimental in the short-term, but may have significant long-term consequences. Additionally the effects may be minor in isolation, but may become more significant in accumulation'.

Ecological Baseline and Project Background

The site is considered to be ecologically connected to the Inner Hebrides and the Minches [candidate] Special Area of Conservation (cSAC), which is designated for harbour porpoise *(Phocoena phocoena)* due to the high predicted and observed densities of individuals. Although the closest point is approximately 140km to the west of the site, harbour porpoise are protected as features of the SAC whether in the site or not, thus any animals within the zone of influence should be considered to be a part of the SAC.

Previous ecological baseline information collected for the site indicates that the following species have the potential to be affected by the proposed works:

- Harbour porpoise*;*
- Common dolphin *(Delphinus delphis)* including a solitary animal known as 'Kylie' which is known to have been a resident off the coast of Largs and Fairlie for a number of years, and is often seen within a few hundred metres of the development site;
- Minke whale *(Balaenoptera acutorostrata);*
- Bottlenose dolphin *(Tursiops truncatus);*
- Humpback whale *(Megaptera novaeangliae);*
- Killer whale *(Orcinus orca);*
- Harbour seal *(Phoca vitulina);*
- Grey seal *(Halichoerus grypus);* and

[1] Email from SNH to Marine Scotland on 12/04/2019: *RE: URGENT - Peel Ports Group Ltd (per EnviroCentre Ltd) – Hunterston Marine Construction Yard Redevelopment, Hunterston, North Ayrshire – Consultation on Request for Screening Opinion – Response Required by 1 April 2019*

- Basking shark *(Cetorhinus maximus)* (although not a marine mammal, this species is included as the coast of the Isle of Islay, approximately 160km west of Hunterston, is a known basking shark hotspot).

The baseline information will be updated via a desk study, using the following sources of information:

- The Joint Nature Conservation Committee (JNCC)[2,3];
- Seawatch Foundation[4];
- Scottish Natural Heritage (SNH)[5];
- National Biodiversity Network (NBN) Atlas[6];
- Whale and Dolphin Conservation (WDC)[7]; and
- The Hebridean Whale and Dolphin Trust (HWDT) Whale Track[8].

A risk assessment relating to marine mammals has already been undertaken for the site at the project outset[9], however since this was issued the standard National Oceanic and Atmospheric Administration (NOAA) guidelines[10], relating to underwater noise modelling, have been updated.

Proposed Scope of Assessment

The modelling is scheduled to be re-visited in the near future by Irwin Carr[11], who regularly carry out noise measurements and modelling from all projects which generate noise underwater including off shore wind farms, harbour expansions, piling, cable laying or shipping traffic; and the risk assessment will be revised accordingly. The resulting MMPP will be peer reviewed by the University of St. Andrews Sea Mammal Research Unit (SMRU)[12], experts in the field of marine mammal ecology research and consultancy and advisor to the Scottish Government.

The underwater noise model will predict how the noise associated with each method of construction of the jetty would affect each hearing group of marine mammal, focussing on the species most likely to be found in the waters off Hunterston as listed above.

Mitigation measures to protect marine mammals will be designed with reference to the outputs of the underwater noise model; a mitigation zone will be implemented as per the anticipated (modelled) dispersion of the underwater noise. Compilation of a Marine Mammal Observer (MMO) Protocol will then be commenced. This will include the lengths of time that pre-piling searches for marine mammals and machinery soft start procedures are required, with reference to the current JNCC guidance 'Statutory nature conservation agency protocol for minimising the risk of injury to marine mammals from piling noise' (August 2010)[13].

The finalised MMPP will document all proposed mitigation and will be submitted along with any future construction licence application, and any EPS licence application that may be required.

[2] JNCC Statutory Nature Conservation Agency Protocol for Minimising the Risk of Injury to Marine Mammals from Piling Noise (2010) available at: http://jncc.defra.gov.uk/pdf/JNCC_Guidelines_Piling%20protocol_August%202010.pdf
[3] Reid, J B, Evans, P G H, and Northridge, S P. JNCC Atlas of Cetacean Distribution in north-west European waters (2003) available at: http://jncc.defra.gov.uk/page-2713#download
[4] Seawatch Foundation Cetaceans of Western Scotland available at: http://seawatchfoundation.org.uk/wp-content/uploads/2012/07/WesternScotland.pdf
[5] SNH About Scotland's Nature: Marine Mammals available at: https://www.nature.scot/plants-animals-and-fungi/mammals/marine-mammals
[6] NBN Atlas (commercially available records only) available from: https://records.nbnatlas.org/explore/your-area#55.9341301|-3.3103042000000187|12|ALL_SPECIES
[7] WDC species guides available at: http://uk.whales.org/species-guide
[8] HWDT sightings data available at: https://whaletrack.hwdt.org/sightings-map/
[9] EnviroCentre Report 8197 Hunterston Construction Yard Marine Mammal Risk Assessment (2018)
[10] https://www.fisheries.noaa.gov/national/marine-mammal-protection/marine-mammal-acoustic-technical-guidance
[11] https://irwincarr.com/services/underwater-noise/
[12] http://www.smru.st-andrews.ac.uk/
[13] It should be noted that this protocol does not document measures to mitigate disturbance effects, but has been developed to reduce to negligible levels of risk of injury or death to marine mammals in close proximity to piling operations.

EnviroCentre Capabilities and Conclusion

EnviroCentre has worked on several projects of a similar nature to Hunterston Marine Yard; a recent example is an MMPP written for proposed construction works at Nigg East Quay, Moray, which is adjacent to the Moray Firth SAC designated for bottlenose dolphins *(Tursiops truncatus)*. Due to the sensitive nature of the site, marine mammal mitigation was appraised by Professor Paul Thompson of the University of Aberdeen Lighthouse Field Station. It was agreed that proposed mitigation relating to construction works, including vibratory and impact piling and dredging were appropriate, and that the project was unlikely to cause significant effects to bottlenose dolphins, nor harbour porpoise.

It is considered that by developing, and implementing the MMPP that will be designed in reference to site specific underwater noise modelling, significant effects from the proposed construction activities, such as lethal or sub-lethal impacts to marine mammals as a result of underwater noise, can be avoided.

In all of the Marine Construction projects that we have been involved in where marine mammals were required to be considered with reference to underwater noise, Marine Mammal Protection Plans are submitted alongside marine construction licence applications for consideration by the Regulators, as mitigation is well understood, readily implemented, and impacts can be mitigated to a level where impacts would not be significant.

EnviroCentre November 2019

Hunterston Construction Yard
Coastal Hydrodynamic and Wave Assessment

November 2019

Hunterston Construction Yard
Coastal Hydrodynamic and Wave Assessment

Client:	Peel Ports Group
Document number:	8958
Project number:	171500
Status:	Issue
Author:	Martin Nichols
Reviewer:	Dr Kenneth A. MacDougall
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Filename:	191107 Coastal Hunterston Construction Yard

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EXECUTIVE SUMMARY

This assessment investigates the potential effects of proposed development works to upgrade the existing Hunterston Construction Yard on the coastal processes including the tidal regime, wave climate and sediment transport with particular consideration to Southannan Sands Site of Special Scientific Interest (SSSI). The proposed works are within an area where similar activities have occurred in the past and they represent a reworking or extension of these previous activities.

The existing baseline tidal regime, wave climate and sediment dynamics in the vicinity of the proposed development works at the Hunterston Construction Yard have been characterised using available information, supported by coastal modelling.

The MIKE by DHI coastal modelling platform has been used to simulate the coastal hydrodynamics and spectral wave conditions in and around Southannan Sands. The hydrodynamic modelling results indicate that the proposed development will not influence water levels and only produce very localised changes in tidal current speeds. These variations are considered to be insignificant in terms of the wider hydrodynamic regime in and around Southannan Sands.

Wave modelling has demonstrated that under mean conditions there will be negligible change to the wave climate as a result of the development. During storm conditions, the results show only very localised changes to the wave climate, at and in the immediate vicinity of the proposed works.

Informed by the baseline study and the coastal modelling, the assessment concludes that any predicted changes to the tidal regime, wave climate and sediment transport processes will be local to the proposed works and will be relatively minor, resulting in no significant impacts.

Based on the present status of the Southannan Sands SSSI, the recent and anticipated changes do not present a risk or threat to the nature conservation designation interest of the site.

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1 INTRODUCTION

1.1 Terms of Reference

This coastal hydrodynamic and wave assessment has been produced in support of the screening opinion request for Hunterston Marine Construction Yard Redevelopment project to Marine Scotland.

This assessment investigates the potential effect of the proposed dredging extent and coastal works on the coastal processes comprising of tidal movements, wave climate and sediment transport with particular consideration to Southannan Sands Site of Special Scientific Interest (SSSI).

1.2 Scope of Report

The scope of the assessment is as follows:

- Characterise the baseline coastal processes around the proposed development;
- Develop a coastal model to simulate hydrodynamic flow and spectral wave conditions around the site for pre- and post- development conditions;
- Characterise the potential changes to the existing coastal processes regime as a result of the proposed development; and
- Identify what impact any changes may have on the surrounding coastal environment, and in particular, the integrity of the Southannan Sands SSSI.

1.3 Report Usage

The information and recommendations contained within this report have been prepared in the specific context stated above and should not be utilised in any other context without prior written permission from EnviroCentre.

If this report is to be submitted for regulatory approval more than 12 months following the report date, it is recommended that it is referred to EnviroCentre for review to ensure that any relevant changes in data, best practice, guidance or legislation in the intervening period are integrated into an updated version of the report.

EnviroCentre do not accept liability to any third party for the contents of this report unless written agreement is secured in advance, stating the intended use of the information.

EnviroCentre accept no liability for use of the report for purposes other than those for which it was originally provided, or where EnviroCentre have confirmed it is appropriate for the new context.

2 HUNTERSTON CONSTRUCTION YARD

2.1 Site Location

The existing Peel Ports Hunterston Marine Construction Yard, lies on the Firth of Clyde, north of the EDF Hunterston Power Station and west of the Hunterston Coal Terminal as shown in Figure 2.1. The site is adjacent to the Offshore Wind Turbine Test Facility operated by SSE, but is otherwise vacant at present.

The site is reclaimed land that has historically been used for industry and currently comprises an access road, service infrastructure, a deep void (dry dock) with a bund in place and a hammerhead quay.

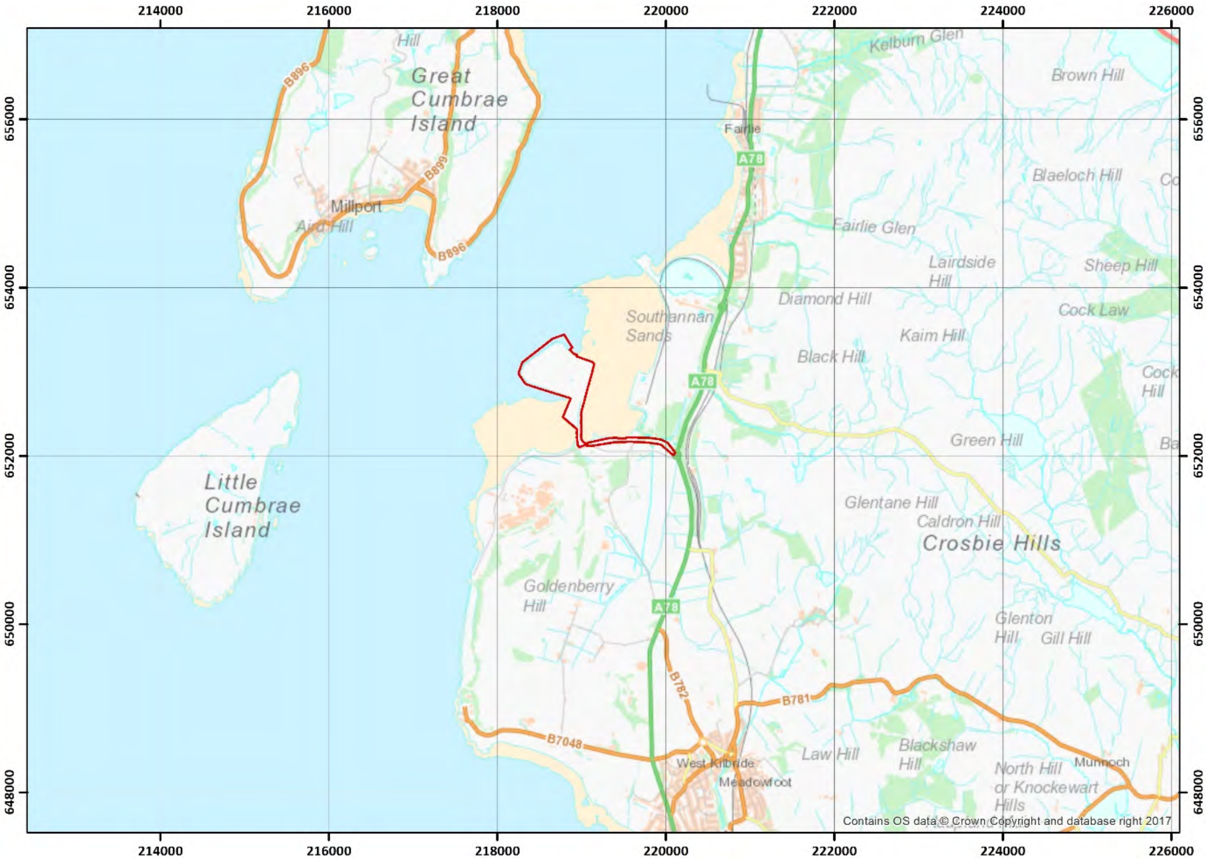


Figure 2.1: Site Location

2.2 Proposed Development

Peel Ports Group are proposing to upgrade the facilities at the Hunterston Construction Yard to enable the continued use of the site for a variety of proposed end uses including construction, repair and subsequent removal on completion, and decommissioning of large marine structures.

The development works include upgrading the quay at the construction yard and a revamped dry dock area with caisson gates to facilitate easier entry of marine assets (Appendix A, Drawing 168612-012). All of these proposed works lie outwith the Southannan Sands of Special Scientific Interest (SSSI).

Dredging to approximately -10 m Chart Datum (CD) at these two locations, with an approximate dredge volume is 615,000 m^3, covering the quay area (423,000 m^3) and the approach to the caisson gates (192,000 m^3), along with construction works to the coastline at the existing quay and western shore of the Construction Yard for the installation of the caisson gates. Two cross sections through the proposed dredging works towards Southannan Sands SSSI are contained in Appendix A (Drawing 171500-002).

The Best Practicable Environmental Option (BPEO) for disposal of the dredge material has identified the following preferred options:

- material re-use as part of the wider site redevelopment; and
- material re-use (partial) at a site along the coast at Ardrossan if dredge and development timings are compatible.

2.3 Background of Historic Industrial Development

The Hunterston Ore Terminal was constructed between 1974 and 1979, which separated Fairlie Sands to the north from Southannan and Hunterston Sands to the south. While the Hunterston Marine Construction Yard was developed to construct oil platforms between 1978 to 1983, which separated Southannan Sands to the north from Hunterston Sands to the south.

The shoreline of Southannan Sands is predominantly formed by an armour stone revetment, apart from the zone between the former coal yard and the Construction Yard, where there is a more natural boundary comprising of a thin strip of salt marsh and maritime grassland.

2.4 Southannan Sands Site of Special Scientific Interest (SSSI)

The Southannan Sands Site of Special Scientific Interest (SSSI) comprises of three discrete areas of sandflats known as Hunterston Sands, Southannan Sands and Fairlie Sands. These discrete areas are separated from each other (south to north) by the presence of the Hunterston marine construction yard and the Hunterston coal terminal conveyor, which extend below the mean low water spring tide.

The SSSI citation describes Southannan Sands as a coastal section that supports one of the best examples of intertidal sandflats habitat within the coastal cell covering the entire Clyde coastline, with the notified natural features being: intertidal marine habitats, saline lagoons and sandflats.

The site was first notified in 1971 as part of Portencross Coast SSSI, then re-notified in 2013 as Southannan Sands SSSI with a reduction in area.

The condition of the SSSI was last assessed in July 2016 and classified as '*Favourable Maintained*' with no negative pressures identified.

The only stated Management Objective in the Site Management Statement for the SSSI produced by Scottish Natural Heritage in 2013 was *"to maintain the extent of the intertidal sandflat habitat by ensuring protection from damaging impacts, in particular any future coastal development"*.

3 BASELINE COASTAL CONDITIONS

3.1 Overview

The baseline conditions at Southannan Sands have been characterised through a review of previous detailed studies undertaken in the area, interpretation of other available data sources and using a numerical coastal model to characterise the hydrodynamic and wave climate and inform the understanding of the sediment transport regime.

A comprehensive characterisation of the coastal processes at Southannan Sands was undertaken in support of the proposed Hunterston Multi-Fuel Power Station in 2010 (Environmental Statement, Chapter 13). The 2010 assessment led by EnviroCentre, included a detailed field study, thorough review of secondary data sources, and development of a MIKE coastal model to develop a robust conceptual model of coastal processes (referred to as the '2010 study' in this report). This has been used to inform the baseline coastal conditions in and around Southannan Sands.

3.2 Bathymetry

The bathymetry of the local area is shown in Drawing 171500-001 (Appendix A) and also in Figure 5.1 and Figure 5.2. Southannan Sands form an extensive area of shallow sublittoral and littoral waters to the north and east of the Construction Yard, which extend out westwards, before dropping steeply into Hunterston Channel down to between -40 to -30 m Ordnance Datum, with similar steep side slopes to the west at Great Cumbrae. Drawing 171500-001 shows two cross sections through the Hunterston Channel in towards Southannan Sands from north-south and west-east directions, clearly defining the character of the area.

3.3 Recent History

The mapped change in the area around Southannan Sands over time is shown in Figure 3.1. Comparison of the mapped low water extents from the Firth of Clyde Admiralty Chart from 1852 through to the present day Ordnance Survey mapping clearly identifies the changes to Southannan Sands brought about by industrial activity that created the Hunterston Terminal, Construction Yard and Nuclear Power Station, and a landward retreat of the low water extent.

Comparison of more recent mapping and the bathymetry data used to develop the coastal model (see Chapter 5), tends to also indicate a slight retreat in the low water, however it is recognised that accurately mapping the extent of mean low water over such an expansive area with shallow gradients is not straightforward.

The coastline at Southannan Sands is also included in the recent National Coastal Change Assessment (NCCA) led by the Scottish Government (Rennie, Hansom & Fitton, 2017; The Scottish Government, 2017). This confirms that there has been negligible change to the coastline of the mean high water spring tide level since the 1970s, which is consistent with the shoreline armouring present along much of the infrastructure in the area. An extract of the coastal conditions is reproduced as Figure 3.2.

Figure 3.1: Review of Mapped Mean Low Water Spring Tide

Figure 6.28: Possible future coastline position in 2050 based on rates between 1970 and Modern MHWS data at Hunterston B Nuclear Power Station. Getmapping are our current providers of Scotland-wide digital aerial imagery© Getmapping plc.

Source: (Rennie, Hansom & Fitton, 2017)

Figure 3.2: Extract from National Coastal Change Assessment covering Hunterston Construction Yard

3.4 Geology

The bedrock underlying Southannan Sands comprises of Devonian sandstone measures, with only one or two localised exposures of rock located close to the high water mark in the east-central sector of Southannan Sands.

At Southannan Sands, there is a large thickness of Pleistocene deposits overlying rock head, which are largely fluvio-glacial in origin. The 2010 investigation included shallow seismic profiling which did not reveal any extensive deposits of muds and sands in the wider area, with most seabed areas indicating the presence of gravelly deposits. The sand deposits that form the seabed over much of the area were interpreted as a thin veneer, a fraction of a metre thick in most places, covering Pleistocene gravel deposits into which the present submarine landscape is cut.

A geological review of available boreholes has been undertaken (enclosed as Appendix B) which indicates that the clay content within the sands has contributed to the relative stability of Southannan Sands.

3.5 Seabed Sediments

Sand is the dominant seabed deposit in the area, with sediments in the north of Southannan Sands being medium sands with exposed cobbles and boulders, while finer sands and some mud are present in the shelter of the Construction Yard.

The 2010 study undertook a comprehensive investigation and assessment of the seabed sediments, which are summarised here within Table 3.1 and Figure 3.3. Sand is the dominant seabed deposit, with the particle size in the northern area of Southannan Sands being slightly coarser than the finer sands to the south of Southannan Sands, in the shelter of the Construction Yard. Gravel was encountered towards the northern extent of Southannan Sands as shell gravel, and also around the mussel beds to the west of the Construction Yard. Finer mud sized sediment was relatively sparse across Southannan Sands with the exception of around the mussel beds and in the areas of the slowest currents, within the dredged area of the Construction Yard quay and around the margins of the southern area of Southannan Sands.

Table 3.1: Summary of Seabed Sediment Type and Distribution from 2010 Study

Bed Sediment	Distribution and Description
Gravel	• In the deep water of the Hunterston Channel gravel is a minor component of the sediment (<1% - 5%) and is all shell dominated. • On the upper, northern slopes off Southannan Sands, there are small zones of mixed shell and lithological gravel, encompassing the exposures of coarse Pleistocene sediments. This gravel deposit is much more extensive on the slopes off Hunterston Sands. • On the outer (northern) Southannan sands there are extensive zones containing a thin layer of cockle/mussel shells over sand. Dense deposits of these shell gravels are found at up to 0.5 m below the bed surface. • On the inner Southannan shore the gravel concentration in the sediment is generally low (<1%). • At most sites sampled, dense gravel deposits were encountered at about 0.3 m or less below the sand bed surface.
Sand	• Sand is the dominant bed deposit in the area. • The sands generally are comprised of well sorted log-normally distributed grain size populations, indicative of the presence of active sand transport processes. These grain populations can be divided by their mean size as shown below (expressed at particle diameter and in phi scale): o <u>Fine sand (<180 µm / 2.5 phi):</u> Particles are easily dispersed into suspension once set in motion and can travel large distances in the water column. The presence of these particles on the seabed is normally indicative of a site conducive to the fallout of fine sand from suspension. o <u>Medium-fine sand (180-220µm / 2.25-2.50 phi):</u> Particles are most easily set in motion by flowing water and are sensitive to energy of the flow in regard to their mode of transport. Under the weak tidal flows of the Hunterston area, bedload transport probably predominates. o <u>Medium sand (>220 µm / 2.25 phi):</u> Particles tend to move near the bed once set in motion (by rolling and saltation), requiring constant high energy conditions to keep them in suspension. The bedload movement that results is much slower than movement in suspension. • Fallout sands are found in the deeper sectors of the Hunterston Channel floor, in the zone sheltered by the Construction Yard, in the dredged zone seaward of the Hunterston Terminal, and in a localised zone on the inner Hunterston Sands. Elsewhere bedload sand predominates. • Sand particles, inspected under the microscope, are seen to be primarily composed of angular and sub-rounded grains of quartz and rock fragments, consistent with local fluvio-glacial sands being the principle source of these deposits.
Mud and Organic Matter	• Mud (sediment <63µm) is generally present at low levels in this environment. • The three areas where muddy sediments are found are: o North east and south west sectors of the Hunterston Channel floor (up to 25% mud) o Mussel bed deposits (>50% mud) o Wave sheltered zone at the Construction Yard and south Southannan Sands (up to 25% mud) • Elsewhere mud forms <10% of the sediment, and in most areas <1%. • The mud comprises approximately 50% silt and 50% clay (range 40-60%). • Organic matter in the sediments is largely associated with the mud fraction. • The only area of elevated organic concentrations is in the over-deepened (dredged) channel off the north shore of the Construction Yard quay, which is floored with a mat of decomposing weed.

Gravel (>2 mm) and coarse substrates
Figure 13.4, 2010 Study

Dominant sand mode (secondary modes shown as text)
Figure 13.5, 2010 Study

Mud (<0.063 mm)
Figure 13.5, 2010 Study

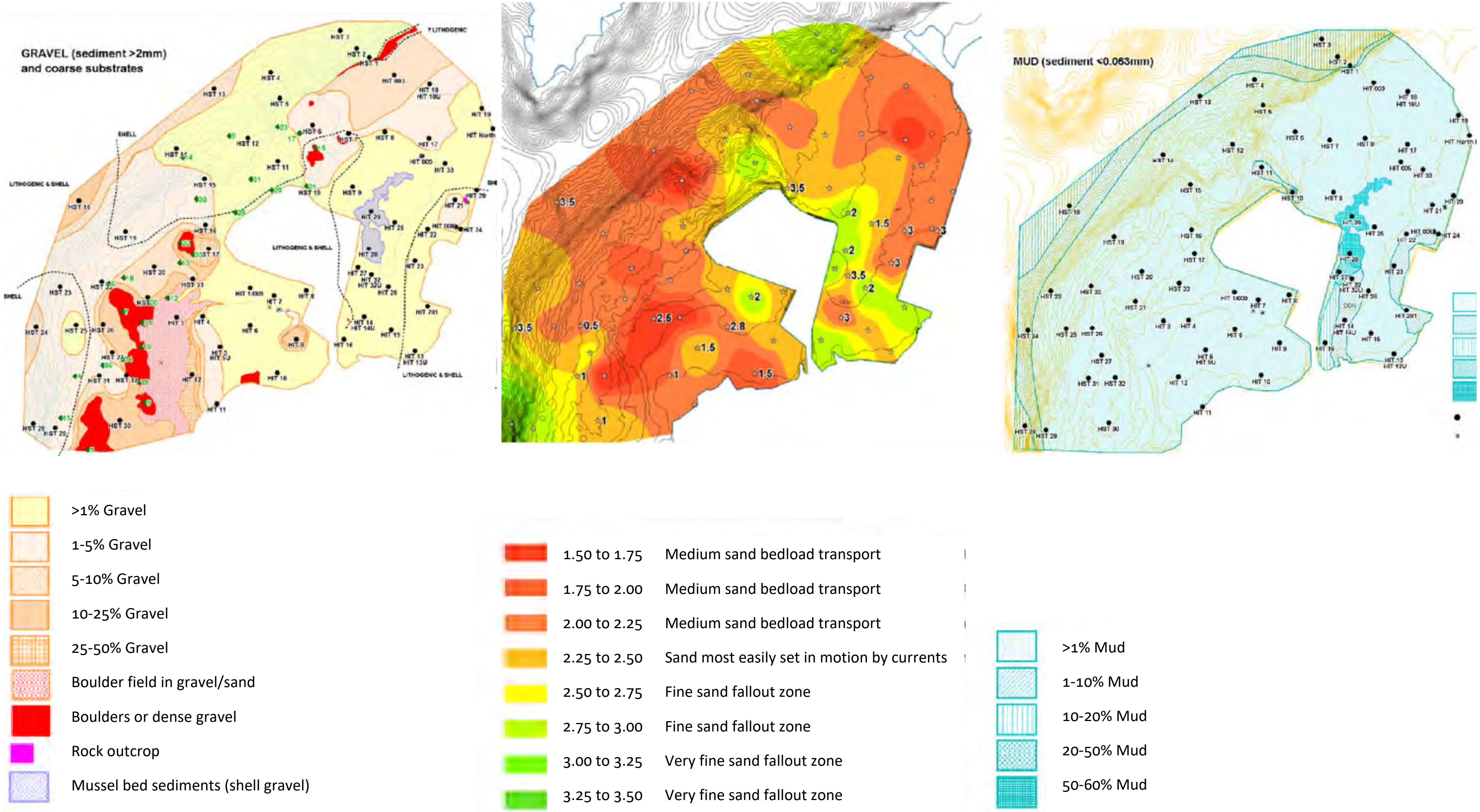


Figure 3.3: Bed Sediment Type and Distribution from 2010 Study

3.6 Tidal Regime

3.6.1 Water Levels

The closest tidal information to Southannan Sands is for Millport, Great Cumbrae, which is less than 3 km away. The astronomical tidal range for Millport from the Admiralty Tide Tables is shown in Table 3.2, where the highest astronomical tide is 3.9 mCD which is equivalent to 2.3 m above Ordnance Datum (AOD).

Table 3.2: Tidal Range at Millport

Tide Condition	Chart Datum (mCD)*	Ordnance Datum (mAOD)**
Highest astronomical tide	3.9	2.3
Mean high water spring	3.4	1.78
Mean high water neap	2.7	1.08
Mean level	1.99	-0.26
Mean low water neap	1.0	-0.62
Mean low water spring	0.4	-1.22
Chart Datum	0.0	-1.62

* Admiralty Tide Tables
** Chart Datum correction for Ordnance Datum is -1.62m (relative to OD at Newlyn)

3.6.2 Tidal Currents

Currents in the study area are primarily driven by the tidal rise and fall, modified to some extent by meteorological conditions (wind forcing, surges). The 2010 study included current monitoring at three locations in and around Southannan Sands, which confirmed that flow velocities in the area were generally low. The distribution of peak flows recorded general values in deep water areas (0.2-0.3 m/s), areas of slacker flows in the shallow bays (<0.2 m/s) and accelerated flow in the narrows between the Hunterston Terminal and the south east point of Great Cumbrae Island (0.7 m/s). The hydrodynamic modelling undertaken in 2010 confirmed these general flow conditions. Further details from the 2019 modelling of the baseline hydrodynamic conditions are contained in Chapter 5.

3.7 Waves

The Firth of Clyde is relatively sheltered from the ingress of large swell waves, however there is a long fetch extending into the Irish Sea from the south-south-west direction. The shelter provides by the surrounding islands in the Firth will limit the wave fetch and reduce the wave energy. Wind waves will have a similar limited fetch, although the direction of the largest fetch is more from a westerly direction.

Waves reaching Southannan Sands will be subject to the processes of refraction and shoaling which will reduce their energy. The effect of these attenuating processes increase in a southerly direction along Southannan Sands.

A more detailed analysis of the baseline wind and wave climate has been undertaken and is provided in Chapter 4, with modelling of these conditions provided in Chapter 5.

3.8 Sediment Dynamics

The local sediment dynamics occurring around Southannan Sands were examined in detail during the 2010 study. The interpretation of the seabed sediment type and distribution provided in Table 3.1 and Figure 3.3 was undertaken along with consideration of recorded current meter readings in the vicinity, drogue tracking, side-scan sonar, aerial photography and hydrodynamic model runs. The summary output figure is presented as Figure 3.4, while the following paragraphs provide an abridged version of the findings.

3.8.1 Bedload Transport

Gravel transport requires high energy conditions, with fine gravel (2 mm) requiring a flow (1 m above bed) exceeding about 0.5 m/s for motion to be initiated. Tidal velocities of this magnitude are not attained within the study area. A wave-induced oscillatory current of about 0.5 m/s is similarly required to move fine gravel. This velocity is achieved under storm wave conditions in water off the outer margins of Southannan Sands.

The result of this intermittent wave action will be to scour emergent Pleistocene deposits and, under the landward residual that exists with flows under shoaling waves, push gravel landwards. This inshore dispersion of gravel is aided by seaweed rafting where seaweed attach to gravel particles and then under storm conditions the drag on the weed overcomes the weight of the stone which then moves landward.

Tidal sand transport as bedload occurs for the medium-fine sands that characterise this area when flow velocity 1 m above the bed exceeds about 0.25 m/s, which equates to a surface flow of 0.4 m/s (as derived from observed near-bed and surface current readings in 2010 study). This 0.4 m/s is considered indicative of conditions where bedload transport of sand might frequently occur and is generally within the Hunterston Channel. Tidal transport due to tide alone will only occur over spring tides and rapid sand transport rates would not be expected, as flows only just exceed the critical thresholds for motion.

The direction of sand transport under refracting/shoaling waves will tend to be at an angle to or normal to the depth contours, particularly in shallow water where refraction is complete, with a marked landward residual for medium-fine sand moving as bedload.

Combined tide/wave sand transport will occur for much of the time, particularly in shallow water. As tidal currents tend to run parallel to the depth contours, and (in shallow water) wave currents normal to them, the two motions will tend not to strongly reinforce or oppose each other. Net transport will be to diffuse sand both upstream and downstream of source areas, with a superimposed long-term landward (wave driven) residual. In deeper water, where refraction is not complete, motion induced by south west waves will tend to preferentially reinforce transport to the north east. Expected transport vectors (black for tide, blue for waves) are plotted in Figure 3.4.

The side-scan sonar survey of the area undertaken as part of the 2010 study identified various bedforms that indicated bedload sand transport. The features ranged from ridges to megaripples, most were quite weak (consistent with intermittent transport or conflicting wave/tide transport) and in a few areas quite strong (but small) forms were noticed. The areas containing these features are plotted in Figure 3.4, and are broadly coincident with the zones of predicted bedload sand transport based on wave and tide characteristics. Intertidally, the aerial photographs identify zones where sand is clearly moving as thin sheets/bars. These zones are plotted in Figure 3.4, and interpreted as resulting from frequently occurring sand transport as a result of the action of wave surge and small amplitude waves that penetrate these areas over the high water period.

Evidence of sand erosion and deposition obtained by comparing the present bathymetry with that mapped in 1852 (Figure 3.1) shows that the low water mark has retreated exposing Pleistocene deposits where previously there was marine sand cover at Brigurd Spit and at the Perch (north of the Construction Yard). At the same time sand has built up along the outer southern shore of the Construction Yard. The changes around the

Construction Yard are consistent with a natural south to north movement of sand on the outer intertidal, where the development of the Construction Yard and approach channel have cut off the supply of sand to the north, and are trapping sand to form a growing accumulation along the southern edge of the Construction Yard. If these changes have taken ~40 years, the indication is that sand bedload transport rates are relatively slow, consistent with the predictions based on wave and tide conditions.

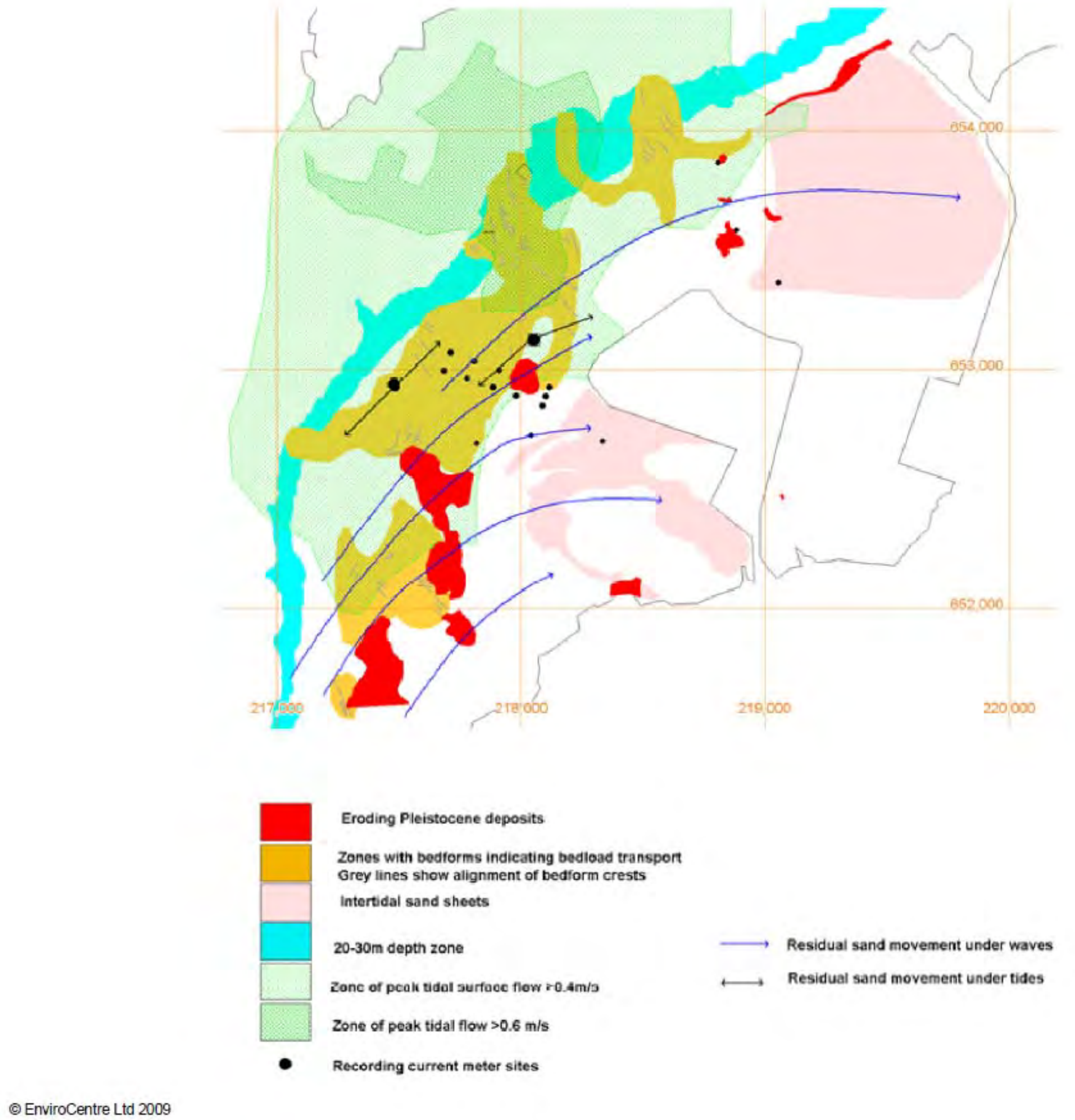


Figure 3.4: Indicators of bedload transport of sand

3.8.2 Accumulation from Suspension

Fallout sand (fine and very fine sand <180µm) is generated at all sites of erosion and attrition within the area, and is rapidly transported in suspension to accumulate in areas where, due to over-deepening or the presence of sheltered conditions, it may accumulate unhindered. These deposits occur naturally in the deeper waters of the Hunterston Channel, and they appear to be an active recent deposit within the intertidal area where they have infilled the former dredge zone at the entrance to the Construction Yard, accumulated in a deeper zone along the southern side of the Construction Yard (created by the construction of the Yard) and accumulated in the wave sheltered area of Southannan Sands, east of the Hunterston Construction Yard.

Approximately 0.2 to 0.3 m of this material (Figure 3.5) appears to have accumulated in the sheltered waters behind the Construction Yard over the ~40 years following construction, an accumulation rate of about 5 mm per year. The rate of movement and accumulation of this material in this area appears to equal or greater than that of coarser (bedload) sands.

Mud is not widely present in the bed sediments of the area which may reflect absence of local mud sources. As mud deposits occur in 'quiet' sites, such as wave-sheltered or deep water sites, it is likely that local wave energy is also responsible for the general absence of mud in the sediments. The development of the Construction Yard has modified the characteristics of the sediments accumulating on inner Southannan Sands, allowing a veneer of fine sand and mud to build up over the previously existing bed of coarser shelly gravelly sands and supporting an actively accumulating mussel mud.

Figure 3.5: Fine Sand and Mud Deposits (0.2 m) Overlying Previous Beach Surface of Shelly Sand

3.8.3 Comparison of Bathymetric Surveys

The original design drawings of the dredge zone of the Quay at the Construction Yard have been reviewed and the dredge zone extended down to -6 mAOD (-4.38 mCD). The most recent bathymetric survey of this area has been used to compare the present bed levels with the original design dredge level as shown in Drawing 171500-003 (Appendix A). The dredge area extends to 32,000 m² and the difference in volume between this and the present bed level is 9,800 m³. The typical change in depth is between 0.0 – 0.6 m, with an average of 0.31 m across the area, with the largest changes observed along the quayside and at the eastern end of the dredge area, where tidal velocities will be lowest. Assuming the last dredge was sometime between construction (~1980) and last active use (~1995), this indicates an average accumulation rate of around 10 mm per year.

4 WAVE, WIND AND WATER LEVEL DATA

4.1 Overview

The coastal wave, wind and water level climate has been characterised through sourcing of various datasets, which have then been processed and analysed.

Offshore wave and wind data has been obtained from the DHI Metocean Data Portal (DHI, n.d.) for an offshore location in the outer Firth of Clyde (55°07'03.6"N 5°22'49.0"W), as shown in Figure 4.1 and Figure 4.2. The offshore location is approximately 75km south-west of the Hunterston Marine Yard. The DHI Metocean Data Portal provides global hindcast wave and wind data, as well as various analytics of these datasets.

Additionally, hindcast tidal water level data has been obtained from the DHI Global Tide Model for the southern model boundary.

Further details on the wave, wind and water level data obtained are presented in the following sections.

4.2 Offshore Wave Data

Hindcast offshore wave data has been obtained from the DHI Metocean Data Portal for location 55°07'03.6"N 5°22'49.0"W, covering the period 27/02/1999 to 28/02/2019. The data is derived from the DHI North Europe MIKE 21 Spectral Wave Model, the extent of which is shown in Figure 4.1, with the data extraction location shown in more detail in Figure 4.2.

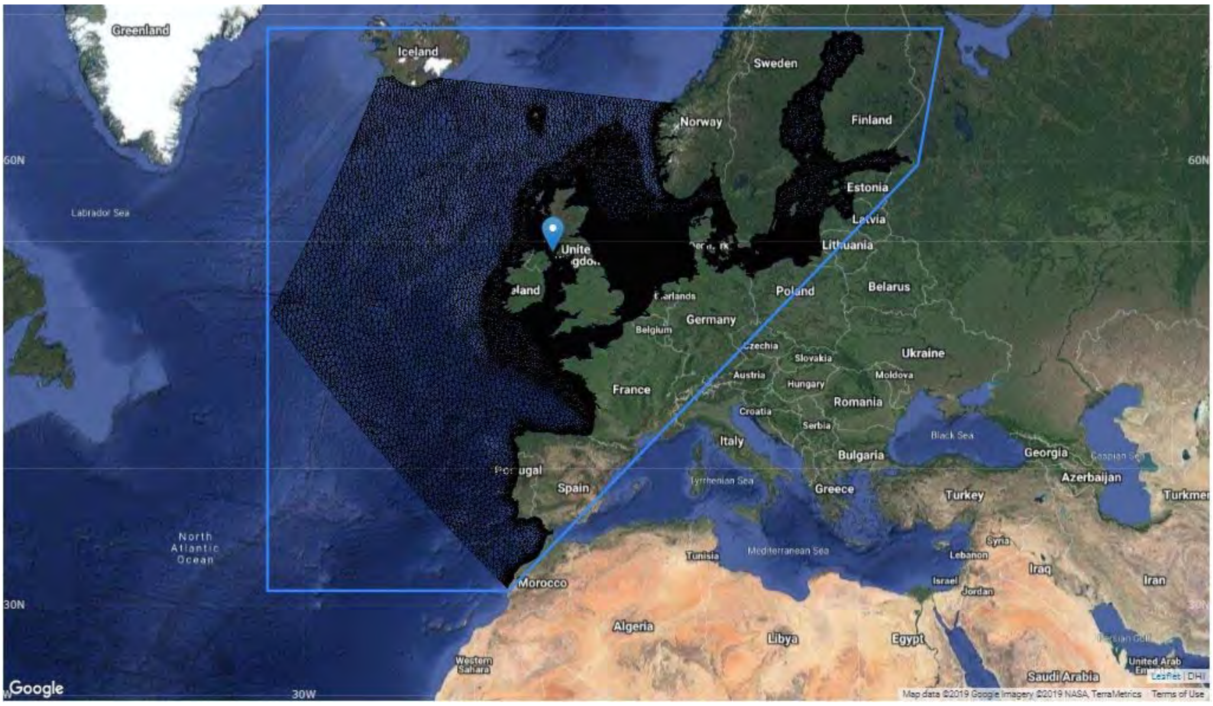


Figure 4.1: DHI North Europe MIKE 21 Spectral Wave Model Extent (Hindcast Data Location – Blue Pin)

Figure 4.2: DHI North Europe MIKE 21 Spectral Wave Model Mesh (Hindcast Data Location – Blue Pin)

The hindcast wave data includes the following components:

- Significant wave height (Hm0);
- Peak wave direction (PWD);
- Peak wave period (Tp);
- Mean wave period (T01);
- Zero-crossing wave period (T02);
- Mean wave direction (MWD); and
- Directional standard deviation (DSD).

The data is summarised in the form of maximum, median and minimum values of key components in Table 4.1. Further analysis of the data is presented in the following figures. Figure 4.3 presents a time-series plot of hindcast significant wave height during the period February 2018 to February 2019. Figure 4.4 shows the directional frequency of significant wave height, highlighting the complete dominance of waves from the 180° and 300° sectors. Given the orientation of the Firth of Clyde, and the position of Hunterston to the north-east of the offshore wave location, the 180 degree sector is therefore considered the key wave sector. Figure 4.5 presents a histogram plotting significant wave height against peak wave direction, again highlighting the dominance of 180° and 300° sectors. Figure 4.6 shows a comparison of DHI wave model values versus altimeter values.

Table 4.1: Summary of DHI Hindcast Wave Data by Directional Sector

Wave Component	180° Sector			300° Sector		
	Max. Value	Med. Value	Min. Value	Max. Value	Med. Value	Min. Value
Significant wave height (Hm0) - Metres	4.97	1.10	0.08	5.55	0.79	0.07
Peak wave period (Tp) - Seconds	19.96	6.68	1.80	19.84	9.50	1.84
Mean wave period (T01) - Seconds	8.51	4.52	1.65	11.62	5.20	1.80
Zero-crossing wave period (T02) - Seconds	7.92	3.95	1.41	10.37	4.17	1.45
Mean wave direction (MWD) - Degrees	195	177	165	315	297	285
Directional standard deviation (DSD) - Degrees	79.5	35.5	8.1	80.4	26.6	8.7

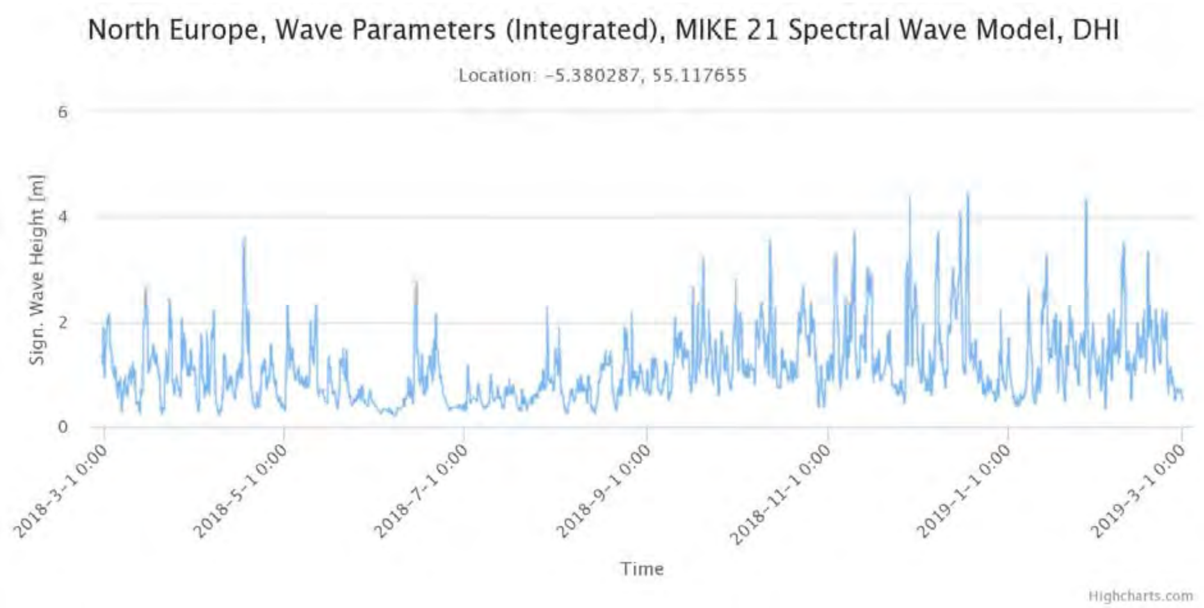


Figure 4.3: Significant Wave Height Time-Series (Feb 2018 – Feb 2019) for Hindcast Data Location

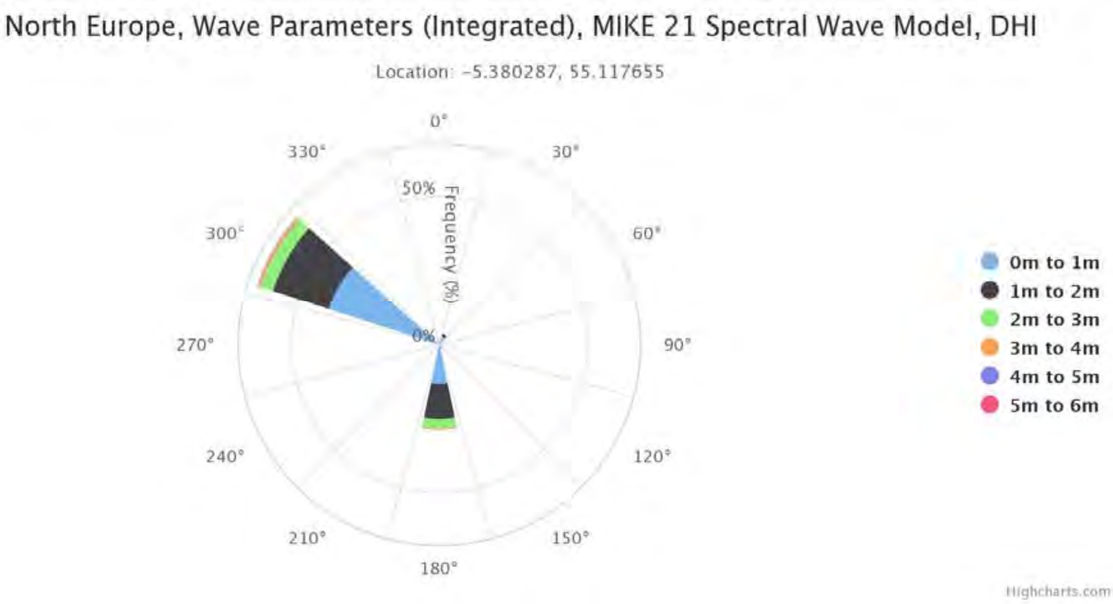


Figure 4.4: Wave Rose Showing Significant Wave Height by Directional Sector for Hindcast Data Location

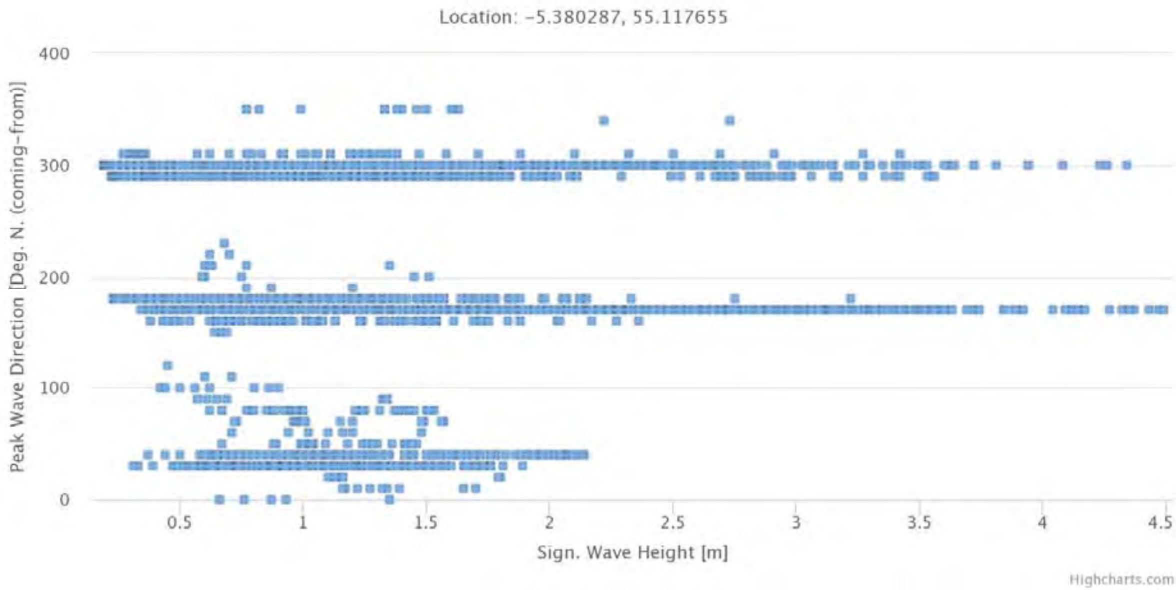


Figure 4.5: Histogram Showing Significant Wave Height vs Peak Wave Direction for Hindcast Data Location

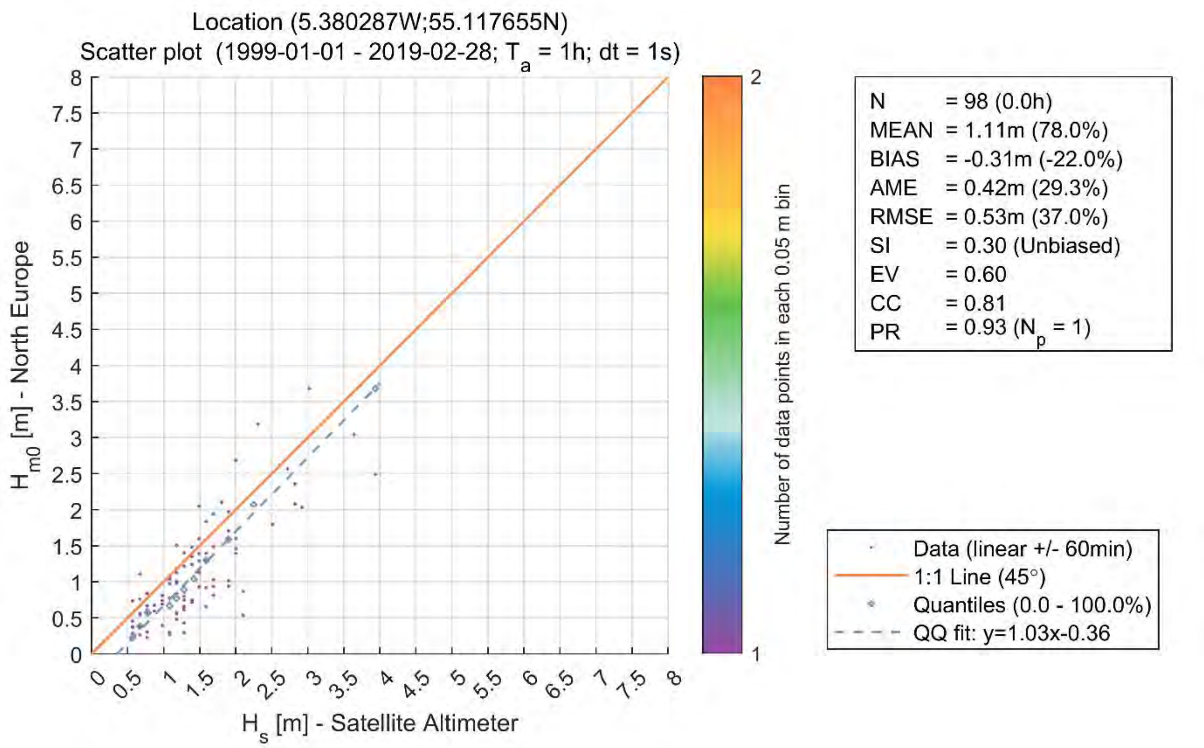


Figure 4.6: Comparison of DHI Wave Model with Satellite Altimeter Values

4.3 Wind Data

Hindcast wind data has also been obtained from the DHI Metocean Data Portal for both the offshore location 55°07'03.6"N 5°22'49.0"W, and for Hunterston Construction Yard, covering the period 01/01/1979 to 31/05/2019. The data is derived from the NCEP NOAA Climate Forecast System Reanalysis (CFSR) Global Wind Model. The hourly data includes the following components:

- Wind Speed at 10m (WS10), [m/s]
- Wind Direction at 10m (WD10), [Deg. N. (coming from)]
- Air Pressure at Mean Sea Level (Pair), [hPa]
- Air Temperature at 2m (Tair2m), [°C]
- Clearness (Clearness), [%]
- Downward SW Radiation (DSWR), [W/m^2]
- Ice Concentration (icecon), [%]
- Sea Surface Temperature (SST), [°C]

A summary of the wind speed and direction data is presented in Table 4.2, whilst Figure 4.7 and Figure 4.8 present wind rose diagrams showing wind speed by directional sector for the offshore hindcast location (as shown in Figure 4.2) and at the nearshore hindcast at the Hunterston Construction Yard respectively. This analysis highlights the predominant wind direction for higher wind speeds is from 270°, whilst the 180° through to 330° sectors are also significant.

Table 4.2: Summary of Hindcast NCEP NOAA Wind Data

Wind Component	Offshore Location			Hunterston Construction Yard		
	Max. Value	Med. Value	Min. Value	Max. Value	Med. Value	Min. Value
Wind Speed at 10m (m/s)	28.6	6.1	0	33.1	6.3	0
Wind Direction at 10m (Degrees)	360	210	0	360	211	0

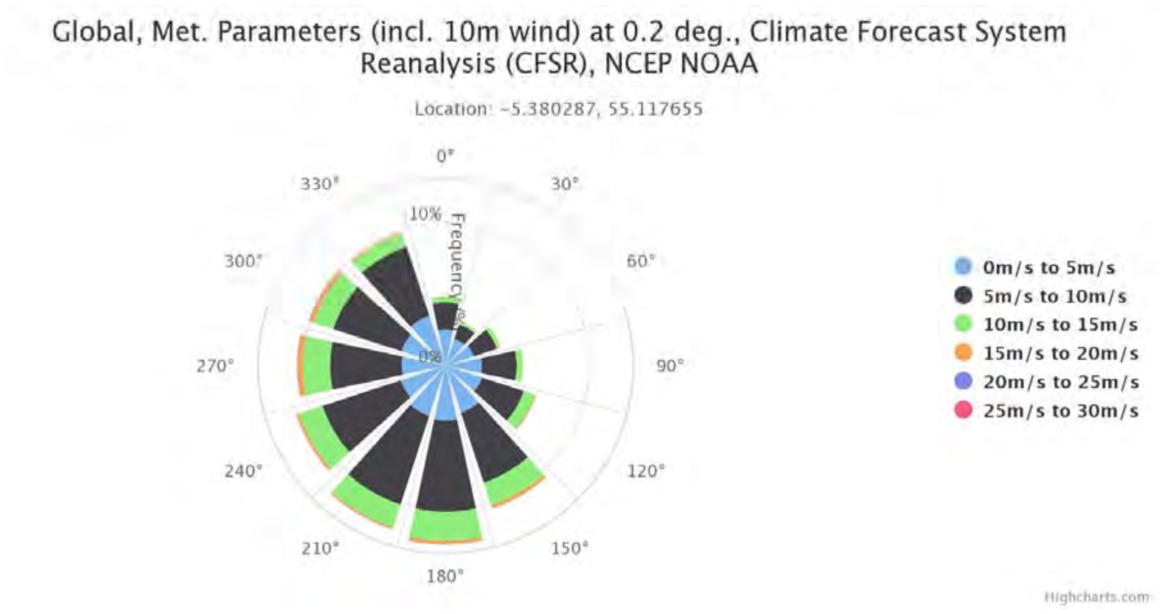


Figure 4.7: Wind Rose Showing Wind Speed by Directional Sector for Offshore Hindcast Data Location

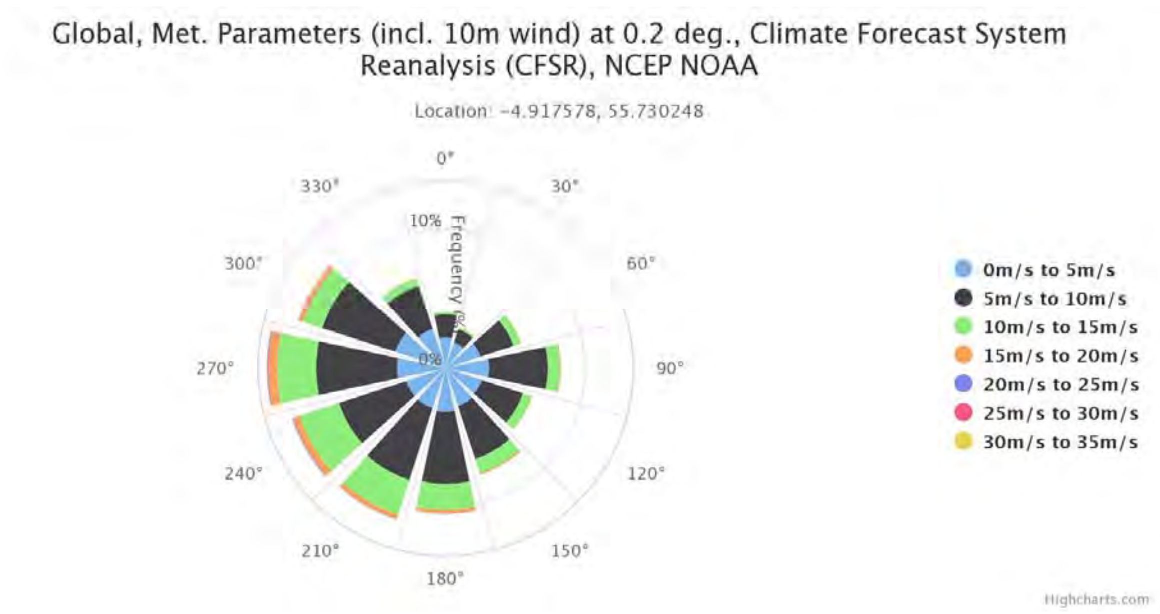


Figure 4.8: Wind Rose Showing Wind Speed by Directional Sector at Hunterston Construction Yard

4.4 Water Level Data

Hindcast tidal water level data has been obtained from the DHI global tide model for the period 1st January 2019 to 2nd February 2019. This data set covers a full tidal cycle of spring and neap tides, including large spring tides extending above MHWS and below MLWS. A graphical representation of the DHI Global Tide Model data is shown in Figure 4.9.

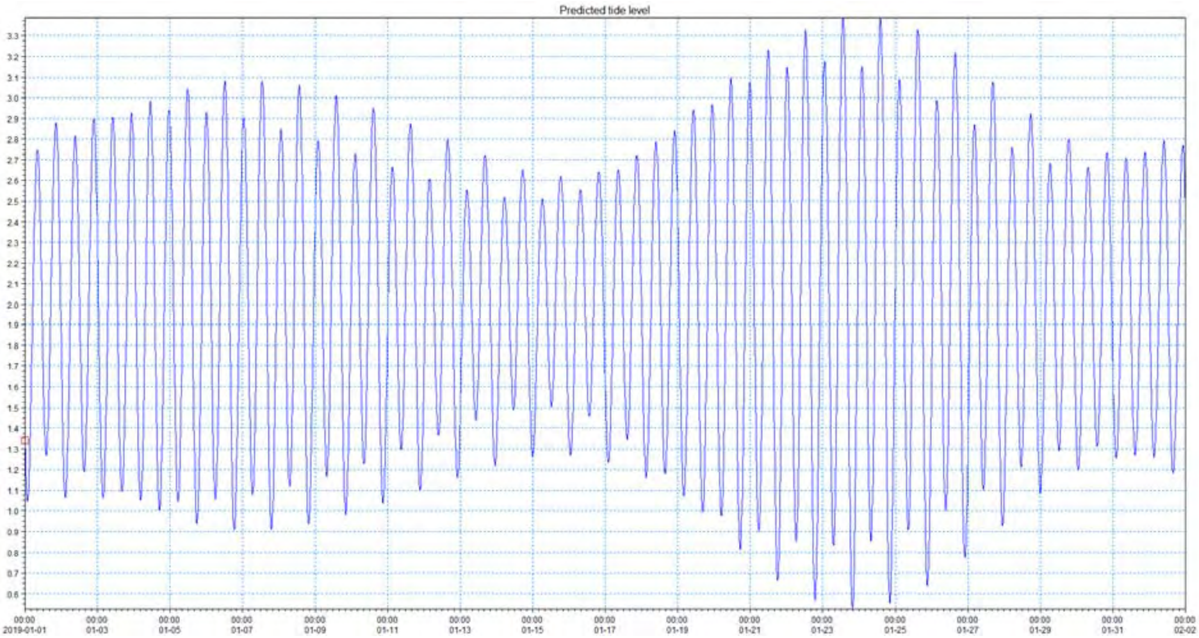


Figure 4.9: DHI Global Tide Model – Tidal Profile at Location on Model Boundary (mCD)

4.5 Extreme Value Analysis

4.5.1 Tidal Water Level

Extreme sea levels have been predicted around the whole UK coastline and published by the Environment Agency as the Coastal flood boundary (CFB) conditions for the UK: Update 2018 (Environment Agency, 2019). These extreme levels include the effects of both tides and storm surge, and the effects of amplification within estuaries and sea lochs. The extreme sea levels, predicted at a point adjacent to Hunterston Sands, are 3.39 mAOD for the 1 in 50 year return period event and 3.65 mAOD for the 1 in 200 year return period event, as presented in Table 4.3.

Table 4.3: CFB Extreme Sea Levels Hunterston (CFB Location 2199)

Return Period (Years)	Water Level (mAOD)	Water Level (mCD)
1	2.67	4.29
2	2.79	4.41
5	2.96	4.58
10	3.09	4.71
25	3.26	4.88
50	3.39	5.01
100	3.52	5.14
200	3.65	5.27
1000	3.97	5.59

4.5.2 Offshore Wave Height

An extreme value analysis (EVA) has been undertaken utilising the in2extRemes package for the R software environment (Gilleland & Katz, 2016). The in2extRemes R package is a specialised EVA software for weather and climate applications developed by the National Center for Atmospheric Research (NCAR), Boulder, Colorado.

The EVA process involves determining Annual Block Maxima values (by calendar year) for the dataset of interest, then fitting a Generalized Extreme Value (GEV) distribution function to the block maxima dataset. The GEV fit is analysed through review of diagnostic plots. From the GEV fit it is possible to obtain return level estimates for the parameter of interest, along with their normal approximation confidence intervals (95%).

The EVA has been undertaken using the block maxima method for the key 180 degree directional sector. Table 4.4 presents a summary of the return period significant wave heights for this sector. Figure 4.10 presents a summary of the EVA GEV fit diagnostics, including a plot of return period significant wave height.

Table 4.4: Significant Wave Height (Hm0) Extreme Value Analysis (180° Sector)

Estimate	Significant Wave Height (m) by Return Period (years)						
	1	**2**	**5**	**10**	**25**	**50**	**200**
Lower confidence	2.88	3.69	4.15	4.36	4.51	4.55	4.54
Central Estimate	3.22	3.95	4.41	4.62	4.83	4.95	5.12
Upper confidence	3.55	4.21	4.66	4.89	5.16	5.36	5.70

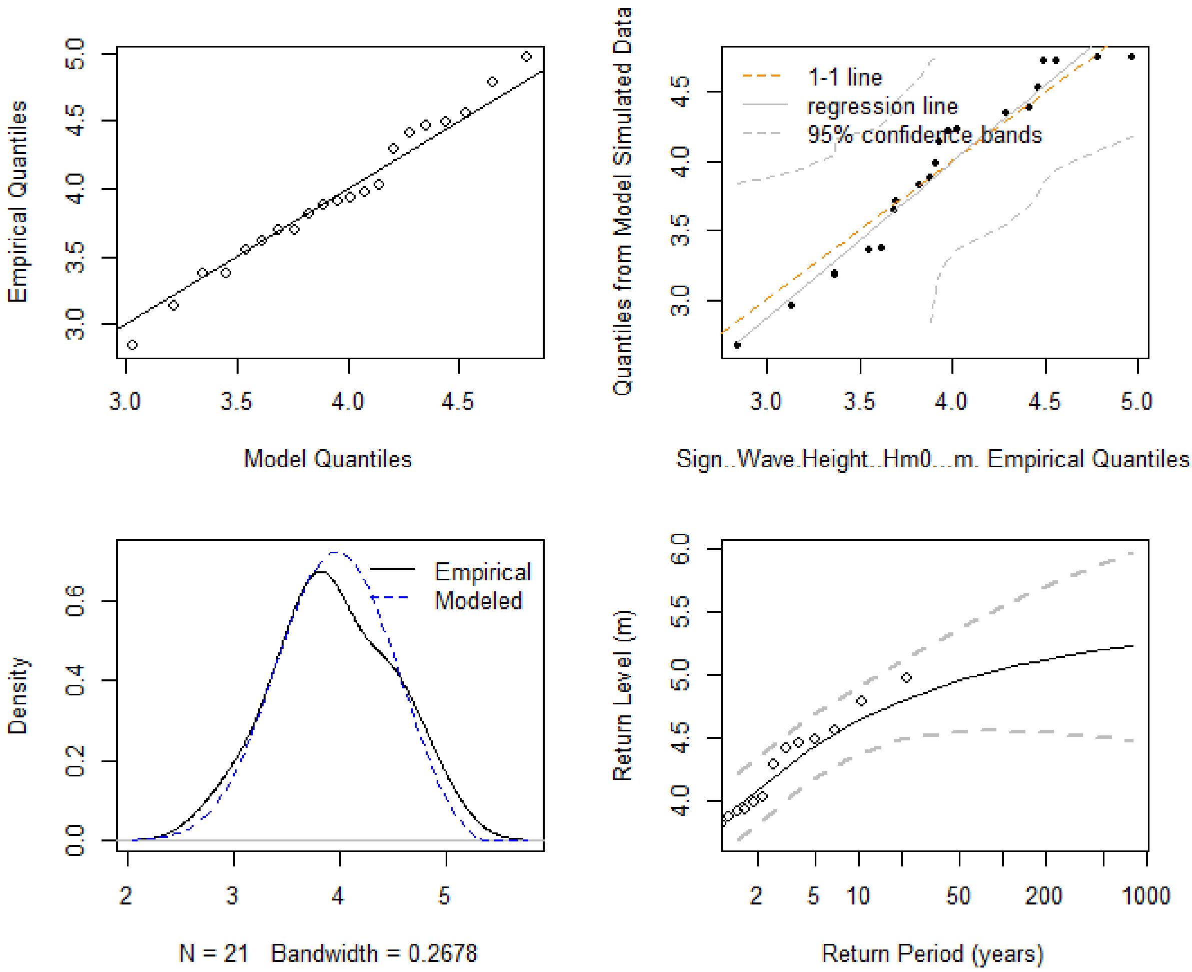


Figure 4.10: EVA Fit Diagnostics for 180° Significant Wave Height at DHI Offshore Hindcast Location

4.5.3 Wind Speed

An EVA has been undertaken on the whole spectrum NCEP NOAA wind dataset described in section 4.3, utilising the in2extRemes package for the R software environment (Gilleland & Katz, 2016).

The EVA process involves determining Annual Block Maxima values (by calendar year) for the dataset of interest, then fitting a Generalized Extreme Value (GEV) distribution function to the block maxima dataset. The GEV fit is analysed through review of diagnostic plots. From the GEV fit it is possible to obtain return level estimates for the parameter of interest, along with their normal approximation confidence intervals (95%). Table 4.5 presents a summary of the EVA by directional sector for key return periods, showing that the highest wind speeds occur from the 270° sector, whilst Figure 4.11 shows the associated fit diagnostics including confidence intervals for the 180° sector.

Table 4.5: Summary of EVA Return Period Directional Wind Speed at DHI Offshore Hindcast Location

Return Period (Years)	Wind Speed at Offshore Hindcast Location (m/s)					
	180°	210°	240°	270°	300°	330°
1	15.8	14.7	15.6	17.2	16.6	14.3
2	18.4	18.3	19.8	20.2	19.9	17.2
5	20.3	21.0	22.6	22.7	21.8	19.5
10	21.4	22.5	24.1	24.3	22.7	20.9
25	22.5	24.2	25.6	26.1	23.5	22.5
50	23.3	25.4	26.6	27.4	23.9	23.6
200	24.4	27.2	28.0	29.8	24.4	25.5

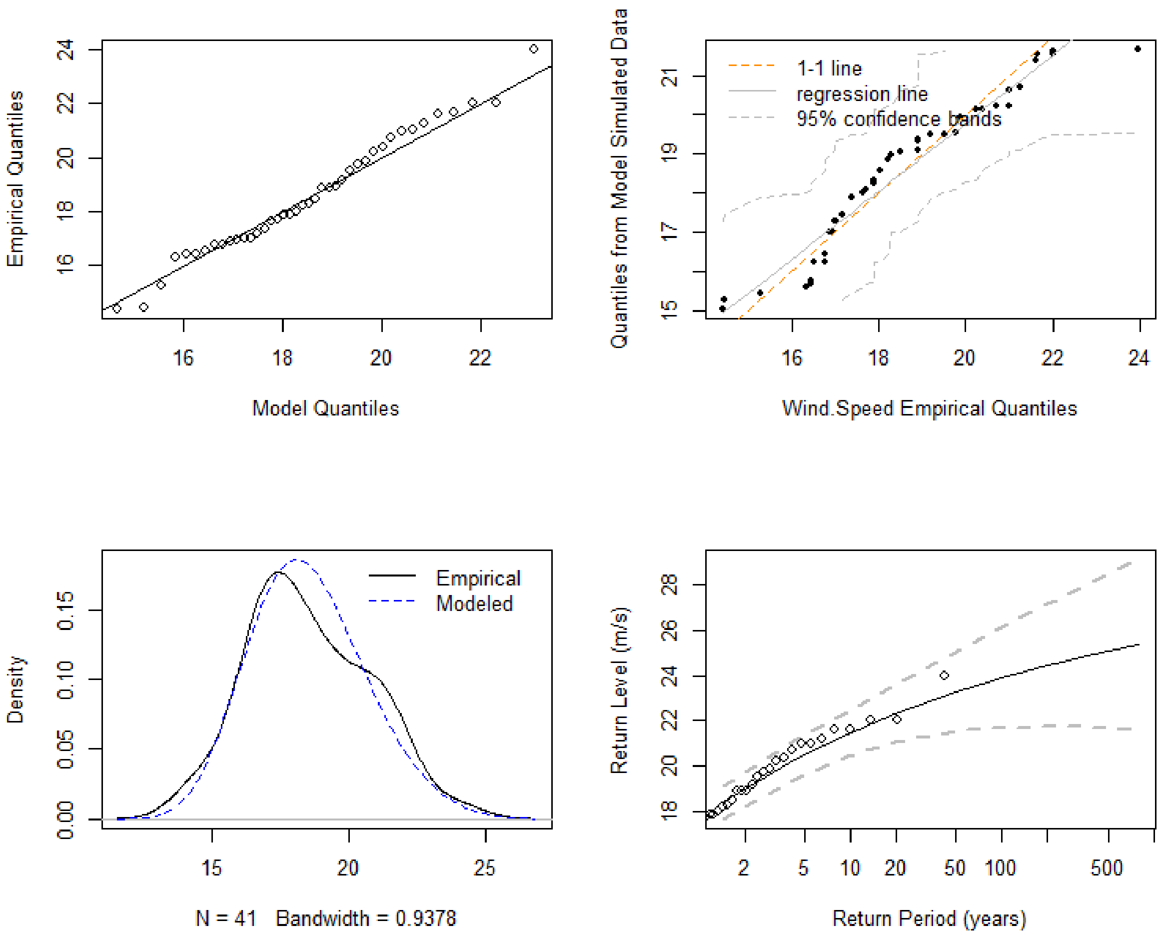


Figure 4.11: EVA GEV Fit Diagnostics for 180° Wind Speed at DHI Offshore Hindcast Location

4.6 Joint Probability of Extreme Values

4.6.1 Joint Probability Methodology

Joint probability analysis is used to predict the probability of occurrence of events in which two or more partially dependent variables have high or extreme values. The DEFRA Join-Sea joint probability methodology (Hawkes, 2005a) has been used to define appropriate extreme conditions for this project. The desk study approach adopted relies on correlation parameters for combinations of variables including sea level and wave height.

The following steps are involved in the application of the methodology:

- Select the variables and any conditions attached to those variables;
- Decide how the variables will be represented;
- Obtain extreme values for each variable;
- Obtain the level of dependence between the variables;
- Apply the desk study approach; and
- Apply the results of the desk study approach.

4.6.2 Dependence of Variables

In order to apply the Join-Sea joint probability method it is necessary to evaluate the dependence between the parameters of interest. For sea level and wave height these dependencies have been computed within the DEFRA Join-Sea joint probability report around the mainland of the UK in the form of correlation parameters, as shown in Figure 4.12.

The Join-Sea guidance (Hawkes, 2005b) highlights that where wave transformation modelling is being undertaken as part of the study, then an offshore joint probability analysis is preferable in the absence of detailed nearshore wave conditions. For offshore joint probability analysis the dependence is purely meteorological, and therefore representative of a larger area. Therefore in the case of this study, in the absence of nearshore wave measurements, and with wave transformation modelling being undertaken, it is considered that offshore joint probability analysis is preferable.

As outlined in section 4.2, offshore hindcast data has been obtained. This offshore data location is positioned within an area where wave height and sea level are considered to be strongly correlated (Millport - Figure 4.12), and a correlation coefficient (ρ) of 0.55 is specified.

When generating wave transformation simulations the extreme value analysis undertaken on the offshore wind data will be used to provide the concurrent wind data i.e. co-incident occurrence of 5 year return period wave and wind. Model sensitivity to wind direction will be considered, with model runs undertaken to examine the impact of varying wind and wave directions.

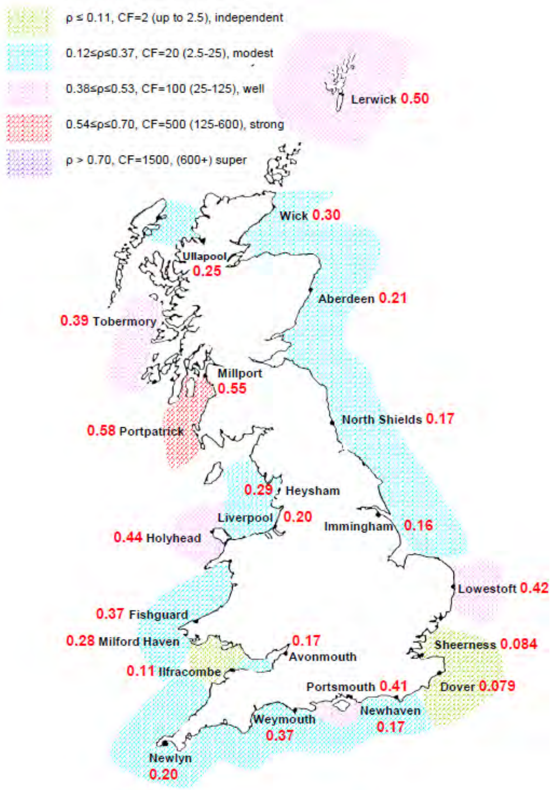


Figure 4.12: Join-Sea sea level and wave height correlation parameters

4.6.3 Combined Offshore Extreme Water Level and Waves

Joint probability calculations have been undertaken with use of the DEFRA spreadsheet model, with calculated extreme values of water level and significant wave height required as inputs. The output is a series of combinations of water level and wave height with the specified joint probability of exceedance, as shown in Table 4.6 and Table 4.7. It is assumed that directional wind speed with the return period of the waves will also occur at the same time as the joint wave and water level event. All return period values of less than 1 year have also been derived by extrapolation in the DEFRA JPA spreadsheet model.

Table 4.6: Extreme Sea Level and Waves Joint Exceedance Return Period – Marginal Return Periods

Marginal return period for present-day sea level (years)	Joint Return Period (Years)					
	2	5	10	25	50	200
	Marginal return period for offshore significant wave height (years)					
0.16	0.52	1.91	5.07	18.45	49.05	200.00
0.5	0.17	0.61	1.62	5.90	15.69	110.93
1	0.08	0.30	0.81	2.95	7.85	55.46
2	0.04	0.15	0.41	1.48	3.92	27.73
5		0.06	0.16	0.59	1.57	11.09
10			0.08	0.30	0.78	5.55
25				0.12	0.31	2.22
50					0.16	1.11
200						0.28

Table 4.7: Joint Exceedance Return Period Extreme Sea Levels and Waves

Present-day sea level (mAOD)	Joint Return Period (Years)					
	2	5	10	25	50	200
	Offshore Significant Wave Height (m)					
2.32	2.54	3.90	4.41	4.76	4.95	5.12
2.53	1.34	2.70	3.73	4.46	4.72	5.05
2.67	0.61	1.97	3.00	4.15	4.55	4.96
2.79	0.20	1.24	2.27	3.63	4.29	4.85
2.96		0.27	1.30	2.66	3.69	4.64
3.09			0.57	1.93	2.96	4.44
3.26				0.97	2.00	4.00
3.39					1.27	3.33
3.65						1.87

4.7 Future Climate

4.7.1 UK Climate Projections

The UK government has published a range of climate projection reports and data for use in the assessment of climate change risks to help plan adapting to a changing climate. The latest set of comprehensive reports produced by UK Climate Projections (UKCP18) was published in 2018 and provides future climate projections for land and marine regions as well as observed (past) climate data for the UK.

The climate projections are presented for a range of different scenarios or Representative Concentration Pathways (RCPs), which reflect different assumptions on future economic, social and physical changes to our environment that will influence climate change. The UKCP18 predictions for carbon dioxide concentrations, along with resulting changes in global mean surface temperatures for the three main RCP scenarios are shown in Figure 4.13.

Under the United Nations Climate Change Paris Agreement the UK is committed to attempt to hold the increase in global average temperature to well below 2°C above pre-industrial levels and to pursue efforts to limit warming to 1.5°C. These targets are in line with those allowed for within RCP 2.6, or the lower end of RCP 4.5, in terms of median global temperature increase by 2100. In terms of Scottish guidance, the Scottish Environment Protection Agency (SEPA) advise that when considering flood risk, a precautionary approach should be adopted and the UKCP18 RCP 8.5 (95^{th} percentile) scenario should be considered.

The RCP predictions for mean sea level change based on an average of UK ports, along with the spatial pattern of sea level change around the UK coastline at year 2100 is shown in Figure 4.14. Review of these predictions highlights that Hunterston is within a zone of lower sea level change in a UK context.

4.7.2 Tidal Water Levels

The UKCP18 future projections of relative sea-level rise were obtained for Millport for the period 2007 to 2100 for the RCP 8.5 scenario. The 95^{th} percentile projections of sea level rise from 2007 to 2050 is +0.28 m, which are considered to provide an appropriate time period for the proposed works at Hunterston. The effect of this at Southannan Sands in terms of low water extents, would be to shift the Lowest Astronomical Tide extent landwards by between 4 – 125 m, and shift the mean low water spring tide extent landward by between 10 – 185 m, as shown in Figure 4.15. In terms of wider projections beyond this timescale, the projected sea level rise from 2007 to 2080 for this scenario is +0.62 m.

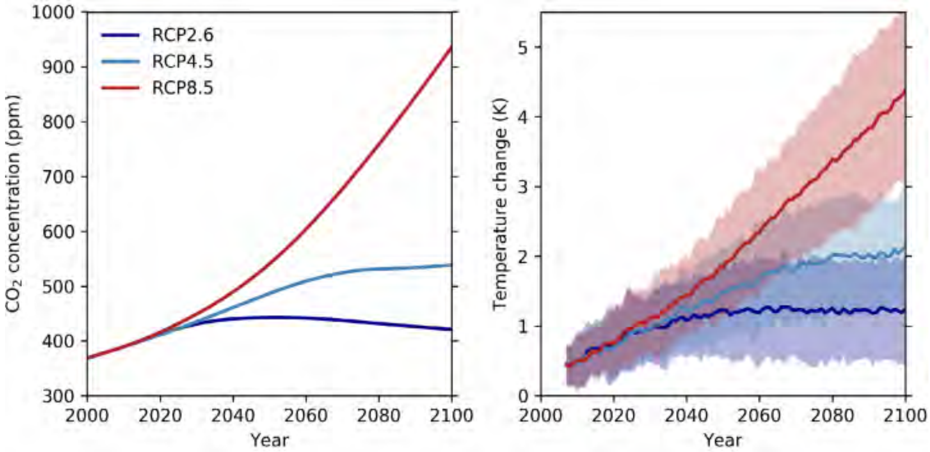


Figure 4.13: UKCP18 RCP predictions for CO2 (left) and global mean surface temperature change (right)

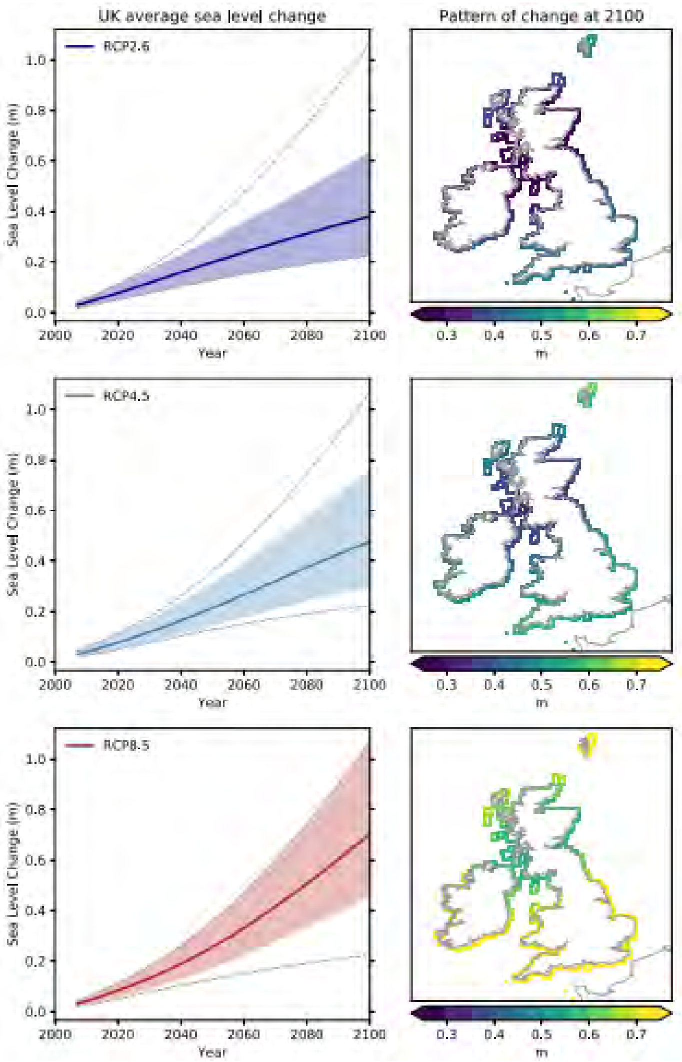


Figure 4.14: UKCP18 sea level change based on average of UK ports (left) and spatial change at 2100 (right)

Figure 4.15: Potential Change in Low Water Extents as a Result of a +0.28 m Sea Level Rise to 2050

4.7.3 Wind

The UKCP18 wind speed analysis concludes that there are no compelling trends in storminess, as determined by maximum gust speeds, from the UK wind network over the last four decades. The global projections over the UK show an increase wind speeds over the UK for the second half of the 21st century for the winter, associated with an increase in frequency of winter storms over the UK, while overall there is no trend in the wind speed over the UK.

4.7.4 Waves

The likely impact of climate change on wave height remains an area of significant uncertainty. The SEPA climate change guidance (SEPA, 2019) does not provide recommended allowances. It is noted that the size of waves at the coast is often limited by depth of water, and therefore sea level is likely to have a greater impact on wave overtopping. The guidance recommends that wave model sensitivity to offshore wave height is tested through an increase of 10 – 20% in offshore wave height to account for changes as a result of climate change.

5 COASTAL MODELLING

5.1 Modelling Overview

The MIKE by DHI coastal modelling platform has been used to simulate the coastal hydrodynamics and spectral wave conditions in and around Southannan Sands.

The model utilises a flexible mesh to represent the offshore and coastal area. The flexible mesh is composed of triangles of varying size and can therefore represent complex coastal alignments or bathymetry accurately. Further details of the model mesh are detailed in section 5.2.

Coastal hydrodynamics have been simulated using the MIKE 21 Flow Model FM module as further described within section 5.3. Wave conditions have been simulated using the MIKE 21 Spectral Wave (SW) Flexible Mesh (FM) module as presented in section 5.4.

5.2 Model Mesh

5.2.1 Bathymetric and Topographic Data

The following bathymetric and topographic survey data has been used to develop the bathymetric model that underlies the model mesh used within the assessment:

- Aspect Surveys bathymetry survey – <1 metre resolution multibeam survey (2018);
- Ambios bathymetry survey data – <1 metre resolution (2009);
- MIKE C-Map Digital Bathymetry – Offshore Firth of Clyde;
- LiDAR Digital Terrain Model – 1 metre resolution (The Scottish Government, n.d.); and
- Aspect Surveys topographic survey of development area (2018).

The datasets have been used to create a combined Digital Terrain Model (DTM) for use within the hydrodynamic and wave modelling. A snapshot of the DTM with bathymetry displayed relative to Chart Datum is presented in Figure 5.1 for the whole model extent, and a zoom view of Hunterston Sands in Figure 5.2.

Post-development DTMs have been generated for two phases of the proposed development, an intermediate phase involving the proposed quay upgrade works and associated dredge, and a final phase encompassing all works including the caisson gate installation and dredge. Figure 5.3 and Figure 5.4 present zoom views of the intermediate phase and final phase DTMs respectively. Both post-development DTMs are identical to the baseline DTM in areas outside the development envelope.

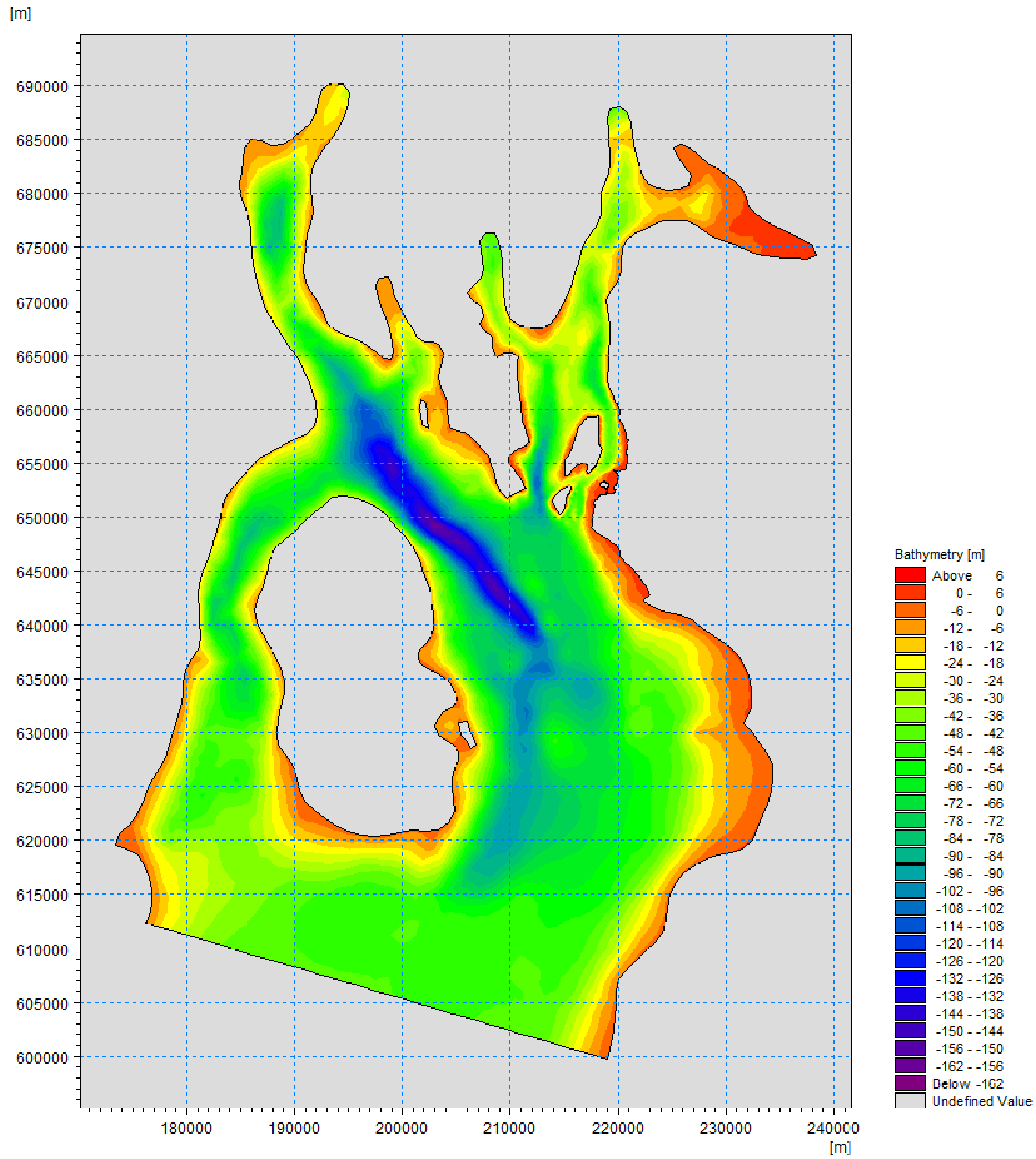


Figure 5.1: Overview of DTM - Model Extent

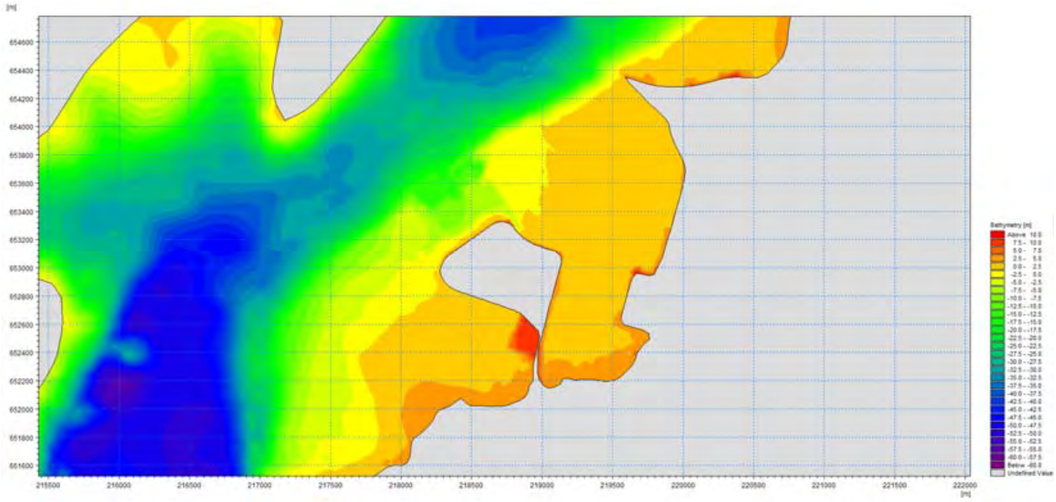


Figure 5.2: Baseline DTM in Vicinity of Southannan Sands

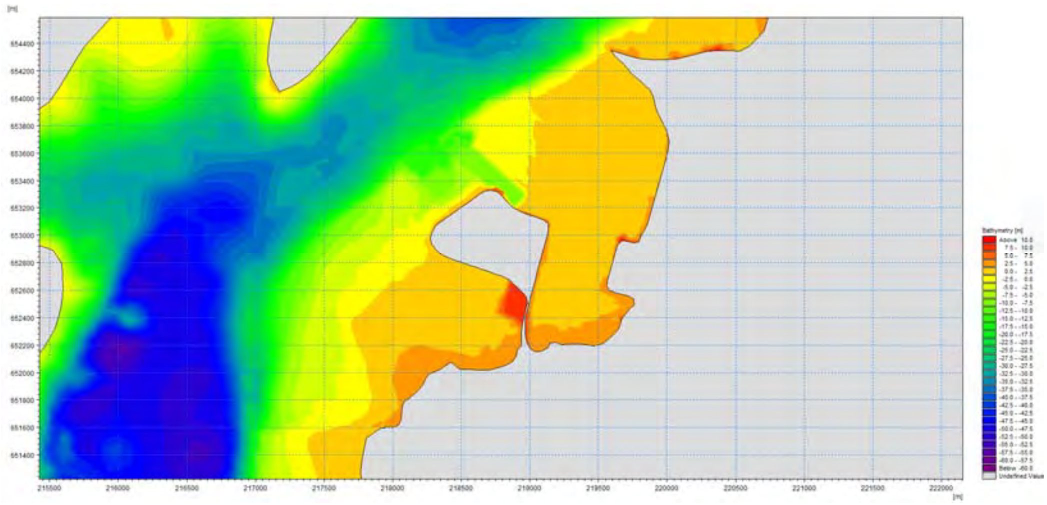


Figure 5.3: Intermediate Phase DTM in Vicinity of Southannan Sands

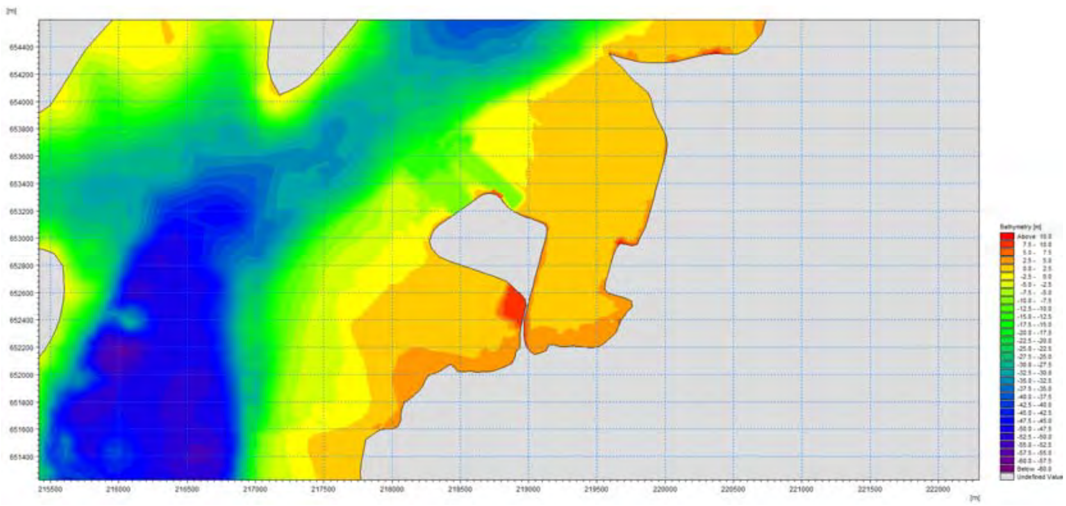


Figure 5.4: Final Phase DTM in Vicinity of Southannan Sands

5.2.2 Flexible Mesh

The model utilises a flexible mesh to represent the offshore and coastal area. The flexible mesh is composed of triangles of varying size and can therefore represent complex coastal alignments or bathymetry accurately.

The model mesh extent and bathymetry is shown in Figure 5.5. The mesh has been generated using the bathymetric data described in section 5.2.1 and has progressive refinement towards Southannan Sands, becoming finer towards the area of interest on adjacent to the marine yard (Figure 5.6).

Two post-development versions of the mesh have been generated using updated bathymetry to include the proposed dredge and quay upgrade (see Figure 5.3 and Figure 5.4), as an intermediate phase, and a final phase also including the caisson gate and dredge to caisson gate entrance. Both of these post-development versions of the mesh are identical to the pre-development mesh in terms of mesh structure, and in terms of bathymetry outside the envelope of proposed works.

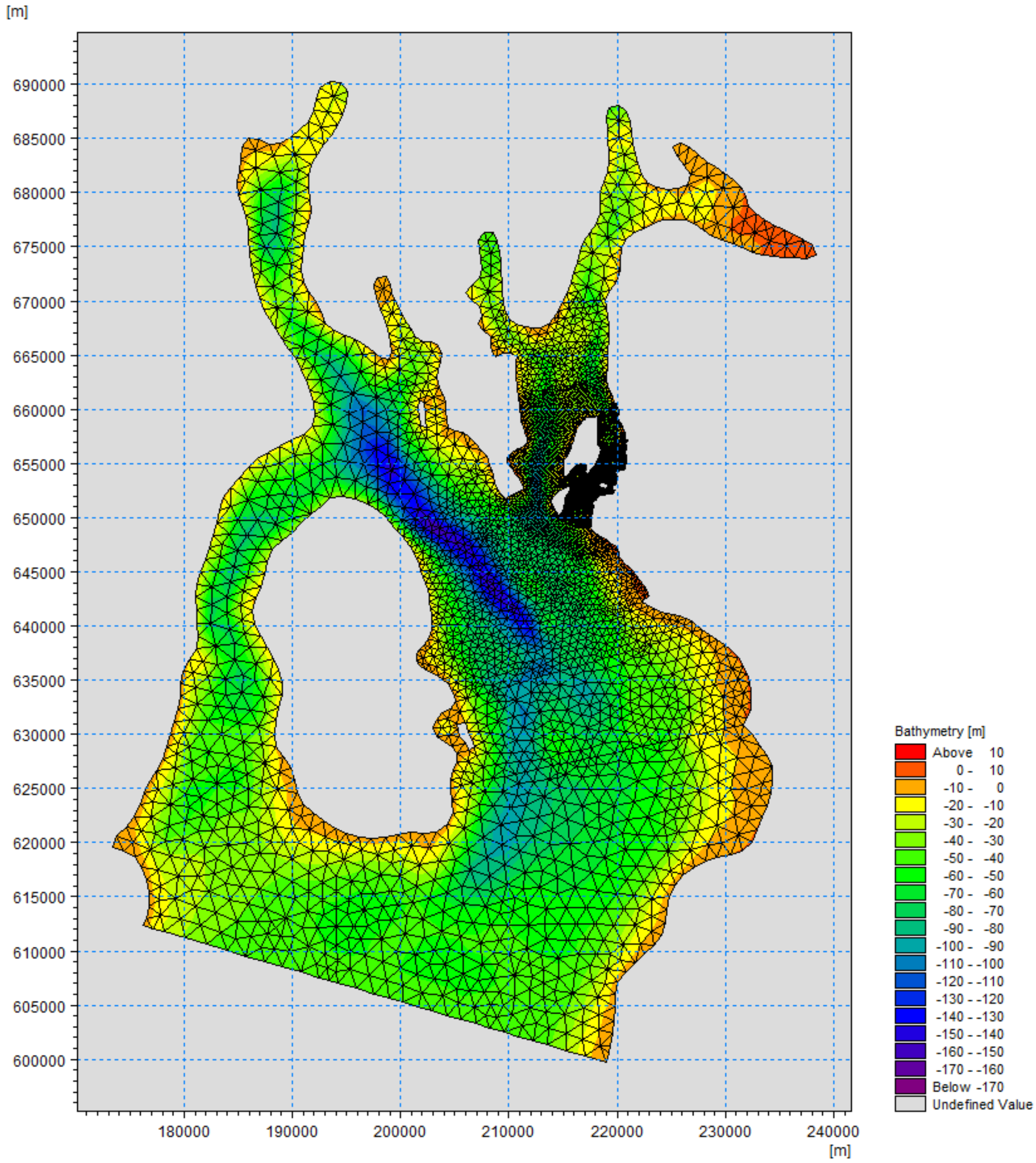


Figure 5.5: Model Mesh Full Extent

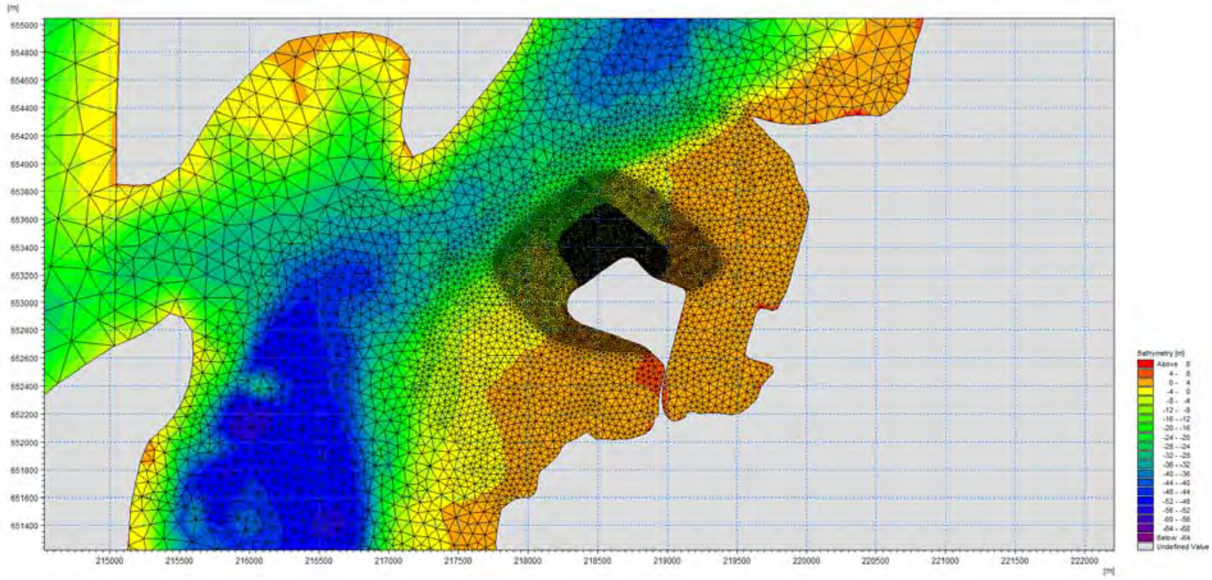


Figure 5.6: Model Mesh Zoom Showing Transitional Refinement of Resolution

5.3 Coastal Hydrodynamics

5.3.1 Hydrodynamic Model and Setup

MIKE 21 Flow Model FM is a modelling package based on a flexible mesh (FM) structure. The modelling system has been developed for applications within oceanographic, coastal and estuarine environments. The Hydrodynamic Module (HD) is the central computational component of the package, solving 2D shallow water equations. The module simulates unsteady flow taking account of bathymetry, sources and external forcing, it consists of continuity, momentum, temperature, salinity and density equations. The latest version of the software, MIKE 2019, has been used within this assessment.

Further details of the MIKE 21 FM HD model setup are provided below:

- For each model simulation the modelled extent includes the entire mesh as described in section 0;
- Boundary input tidal conditions have been derived from hindcast data as described in section 4.4; and
- Model simulations are run with the hindcast dataset for a tidal cycle extending from the 15th January 2019 to 26th January 2019, a period covering both neap and spring tides.

The modelling has been undertaken with the following computing specification:

- Dell Precision 5820 Tower (64GB RAM; 14 Cores – Intel Xeon CPU (2.5GHz)).
- Windows 10 Pro 64-bit operating system.

5.3.2 Model Outputs and Simulations

The MIKE 21 FM HD model simulations have been setup to produce results as both point and area outputs. The outputs include the following key parameters:

- Surface elevation;
- Current speed;
- Current direction; and
- Bed shear stress

The area outputs are generated for the whole model extent, whilst point outputs are generated at 15 locations, as detailed in Table 5.1 and shown in Figure 5.7 and Figure 5.8. An overview of the key model simulations undertaken using the MIKE 21 FM HD model is presented in Table 5.2.

Table 5.1: Model Point Output Locations

Easting	Northing	Point Output Location
218400	653300	Point 1
218850	653280	Point 2
218800	653400	Point 3
218900	653350	Point 4
219000	653300	Point 5
219500	653600	Point 6
219400	652900	Point 7
218500	654400	Point 8
217000	653000	Point 9
218200	652700	Point 10
219000	653700	Point 11
219200	653400	Point 12
219200	653200	Point 13
216000	649000	Point 14
215000	638000	Point 15

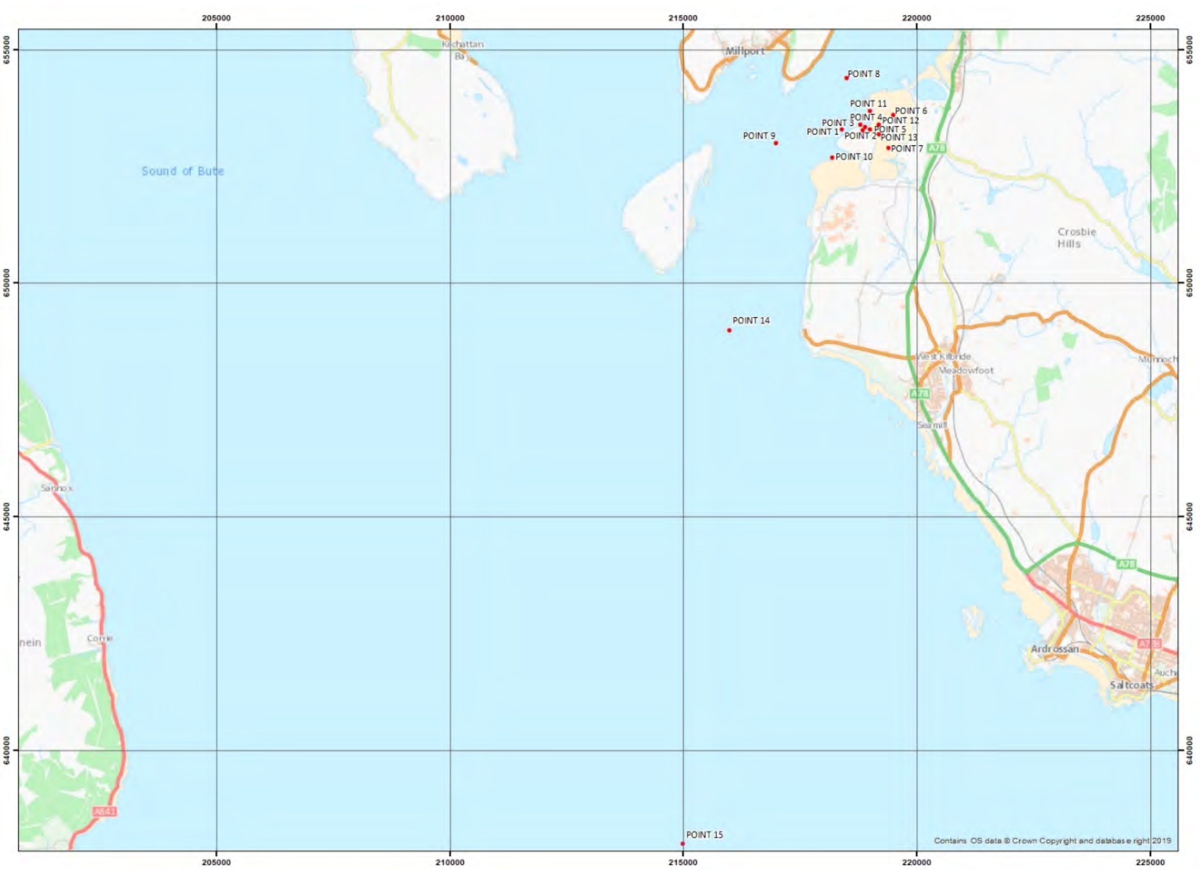


Figure 5.7: Model Point Output Locations Overview

Figure 5.8: Model Point Output Locations in Vicinity of Hunterston Sands

Table 5.2: Overview of HD Model Simulations

HD Run	Description
HD_Baseline_Run7	Tidal time-series run with Baseline mesh and bathymetry.
HD_Intermediate_Run4	Tidal time-series run with Intermediate phase mesh and bathymetry.
HD_Final_Run4	Tidal time-series run with Final phase mesh and bathymetry.

5.3.3 Model Validation

Validation of the model has been undertaken through comparison of baseline modelled tidal levels with Admiralty tide predictions (UKHO, 2019) for the same tide, at both Millport and Greenock. This comparison highlights that the model predicts levels within 0.05 m of the Admiralty predicted levels at high and low tide. The model is therefore considered to perform well.

5.3.4 Results

A summary of key model results is presented below, with further detailed results outputs contained in Appendix C.

Observations on the hydrodynamic model Baseline run (HD_Baseline_Run7) results are:

- Comparison of baseline model results for spring and neap tidal cycles highlights that the highest current speeds are observed during spring tides.

- Baseline model results show that current speeds are higher during the ebb and flood tide than at high or low water.
- Comparison of baseline model results for ebb and flood tide highlights that in the vicinity of Southannan Sands, the ebb tide produces higher current speeds than the flood tide.
- Figure 5.9 presents baseline model tidal current speeds during the mid-ebb phase of a spring tide in the vicinity of Southannan Sands.
- Current speeds can be seen to vary from above 0.4 m/s in the deeper water of Hunterston Channel, to less than 0.05 m/s in the shallow margins of Southannan Sands.
- Peak modelled speeds within the SSSI designation are observed on the margin of the designation around the Mean Low Water Spring (MLWS) tide level (0.2 – 0.3 m/s), and around the north-eastern corner of the marine yard (0.2 – 0.4 m/s).

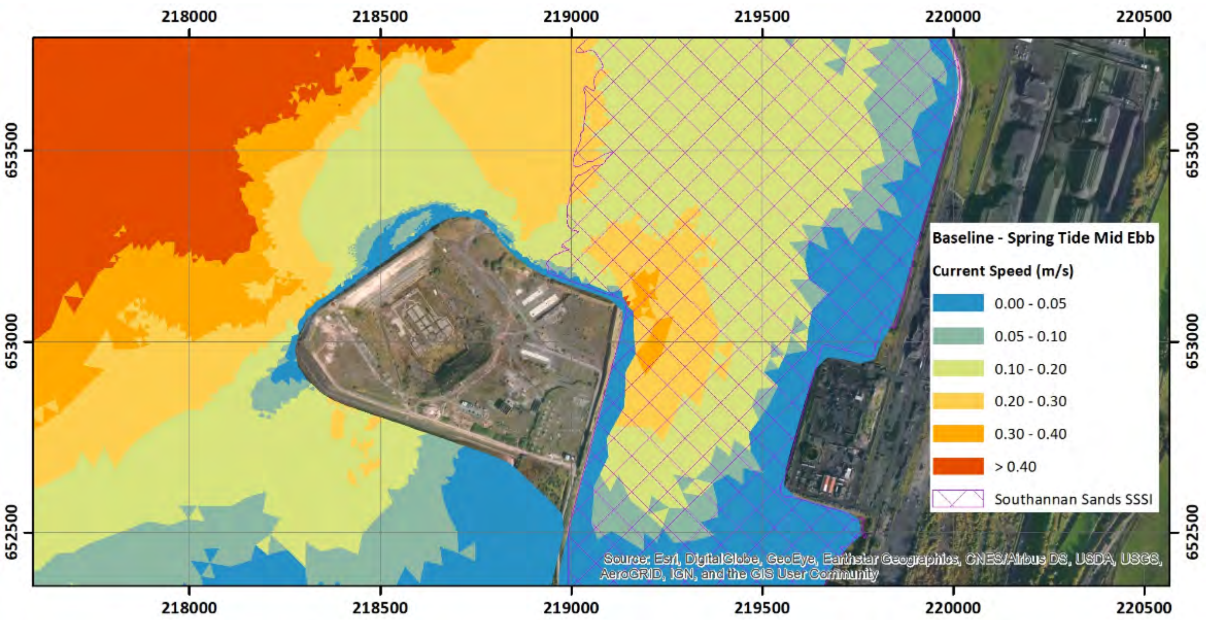


Figure 5.9: Baseline Conditions – Current Speed at Mid Ebb of Spring Tide

Observations on the hydrodynamic model Intermediate run (HD_Intermediate_Run4) and Final run (HD_Final_Run4) results are:

- Comparison of the Intermediate and Final model run results highlight that both models produce very similar results in the immediate vicinity of the SSSI and quay upgrade zone.
- Further offshore, and in the particularly in the vicinity of the proposed caisson gate dredge greater variation between the results of the two models is observed.
- Modelled water levels from the baseline and final phase scenarios have been compared at two locations within the model to examine any changes:
  - Point 3 (within the quay dredge zone, see Figure 5.8): The model results presented in Figure 5.10 show that the proposed dredge is not predicted to alter water levels within the dredge zone.
  - Point 13 (on Southannan Sands SSSI near the quay dredge zone, see Figure 5.8): The model results presented in Figure 5.11 show that no changes to water levels are observed outwith the dredge zone on Southannan Sands.
- Predicted changes in current speed between the baseline and final phase scenarios have been compared at the same two locations within the model as noted above, to examine any changes:
  - Point 3 (within the quay dredge zone): The current speeds are predicted to reduce within the dredge zone as shown in Figure 5.12.

- Point 13 (on Southannan Sands SSSI): The current speeds as shown in Figure 5.13 do not indicate any change.

- The peak Final modelled current speed at Point 3 within the quay dredge zone is 0.14 m/s during ebb spring tide, with the equivalent figure at point 13 on Hunterston Sands around 0.28 m/s.
- A differential plot of the Final phase current speed versus Baseline current speed during mid ebb of a spring tide is presented in Figure 5.14.
- Review of this figure highlights that the proposed dredge will produce a reduction in tidal current speed of between -0.2 and -0.05 m/s within the quay dredge zone. However, on the south-eastern margin of the quay dredge zone at the boundary of the SSSI, the results indicate only a small increase in tidal current speed of between 0.05 and 0.10 m/s, and very locally between 0.10 and 0.15 m/s.
- A small area between the quay dredge (intermediate phase) and caisson gate dredge pocket also shows similar increases in current speeds.

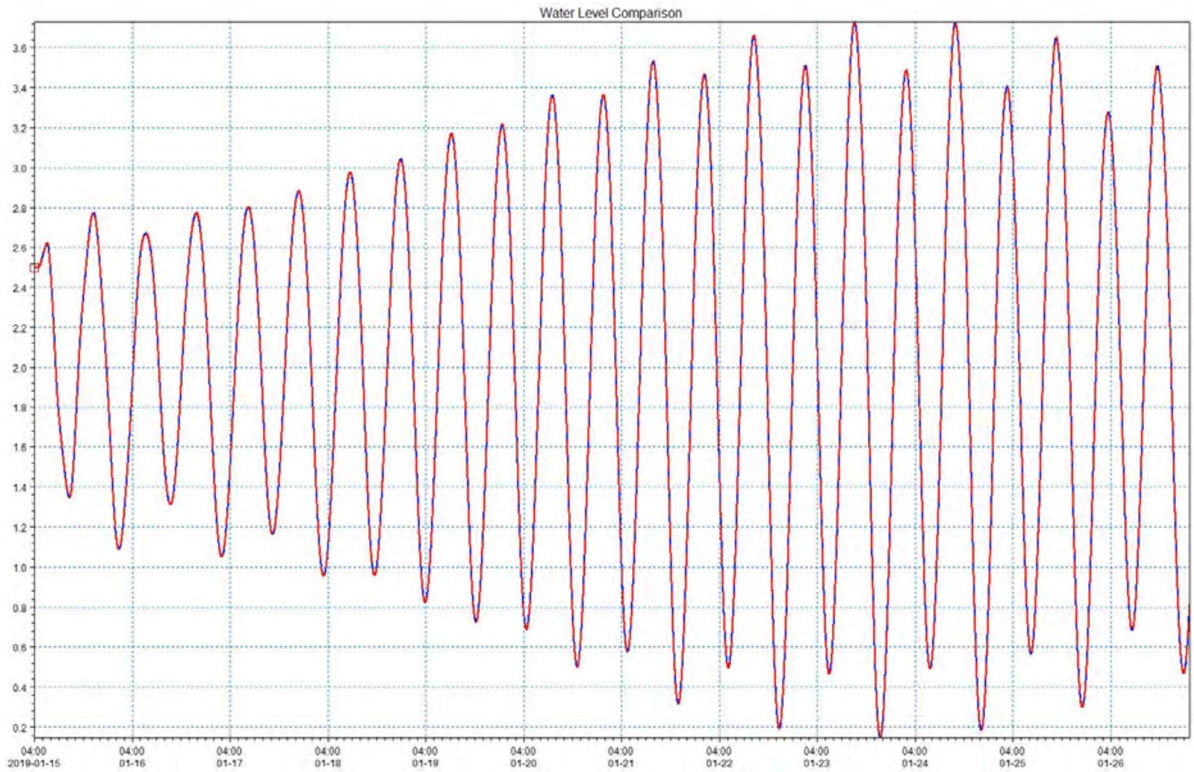


Figure 5.10: Comparison of Baseline (Blue) & Final Phase (Red Dash) Water Levels (mCD) at Point 3

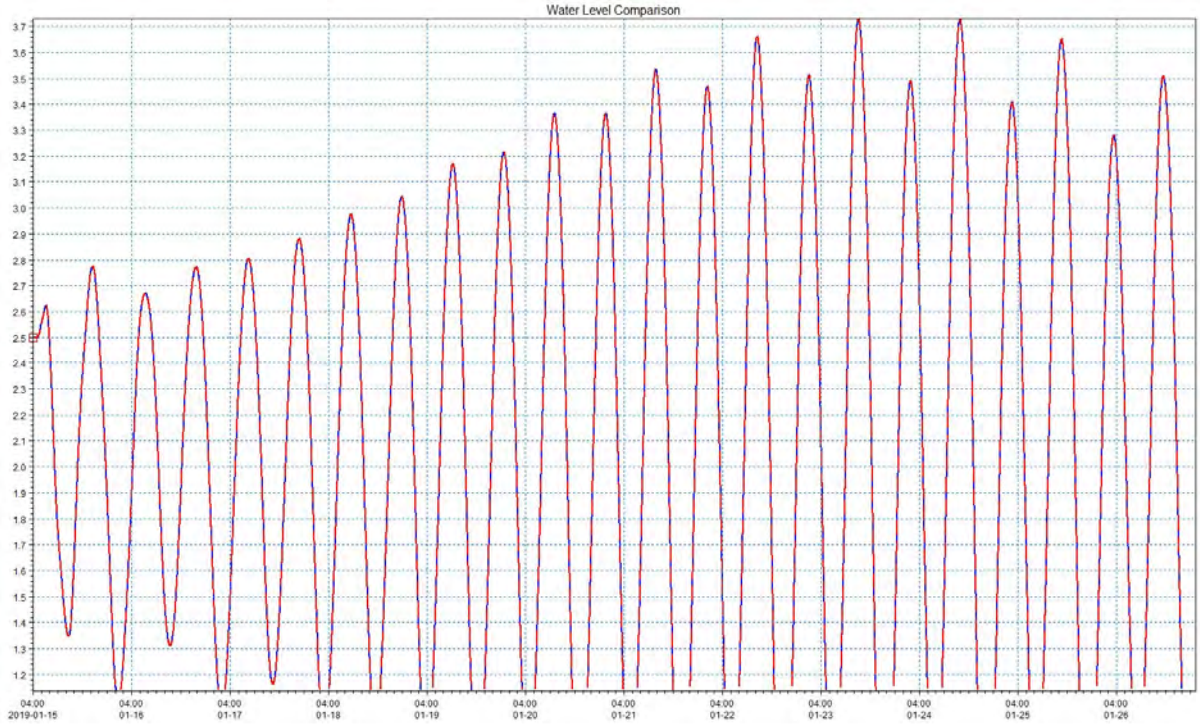


Figure 5.11: Comparison of Baseline (Blue) & Final Phase (Red Dash) Water Levels (mCD) at Point 13

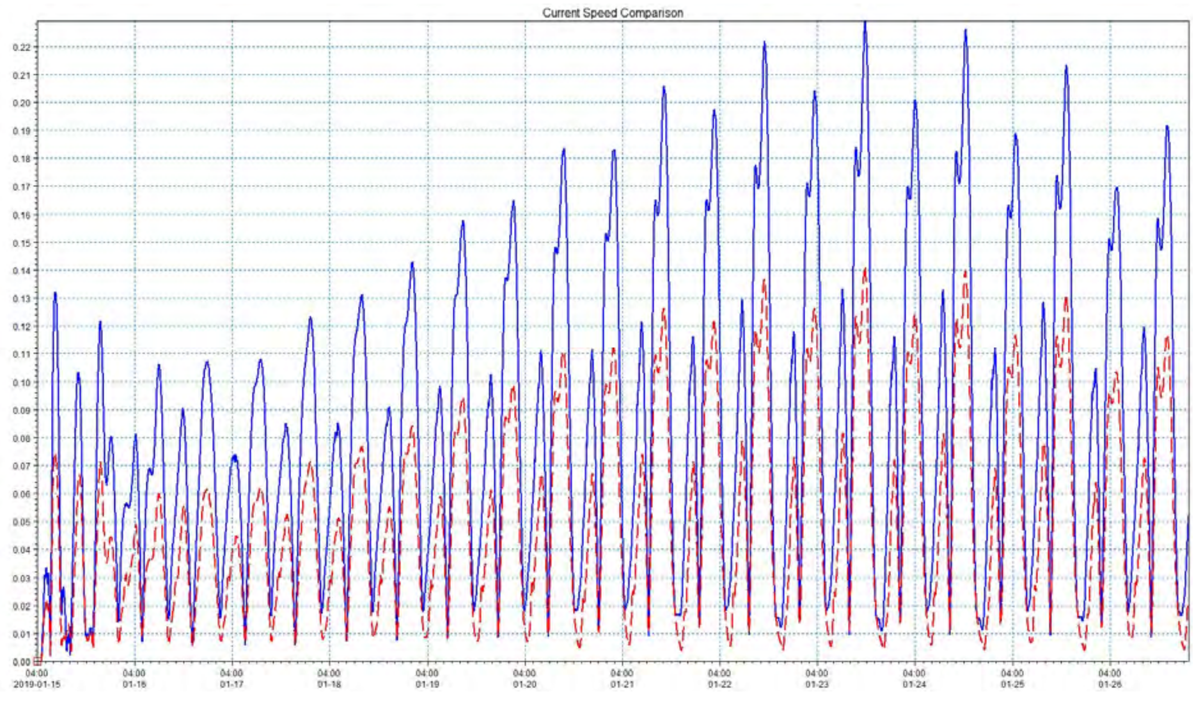


Figure 5.12: Comparison of Baseline (Blue) & Final Phase (Red Dash) Current Speed (m/s) at Point 3

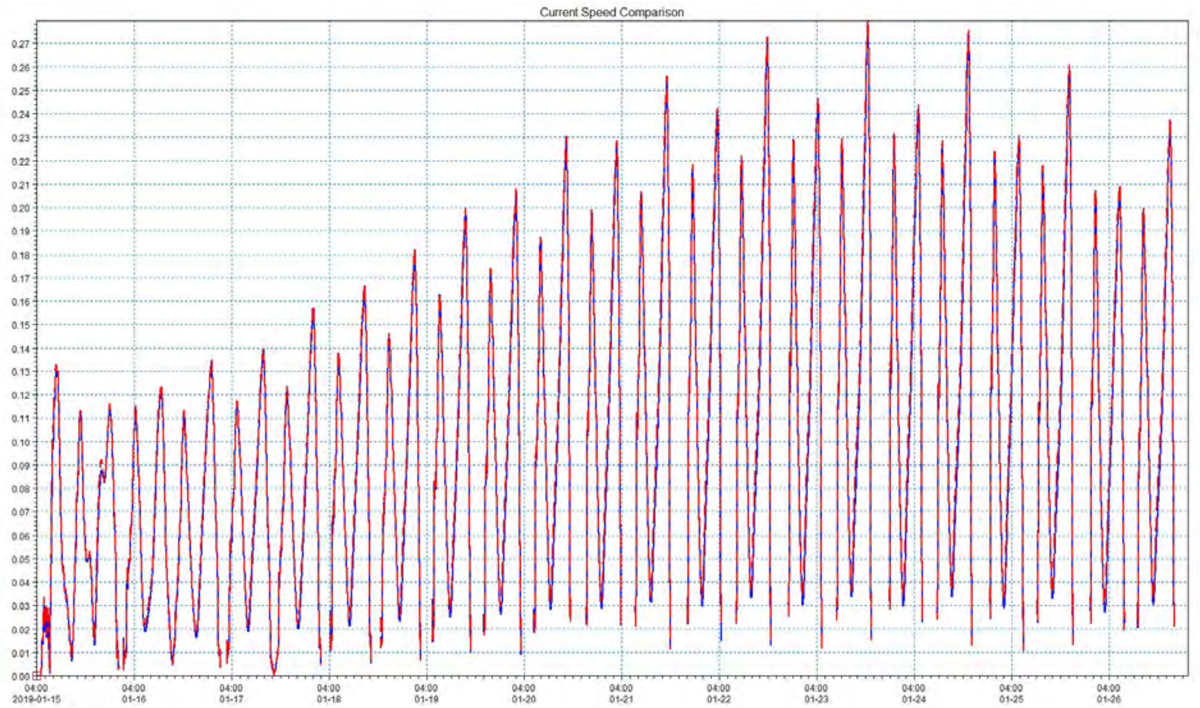


Figure 5.13: Comparison of Baseline (Blue) & Final Phase (Red Dash) Current Speed (m/s) at Point 13

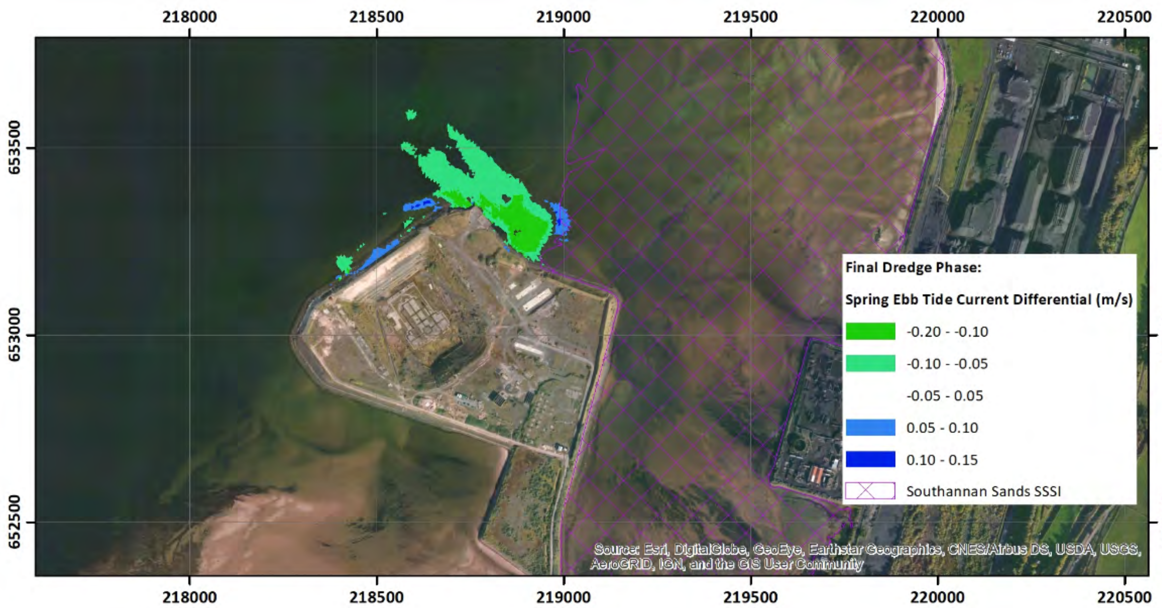


Figure 5.14: Spring Tide Mid-Ebb Current Speed Differential Between Final Phase and Baseline Scenario

5.4 Spectral Wave Modelling

5.4.1 Spectral Wave Model and Setup

Offshore to inshore wave transformation modelling has been undertaken using the MIKE 21 Spectral Wave (SW) Flexible Mesh (FM) module. MIKE 21 SW FM is a new generation spectral wind-wave model based on unstructured meshes. The latest version of the software, MIKE 2019, has been used in this assessment. The model simulates the growth, decay and transformation of wind-generated waves and swell in offshore and coastal areas.

MIKE 21 SW FM includes the following physical phenomena:

- Wave growth by action of wind;
- Non-linear wave-wave interaction;
- Dissipation due to white-capping, bottom friction, and depth-induced wave breaking;
- Refraction and shoaling due to depth variations;
- Wave-current interaction;
- Effect of time-varying water depth; and
- Effect of flooding and drying.

The main computational features of MIKE 21 SW FM are as follows:

- Fully spectral and directionally decoupled parametric formulations;
- Source functions based on state-of-the-art 3rd generation formulations;
- Instationary and quasi-stationary solutions;
- Optimal degree of flexibility in describing bathymetry and ambient flow conditions using depth adaptive and boundary fitted unstructured mesh;
- Effects of ice coverage;
- Coupling with hydrodynamic flow model for modelling of wave-current interaction and time-varying water depth;
- Flooding and drying in connection with varying water levels;
- Cell-centred finite volume technique;
- Time integration using a fractional step approach and an efficient multi-sequence method; and
- Extensive range of model output parameters (wave, swell, air-sea interaction parameters, radiation stress tensor, spectra etc.).

The model mesh previously described in section 0 has been utilised for the MIKE 21 SW modelling.

Further details on the spectral wave model setup are provided below:

- For each model simulation the modelled extent includes the entire mesh (section 0);
- Boundary input wave conditions have been derived from hindcast data (sections 4.2 and 4.5.2);
- Constant wind conditions are applied across the model extent, wind conditions are derived from extreme value analysis of hindcast wind data (section 4.5.3);
- Constant water level conditions are applied across the model extent (section 3.6.1 and 4.5.1);
- The spectral wave model applies fully spectral formulation basic equations; and
- Model simulations are run for a minimum of 15 time-steps (15 hours) to account for wind energy input to the spectrum.

The modelling has been undertaken with the same computing setup described previously in section 5.3.1.

5.4.2 Model Outputs and Simulations

The spectral wave model simulations have been setup to produce results as both point and area outputs. The outputs include a number of wave items including the following key parameters:

- Significant wave height;
- Maximum wave height;
- Peak wave period;
- Mean wave direction; and
- Directional standard deviation.

The area outputs are generated for the whole model extent, whilst as with the hydrodynamic model, point outputs are generated at the locations described in section 5.3.2.

An overview of the model simulations undertaken using the MIKE 21 SW FM model is presented in Table 5.3 along with key input parameters.

Table 5.3: Overview of the Spectral Wave (SW) Model Simulations and Key Input Parameters

SW Run	Model Scenario Set-up					Key Input Parameters		
	Development Condition	Return Period (yr)	Wave Dir	Wind Dir	Sea Level	Significant Wave Height (m)	Wind Speed (m/s)	Sea Level (mCD)
1	Baseline	5	180°	180°	HAT	4.41	20.3	3.9
2	Baseline	5	180°	210°	HAT	4.41	21.0	3.9
3	Baseline	5	180°	240°	HAT	4.41	22.6	3.9
4	Baseline	5	180°	270°	HAT	4.41	22.7	3.9
5	Baseline	5	180°	300°	HAT	4.41	21.8	3.9
6	Baseline	5	180°	330°	HAT	4.41	19.6	3.9
7	Baseline	2	180°	270°	HAT	3.95	20.2	3.9
8	Baseline	50	180°	270°	HAT	4.95	27.4	3.9
9	Baseline	5+CC	180°	270°	HAT +0.28m	4.85	22.7	4.18
10	Baseline	Mean	180°	206°	HAT	1.26	6.58	3.9
11	Intermediate	5	180°	240°	HAT	4.41	22.6	3.9
12	Intermediate	5	180°	270°	HAT	4.41	22.7	3.9
13	Intermediate	5	180°	300°	HAT	4.41	21.8	3.9
14	Final	5	180°	240°	HAT	4.41	22.6	3.9
15	Final	5	180°	270°	HAT	4.41	22.7	3.9
16	Final	5	180°	300°	HAT	4.41	21.8	3.9
17	Intermediate	Mean	180°	206°	HAT	1.26	6.58	3.9
18	Final	Mean	180°	206°	HAT	1.26	6.58	3.9
19	Intermediate	2	180°	270°	HAT	3.95	20.2	3.9
20	Intermediate	50	180°	270°	HAT	4.95	27.4	3.9
21	Intermediate	5+CC	180°	270°	HAT +0.28m	4.85	22.7	4.18
22	Final	2	180°	270°	HAT	3.95	20.2	3.9
23	Final	50	180°	270°	HAT	4.95	27.4	3.9
24	Final	5+CC	180°	270°	HAT +0.28m	4.85	22.7	4.18

5.4.3 Results

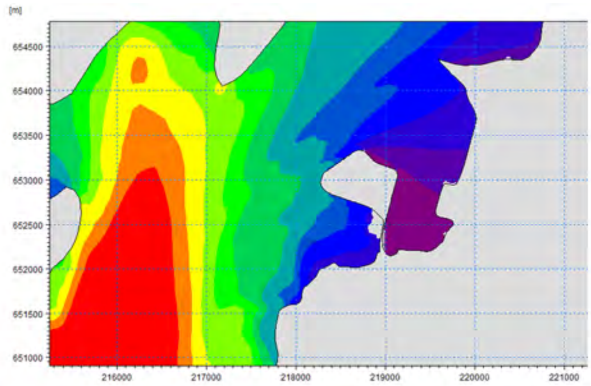
A summary of key model results is presented below, with further detailed results outputs contained in Appendix D.

Observations on the spectral wave model Baseline run results are detailed below:

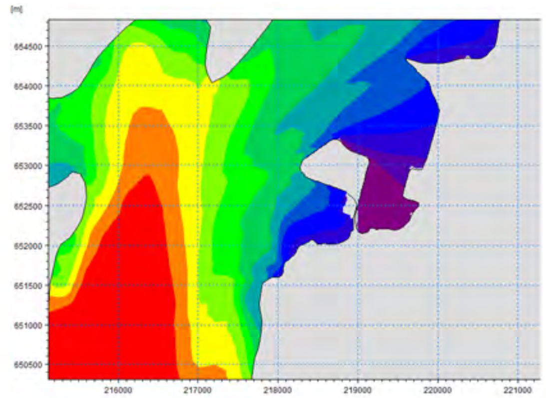
- Review of Baseline runs 1 to 6 (see Figure 5.15) highlights that offshore of the proposed caisson gates the highest significant wave heights can be expected to occur during wind from the 240° sector (SW Run 3), with wind from the 270° sector (SW Run 4) also producing similar wave heights.
- In the vicinity of the proposed quay upgrade and the adjacent SSSI, the model results indicate that the highest significant wave heights occur during wind from the 300° sector (SW Run 5).
- Baseline significant wave heights adjacent to the proposed caisson gates range between 0.95 m and 1.40 m under wind forcing from the 240° sector (SW Run 3).
- Similarly, under wind forcing from the 270° sector (SW Run 4), significant wave height in this area ranges between 0.95 m and 1.25 m.
- In the vicinity of the proposed jetty development and the adjacent SSSI, significant wave heights range between 0.60 m and 0.85 m under wind forcing from the 300° sector (SW Run 5).
- Under mean wave and wind conditions significant wave heights in the vicinity of the proposed caisson gates are predicted to be between 0.10 m and 0.25 m. For the same conditions, further east around the proposed quay works and on Southannan Sands, predicted significant wave heights are less than 0.10 m.
- Review of climate change sensitivity model run results (SW Run 9) highlights that a future climate rise in sea level, and increase in offshore swell height, is unlikely to result in significant changes to wave height in the vicinity of Southannan Sands or the proposed works.

Observations on the spectral wave model Intermediate and Final Phase run results are detailed below:

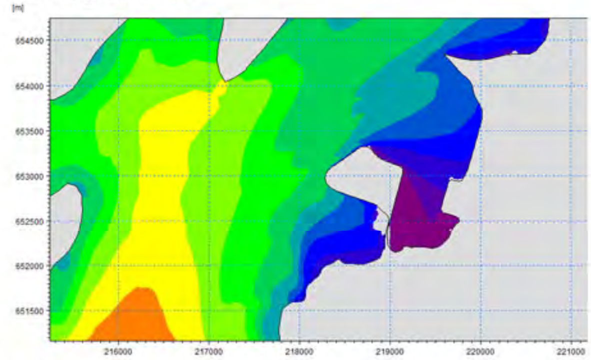
- Comparison of the Intermediate and Final model run results highlights that both models produce very similar results in the immediate vicinity of the SSSI and quay upgrade zone.
- Further offshore, and in the particularly in the vicinity of the proposed caisson gate dredge zone, greater variation between the results of the two models is observed.
- A differential plot of the final phase significant wave height versus baseline significant wave height during wind forcing from the 240° sector is presented in Figure 5.16. Review of this figure highlights that the final phase conditions are predicted to produce an increase in significant wave height of between 0.05 m and 0.25 m within the dredge zone adjacent to the proposed caisson gates. However, elsewhere, including the Southannan Sands SSSI, no significant change in wave height is predicted.
- A similar differential plot of the final phase significant wave height versus baseline significant wave height during wind forcing from the 300° sector is presented in Figure 5.17. Review of this figure highlights that the proposed dredge is predicted to produce an increase in significant wave height of between 0.05 m and 0.10 m within the dredge zone adjacent to the proposed caisson gates. However, elsewhere, no significant change in wave height is predicted other than a small area of minor reduction in significant wave height (-0.05 m to -0.10 m) immediately to the south-east of the quay dredge zone, on the margin of the Southannan Sands SSSI designation.
- Review of the differential plot for the final phase significant wave height versus baseline significant wave height during mean wave and wind conditions (Appendix D), highlights that no significant change in wave height is predicted under these conditions.



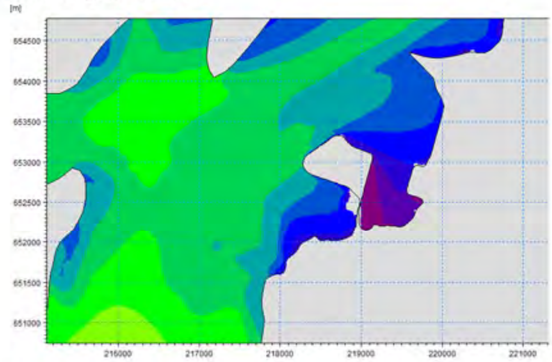
180 Degree Wind



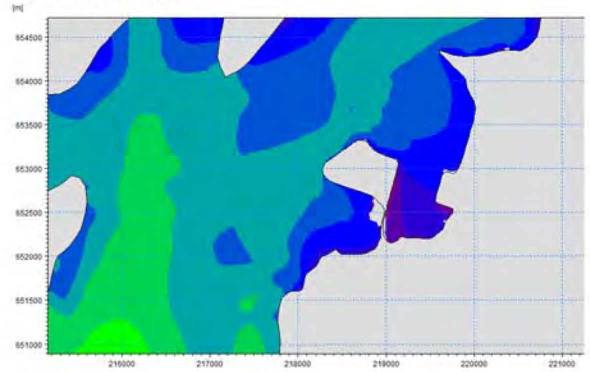
210 Degree Wind



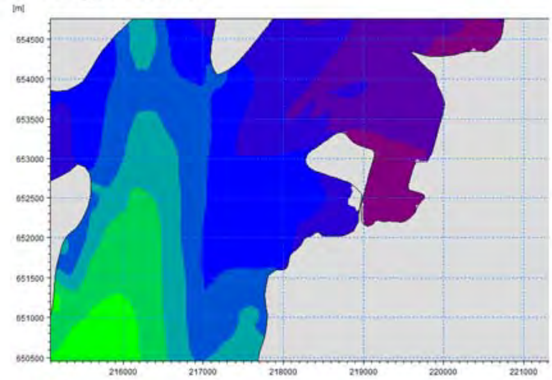
240 Degree Wind



270 Degree Wind



300 Degree Wind



330 Degree wind

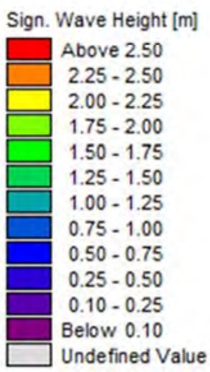


Figure 5.15: Summary of Baseline Wind Direction Sensitivity Analysis (SW Run 1 – 6)

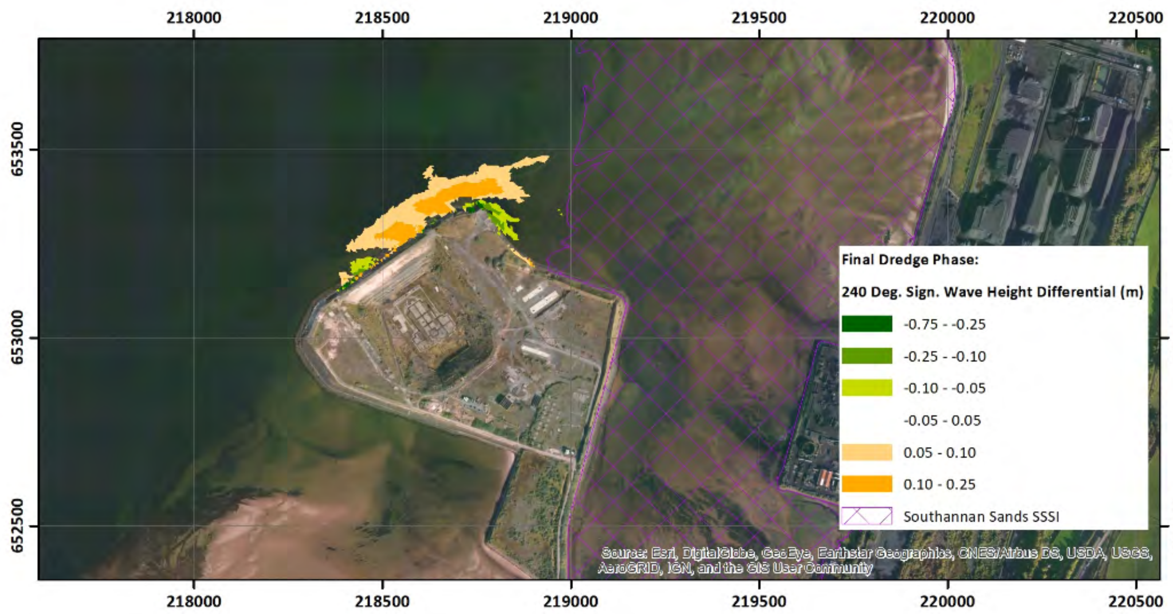


Figure 5.16: Significant Wave Height Differential (240° sector) Between Final Phase and Baseline

Figure 5.17: Significant Wave Height Differential (300° sector) Between Final Phase and Baseline

6 ASSESSMENT OF PROPOSED DEVELOPMENT ON COASTAL ENVIRONMENT

6.1 Impact on Coastal Processes

6.1.1 Tides

The tidal water levels have been compared for the baseline and final development conditions at the edge of Southannan Sands SSSI close to the proposed quay upgrade works (Figure 5.11). This comparison highlights that there is no predicted change in water levels as a result of the development.

The hydrodynamic modelling has simulated full neap and spring tidal cycles, confirming that the larger magnitude tidal currents occur on Southannan Sands during the spring ebb tide. Comparison of the model results for the mid ebb spring tidal currents (Figure 5.12 and Figure 5.14) indicates that there would be localised reductions in tidal current speeds of 0.05 - 0.20 m/s within the proposed dredge areas, which would reduce the tidal current speeds in these areas to 0 - 0.05 m/s. Beyond the immediate vicinity of the proposed dredge zones, comparison of modelling results indicates there would a slight, localised increase in tidal velocities to the east of the quay dredge zone on the margin of Southannan Sands of 0.05 – 0.10 m/s (Figure 5.14), however on Southannan Sands, no observable change is predicted (Figure 5.13).

While the modelling results presented above indicate that the proposed development will produce localised changes in tidal current speeds, it is considered that these variations are insignificant in terms of the wider hydrodynamic regime in and around Southannan Sands, with post development speeds of a similar nature to those observed under existing conditions.

The assessment concludes that there will be no significant impact from the proposed development on tidal levels or current speeds.

6.1.2 Waves

The assessment has confirmed that the proposed development area is most exposed to swell waves from the south (180°). The largest significant wave heights occur in the area of the caisson gates during swell waves from 180° with wind forcing from the west (240°), while the area around the quay upgrade works, including the adjacent Southannan Sands, experience the largest significant wave heights from wind forcing from the west-north-west direction (300°).

Wave modelling results during storm conditions have shown that the effect of the proposed quay dredge alone will slightly increase the wave climate immediately west of the dredge zone during wind forcing from 240° through to 300°. During these conditions, there is negligible change in the wave climate within and to the east of the dredge area towards Southannan Sands, with the exception of a marginal reduction during waves from 300° (Appendix D).

When the entire final development is considered, the modelling results show that the wave climate during storm conditions close to the north-western shore of the Construction Yard, in the immediate vicinity of the proposed works, increases slightly, while the zone around the quay dredge area remains similar to the conditions as assessed for the quay dredge alone (Figure 5.17).

During mean wind and wave conditions, model results indicate that there will be negligible change to the wave climate (Appendix D).

The assessment concludes that there will be no significant impact from the proposed development on wave climate.

6.1.3 Sediment Transport (Coastal Morphology)

The sediment transport regime is driven by the tidal regime and wave climate, along with availability of sediment. The modelling results have demonstrated that there will be no significant impact to either the tidal regime or the wave climate. The proposed works are within a zone that has historically been dredged, and as a result, remains a low energy, depositional environment with limited sediment connectivity to the adjacent Southannan Sands. The proposed development is not predicted to alter these existing conditions.

The assessment concludes that there will be no significant impact from the proposed development on sediment transport.

6.2 Impact on Designations

The predicted zone of change to coastal processes from the proposed development in relation to designated Southannan Sands SSSI is not considered significant, either in extent or magnitude. The designated area of the Southannan Sands SSSI is 150.37 hectares. The zone where tidal currents are predicted to marginally increase extends to 0.10 hectares, or 0.07% of the designated area, while the zone where the wave climate is predicted to marginally decrease extends to 0.21 hectares, or 0.14% of the designated area.

Based on the present status of the Southannan Sands SSSI, the recent and anticipated changes do not present a risk or threat to the nature conservation designation interest of the site.

7 CONCLUSIONS

The existing baseline tidal regime, wave climate and sediment dynamics in the vicinity of the proposed development works at the Hunterston Construction Yard have been characterised using available information, supported by coastal modelling.

Given the proximity of the Southannan Sands SSSI to the proposed development, it is considered a sensitive receptor to any potential changes to the coastal regime resulting from the development.

The baseline coastal conditions are observed to be relatively stable and the recently assessed condition of the SSSI is '*Favourable Maintained*'.

The proposed works are within an area where similar activities have occurred in the past and they represent a reworking or extension of these previous activities.

The coastal hydrodynamics and wave modelling undertaken has identified that any predicted changes to the tidal regime, wave climate and sediment transport processes will be local to the proposed works and will be relatively minor, resulting in no significant impacts.

Based on the present status of the Southannan Sands SSSI, the recent and anticipated changes do not present a risk or threat to the nature conservation designation interest of the site.

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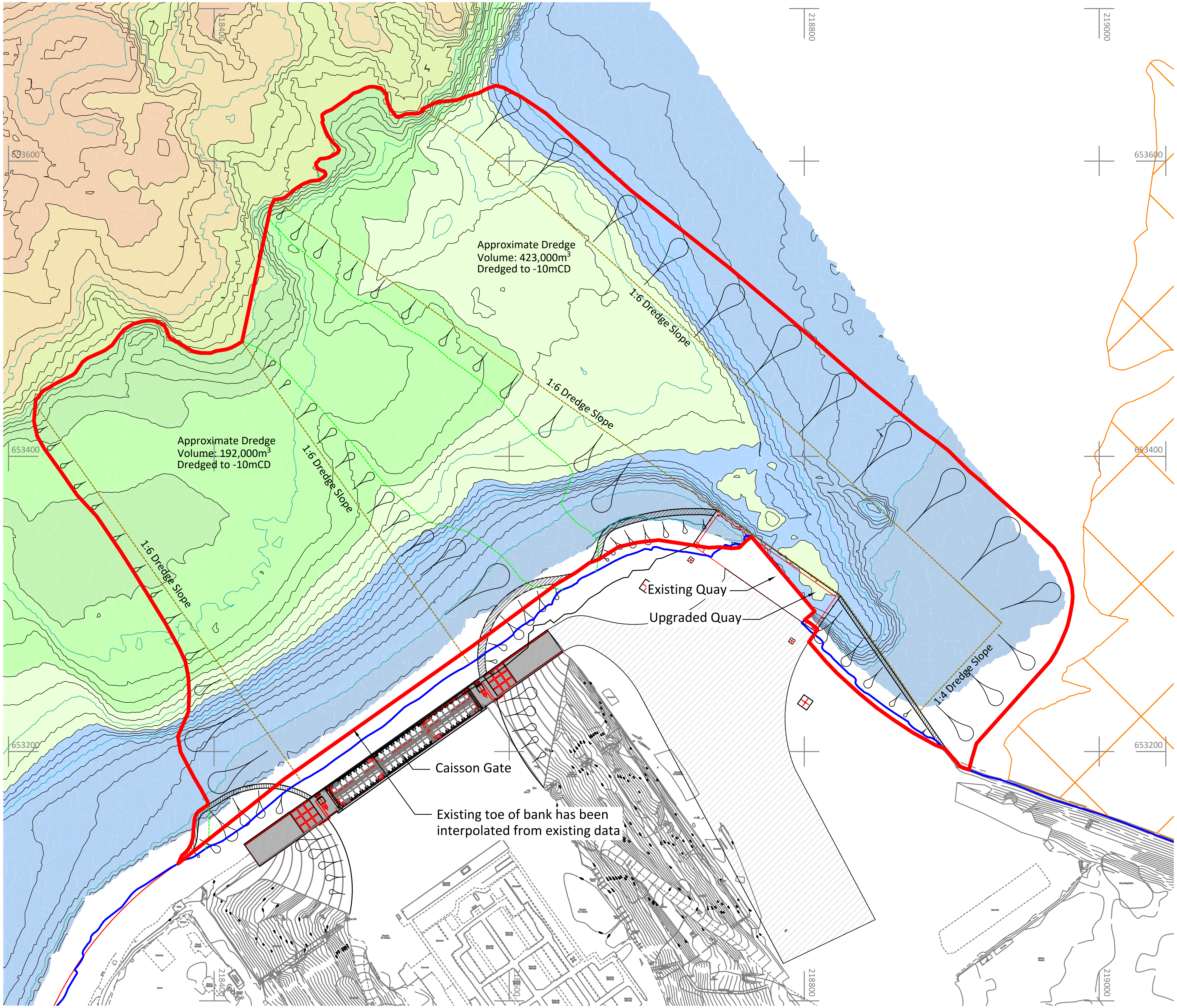
UKHO (2019). *Admiralty Tide Tables Volume 1B: United Kingdom and Ireland (Excluding Isles of Scilly, English Channel to River Humber, Channel Islands and European Channel Ports)* (Vol. 1).

APPENDICES

A DRAWINGS



Notes

- 2019 Proposed Works Outline: Plan Area - 175,600m²
- Mean High Water Springs Derived from UKHO (2019). *Admiralty Tide Tables Volume 1B: United Kingdom and Ireland.*
- Site of Special Scientific Interest - Southannan Sands

Bathymetric Data Height Ranges (mCD)

- < -16
- < -14
- < -12
- < -10
- < -8
- < -6
- < -4
- < -2
- < 0

Engineering detail as produced by Arch Henderson (Refer to Drawing Numbers: 185060/251, 185060/351 and 185060/354).

Approximate Dredge Volumes calculated to Mean Low Water Springs by Envirocentre.

Levels outwith survey areas have been interpolated from interpolated from existing bathymetric and topographic data.

Do not scale this drawing

Rev	Date	Amendment	Initials
B	14/02/19	Dredge area increased	JS
A	14/02/19	Dredge area revised	JS

ENVIRO Centre

Craighall Business Park, Eagle Street, Glasgow, G4 9XA
Tel: 0141 341 5040
Fax: 0141 341 5045

Client
Peel Ports Group

Project
Hunterston Marine Yard

Title
Hunterston Construction Yard: Proposed Works Outline 2019

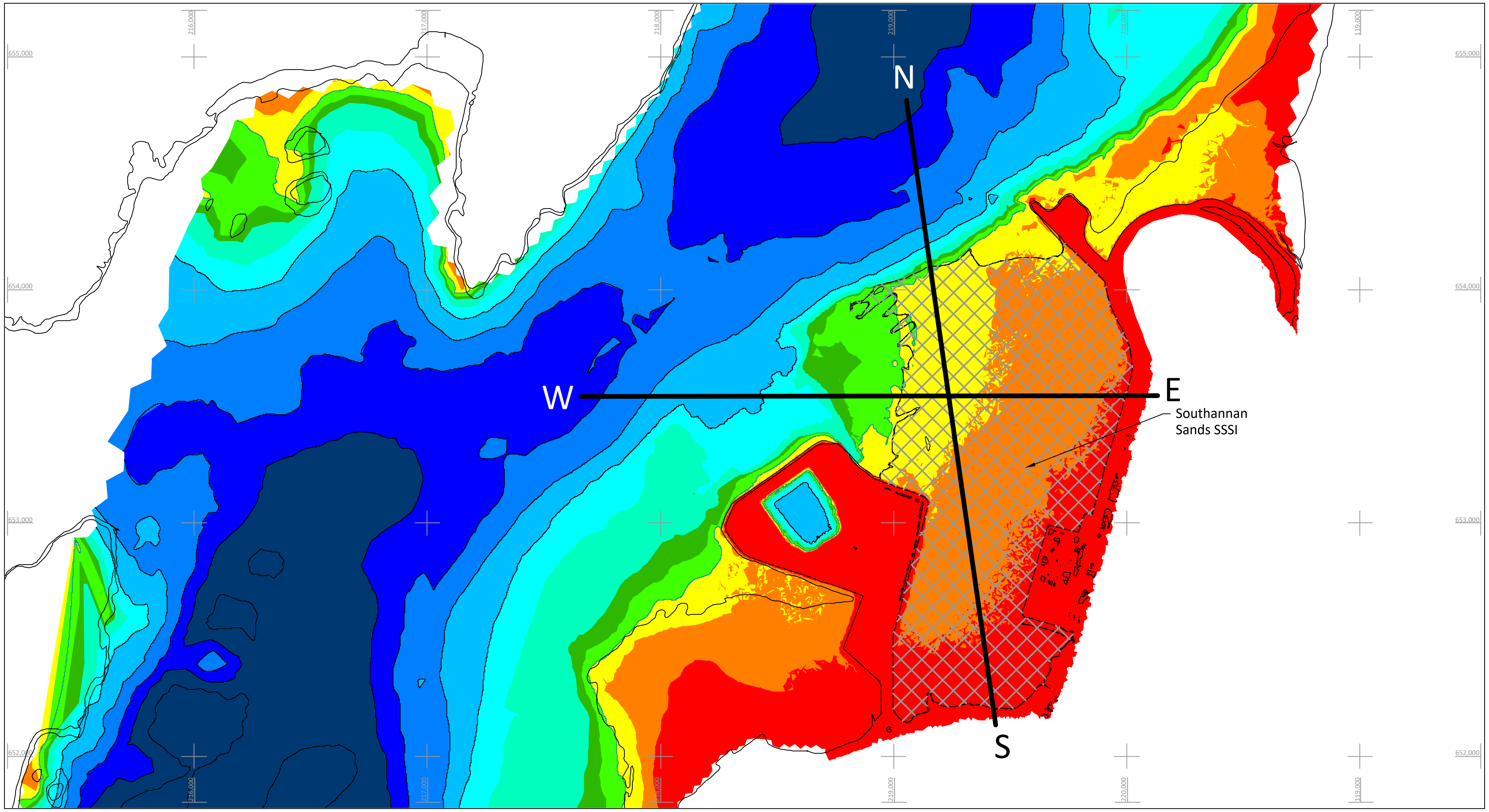
Status
FINAL

Drawing No.
168612-019

Revision
B

File path:s:\168612 hunterston\drgs\cad

Scale		Date
1:2,500	A3	7 February 2019
Drawn	Checked	Approved
JS	EC	CGF



Notes

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Depth range
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1 to 2 mCD
0 to 1 mCD
-1 to 0 mCD
-2 to -1 mCD
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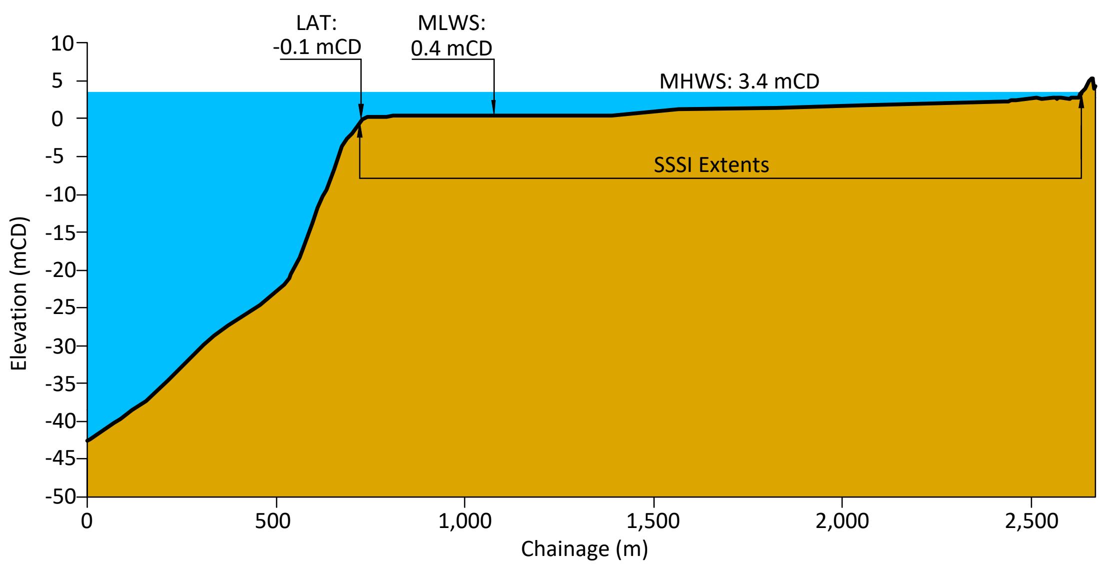
-10 to -5 mCD
-20 to - 10 mCD
-30 to -20 mCD
-40 to - 30 mCD
< -40 mCD



North to South Section (N-S)

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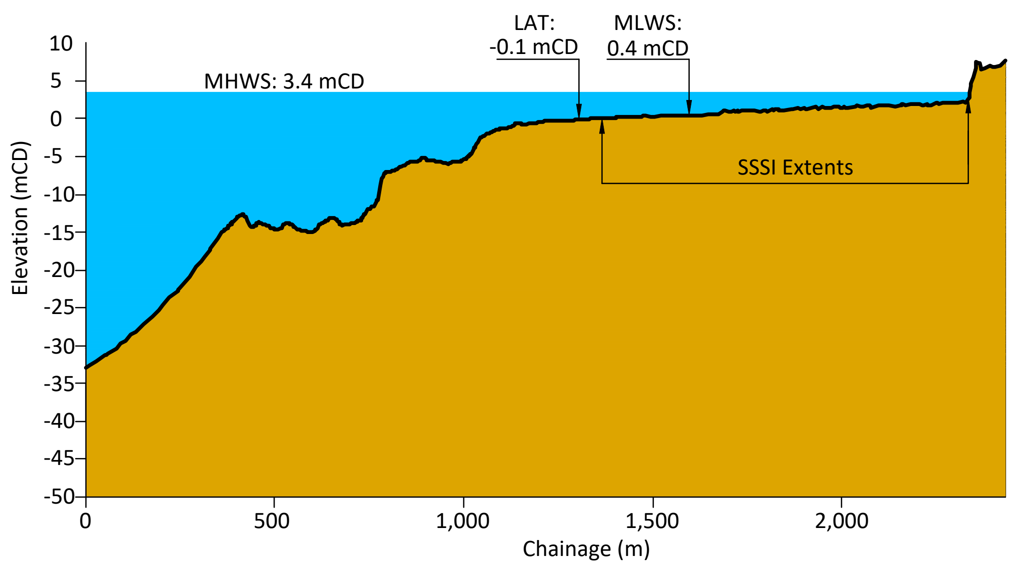
Vertical Scale 1:1,000



West to East Section (W-E)

Horizontal Scale 1:20,000
Vertical Scale 1:1,000

Do not scale this drawing

Rev	Date	Amendment	Initials

EnviroCentre
Craighall Business Park, Eagle Street, Glasgow, G4 9XA
Tel: 0141 341 5040
Fax: 0141 341 5045

Client: Peel Ports Group

Project: Hunterston Marine Yard

Title: Baseline Bathymetric Data

Status: FINAL

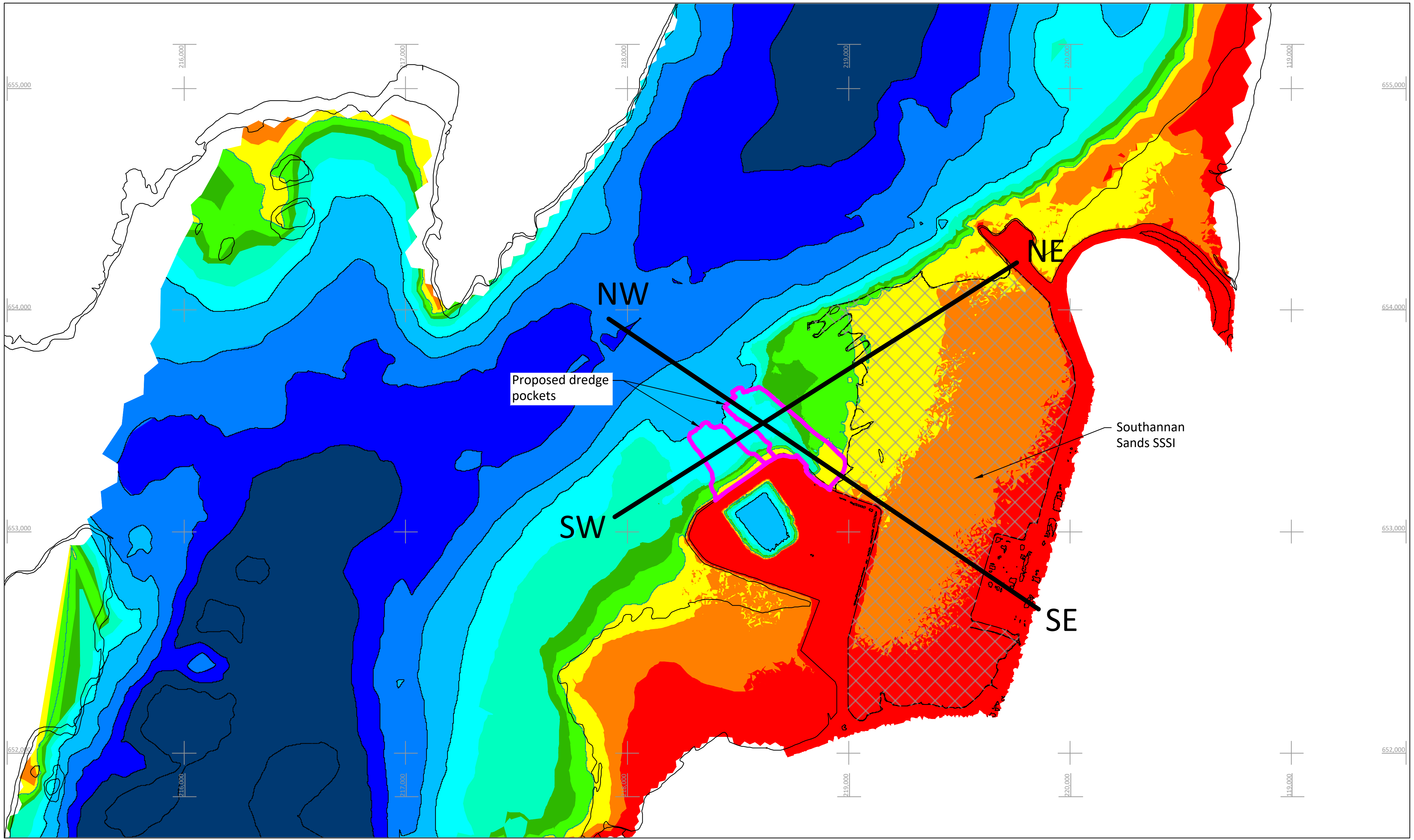
Drawing No.: 171500-001

Revision:

File path:s:\171500\drgs\cad

Scale: 1:20,000 | A3 | Date: 05 November 19

Drawn: JS | Checked: MN | Approved: KMD



Notes

Depth Range m Chart Datum (mCD)

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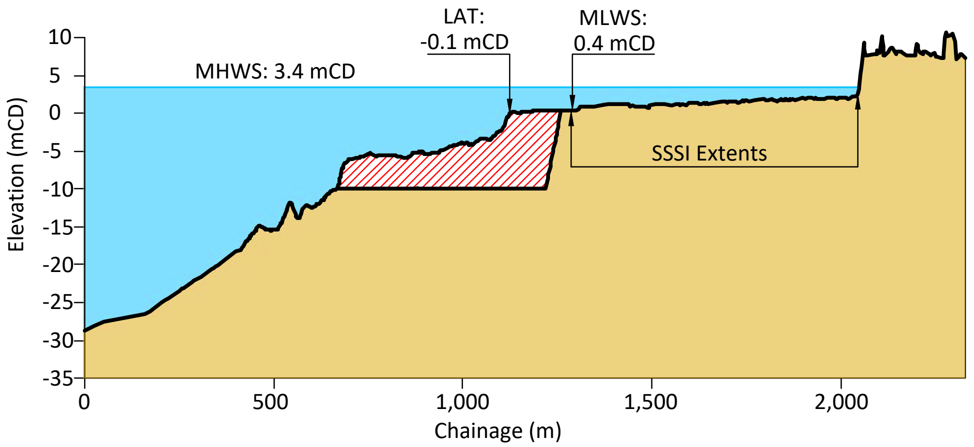
1 to 2 mCD	
0 to 1 mCD	
-1 to 0 mCD	
-2 to -1 mCD	
-5 to - 2 mCD	
-10 to -5 mCD	
-20 to - 10 mCD	
-30 to -20 mCD	
-40 to - 30 mCD	
□ -40 mCD	



Northwest to Southeast Section (NW-SE)

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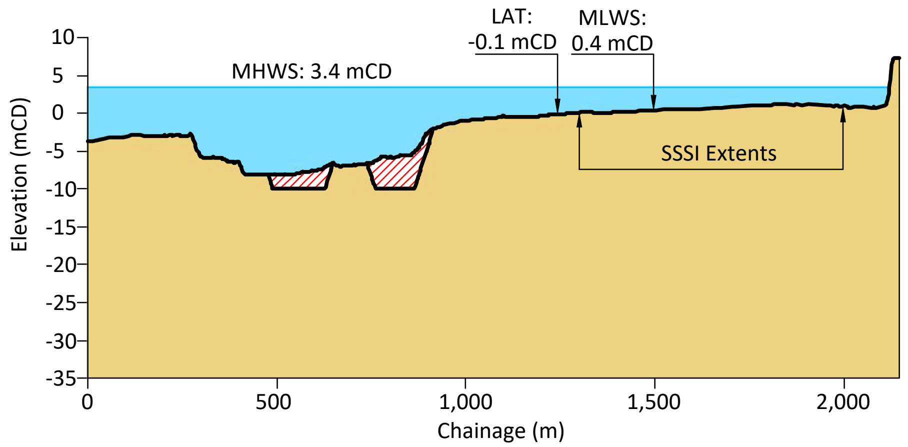
Vertical Scale 1:1,000



Southwest to Northeast Section (SW-NE)

Hori□ontal Scale 1:20,000
Vertical Scale 1:1,000

Do not scale this drawing

Rev	Date	Amendment	Initials

ENVIRO Centre
Craighall Business Park, Eagle Street, Glasgow, G4 9XA
Tel: 0141 341 5040
Fax: 0141 341 5045

Client: Peel Ports Group

Project: Hunterston Marine Yard

Title: Baseline and Proposed Dredge Bathymetric Data

Status: FOR INFORMATION

Drawing No.: 171500-002

Revision:

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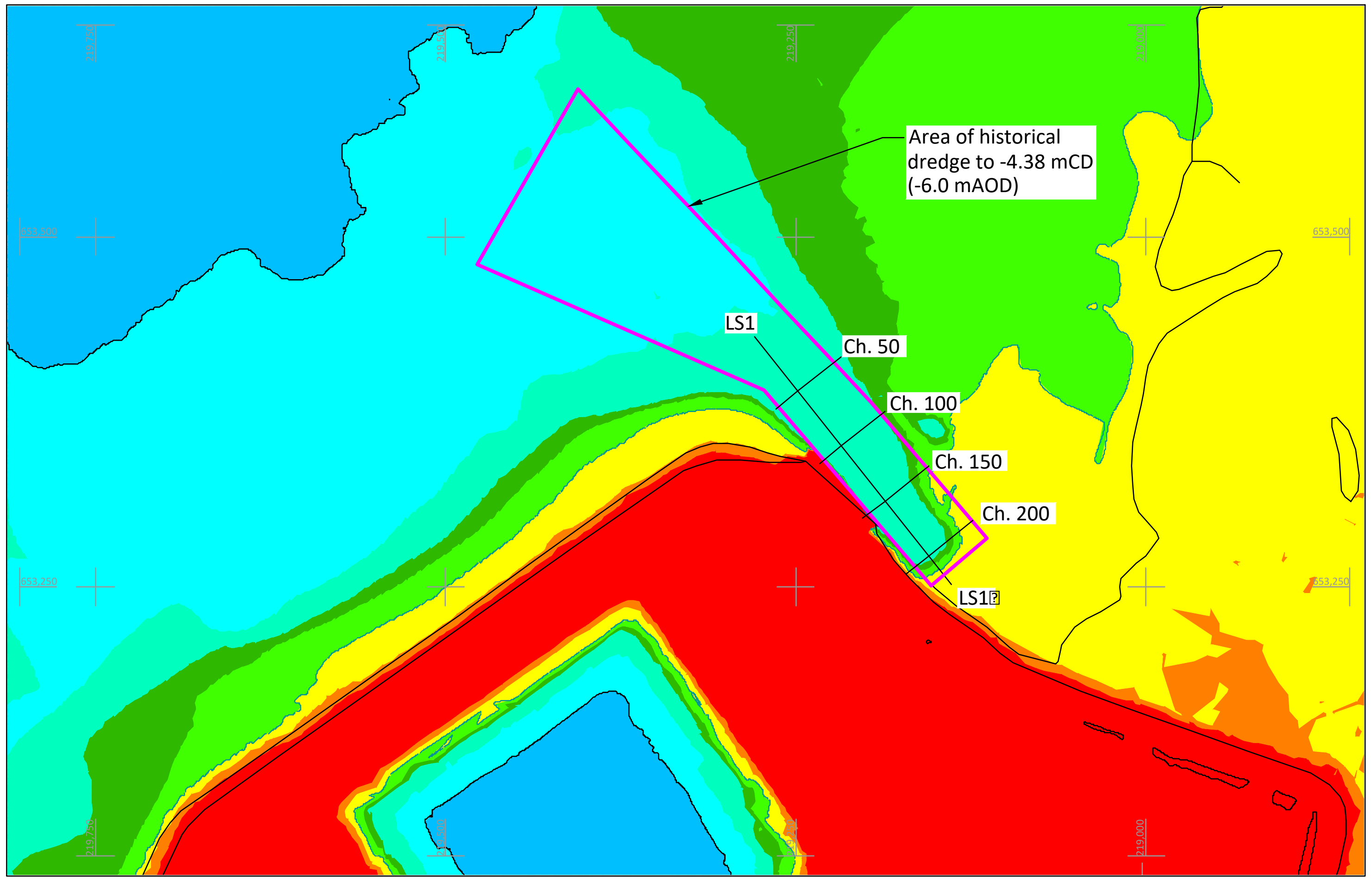
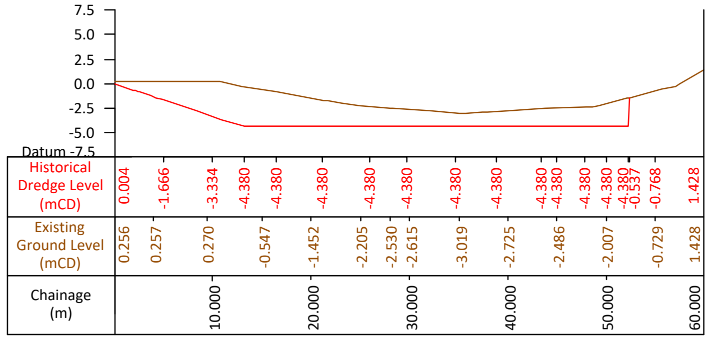
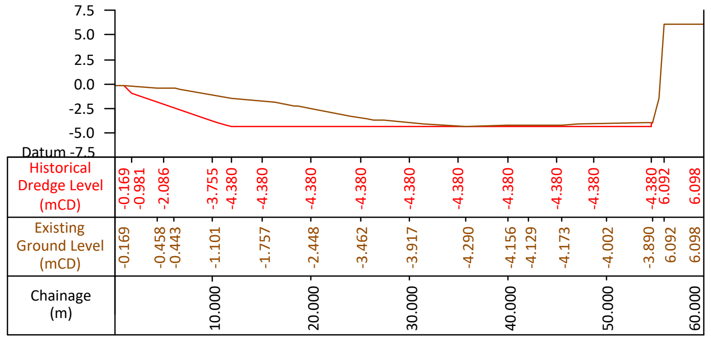
Drawn	Checked	Approved
JS	MN	KMD





Cross Section 200m Chainage

Scale 1:750



Cross Section 150m Chainage

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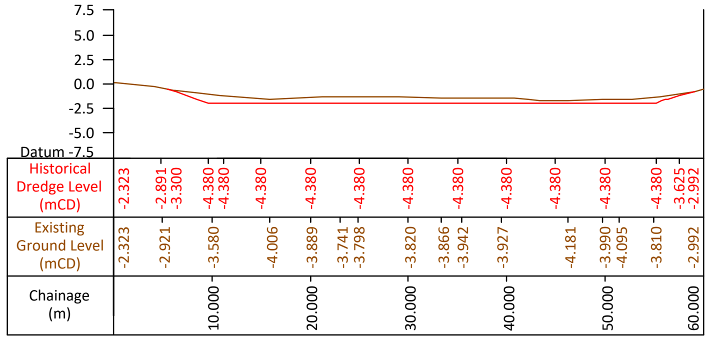

Cross Section 50m Chainage

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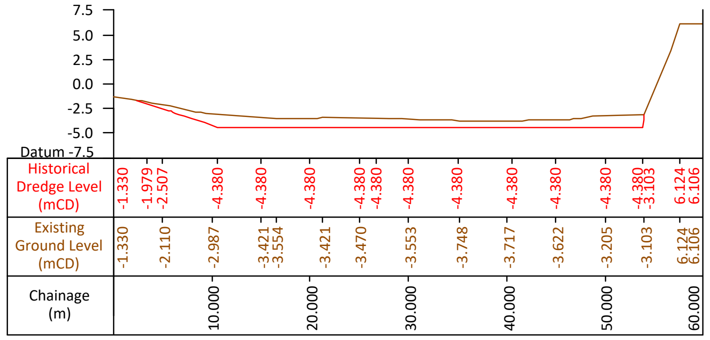
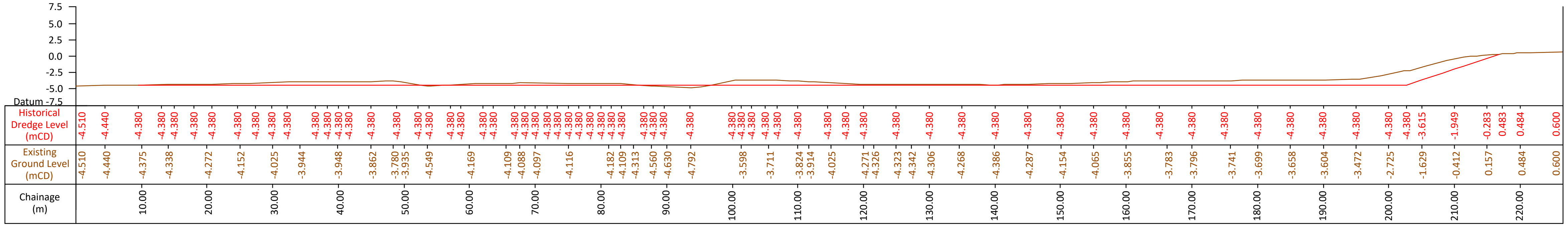


Cross Section 100m Chainage

Scale 1:750



Long Section (LS1 - LS1)

Scale 1:750

Notes

Depth Range m Chart Datum (mCD)

- 2 mCD
- 1 to 2 mCD
- 0 to 1 mCD
- -1 to 0 mCD
- -2 to -1 mCD
- -5 to - 2 mCD
- -10 to -5 mCD
- -20 to - 10 mCD
- -30 to -20 mCD
- -40 to - 30 mCD
- -40 mCD

Historical dredge extent as per Ayrshire Marine Constructors Drawing ref 2073/02/42 dated 08/79.

Do not scale this drawing

Rev	Date	Amendment	Initials

ENVIRO Centre
Craighall Business Park, Eagle Street, Glasgow, G4 9XA
Tel: 0141 341 5040
Fax: 0141 341 5045

Client: Peel Ports Group

Project: Hunterston Marine Yard

Title: Baseline Bathymetric Data and Historical Dredge Extent

Status: FOR INFORMATION

Drawing No.: 171500-003 | Revision:

File path:s:\171500\drgs\cad

Scale	A3	Date
1:5,000		05 November 19

Drawn	Checked	Approved
JS	MN	KMD

B GEOLOGICAL REVIEW

Desk Study Appraisal – Geological Formation of Southannan Sands

1. Introduction

Southannan Sands is located on the Firth of Clyde between Fairlie and Hunterston House. It is the location of the Hunterston Construction Yard, and a disused coal terminal which has a large jetty, known as Hunterston Terminal. These two industrial sites sub-divide Southannan Sands into Fairlie Sands north of the Terminal and jetty, Southannan Sands between the Terminal and the Construction Yard, and Hunterston Sands south of the Construction Yard. The three make up the Southannan Sands Site of Special Scientific Interest (SSSI), as designated by Scottish National Heritage (SNH).

This investigation has observed the sedimentary nature of the land form through a series of pre-existing boreholes to interpret the depositional origins of the site. This will be covered through the following sections of this report:

- Borehole data and sedimentary descriptions;
- Depositional controls and landform interpretation; and
- Conclusions.

2. Borehole Data and Sedimentary Descriptions

There have been a large number of boreholes drilled within and around Southannan Sands as part of the development of the industrial sites which are now located there. Twenty-nine of these boreholes have been examined to build an understanding of how the superficial sediments in this area have been deposited, and are shown in Table 1.

Overall, a general sedimentary pattern emerged from these sediments. In most boreholes, there were three notable beds of superficial strata:

i. first a layer of loose sediment, commonly recorded as a silty sand;
ii. below the loose sediment, a bed of dense silty clayey sand with shell fragments; and
iii. finally, a bed of firm boulder clay which laid on top of the bedrock.

Each of these three layers displayed some textural variation across the area, maybe most notably with the boulder clay which varied with its sorting. There were occasional firm clay beds which did not have other clastic material within it, although these were still considered as being part of the boulder clay layer.

There was some variation in the thicknesses of the loose silty sands and dense silty clayey sands across the area. This is partially due to the depositional setting, though human judgement is also likely a part of this too, as the two beds are similar in their texture and composition.

Approximately half of the boreholes penetrated into the bed rock below the boulder clay bed. The underlying bedrock was consistently red – quartzitic sandstones and conglomerates, resembling the Upper Devonian sandstones which outcrop in that area.

From the borehole logs, the reduced level of the surface, the thickness of loose sediment, the reduced level depth to the boulder clay, and the reduced level depth to the bed rock head have been recorded for building geological models (Figures 1, 2, 3, and 4).

Number	Name	E	N	Year Drilled	Drilled for
1	HOT 2	219044	654473	1971	Clyde Port Authority
2	HOT 3	219072	654485	1971	Clyde Port Authority
3	HOT 4	219109	654530	1971	Clyde Port Authority
4	HOT 7	219139	654564	1971	Clyde Port Authority
5	HOT 8	219162	654658	1971	Clyde Port Authority
6	HOT 11	219305	654749	1971	Clyde Port Authority
7	HOT 17	219357	654306	1971	Clyde Port Authority
8	HOT 19	219496	654240	1971	Clyde Port Authority
9	HOT 12A	219447	654949	1971	Clyde Port Authority
10	HOT 14A	219143	654407	1971	Clyde Port Authority
11	HMS 12	218550	652600	1975	BGS
12	HMS 11	218400	653000	1975	BGS
13	HMS 14	219250	653400	1975	BGS
14	HMS 6	218800	653000	1975	BGS
15	HMS 8	218650	653500	1975	BGS
16	HMS 10	218500	653300	1975	BGS
17	HMS 15	219350	653800	1975	BGS
18	HMS 4	218950	653900	1975	BGS
19	HMS 26	219220	653870	1975	BGS
20	HMS 5	218650	653950	1975	BGS
21	HMS 13	219000	653200	1975	BGS
22	HMS 7	218400	653700	1975	BGS
23	HMS 9	218300	653500	1975	BGS
24	HOT 24	220000	653925	1971	Clyde Port Authority
25	HOT DR4	219698	653040	1975	Clyde Port Authority
26	HOT DR57	219736	652577	1975	Clyde Port Authority
27	HOT DR53	219672	652857	1975	Clyde Port Authority
28	HOT 26	220198	653846	1971	Clyde Port Authority
29	HOT E18	219806	652294	1973	Clyde Port Authority

Table 1: The boreholes and their locations used to build an understanding of the depositional environment of the superficial sediments at Southannan Sands. HOT – Hunterston Ore Terminal; HMS – Hunterston Marine Study. Borehole data sourced from GeoRecordsPlus.

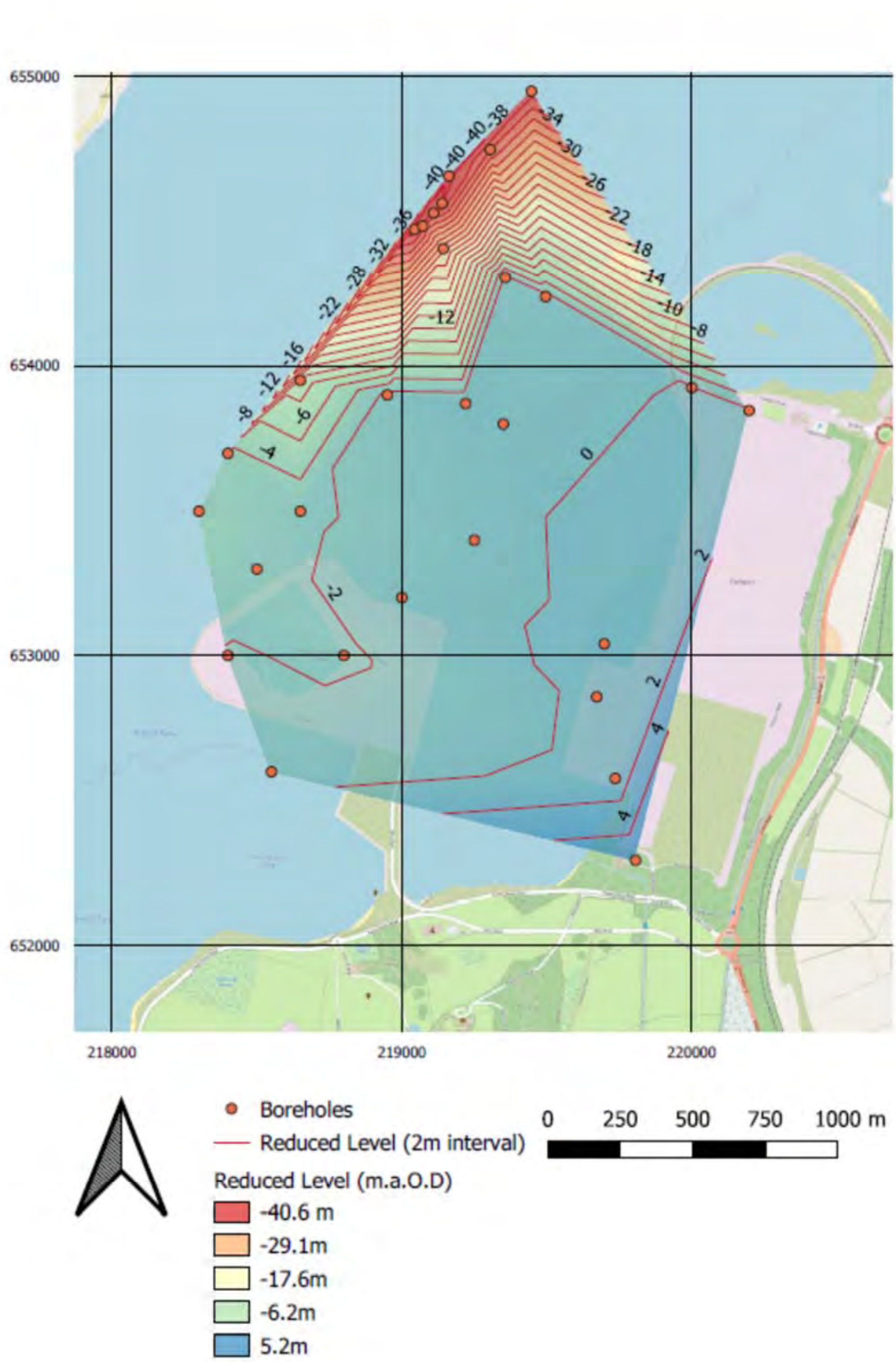


Figure 1: The reduced level to the sediment surface. Modelled using borehole data and QGIS.

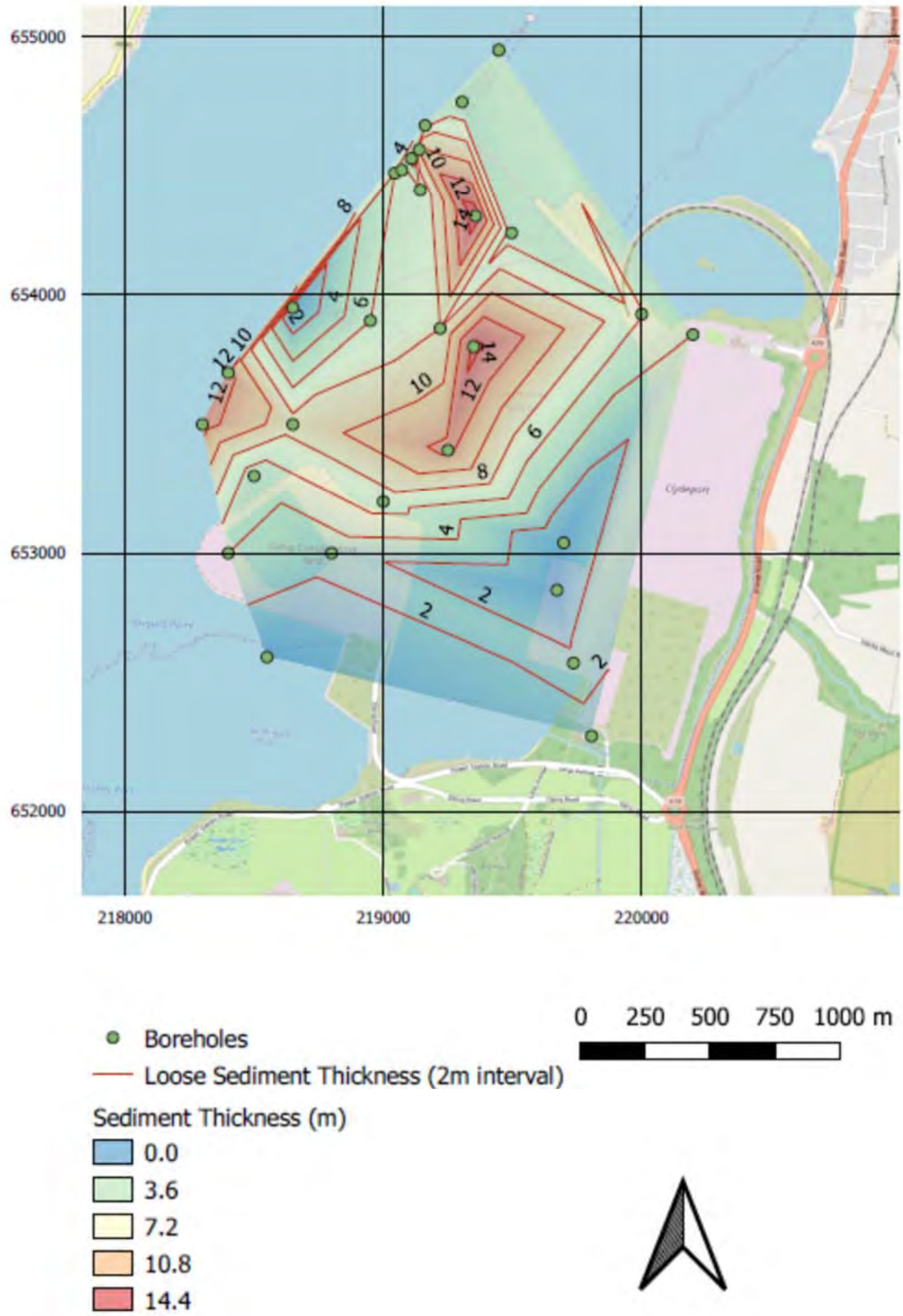


Figure 2: The thickness of superficial sediment specifically identified as loose in the borehole logs. Modelled using borehole data and QGIS.

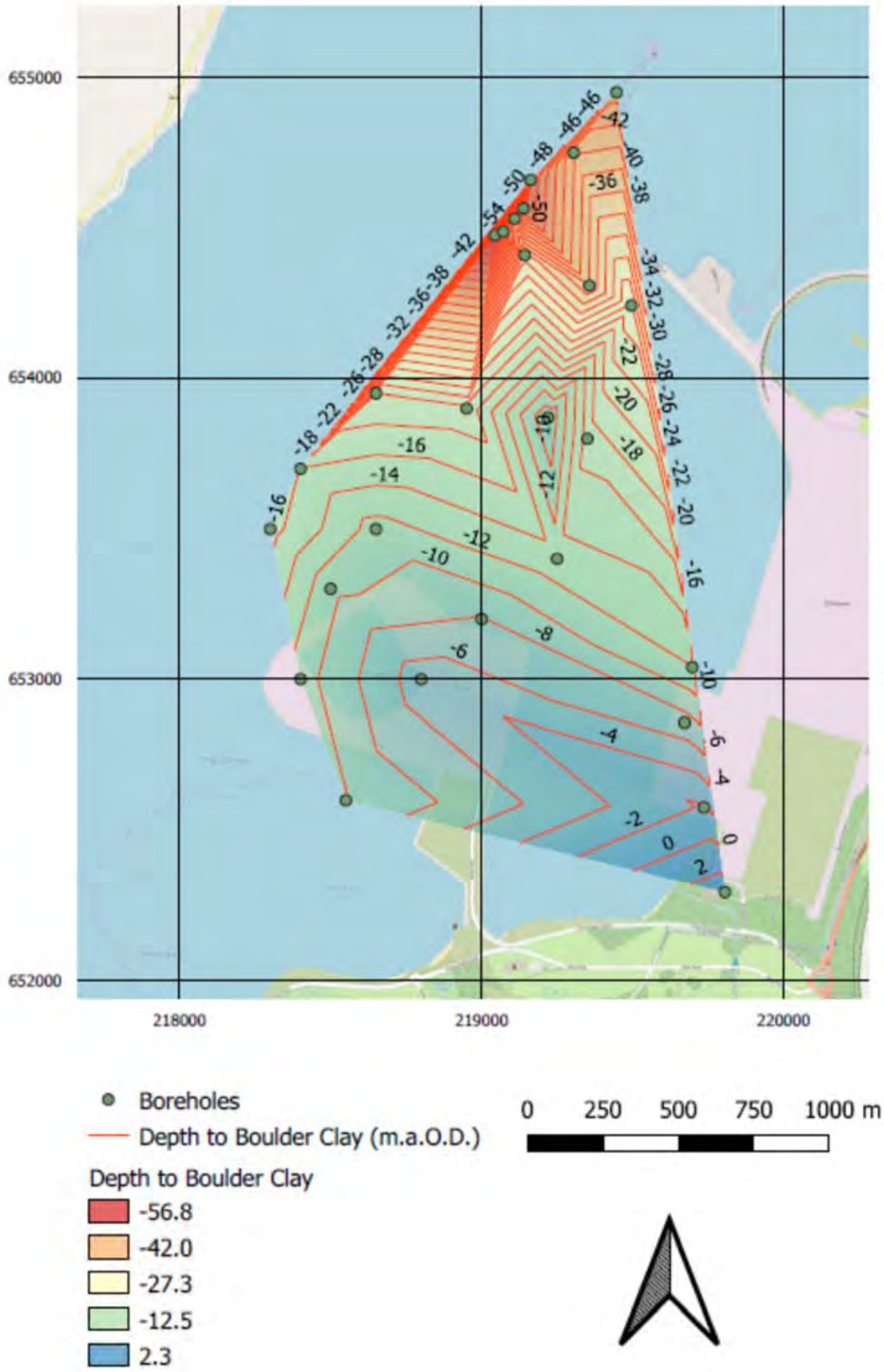


Figure 3: The reduced level depth to the boulder clay. Modelled using borehole data and QGIS.

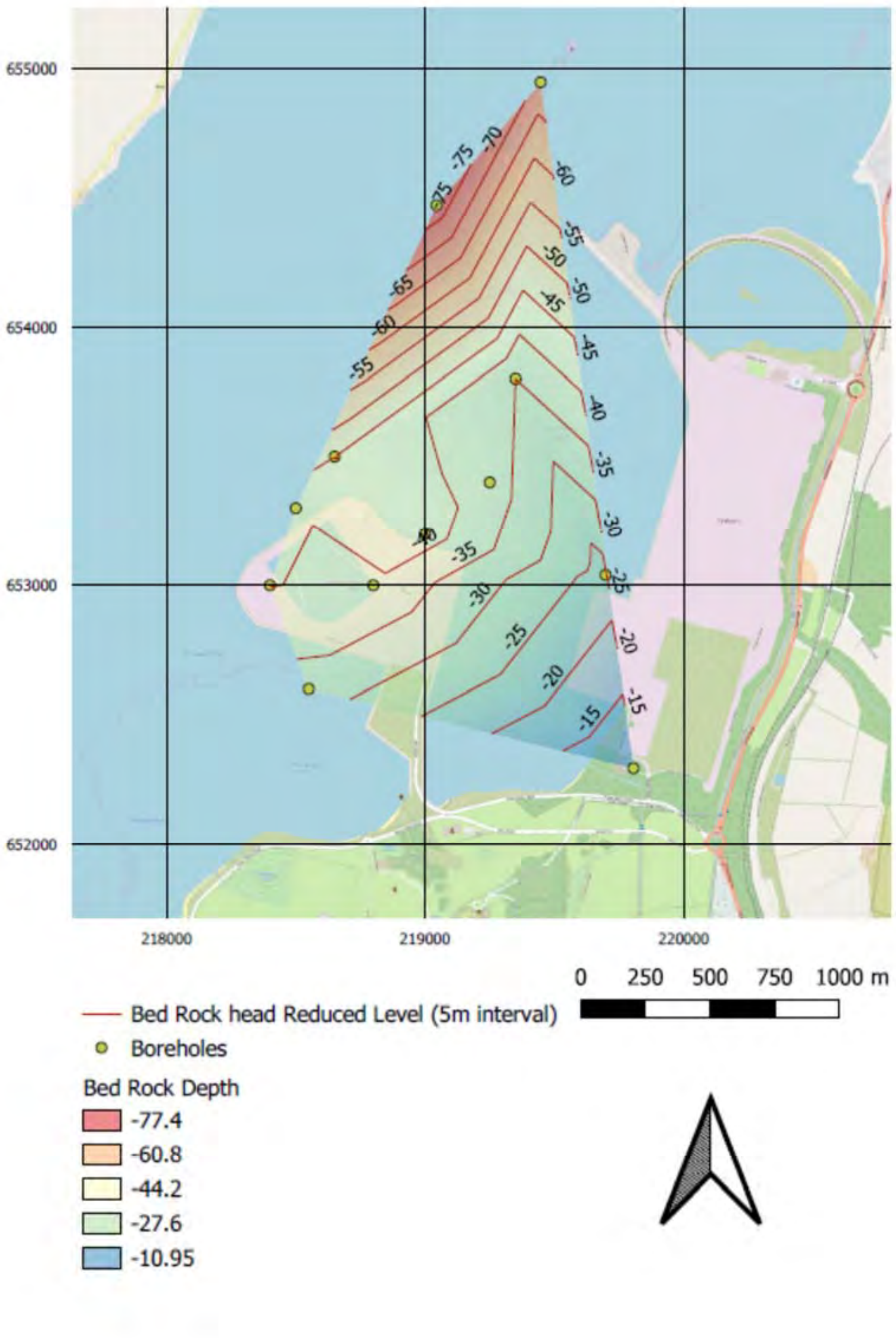


Figure 4: The reduced level depth to the bed rock. Modelled using borehole data and QGIS.

3. Depositional Conditions and Landform Interpretation

On the BGS geological map, the superficial sediments are recorded as being marine sands and gravels, though the material in the boreholes does not reflect this. The superficial sediments observed in the Southannan Sands boreholes indicate three phases of deposition under glacial, fluvial, and marine conditions. They also form an interesting geomorphological feature, which has been controlled by the other local land forms.

The dominant hard-rock landform which has driven the formation of the geomorphological feature is the Hunterston headland, where the Hunterston power station is located, at the southern boundary of Southannan Sands SSSI. The headland comprises igneous rocks associated with the Clyde Plateau Volcanics. These rocks were much more resistant to Pleistocene glacial erosion than the Upper Devonian sandstones and conglomerates, which comprise the majority of the bedrock along the coast and in the Firth.

The bed rock model can be used to interpret the conditions prior to the deposition of the superficial sediments. The depth to the bed rock generally increases toward the sea (Fairlie Roads), forming a north-west facing slope and reaching a depth of 75m below ground level at the deepest measured point. This steepest part of sloping bed rock is from the edge of Southannan Sands into the Firth. The topography of the slope suggests a landform more typical of fluvial erosion, with a steep sided "V" shaped valley. This may be a result of fluvial erosion as part of the multiple lesser glacial and interglacial stages which occurred prior to the Pleistocene glaciation.

Directly above the bedrock lies the boulder clay layer, indicating the oldest depositional environment of the superficial sediments was glacially controlled. The modelled top of the boulder clay indicates an interesting depositional feature, in that it has accumulated directly behind the headland, and slopes away to the north. This indicates the headland not only resisted glacial erosion, but acted as a depositional point for glacial material. This material will have been deposited during a glacial period of the Pleistocene, when sea levels were considerably lower than in the present time.

As the glacial period passed over to the current interglacial, the water stored as ice within the glaciers was released, returning the sea level to its current position. The water will have been returned from the glaciers to the sea by glacial outwash rivers, which have considerable erosive power. The steep slope of the boulder clay toward the centre of the Firth could be an indication of such a fluvial system, though no depositional evidence has been identified.

Through the Holocene, Southannan Sands has been further built by intertidal marine deposition. Over-lying the boulder Clay is a reasonably consistent bed of dense silty, clayey sand with shell fragments. This indicates a low energy and reasonably stable marine environment where this material has been able to accumulate.

The upper most layer, the loose sediment, is the most recent deposit in this area. It is almost identical to the dense sand layer which underlies it, though has not been compacted. The thickest layers of loose sediment have accumulated on the north facing slope of the boulder clay where there has been the most space to accommodate the material. This material is likely still accumulating slowly under conditions more akin to a mid to distal fluvial fan than to other coastal and marine depositional settings. Likely due to the clay content, this material has enough cohesive strength to have remained essentially unchanged in form since the earliest maps of this area were produced, despite the introduction of the significant industrial sites.

4. Conclusions

The borehole data has revealed an interesting geomorphological landform, in what appears to be a submerged crag and tail glacial feature. The boulder clay which this feature comprises is a very firm clay which is overlain by dense sediment. The current depositional environment is allowing for the steady accumulation of a cohesive material which has resisted the changes brought to it by industrial development (Figure 5). Its resistance to these changes is almost certainly due to its textural characteristics, which give the material a cohesive nature.

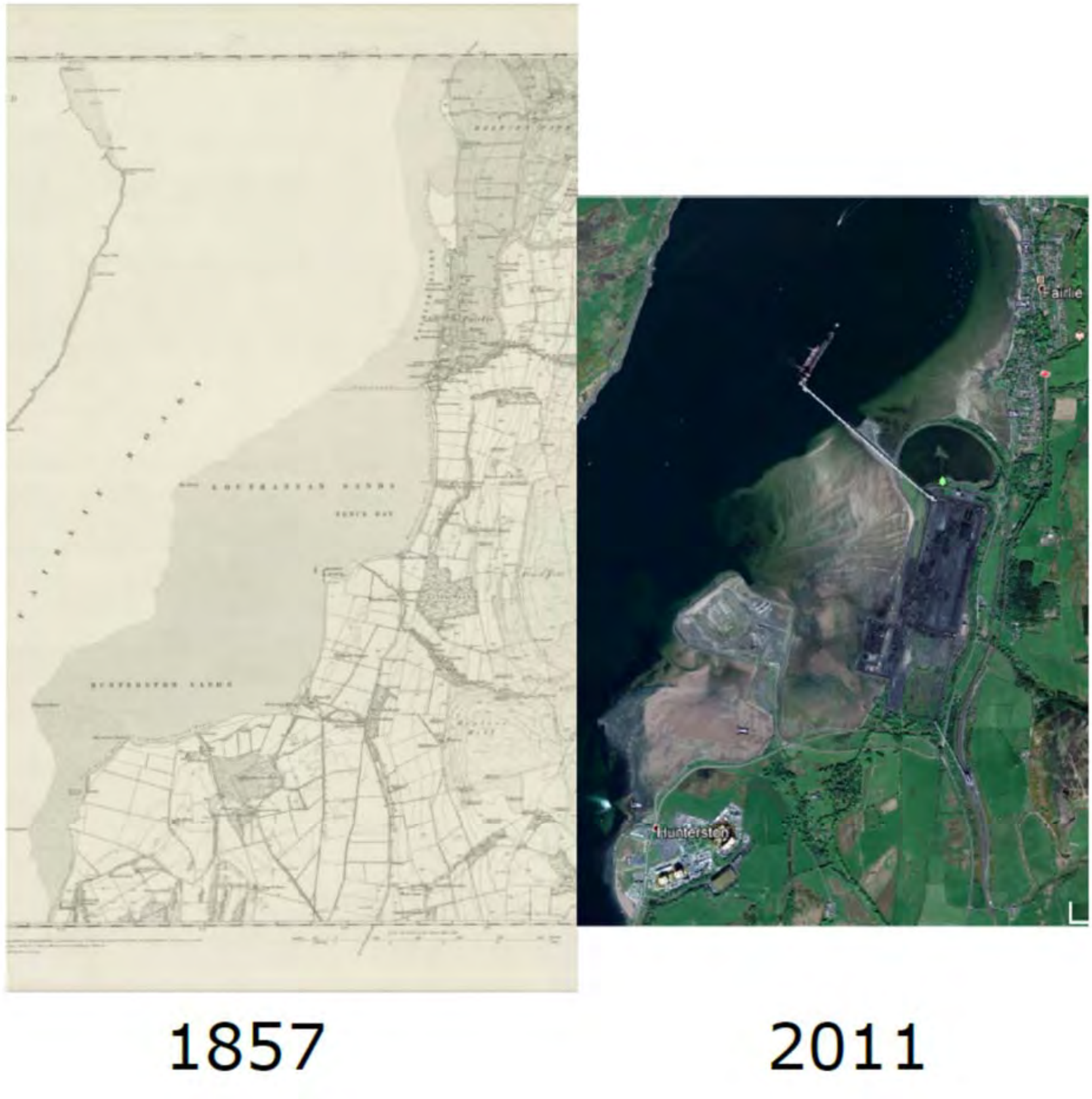
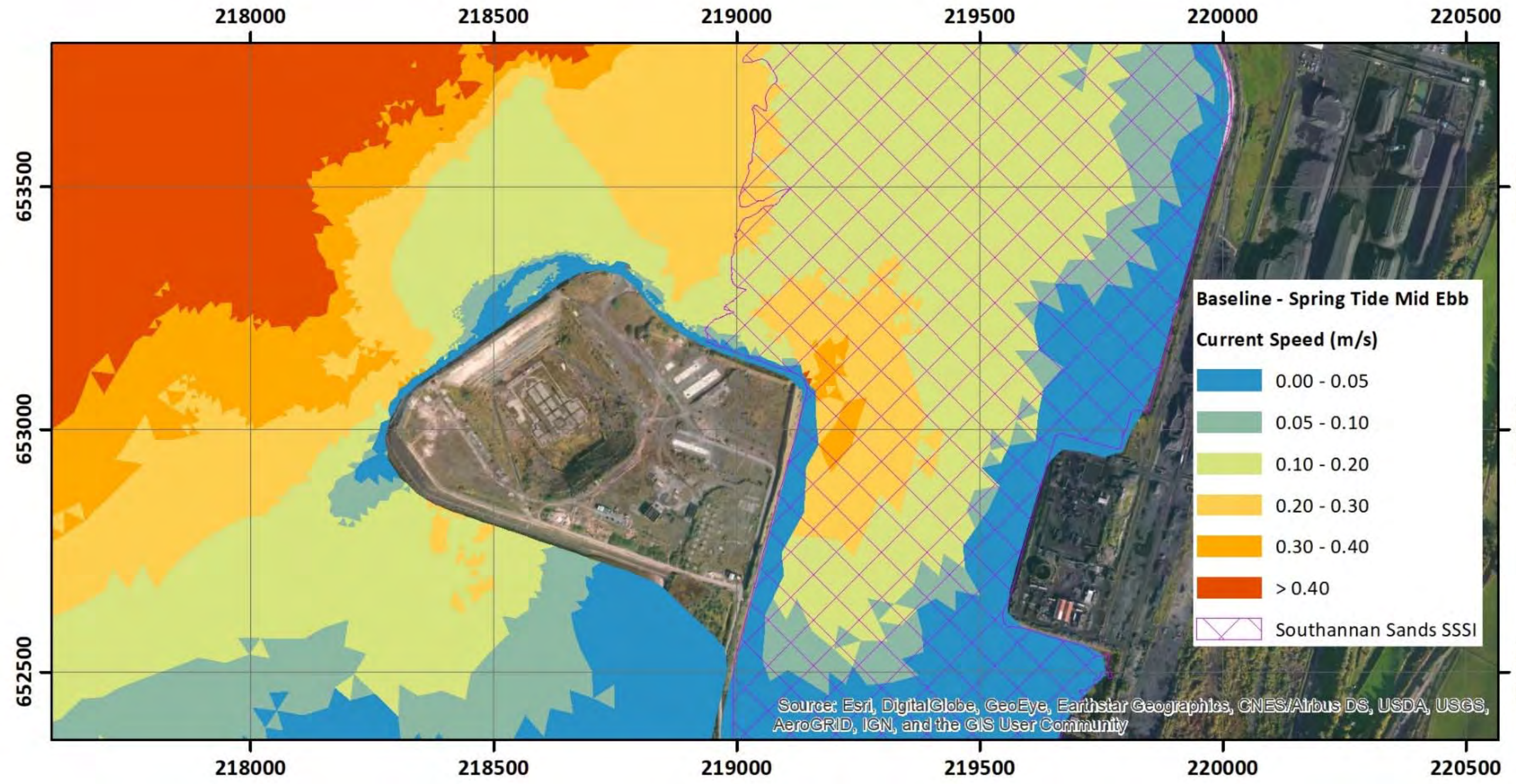


Figure 5: Despite the industrial development of the site, the superficial sediments that make up Southannan Sands have remained unchanged in over 150 years. (Sources; 1857 map, National Library of Scotland [online]; 2011 aerial image, Google Earth)

C HYDRODYNAMIC MODEL RESULTS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0.10 - 0.20
0.20 - 0.30
0.30 - 0.40
> 0.40
Southannan Sands SSSI
218000
218500
219000
219500
220000
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653500
653000
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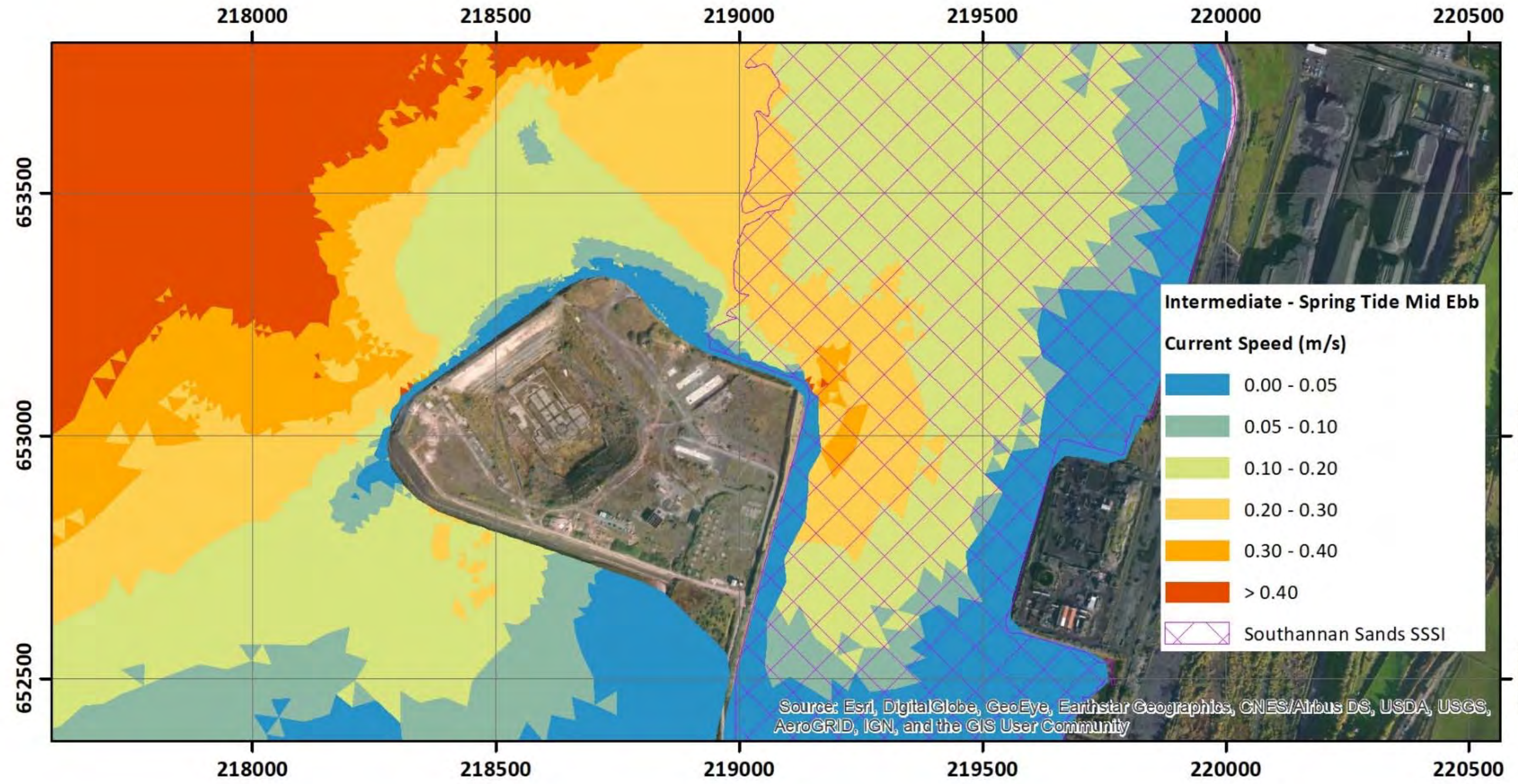
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community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Current Speed (m/s)
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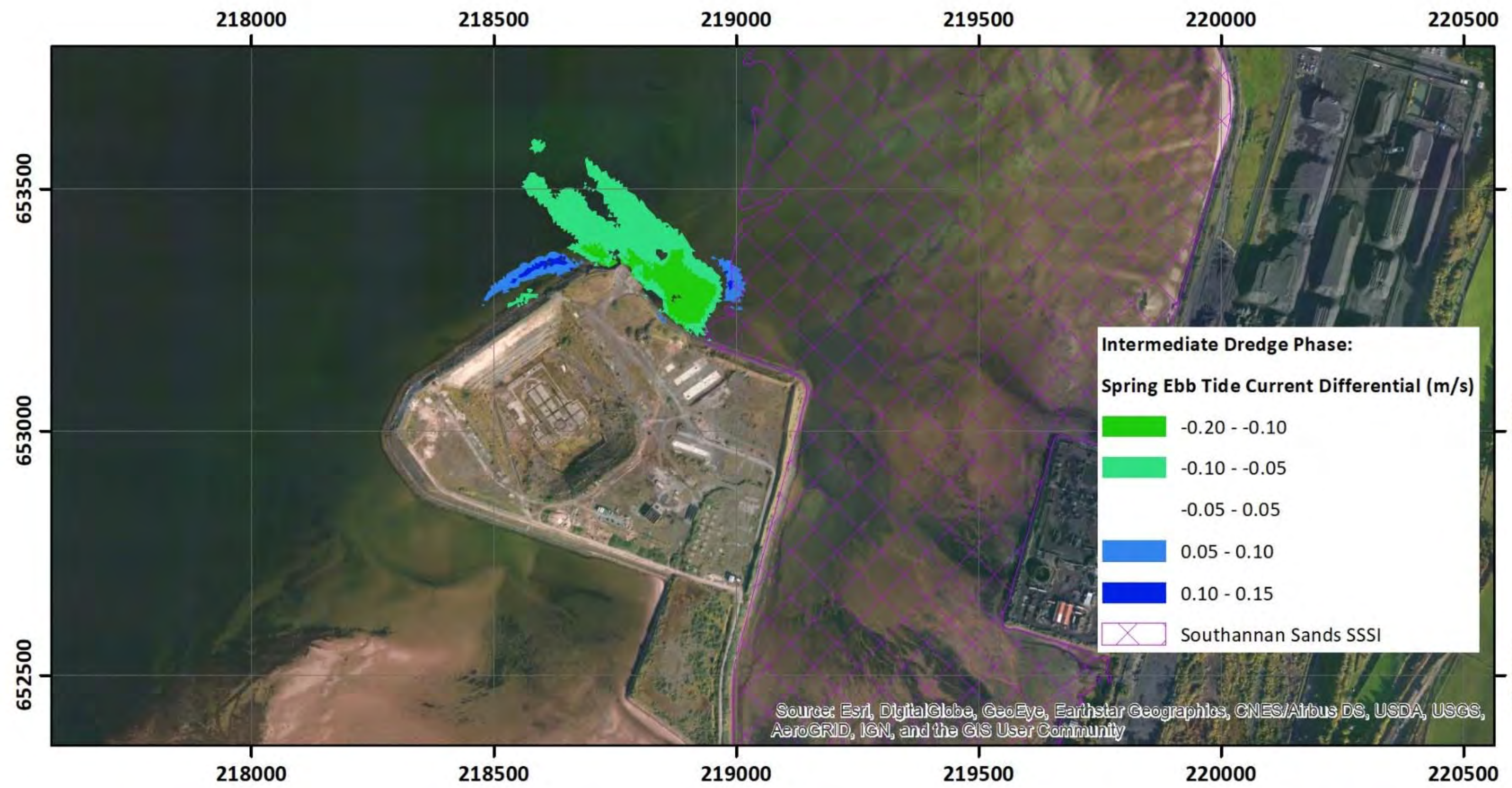
0.05 - 0.10
0.10 - 0.20
0.20 - 0.30
0.30 - 0.40
> 0.40
Southannan Sands SSSI
218000
218500
219000
219500
220000
220500
653500
653000
652500
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community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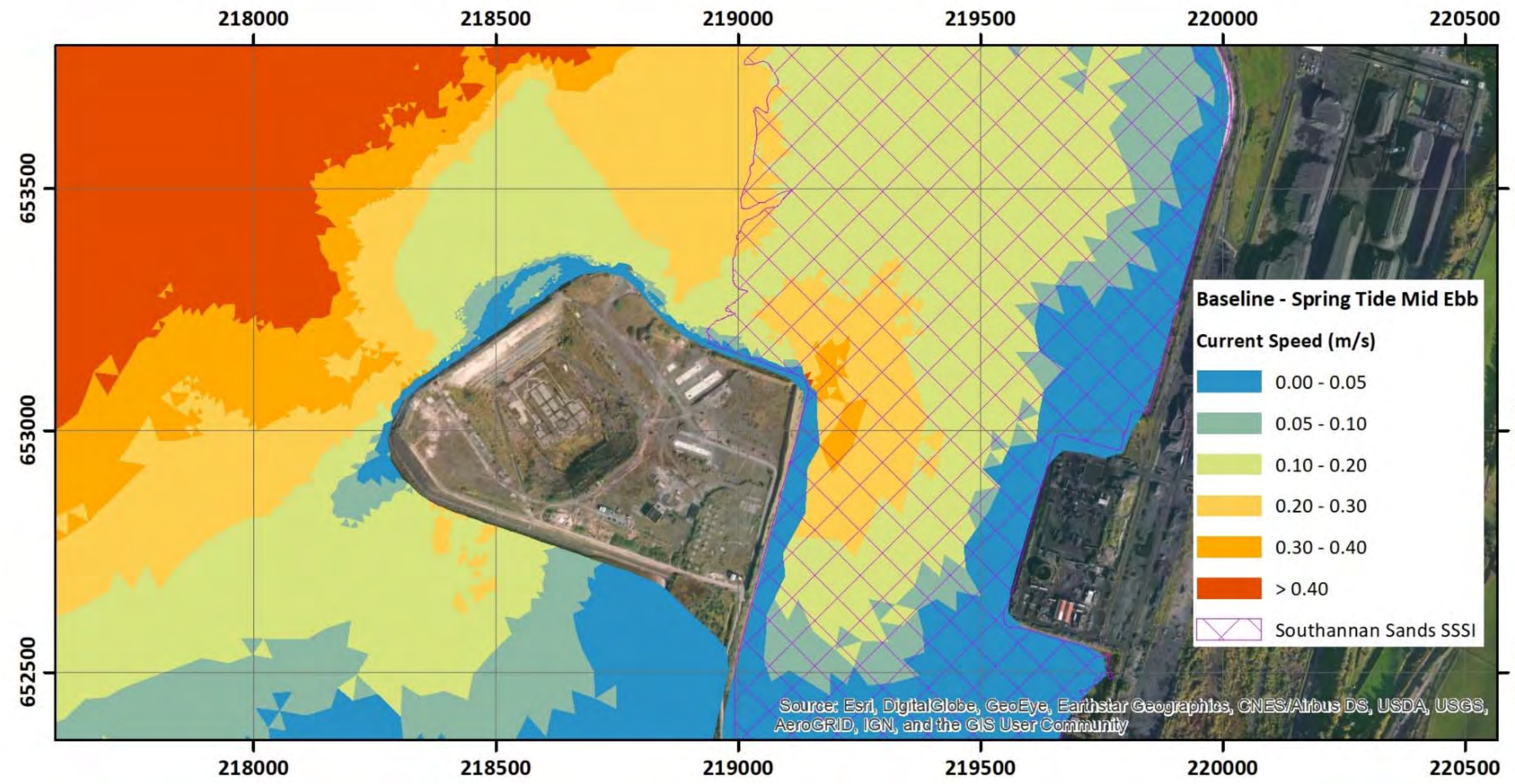
Spring Ebb Tide Current Differential (m/s)
-0.20 - -0.10
-0.10 - -0.05
-0.05 - 0.05
0.05 - 0.10
0.10 - 0.15
Southannan Sands SSSI
218000
218500
219000
219500
220000
220500
653500
653000
652500
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community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Current Speed (m/s)
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0.20 - 0.30
0.30 - 0.40
> 0.40
Southannan Sands SSSI
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
218000
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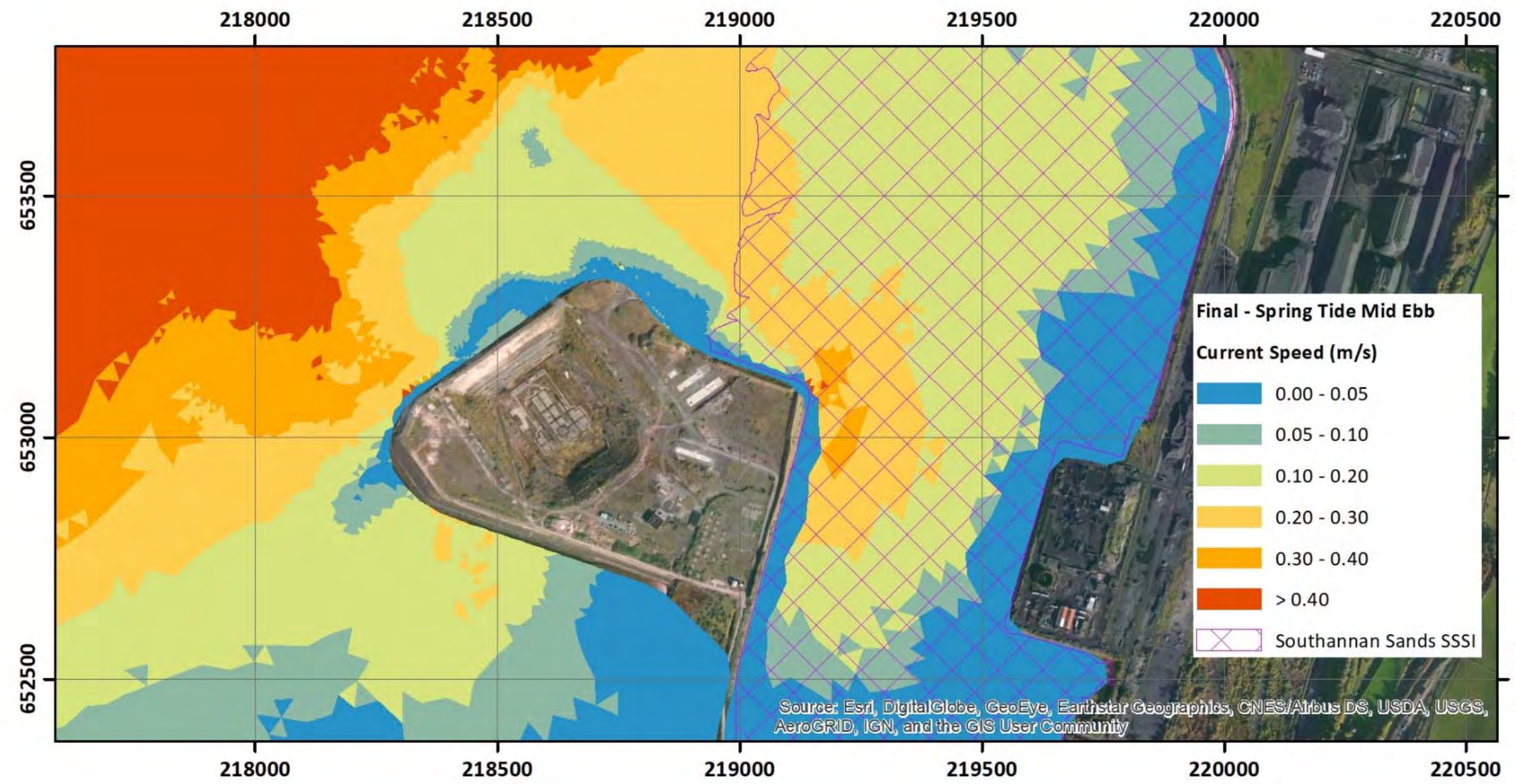
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Current Speed (m/s)
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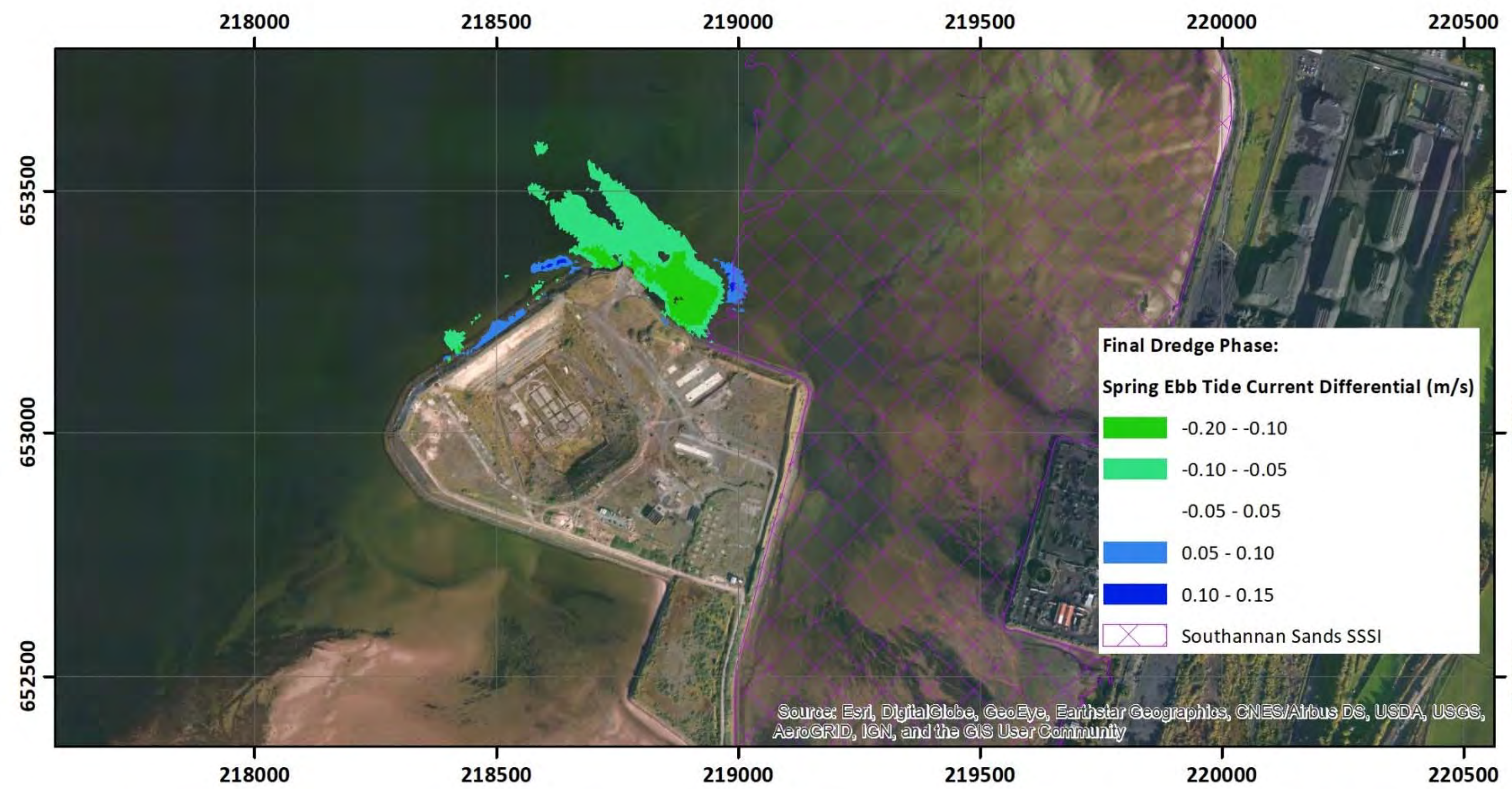
0.20 - 0.30
0.30 - 0.40
> 0.40
Southannan Sands SSSI
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
218000
218500
219000
219500
220000
220500
653500
653000
652500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Spring Ebb Tide Current Differential (m/s)
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-0.10 - -0.05
-0.05 - 0.05
0.05 - 0.10
0.10 - 0.15
Southannan Sands SSSI
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
218000
218500
219000
219500
220000
220500
653500
653000
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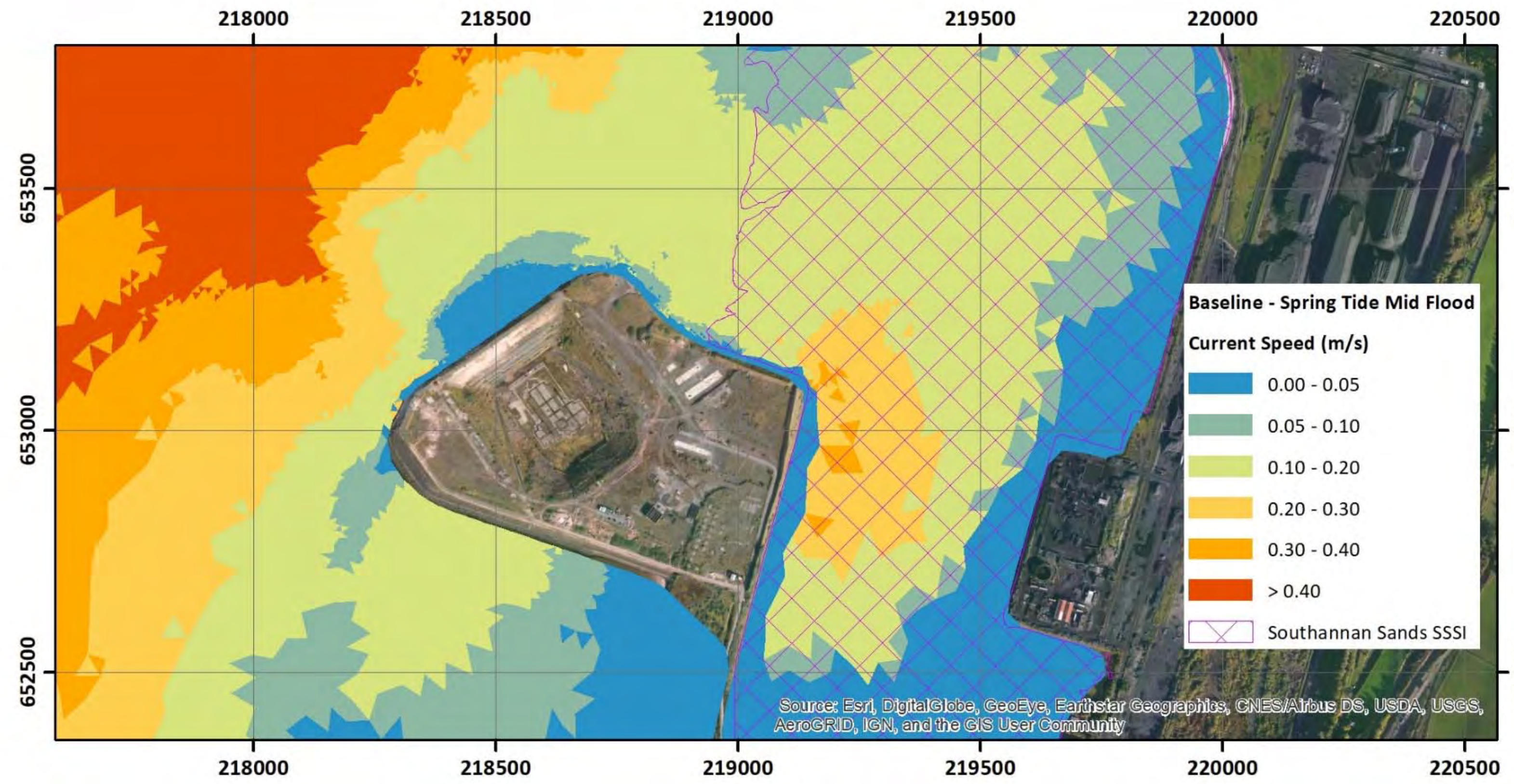
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Current Speed (m/s)
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0.05 - 0.10
0.10 - 0.20
0.20 - 0.30
0.30 - 0.40
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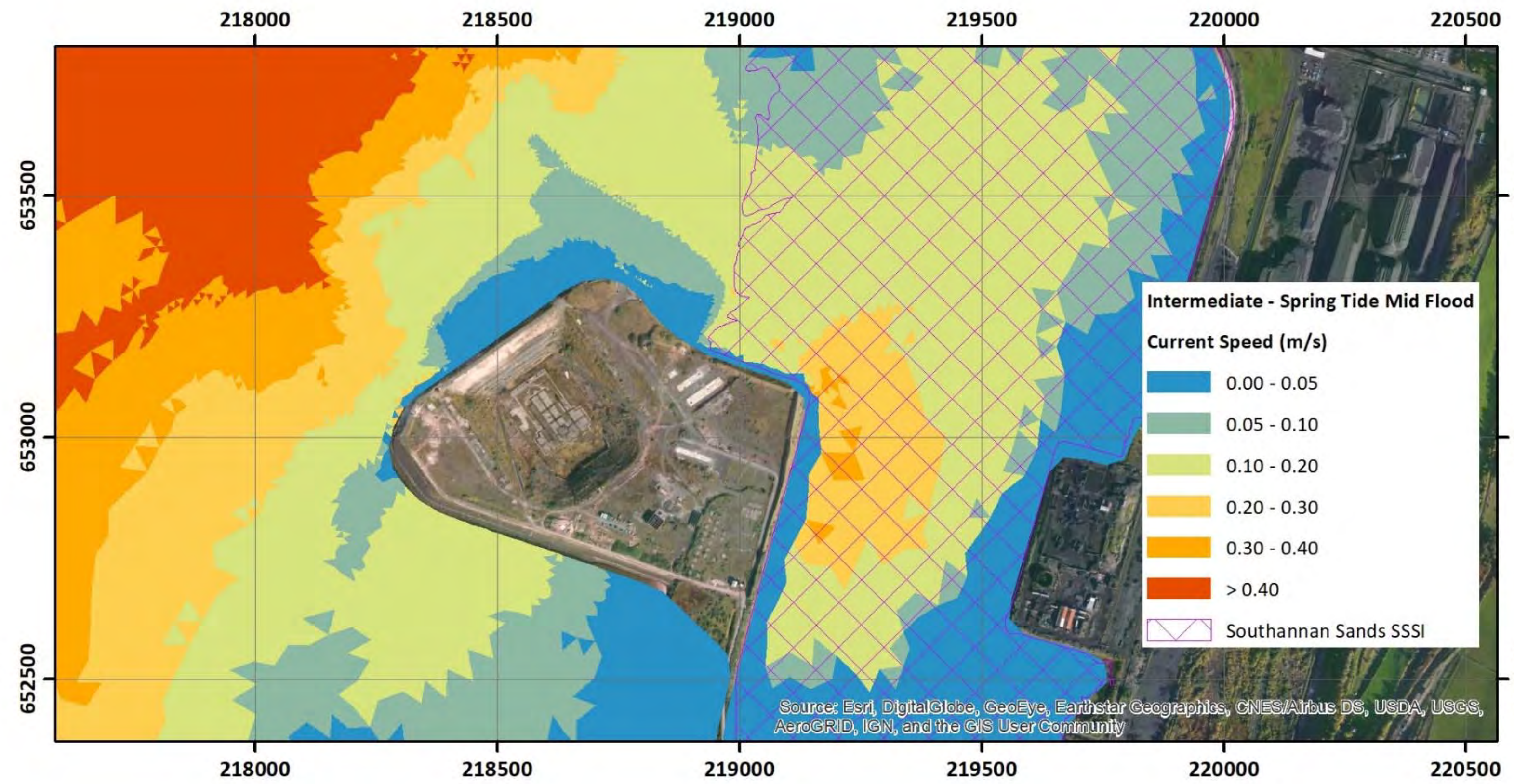
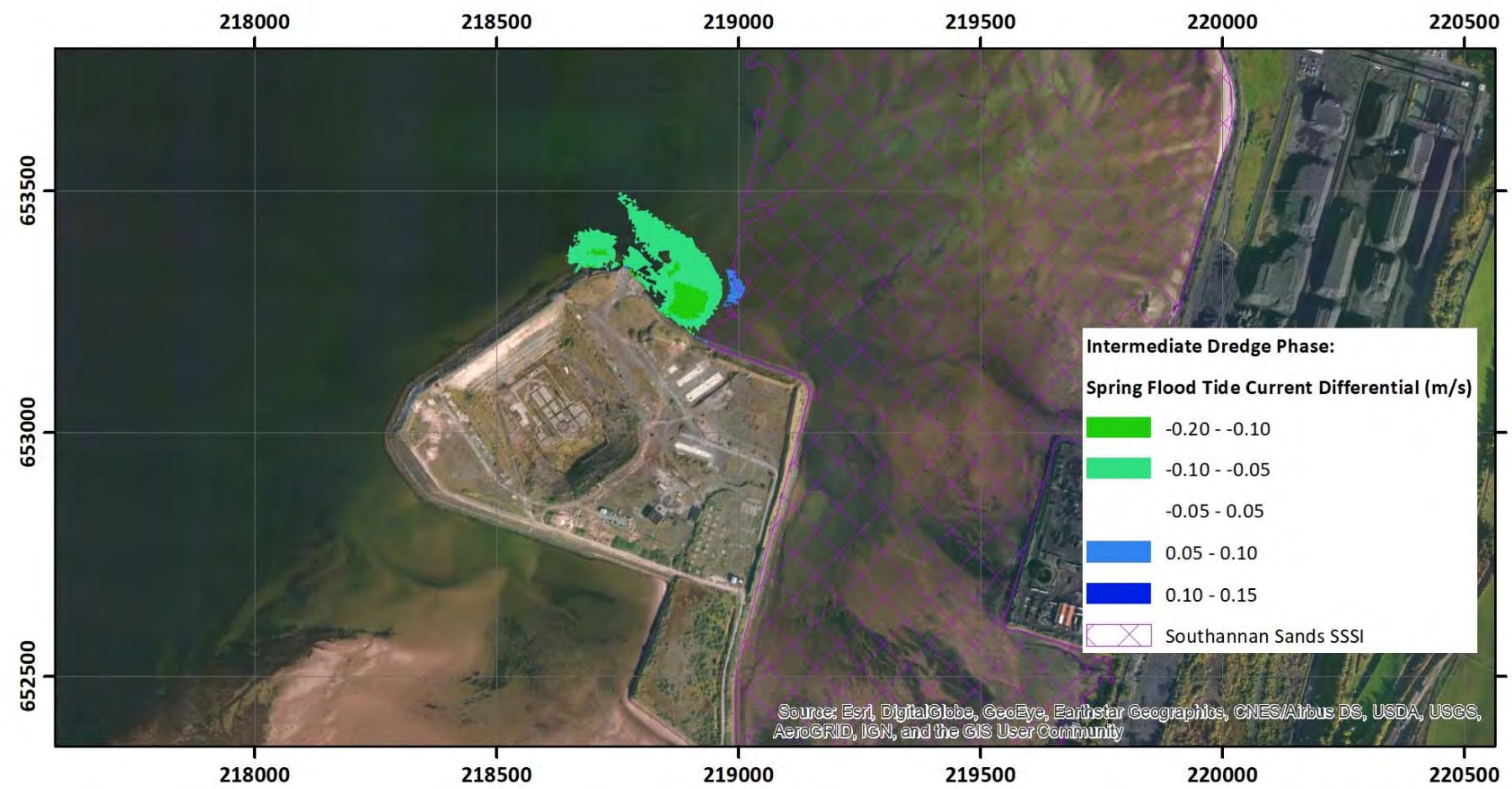
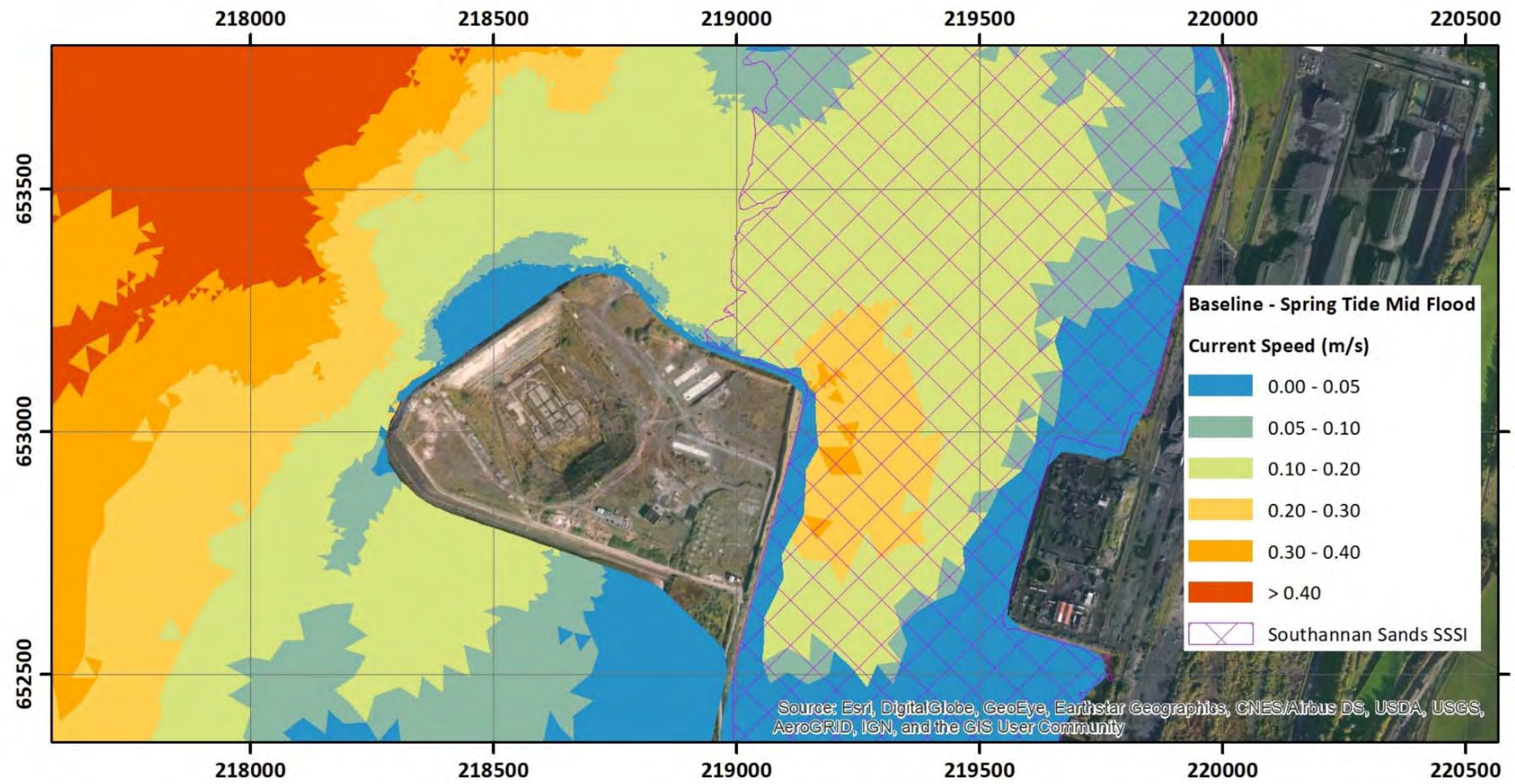
Southannan Sands SSSI
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community


Intermediate - Spring Tide Mid Flood
Current Speed (m/s)
0.00 - 0.05
0.05 - 0.10
0.10 - 0.20
0.20 - 0.30
0.30 - 0.40
> 0.40
Southannan Sands SSSI
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community


Intermediate Dredge Phase:
Spring Flood Tide Current Differential (m/s)
-0.20 - -0.10
-0.10 - -0.05
-0.05 - 0.05
0.05 - 0.10
0.10 - 0.15
Southannan Sands SSSI
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community


Baseline - Spring Tide Mid Flood
Current Speed (m/s)
0.00 - 0.05
0.05 - 0.10
0.10 - 0.20
0.20 - 0.30
0.30 - 0.40
> 0.40
Southannan Sands SSSI
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
218000
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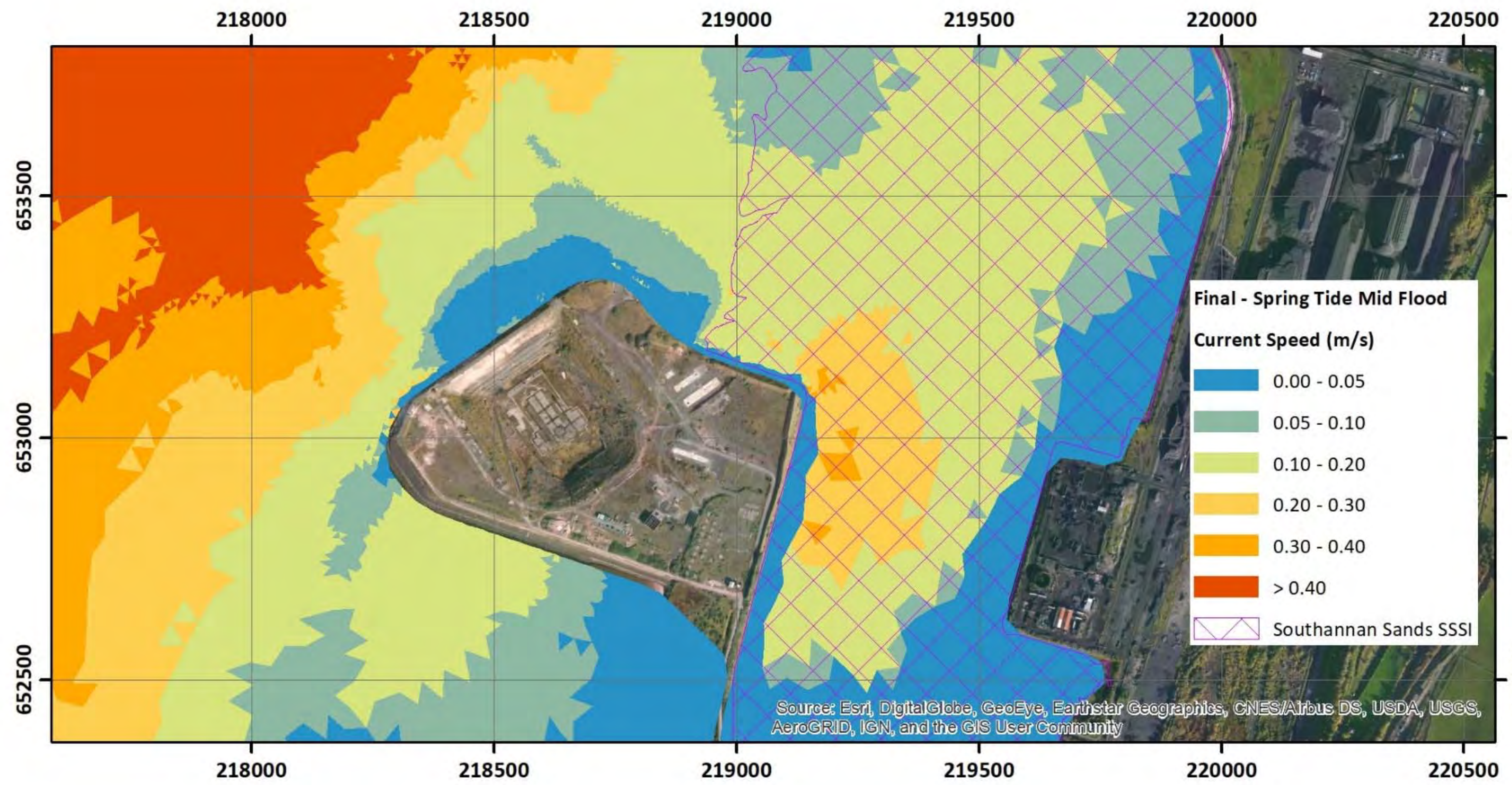
Final - Spring Tide Mid Flood
Current Speed (m/s)
0.00 - 0.05
0.05 - 0.10
0.10 - 0.20
0.20 - 0.30
0.30 - 0.40
> 0.40
Southannan Sands SSSI
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
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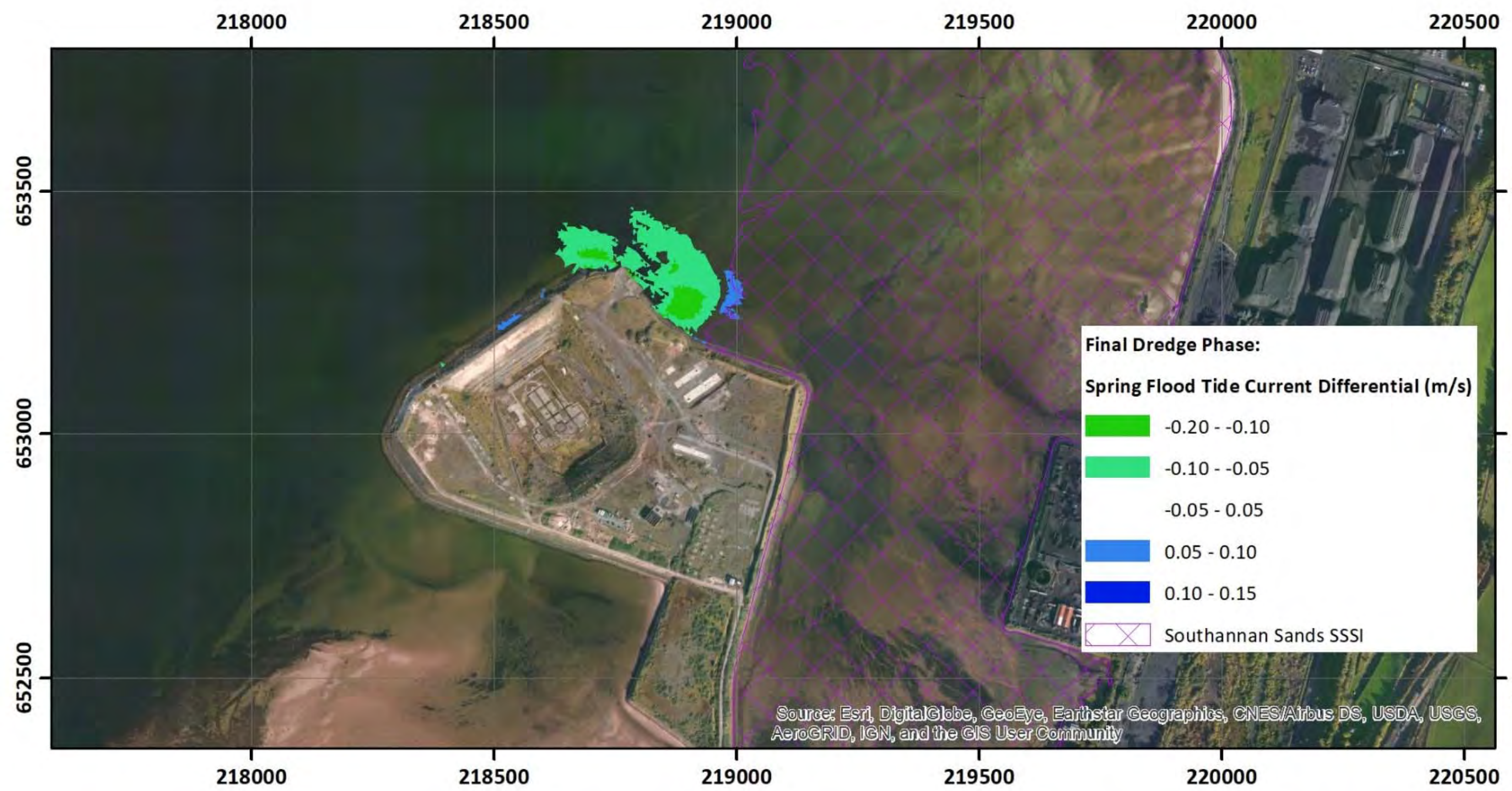
Final Dredge Phase:
Spring Flood Tide Current Differential (m/s)
-0.20 - -0.10
-0.10 - -0.05
-0.05 - 0.05
0.05 - 0.10
0.10 - 0.15
Southannan Sands SSSI
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
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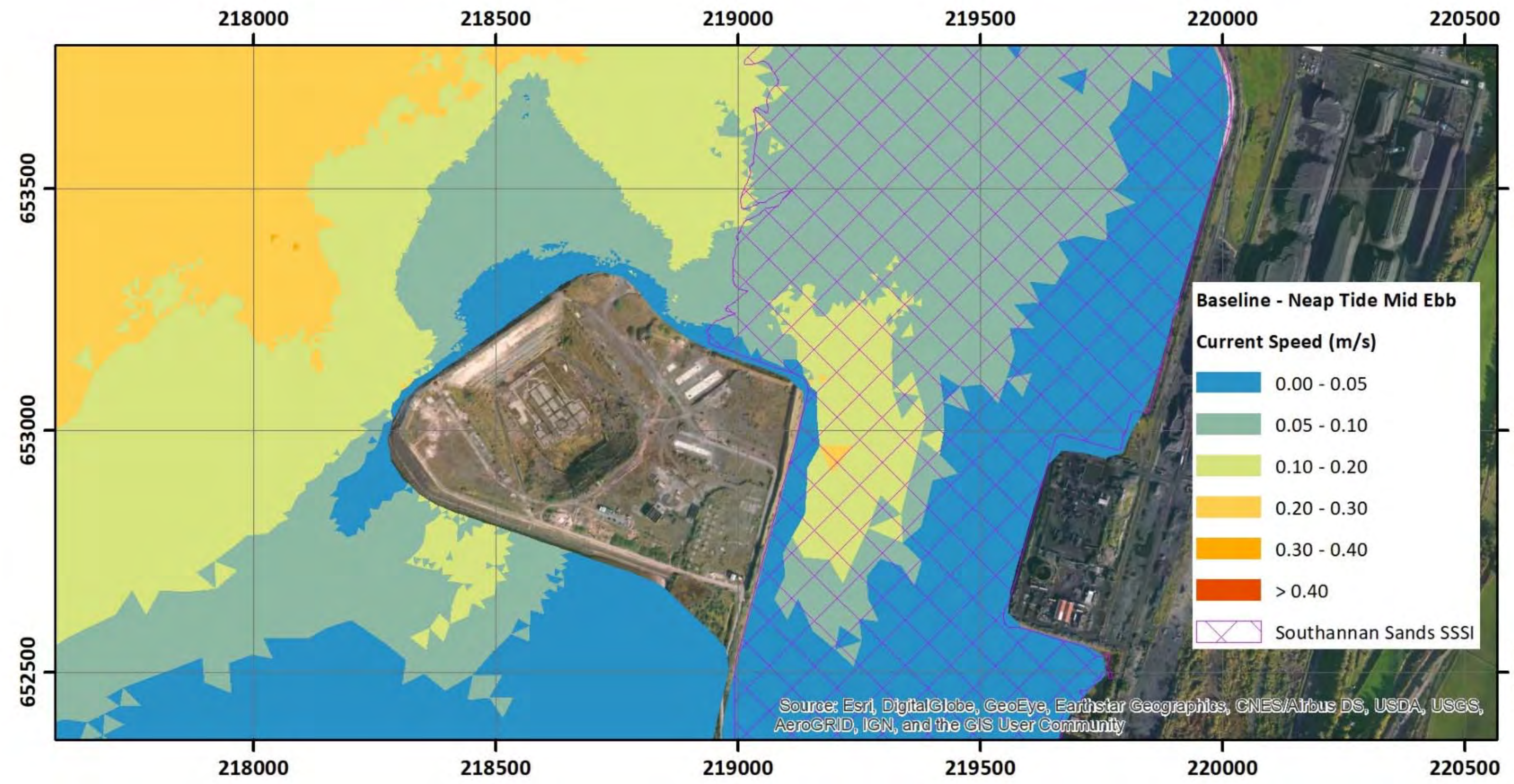
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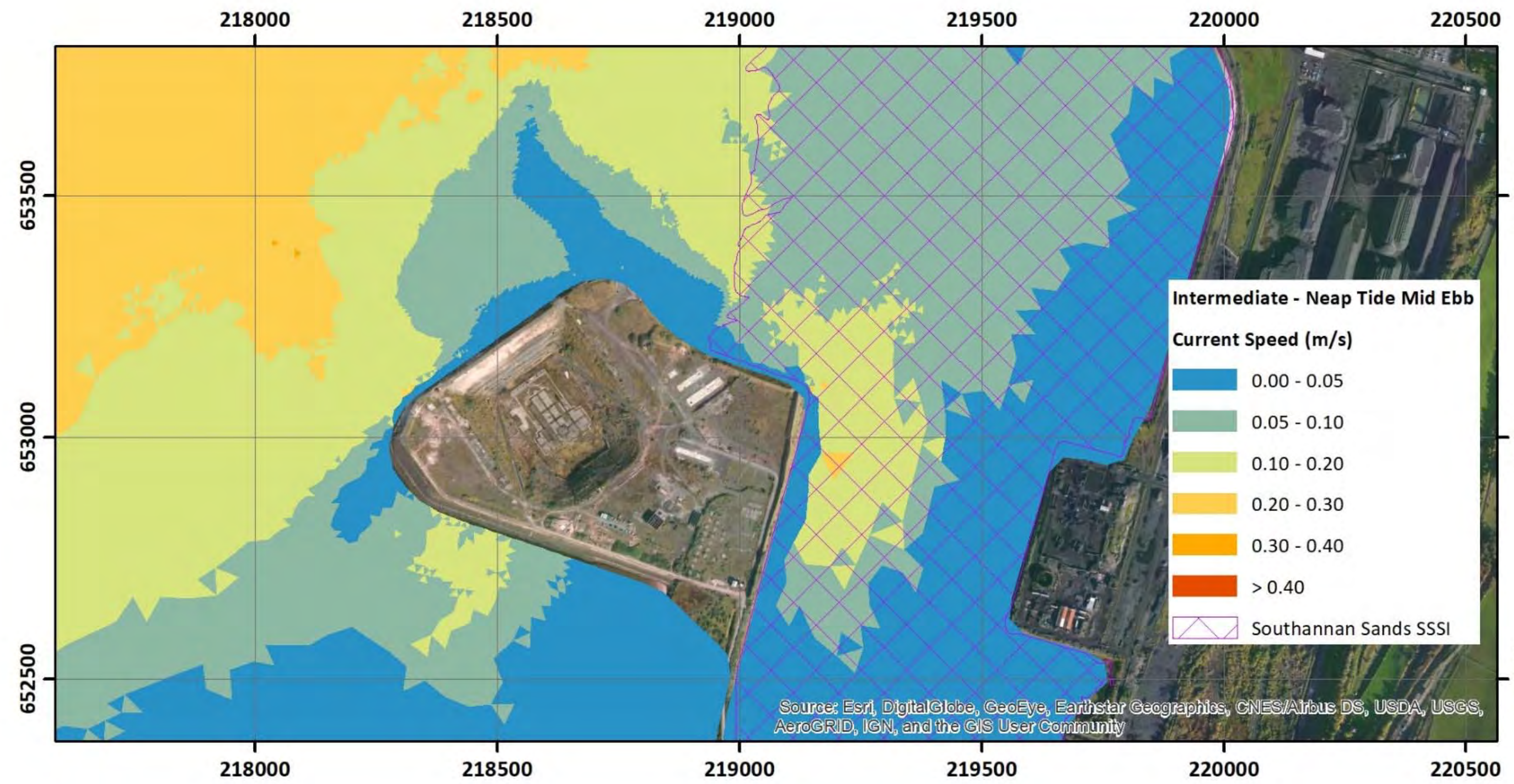
Baseline - Neap Tide Mid Ebb
Current Speed (m/s)
0.00 - 0.05
0.05 - 0.10
0.10 - 0.20
0.20 - 0.30
0.30 - 0.40
> 0.40
Southannan Sands SSSI
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community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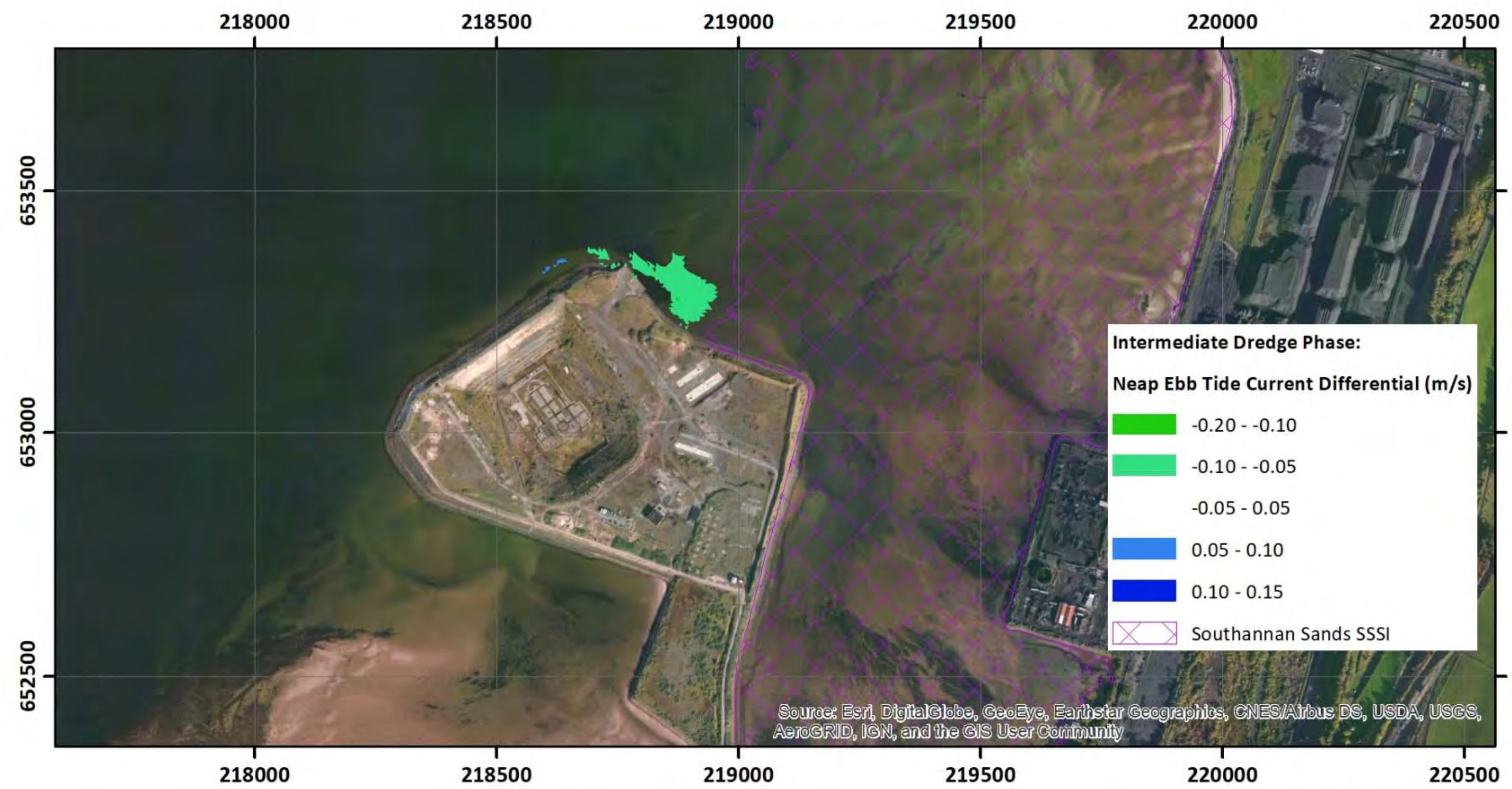
Intermediate - Neap Tide Mid Ebb
Current Speed (m/s)
0.00 - 0.05
0.05 - 0.10
0.10 - 0.20
0.20 - 0.30
0.30 - 0.40
> 0.40
Southannan Sands SSSI
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community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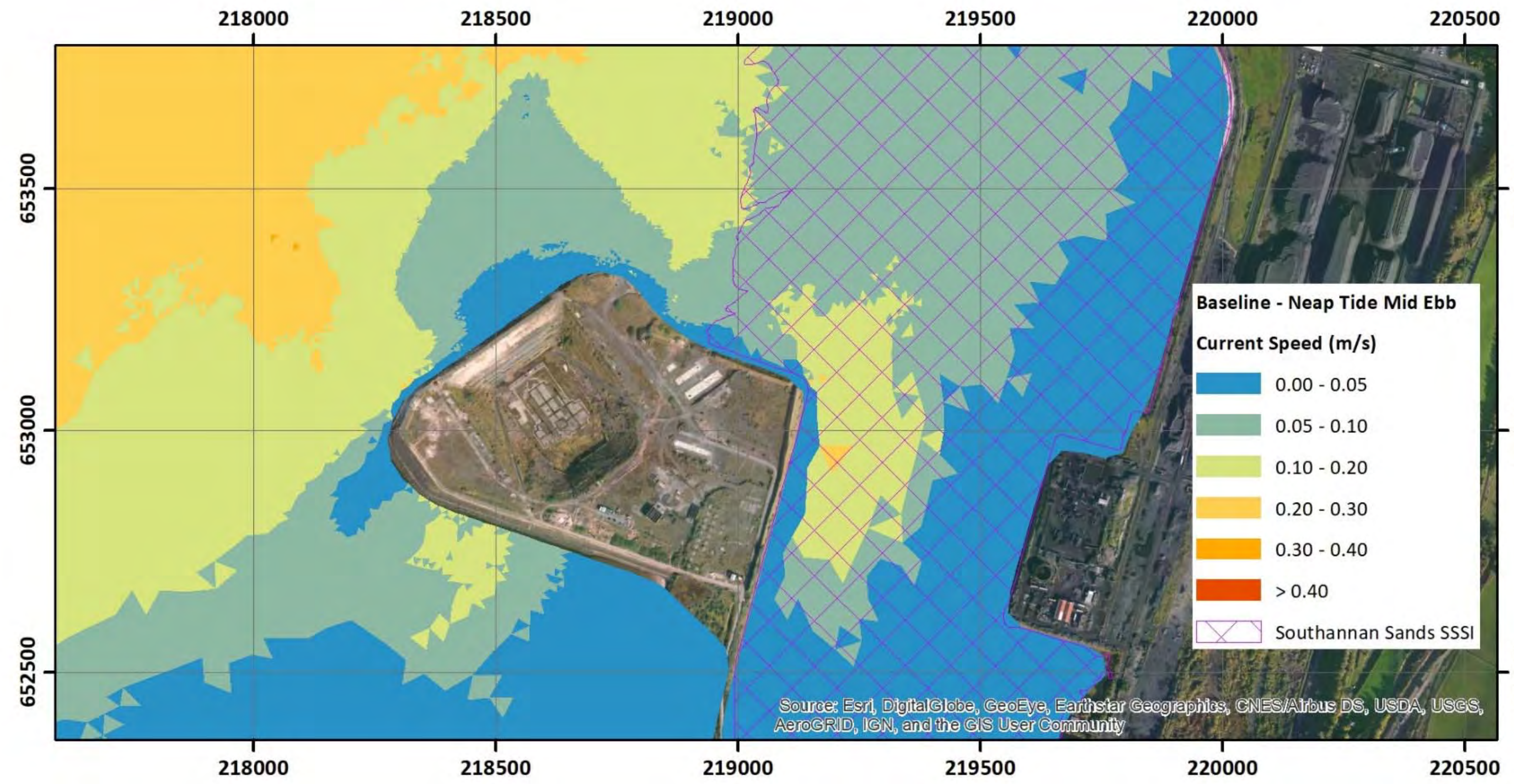
Intermediate Dredge Phase:
Neap Ebb Tide Current Differential (m/s)
-0.20 - -0.10
-0.10 - -0.05
-0.05 - 0.05
0.05 - 0.10
0.10 - 0.15
Southannan Sands SSSI
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community


Baseline - Neap Tide Mid Ebb
Current Speed (m/s)
0.00 - 0.05
0.05 - 0.10
0.10 - 0.20
0.20 - 0.30
0.30 - 0.40
> 0.40
Southannan Sands SSSI
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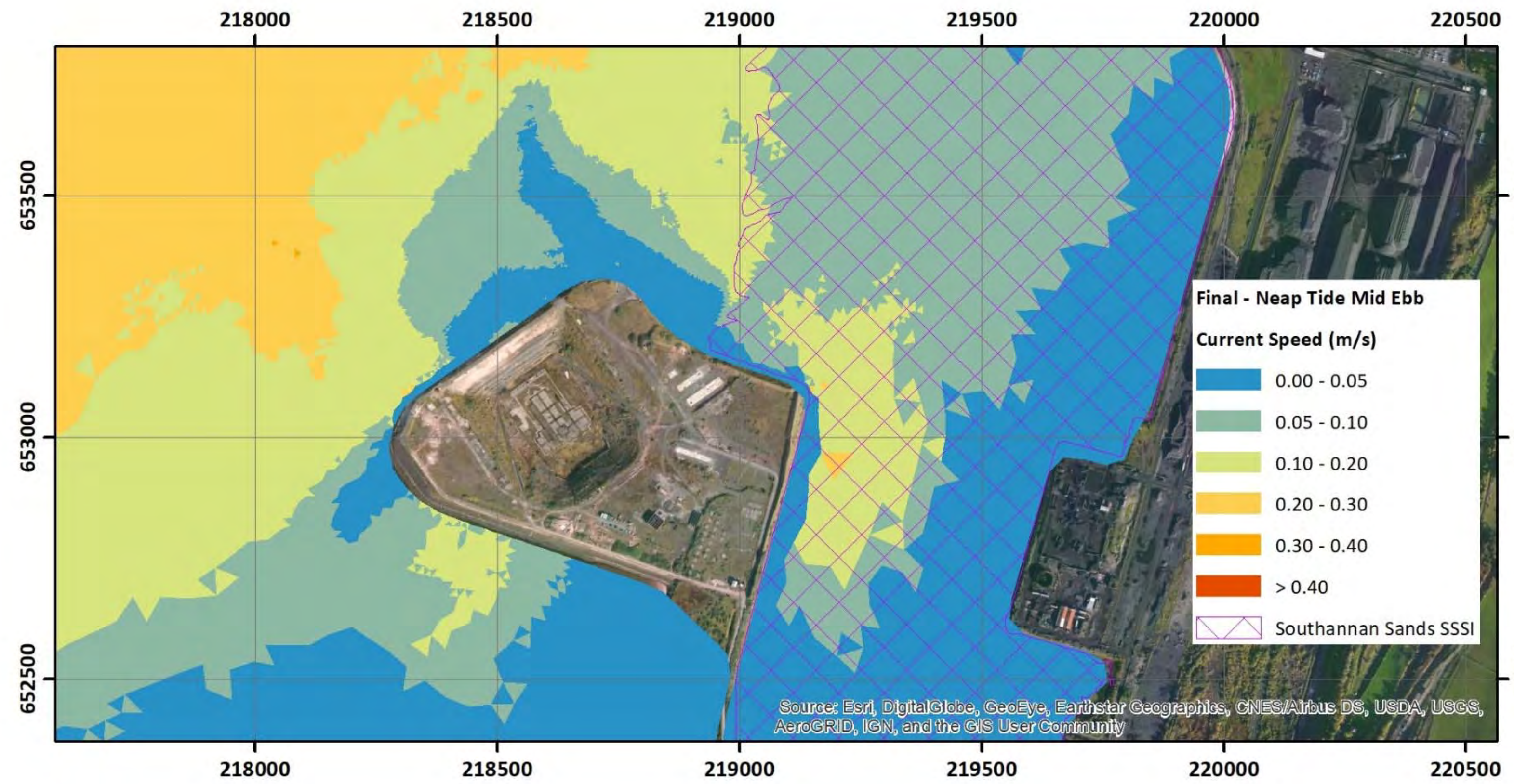
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community


Final - Neap Tide Mid Ebb
Current Speed (m/s)
0.00 - 0.05
0.05 - 0.10
0.10 - 0.20
0.20 - 0.30
0.30 - 0.40
> 0.40
Southannan Sands SSSI
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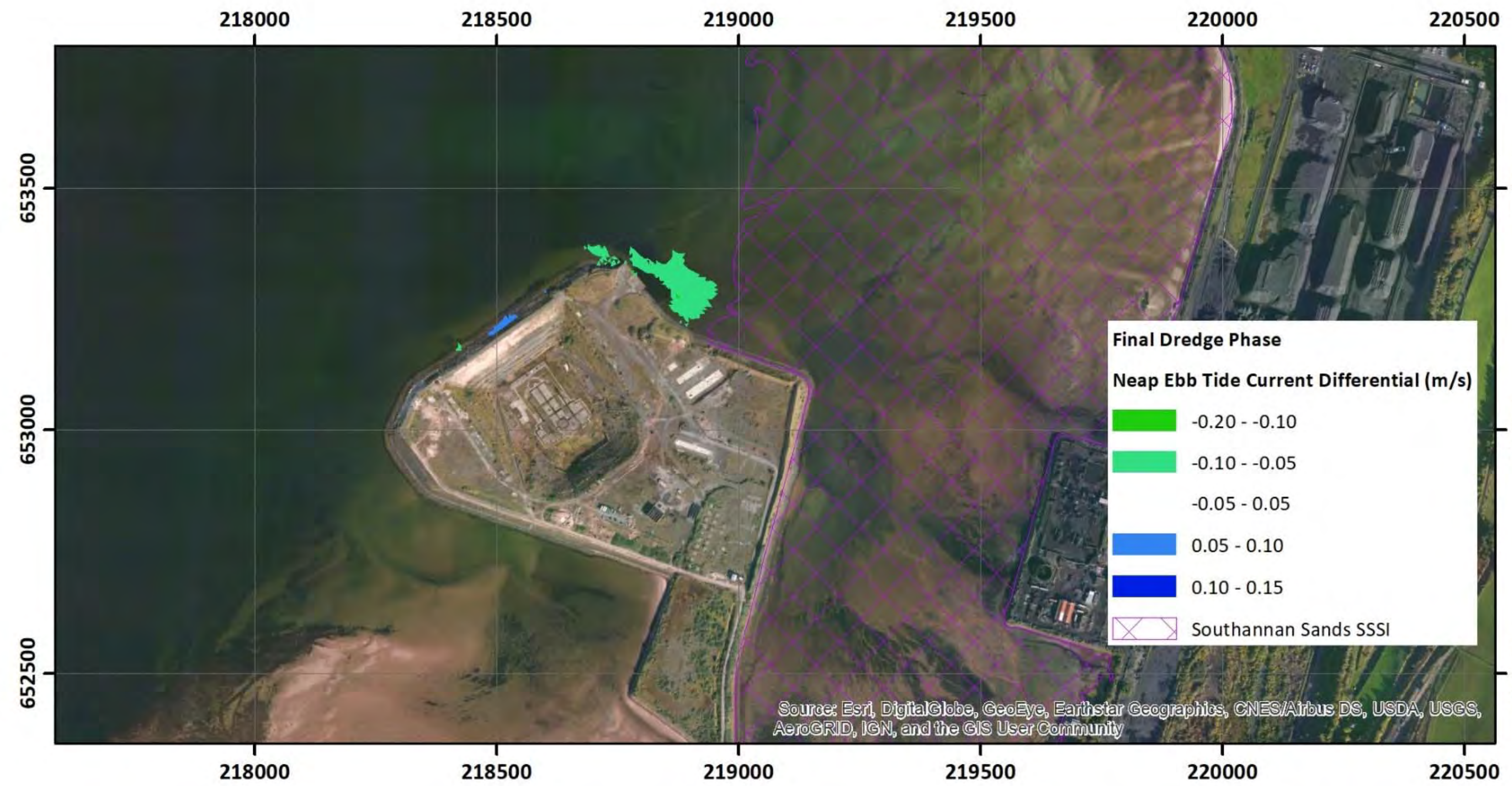
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community


Final Dredge Phase
Neap Ebb Tide Current Differential (m/s)
-0.20 - -0.10
-0.10 - -0.05
-0.05 - 0.05
0.05 - 0.10
0.10 - 0.15
Southannan Sands SSSI
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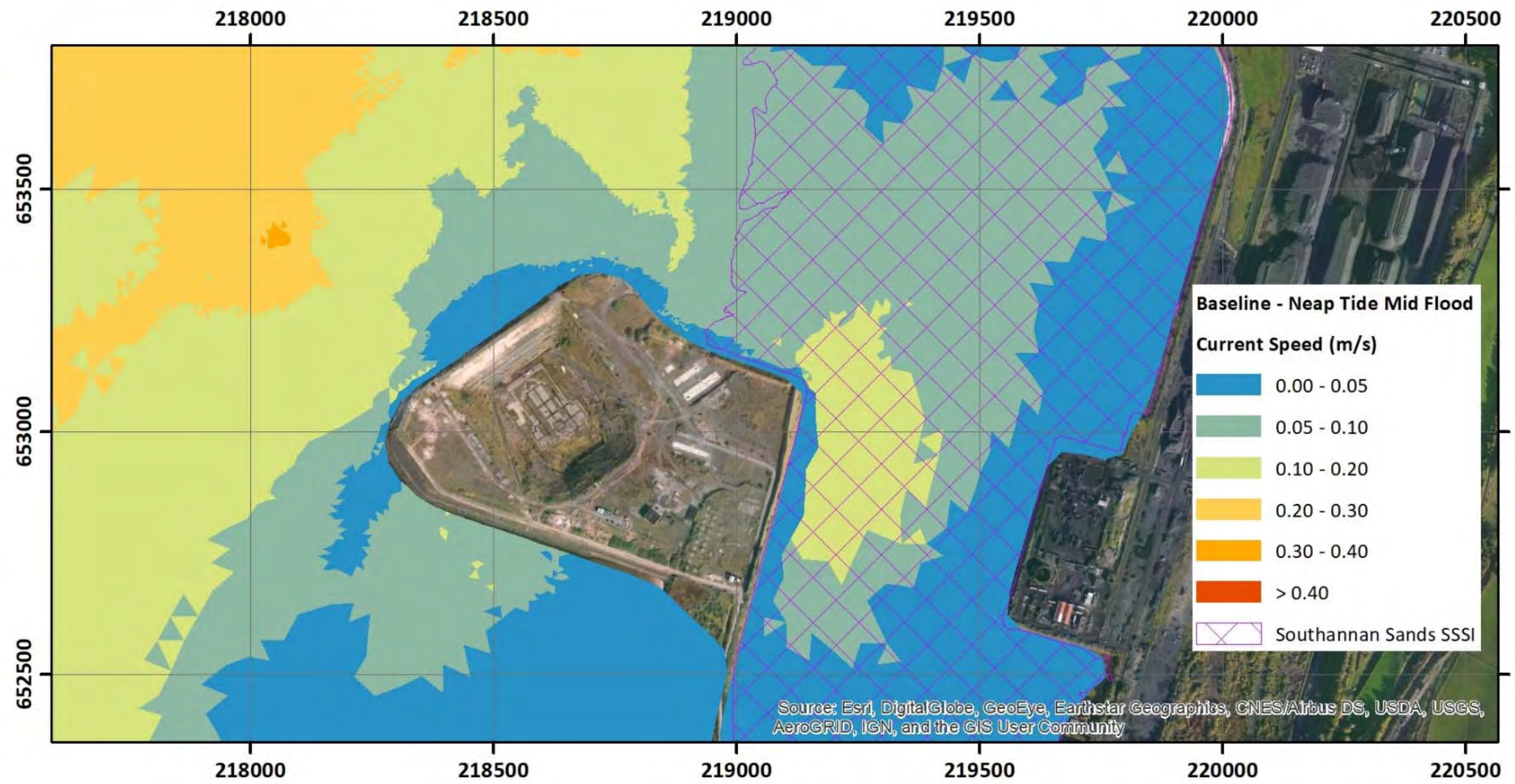
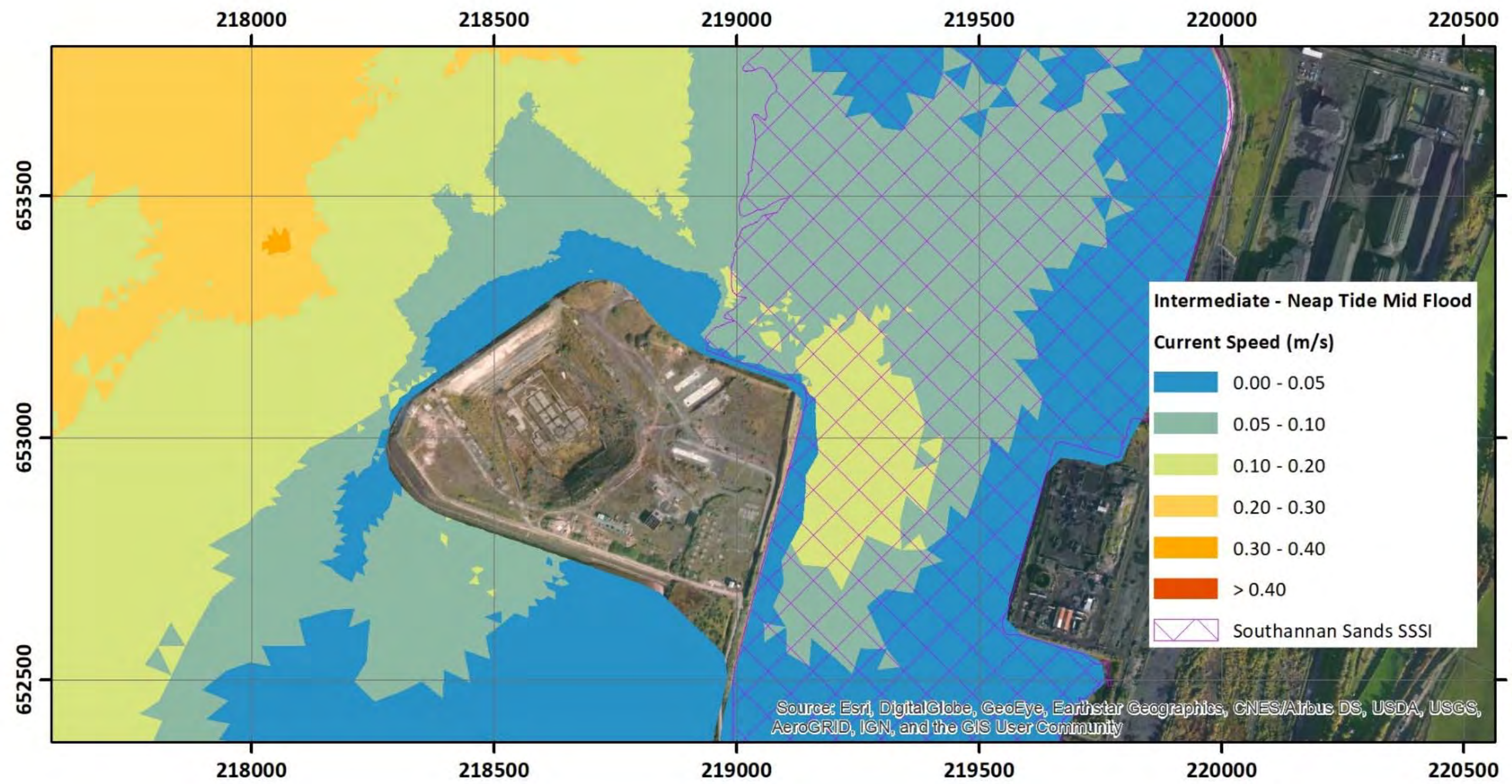
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community


Baseline - Neap Tide Mid Flood
Current Speed (m/s)
0.00 - 0.05
0.05 - 0.10
0.10 - 0.20
0.20 - 0.30
0.30 - 0.40
> 0.40
Southannan Sands SSSI
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
218000 218500 219000 219500 220000 220500
653500 653000 652500


Intermediate - Neap Tide Mid Flood
Current Speed (m/s)
0.00 - 0.05
0.05 - 0.10
0.10 - 0.20
0.20 - 0.30
0.30 - 0.40
> 0.40
Southannan Sands SSSI
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
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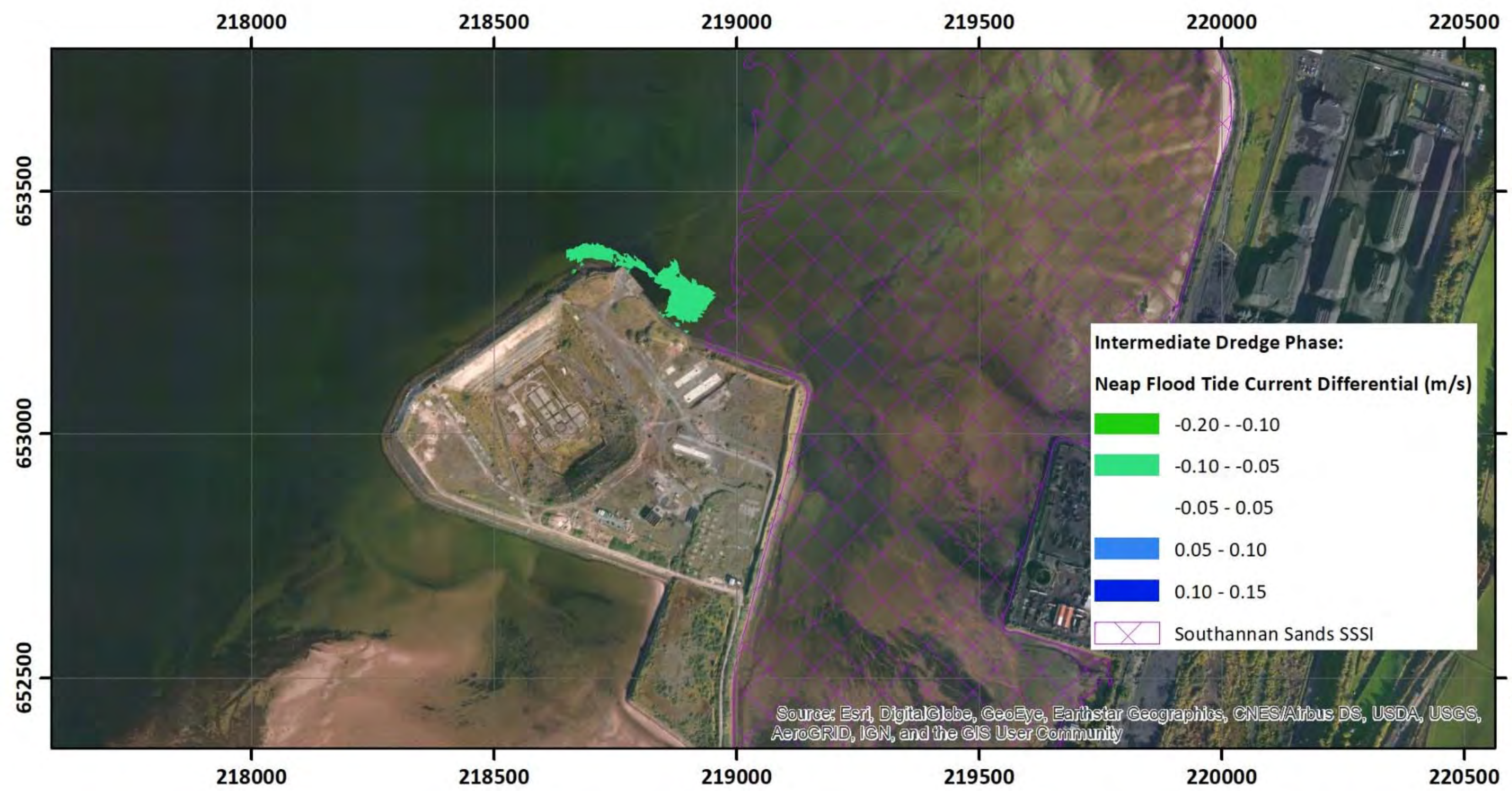
653500 653000 652500


Intermediate Dredge Phase:
Neap Flood Tide Current Differential (m/s)
-0.20 - -0.10
-0.10 - -0.05
-0.05 - 0.05
0.05 - 0.10
0.10 - 0.15
Southannan Sands SSSI
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
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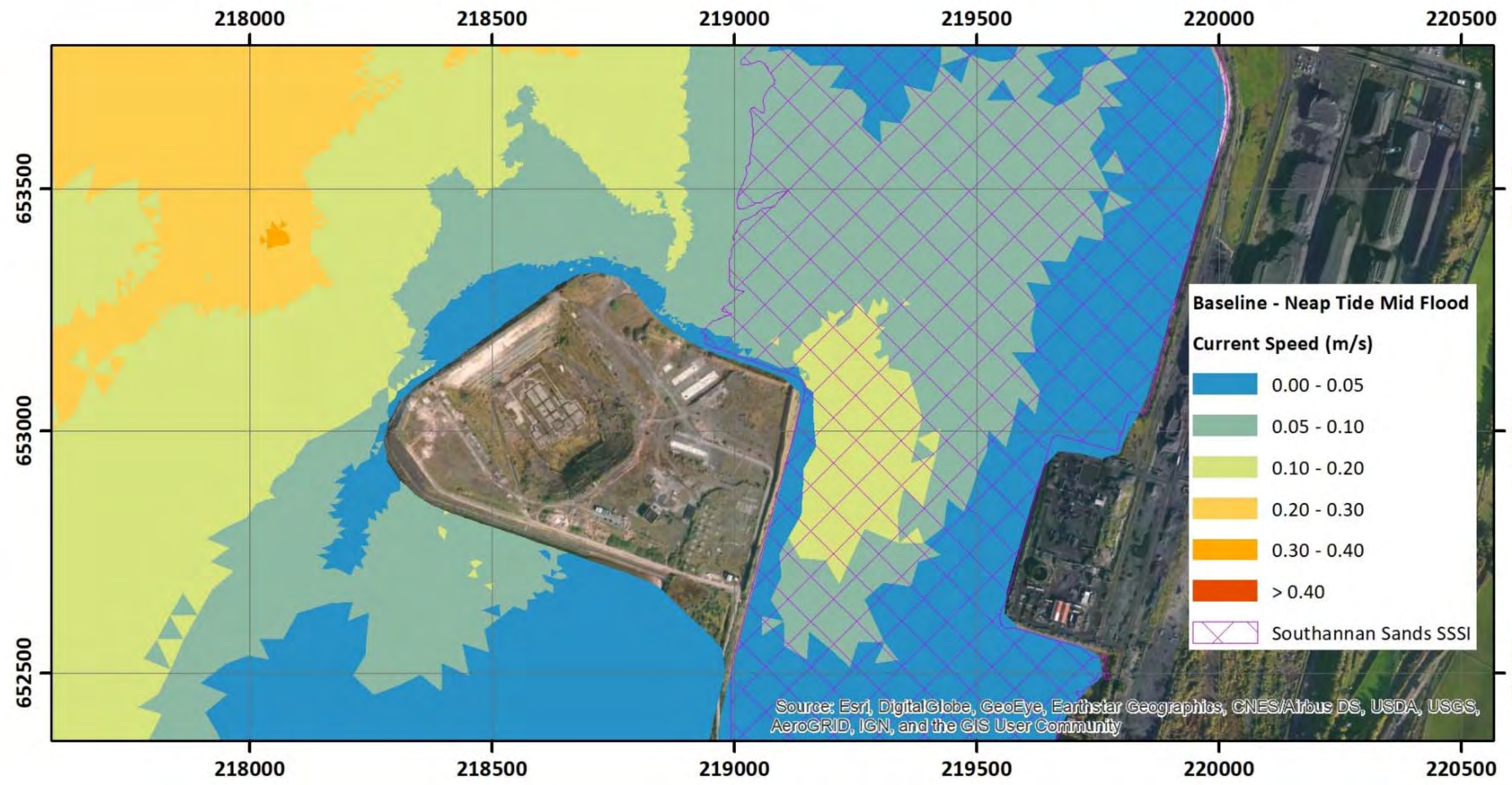
653500 653000 652500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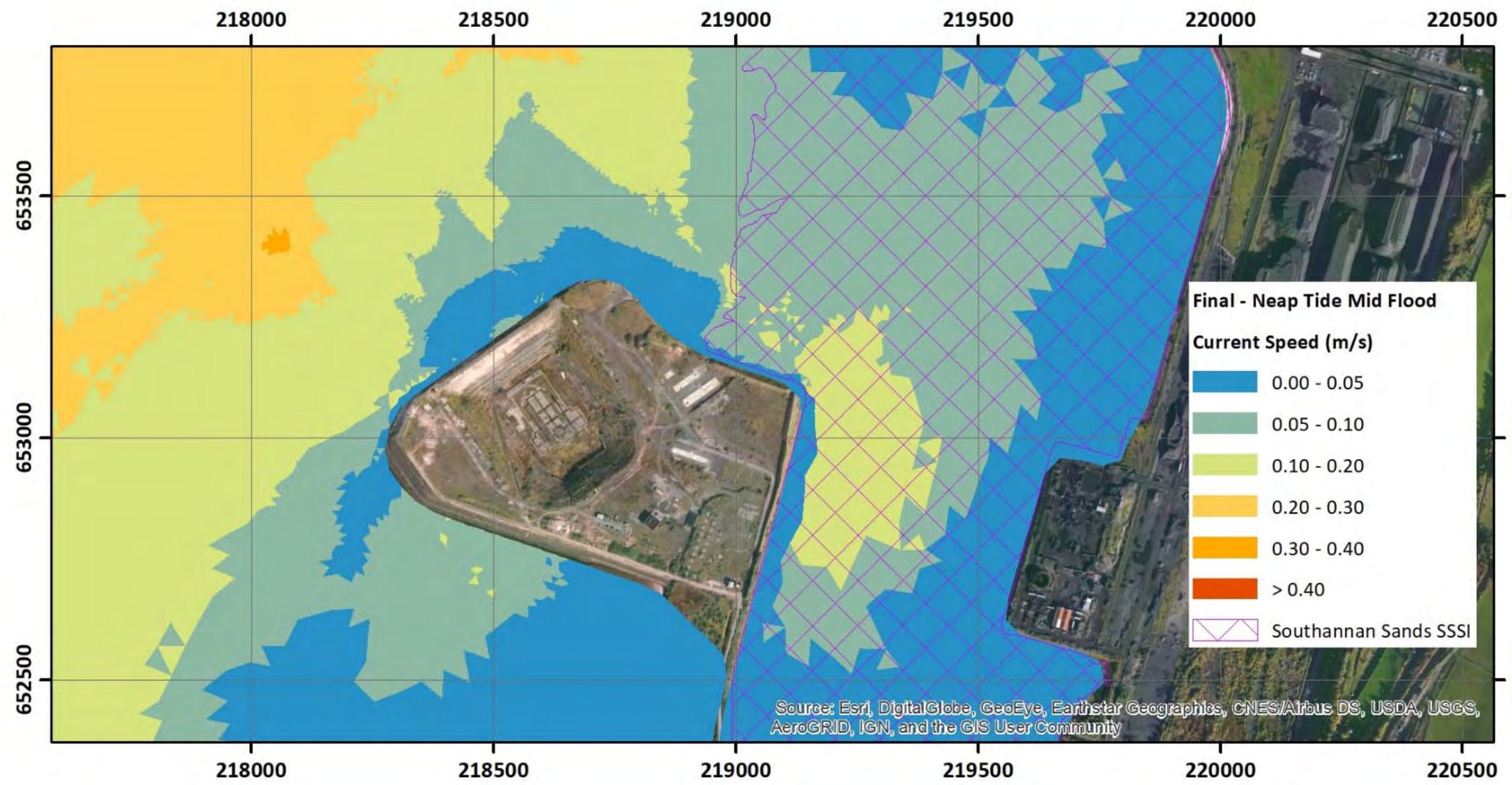
Baseline - Neap Tide Mid Flood
Current Speed (m/s)
0.00 - 0.05
0.05 - 0.10
0.10 - 0.20
0.20 - 0.30
0.30 - 0.40
> 0.40
Southannan Sands SSSI
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community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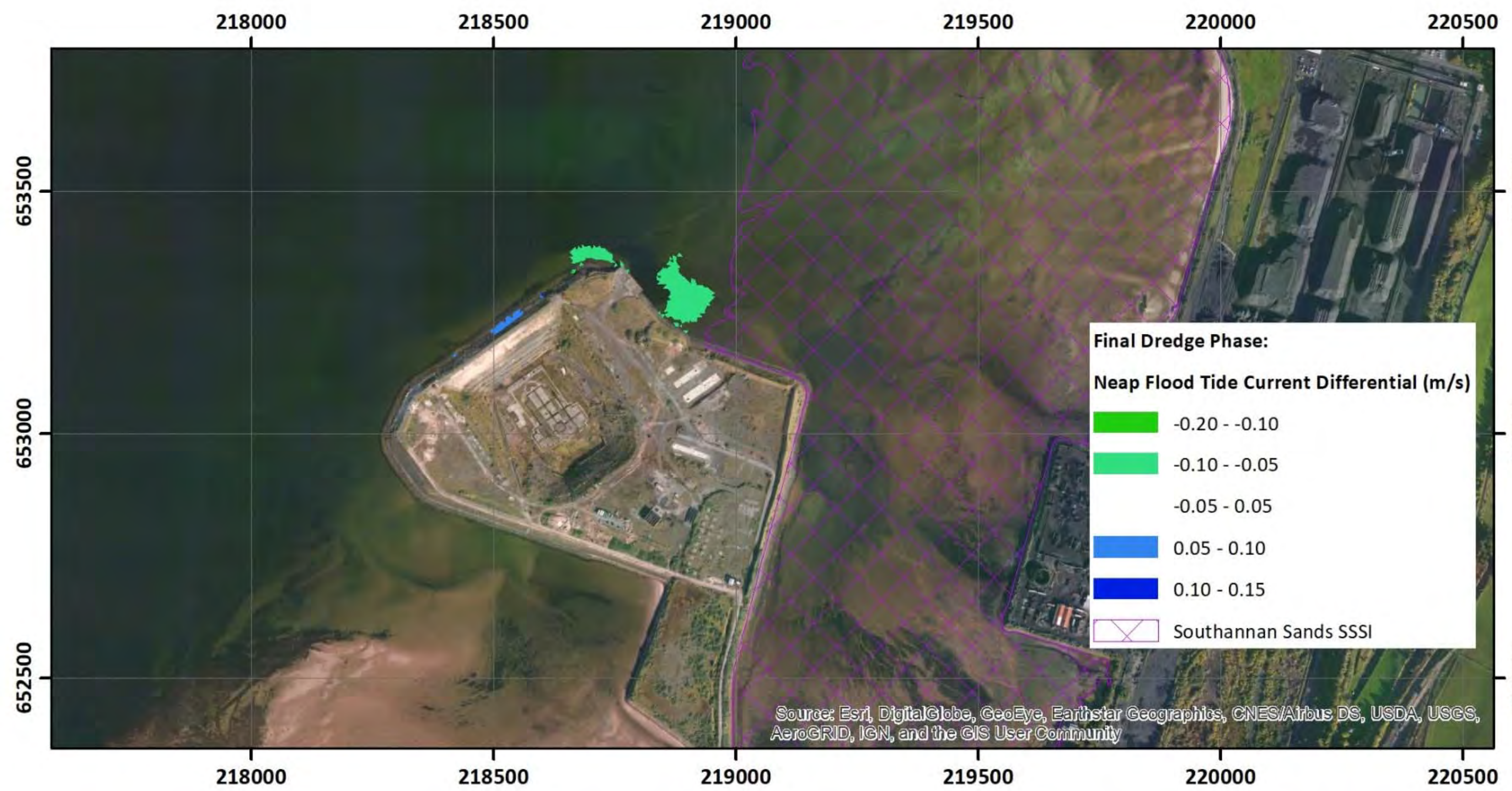
Final - Neap Tide Mid Flood
Current Speed (m/s)
0.00 - 0.05
0.05 - 0.10
0.10 - 0.20
0.20 - 0.30
0.30 - 0.40
> 0.40
Southannan Sands SSSI
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community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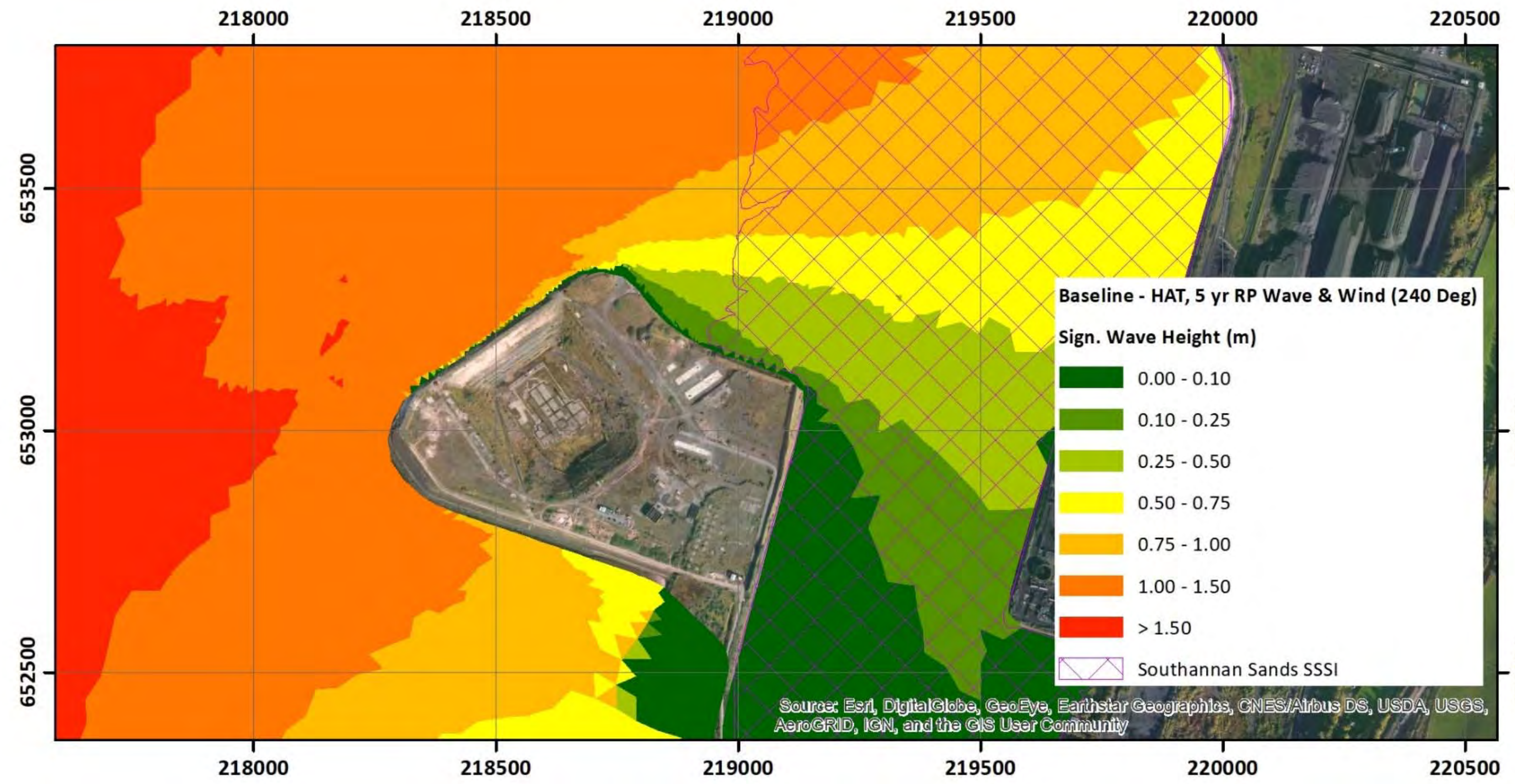
653500
653000
652500
Final Dredge Phase:
Neap Flood Tide Current Differential (m/s)
-0.20 - -0.10
-0.10 - -0.05
-0.05 - 0.05
0.05 - 0.10
0.10 - 0.15
Southannan Sands SSSI
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

D SPECTRAL WAVE MODEL RESULTS


Baseline - HAT, 5 yr RP Wave & Wind (240 Deg)
Sign. Wave Height (m)
0.00 - 0.10
0.10 - 0.25
0.25 - 0.50
0.50 - 0.75
0.75 - 1.00
1.00 - 1.50
> 1.50
Southannan Sands SSSI
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
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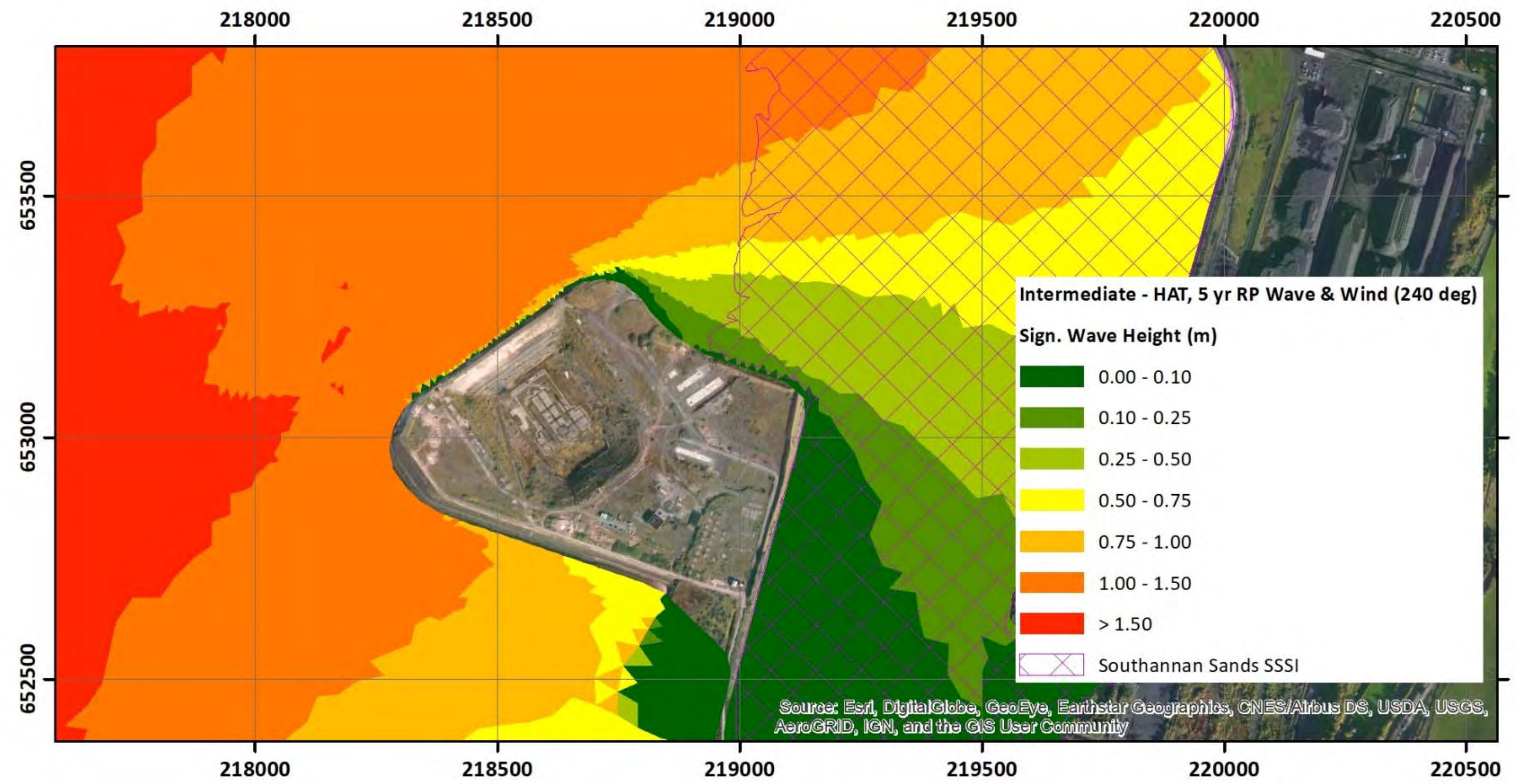
Intermediate - HAT, 5 yr RP Wave & Wind (240 deg)
Sign. Wave Height (m)
0.00 - 0.10
0.10 - 0.25
0.25 - 0.50
0.50 - 0.75
0.75 - 1.00
1.00 - 1.50
> 1.50
Southannan Sands SSSI
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
218000
218500
219000
219500
220000
220500
653500
653000
652500


Intermediate Dredge Phase:
240 Deg. Sign. Wave Height Differential (m)
-0.75 - -0.25
-0.25 - -0.10
-0.10 - -0.05
-0.05 - 0.05
0.05 - 0.10
0.10 - 0.25
Southannan Sands SSSI
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
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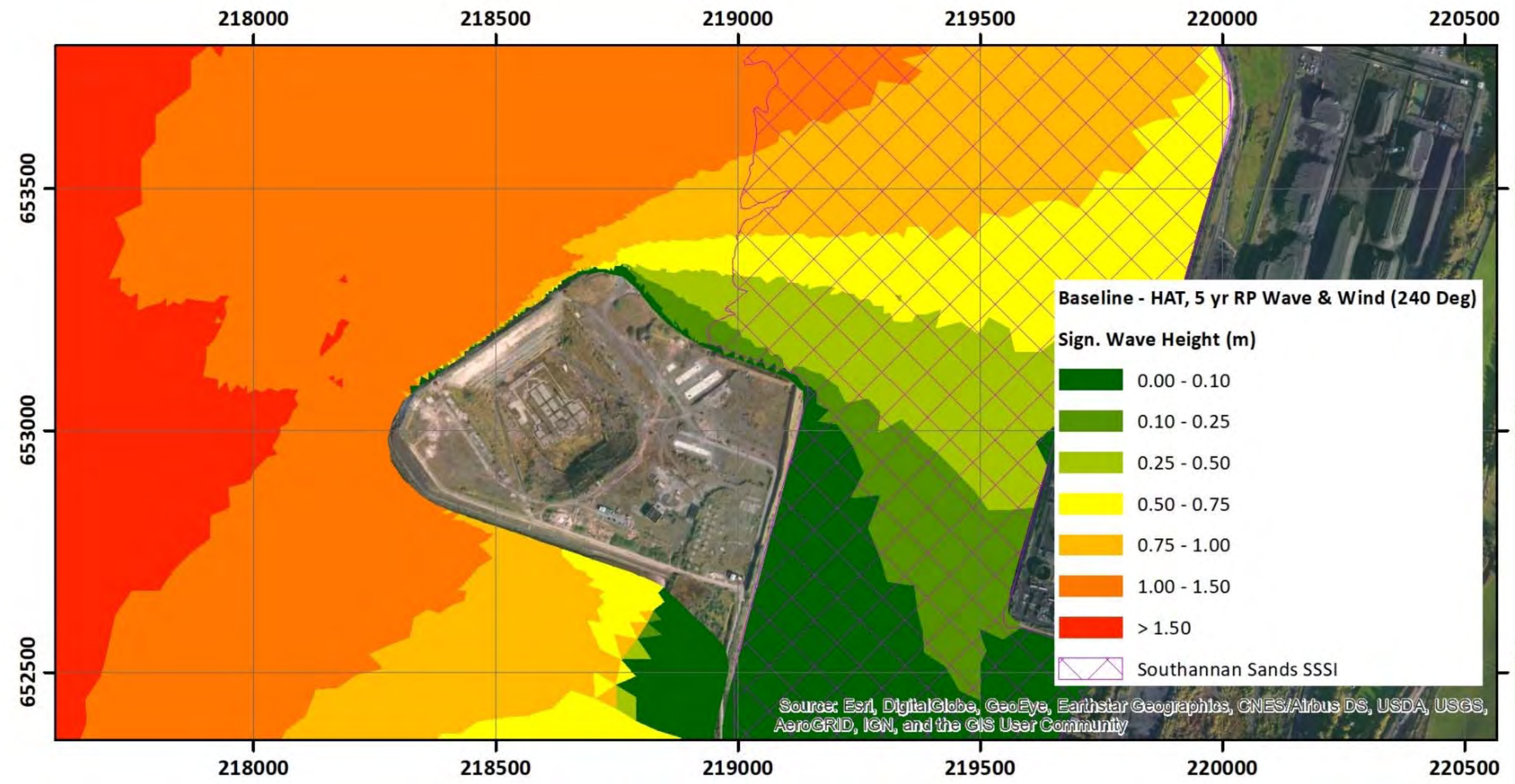
Baseline - HAT, 5 yr RP Wave & Wind (240 Deg)
Sign. Wave Height (m)
0.00 - 0.10
0.10 - 0.25
0.25 - 0.50
0.50 - 0.75
0.75 - 1.00
1.00 - 1.50
> 1.50
Southannan Sands SSSI
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
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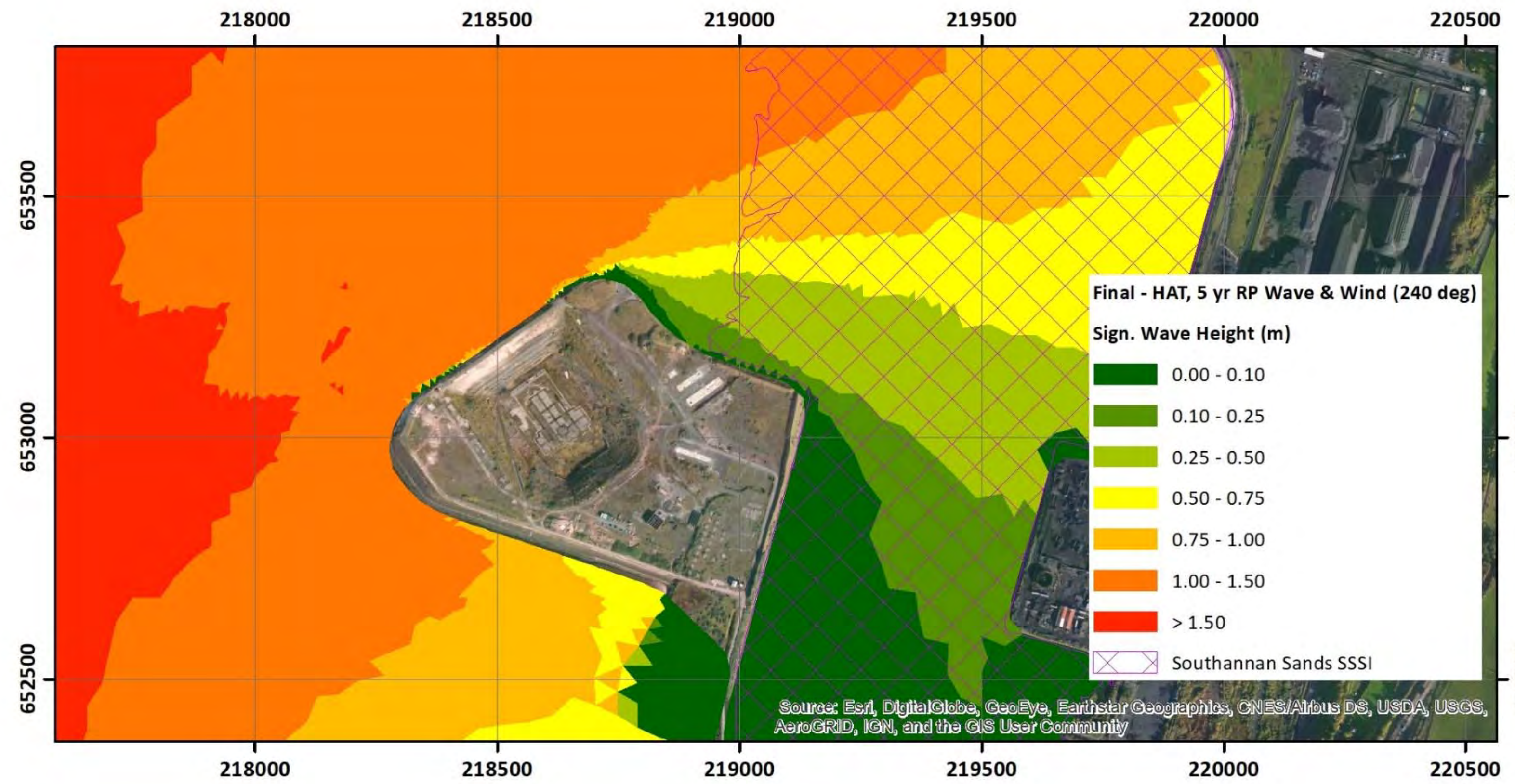
Final - HAT, 5 yr RP Wave & Wind (240 deg)
Sign. Wave Height (m)
0.00 - 0.10
0.10 - 0.25
0.25 - 0.50
0.50 - 0.75
0.75 - 1.00
1.00 - 1.50
> 1.50
Southannan Sands SSSI
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
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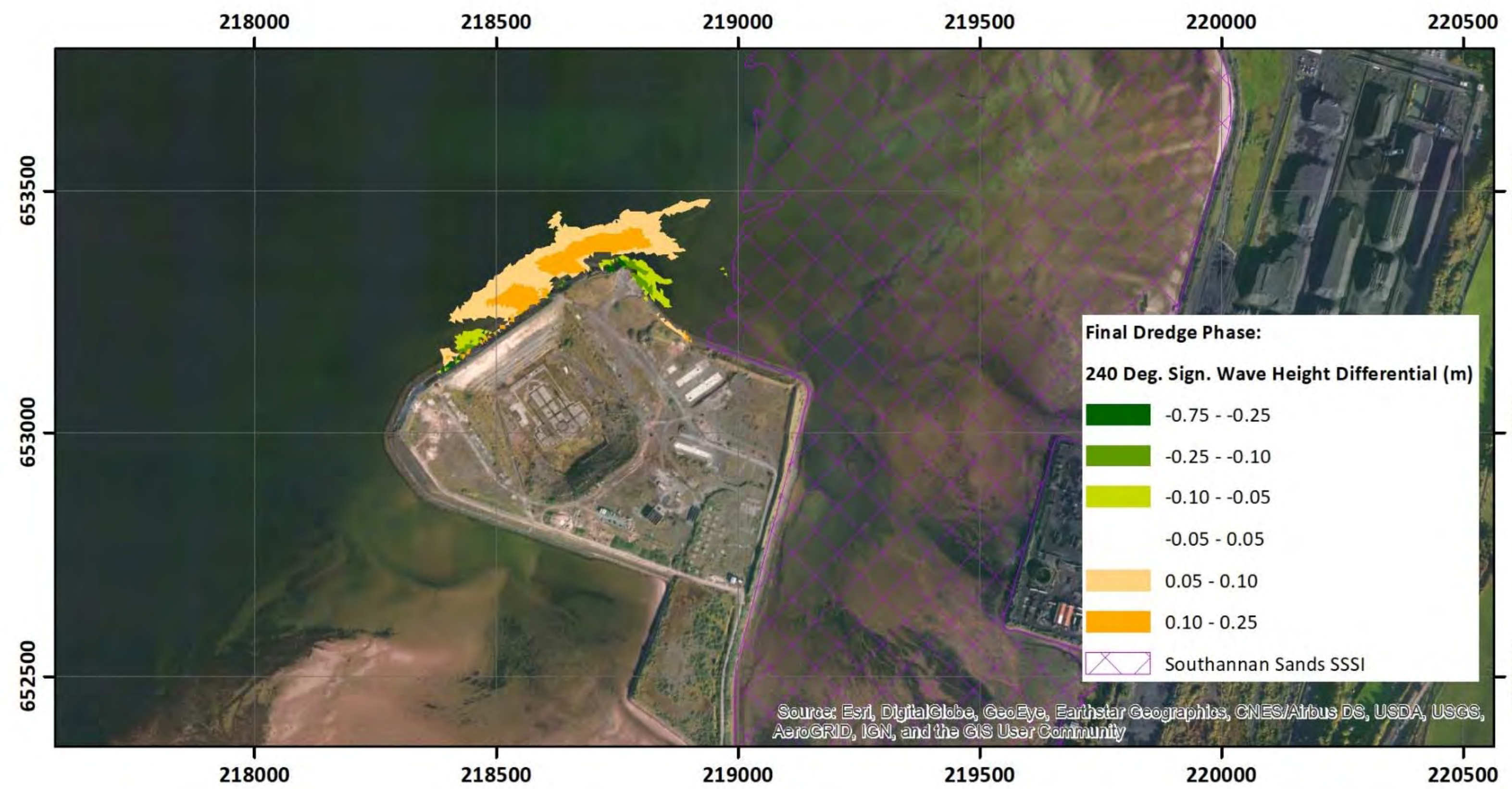
Final Dredge Phase:
240 Deg. Sign. Wave Height Differential (m)
-0.75 - -0.25
-0.25 - -0.10
-0.10 - -0.05
-0.05 - 0.05
0.05 - 0.10
0.10 - 0.25
Southannan Sands SSSI
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
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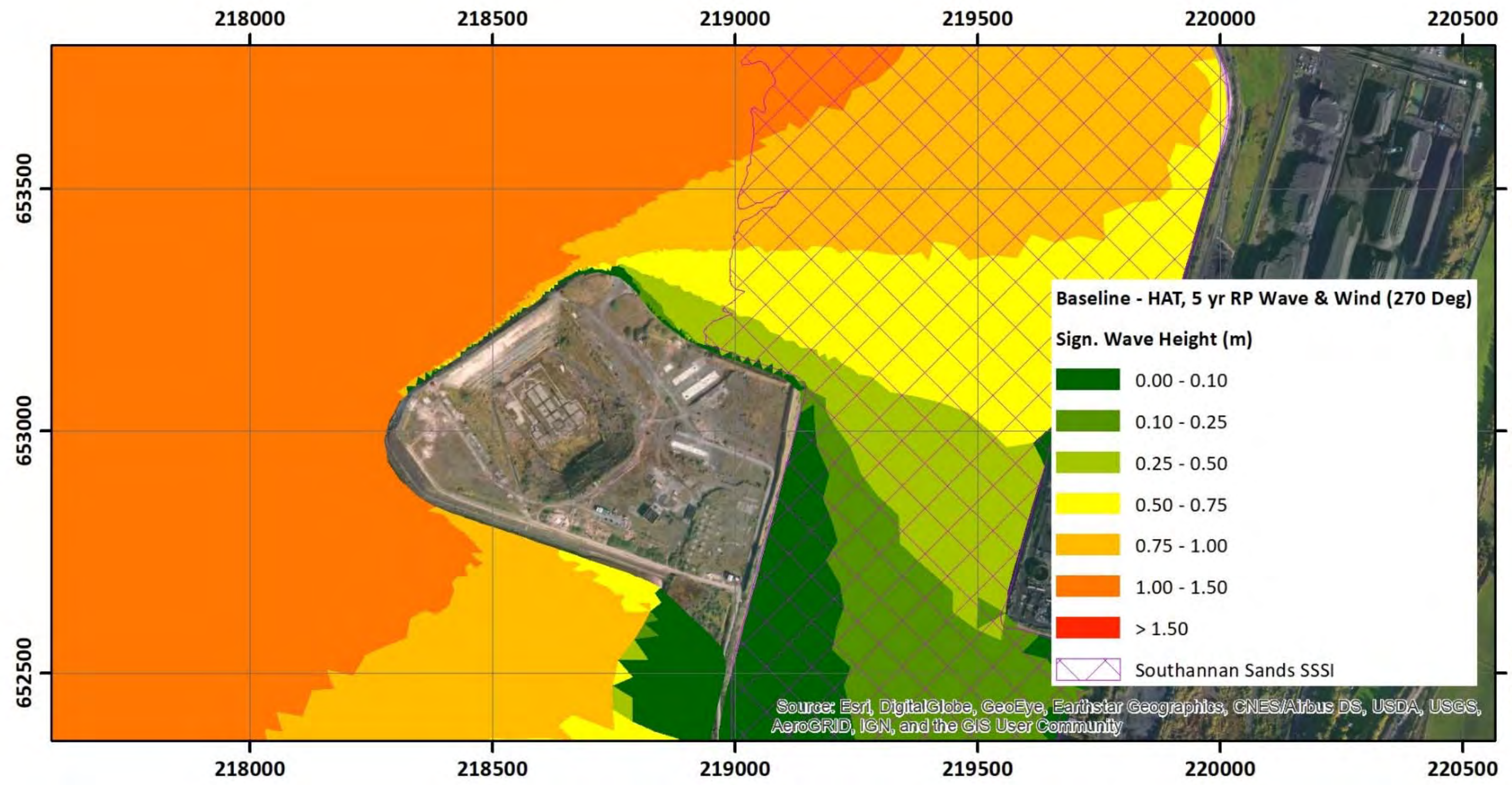
Baseline - HAT, 5 yr RP Wave & Wind (270 Deg)
Sign. Wave Height (m)
0.00 - 0.10
0.10 - 0.25
0.25 - 0.50
0.50 - 0.75
0.75 - 1.00
1.00 - 1.50
> 1.50
Southannan Sands SSSI
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
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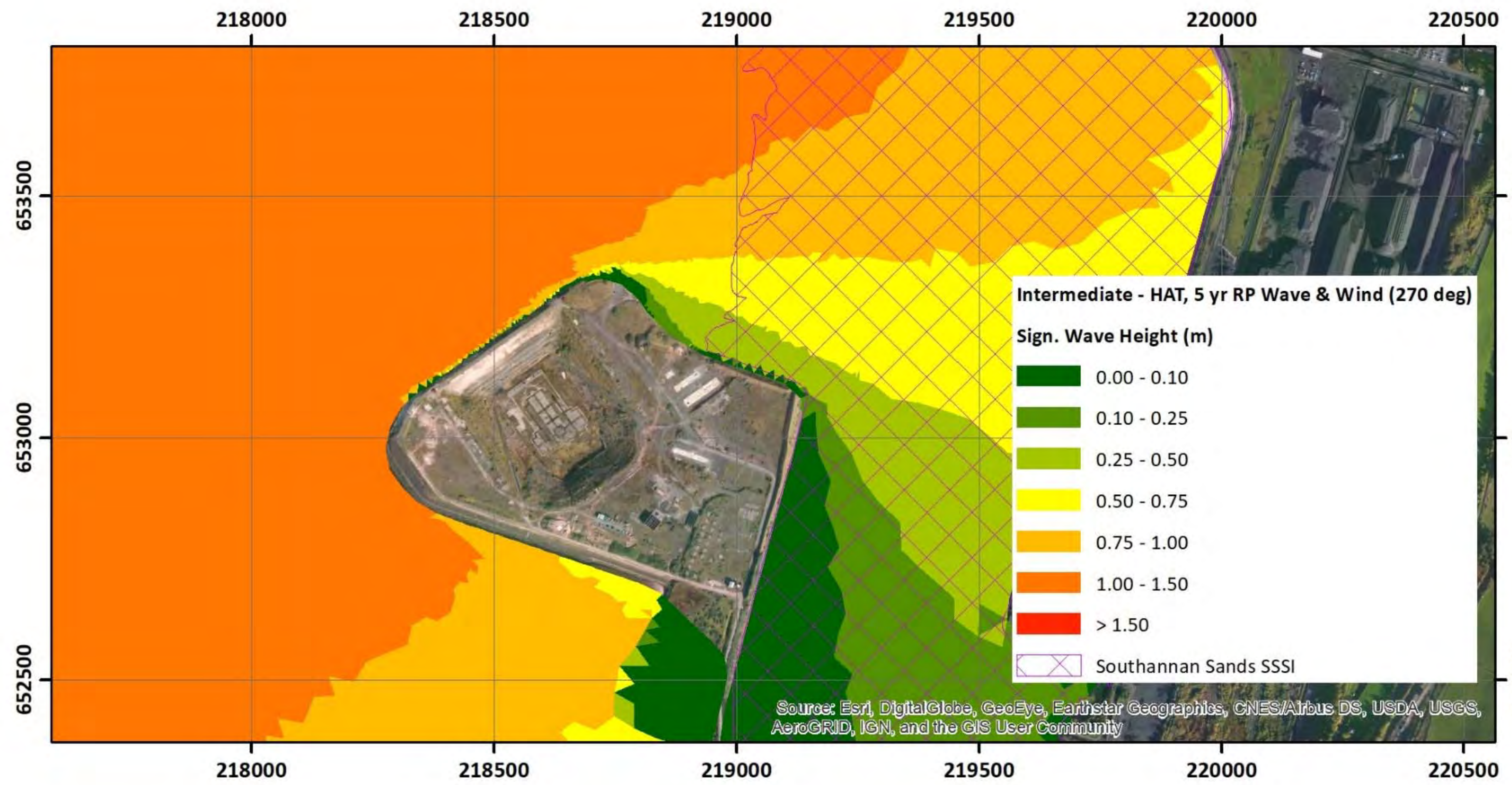
652500


Intermediate - HAT, 5 yr RP Wave & Wind (270 deg)
Sign. Wave Height (m)
0.00 - 0.10
0.10 - 0.25
0.25 - 0.50
0.50 - 0.75
0.75 - 1.00
1.00 - 1.50
> 1.50
Southannan Sands SSSI
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
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220000
220500
653500
653000
652500


Intermediate Dredge Phase:
270 Deg. Sign. Wave Height Differential (m)
-0.75 - -0.25
-0.25 - -0.10
-0.10 - -0.05
-0.05 - 0.05
0.05 - 0.10
0.10 - 0.25
Southannan Sands SSSI
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
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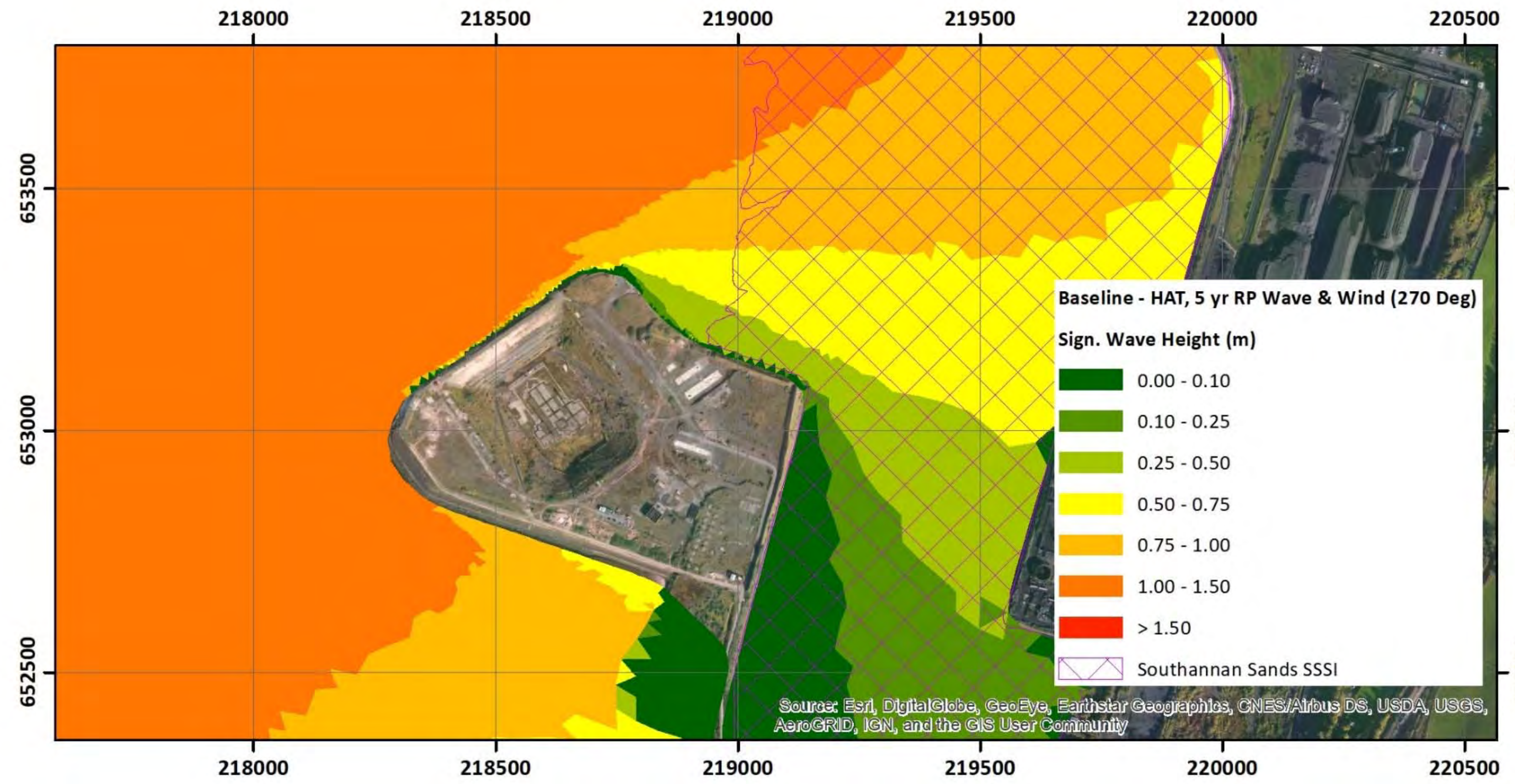
Baseline - HAT, 5 yr RP Wave & Wind (270 Deg)
Sign. Wave Height (m)
0.00 - 0.10
0.10 - 0.25
0.25 - 0.50
0.50 - 0.75
0.75 - 1.00
1.00 - 1.50
> 1.50
Southannan Sands SSSI
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
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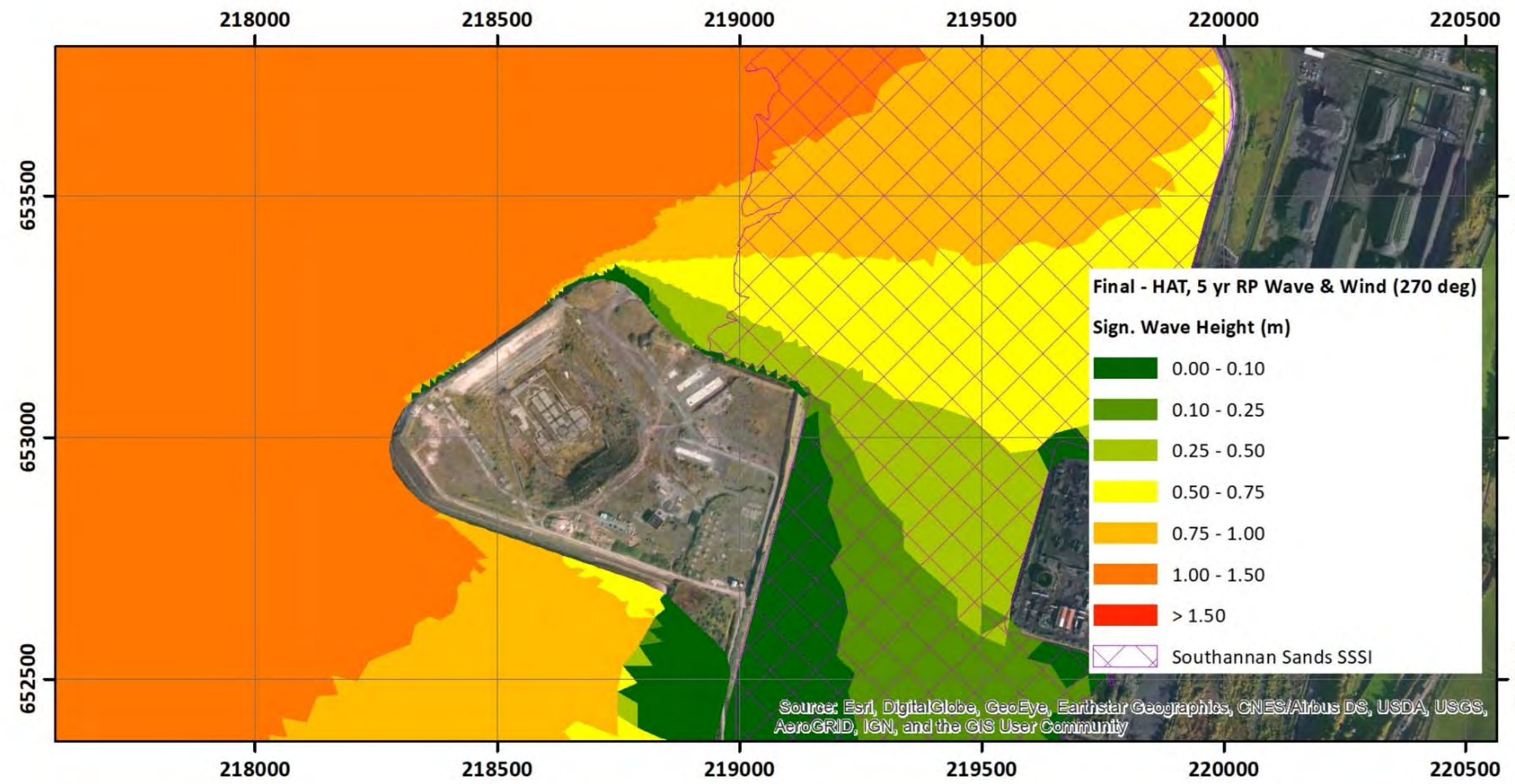
Final - HAT, 5 yr RP Wave & Wind (270 deg)
Sign. Wave Height (m)
0.00 - 0.10
0.10 - 0.25
0.25 - 0.50
0.50 - 0.75
0.75 - 1.00
1.00 - 1.50
> 1.50
Southannan Sands SSSI
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
218000
218500
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653500
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652500


Final Dredge Phase:
270 Deg. Sign. Wave Height Differential (m)
-0.75 - -0.25
-0.25 - -0.10
-0.10 - -0.05
-0.05 - 0.05
0.05 - 0.10
0.10 - 0.25
Southannan Sands SSSI
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
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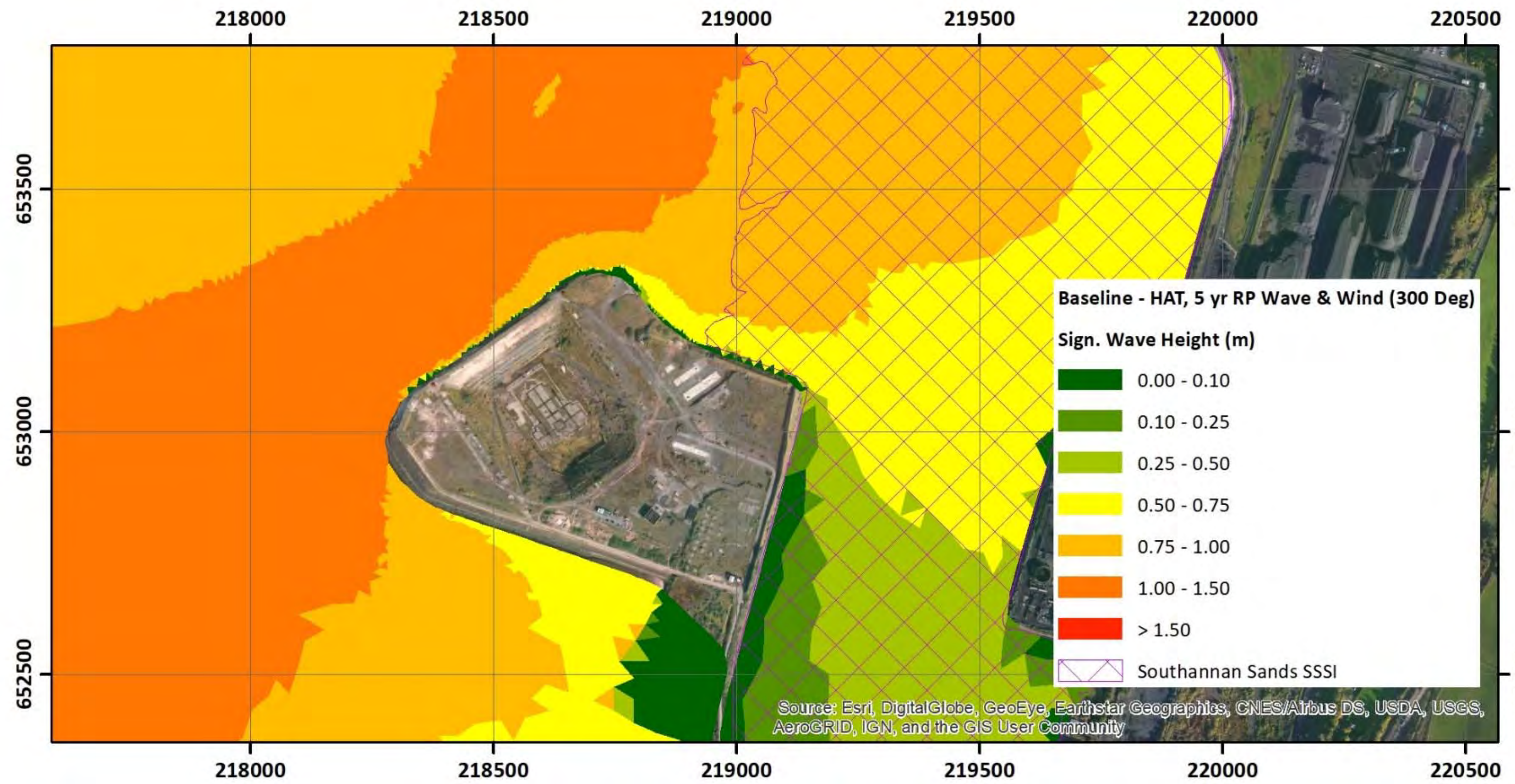
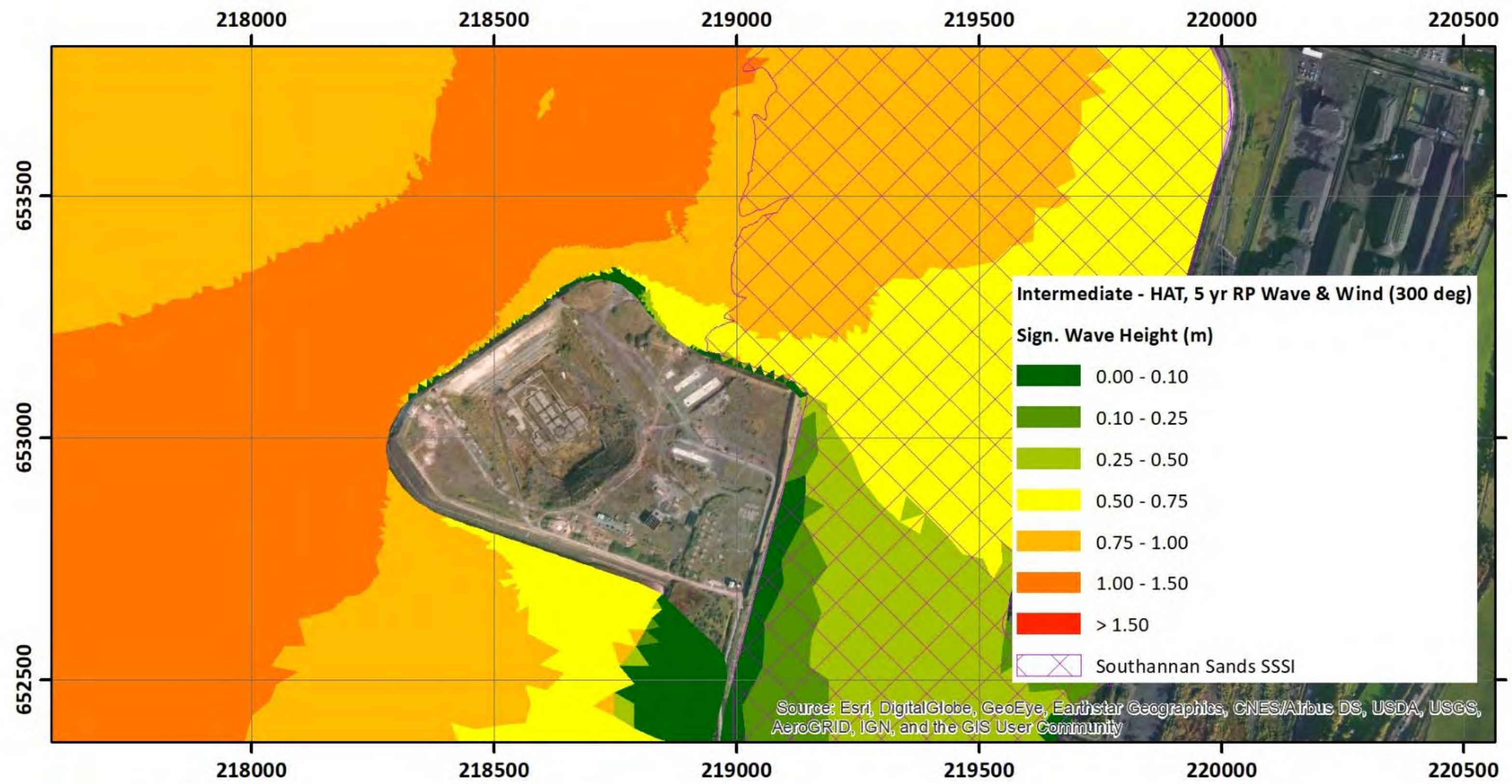
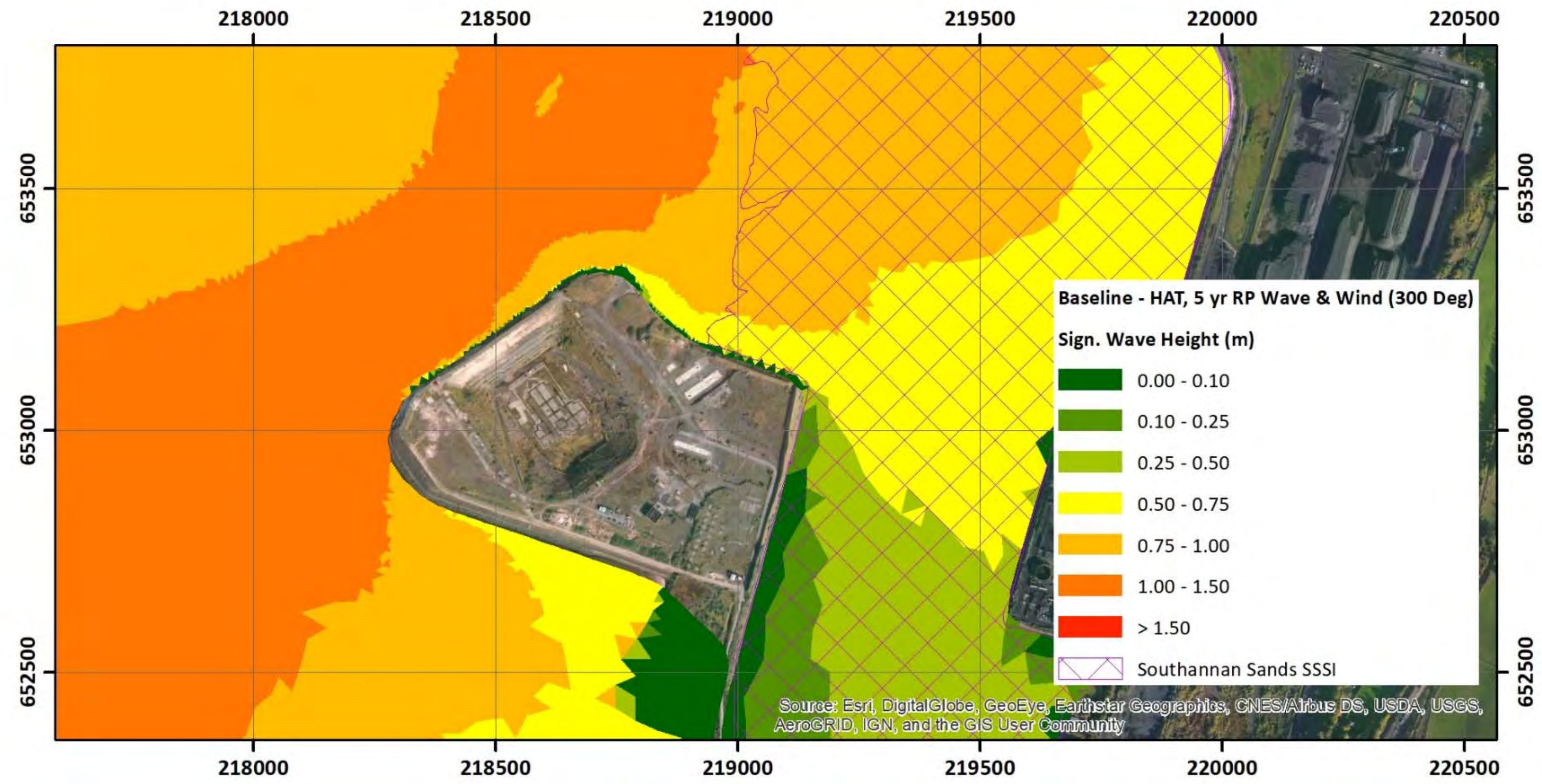

Baseline - HAT, 5 yr RP Wave & Wind (300 Deg)
Sign. Wave Height (m)
0.00 - 0.10
0.10 - 0.25
0.25 - 0.50
0.50 - 0.75
0.75 - 1.00
1.00 - 1.50
> 1.50
Southannan Sands SSSI
218000
218500
219000
219500
220000
220500
653500
653000
652500
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community


Intermediate - HAT, 5 yr RP Wave & Wind (300 deg)
Sign. Wave Height (m)
0.00 - 0.10
0.10 - 0.25
0.25 - 0.50
0.50 - 0.75
0.75 - 1.00
1.00 - 1.50
> 1.50
Southannan Sands SSSI
218000
218500
219000
219500
220000
220500
653500
653000
652500
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community


Intermediate Dredge Phase:
300 Deg. Sign. Wave Height Differential (m)
-0.75 - -0.25
-0.25 - -0.10
-0.10 - -0.05
-0.05 - 0.05
0.05 - 0.10
0.10 - 0.25
Southannan Sands SSSI
218000
218500
219000
219500
220000
220500
653500
653000
652500
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community


Baseline - HAT, 5 yr RP Wave & Wind (300 Deg)
Sign. Wave Height (m)
0.00 - 0.10
0.10 - 0.25
0.25 - 0.50
0.50 - 0.75
0.75 - 1.00
1.00 - 1.50
> 1.50
Southannan Sands SSSI
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
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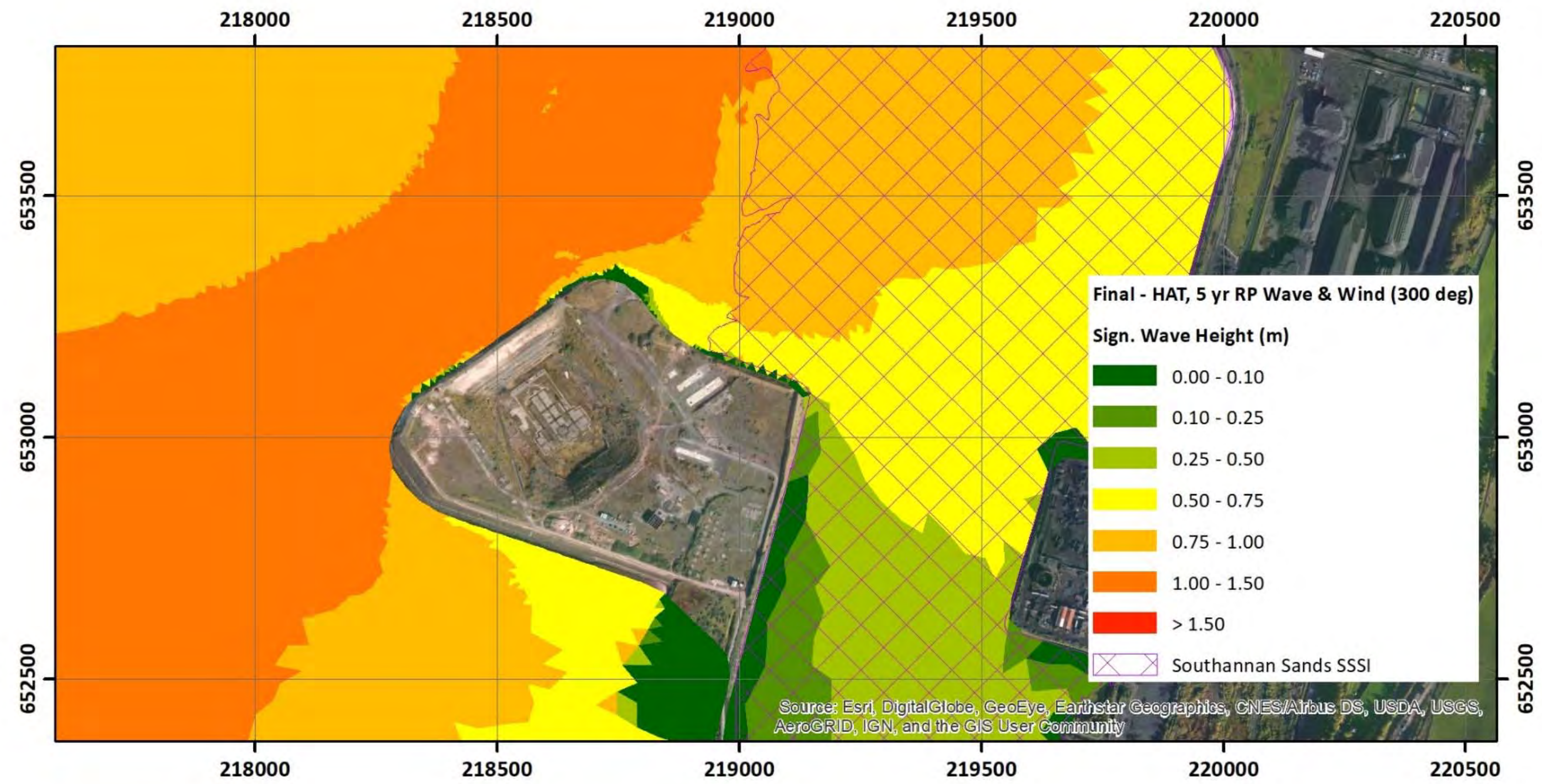
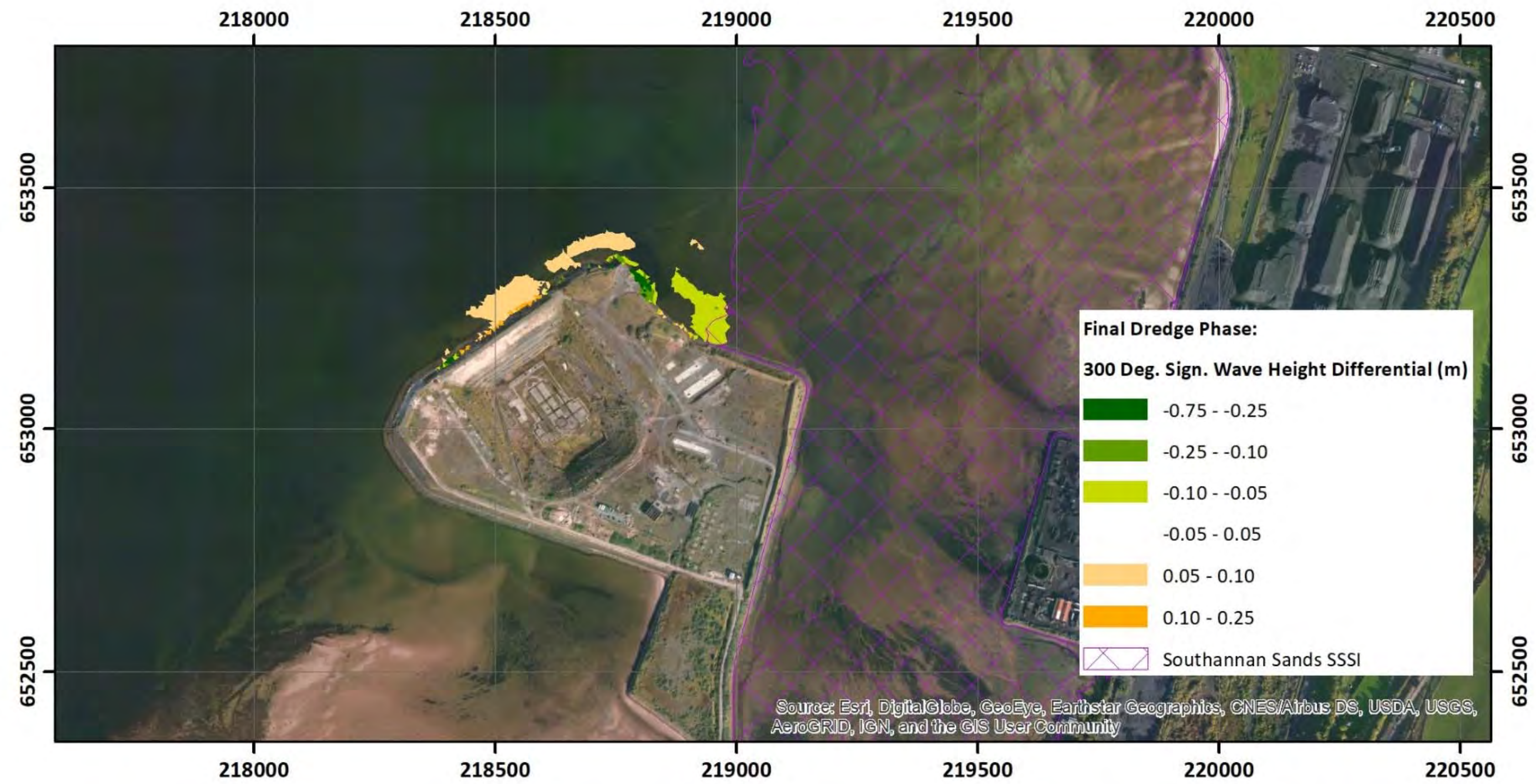
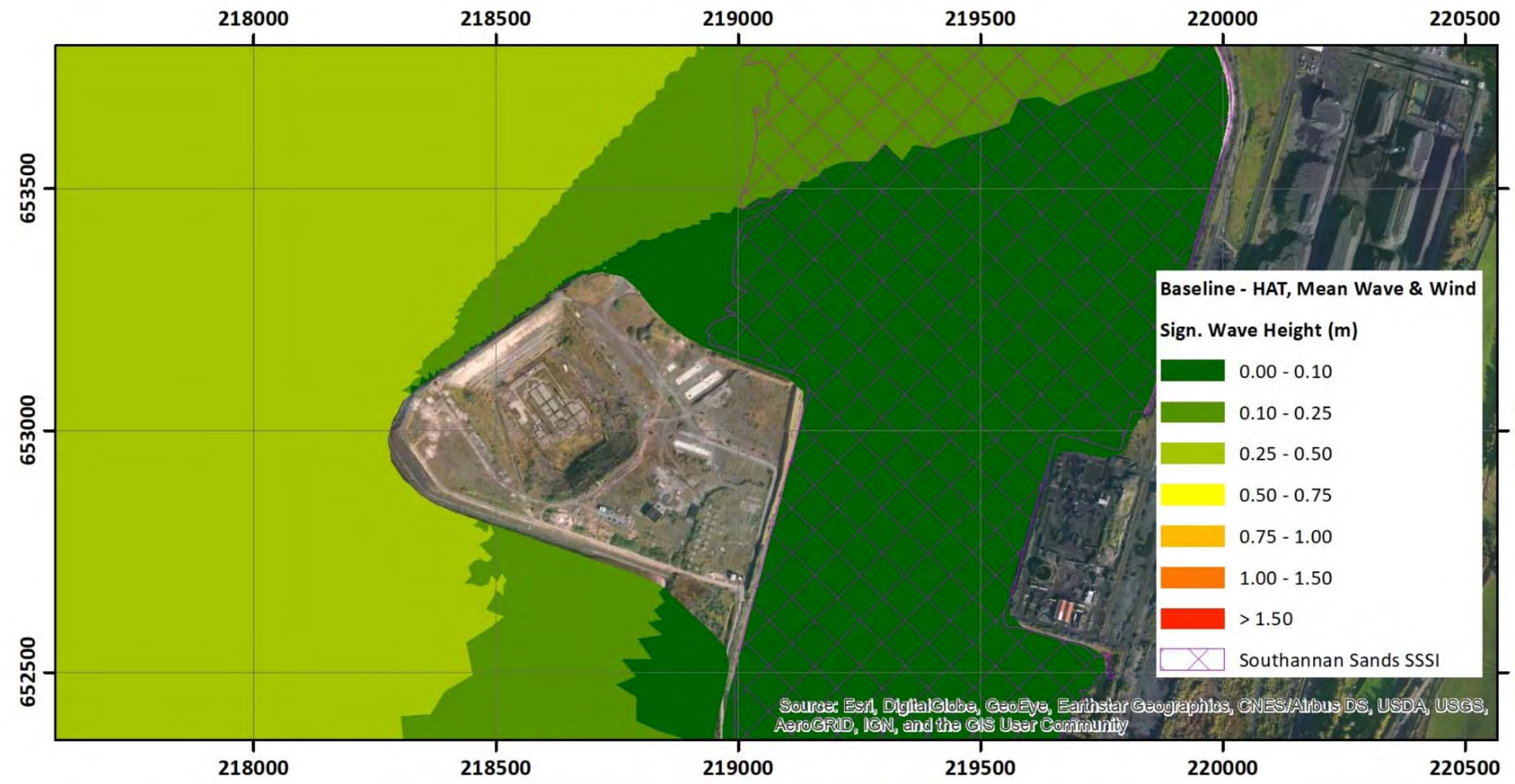
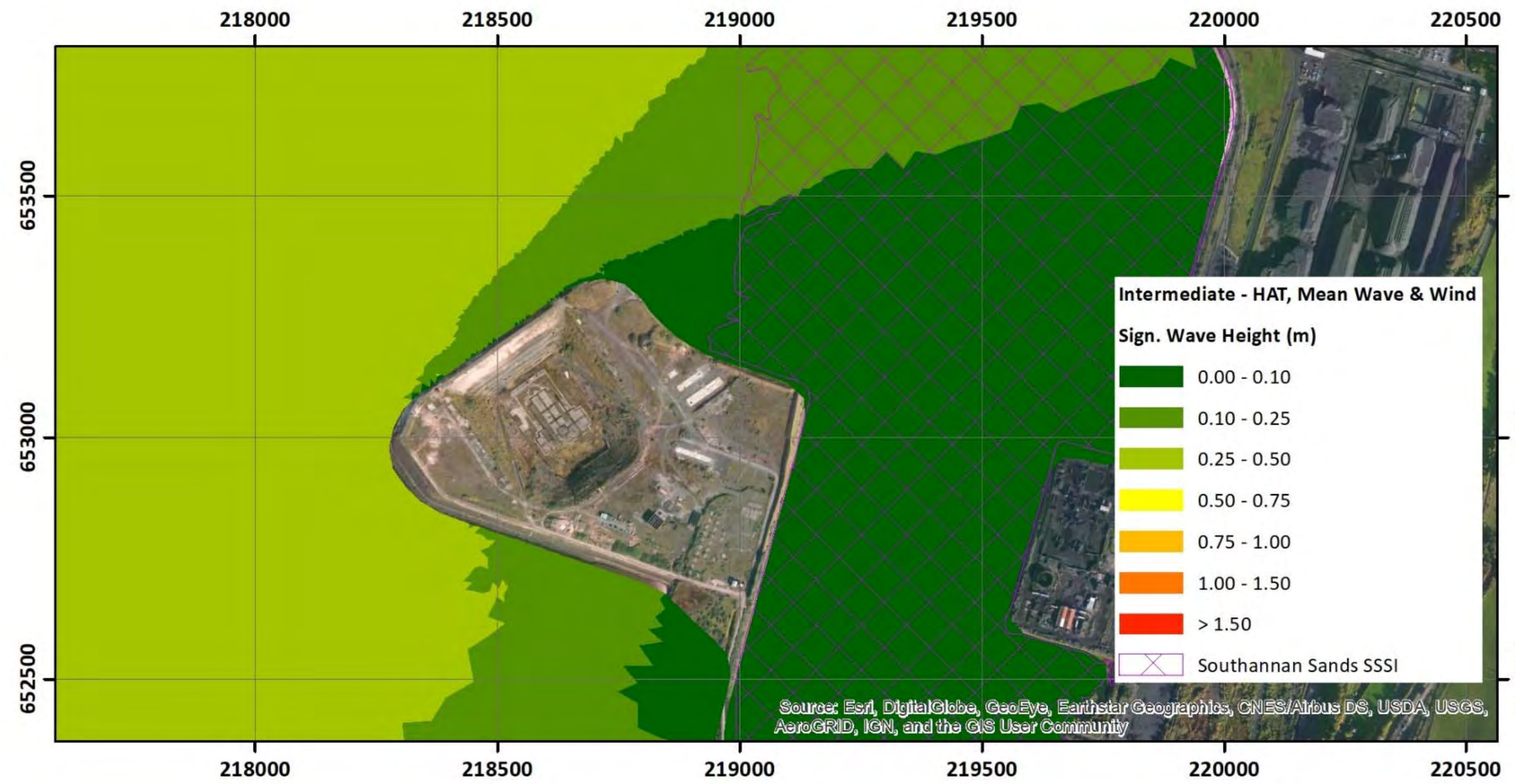
653000
652500

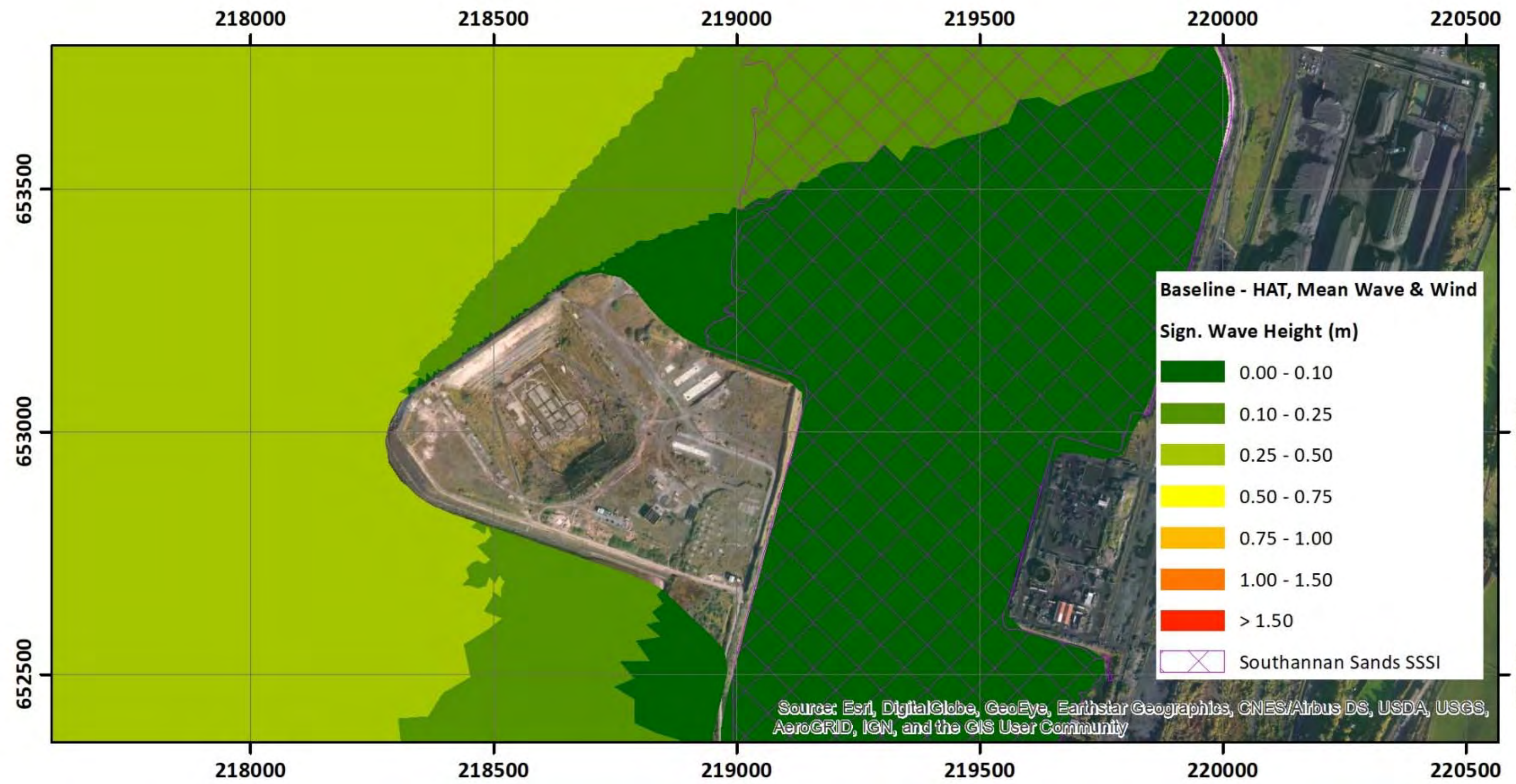

Final - HAT, 5 yr RP Wave & Wind (300 deg)
Sign. Wave Height (m)
0.00 - 0.10
0.10 - 0.25
0.25 - 0.50
0.50 - 0.75
0.75 - 1.00
1.00 - 1.50
> 1.50
Southannan Sands SSSI
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
218000
218500
219000
219500
220000
220500
653500
653000
652500

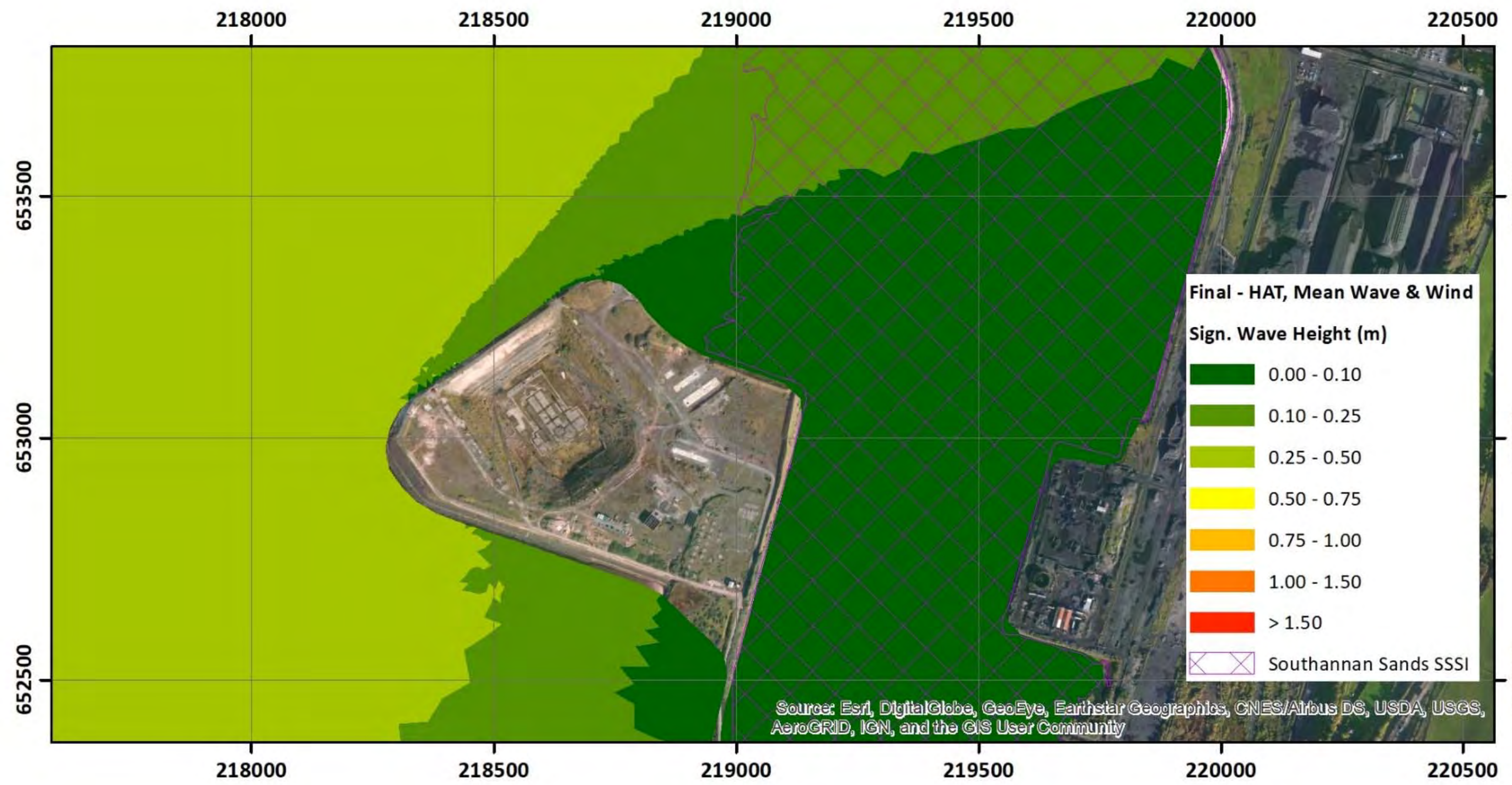

Final Dredge Phase:
300 Deg. Sign. Wave Height Differential (m)
-0.75 - -0.25
-0.25 - -0.10
-0.10 - -0.05
-0.05 - 0.05
0.05 - 0.10
0.10 - 0.25
Southannan Sands SSSI
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
218000
218500
219000
219500
220000
220500
653500
653000
652500


Baseline - HAT, Mean Wave & Wind
Sign. Wave Height (m)
0.00 - 0.10
0.10 - 0.25
0.25 - 0.50
0.50 - 0.75
0.75 - 1.00
1.00 - 1.50
> 1.50
Southannan Sands SSSI
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community


Intermediate - HAT, Mean Wave & Wind
Sign. Wave Height (m)
0.00 - 0.10
0.10 - 0.25
0.25 - 0.50
0.50 - 0.75
0.75 - 1.00
1.00 - 1.50
> 1.50
Southannan Sands SSSI
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community


Intermediate Dredge Phase:
Mean Sign. Wave Height Differential (m)
-0.75 - -0.25
-0.25 - -0.10
-0.10 - -0.05
-0.05 - 0.05
0.05 - 0.10
0.10 - 0.25
Southannan Sands SSSI
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community


Baseline - HAT, Mean Wave & Wind
Sign. Wave Height (m)
0.00 - 0.10
0.10 - 0.25
0.25 - 0.50
0.50 - 0.75
0.75 - 1.00
1.00 - 1.50
> 1.50
Southannan Sands SSSI
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
218000
218500
219000
219500
220000
220500
653500
653000
652500


Final - HAT, Mean Wave & Wind
Sign. Wave Height (m)
0.00 - 0.10
0.10 - 0.25
0.25 - 0.50
0.50 - 0.75
0.75 - 1.00
1.00 - 1.50
> 1.50
Southannan Sands SSSI
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
218000
218500
219000
219500
220000
220500
653500
653000
652500


Final Dredge Phase:
Mean Sign. Wave Height Differential (m)
-0.75 - -0.25
-0.25 - -0.10
-0.10 - -0.05
-0.05 - 0.05
0.05 - 0.10
0.10 - 0.25
Southannan Sands SSSI
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
218000
218500
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653500
653000
652500