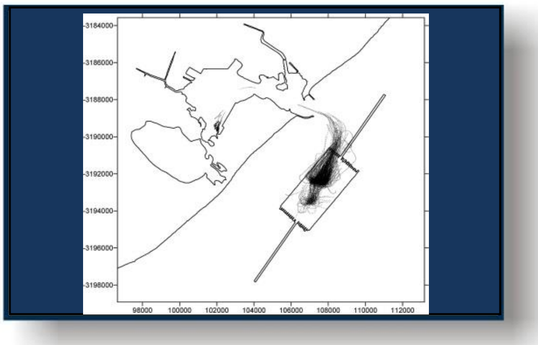
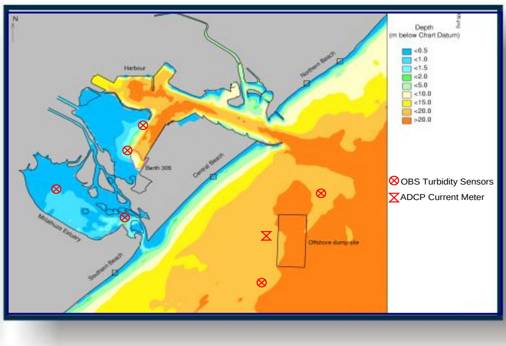
Port of Richards Bay Capacity Expansion EIA:

Dredging and Dredge Spoil Disposal Modelling Specialist Study





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Port of Richards Bay Capacity Expansion EIA:

Dredging and Dredge Spoil Disposal Modelling Specialist Study

Prepared for:

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Jointly prepared by:

CSIR, Natural Resources and the Environment and **WSP Group Africa (Pty) Ltd**

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This report was compiled by:

Roy van Ballegooyen	WSP Coastal Africa (Pty) Ltd Stein House, Brandwacht Office Park Stellenbosch 7599, South Africa Tel: + 27 21 883 9260 Tel: + 27 21 883 3212 Email: Roy.vanBallegooyen@WSPGroup.co.za
Brent Newman	CSIR, Natural Resources and the Environment 359 King George V Avenue, Glenwood, Durban, South Africa Tel: + 27 31 242 2377 Fax: + 27 31 261 2509 Email: bnewman@csir.co.za
Patrick Shabangu	CSIR, Natural Resources and the Environment PO Box 320, Stellenbosch 7599, South Africa Tel: + 27 21 888 2562 Fax: + 27 21 888 2693 Email: @csir.co.za
Gert Jacobs	WSP Coastal Africa (Pty) Ltd Stein House, Brandwacht Office Park Stellenbosch 7599, South Africa Tel: + 27 21 888 9260 Fax: + 27 21 883 3212 Email: Gert.Jacobs@WSPGroup.co.za

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CSIR
P O Box 320
STELLENBOSCH 7599
South Africa

Tel: + 27 21 888-2400
Fax: + 27 21 888-2693
Email: rvballeg@csir.co.za

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Scope of Work

This study comprises a specialist modelling study to inform the assessment of the potential environmental impacts associated with the dredging and dredge spoil disposal activities planned for the Port of Richards Bay Capacity Expansion project. The assessment of the potential environmental impacts associated with capital dredging requires that:

- The suitability of sediments for potential (offshore) disposal needs to be assessed against accepted sediment quality guidelines;
- The potential impacts of dredging and dredge spoil disposal activities need to be predicted and assessed. The primary concern is the potential environmental impacts associated with the elevation of water column turbidity and potential inundation/smothering effects on benthic biota, however other potential effects such as aesthetic and noise impacts also need to be assessed;
- The potential impacts of offshore dredge spoil disposal activities on offshore ecosystems and the adjacent shoreline be assessed and, where relevant, mitigation measures introduced.

An assessment of the quality of sediments to be dredged has been undertaken in a companion report (CSIR, 2013a). This information has been used to screen dredge spoil disposal options as well as inform this dredging and dredge spoil disposal modelling study. The requisite baseline reports on the water quality (CSIR, 2013b) and specifically the water column turbidity observed in the port in its present layout (CSIR, 2013c) have been produced and provide a context for this modelling study.

This specialist study focussed on the prediction of potential turbidity and smothering impacts associated with dredging and dredge spoil disposal activities. The assessment of these impacts has been achieved by the set-up and calibration of a three dimensional model that is used to predict the extent, severity and duration of changes in turbidity, water quality and smothering effects associated with dredging and dredge spoil disposal activities. Specifically, this requires a characterisation of the extent of dispersal of dredge spoil from the proposed offshore dredge spoil disposal site. The model results are summarised in terms of exceedance of dredging (water quality) guidelines and other relevant guidelines that have been determined in consultation with other specialists assessing potential impacts in the marine environment.

Where relevant, mitigation measures are proposed. Inputs are also made for the Environmental Management Programme (EMP). Specifically, inputs are made into the sampling design of monitoring activities and compliance monitoring associated with dredging activities.

Roy van Ballegooyen
Coastal Systems Research Group
Natural Resources and the Environment CSIR
Stellenbosch, South Africa July 2015

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Glossary

Acute toxicity:	Rapid adverse effect (*e.g.* death) caused by a substance in a living organism. Can be used to define either the exposure or the response to an exposure (effect).
Anoxia:	The absence or near absence of oxygen, *i.e.* < 0.1 ml O_2/ℓ.
Anthropogenic:	Caused by human activity.
Bathymetry:	The sea bed "topography" derived from measurements of depths of water in oceans, seas, and lakes.
Benthic:	Referring to organisms living in or on the sediments of aquatic habitats (lakes, rivers, ponds, etc.).
Benthos:	The sum total of organisms living in, or on, the sediments of aquatic habitats.
Beach:	The zone of unconsolidated material that extends landward from the low water line to the place where there is marked change in material or physiographic form, or to the line of permanent vegetation (usually the effective limit of storm waters). The seaward limit of a beach – unless otherwise specified – is the mean low water line.
Bio-available:	Able to enter an organism through its cells, skin, gills or gut and thereby cause an impact. In contrast, contaminants which are not bio-available may, for example, form part of the insoluble crystalline matrix of a mineral and will not impact organisms.
Biodiversity:	The variety of life forms, including the plants, animals and micro-organisms, the genes they contain and the ecosystems and ecological processes of which they are a part.
Biota:	The sum total of the living organisms of any designated area.
Contaminant:	Biological (*e.g.* bacterial and viral pathogens) and chemical introductions capable of producing an adverse response (effect) in a biological system, seriously injuring structure or function or producing death.
Oceans & Coasts, DEA:	Oceans and Coasts Division, Department of Environmental Affairs.
Diffraction: (of water waves)	The phenomenon by which energy is transmitted laterally along a wave crest. When a part of a train of waves is interrupted by a barrier, such as a breakwater, the effect of diffraction is manifested by propagation of waves into the sheltered region within the barrier's geometric shadow.
Direction Notation:	*Wind and Wave Direction Notation:* Both wind and wave directions indicate the direction from which the wind blows or the waves come, *e.g.* SSW refers to winds/waves originating from a south-south-westerly direction. *Current Direction Notation:* Current directions indicate the direction towards which the current flows.

EIA:	Environmental Impact Assessment.
Elutriation analyses:	Procedure for estimating the concentration of contaminants that could be released from sediments during dredging activities or sea dumping.
Endemic:	Biological species or taxon restricted to a particular geographic area.
Guideline trigger values:	Concentrations (or loads) of the key performance indicators measured for the ecosystem, below which there exists a low risk that adverse biological (ecological) effects will occur. They indicate a risk of impact if exceeded and should 'trigger' some action, either further ecosystem specific investigations or implementation of management/remedial actions.
Habitat:	The place where a population (*e.g.* animal, plant, micro-organism) lives and its surroundings, both living and non-living.
Hopper:	Tank on a dredger or a barge that receives and contains dredge spoil.
Hopper overwash:	The practice of allowing low concentration sediment slurry to flow overboard allowing the build-up of more concentrated slurries in the hopper.
Hypoxia	Low oxygen levels in the water column and/or sediments, *i.e.* < 2ml O_2/ℓ.
Lean Mixture overboard: (LMOB)	Lean Mixture Overboard systems typically are used at the beginning and end of a dredge cycle when the majority of the material entering the hopper will be water with a small amount of fine material, which is discharged to the sea via an overflow system.
Lithogenic:	Having its origin in the lithosphere, *i.e.* of natural origin rather than from the influence of human activities.
Longshore:	Parallel to and near the shoreline (same as "alongshore").
Longshore current:	The littoral current in the breaker zone moving essentially parallel to the shore, usually generated by waves breaking at an angle to the shoreline.
Macrofauna:	Animals >1 mm.
MPA:	Marine protected area.
NTU:	nephelometric turbidity units, a measure of the light scattering properties of a volume of water.
PAH:	Polycyclic Aromatic Hydrocarbon.
Peak wave period (T_p):	Defined as the wave period that corresponds to the wave period (or frequency) with the maximum wave energy as derived from the spectral wave energy distribution, commonly referred to as the wave spectrum**.**
Pollution:	The introduction of unwanted components into waters, air or soil, usually as result of human activity; *e.g.* hot water in rivers, sewage in the sea, oil on land.
Population:	Population is defined as the total number of individuals of a species or taxon.
Refraction:	(of water waves). The process by which the direction of a wave moving in shallow water at an angle to the contours is changed: The part of the wave advancing in shallower water moves more slowly than that part still

	advancing in deeper water, causing the wave crest to tend towards alignment with the underwater bathymetry contours.
Sediment:	Unconsolidated mineral and organic particulate material that settles to the bottom of aquatic environment.
Significant wave height (H_{mo})	The significant wave height is determined from the zeroth moment of the wave energy spectrum. The moments of the spectrum, m_n, are determined as follows: $m_n = \int_{f_1}^{f_2} f^n S(f)\, df$ where m_n = the nth moment of the spectrum defined by S(f) f = wave frequency (Hz) f_1, f_2 = the spectral low and high frequency limits $S(f)$ = wave spectral density (m2/Hz) The significant wave height (H_{mo}) is calculated from the zeroth moment $H_{mo} = 4\sqrt{m_o}$
South African Water Quality guidelines	This refers to the South African water quality guidelines for the coastal and marine waters (DWAF 1995).
Species	A group of organisms that resemble each other to a greater degree than members of other groups and that form a reproductively isolated group that will not produce viable offspring if bred with members of another group.
Surficial sediments:	Those sediments on the seabed located at the seawater - seabed interface.
Suspended material:	Total mass of material suspended in a given volume of water, measured in mg/ℓ.
Suspended matter:	Suspended material**.**
Suspended sediment:	Unconsolidated mineral and organic particulate material that is suspended in a given volume of water, measured in mg/ℓ.
Surficial	The surface layers of, *e.g.*, sediments.
Thermocline	a vertical gradient in sea water temperature that has a significant impact on vertical mixing of the water column and the vertical shear in currents in the ocean.
TNPA:	Transnet National Ports Authority.
TCP	Transnet Capital Projects
Toxicity:	The inherent potential or capacity of a material to cause adverse effects in a living organism.
TPH:	Total Petroleum Hydrocarbons.

Turbidity:	Measure of the light-scattering properties of a volume of water, usually measured in nephelometric turbidity units.
Upwelling:	The process of transporting deeper, usually colder water to or towards the sea surface.
Vulnerable:	A taxon is vulnerable when it is not Critically Endangered or Endangered but is facing a high risk of extinction in the wild in the medium-term.
Wave period:	(1) The time required for two successive wave crests to pass a fixed point. (2) The time, in seconds, required for a wave crest to traverse a distance equal to one wave length.

1 INTRODUCTION

1.1 Background

The Transnet Port Terminals in Richards Bay are targets for major demand growth in bulk and break-bulk products up to 2040, with the bulk of the demand expected to be realised in the next 10 years. The current terminal facilities and machinery are near their operational capacity and many of the assets are at or near the end of their useful life, requiring major refurbishment and/or replacement. Transnet therefore needs to expand capacity and recapitalise facilities in the Port of Richards Bay, to cater for the increase in general freight demand.

The FEL-1 study for the Richards Bay Capacity Expansion Programme was completed in July 2012, with the project receiving a "green" status from Transnet's Gate Review Panel. The FEL-2 study commenced in October 2012, with ten possible expansion options taken forward from the FEL-1 study for further engineering development. The FEL-2 study identified a number of priority option layouts, namely Options 1A, 1D and 3A (Aurecon, 2013). This specialist study addresses environmental issues associated with dredging and dredge spoil disposal for Option 3A. Specifically the study comprises a modelling study to inform primarily the marine ecological environmental impacts associated with changes in water column turbidity and in benthic habitats due to dredging and dredge spoil disposal activities. A more detailed description of the Option 3A development scenario is provided in Section 2 of this report.

1.2 Scope of Work

The assessment of the potential environmental impacts associated with the proposed capital dredging requires that:

- The suitability of sediments for potential (offshore) disposal needs to be assessed against accepted sediment quality guidelines;
- The potential impacts of dredging and dredge spoil disposal activities need to be predicted and assessed. The primary concern is the potential environmental impacts associated with the elevation of water column turbidity and potential inundation/smothering effects on benthic biota, however other potential effects such as aesthetic and noise impacts also need to be assessed;
- The potential impacts of offshore dredge spoil disposal activities on offshore ecosystems and the adjacent shoreline be assessed and, where relevant, mitigation measures introduced.

An assessment of the quality of sediments to be dredged has been undertaken in a companion report (CSIR, 2013a). This information has been used to screen dredge spoil disposal options as well as inform this dredging and dredge spoil disposal modelling study. The requisite baseline reports on the water quality (CSIR, 2013b) and specifically the water column turbidity observed in the port in its present layout (CSIR, 2013c), have been produced and provide a context for this modelling study.

This specialist study comprises a specialist modelling study to inform the assessment of the potential environmental impacts associated with dredging and dredge spoil disposal activities and is focussed on the prediction of potential turbidity, smothering and shoreline impacts associated with dredging and dredge spoil disposal activities.

The assessment of water quality and smothering impacts has been achieved by the set-up and calibration of a three dimensional model that is then used to predict the extent, severity and duration of changes in turbidity, water quality and smothering associated with dredging and dredge spoil disposal activities. Specifically, this requires a characterisation of the extent of dispersal of dredge spoil from the proposed offshore dredge spoil disposal site. The model results are summarised in terms of exceedance of dredging (water quality) guidelines as well as and other relevant guidelines that have been determined in consultation with other specialists assessing potential impacts in the marine environment.

Where relevant, mitigation measures are proposed. Inputs are made to the Environmental Management Programme (EMP) for the proposed dredging activities, specifically inputs into the sampling design of compliance monitoring and other relevant monitoring activities associated with the proposed dredging activities.

1.3 Assumptions and limitations

The following assumptions and limitations apply to this specialist study:

- The modelling assessment of the dredging and dredge spoil disposal is based on the project description communicated to the specialist both prior to the commencement of the study and during the study. Where this information has been deficient, particularly in terms of the dredging description, the specialists compiling this study have provided the necessary specifications based on their experience of similar dredging projects under the assumption that this will be acceptable to all relevant parties having an interest in the Port of Richards Bay Capacity Expansion EIA;
- The modelling study is intended to inform the ecological specialist study assessing the potential impacts of the proposed dredging activities;
- Specifically excluded from the study is the assessment of potential dredge spoil disposal impacts on the adjacent shoreline in terms of any influence that the dredge spoil disposal mound may have on the wave climate and consequently on possible shoreline erosion and/or accretion. This would require a more detailed specification of dredge spoil disposal activities than is presently available, specifically this would require an accurate quantification of the volumes of dredge spoil to be disposed of at the offshore dredge disposal site. Should there be residual concerns around this issue such impacts may need to be the subject of a detailed specialist shoreline impact assessment study.

1.4 Structure of the Report

The structure of the report is as follows. Section 1 provides a brief introduction to the project together with the scope of work proposed for the assessment of the potential environmental impacts associated with the capital dredging required for the proposed project. A more comprehensive project description and associated dredging activities is provided in Section 2. A detailed description of the environments that may be affected by the proposed activities is provided in Section 3. Section 4 provides a description of the likely environmental impacts as well as environmental quality guidelines of relevance to the assessment.

The three-dimensional hydrodynamic and sediment transport model set-ups, calibration and model simulations of changes in water column turbidity, water quality and sediment deposition and re-distribution are reported in Section 5. Section 6 provides the results of the modelling study while the recommendation on the monitoring are provided in Section 7. The conclusions and recommendations of the study are summarised in Section 8.

2 PROJECT DESCRIPTION

The Port of Richards Bay is situated 160 km northeast of Durban and 465 km southwest of Maputo, Mozambique. The Port of Richards Bay consists of the Transnet operated Dry Bulk Terminal (DBT) and Multi-Purpose Terminal (MPT), along with the privately operated Richards Bay Coal Terminal. Other private operators within the port include several wood chip export terminals and a bulk liquid terminal (Aurecon, 2012a). The port occupies 2 157 ha of land area and 1 495 ha of water area at present, but has the potential of expanding substantially if required, making Richards Bay potentially one of the largest ports worldwide.

Exports remain the primary activity of the Port of Richards Bay that serves the coalfields of Kwa-Zulu Natal and Mpumalanga, together with timber and granite exporters from as far away as the Eastern and Northern Cape.

A dedicated railway line, designed specifically to handle the majority of South Africa's coal exports, connects the port with Mpumalanga and Gauteng. Other rail links connect Richards Bay with Durban in the south and Swaziland and Mpumalanga to the north. The port also has extensive rail and conveyor belt systems servicing the berths from nearby factories and plants.

The existing port layout and proposed changes to this layout associated with the Richards Bay Capacity Expansion Programme, are summarised in Section 2.1 below.

2.1 Existing and Proposed New Infrastructure

A brief description of the existing port infrastructure and layout is provided below, followed by a more detailed description of the proposed new infrastructure and associated changed layout(s) for development Option 3A.

2.1.1 Existing Port Infrastructure

The layout of the existing Port of Richards Bay is indicated in Figures 2.1 and 2.2 below. The entrance channel is maintained to a depth -23.9 m CD offshore of the breakwaters, -21.9 m CD just inshore of the breakwaters and -19.4 m CD along most of the entrance channel. The main basin areas of the port (bulk cargo quay and the bulk coal quay) are maintained at a depth of -18.9 m CD. The smaller basins, Inner Basins 1 and 2 (Figure 2.1) are maintained at depths of -14.4 m CD and -14.6 m CD, respectively. The small craft harbour and the approach channel and reclamation berth near the port entrance are maintained to a depth of -7.9 m CD.

An extended sandspit separates these inner basins from a shallow mudflat area to the south. On the mudflats the depth typically ranges between 0.2 and 0.5 m CD, deepening to approximately -1.5 m CD on the eastern edge of the mudflat towards the Richards Bay Coal Terminal Basin.

North of the entrance channel lies the repair quay, the small craft harbour and the dredger berth just inside the port entrance. To the south of the entrance channel lies a changing shoreline along which has been built a number of stabilising structures and groins to protect existing infrastructure (roads, *etc*). The ecologically important Echwebeni Natural Heritage site is located adjacent to the Richards Bay Coal Terminal on the southern side of the inner extremity of the entrance channel (see Figure 2.1).

Figure 2.1: The existing layout of the Port of Richards Bay (Source: GoogleEarth, 2015).

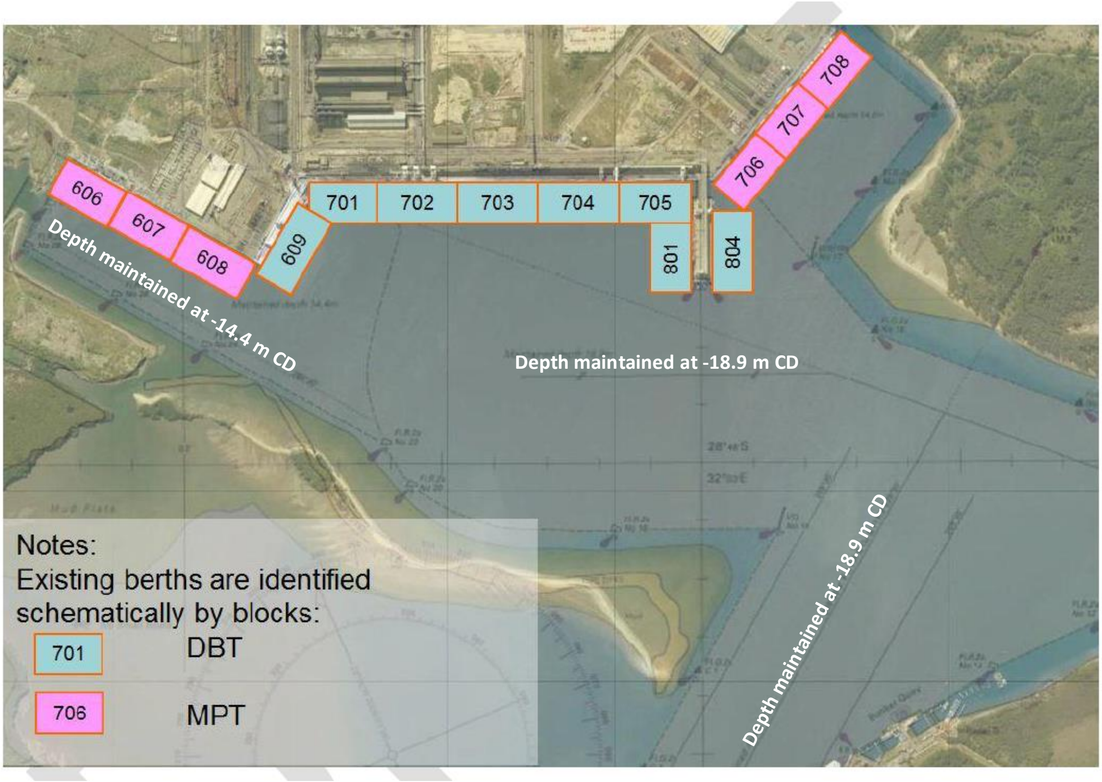

Figure 2.2: The layout of the existing dry Bulk (DBT) and Multi-purpose (MPT) terminals of the Port of Richards Bay that handle the dry bulk and break bulk commodities (Aurecon, 2012a).

2.1.2 Proposed New Port Infrastructure

The new development under consideration in this report is the proposed Port of Richards Bay Capacity Expansion Option 3A development (Figure 2.3) that comprises the following infrastructural components:

- The construction of two new Panamax size berths (604 and 605) to accommodate multipurpose vessels (600 series berths denoted break bulk in Figure 2.3). The proposed depths of the berths and approach channel will be -15.5 m CD. There are two potential layouts, the first having a basin width of 315 m representing a required or minimum width and the second a wider basin of 440 m representing a preferred basin width (Figure 2.4)
- The extension of the DBT finger jetty by 340 m to accommodate two new coal berths (Berths 801 and 804).
- Associated dredging of berths and approach channels.

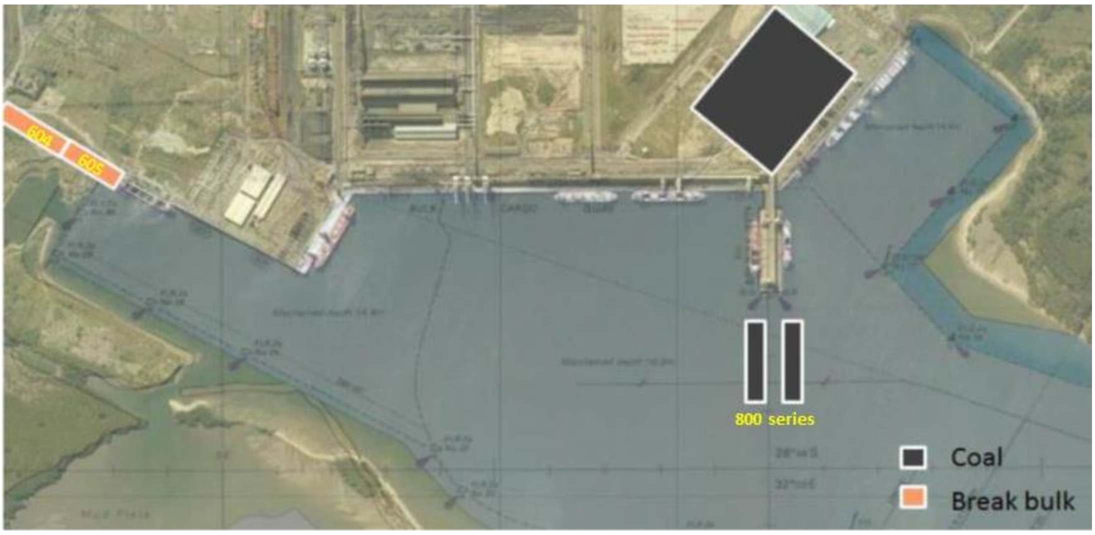

Figure 2.3: **Option 3A infrastructural components (Aurecon, 2012a).**

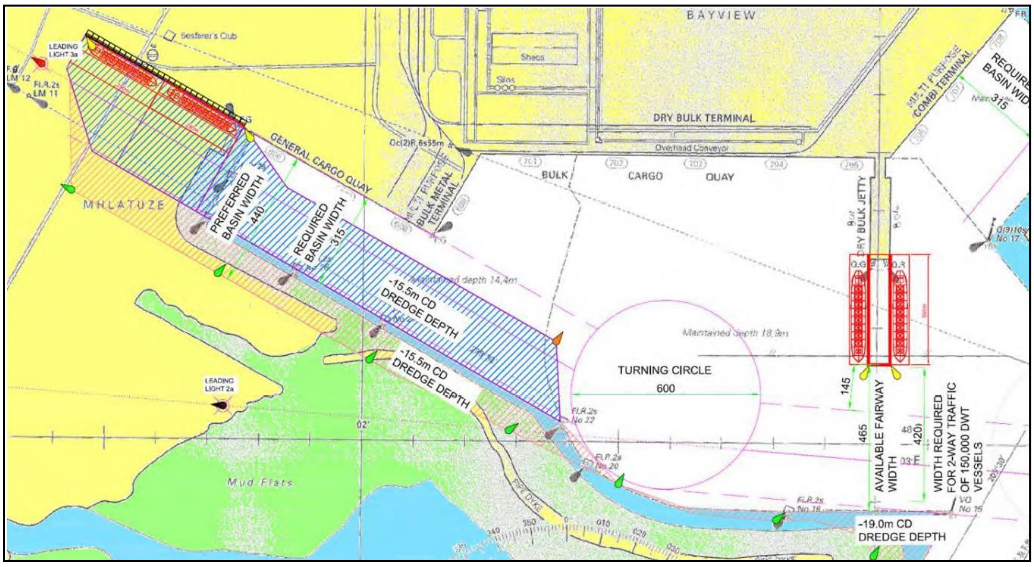

Figure 2.4: **Option 3A layout and dredge depths (Aurecon, 2013, 2014).**

2.2 Description of Dredging Activities

There are a number of options for the removal of material for the development of the berths and approach channels. These are all described in Aurecon (2012a,b) and BKS (2013), the former providing a description of possible dredge technologies and the latter a description of possible dredge spoil disposal options.

It is not clear whether the dredging will take place in phases or not, consequently it has been assumed in this study that, once commenced, the dredging will continue uninterrupted until completed. This constitutes a conservative assumption in terms of the likelihood of elevated turbidity levels as it assumes the maximum dredge rates and consequently the maximum sediment loading in the water column both at the dredging location and at the dredge spoil disposal site. However, this assumption may not be conservative in terms of the duration of impacts should the dredging occur over a significantly longer period.

Presently it is not clear when dredging will commence or whether it will be constrained to any particular season. For the purpose of assessing impacts a single dredge duration has been assumed that commences in late winter/early spring and extends into summer. This is a similar period to the last major capital dredging operation undertaken in the Port of Richards Bay, namely the development of Berth 306 at the Richards Bay Coal terminal. This assumption is largely an expedience driven by the limited data available to the modelling study but nevertheless is considered to be sufficiently representative of the conditions under which dredging operations are likely to occur.

Although seasonality exists in terms of wind and wave driven flows and turbulence (higher wind speeds and higher wave conditions occur in winter compared to summer), the flows in the vicinity of the dredge spoil disposal site are predominantly due to the influence of the large-scale offshore flows associated with the Agulhas Current that itself displays no clear seasonality. The selection of different start date for the dredging, while likely to have some influence on the modelling outcomes[1], is unlikely to change the conclusions of the modelling study or any ecological assessments based on the modelling study.

2.2.1 Quantities to be dredged

It is difficult to estimate the total *in-situ* volume of material to be dredged for the Option 3A development from existing documentation supplied to the specialist team (Aurecon, 2012a,b, 2013; BKS, 2013). There exist a number of reasons for this uncertainty. First, the proposed developments have been broadly characterised in many of the FEL-2 documents as the “Port Expansion Project” that includes all possible development options (Options 1A, 1D and Option 3A) for the 500, 600 and 800 series of berths.

It is estimated that up to 9.718 million m^3 of material will need to be dredged depending on the development option selected (BKS, 2013). Further it is noted in Aurecon (2013) that Option 3A will required the least dredging due to the fact that only Panamax vessels are planned to be accommodated

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[1] The modelling, in focussing on late winter and early spring, is biased towards higher wave conditions (that will result in increased sediment re-suspension, particularly at the offshore dredge spoil disposal site). There will also be a bias to higher wind conditions (especially from the SW sector) and a greater predominance of SW winds compared to summer conditions when NE winds conditions are more prevalent. The results obtained therefore will be conservative both in terms of elevated water column turbidity and re-distribution of sediments from the offshore dredge spoil disposal site. However there will be a slight bias in the direction of the distribution of higher turbidity waters from the dredge spoil disposal site, with the model indicating increased water column turbidity extending predominantly northeastwards from the dredge spoil disposal site whereas in summer there will be a greater degree of elevated turbidity in waters southwest of the dredge spoil disposal site.

for this option, resulting in the proposed dredge depths of -15.5m CD as opposed to the greater depths (-19.0 m CD) required for the other preferred options (Options 1A and 1D). Consequently the anticipated dredge volumes for Option 3A are expected to be less than the 9.7 million m^3 suggested in the above reports as the maximum for all of the preferred options under consideration.

Dredge volumes assuming no excavation "in the dry"

In the absence of more detailed available information, the dredge quantities for the narrow and wide basin layout options have been estimated from expected differences between the proposed new dredged depths and the existing water depths in the port, as well as elevations of terrestrial areas to be dredged (and excavated). For the purposes of estimating the dredge volumes an average terrestrial land elevation of 5m above mean sea level (MSL) has been assumed. This corresponds to an elevation of the terrestrial areas to be dredged (and excavated) of just under 6m above CD. Included in the estimated dredge volumes is the narrow area to the north of the sand spit that needs to be dredged to a water depth of -19.0 m CD.

Based on these assumptions the estimated dredge volumes are 4.695 million m^3 and 8.850 million m^3 for the narrow and wide basin layouts, respectively (see Figure 2.5, Figure 2.6 and Table 2.1). To provide a conservative estimate of the material to be dredged (and excavated), an allowance of approximately 5% has been made for possible "over-dredging" or excavation of additional material. The assumed dredge quantities are therefore assumed to be approximately 4.930 million m^3 for the narrow basin option and 9.293 million m^3 for the wide basin option.

Dredge volumes assuming excavation of some of the material "in the dry"

How much of the total material to be removed (to create the berths) that will be dredged and how much will be excavated "in the dry", is uncertain. The extent to which excavation "in the dry" occurs will be determined by practicalities such as the disposal or re-use of these excavated sediments.

If the present terrestrial areas are to be excavated to a depth of MSL (+1.09 m CD) then the volumes of material to be excavated will be approximately 0.715 million m^3 and 1.168 million m^3 for the narrow and wide basin options, respectively. The amount of material to be dredged accordingly will be reduced to 3.980 million m^3 and 7.682 million m^3 for narrow and wide basin options, respectively. If a 5% allowance is made for over-dredging or unexpected additional material to be dredged, then these dredge volumes increase to 4.179 million m^3 and 8.807 million m^3, respectively.

Similarly if the terrestrial areas are to be excavated to a depth of -5m CD then the volumes to be excavated "in the dry" will be approximately 0.858 million m^3 and 1.402 million m^3, for the narrow and wide berth layout options, respectively. This leaves volumes remaining to be dredged of 3.122 million m^3 or 6 .280 million m^3 for the narrow and wide berth layout options, respectively. If a 5% allowance is made for over-dredging or unexpected additional material to be dredged, then these dredge volumes increase to of 3.278 million m^3 and 6.594 million m^3 for the narrow and wide berth layout options respectively.

The above estimates of potential dredge volumes are summarised in Table 2.1 below.

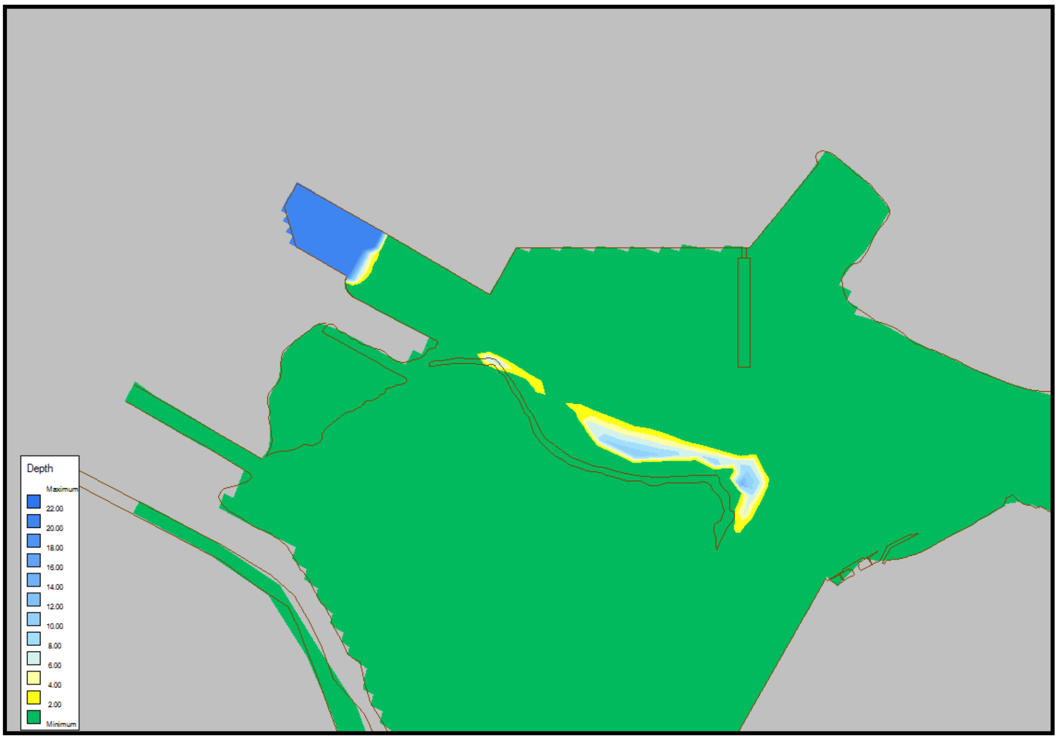

Figure 2.5: Estimated depth of sediment that needs to be dredged or excavated for the Option 3A narrow basin layout.

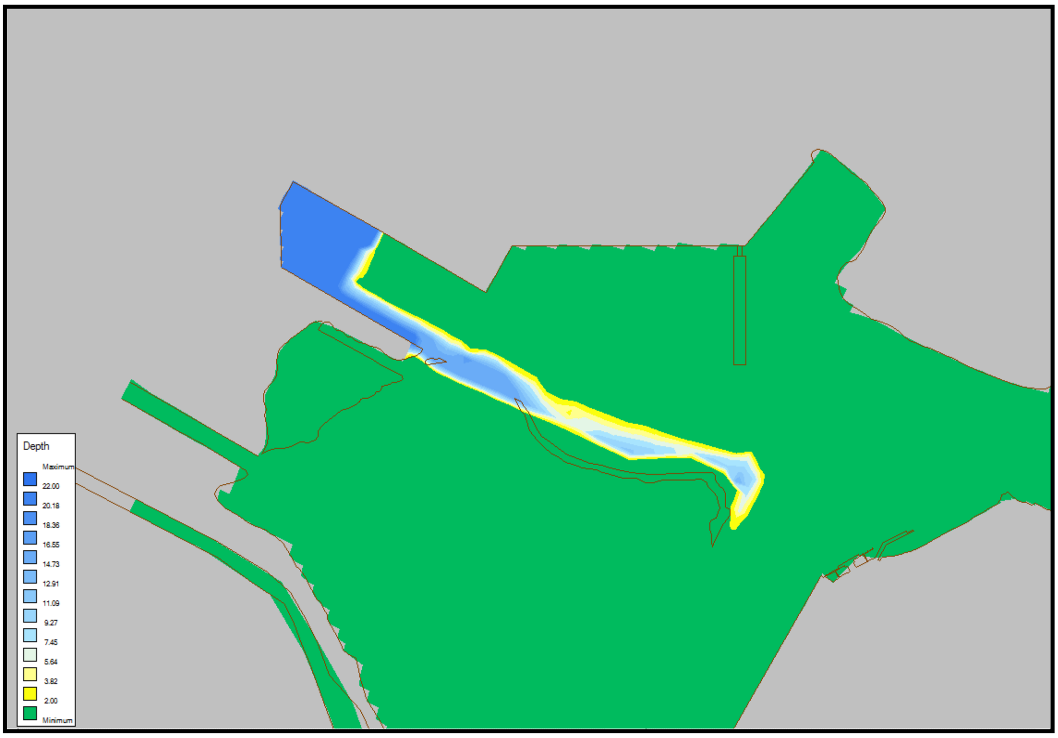

Figure 2.6: Estimated depth of sediment that needs to be dredged or excavated for the Option 3A wide basin layout.

Table 2.1: Estimated sediment volumes of the material to be dredged during the Port of Richards Bay Capacity Expansion project.

	Estimated volumes (million m^3)		Estimated volumes + 5% (million m^3)	
	Narrow layout	Wide Layout	Narrow layout	Wide Layout
Total material to be removed	4 695 000	8 850 000	4 929 750	9 292 500
Option 1 (No material excavated in the dry thus all material to be dredged)				
"In the dry"	-	-	-	-
Dredged	4 695 000	8 850 000	**4 929 750**	**9 292 500**
Option 2 (Material up to MSL excavated "in the dry" and the remainder to be dredged)				
"In the dry"	715 000	1 168 000	750 750	1 226 400
Dredged	3 980 000	7 682 000	4 179 000	8 066 100
Option 2 (Material up to -5m CD excavated "in the dry" and the remainder to be dredged)				
"In the dry"	858 000	1 401 600	900 900	1 471 680
Dredged	3 122 000	6 280 400	3 278 100	6 594 420

As this study is intended to assess the potential impacts of dredging and dredge spoil disposal, we have taken the most conservative approach and assumed that all of the material to be removed to develop the berths and ensure safe navigation within the port, will be removed by dredger (*i.e.* it is assumed that no excavation and removal of material will occur "in the dry"). If a 5% allowance is made for potential over-dredging or unexpected additional material that may need to be dredged, the dredge volumes to be assessed are approximately 9.293 million m^3 for the wide basin or 4.930 million m^3 for the narrow basin option.

It is likely for both environmental and cost reasons that the preferred basin width will be the narrower layout option. Consequently we have assessed only this "most likely" option. The dredge volume assumed for this study therefore is approximately 4.930 million m^3.

2.2.2 Physical characteristic of the Material to be Dredged

It is important that the physical characteristics of the material to be dredged is known as it largely determines what dredging technology is best suited to the dredging activities, the extent to which there can be a beneficial use for the sediments dredged, the volumes to be disposed of at the offshore dredge disposal site and also the turbidity that will be generated at both the dredging and dredge spoil disposal locations.

A review of the available geotechnical information (Aurecon 2012b, BKS, 2013) suggests that the sediments in the area of interest generally comprise sediments that are predominantly sandy in nature overlying Cretaceous bedrock. Silty clays and clayey silts are stated to be virtually absent from available geotechnical borehole data in the vicinity of the proposed new 600 series berths. The estimates of dredge material in the FEL-2 marine engineering report (Aurecon, 2012a) however suggest substantial quantities of clays to be dredged for the Option 3A development. It should be noted that no borehole data exists for the area to be dredged for berths 604 and 605 and only limited data for the surrounding areas (Aurecon, 2012b), implying that the exact nature of the sediments to be dredged remains relatively uncertain.

An initial assessment of all of the material to be dredged as part of the overall Port Expansion Project that includes all possible development options (Options 1A, 1D and Option 3A) for the 500, 600 and 800 series of berths, suggested grain size distributions as described in Table 2.2 below (BKS, 2013). However subsequent communications with the engineering and environmental assessment practitioners as well as the final FEL-2 design report (Aurecon, 2012a) suggest a significantly different assumed distribution of grain sizes and sediment types (Table 2.3). The latter are the size distributions assumed for this study. Note that the volumes reported in Tables 2.2 are based on the original dredge volume estimate of ~ 9.7 million m^3 and not the approximately 4.930 million m^3 used for this study. In Table 2.3 the volumes to be dredged have been adjusted to the estimated dredge volume for the narrow layout option. There is no reason to believe that this change in the estimated dredge volume will have a significant influence on the assumed size distribution for this study.

Table 2.2: Grain size distribution and sediment volumes for the material to be dredged during the Port Expansion project (BKS, 2013).

Sediment Type	% sediment type	Volume of sediment type
Gravel	22%	2 121 000
Sand	4%	394 000
Soft Clay	32%	3 093 000
Stiff Clay	14%	1 326 000
Rock	29%	2 784 000
Total	**100%**	**9 718 000**

Table 2.3: Grain size distribution and sediment volumes for the material to be dredged for the Option 3A port development component of the Port Expansion project (Aurecon, 2012a).

Sediment Type	% sediment type	Volume of sediment type*	
		Narrow Basin	Wide Basin
Gravel	-	-	-
Sand	4%	197 190	371 700
Silt	0%	0	0
Soft Clay	34%	1 676 115	3 159 450
Stiff Clay	14%	690 165	1 300 950
Rock	48%	2 366 280	4 460 400
Total	**100%**	**4 929 750**	**9 292 500**

* Includes a 5% increase in the estimated volumes to be dredged to allow for potential over-dredging or inaccuracies in the estimates of material to be dredged. This is done to ensure a conservative assessment of potential dredging impacts.

2.2.3 Dredging Technology, Dredging Durations and Dredging Rates

The duration of the dredging operations is determined by the dredging technology used and the quantity of material to be dredged. The exact dredging technology to be used will determine not only the dredging duration but also sediment loading at the dredging locations. Furthermore, the different dredge technologies proposed for the project[2] (*i.e.* a Cutter Suction Dredger (CSD) or the use of a combination of a Trailing Suction Hopper Dredger (TSHD) and Backhoe dredger (BH)) are likely to have different outcomes in terms of mobility of the dredge spoil disposed at the offshore dredge spoil disposal site, particularly where there is a large quantity of fines in the dredge spoil.

The material from a BH tends to remain more consolidated when disposed at an offshore disposal site and consequently is less likely to be re-suspended and become mobile (*i.e.* is likely to result in a lesser elevation in water column turbidity during storms, *etc.*). Conversely, the material from a CSD (and to a lesser extent from a TSHD) will not remain consolidated to the same extent as material from a BH operation and consequently is more likely to be re-suspended and display greater mobility at the offshore dredge spoil disposal site, with an associated greater elevation in water column turbidity. These differences in behaviour are expected to amplify with increasing fines content in the material to be dredged. For the above reasons it is important that there is a sufficient knowledge of the proposed dredge technology (or technologies) to allow a robust assessment of likely turbidity and sediment movement in the dredging and dredge spoil disposal modelling study.

It is stated in the FEL-2 study (Aurecon, 2012a) that the preferred dredge technology is one of two combinations of dredging technologies. The first of these comprises the use of one barge-loading CSD with five 3 700 m^3 barges to transport the material to the offshore disposal site located approximately 10 km offshore. The second proposed dredge technology is the use of a combination of a TSHD to dredge sands, silts and soft clays and the use of a BH dredger to dredge the stiff clays and rock material. Here it is assumed that four barges (size not specified) will be used to transport the material to the dredge spoil disposal site (located approximately 10 km offshore).

Using dredging production rates for CSD, TSHD and BH dredgers reported in Pullar and Hughes (2009), indicative high and low “effective” dredge rates and dredge durations have been estimated for *in-situ* dredge quantities of 4.930 million m^3 (narrow layout) and 9.293 million m^3 (wide layout). This provides indicative dredging durations for the various dredge technologies (see Table 2.4).

Additional information on possible dredging technologies, dredging scenarios and sediment loading of the water column due to dredging activities is provided in (Bray, 1997, van Ballegooyen *et al*., 2006 and Pullar and Hughes, 2009).

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[2] Two international dredging contractors have proposed two different methods of dredging for the Richards Bay FEL-2 study (Aurecon, 2012a). Jan de Nul proposed one barge-loading CSD dredger and five 3 700m^3 barges to transport the material to an offshore disposal site 10 km offshore. All material will be dredged with the single dredge. Van Oord proposed the use of one TSHD for the sands, silts and soft clays, with a backhoe dredge being employed to dredge the stiff clays and rock material, with 4 barges (size not specified) for transportation to the disposal site approximately 10km offshore.

Table 2.4: Effective dredging rates and durations for various dredge technologies for proposed dredge volumes of 4.930 million m^3 (narrow layout) and 9.293 million m^3 (wide layout).

	Small Backhoe	Medium Backhoe	Large Backhoe	TSHD (low rate)	TSHD (high rate)	CSD (low rate)	CSD (medium rate)	CSD (high rate)
Rate of dredging (m^3/h)	200	400	800	1 000	12 500	500	1 500	3 000
Rate of dredging assuming 100 operational hours/week (m^3/week)	20 000	40 000	80 000	100 000	1 250 000	50 000	150 000	300 000
Rate of dredging assuming 140 operational hours/week (m^3/week)	28 000	56 000	112 000	140 000	1 750 000	70 000	210 000	420 000
Duration of dredging assuming **dredge volumes of 4.930 million m^3** and **100 operational hours/week** (weeks)	246.5	123.3	61.6	49.3	3.9	98.6	32.9	16.4
Duration of dredging assuming **dredge volumes of 4.930 million m^3** and **140 operational hours/week** (weeks)	176.1	88.0	44.0	35.2	2.8	70.4	23.5	11.7
Duration of dredging assuming **dredge volumes of 9.293 million m^3** and **100 operational hours/week** (weeks)	464.7	232.3	116.2	92.9	7.4	185.9	62.0	31.0
Duration of dredging assuming **dredge volumes of 9.293 million m^3** and **140 operational hours/week** (weeks)	331.9	165.9	83.0	66.4	5.3	132.8	44.3	22.1
Sediment Loading Rate (kg dry material/m^3 dredged)	25	17	12			3 to 6 (no LMOB*) 13 to 16 (with LMOB*)		

* LMOB refers to lean mixture overboard, which is a process where overflow is allowed from the hoppers, the purpose being to increase the sediment volume in each hopper load. This overflow water has a relatively high concentration of fine sediments and this significantly increases the sediment loading at the dredging location.

For the purposes of this study we have assumed that CSD dredging operation[3] with a CSD capable of a just more than medium effective dredging rate (263 400 m^3 per week). This results in an estimated dredging duration of 18.7 weeks or approximately 131 days of continuous dredging operations. In terms of dredge spoil disposal a barge size of 3 700 m^3 has been assumed. For the above assumed effective dredge rates, this implies that 21 barge trips to the dredge spoil disposal site will be required for each day of dredging, *i.e*. a total of 2 880 trips. These dredging rates are similar to those that occurred for the Berth 306 development where a total of 3,840,361 m^3 of material was dredged and disposed of at the offshore dredge spoil disposal site in 882 barge trips (average of 4,354 m^3 of *in-situ* dredged sediment per 10 330 m^3 hopper load) over a period of 22 weeks. This suggests that the hoppers contained 27%

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[3] Should other combinations of dredge technologies be used, the dredge description may change significantly. Specifically, the resultant environmental impacts may change significantly due to changes, dredge durations, changes in the sediment loading at the dredging locations as well as the likely changes in behaviour (re-suspension and mobility) of the dredge spoil disposed at the offshore dredge spoil disposal site.

sediments by weight (dry weight) per hopper load. In this study it is assumed that the barges contain 30% sediments by weight, a slightly higher percentage of sediments than occurred during the Berth 306 dredging.

Dredging activities for the Berth 306 development commenced on the 6 August 2005 and ended in early January 2006, with the last spoils being disposed of early on the morning of 5th January 2006. This gave and effective dredge rate of approximately 175 000 m^3 per week, *i.e.* a dredge rate approximately 78% of that assumed for this study. The dredging programme undertaken at that time therefore is similar to that assessed in this modelling study, the major differences being 28% increase in the volume of sediments being dredged and an approximate 50% increase in the assumed dredging rate (due to the assumption of a slightly shorter dredging duration for the increased volume of sediments assumed for this study).

This leads to a quite a conservative assessment in terms of the sediments being released into the marine environment due to dredging activities. Consequently the results of the modelling study may be considered indicative of potential impacts associated with the dredging and disposal of larger dredge volumes of sediments over a somewhat longer time period.

2.2.4 Dredge Spoil disposal

The possibilities for the disposal and/or beneficial use of the dredged material has been discussed in some detail in BKS (2013), based largely on a number of previous feasibility studies by the CSIR (*e.g*. CSIR, 1994a, 2000, 2002, 2004a,b, 2005a).

The dredge spoil disposal and or beneficial use options considered were as follows:

- Land creation (sand, silt): No need was identified for land creation in Richards Bay (for plans up until the year 2060).
- Land improvement (sand, silt): This includes the improvement of the quality of soil and/or making the land functional by elevating it above flood levels. At that stage no need for land improvement was identified within this study in Richards Bay.
- Offshore berms (sand): This involves the construction of offshore sand berms for the protection/nourishment of adjacent beaches. These have been previously evaluated (e.g. CSIR, 1994a) as a nourishment method (*i.e*. as feeder berms) for the northern beaches in Richards Bay, however and environmental concern is the suspension of fine material in the water column during the placement of the sediments. It may be necessary to separate sand from clay to make this option viable.
- Beach nourishment (sand): There is a clear need for sand for beach nourishment on the northern beaches of Richards Bay, in addition to sand routinely supplied from maintenance dredging operations. However the efficacy of this would need to be carefully evaluated, particularly given that the dredge material is assumed to constitute mainly clays (48%) and rock (48%).
- Capping of waste sites (sand, clay): Sand material can be used for capping of contaminated material disposal sites on the seabed for which sand, clay or mixed materials can be used. However there is at present no requirement for this in Richards Bay.
- Capping at landfill sites: This requires clay, and while a viable usage from the dredge material, it may require separation of clays from other size fractions. Furthermore, depending on the origin of the material and how it was excavated or dredged, the available material may not be suitable for this purpose.

- Replacement fill (sand): Fill is a beneficial use that can be considered when dredged material has superior physical qualities compared to soils near the dredging site. The material proposed to be dredged comprises mainly clays that are unsuitable for this purpose; however the large percentage of rock may be useful for this purpose.
- Other on-land uses: Other on-land uses such as construction material (present dredged material mostly not suitable) and habitat generation (for which fines are quite suitable).

Based on the size distributions of the material to be dredged (mainly rock and clays), the chances are that most of the fines (clays and small percentage of sand) will be disposed of at the offshores dredge spoil disposal site. The rock in principle could be used for fill, however it is a relatively large quantity of rock and, furthermore, the rock may not be entirely suitable for this purpose. The rock could also be disposed of at the offshore dredge spoil disposal site, however this may not be wise as it will remain on the dredge spoil disposal site and not be redistributed as would be the finer materials. The sequence of dredging this material (clays first and then rock or rock and clay together) suggests that the disposal of the rock at the offshore site will severely hinder the movement of fines off the dredge spoil disposal site and therefore limit the future use of this site for the disposal of dredge spoil. The resulting "semi-permanent" change in water depth has the potential to have long-term effects on adjacent shorelines or, as a minimum, change the longer-term longshore sediment transport dynamics along the Central Beach section of the shoreline.

Nevertheless, for the purposes of this assessment we have assumed that all of the dredged material (including rock) will be disposed of at the offshore dredge spoil disposal site as this provides a worst case scenario in terms of changes on the seabed at, and in the vicinity of, the dredge spoil disposal site. The inclusion of rock in the model simulations does not change the sediment loading of the water column as it is almost exclusively the fines being dredged and dumped that result in elevated turbidity in the water column. At the site of dredging, all material dredged is considered to contribute to the sediment loading of the water column. At the dredge spoil disposal site it is only the fine material that is considered to generate a sediment loading in the water column. Thus the consequences in terms of elevated water column turbidity are limited should the rock material be included or excluded from the model simulations.

2.2.5 Potential Dredging Scenarios

In terms of potential environmental impacts, the sediment loading (S_d) at the dredging location ranges between 3 and 6 kg dry material per m^3 of *in-situ* material dredged by a CSD, while for TSHD the sediment loading (Sd) at the dredging location ranges between 1 and 7 kg dry material per m3 of in-situ material dredged (Kirby and Land, 1991; Pennekamp and Quaak, 1998). For a BH the sediment loading (S_d) in kg dry material per m^3 of *in-situ* material dredged at the dredging location ranges between 12 for a BH with large bucket and 25 for a BH with a small bucket (Kirby and Land, 1991)

Provided that the dredging rates of a TSHD dredging rates do not exceed those of the CSD, the assumed use of only CSD dredging technology will provide conservative model results both in terms of the loading at the dredging location and at the offshore dredge spoil disposal site. Given that, if a TSHD is used, a significant proportion of the material to be dredged (*i.e.* the rock) will have to be removed by BH (that typically has a low dredging rate), the sediment loading rates associated with a TSHD/BH combination is expected to be significantly lower than for the use of only a CSD for the dredging programme. The exception will be the initial 10 weeks or so of dredging when the when the dredging rates of the TSHD/BH combination are likely to be comparable to a CSD operation, as will be the sediment loading rates. It should be noted that most of the overlying sediments will need to be removed by excavation or TSHD before the BH can access the deeper rock, therefore it is unlikely that both a TSHD and BH will be deployed simultaneously for significant periods.

The nature of the material from CSD dredging operations (largely a slurry with some clumps of clay) will, in all likelihood, result in a greater loss of fines into the water column during disposal. Furthermore this material is likely to display a higher mobility once deposited on the seabed. BH dredging operations are expected to result in a greater “clumping” of dredge material, which is likely to release less fines into the water column when disposed at the dredge spoil disposal site and also is likely to display a lesser mobility than dredge spoil generated by a CSD. These differences in the two operations are likely to increase for increasing amounts of muds in the material to be dredged.

At face value the CSD dredging operations are likely to result in the greatest environmental impacts. However, BH dredging operations may result in more persistent but lower intensity impacts due to the longer duration of dredging operations. Also, if the effect of potential lean mixture overboard operations are ignored, the sediment loading, S_d, (in kg dry material/m^3 dredged) at the dredging location is generally much higher for BH operations. The difference is significantly less once the sediment loading rate is calculated in terms of kg dry material per second (*i.e.* when the differential in effective dredging rates is taken into account - see last row of Table 2.5).

Table 2.5: Indicative sediment loading rates for the various dredging technologies proposed for the Richards Bay Port Expansion Option 3A development assuming an *in-situ* dredge volume of 4.930 million m^3.

	Small Backhoe	Medium Backhoe	Large Backhoe	TSHD for soft material	CSD only
Volume of material to be dredged (m3 of in-situ material	2 366 400 (48% of the total)			2 563 600 (54% of the total)	4 930 000
Rate of dredging (m^3/h)	200	400	800	1 820	1880
Rate of dredging assuming 140 operational hours/week (m^3/week)	28 000	56 000	112 000	255 000	263 400
Duration of dredging assuming dredge volumes of 4.930 million m^3 and 140 operational hours/week (weeks)	84.5	42.3	21.1	10.1	18.7
Sediment Loading Rate (kg dry material/m^3 dredged)	25	17	12	1 to 7 (no LMOB) 11 to 17 (with LMOB)	3 to 6 (no LMOB) 13 to 16 (with LMOB)
Sediment loading rate (**S_d**) for assumed rate of dredging (tonnes dry material/week)	700	952	1 344	255 to 1 785 (no LMOB) 2 805 to 4 335 (with LMOB)	790 to 1 580 (no LMOB) 3 425 to 4 215 (with LMOB)
Sediment loading rate (**S_d**) for assumed rate of dredging (kg dry material/s)	1.16	1.57	2.22	0.42 to 2.95 (no LMOB) 4.648 to 7.17 (with LMOB)	1.31 to 2.61 (no LMOB) 5.66 to 6.97 (with LMOB)

* LMOB refers to lean mixture overboard, which is a process where overflow is allowed from the hoppers, the purpose being to increase the sediment volume in each hopper load.

The effective dredging rates assumed for the modelling study are summarised in Table 2.6 below. These have been translated into the sediment loading rates used in the modelling study reported in Table 2.7.

Table 2.6: The effective dredging rates and sediment loading rates at the dredge site that have been used in the modelling study for an assumed dredge volume of 4.930 million m^3.

	CSD
Volume to be dredged (m^3 *in-situ* material)	4 292 750
Assumed rate of dredging (m^3/of *in-situ* material/week)	263 400
Sediment Loading Rate (**S_d**) (kg dry material/m^3 dredged)	3*[1] (13)*[2]
Sediment loading rate for assumed rate of dredging (tonnes dry material/week)	790 (3 424)*[2]
Sediment loading rate (**S_d**) for assumed rate of dredging (kg dry material/s)	1..307 (5.662)*[2]

*[1] Given that a large percentage of the material to be dredged is rock and that the rock has been included when estimating loading rates (*i.e.* is taken to be a source of fines for suspension into the water column at the dredging site), the lowest end of the range of turbidity loading (3 kg / m^3 of *in-situ* dredge material) has been assumed for the model simulations.

*[2] Estimated sediment loading rate should the dredging operation permit lean mixture overboard (LMOB). Under these circumstances an additional sediment loading (S_d) of 10 kg dry material/m^3 for the lean mixture released overboard during filling of the hopper needs to be added to that typically generated by a CSD dredging operation (CSIR, 2004a, van Ballegooyen *et al*., 2006).

Table 2.7: The sediment loading rates at the dredge spoil disposal site that have been used for the modelling study assuming a dredge volume of 4.930 million m^3.

Type of material	**% of in-situ dredge material**	**Dry density of sediment fraction in hopper**	**Mass of sediment fraction per dump (kg)**	**Discharge flow rate per 6 min dump (m3/s)**	**Dry density of sediment fraction in hopper (kg/m3)**	**Sediment loading of fraction (kg/s)**
Rock	48.0	382	1 411 920	10.278	381.60	3922
Gravel	0	0	0		0.00	0
Sand	4	32	117 660		31.80	327
Mud (10%)	4.8	38	141 192		38.16	392
Mud (90%)	43.2	343	1 270 728		343.44	3530
Total	**100**	**795**	**2 941 500**		**795.00**	**8171**

The estimated sediment loading in Table 2.7 above is based on the following assumptions:

- a barge volume of 3 700 m^3 of which 30% comprises sediments when full and ready to sail to the dredge spoil disposal site;
- it takes 6 minutes for the barge to empty once the barge doors have been opened;
- all of the rock, gravel, sand and 90% of the muds are deposited at the seabed (*i.e.* are released into the bottom layer of the model), while the remaining 10% of the muds are assumed to be released into the water column (*i.e.* distributed evenly in all the vertical model layers).

In terms of the duration (rather than the intensity) of impacts, the assumption of any of the BH dredging operations will constitute a worst case scenario in terms of impacts where duration is the major consideration. However, the persistence of the expected turbidity effects is likely to be somewhat mitigated by the fact that the release of sediments into the water column during dredge spoil disposal and subsequent re-suspension of this material is likely to be significantly less for dredging operations utilising a BH alone (or in combination with a TSHD being proposed as an alternative here) compared to CSD dredging operations.

The assumption of CSD dredging operations where lean mixture overboard is allowed constitutes a worst case scenario in terms of assessing potential environmental impacts. Should lean mixture overboard not be considered, the CSD dredging scenario would still constitute a worst case scenario under the assumption that i) the greatest concerns in terms of turbidity impacts are likely to be those in the marine environment external to the port and that ii) the sediments re-suspended at the dredging site are largely retained within the port in close proximity to the dredging operations.

In summary, in terms of:

- the sediment loading rates at the dredging site;
- the rate of release of fines into the water column during dredge spoil disposal at the dredge spoil disposal site, and;
- the mobility and likely re-suspension of dredge spoil once on the seabed;

the assumption of a CSD dredging operation allowing lean mixture overboard comprises a conservative assumption in terms of assessing potential environmental impacts of the capital dredging required for the Port of Richards Bay Capacity Expansion Option 3A development.

3 ENVIRONMENTAL CONDITIONS

The marine and coastal environment encompassing the Port of Richards Bay has been extensively, and repetitively, described in the various EIAs, SEAs and specialist studies conducted as part of the overall port development (*e.g.* CSIR, 1998a, 2003, 2005b, 2009). The synopsis below is taken mainly from these reports. It focuses primarily on those coastal processes and areas where local marine ecosystems and beneficial uses or activities may be directly or indirectly affected by the capital dredging activities proposed for the Port of Richards Bay Capacity Expansion Option 3A development.

3.1 Coastal Morphology and Bathymetry

In terms of this study the regional features of importance are (Figure 3.1):

- The Mhlatuze Estuary that constitutes an important habitat and through which turbid waters flow into the adjacent ocean during high rainfall events;
- The Port of Richards Bay and features within the port such as
  - the often turbid mud flats,
  - the sandspit that separates the mud flats from the inner basins of the port,
  - the freshwater inflows through the Mzingazi and Bhizolo Canals
  - the deep port entrance channel in which the flow is tidally dominated and where there is some exposure to swell
- The beaches surrounding the port comprising:
  - the Southern Beach to the south of the mouth of the Mhlatuze Estuary,
  - the Central Beach located between the Mhlatuze Estuary mouth and the port entrance, and
  - The beaches to the north of the port entrance that are subject to fairly severe shoreline erosion.

Figure 3.1: Key physiographic features of the region.

The bathymetry in the vicinity of the Port of Richards Bay is fairly complex. In the offshore region the continental shelf break that is located close inshore (< 5 km from the coastline) at Cape St Lucia north of the port and is located further offshore on moving southwards (~ 20 km from the coastline opposite the Port of Richards Bay). The continental shelf break is located even further offshore in the vicinity of Durnford Point where the continental shelf break is more 35 km from the coastline. There exists a large shallow region to the south of Richards Bay known as the Durnford Shoals. These large scale changes in bathymetry strongly influence the waves and currents in the region offshore of the Port of Richards Bay.

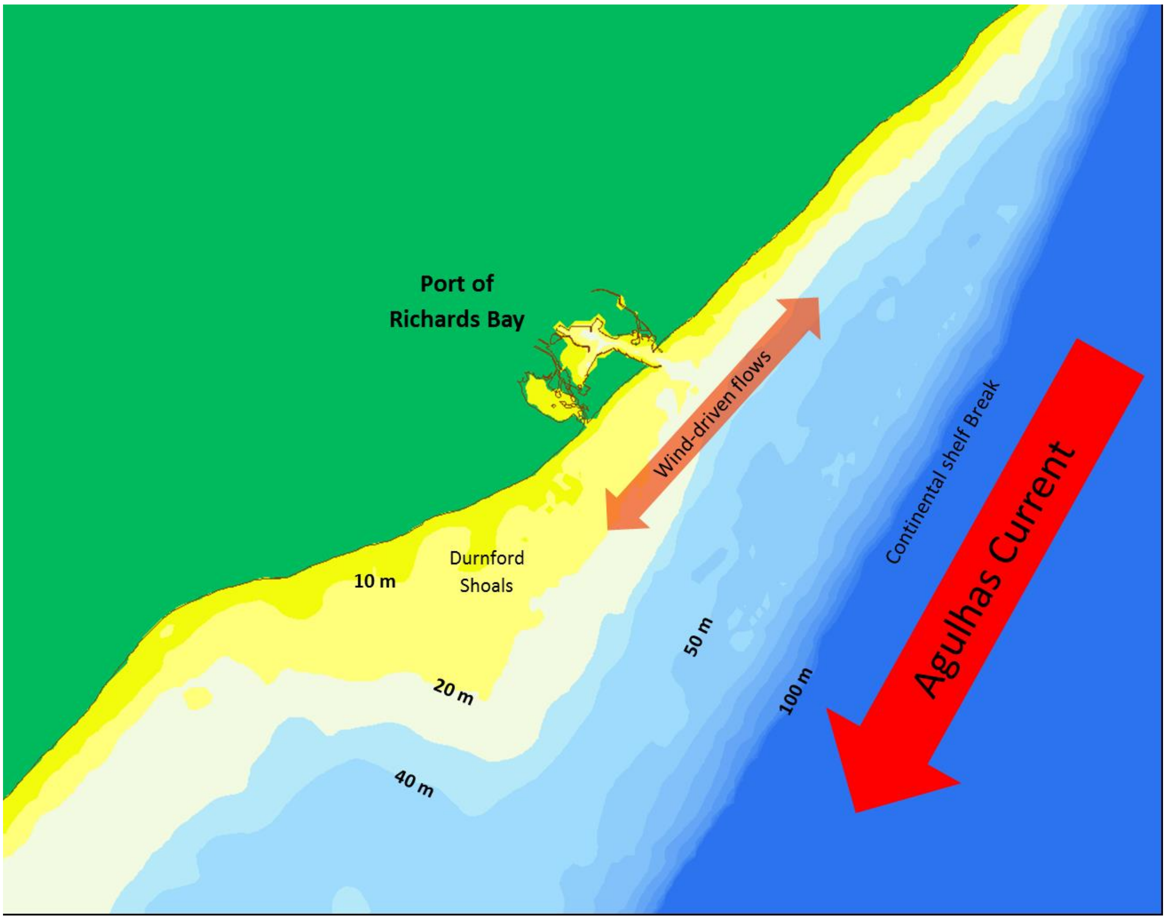


Figure 3.2: Large-scale bathymetry offshore of the Porto of Richards Bay.

A more detailed bathymetry for the Port of Richards bay and its immediate surrounds is provided in Figure 3.3 below. Important features within the port are the shallow mudflats, the sandspit that separates these shallow and often turbid waters of the mudflats from the deeper shipping basins both to the north (Inner Basins 1 to 3 maintained to a depth of -18.9 m CD) and to the southeast (Richards Bay Coal Terminal Basin maintained to a depth -19.4 m CD). The deeper navigation channel leading to the port entrance extends approximately 4 km seawards before the depth in the channel is the same as that of the continental shelf surrounding the channel.

The adjacent Mhlatuze Estuary, in general, is shallow except for some of the braided channels and areas closer to the estuary mouth where depths of up to -2m CD occur.

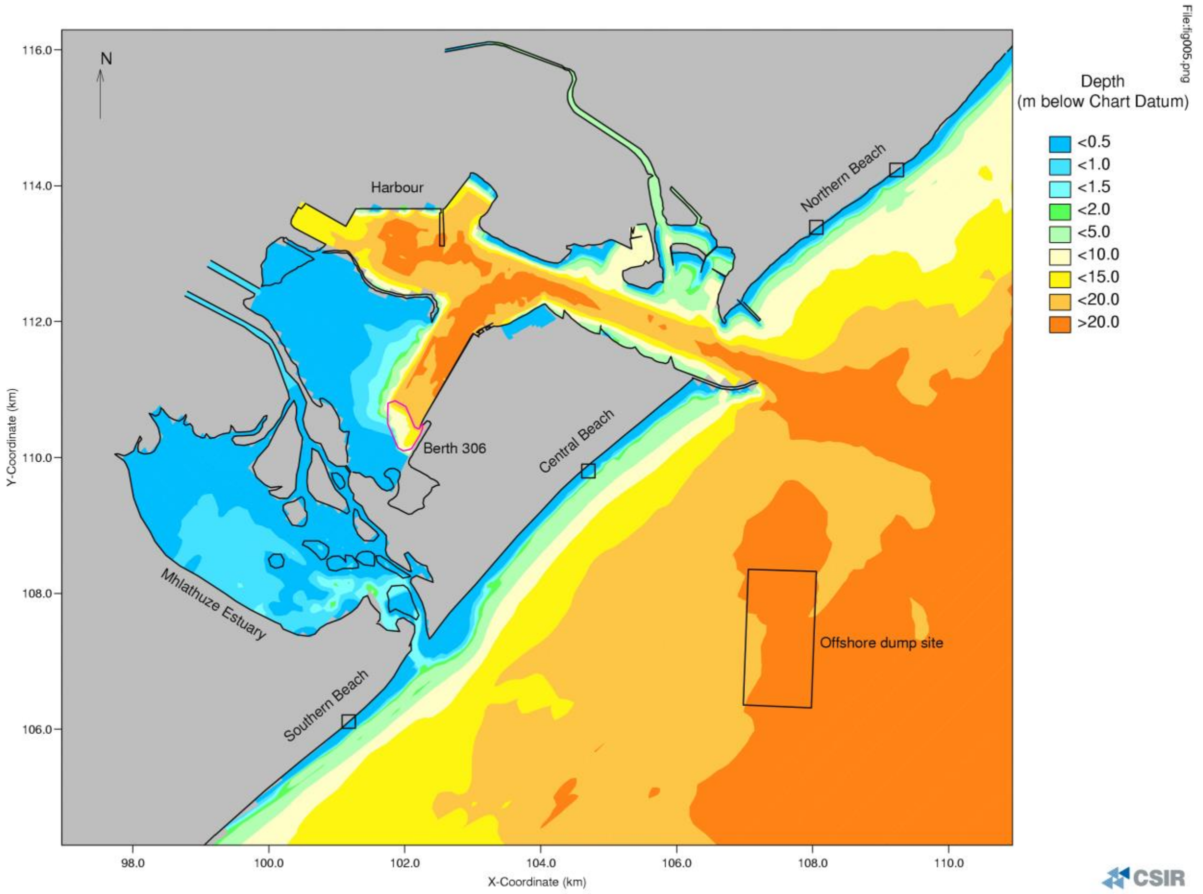


Figure 3.4: **Detail of the bathymetry in the immediate environs and within the Port of Richards Bay and the Umhlatuze Estuary (CSIR, 2004c, 2005a)**

An offshore bathymetric feature of relevance to this study is the dredge disposal mound that exists offshore of the Central beach in an approximate -20 m CD water depth. The present height of this dredge spoil disposal mound is uncertain, however it was sufficiently significant (-11 m CD) after the Berth 306 dredge spoil disposal operations to have constituted a navigation hazard (Ramsay, *pers. comm*.). There is however evidence that much of the dredge spoil disposed of at this site during the Berth 306 capital dredging has been dispersed, resulting in a less significant bathymetric feature (van den Bossche *et al*., 2007).

3.2 Climate

3.2.1 Synoptic Conditions

Richards Bay is located within the subtropical high-pressure belt. Its climate is controlled to a large extent by the seasonal north-south migration of this belt, but more specifically, its relative position to the Indian Ocean Anticyclone and the continental high-pressure cell located over the southern African interior. The resultant anti-cyclonic circulation with fine stable weather is dominant throughout the year. The position and intensity of the two high-pressure cells determines the extent to which tropical easterlies and the mid-latitude cyclones (cold fronts) moving eastwards past the subcontinent interrupt the prevailing fine conditions. During the summer months, the high-pressure belt is weakest and moves southwards, allowing tropical easterly incursions over the region. The high-pressure belt intensifies and moves northward in winter when mid-latitude cyclones (cold fronts) strongly influence the region (CSIR, 1998a, 2003). The synoptic conditions determining wind conditions are described in greater detail in Section 3.2.5 below.

3.2.2 Precipitation

Richards Bay receives an annual average rainfall of 1 228mm (CSIR, 2005b). The rainfall is seasonal and occurs mainly in summer, from October to March, with peak rainfall occurring in late summer (January and February). Rainfall in winter, associated with the passage of frontal weather from the south-west, is not uncommon. The mean monthly rainfall totals from the South African Weather Service (SAWS) 20-year climate record (SAWB, 1992) are presented in Table 3.1.

3.2.3 Air Temperature

Air temperatures in Richards Bay are moderate to high for most of the year and the summers are humid. In summer the average daily maximum temperature is 28°C with extremes exceeding 40°C, while in winter the average maximum temperature is 23°C with extremes in the region of 34°C. Monthly averages and extreme temperatures from the SAWS 20-year climate record (SAWB, 1992) are presented in Table 3.1. Extreme temperatures frequently occur due to berg wind conditions. Annual average relative humidity levels are 82% (08h00) and 67% (14h00), respectively.

Table 3.1: Mean monthly and monthly extreme temperatures at Richards Bay including average monthly rainfall (CSIR, 2005b)

Month	Temperature (ºC)			Rainfall (mm)
	Average	Maximum	Minimum	
Jan	25.2	29.2	21.1	172
Feb	25.0	28.9	21.2	167
Mar	24.6	28.9	20.4	107
Apr	22.5	27.0	18.1	109
May	20.0	24.8	15.2	109
Jun	17.7	23.1	12.3	57
Jul	17.6	23.0	12.3	60
Aug	19.0	24.0	14.1	65
Sep	20.3	24.9	16.0	77
Oct	21.3	25.4	17.3	105
Nov	22.7	26.7	18.6	114
Dec	24.5	28.7	20.4	86
Annual	21.7	26.2	17.3	1228

3.2.4 Insolation

Sunshine duration of 70 % occurs during the winter months while cloudy weather is experienced during the summer months, resulting in a more limited sunshine duration of about 45 %. The average annual cloud cover is 50 %, 47.5 % and 61.25 % for 08h00, 14h00 and 20h00, respectively (Burger & Thomas, 2003).

3.3 Winds

A typical sequence of weather events along this section of the coast is as follows (*e.g*. Preston-Whyte, 1975). Before the arrival of the coastal low (and following cold front) along the coast, the wind generally blows from the northeast. Preceeding the coastal low often are the occurrence of warm north-westerly berg winds. As the coastal low approaches the barometric pressure starts dropping and the wind freshens. On the passing of the coastal low the wind rapidly (within an hour, depending on the speed and intensity of the coastal low) changes from north-easterly to often strong south westerly or south-south-westerly winds, the so-called "buster" (Hunter, 1988). Occasionally these SS or SSW winds reach gale force in summer, especially further offshore (Hunter, 1988). These strong south-westerly winds can persist for a day or more, before the wind direction backs to southeast and finally returns to north-easterly winds. Under extreme conditions the total change in wind velocity may exceed 20 m/s and are associated with significant drops in temperature (Schumann, 1984). The effect of the coastal low on offshore winds is uncertain but is considered to extend to between 50 km to 100 km offshore (CSIR, 1998a). It should be noted that not all coastal lows propagating along the southern African coastline reach KZN and even less the northern KZN region (*i.e.* Richards Bay).

The above basic weather pattern sometimes can be masked by more dominant synoptic situations (Hunter, 1998) that often lead to more extreme weather conditions, these being:

- cyclogenisis and an intense migratory high, a more intense development of the basic weather cycle described above that leads to gale force south-southwesterly winds and heavy swell conditions;
- A stationary low northeast of Durban that typically results in strong winds with a significant onshore component.
- A cut-off low that leads to strong southerly wind conditions and depending on its location may lead to a strong onshore wind component. Such events are often associated with flooding.
- The rare occurrence of tropical cyclones that lead to gale force south-westerly to south-easterly winds and flooding.

The three former sequences are expected to occur once or more annually, while the latter is a rarer occurrence. These events are relevant to this study in that, not only do they lead to significant re-suspension and movement of sediments, they also result in large volumes of sediment-laden waters entering the marine environment from the adjacent catchments.

Other than these synoptically driven winds, a complex pattern of thermo-topographically induced wind exists in the Richards Bay area that manifest as sea-land breezes by night and day, respectively (Langenberg, 1981; Boegman, 1993). There is a higher frequency of north-westerly winds during the night (land breeze) compared to a higher frequency of south-easterly / easterly winds during the day (sea breeze). Periods of calm are relatively infrequent in Richards Bay and occur approximately 7% of the time, with a higher frequency during the night (CSIR, 2003).

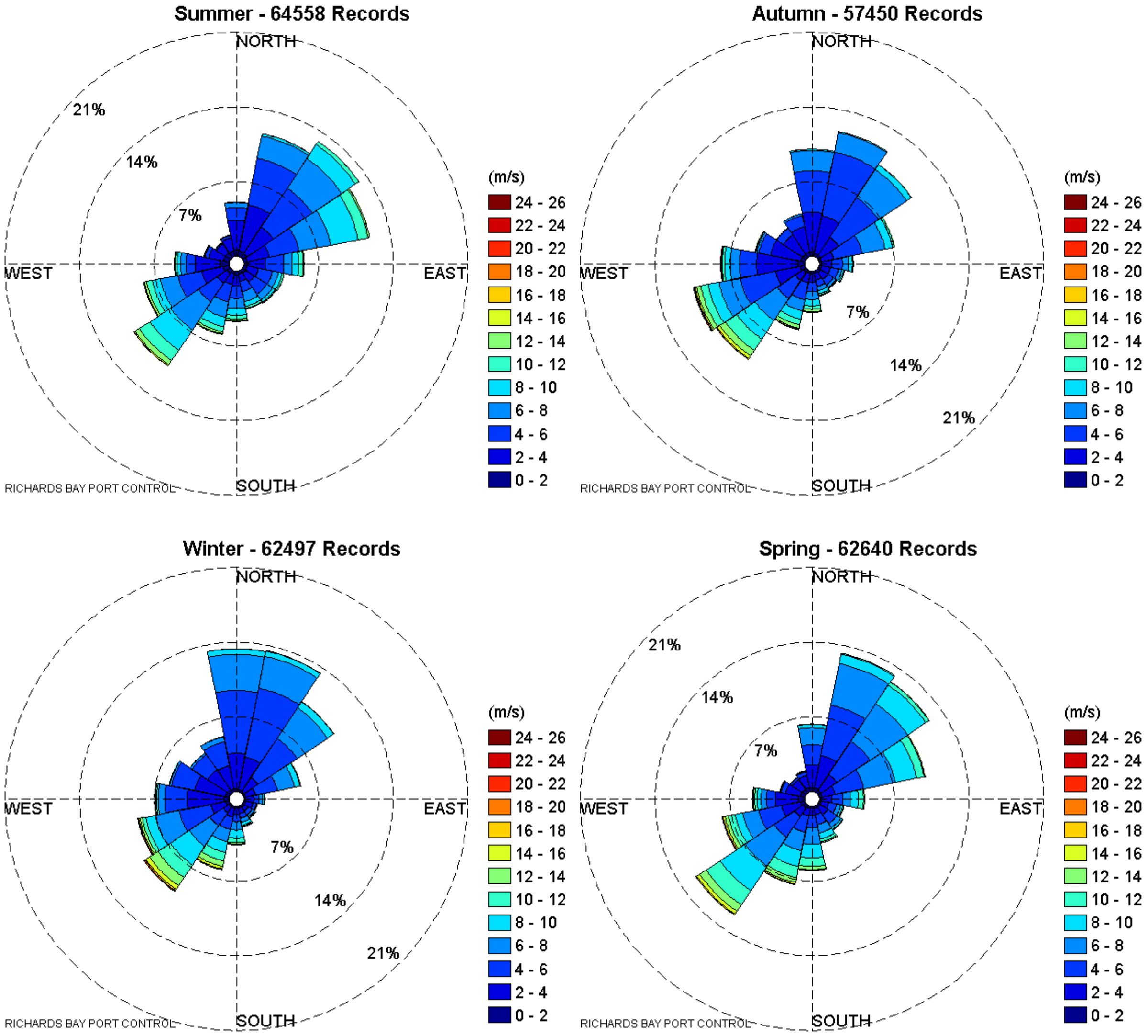
Unlike temperature and rainfall, a long-term wind record does not exist for Richards Bay. Numerous shorter to medium term records confirm that the prevailing winds in Richards Bay are predominantly north-easterly, associated with high-pressure systems and fine weather, and south-westerly winds that are associated with westerly waves and frontal weather.

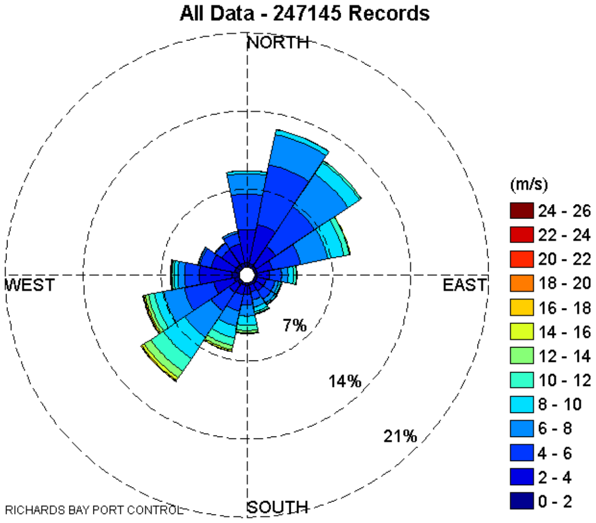
Wind data for a site just north of the Port of Richards Bay (Arboretum) indicate an annual frequency of occurrence of north-easterly winds of more than 20%, with the combined frequency of south-westerly and south-south-westerly winds also exceeding 20% (CSIR, 2005b). The wind speeds from both of these sectors are generally moderate with strong south-westerly winds in excess of 8 m/s occurring at times.

Wind records from the Integrated Port Operations Safety System (IPOSS) at Port Control and particularly the more exposed southern breakwater site (Figure3.5), indicate a much stronger wind regime than that described above. The median wind speed on the southern breakwater is approximately 30 to 40% greater than that recorded at more inland sites surrounding the Port of Richards Bay and is considered to be more representative of the coastal and open water wind climate. It is for this reason that the winds measured on the southern breakwater have been used in this modelling study. The NCEP winds measured further offshore are deemed less appropriate for use as wind-forcing in the port and surrounding nearshore waters as, *inter alia*, the rapid changes in winds associated with more localised features such as the coastal low are not well-represented in these data.

Figure 3.5: Location of the IPOSS wind measurement sites at Port Control and on the extremity of the southern breakwater.

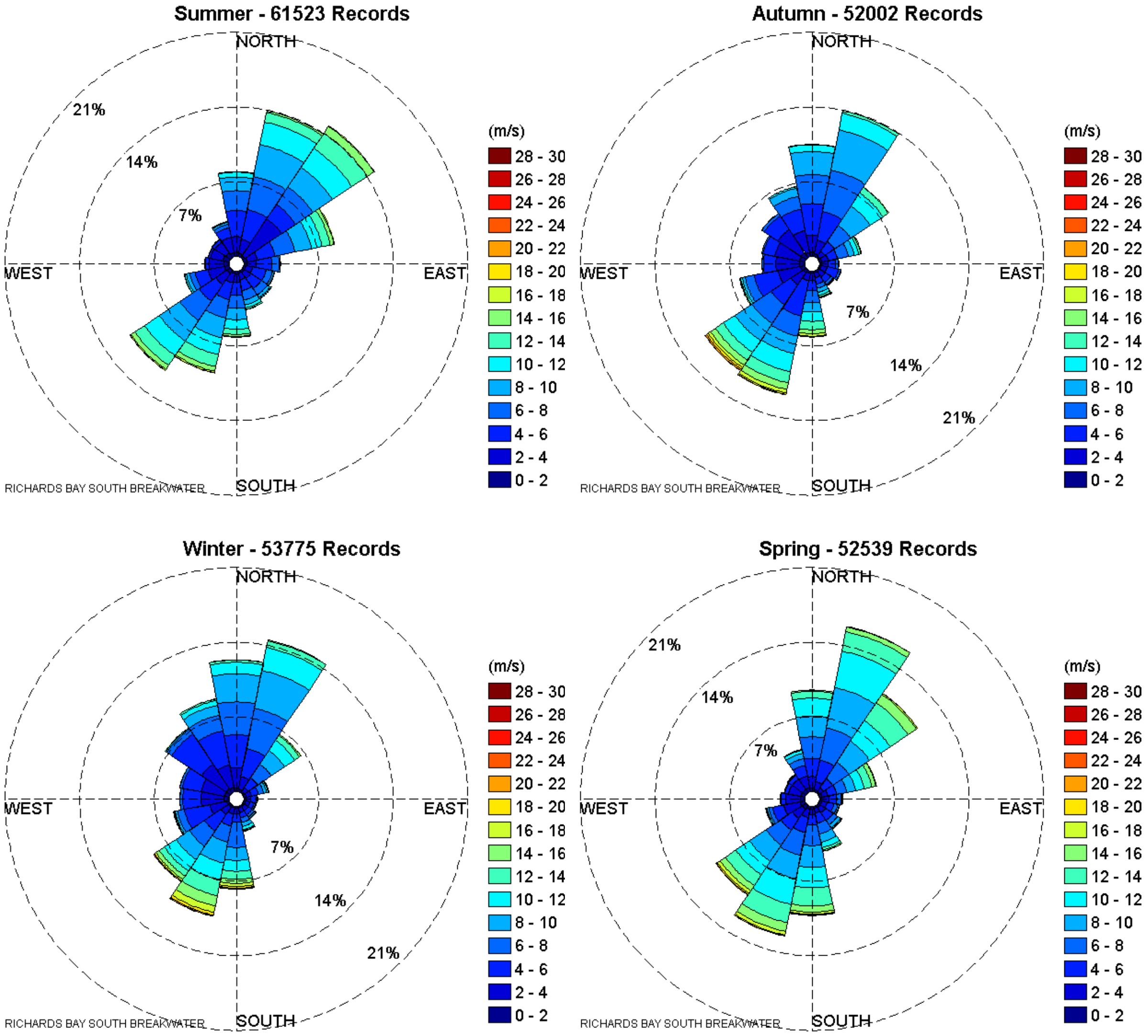
Winter and spring tend to be the stormiest months with strong SW winds being experienced in both seasons. In summer the more frequent winds are north-easterly winds which also are stronger than the NE winds observed in other seasons. The strongest winds in all seasons (less so in summer) are from SW to SSW (Figures 3.6 and 3.7). The offshore winds increase in winter due to the increased occurrence of land-sea breezes (Figure 3.6) however these offshore wind components are much less obvious in the winds measured on the southern breakwater.

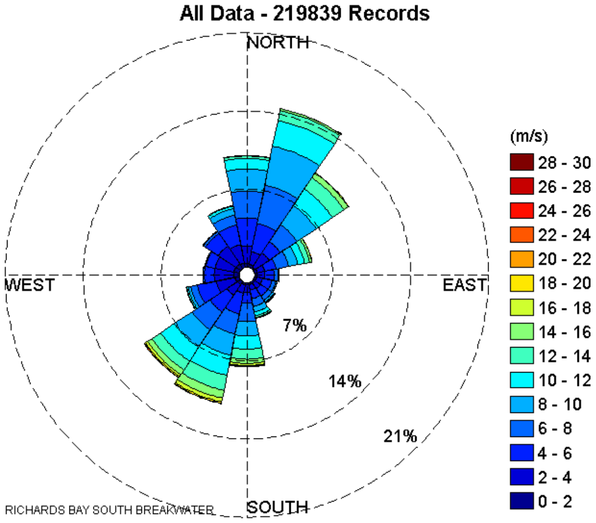




Period	2005-01-01 to 2015-01-31
Station	RICHARDS BAY PORT CONTROL
Position	28.79704 S, 32.09915 E
Height above surface	17.0 m
Records	247145

Figure 3.6: Annual and seasonal wind roses for the wind measured at Richards Bay Port Control.





Period	2005-01-01 to 2015-01-31
Station	RICHARDS BAY SOUTH BREAKWATER
Position	28.81399 S, 32.0978 E
Height above surface	8.0 m
Records	219839

Figure 3.7: **Annual and seasonal wind roses for the wind measured on the southern breakwater of the Port of Richards Bay.**

3.4 Tides

Tides around South Africa are classified as semi-diurnal microtidal, with a dominant M_2 tide (*i.e.* there are two high tides and two low tides per day), and tidal amplitudes generally below 2 m. A substantial spring-neap variation exists, with amplitudes as little as 0.5 m at neap tides and on occasion over 2 m at spring tides (South African Navy Tide Tables). The tides in Richards Bay thus are semi-diurnal and have a mean spring and neap tidal range of 1.86 m and 0.50 m, respectively (SAN Hydrographer, 2014).

The tidal period is 12 hours and 25 minutes, with a slight diurnal inequality. The tides propagate from west to east from an amphidromic point in the Southern Ocean. The tidal phase lag along the East Coast however is small and consequently irrelevant for the scale of modelling being undertaken here. The tidal characteristics for the Port of Richards Bay are listed in Table 3.2 below.

Longer-period water level variations also occur as a result of meteorological influences, particular wind. Coastal trapped waves along the south coast have sea level amplitudes that on occasion are in excess of 0.5 m (Schumann and Brink, 1990), however these changes in water level associated with meteorological conditions are less than for more southerly locations along the South African coastline (van Ballegooyen, 1996).. Net water level variations thus are a combination of longer period wind and wave set-up as well as shorter-period tidal variations. Offshore current variability associated with the Agulhas Current may result in additional low (periods of 20 days or more) and relatively small water level variations (van Ballegooyen, 1996).

Table 3.2: Tide Characteristics for the Port of Richards Bay.

Tide	Height (m) above Chart Datum
Highest Astronomical Tide	2.47
Mean High Water Spring	2.11
Mean High Water Neap	1.48
Mean Level	1.20
Mean Low Water Neap	0.97
Mean Low Water Spring	0.27
Lowest Astronomical Tide	0.00

Presently Chart Datum (CD) relative to Land Levelling Datum (LLD) is assumed to be -1.015 m and Mean Level (ML) is +1.2 m CD. Prior to 31 December 1997, CD relative to LLD was defined as -0.9 m and ML was defined as +1.09 m CD.

Tidal currents are significant both within the Port of Richards Bay and the Mhlathuze Estuary, particularly in the vicinity of the harbour entrance, the mouth of the estuary and shallow regions both within the Estuary and the harbour.

3.5 Waves

Knowledge of the offshore wave conditions at Richards Bay is important in that waves exert significant event scale effects on nearshore currents and sediment distributions both nearshore and in deeper water (i.e. at the dredge disposal site).

The currents in the surf-zone and the shallow nearshore region and, to a much lesser extent; the currents across the harbour entrance are determined by prevailing wave conditions. The direction of the wave-driven currents along the shoreline depend on the angle of incidence of the waves at the coastline. The more oblique the arrival of the waves at the shoreline, generally the stronger the flows. Furthermore, sediment transport at Richards Bay beaches (and at beaches inside the harbour mouth) is primarily driven by waves.

As noted above waves are not only important for their role in driving currents, but also in determining the sediment movement and distributions, particularly of fine sediments, on the seabed at locations exposed to wave action. The swell and wind-generated waves typically generate bed shear stress at the seabed that either maintain sediments in suspension or re-suspend sediments that have already been deposited on the seabed. The magnitude of the bed shear stress generated is a function of wave height and wave period, as well as current velocities where these are of sufficient magnitude.

In the harbour and adjacent estuary the wave turbulence keeping the fine sediments in suspension is a consequence of both swell and longer waves penetrating into the port as well as locally-generated wind-waves. Currents, particularly tidal currents, are also expected to play a role in limiting the deposition of sediments in these environments where these currents are of significant magnitude.

Further offshore, the wind-driven currents and those due to the influence of larger-scale flow associated with the close proximity of the Agulhas Current may constitute a significant contributory factor to the re-suspension and re-distribution of sediments. However, at the dredge spoil disposal site, the re-suspension in the sediments is expected to be largely due to wave turbulent stresses while the advection of the re-suspended sediments are determined predominantly by the wind-driven and larger scale flows.

The wave conditions in the entrance channel to the Port of Richards Bay also are important due to the limited under keel clearances of vessels utilising the port.

NCEP hind cast wave data (from the NOAA/NCEP WAVEWATCH III Global Model) at position (29.00°S; 32.5.°E), located beyond the continental shelf break, have been used to characterise the deep water wave climate (Figure 3.8). These data show a clear predominance of SSW swell with lesser occurrence on onshore wave conditions comprising predominantly easterly waves (Figure 3.9), especially in summer and autumn. A small NE wave component is observed during Spring. The highest wave conditions (SSW) occur during Winter and to a lesser extent Spring.

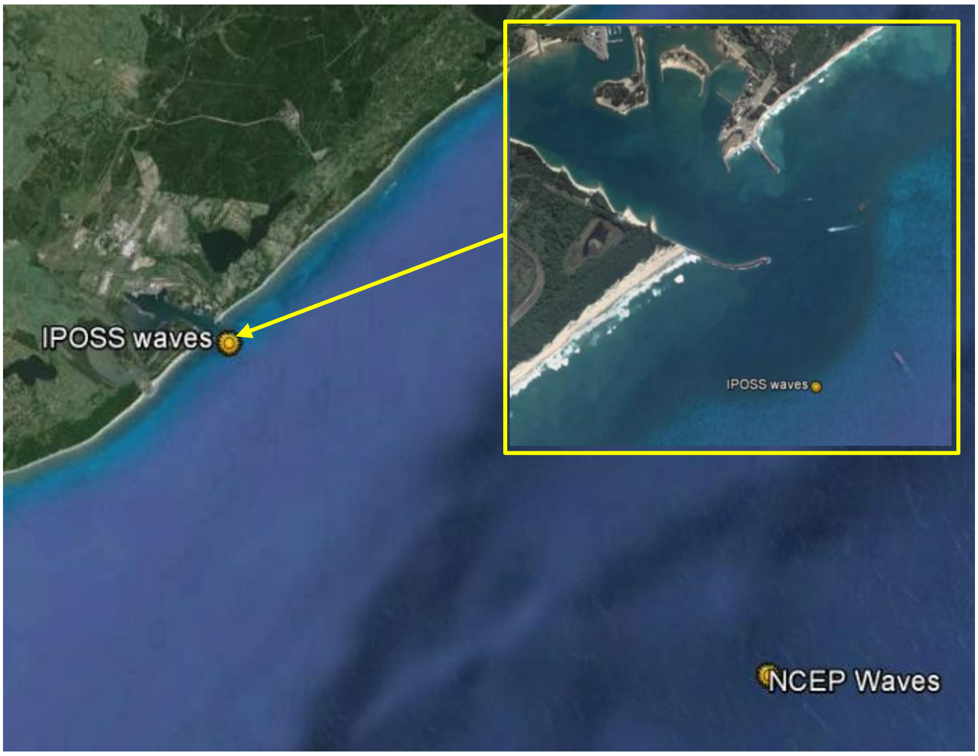
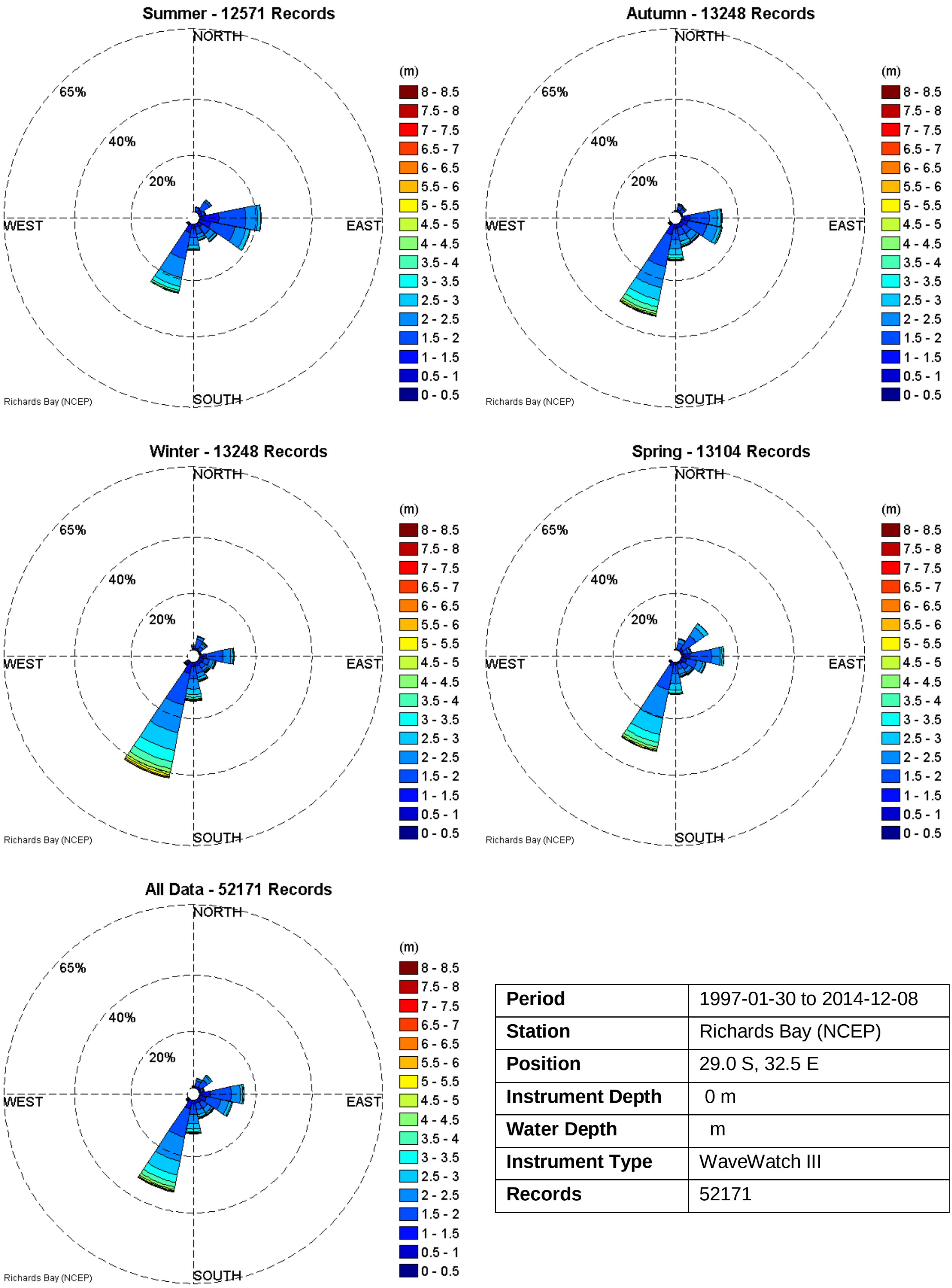


Figure 3.8: Location of the NCEP wave and IPOSS waves measurement locations offshore of the Port of Richards Bay.

These deep sea waves are refracted as they move landwards into shallower waters with all but the shorter period waves (sea as opposed to swell) becoming more shore normal in direction. The resultant nearshore wave distribution has been measured at a site some 2 km south of the southern breakwater in an approximate water depth of-19 m CD (Figure 3.8). At this location, the wave are predominantly from SSE, however SE and SSE wave components are not uncommon, particularly during the summer months Figure 3.10). As expected the highest waves are observed during the winter months and to a lesser extent in Spring.

The wave conditions in the Port of Richards Bay and the Mhlathuze Estuary have been simulated for a range of offshore wave and local winds condition (CSIR, 2000). The results of these simulations (Figures 3.11 to 3.14) provide some important insights into the wave conditions prevailing within the port environs, within the adjacent estuary and in the marine environment offshore of the Port of Richards Bay.

For these studies, the offshore wave conditions imposed at the offshore boundary of the wave model were such that the simulated inshore wave conditions recovered from the model at the location of the IPOSS wave measurement locations are the same as those actually recorded. This is also the approach used in this modelling study due to deficiencies in the NCEP data recorded offshore of the Port of Richards Bay (see Section 5.3.3 on wave calibration).



Summer - 12571 Records

Autumn - 13248 Records

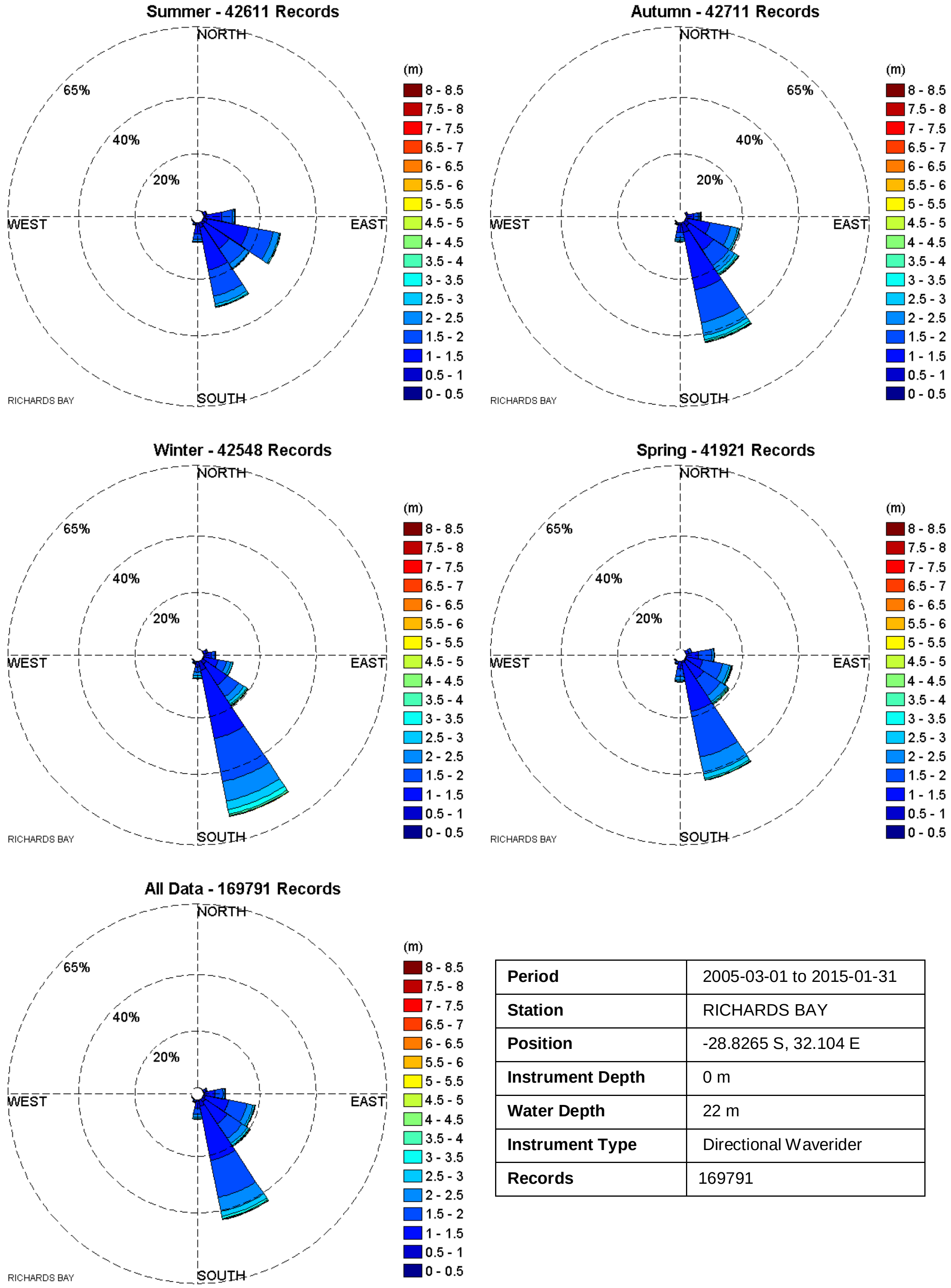
Winter - 13248 Records

Spring - 13104 Records

All Data - 52171 Records

Period	1997-01-30 to 2014-12-08
Station	Richards Bay (NCEP)
Position	29.0 S, 32.5 E
Instrument Depth	0 m
Water Depth	m
Instrument Type	WaveWatch III
Records	52171

Figure 3.9: Annual wave rose for the NCEP wave data measured at a deep water location offshore of the Port of Richards Bay (see Figure 3.8 for the NCEP wave data “measurement” location).



Period	2005-03-01 to 2015-01-31
Station	RICHARDS BAY
Position	-28.8265 S, 32.104 E
Instrument Depth	0 m
Water Depth	22 m
Instrument Type	Directional Waverider
Records	169791

Figure 3.10: Wave roses indicating wave height (H_{mo}) vs wave direction for wave data from the Richards Bay IPOSS measurement system.

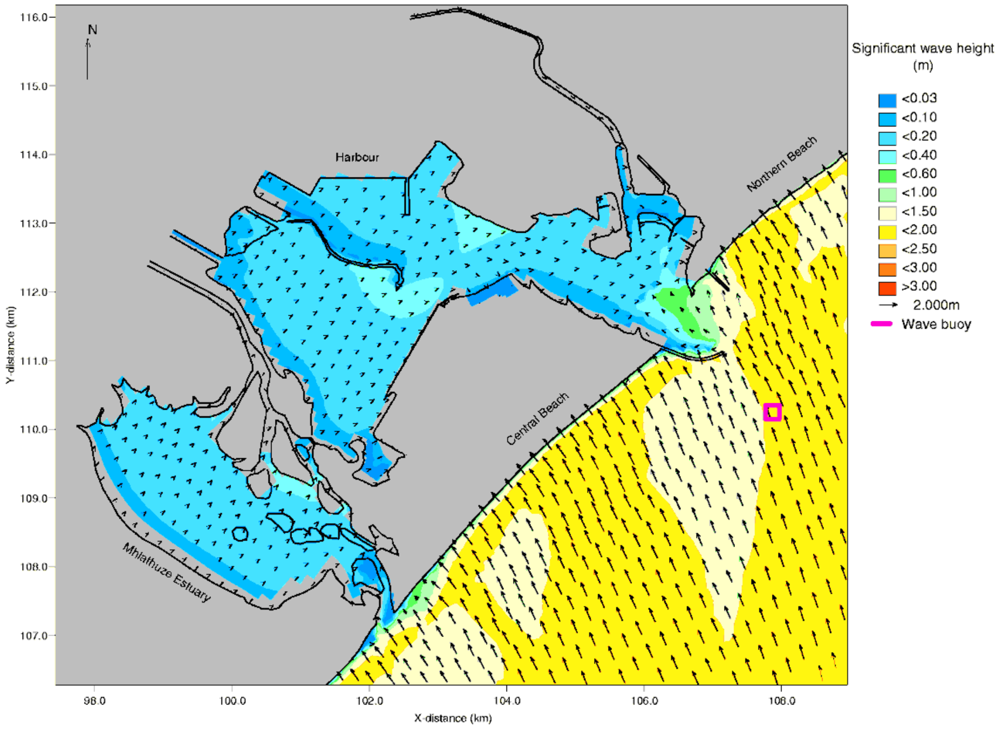


Figure 3.11: Significant wave height and direction for low to moderate wave conditions at wave buoy (H_{mo} = 1.5 m T_p = 10s, Direction SSE) and moderate SW winds (wind speed 7 m/s). (after CSIR, 2000).

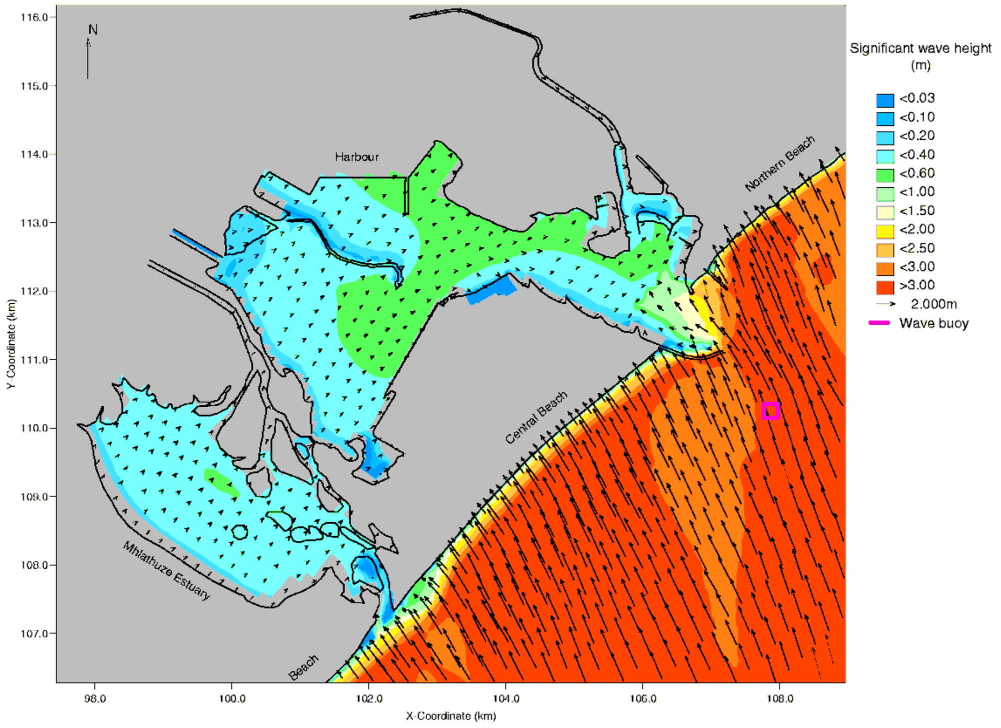


Figure 3.12: Significant wave height and direction for high wave conditions at wave buoy (H_{mo} = 3 m T_p = 14s, Direction SSE) and strong SW winds (wind speed 16 m/s). (after CSIR, 2000).

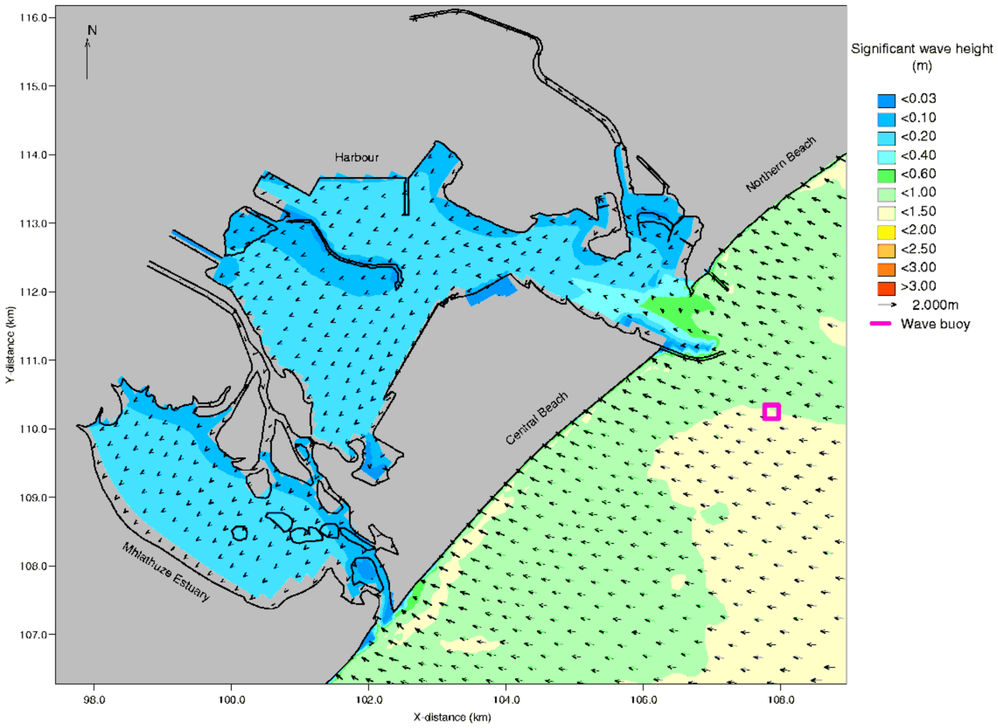


Figure 3.13: Significant wave height and direction for low to moderate wave conditions at wave buoy (H_{mo} = 1.5 m T_p = 10s, Direction ESE) and moderate NE winds (wind speed 6 m/s). (after CSIR, 2000).

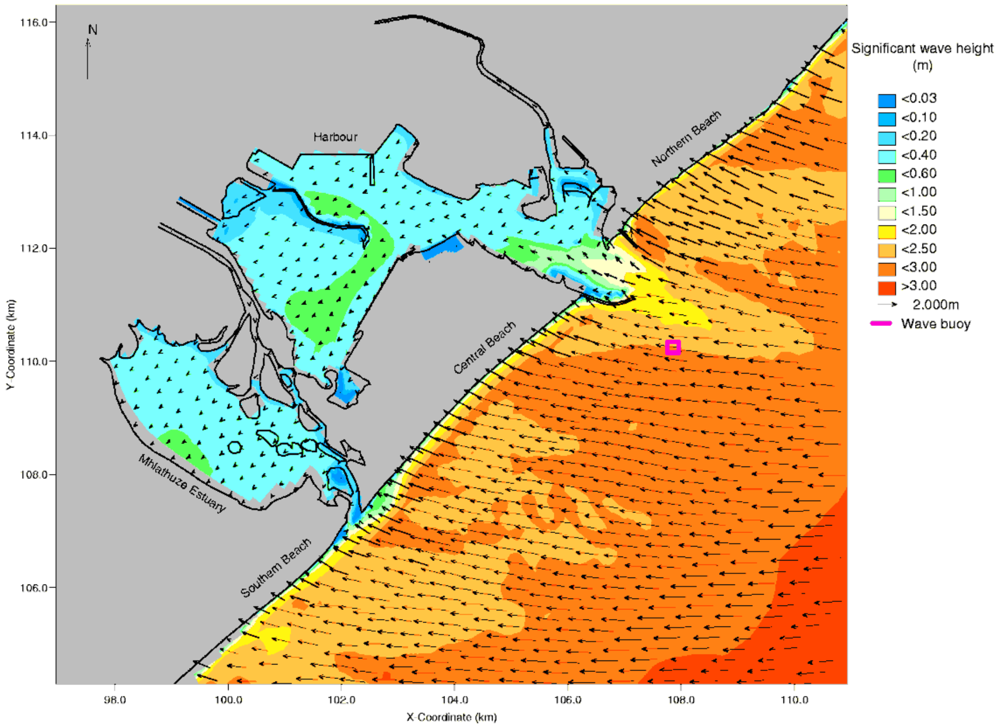


Figure 3.14: Significant wave height and direction for high wave conditions at wave buoy (H_{mo} = 3 m T_p = 14s, Direction ESE) and strong NE winds (wind speed 14 m/s). (after CSIR, 2000).

Wave simulations for SSE wave conditions under low to moderate offshore wave conditions (H_{mo}=1.5 m and T_p=10s[*1]) and moderate SW winds (wind speed = 7 m/s) indicate a minimal penetration of wave energy into the harbour (Figure 3.11) and a narrow surf zone along the coast. Waves from a SSE direction reach the shoreline at an oblique angle and will tend to drive a northward flowing surf zone current (Figure 3.20). The moderate SW wind generates wind waves that reach a height of approximately 0.20 m at the north-eastern side of the harbour (and the estuary). Simulations for high offshore wave conditions from the SSE (H_{mo}=3.0 m and T_p=14s) and strong SW winds (wind speed = 16 m/s) indicate a significantly increased surf zone width due to the increased incident wave height (Figure 3.12), while the strong SW wind generates wind waves that exceed 0.4 m at the north-eastern side of the harbour. Evident in both Figure 3.11 and 3.12 is the important role of that the sandspit has in providing protection to the 600 and 700 series of berths from such wind waves.

Wave simulations for ESE wave conditions under low to moderate offshore wave conditions (H_{mo}=1.0 m and T_p=8 s) and moderate NE winds (wind speed = 6 m/s) indicate a significant penetration of wave energy into the harbour (Figure 3.13). Waves from a ESE direction reach the shoreline at an oblique angle and that will tend to drive a southward flowing surf zone current. A moderate NE wind generates wind waves that reach a height of approximately 0.18 m at the south-western side of the harbour (and the estuary). Simulations for ESE wave conditions under high offshore wave conditions (H_{mo}=2.5 m and T_p=11s) and strong NE winds (wind speed = 14 m/s) indicate a significantly increased surf zone width due to the increased incident wave height (Figure 3.14), while the strong NE winds generates wind waves that exceed 0.4 m at the southwestern side of both the harbour and Estuary. Evident in both Figure 3.13 and 3.14 is the role of the sand spit in providing protection to the mudflats from wind waves under NE wind conditions. Strong wind conditions result in the waters overlying the mudflats becoming quite turbid. The existence of the sandspit provides a degree of protection from the wind waves being generated that stir up the bottom sediments to create turbid conditions.

Long wave energy is known to exist off the coast of KZN. Long waves have been recorded within Richards Bay (berth 609 and 701), however the occurrence of conditions leading to these long wave motions in the port are seemingly rare and most of the long wave energy recorded lies at periods exceeding 200 s (CSIR, 2005b). The existing long wave energy therefore is not expected to result in mooring motions and cargo handling problems of sufficient magnitude and regularity to be of major concern (CSIR, 1994b; Rossouw *et al.*, 2013). The sand banks, the sand spit and irregular shoreline of the existing port layout are considered to limit the long wave energy within the port.

3.6 Water Column Stratification

Water column stratification is important in that it affects the oceans response to wind and current forcing and therefore the vertical distribution of flow velocities. Generally the higher the water column stratification, the greater the vertical shear in the horizontal flow velocities and *vice versa*.

Water temperature in the region offshore of the Port of Richards Bay is strongly influenced by close proximity of the Agulhas Current. It is in this region where the Agulhas current brings cold waters closer to the sea surface in a process that has been termed topographically driven upwelling. Depending on the local winds, these cold waters may be exposed at the sea surface or remain subsurface. When the Agulhas Current is far offshore the seawater temperatures are generally lower and water column stratification is generally weaker than when the Agulhas Current is located closer inshore. When closer

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[*1] H_{mo} denotes significant wave height and T_p the peak wave period.

inshore the warmer surface waters of the Agulhas Current and the resultant upwelling that occurs on the inner edge of the Agulhas Current enhance the water column stratification. Similarly local winds may enhance or suppress the upwelling of colder deeper waters and depending on the circumstances may enhance or weaken the water column stratification.

While measurements further offshore (mid-self to shelf-break) indicate an often moderate to highly stratified water column, there are occasions (e.g. during fully developed upwelling conditions) when the water column is largely isothermal. Water column profiling measurements from the Berth 306 dredge monitoring programme (Pillay *et al.*, 2008a), while displaying the expected seasonal variation, suggest that the water column offshore of Richards Bay is surprisingly weakly stratified given the nature of the flows and physical processes prevailing in the region. There were however two or three occasions in early to late summer) when the water column stratification seemed to be significant, less so for the sites in the immediate vicinity of the dredge spoil disposal site and more so for sites extending northwards from the dredge spoil disposal site (Figures 3.15, 3.16 and 3.17).

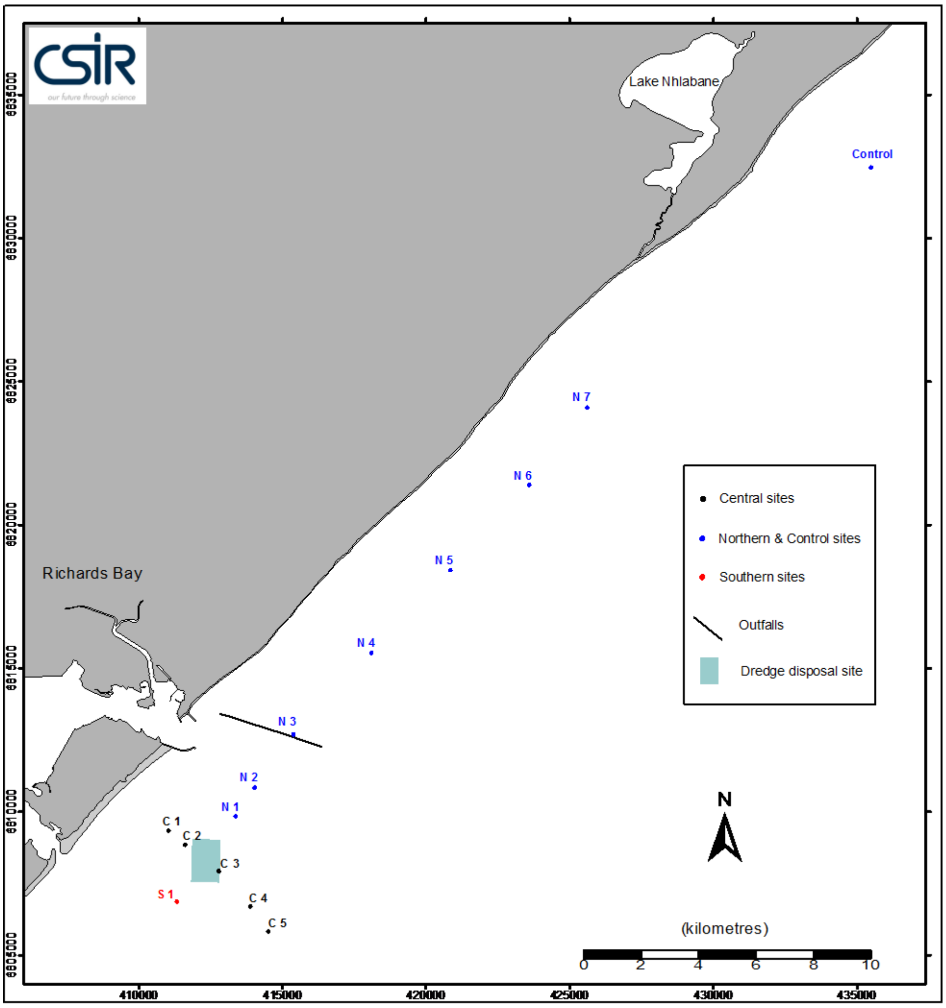

Figure 3.15: Location of the offshore water quality measurement sites at which temperature profiles shown in Figures 3.16 and 3.17 were measured.

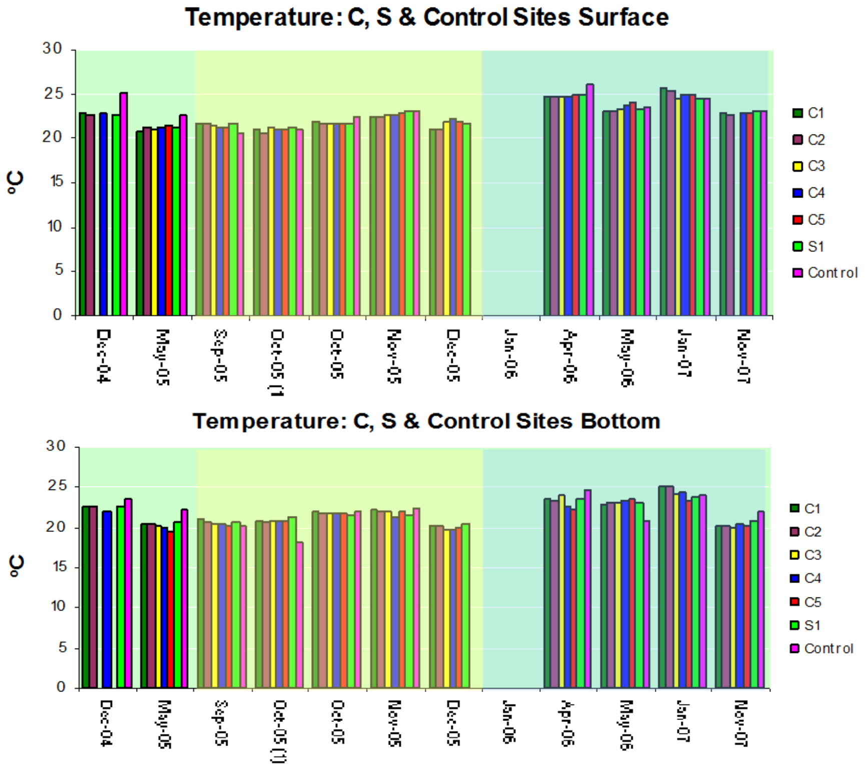

Figure 3.16: Surface and bottom water temperatures in the vicinity of the dredge spoil disposal site and stretching southwards.

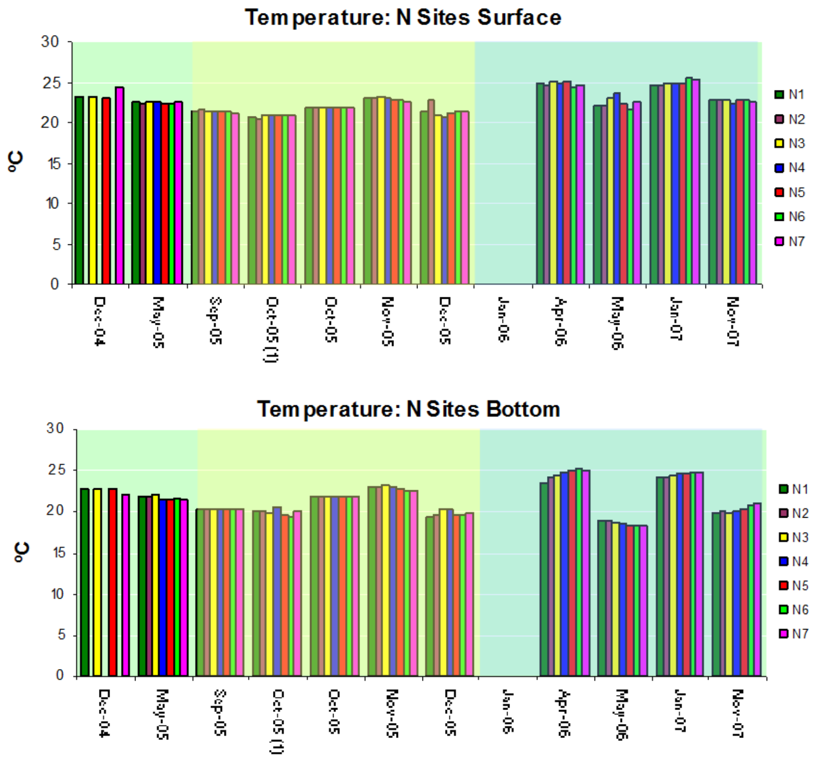

Figure 3.17: Surface and bottom water temperatures for sites extending northwards from the dredge spoil disposal site.

Historical measurements of surface and bottom salinity and temperature within the Port of Richards Bay (reported in CSIR, 2005b) indicate that significant vertical stratification of the water column occurred on a couple of occasions during the summer period. Given that the bottom temperatures observed on these occasions seemingly are similar to those measured at other times of the year and that the surface temperatures observed on these occasions are elevated compared to other times of the year, the observed stratification may simply be a consequence of local heating of the surface waters under relatively calm conditions and not necessarily indicative of cold bottom water intrusions into the harbour. (A cursory examination of wind conditions during these stratification episodes indicated that on one occasion the observations of stratification were made just prior to weak NE winds changing to strong SW winds. On the other occasion no such clear relationship with winds existed.)

Profiling measurements undertaken in the Port of Richards Bay during monitoring programme for the Berth 306 capital dredging project were mostly in shallow water and therefore not suitable for assessing the degree of temperature stratification within the Port of Richards Bay. However more recent measurements at a number of sites around the port undertaken for the Richards Bay Capacity Expansion project (CSIR, 2013b), that included measurements in the deeper shipping channels, indicate an approximate 2 °C temperature difference between the surface and bottom waters over an approximate 20 m change in water depth (Figures 3.18 and 3.19). This is consistent with other data measured within the port during summer months. In winter it is expected that the water column will be largely isothermal.

Figure 3.18: Map of Richards Bay showing the positions were in situ water quality measurements (*i.e.* temperature profiles) were made.

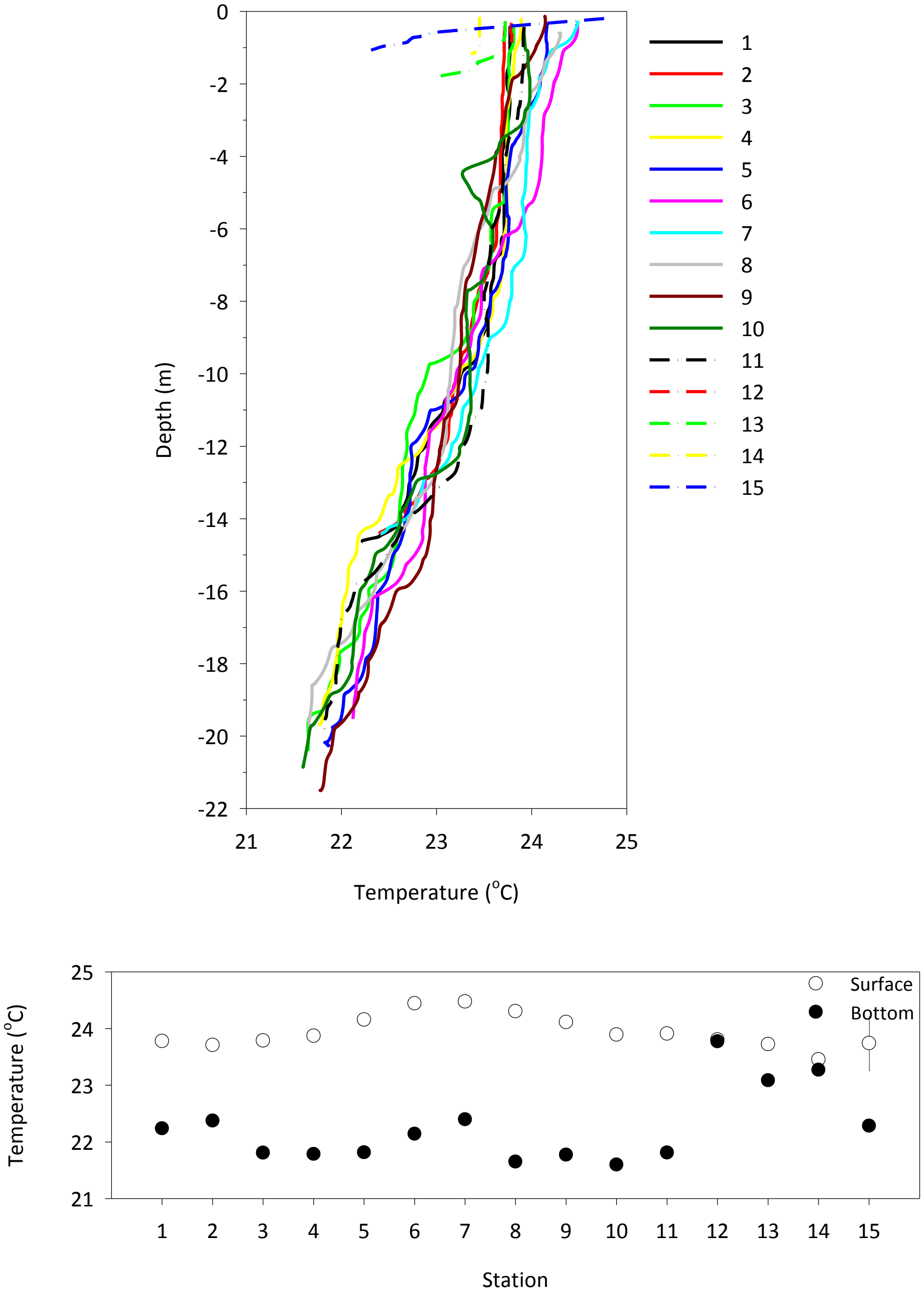

Figure 3.19: Temperature profiles (upper panel) and temperature differences between the surface and bottom waters as measured on 13 February 2013 (CSIR, 2013b).

Based on the above observations, together with limitations in available data to inform the modelling study, it was decided not to include stratification effects in the modelling study. Water temperature near the seabed observed in the ADCP mooring data at a location just to the southwest of the dredge spoil disposal show one or two significant events per month in late spring and summer, suggesting that the exclusion of stratification effects in the model may on occasion be significant (CSIR, 2009). However given the manner in which the modelling was approached, if anything, this will result in a more conservative assessment in terms of turbidity impacts in the water column, *i.e.* the vertical shear in the model will be less than occurs in reality during such stratification events, resulting in an overestimate of the potential for re-suspension of dredge spoil during these stratification events.

3.7 Currents

For the Port of Richards Bay and its surrounds, three zones of current forcing may be identified upon moving offshore. In the inshore region, the currents are predominantly wave-driven except in the vicinity of the mouth of the harbour and the Mhlathuze Estuary where tidally driven flows predominate. In the zone between the surf zone and the inshore edge of the Agulhas Current (located approximately 10 to 30 km offshore), the currents are predominantly wind-driven (CSIR, 1981; Schumann, 1981) with an increasing influence of the Agulhas Current upon moving offshore. The Agulhas Current dominates at the shelf break and beyond.

The wind-driven currents have a periodicity of 4 to 6 days (Bang & Pearce, 1978) and lag the local winds by approximately 18 hours (Schumann, 1981). There is evidence in this region of the surface waters having a more offshore tendency with the deeper waters having an onshore tendency. This is consistent with dynamic upwelling that occurs at the inshore edge of the Agulhas Current (Lutjeharms *et al*., 1989). The presence of cold upwelled water offshore of the mouth of Richards Bay has significance in that cold water on occasion may enter the deeper regions of the bay. The resultant water column stratification and associated potential for increased vertical shear in currents in the bay is expected to provide conditions for a more rapid flushing of the waters of Richards Bay than would normally be expected. This effect however is expected to be quite limited

A number of model simulations of the currents in Richards Bay have been undertaken (*e.g*. CSIR, 1998a, 1999, 2000, 2004a,b,c). Only one of these studies considered the effects of water column stratification (CSIR, 1998b), however these model simulations were focussed on storm water discharges into the mouth of the Port of Richards Bay and did not report extensively on three dimensional flows within the port. Given the high resolution modelling required (particularly in the surf-zone) and the fact that the focus was strongly on surf-zone processes, the modelling undertaken mostly comprised two-dimensional (2D) hydrodynamic simulations (CSIR, 2000, 2004a,b,c). While such 2D modelling adequately simulates wave-driven currents (and to a large extent tidal currents), three dimensional (3D) processes such as vertical shear in currents (due to wind forcing and stratification effects) and local wind-driven re-circulation are excluded. Given the lack of measured data in the Port of Richards Bay, the importance of these 3D processes in determining the water quality within the bay is uncertain, however it is deemed prudent to include these processes modelling studies focussed on detailed water quality processes with the harbour. In the present modelling study three-dimensional flows are modelled however stratification effects and any influence that these may have in changing the vertical shear in horizontal flows are not included in the model.

The main circulation features within the Port of Richards Bay as indicated by these modelling studies (CSIR, 2000, 2004a,b,c;) and summarised in CSIR (2005b) are as follows:

- Strong tidal currents occur in the mouth of the Mhlathuze Estuary where predicted current speeds exceed 1.4 m/s at spring ebb and flood (*e.g*. Figure 3.20 and 3.21). Tidal currents in entrance of the harbour are predicted to rarely exceed 0.2 m/s at spring ebb and flood, however for high wind conditions the spring flood and ebb flows in the port entrance may significantly exceed 0.2 m/s (Figures 3.22 and 3.23). Tidal currents are also significant in shallow regions such as the mudflats on the south-west side of the bay and the mangrove regions, particularly the mangroves south of RBCT;
- Under high SW winds and spring ebb flow conditions, current of up to 0.5 m/s may be generated on the northern side of the mudflats (Figures 3.22 and 3.23) while under strong NE winds the

flows are somewhat reduced and concentrated on the southern side of the mudflats (Figures 3.24 and 3.25);

- Under SW winds clockwise flows are generated on the mudflats both during spring flood and ebb conditions (Figures 3.20 & 3.21 and 3.22 & 3.23). Conversely, under NE winds conditions an anti-clockwise residual circulation develops over the mudflats during both spring flood and ebb conditions (Figures 3.24 & 3.25). The magnitude of these residual circulations increase with increasing wind speeds.
- In general, the surf zone current follows the wave direction in all conditions modelled (*i.e.* SSE waves drive the surf zone current northward and the ESE waves drive the surf zone current southward), except when winds are strong enough to reverse weaker inshore wave-driven currents associated with low wave conditions *(e.g*. a northward inshore current due to the low to moderate SSE wave is reversed by strong NE winds). Consequently, surf-zone currents may flow in an opposite direction to the wind-driven currents prevailing further offshore (*e.g.* a combination of ESE waves and strong SW winds will result in southward flowing surf zone currents and northward flowing wind-driven currents further offshore).

Significant freshwater inflows into the Port of Richards Bay through the Bhizolo, Manzamnyama and Mzingazi Canals occur on occasion. These inflows have the potential to set up locally significant flows within the harbour and also locally affect water column stratification. Walmsley *et al*., (1999) report that there is no monitoring of the fresh water flowing into the Port of Richards Bay, however limited data on these inflows is believed to exist (Archibald, Schoonees, *pers. comm.)*.

The key wind, wave, current and sediment transport processes within the Port of Richards Bay and its immediate surrounds have been schematised in Figure 3.26 (CSIR, 2005b). The major hydrodynamic features may be summarised as follows:

- Strong tidal currents occur in the narrow mouth of the Mhlathuze Estuary. The tidal currents in the mouth of the harbour are much smaller in magnitude and are considered to range from approximately 0.03 m/s during neap tides to approximately 0.17 m/s during spring tides (CSIR, 1998b). Under certain wind conditions the wind-driven component of the flow in the harbour mouth is expected to reinforce these tidal flows. The tidal flows diminish towards the inner recesses of the harbour;
- Strong wind-driven flows occur within the port under higher wind conditions, particularly in the shallow regions. Strong SW winds set-up a residual clockwise circulation on the mudflats on the south-west side of the harbour. Conversely, strong NE winds set up an anticlockwise residual circulation;
- Freshwater inflows via the Bhizolo Canal, the Manzamnyama Canal and particularly the Mzingazi Canal are expected to set-up locally significant flows in the harbour;
- Accretion and erosion problems occur within the harbour due to wave action. Regions of shoreline erosion and accretion within the Port of Richards Bay are indicated in Figure 3.26;
- Wave action and wave-driven surf-zone currents result in significant sediment transport along the beaches. The magnitude and direction of these near shore current are variable and are determined by the prevailing near shore wave direction, however there is a strong net transport to the north.

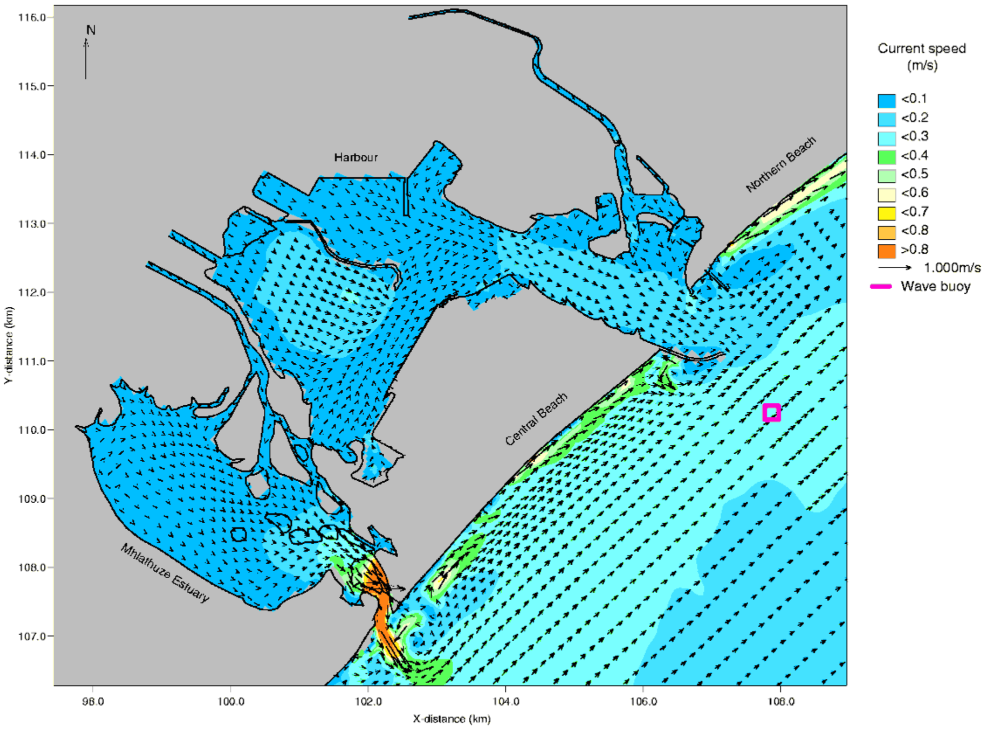

Figure 3.20: Current speed and direction at spring ebb under low to moderate wave conditions (H_{mo} = 1.5 m Tp = 10s, Direction SSE at wave buoy) and moderate SW winds (wind speed 7 m/s). (after CSIR, 2000).

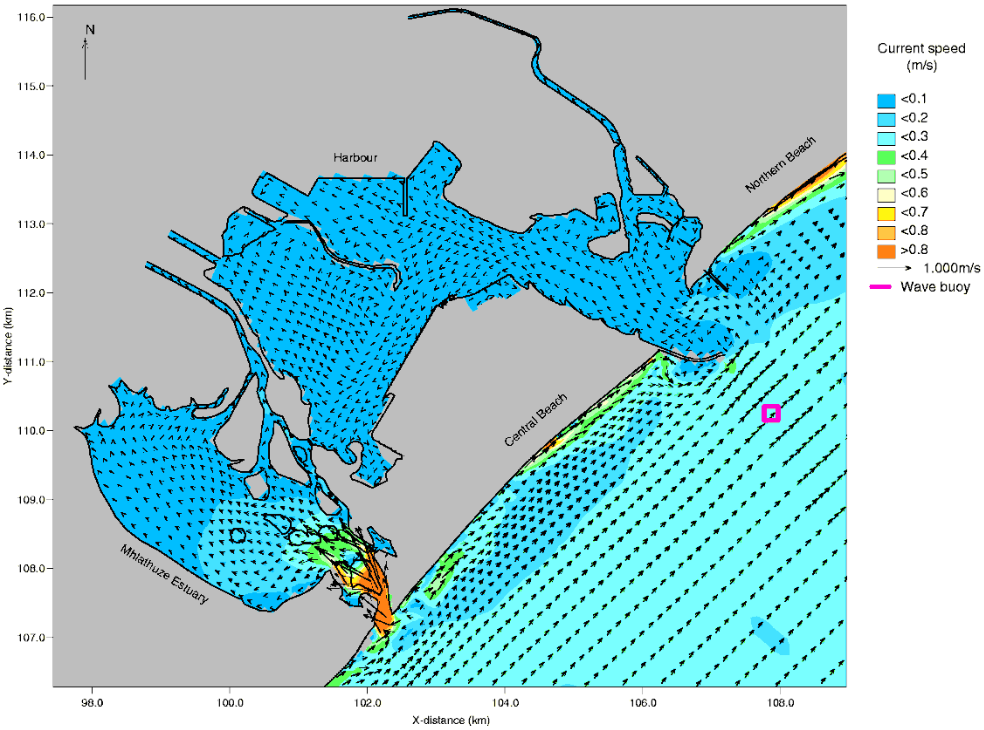

Figure 3.21: Current speed and direction at spring flood under low to moderate wave conditions (H_{mo} = 1.5 m Tp = 10s, Direction SSE at wave buoy) and moderate SW winds (wind speed 7 m/s) (after CSIR, 2000).

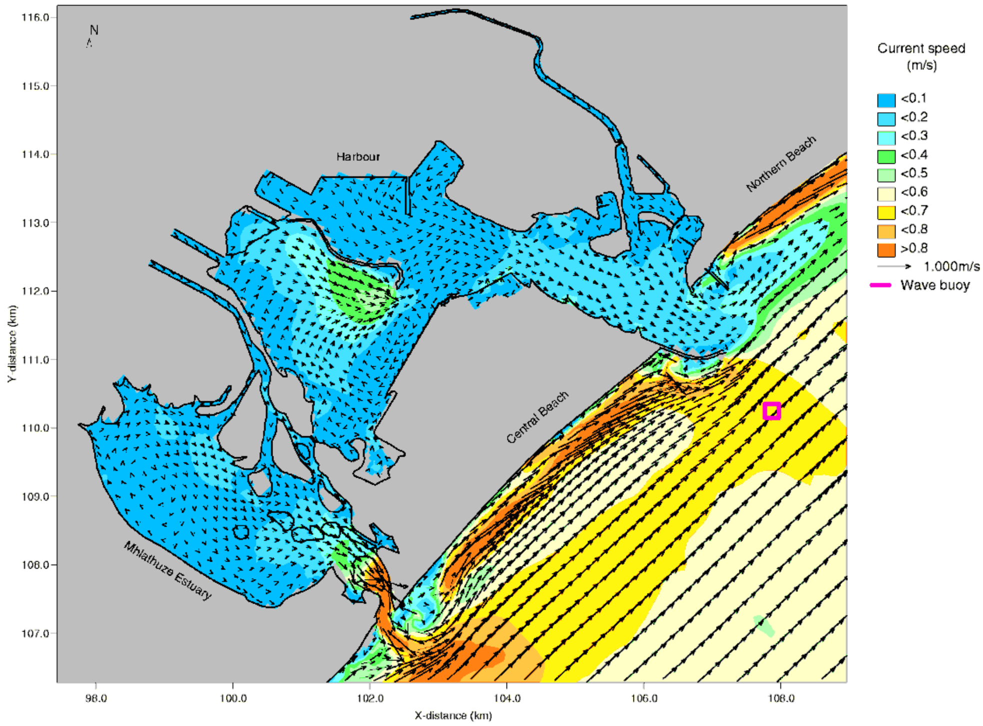

Figure 3.22: Current speed and direction at spring ebb under low to moderate wave conditions (H_{mo} = 3.0 m Tp = 14s, Direction SSE at wave buoy) and strong SW winds (wind speed 16 m/s). (after CSIR, 2000).

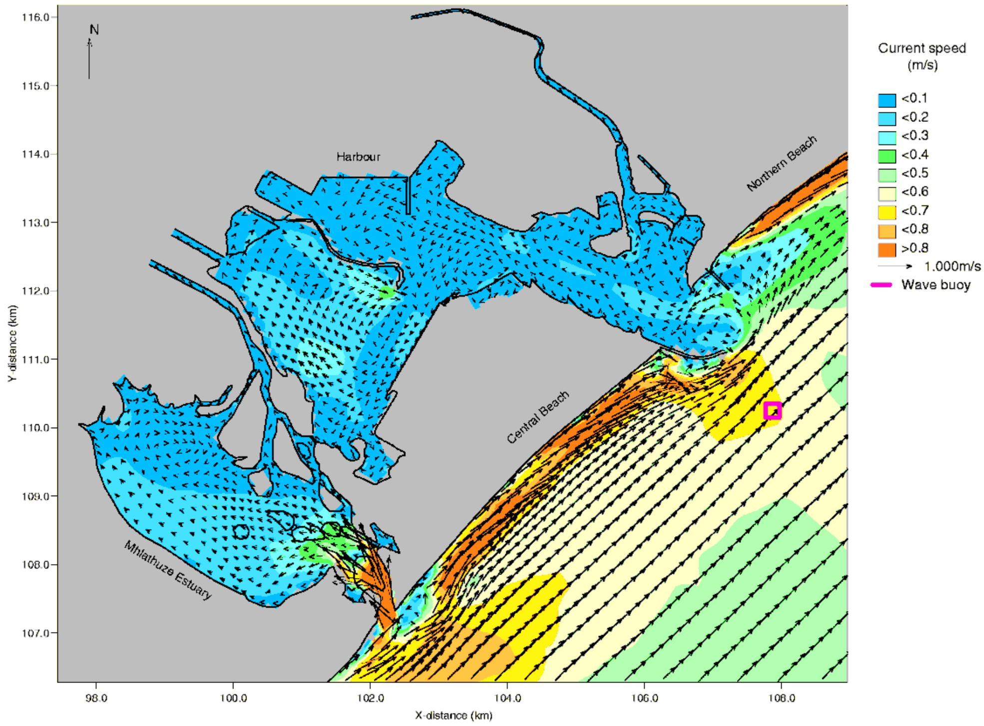

Figure 3.23 Current speed and direction at spring flood under low to moderate wave conditions (H_{mo} = 3.0 m Tp = 14s, Direction SSE at wave buoy) and strong SW winds (wind speed 16 m/s). (after CSIR, 2000).

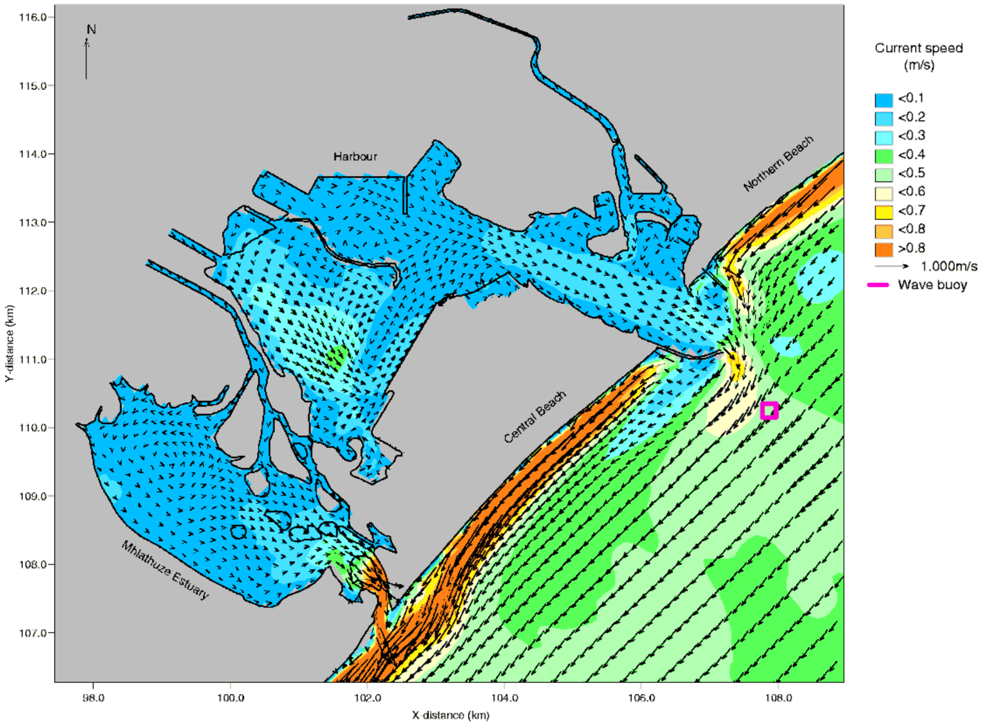

Figure 3.24: Current speed and direction at spring ebb under low to moderate wave conditions (H_{mo} = 2.5 m Tp = 11s, Direction ESE at wave buoy) and strong NE winds (wind speed 14 m/s). (after CSIR, 2000).

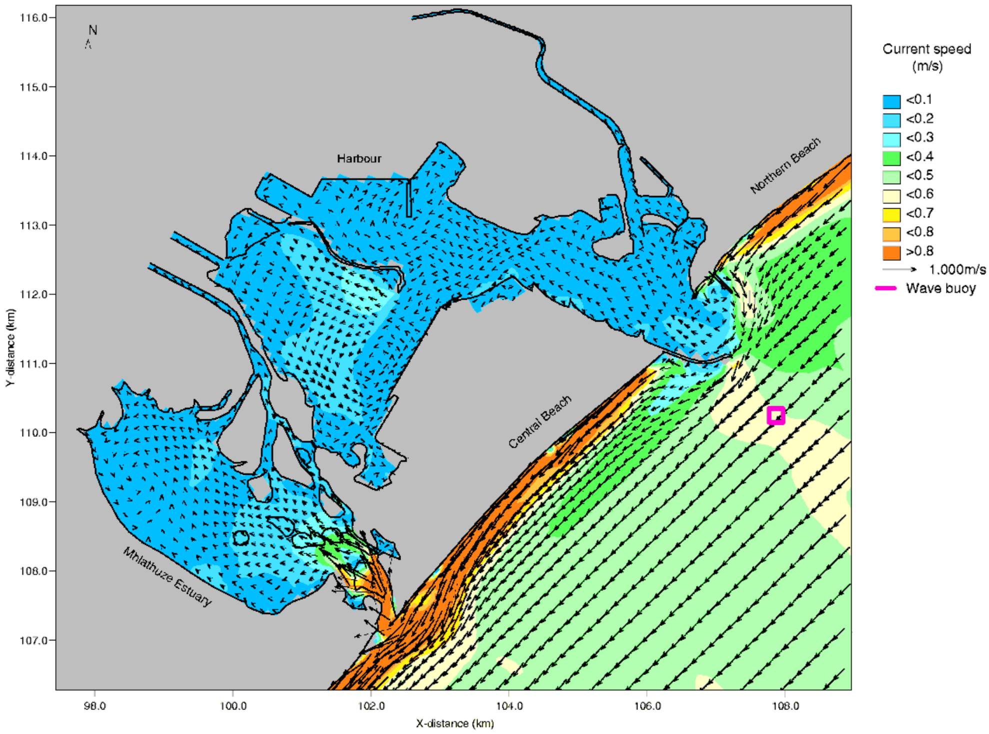

Figure 3.25: Current speed and direction at spring flood under low to moderate wave conditions (H_{mo} = 2.5 m Tp = 11s, Direction ESE at wave buoy) and strong NE winds (wind speed 14 m/s). (after CSIR, 2000).

Figure3.26: Schematic of the major hydrodynamic processes.

3.8 Water Quality

The water quality within the Port of Richards Bay has been described in CSIR (2013b) where potential threats to water quality within the Port of Richards Bay have been identified. Previous water quality sampling to characterise dredging impacts were not suitable for developing an appropriate water quality baseline for the present study due to their sparse coverage and limited sampling of the port in areas potentially impacted by the proposed Port of Richards Bay Capacity Expansion capital dredging activities. The key variables of concern when assessing dredging activities, namely dissolved oxygen, turbidity and suspended sediment concentrations are summarised below.

3.8.1 Dissolved Oxygen

The dissolve oxygen values measured as part of the baseline surveys (CSIR, 2013b) range between just below 6 mg/ℓ to more than 8 mg/ℓ while the percentage saturation of dissolved oxygen concentrations range between approximately 80% to more than 120% (Figure 3.27). In general the dissolved oxygen concentrations decrease with depth. Bottom water dissolved oxygen concentrations at numerous of the deeper water stations fell marginally below the South African Water Quality Guidelines for Coastal Marine Waters target of 6 mg/ℓ that must be met 95% of the time, but exceeded the target of 5 mg/ℓ that must be met 99% of the time (Figure 3.28). These observations were for a summer period when stratification effects are the most significant. It is therefore expected that the dissolved oxygen concentrations in the water column, particularly in the deeper waters, generally would exceed those measured in this study, especially in the winter months when the water column is much less stratified or well-mixed. It is only in the late summer months, when stratification is likely to be the most significant, that one would expect the dissolved oxygen concentrations to be lower in the near bottom waters than those observed during the February 2013 survey.

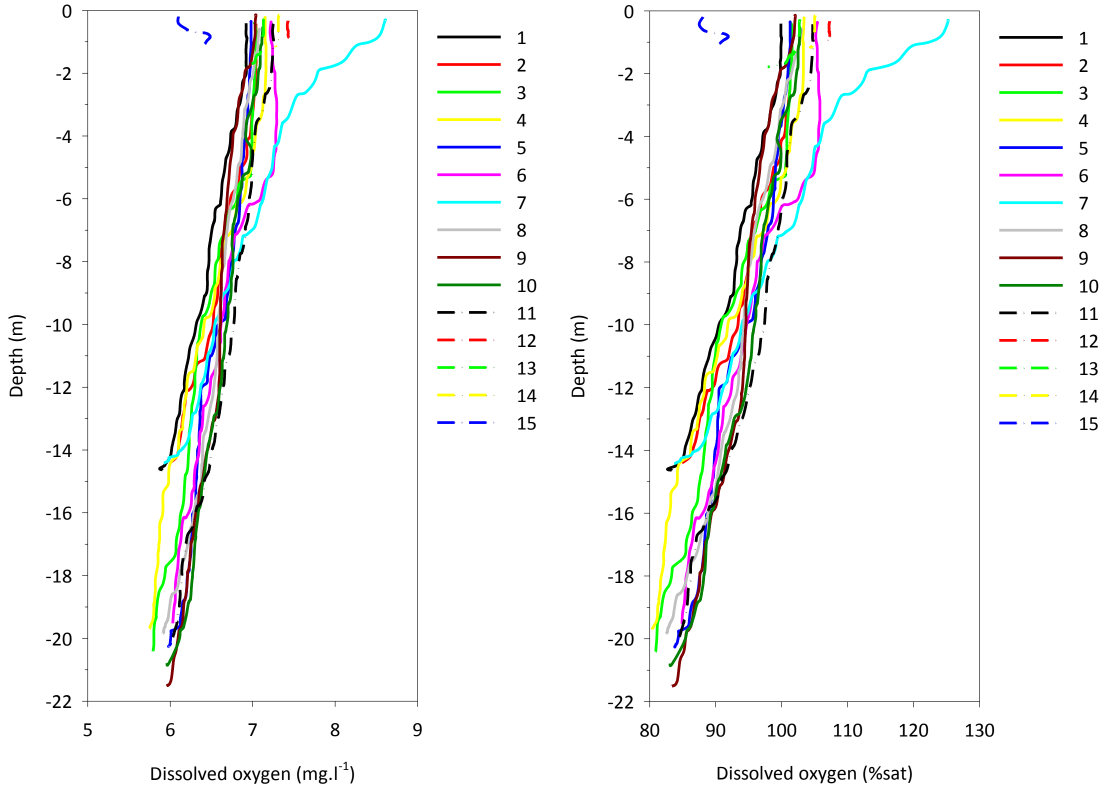

Figure 3.27: Dissolved oxygen concentration and saturation profiles for the water column in Richards Bay on the 5th of February 2013 (Source: CSIR, 2013b)

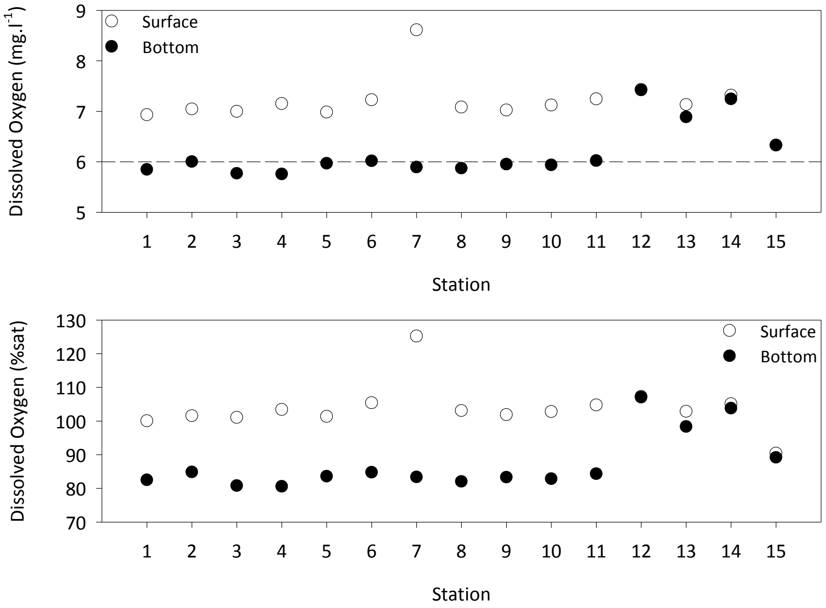

Figure 3.28: Comparison of the dissolved oxygen concentration and percentage saturation of surface and bottom waters in Richards Bay on the 5th of February 2013 (Source: CSIR, 2013b).

3.8.2 Turbidity and Total Suspended Solids Concentration

The most critical measurements when assessing potential dredging impacts are turbidity and total suspended sediment concentrations in the water column. Although turbidity and total suspended solids concentrations in the water column, in principle, should display a strong relationship to one another this is not always the case (CSIR, 2013c). Poor relationships may come about because the total weight of particles in suspension is a direct function of their number, size and specific gravity, but turbidity is a direct function of the number, surface area and refractive index of the particles but an inverse function of their size. Dissolved substances, which are not part of the suspended solids load, affect turbidity but not the suspended solids concentration as they pass through a 45 µm pore size filter (*i.e.* the filter generally used when determining total suspended solids concentrations). This also may contribute to a poor relationship between turbidity and total suspended solids concentrations. It is for this reason that both turbidity and suspended sediment concentrations are reported here.

The turbidity and suspended sediment concentrations observed in the Mhlatuze Estuary, in the Port of Richards Bay (and its immediate environs) and offshore in the vicinity of the dredge spoil site and beyond, have been summarised by Weerts (2008). In the Mhlatuze estuary turbidity typically ranges from 10 NTU to more than 60 NTU on occasion, however typical values are in the 15 to 30 NTU range. Using the relationships developed in CSIR (2013c), this translates into typical suspended sediment concentrations of between approximately 25 and 50 mg/ℓ. In the Port of Richards Bay there is a strong spatial variation in the turbidity observed with the highest turbidity being observed on the mudflats, increasing towards the Bhizolo Canal (Weerts, 2008). The observed turbidity is much lower through most of the water column in the deeper waters of the shipping canals and berths however the turbidity measured near the seabed may be high due to the increased fines content of the sediments in these deeper waters. The measured distribution of the observed *in-situ* turbidity (measured in the field using a profiler) and turbidity and suspended solid concentrations obtained in the laboratory from field samples are given in Figure 3.30 (CSIR, 2013c). The location of the profiling and the sampling are indicated in Figure 3.29 below.

Figure 3.29: Locations in the Port of Richards Bay were turbidity profiling and water sampling for the laboratory measurement of turbidity and analysis of suspended sediment concentrations.

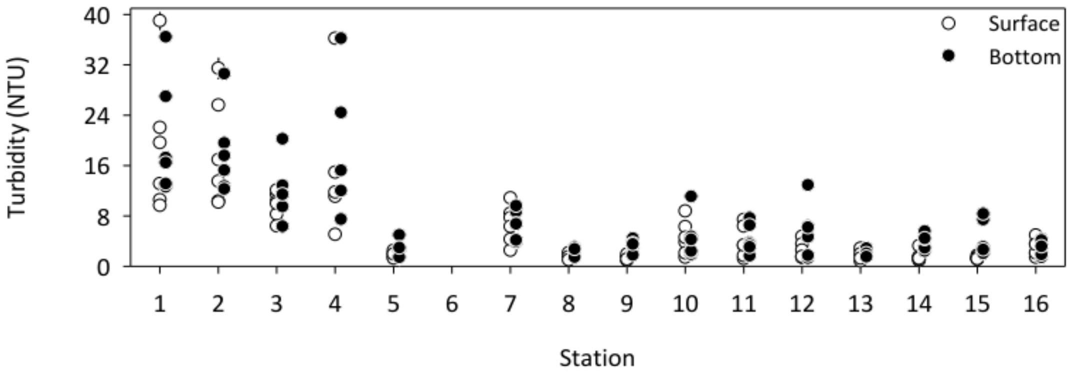

Figure 3.30: ***In-situ* measurements of turbidity at the surface and near the bottom at the locations indicated in Figure 3.28.**

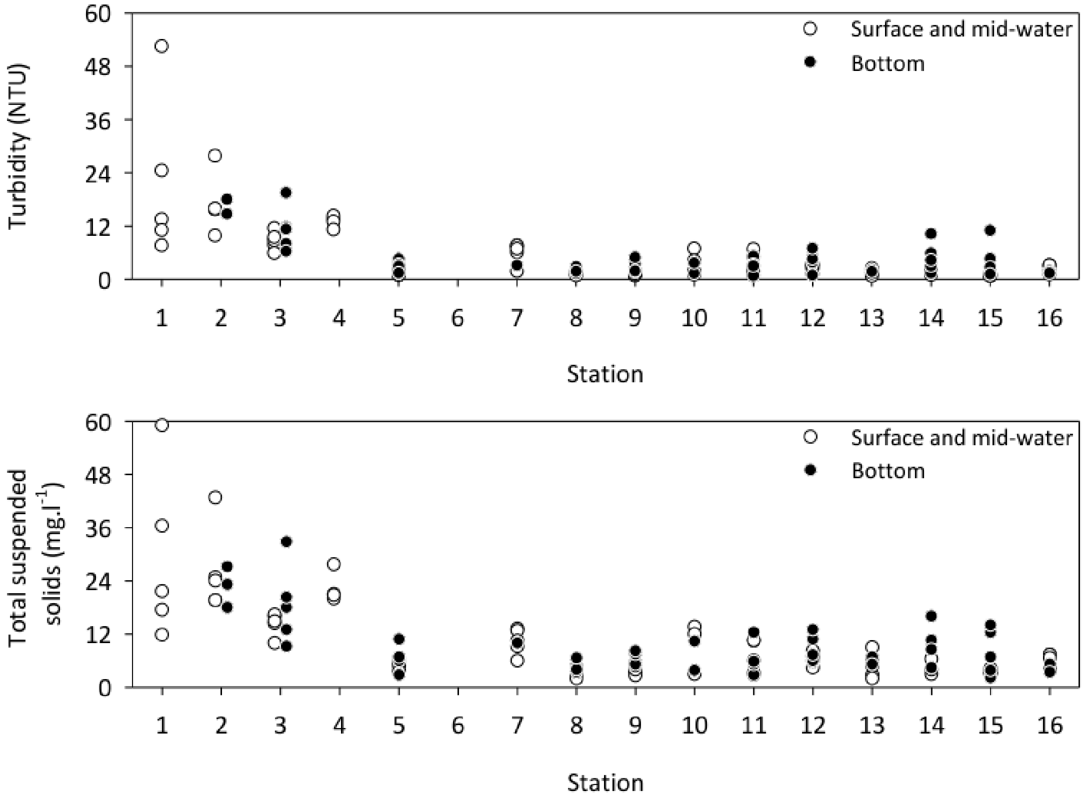

Figure 3.31: **Measurements of turbidity suspended sediment concentrations from sampled obtained at the sea surface and near the bottom at the locations indicated in Figure 3.28.**

Turbidity measurements undertaken during the Berth 306 capital dredging monitoring programme, suggest that water column turbidity in the vicinity of the proposed dredge spoil disposal site and along an SW to NE axis through the site typically ranges between 2 and 8 NTU in the surface waters and 2 NTU and 16 NTU near the seabed (Weerts, 2008). Using the relationships between NTU and suspended sediment concentrations in mg/ℓ reported in CSIR (2013c), this translates into a range of suspended sediment concentrations of between 3 and 12 mg/ℓ for the surface waters and 3 and 24 mg/ℓ for the near bottom waters. It should be noted that the higher values were observed during dredge spoil disposal activities.

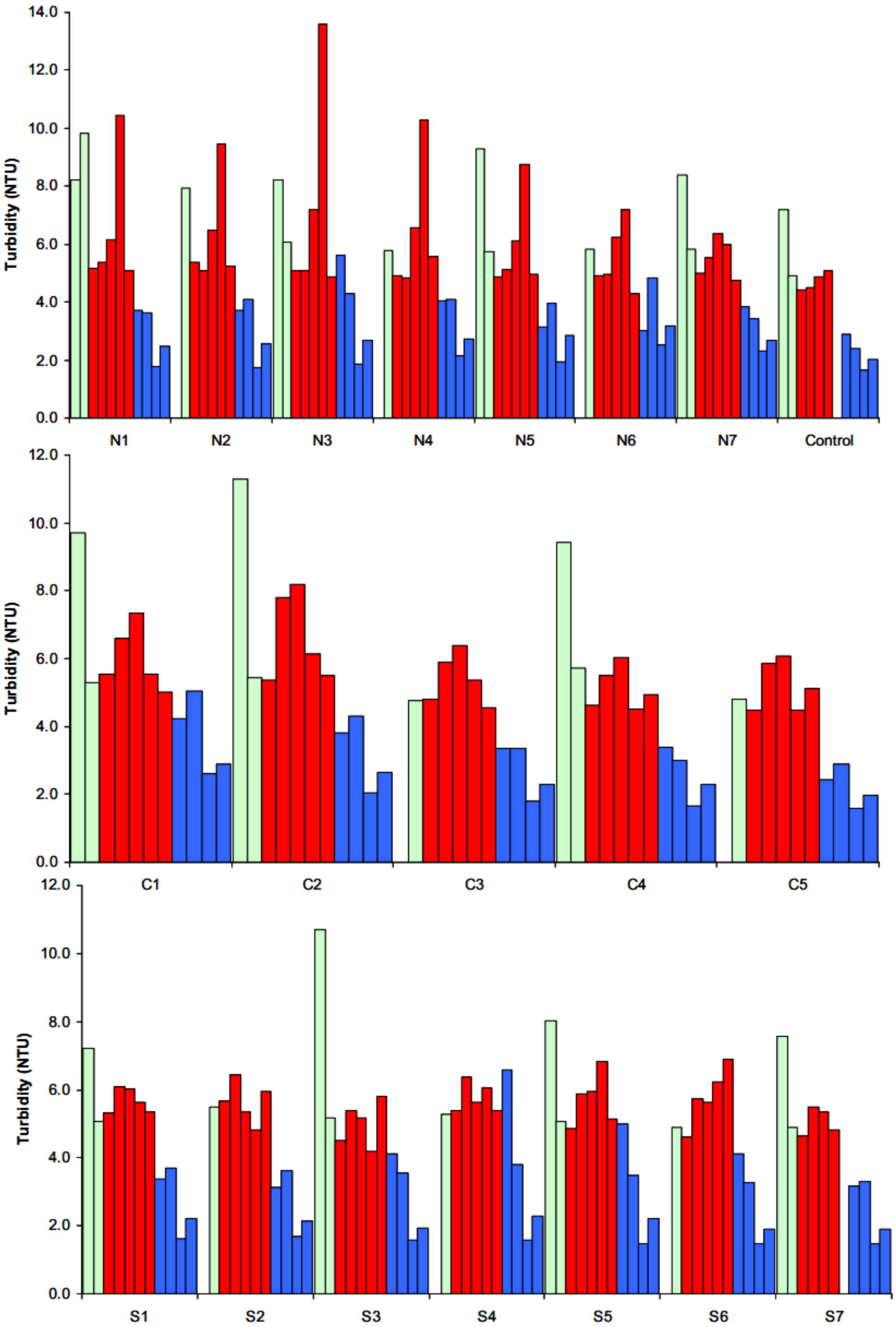

Figure 3.31: Water column averaged turbidity measured at the offshore locations indicated in Figure 3.15 (Source: Weerts, 2008).

The depth-averaged turbidities measured in the vicinity of the dredge spoil disposal site are presented in Figure 3.31 above. If these are to be interpreted as suspended solid concentrations, the NTU value need to be multiplied by approximately a factor of 1.53 (CSIR, 2013c). It is interesting that these turbidity values did not display clear and unequivocal evidence of the expected elevation in turbidity associated with dredge spoil disposal, possibly due to the confounding effects of seasonality with respect to the sediment-laden inflows into the marine environment that occur in this region. However there exists periods during the dredging when there seemingly was elevated turbidity in the vicinity of the dredge spoil disposal site, including one occasion (27/11/2005) where elevated turbidity (~ + 5 NTU compared to pre-dredging values) was observed stretching some 12 km north of the dredge spoil disposal site (Weerts, 2009).

Continuous measurements of turbidity using optical backscatter (OBS) instrumentation on moorings located both to the north (location K) and the south (location L) of the dredge spoil disposal site (Figure 3.32) indicate a number of occasions where there is significant elevation of water column turbidity. While there were issues with the bio-fouling and subsequent calibration of these instruments, there is reasonable confidence in the limited periods of data presented in Figure 3.33. These observations indicate the expected temporal variability in turbidity associated with wind, wave and current events. Significant is that the profiling from the field exercises reported in Weerts (2009) only co-incided with the period of valid OBS time series data on two occasions. Furthermore, on only one of these occasions did the turbidity profiling from the field surveys co-incide with a period of elevated turbidity identified in the OBS mooring data (26-27/11/2005). This is the occasion identified in Weerts (2009) when the most extreme elevations in turbidity were observed stretching northwards of the dredge spoil disposal site. The above suggests that if the monitoring of the offshore region were to have been more regular, the chances are that more such events would have been observed in the data from the offshore profiling surveys.

Figure 3.32: Locations of the OBS moorings K and L during the Berth 306 Dredge monitoring programme.

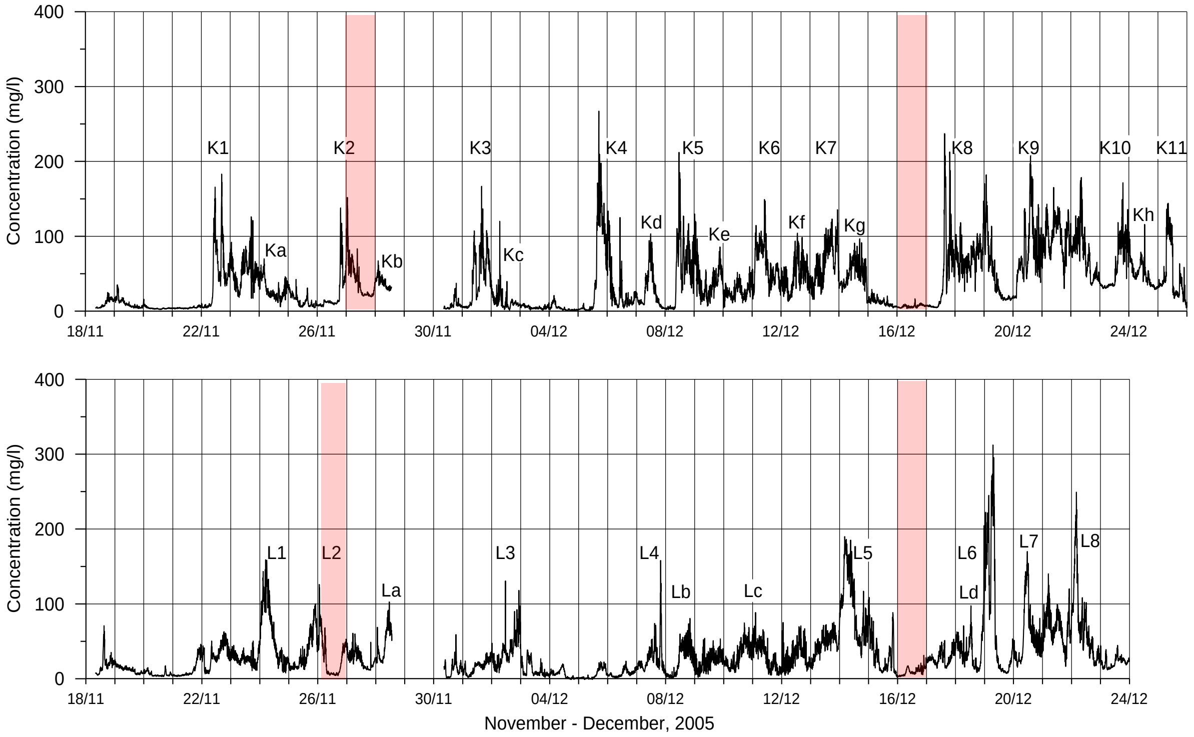

Figure 3.33: **Time series of turbidity recorded by OBSK (top) and OBSL (bottom) for the data of Period A. The “significant” events have been marked (K1 – K11 and L1 – L8), while smaller events are also indicated (Ka – Kh and La – Ld). There is very little visual correlation between the significant events of the two records which is not unexpected as the two measurement sites were on opposite sides of the dredge spoil disposal site. The shaded area represent the days when concurrent turbidity profiling was undertaken in the offshore region.**

The implication of these observations is that care should be taken in using the profiling data alone to develop an environmental baseline for turbidity in the offshore region. Furthermore, even greater care should be taken in using only the profiling data (that has limited temporal resolution) to set thresholds for compliance monitoring and management of dredging activities as has been done in CSIR (2013c).

4 KEY ISSUES OF CONCERN

The key issues of concern and the water and sediment guidelines of relevance to assessing the potential impacts of the proposed dredging activities are summarised below.

4.1 Potential Impacts of Dredging

The detail of the potential ecological impacts and impacts on the existing beneficial uses of capital dredging have been discussed in great detail elsewhere (*e.g*. Dankers, 2002; Anchor Environmental, 2003; Bray, 2008; CSIR, 2013c). However to provide context this study, the potential impacts of capital dredging are summarised below:

- Long-term changes in hydrodynamics and water quality due to changes in port layout or deepening of channels or other areas within the port.
- Habitat destruction due to the removal of sediments;
- Smothering effects on benthos;
- Suppression of primary productivity due to light limitation due to increased water column turbidity;
- Effects of excessive suspended particulate matter on the feeding rate of invertebrate filter feeders, reducing their growth and productivity;
- Clogging of gills of fish and crustacea;
- Effects of increased turbidity on the feeding success of visual predators;
- Potential toxicity effects should the sediments to be dredged by contaminated with trace metals;
- Aesthetic impacts of dredge plumes.

These potential impacts are schematised in Figure 4.1 below.

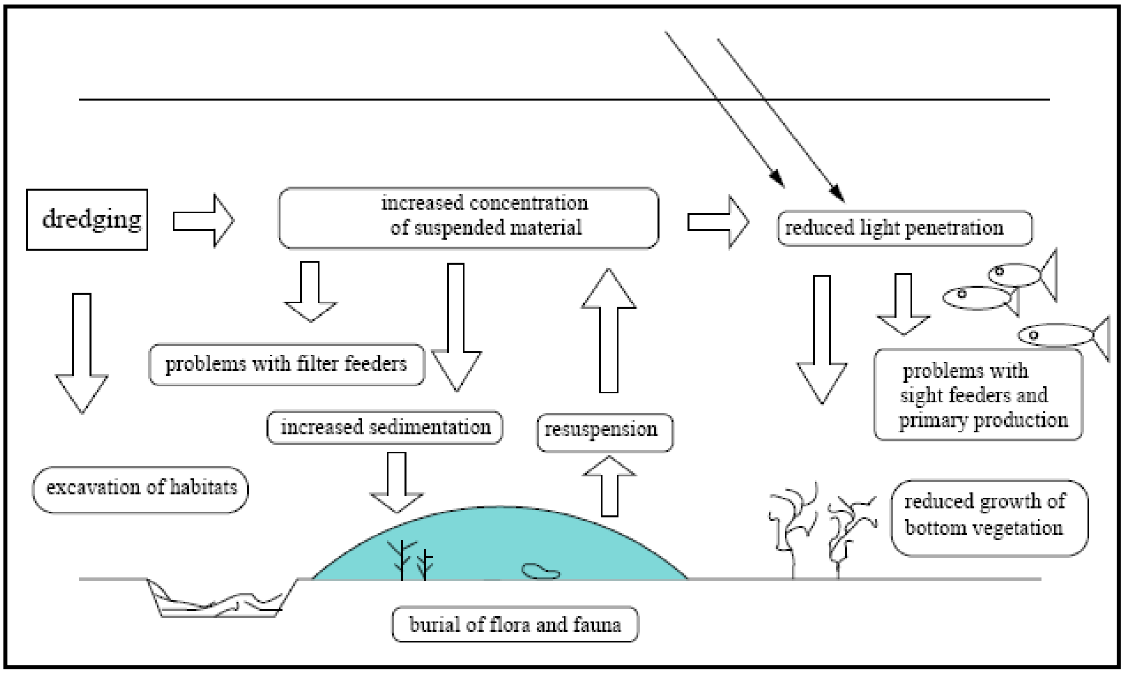

Figure 4.1: Schematisation of the effects that dredging and dredge disposal activities may have on ecosystems (after Dankers, 2002).

The visual impacts specific to the marine environment are assessed in this report and are intended to inform the overall visual impact assessment for the project where all potential visual (aesthetic) impacts are summarised. Furthermore, potential impacts associated with dredge spoil re-suspension and deposition in existing navigation channels also are addressed in this report.

All other potential environmental impacts in the marine environment have been assessed in the relevant specialist reports. This modelling report primarily serves to inform the impact assessments in the ecological specialist report.

Specifically excluded from the study is the assessment of potential dredge spoil disposal impacts on the adjacent shorelines. This would require a more detailed specification of dredge spoil disposal activities than is presently available, specifically the precise quantity of dredge spoil to be disposed of at the offshore dredge spoil disposal site as this will determine the height of the dredge mound to be taken into consideration when assessing likely shoreline impacts.

4.2 Relevant Water and Sediment Quality Guidelines

Here the water and sediment quality guidelines of relevance are summarised. The guidelines relate to potential visual impacts, ecological impacts of elevated turbidity in the water column, potential toxicological effects associated with the dredging of contaminated sediments, and potential smothering effects (including possible impacts of changes in grain size distribution in benthic habitats).

While guidelines can be specified for the assessment of visual impacts, the impact of elevated turbidity (or suspended sediment concentrations) in the water column and potential toxicological effects, no clear guidelines exist for smothering effects and changes in grain sizes in benthic habitats. The latter are assessed in the Marine Ecology specialist study (Cyrus and Olivier, 2014a,b), informed by literature and expert opinion rather than specific guidelines.

Water quality guidelines deemed to be relevant to this study are:

- The South African Water Quality Guidelines for Coastal Marine Waters (Natural Environment) (DWAF, 1995) are utilized to determine the maximum upper limits for dissolved trace metals in the water column and as an initial guideline for suspended sediments in the water column;
- Water quality guidelines for suspended sediment concentrations in the water column from dredging activities relevant to the west coast of southern Africa (EMBECON, 2004).
- Site-specific thresholds of concerns developed in the turbidity baseline study (CSIR, 2013c).

4.2.1 Water Column Guidelines.

The South African water quality guidelines of relevance to water column parameters in this assessment are indicated in Table 4.1.

Table 4.1: Water Column: Recommended South African Water Quality guidelines or target values for the protection of marine ecosystems

CONSTITUENT	TARGET VALUE
The following target values apply to marine waters outside a specific sacrificial zone:	
Colour/turbidity/clarity	Should not be more than 35 *Hazen units* above ambient concentrations (colour) Should not reduce the depth of the euphotic zone by more than 10% of ambient levels measured at a suitable control site (turbidity).
Suspended solids	Should not be increased by more than 10% of ambient concentrations. This is largely based on aesthetic impacts.
Dissolved oxygen	Dissolved oxygen should not fall below 5 mg/ℓ (99% of the time) and below 6 mg/ℓ (95% of the time).
Ammonium, Nitrate, Nitrite, Phosphate, Silicate	Waters should not contain concentrations of dissolved nutrients that are capable of causing excessive or nuisance growth of algae or other aquatic plants or reducing dissolved oxygen concentrations below the target range indicated for *Dissolved oxygen* (see above).
Ammonia	20 μg N per litre (as NH_3) or 600 μg N per litre (as NH_3 plus NH_4^+)
Arsenic (As)	12 μg/ℓ
Cadmium (Cd)	4 μg/ℓ
Chromium (Cr)	8 μg/ℓ
Copper (Cu)	5 μg/ℓ
Lead (Pb)	12 μg/ℓ
Mercury (Hg)	0.3 μg/ℓ
Nickel (Ni)	25 μg/ℓ
Zinc (Zn)	25 μg/ℓ

The South African water quality guideline for suspended solids (*i.e.* the suspended solids should not be increased by more than 10% of ambient concentrations) is not believed to be appropriate here. More site-specific guidelines targeting dredging operations have been developed for South African west coast systems (EMBECON, 2004) and from more detailed studies undertaken for Table Bay (Steffani *et al*., 2003) and are considered to also have relevance in the Richards Bay region. However of greatest relevance are the thresholds identified in CSIR (2013c) that, if exceeded, would require management of dredging activities to reduce the turbidity and suspended solid concentrations to below these thresholds. Proposed guidelines for suspended solids in the water column from the above studies are:

- Steffani *et al*. (2003) established guidelines for suspended sediment concentrations for ecologically sensitive areas in and around Table Bay (*e.g.* the kelp beds found close to the shoreline around Robben Island, as well as the kelp beds of the Cape Point National Park). These guidelines, although derived for a West Coast system, have been used in a number of previous capital dredging studies in South Africa. These are considered to be sufficiently conservative for the assessment being undertaken here. The guidelines are as follows:
    - < 20 mg/ℓ, low risk, monthly average goal;
    - 20 - 80 mg/ℓ, medium risk, permissible for short periods, that is, 2-3 days;
    - > 80 mg/ℓ, unacceptable high risk, requires mitigation action.

- EMBECON (2004) reviewed the scientific literature on the effects of varying suspended sediment concentrations on a range of biota and showed that total suspended sediment concentrations <100 mg/ℓ represented limited risks for biota.
- The Operational Environmental Management Plan (TNPA, 2009) for dredging in the Port of Ngqura identified a thresholds of a suspended sediment concentration of 100 mg/ℓ (50 mg/ℓ for sensitive sites) as a warning threshold indicating that mitigation measures needed to be implemented and a threshold of a suspended sediment concentration of 150 mg/ℓ (80 mg/ℓ for sensitive sites), the exceedance of which would lead to cessation of dredging activities. The selection of thresholds would have had a scientific basis but could possibly be considered site specific;
- Site specific thresholds suggested for use in managing dredging impacts in Richards Bay (CSIR, 2013c) include:
    a. Turbidity of 93 NTU or total suspended sediment concentrations of 142 mg/ℓ for location in the Bhizolo Canal of on the mudflats;
    b. Turbidity of 66 NTU or total suspended sediment concentrations of 100 mg/ℓ for all other locations in the Port of Richards Bay;
    c. Turbidity of 10.2 NTU or total suspended sediment concentrations of 16.4 mg/ℓ for offshore location in the vicinity of the dredge spoil disposal site. There however, exist some concerns around the validity of this threshold due to the limited temporal resolution of the profiling data used to derive this threshold and a likely resultant bias in the data (see Section 3.8.2 of this report) towards lower values.

The application of water quality guidelines generally require that the background (or ambient) suspended sediment concentrations be known. However, the ambient suspended sediment concentrations are often difficult to define as short-term events, such as storms, can increase the suspended sediment concentration by two orders of magnitude for short periods as can river inflows into marine environment. Nearshore organisms therefore experience and survive large fluctuations in suspended sediment concentrations (*e.g.* CSIR, 1998c). It is for this reason that the above guidelines values are used only to present the results of the modelling study.

In assessing potential aesthetic effects we have used the same conservative guideline for suspended sediment concentrations as was used in a similar dredging study in Table Bay, where similar upwelling dynamics and inflows of bottom waters can lead to low turbidity conditions in the water column. Thus, a conservative guideline of 10 mg/ℓ elevation in suspended sediments in the upper water column has been assumed for a threshold above which plumes are likely to be visible in the marine environment (*i.e.* to assess potential aesthetic impacts).

The model has been set up to simulate dilutions relevant to assessing trace metal concentrations entering the water column during the dredging process. However, given:

- that in the area to be dredged that the metal contamination indicates that a maximum of three metals exceed Warning Level of the sediment quality guidelines, two exceed Level 1 of the sediment guidelines and none exceed the Level II sediment quality guidelines;
- the fact that previous elutriation studies (albeit in a West Coast environment) have indicated that only 0.2% of the trace metal concentrations in the sediments enter the water column (van Ballegooyen *et al.*, 2006) and that in CSIR (2013c) it is stated that there is a high likelihood that the trace metals at the most seriously contaminated sites are likely to be in particulate form

rather that the metal-sorbed form (only the metal-sorbed form can be remobilised into the water column during dredging);
- that only the surficial sediment (that form a very small percentage of the material proposed to be dredged), are contaminated;

the model results have not been assessed for potential toxicological effects of trace metals.

If necessary, the model results could be assessed in terms of achievable dilutions of trace metals and the extent to which there would be compliance with the South African water quality guidelines. However, for the reasons stated above, such an analysis at this stage is considered to be superfluous. It would be more sensible, should it be deemed necessary, to better understand the risks posed by the contaminated sediments as suggested in CSIR (2013c) before undertaking a detailed analysis of the model results on contaminated sediments as these model results are based on assumptions (assumed percentages of metals entering the water column) around which there remains some uncertainty.

4.2.2 Sediment Quality Guidelines.

The potential toxicological significance of metal concentrations in sediment has been evaluated by comparison with sediment quality guidelines used by the Department of Environmental Affairs to determine if sediment identified for dredging in South African coastal waters is of a suitable quality for unconfined openwater disposal (CSIR, 2013b).

Three guidelines were defined, namely the Warning Level, Level I and Level II (Table 4.2). The Level I and Level II are used for decision-making. The Warning Level is only used to provide a warning of incipient metal contamination. Sediment with metals at concentrations equivalent to or lower than the Level I guideline is taken as posing a low risk to bottom-dwelling organisms and is suitable for unconfined openwater disposal. Sediment with metals at concentrations equal to or higher than the Level II guideline is taken as posing a high risk to bottom-dwelling organisms and in the absence of other information to refute this conclusion is considered unsuitable for unconfined openwater disposal. Sediment with metals at concentrations between the Level I and Level II is taken as posing a potential risk to bottom-dwelling organisms, with the degree of risk increasing as the concentration approaches the Level II. Using these guidelines a decision can be made whether the sediment is of a suitable quality for unconfined openwater disposal after considering the number of metals at concentrations that exceed the Level I and the magnitude of exceedance at a particular station.

Table 4.2: Sediment quality guidelines used to determine whether sediment identified for dredging in South African coastal waters is of a suitable quality for unconfined openwater disposal.

Metal	Warning Level	Level I	Level II
Arsenic	42	57	93
Cadmium	1.2	5.1	9.6
Chromium	135[a]/250[b]	260	370
Copper	110	230	390
Mercury	0.43	0.84	1.5
Nickel	62[a]/88[b]	140	370
Lead	110	218	530
Zinc	270	410	960

a - for Eastern and Western Cape, b - for KwaZulu-Natal

5 TURBIDITY MODELLING STUDY

The modelling of dredging and dredge spoil disposal impacts has been undertaken using the Deltares DELFT3D-WAVE and DELFT3D-FLOW (including the sediment capability) software (Booij *et al.*, 1999; Lesser *et al*., 2004; Deltares, 2011a,b). This requires the set-up of a DELFT3D-WAVE to provide time series of wave conditions to the DELFT3D-FLOW three-dimensional wave model that in turn is used to determine sediment transport of the material being dredged and disposed of at the offshore dredge spoil disposal site. These models have been set-up for a 6 month duration, namely from 1 August 2005 to 31 January 2006.

5.1 Processes modelled

The objective of the modelling is to simulate the transport and fate of the predominantly the fine component of the dredged material, both at the site of dredging inside the port and at the dredge spoil disposal site. Accordingly the model needs to account for the following dominant physical processes:

- Refraction of deep water waves to determine the wave conditions throughout the model domain, particularly at the dredge spoil disposal site and in the surf zone;
- Generation of wind-waves inside the port and the estuary;
- The effect of waves on currents via forcing, enhanced turbulence and enhanced bed shear stress;
- Generation of tidal currents in the port and in the estuary;
- Generation of wind-driven currents in the port, estuary and offshore;
- Vertical mixing processes and possibly water column stratification;
- The introduction of a source of suspended sediment and the advection-dispersion of the resulting turbid plume;
- The settling-deposition-resuspension of the sediment particles and the evolution of the dredge spoil mound over time.

All these processes are accounted for by the relevant models forming part of the DELFT3D modelling system, developed by WL|Delft Hydraulics in the Netherlands. These comprise the wave model (DELFT3D-WAVE), the hydrodynamic model (DELFTD-FLOW) and the suspended sediment model (DELFT3D-SED), as described below.

The core of the modelling has been undertaken using the DELFT3D-SED model that comprises an extended capability of the DELFT3D-FLOW model. The DELFT3D-SED model can be run in two modes. The first mode is one where there is no feedback between the hydrodynamics and the evolving seabed. The second mode is one where there is feedback between the changes in the seabed and the hydrodynamics. In the present study that is focussed on the transport and fate of the fine dredge spoil only, DELFT3D-SED is used without feedback from the changes in the seabed.

5.2 Co-ordinate Systems and Bathymetry used in the Models

5.2.1 Co-ordinate system

Note that a local coordinate system based on a WGS84 projection and Lo_{31} coordinates (X_{WG31} ,Y_{WG31}) and has been applied in the modelling. A linear transformation is applied to provide model coordinates (X_{model} ,Y_{model}) which are positive and increase from south to north and from west to east. The transformation used is:

$$X_{model} = -Y_{WG31}$$

$$Y_{model} = 3\,300\,000 - X_{WG31}$$

5.2.2 Bathymetry

A detailed bathymetry of the model domain was compiled by combining the following datasets:

- S A Navy hydrographic chart 132 – Tongaat Bluff to Richards Bay
- S A Navy hydrographic chart 133 – Durnford Point to Leven Point
- S A Navy hydrographic chart 1032 – Richards Bay
- S A Navy hydrographic chart 1033 – Richards Bay Harbour
- The inshore survey conducted by CSIR in 1995 (CSIR, 1996)
- The nearshore survey conducted by Portnet in 1995 (CSIR, 1996)
- The beach profiling survey conducted in 1995 (CSIR, 1996)
- The survey of the Mhlathuze Estuary conducted by CSIR in 1997 (CSIR, 1998d)
- Detailed dredging survey data inside the port provided by Portnet

The resulting GIS database comprised 58 000 depth points. These data were then supplemented by a survey of the corridor of the two pipelines located just north of the Port of Richards Bay (Jan 2005). Also available to the study was the three surveys undertaken as part of the Berth 306 capital dredging project. These included a pre-dredging survey (Ramsay and MacHutchon, 2005) of the dredge spoil disposal site undertaken in July 2005, an immediate post-dredging survey of the dredge spoil disposal site undertaken in January 2006 (Ramsay and MacHutchon,2006) and one further survey of the dredge spoil disposal site undertaken approximately 18 months 2006 and July 2007.later in July 2007 (van Den Bossche *et al.*, 2007). The MGS bathymetry data sets (Ramsay and MacHutchon, 2005, 2006) that were supplied at a nominal 2m resolution, were decimated to a nominal 10 m resolution before being incorporated in to the bathymetric database.

The bathymetric database used in this modelling study the bathymetry database comprised the original bathymetry database used in earlier studies (CSIR, 2000, 2004a, 2004b) supplemented by:

- The bathymetric survey along the corridor of the two pipelines located north of the Port of Richards Bay (Jan 2005);
- The pre-dredging bathymetry survey of Ramsay and MacHutchon (2005) undertaken in July 2005;

The reason for selecting the July 2005 bathymetric data for inclusion into the pre-dredging databse used in the modelling study is that it is not clear to what extent the dredge spoil from the Berth 306 capital dredging has been re-distributed from the dredge spoil disposal site. Van Den Bossche *et al*. (2007) and Weerts (2009) discuss the movement of sediment from the dredge spoil disposal site based on the three surveys (June 2005, January 2006 and July 2007) indicating that a substantial change had occurred between the January, however this most likely can be attributed to the major storm event that occurred in the region on 18 to 19 March 2007 that also led to widespread damage to shoreline infrastructure along the Durban coastline. The use of the July 2005 bathymetric data is based on the assumption that the Jul 2005 data represent a long-term configuration of the dredge spoil site due to maintenance dredging activities.

These data were mapped onto the depth points of the computational grids by triangular interpolation. The resulting model bathymetry for the large-scale wave modelling is shown in Figure 5.3, while the bathymetry used for the nested grid wave modelling and the flow modelling are detailed in Figures 5.4 and 5.5. All depths and tidal levels in this study are referenced to the pre-1998 Chart Datum located 0’9 m below Mean Sea Level. Consequently all water levels in the study have also been reference to the pre-1998 Chart Datum.

The computational grids and bathymetry used in the wave and hydrodynamic modelling are reported under the relevant wave and hydrodynamic modelling sections below.

5.3 Wave Simulations

This was simulated using the DELFT3D-WAVE (SWAN) refraction module. The results were coupled to the DELFT3D-FLOW hydrodynamic module to simulate the wave-driven currents in addition to wind-driven and tidal currents.

The following processes need to be accounted for to transform a deep water incident wave condition to the local conditions within the bay:

- refraction (*i.e.* change in wave direction in shallow water);
- depth-induced wave breaking;
- depth-induced shoaling (*i.e.* increase in wave height in shallow water); and
- bottom friction (*i.e.* seabed effects that reduce the wave height).

5.3.1 Description of the Wave Model

The third-generation wave generation and refraction model SWAN (Simulating Waves Nearshore) was applied (Booij *et al.*, 1999). SWAN is run within the DELFT3D-WAVE environment (Deltares, 2011a), which provides a convenient interface for pre- and post-processing and for including wave-current interactions.

The SWAN model is based on the discrete spectral action balance equation and is fully spectral (in all directions and frequency), implying that short-crested random wave fields propagating simultaneously from widely different sources can be accommodated (*e.g.* a swell with superimposed wind sea). SWAN computes the evolution of random, short-crested waves in coastal regions with deep, intermediate and shallow water and ambient currents. The SWAN model accounts for refractive propagation due to currents and depth and is capable of representing the processes of wave generation by wind, dissipation by white capping, bottom friction and depth-limited wave breaking and non-linear wave-wave interactions (quadruplets and triads) explicitly with state-of-the-art formulations. Wave blocking by currents is also explicitly represented in the model. Diffraction (*i.e.* the lateral transfer of energy along the wave crest) is not explicitly modelled in SWAN.

5.3.2 Model Set-up

The computational grid, bathymetry and wave conditions used in the wave model simulations are described in detail below.

Computational grids

For the wave modelling, two computational grids were used. The larger outer computational grid (Figures 5.1 and 5.2) extended beyond the limits of the hydrodynamic model, both to ensure that i) wave conditions were available over the full extent of the hydrodynamic model and ii) that the wave conditions at the offshore boundary are applied in water depths where refraction has not yet occurred. The lateral boundaries are also located far from the region of interest to prevent inaccuracies in boundary conditions affecting the calculations in the area of interest.

Where the grid used by Delft3D-WAVE overlaps that of Delft3D-FLOW, the computational grids from the two modules are exactly the same (i.e. the nested wave grid and the hydrodynamic flow grid are the same. The advantage of using the same grid for the wave and flow simulations (Figure 5.3) is that there is no loss of information due to interpolation between the different modules because the Delft3D-FLOW grid coincides with the Delft3D-WAVE grid.

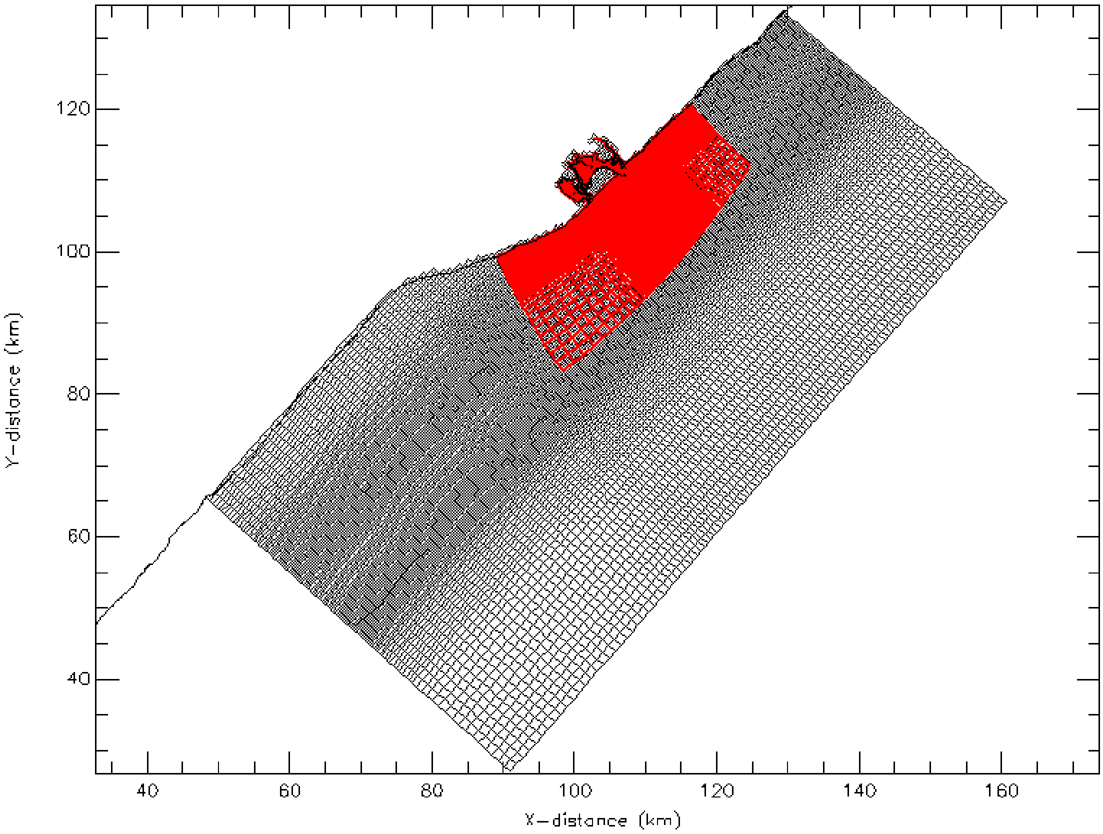

Figure 5.1: **Large computation grid (black) and the nested higher resolution wave grid (red) used in the wave model simulations. This nested wave grid is the same as that used in the FLOW modelling.**

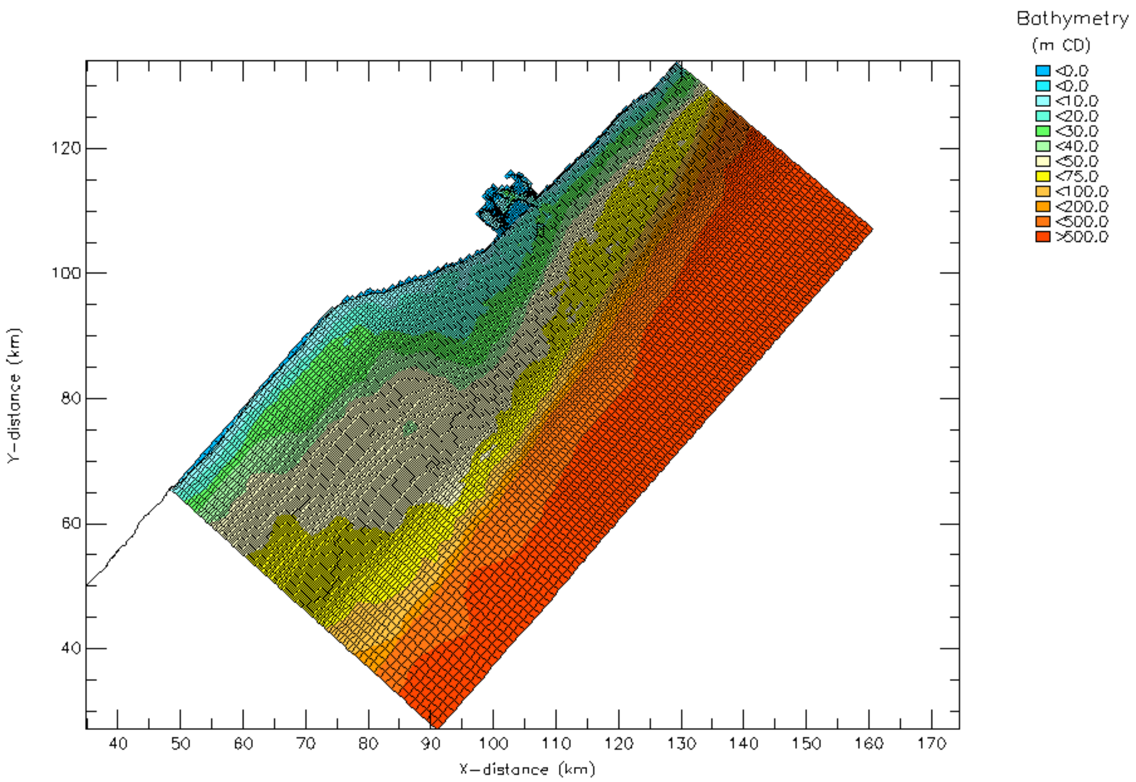

Figure 5.2: Large computational grid used for the wave model simulations.

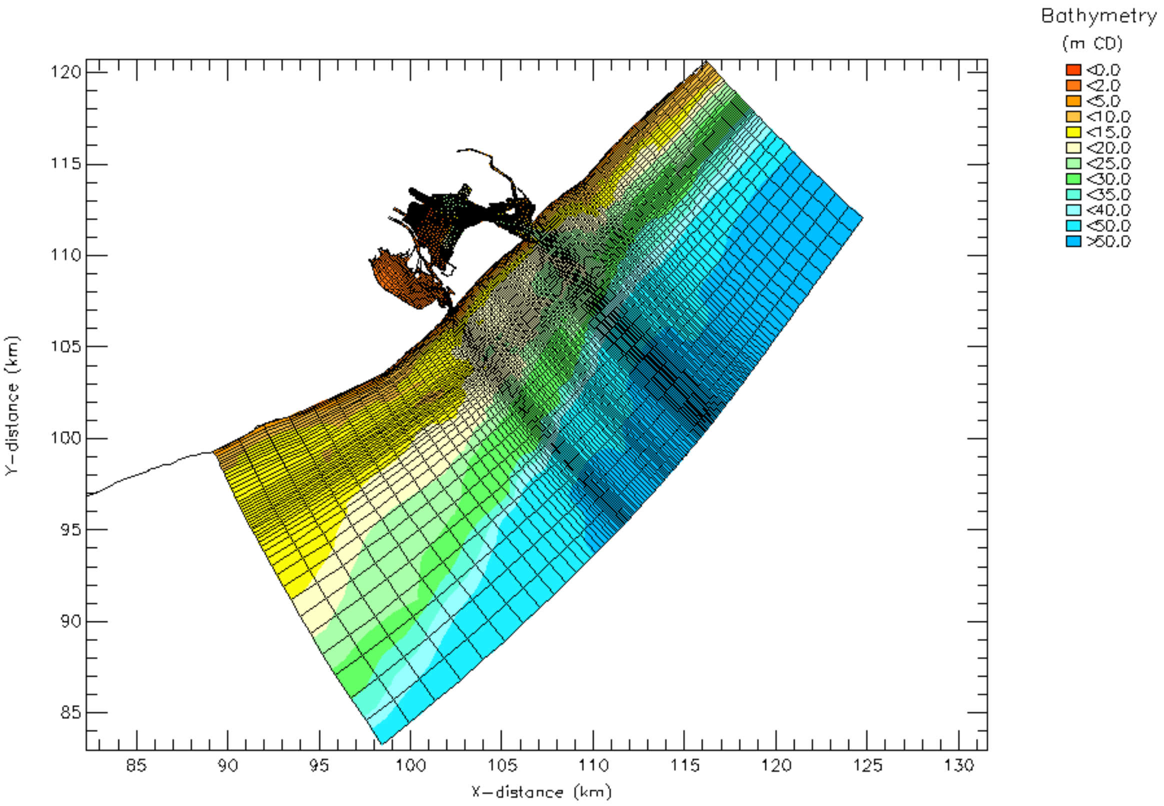

Figure 5.3: Computational grid used for the nested wave and also the FLOW model simulations.

Computational grids

The bathymetry used in the large wave grid is presented in Figure 5.4, while that used in the nested wave and flow computational grid are presented in Figures 5.5 and 5.6 below.

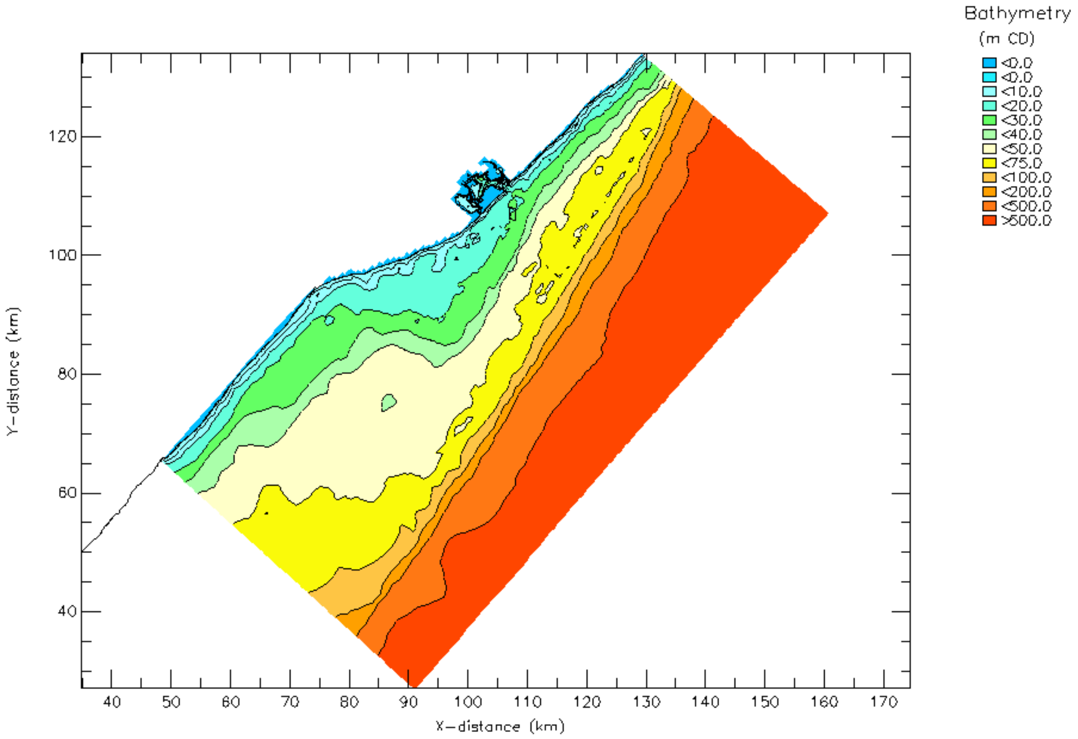

Figure 5.3: **Bathymetry used for the large computational grid utilised for the wave modelling.**

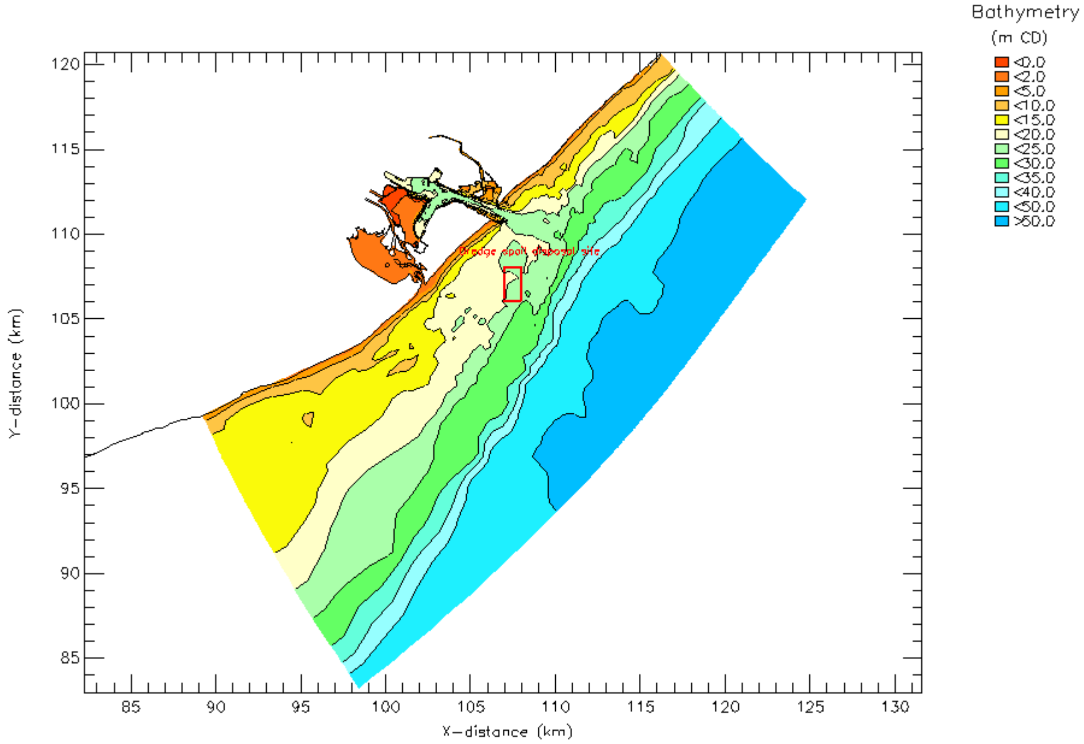

Figure 5.4: **Bathymetry used in the computational grid utilised for the nested wave and also the FLOW model simulations.**

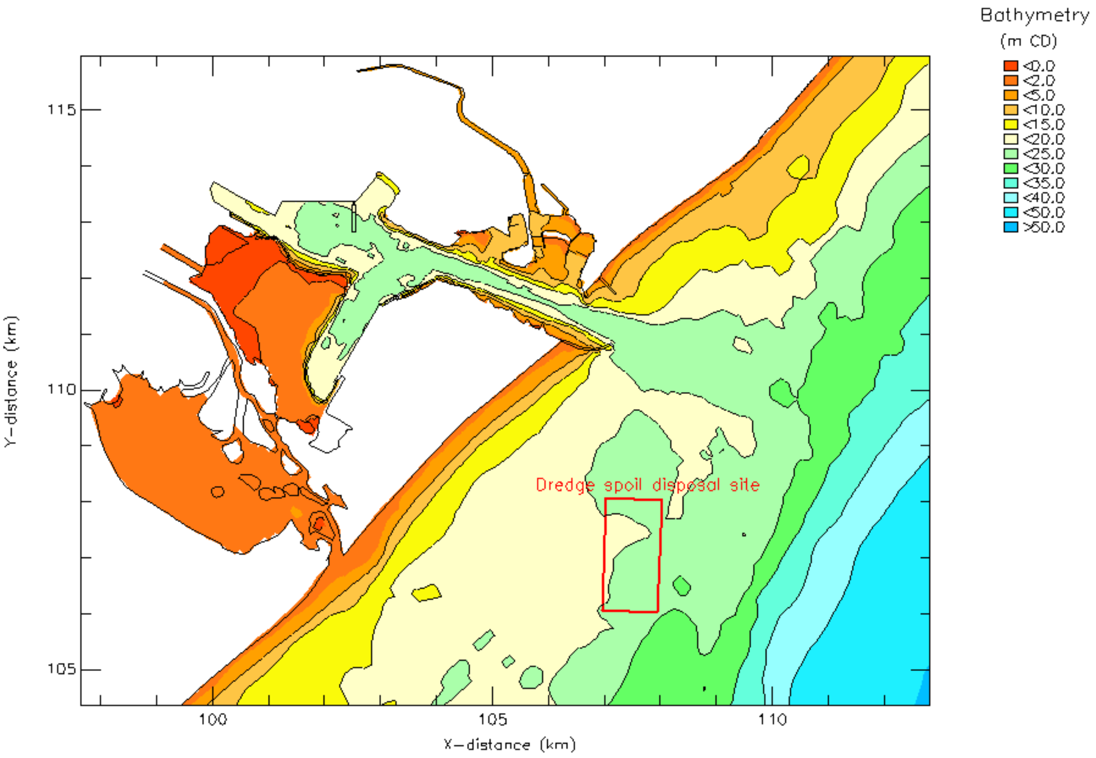

Figure 5.5: **Zoomed in view of the bathymetry used in the computational grid utilised for the nested wave and also the FLOW model simulations.**

Offshore wave conditions

To execute Delft3D-WAVE, the model requires an offshore wave climate. For the modelling, initially wave data obtained from National Centre for Environmental Prediction (NCEP) for the offshore location 29.0 S; 32.5 E was used in the modelling study, this being the closest NCEP data point to Richards Bay. However it proved difficult to calibrate the wave model using these data. The data used for the model calibrations were those measured for the IPOSS systems at a location some 2 km south of the southern breakwater of the Port of Richards Bay (see Figure 3.8 for the location of these measurements).

A more detailed analysis of the model results using the NCEP wave forcing indicated a number of reasons for the deficiencies in the wave model calibrations. These included the fact that the NCEP wave data tended to indicate peak wave periods that often were substantially less than those indicated in the calibration times series, i.e. the NCEP data often underestimates the peak wave periods. Furthermore the NCEP data contained much more easterly wave energy than is suggested by the measured data.

For this reason the wave modelling was re-commenced using a different approach. This approach is that used in a number of the previous studies where a database of model results is developed by running all possible offshore wave conditions that could lead to the wave characteristics measured at the IPOSS wave buoy calibration time series measurement point. A look up table was then developed that allowed the synthesis of an appropriate wave time series to apply at the model boundary that would result in the modelled data at the IPOSS wave buoy time series measurement point matching the measured data.
There are a few limitations associated with this approach (*e.g*. there is a degree of grid dependency in this approach. Measured wave data need to be available for the duration of the model simulations, *etc.*). However, provided that the computational domains are well designed and the look-up table is sufficiently comprehensive, the advantages of using such an approach far exceed an approach using the somewhat

deficient NCEP wave data. The most important consideration being that this approach ensures the temporal accuracy of the wave heights and periods at the dredge disposal site which is important to this study.

5.3.3 Model Calibration

Time series of the modelled wave characteristics and measured data at the IPOSS wave buoy measurement location are plotted in Figures 5.6 to 5.11 below. These data indicate a close correspondence between the modelled and measured data however a few small discrepancies do occur. These discrepancies are associated mostly with occasions when the winds swing rapidly from northeasterly to southwesterly (*i.e.* the southwesterly buster). During this transition, the intermediate period NE waves (i.e. swell with short to medium wavelengths) cease and there exists a very short period when the measured waves comprise local seas from the SW generated by the high winds. These quickly give way to long period SW swell. The look-up table method is not well-suited to handling this short period wave energy from the SW. It is generally under these circumstances that there exists a discrepancy between the modelled results and the measured data. The wave input times series at the open boundaries of the wave model needed to be adjusted to ensure accurate wave predictions under these circumstances. It should be noted that these differences in predicted wave height and direction generally occur only for peak wave periods< 6 seconds. The contribution of these short period waves to the generation of the near bottom turbulence that causes sediment re-suspension at the dredge spoil disposal site is negligible. Thus any discrepancies that occur between the modelled and measured wave for these short periods when wave heights are dominated by locally wind generated sea, are not deemed to be of great concern for the present study.

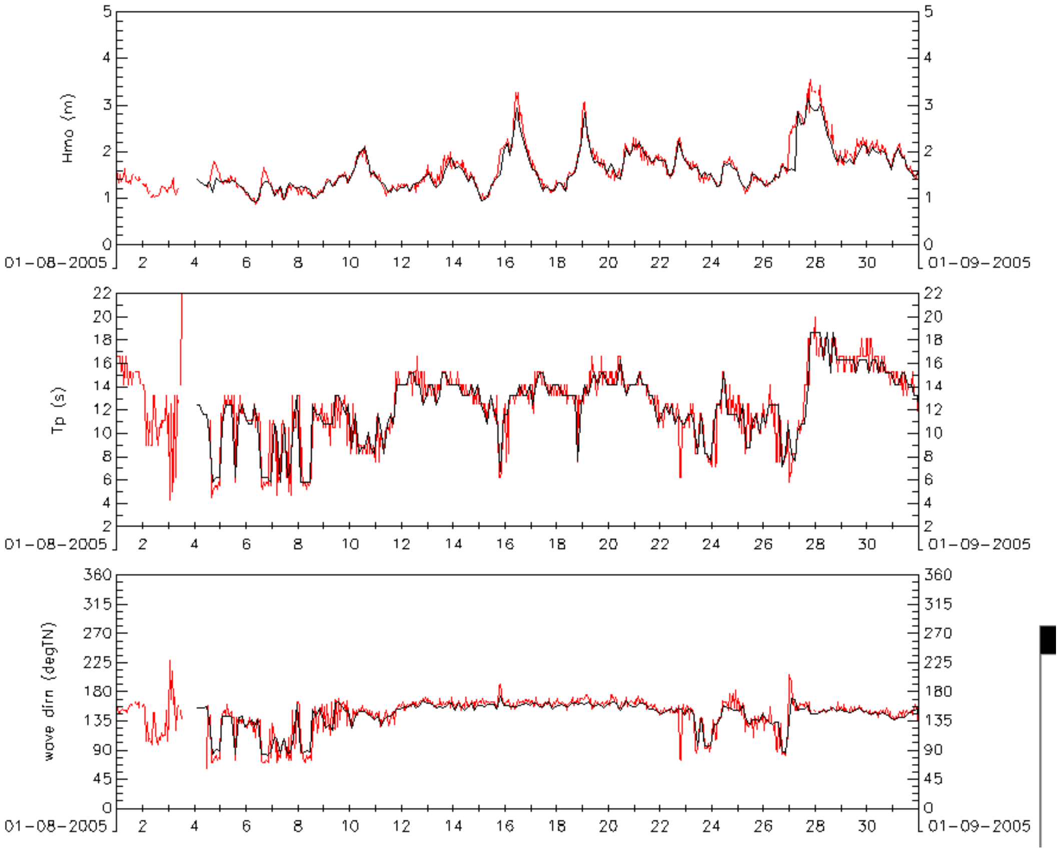

Figure 5.6: **Comparison between the measured (red) and modelled (black) wave parameters at the IPOSS wave buoy location (see Figure 3.8 for the location) for August 2005.**

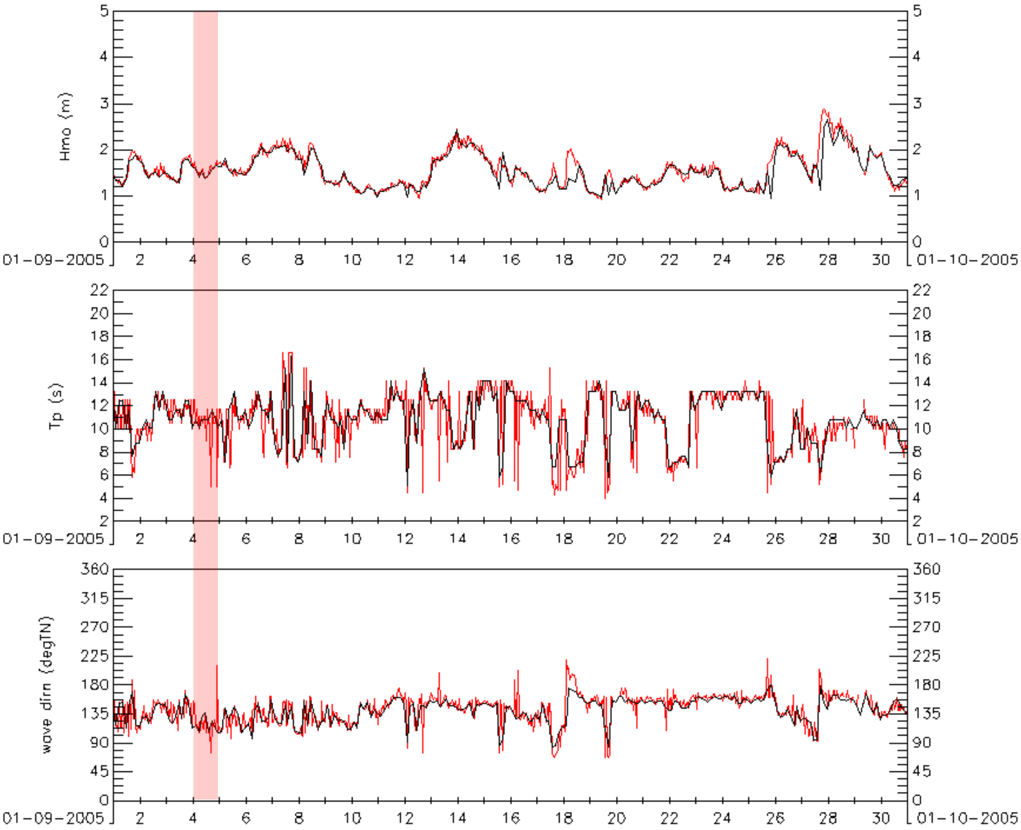

Figure 5.7: Comparison between the measured (red) and modelled (black) wave parameters at the IPOSS wave buoy location (see Figure 3.8 for the location) for September 2005.

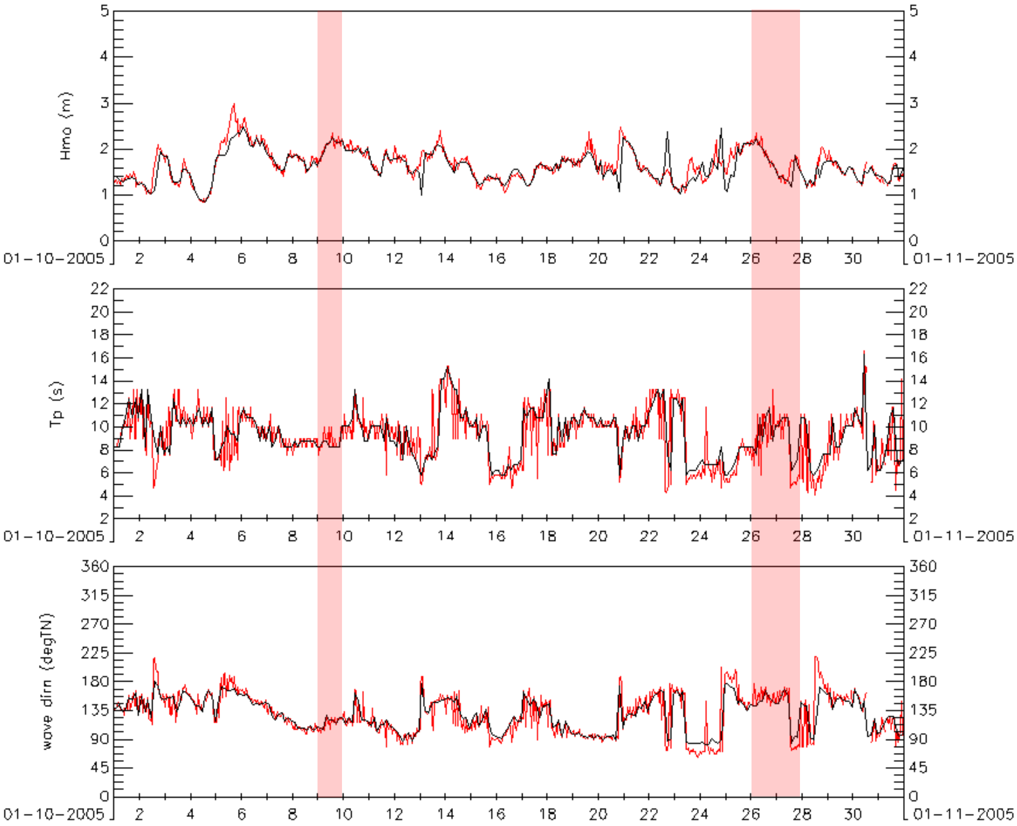

Figure 5.8: Comparison between the measured (red) and modelled (black) wave parameters at the IPOSS wave buoy location (see Figure 3.8 for the location) for October 2005.

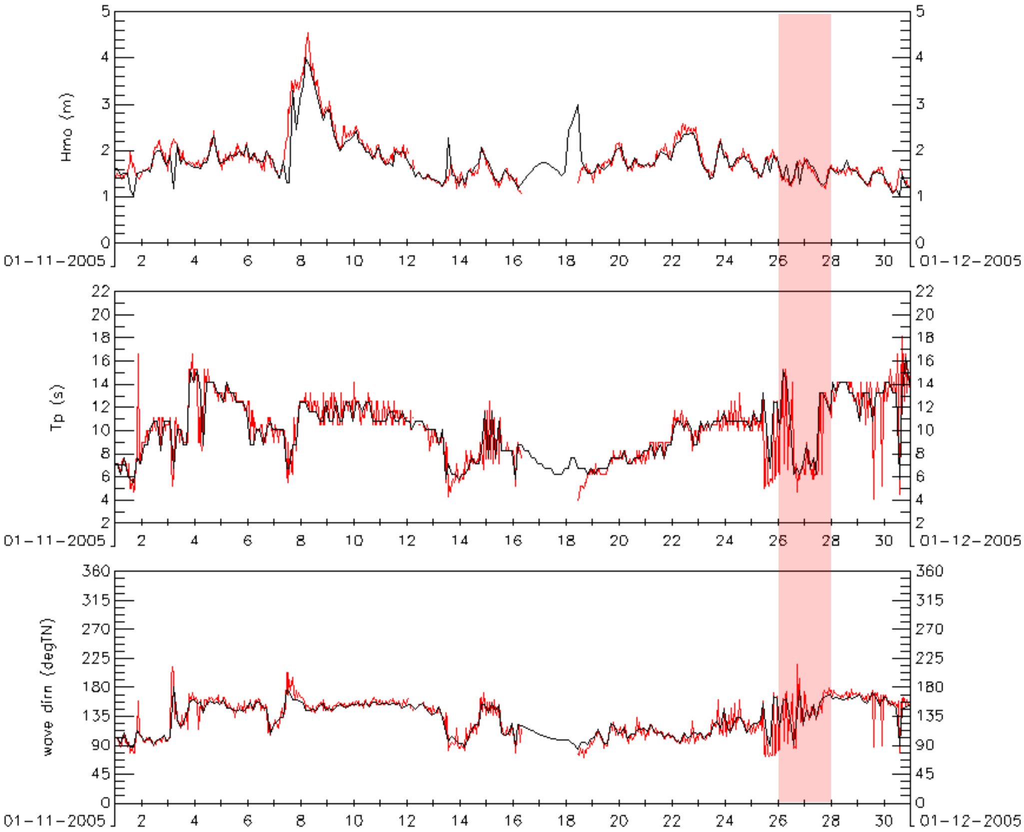

Figure 5.9: **Comparison between the measured (red) and modelled (black) wave parameters at the IPOSS wave buoy location (see Figure 3.8 for the location) for November 2005.**

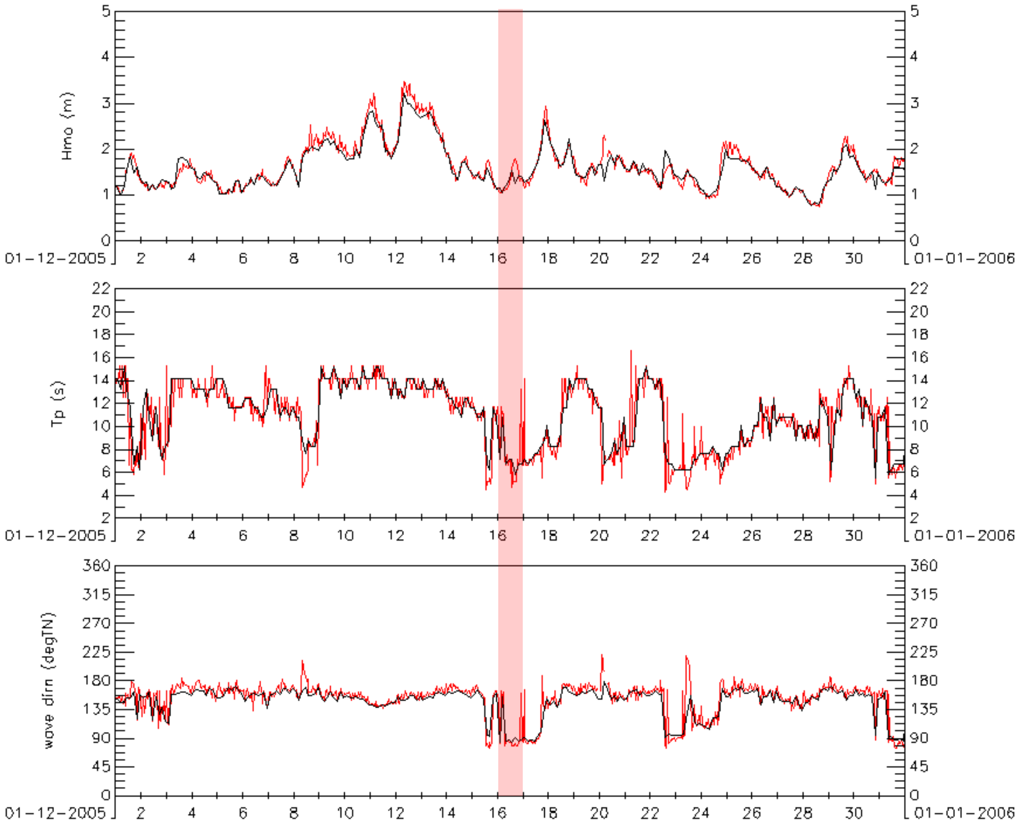

Figure 5.10: **Comparison between the measured (red) and modelled (black) wave parameters at the IPOSS wave buoy location (see Figure 3.8 for the location) for December 2005.**

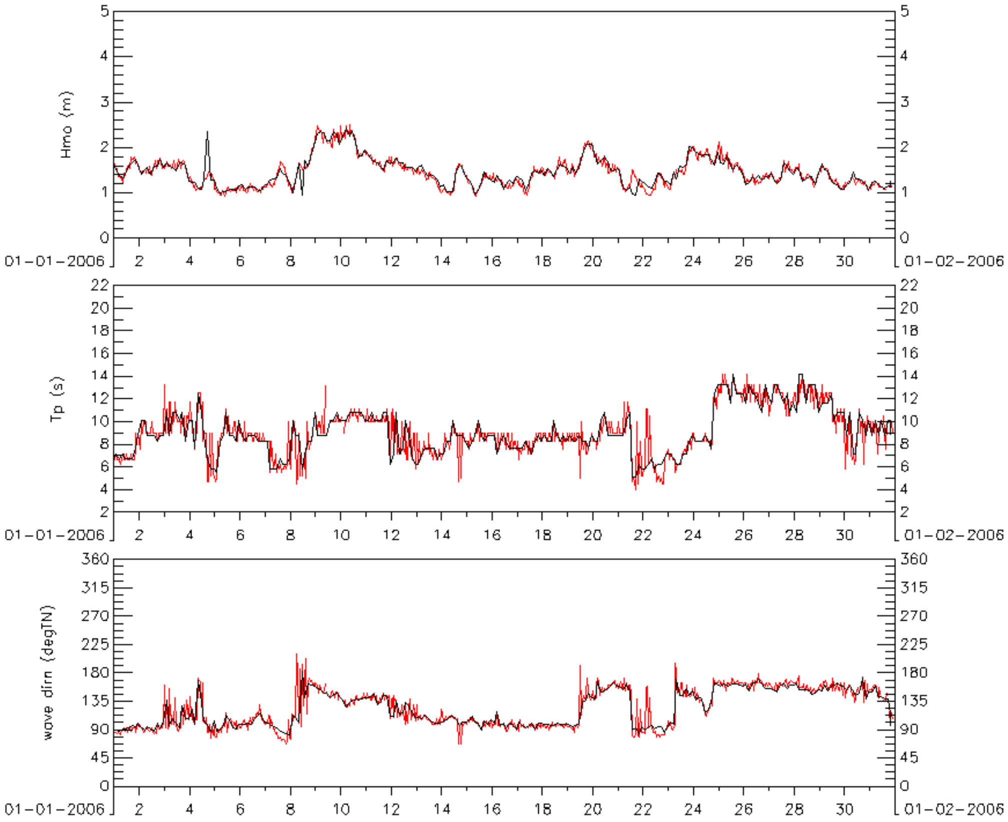

Figure 5.10: **Comparison between the measured (red) and modelled (black) wave parameters at the IPOSS wave buoy location (see Figure 3.8 for the location) for January 2006.**

Note: Indicated on Figures 5.6 to 5.11 as vertical shaded areas are the dates of the offshore profile sampling that took place as part of the Berth 306 dredge monitoring programme. It is notable that, except for the sampling of 26 to 27 October 2005, all of sampling took place at periods of low or relatively low wave conditions. This has implications for the use of solely the profiling data to develop an environmental baseline and/or turbidity thresholds for the dredge monitoring compliance programme (see discussion in section 3.8.2 of this report).

5.4 Hydrodynamic Simulations

The objective of the flow modelling is to accurately simulate the flow both within the Port of Richards Bay and those in the offshore region that will influence the re-suspension and re-distribution of sediments from the dredge spoil disposal site. Considering that the main aspects forcing water movement are wind, waves, tides, the Agulhas Current and to a lesser extent water column stratification, the following processes need to be adequately simulated in the hydrodynamic model:

- tidal forcing;
- wind forcing;
- wave forcing in the surf-zone;
- the influence of the Agulhas Current;
- baroclinic effects (*i.e.* currents and vertical mixing) insofar as they affect vertical shear in horizontal velocities;
- the effect of the earth's rotation (Coriolis force); and
- combined bed shear stresses due to currents and waves.

Since many of these processes are strongly three-dimensional, a three-dimensional hydrodynamic model is required, as described below. Note however that stratification effects are not directly simulated in the model.

5.4.1 Description of the Hydrodynamic Model

Delft3D-FLOW (Lesser *et al.*, 2004) is a three-dimensional hydrodynamic model that includes formulations and equations that take into account the processes listed above.

The system of equations in Delft3D-FLOW comprise the horizontal momentum equations and the continuity equation, the equation of state and the advection-diffusion equation for heat, salt and other conservative tracers which are solved using the Alternating Direct Implicit scheme. Vertical turbulence is modelled using the k-ε turbulence closure model. The computation grid used in the flow modelling is the same as the nested grid used in the wave modelling (Figure 5.3) and comprises an irregularly-spaced, orthogonal, curvilinear grid in the horizontal and a sigma coordinate grid in the vertical.

The equations and their numerical implementation are described in Lesser *et al*. (2004). The wave forcing is obtained from the wave energy dissipation rate computed by the wave refraction model. Enhanced bed stresses due to wave effects are incorporated in the model using the friction formulation of Fredsøe (1984).

5.4.2 Model Set-up

The hydrodynamic grid has been refined in the vicinity of the mouth of both the Umhlatuze Estuary and the Port of Richards Bay. In addition the resolution of the grid has been increased over the dredge spoil disposal site. The grid resolution along the shoreline has also been increases to allow for the better representation of surf-zone currents.

The grid includes the future port layout rather than the existing port layout. This may lead to small inaccuracies in model results in the port. However, there was a need to select either a present or the future layouts for the model simulations. The latter was chosen.

Table 5.1: Hydrodynamic model parameters.

Parameter	Value
Background Agulhas Current	as per measured data
Wind drag coefficient (C_d) at 0 m/s at 100 m/s	0.0011 0.0065
Constant salinity	35.2 ppt
Horizontal eddy viscosity	1 $m^2.s^{-1}$
Background vertical eddy viscosity	0.000 001 $m^2.s^{-1}$
Horizontal eddy diffusivity	1 $m^2.s^{-1}$
Background vertical eddy diffusivity	0.000 001 $m^2.s^{-1}$
Bed friction formulation	White-Colebrook
Nikuradse roughness length (k_s)	Spatially varying mostly 0.03 m but increasing to 0.05 in the Umhlatuze Estuary and in the vicinity of the estuary mouth
Correction for sigma coordinates	Off
Horizontal Forester filter	On
Vertical Forester filter	Off
Time step	1 minute

The winds measured at the extremity of the southern breakwater were used to force the model. High resolution "jitter" in these data were removed by using a 5 point Hanning filter. Measured currents from the ADCP deployed as part of the Berth 306 monitoring programme were also utilised to force the model. The water levels at the open boundaries of the model were calculated using a "reduced physics" approach that allows the currents at the ADCP measurement site to be retrieved from the model simulations (Shabangu, 2015). The tidal component of the water level imposed at the open boundary of the model comprises the predicted tide using constituents previously supplied by the South African Navy Hydrographic Office.

Both salinity and temperature were assumed to be constant in the model.

5.4.3 Model Calibration

Data that was utilised for calibration comprises the current measurements measured (in an approximate 20 m water depth) to the southwest of the dredge spoil disposal site during the Berth 306 Dredge Monitoring programme (Figure 5.11). The initial calibration of the model was undertaken without including wave effects. The calibration was relatively straightforward. However once the waves were included in the flow model results, the calibrations deteriorated somewhat due to the influence of the wave of the bottom friction in the flow model. The inclusion of the waves required that the model be re-calibrated taking into account these wave effects.

Comparisons of the measured and modelled currents at the ADCP site are plotted in Figures 5.12 to 5.14. The current speeds are presented as northerly and easterly components of the measured and modelled currents at an approximate 13 m water depth (i.e. the depth most likely to represent the depth integrated flow).

Figure 5.11: Location of the ADCP measurements used both to force and calibrated the hydrodynamic model.

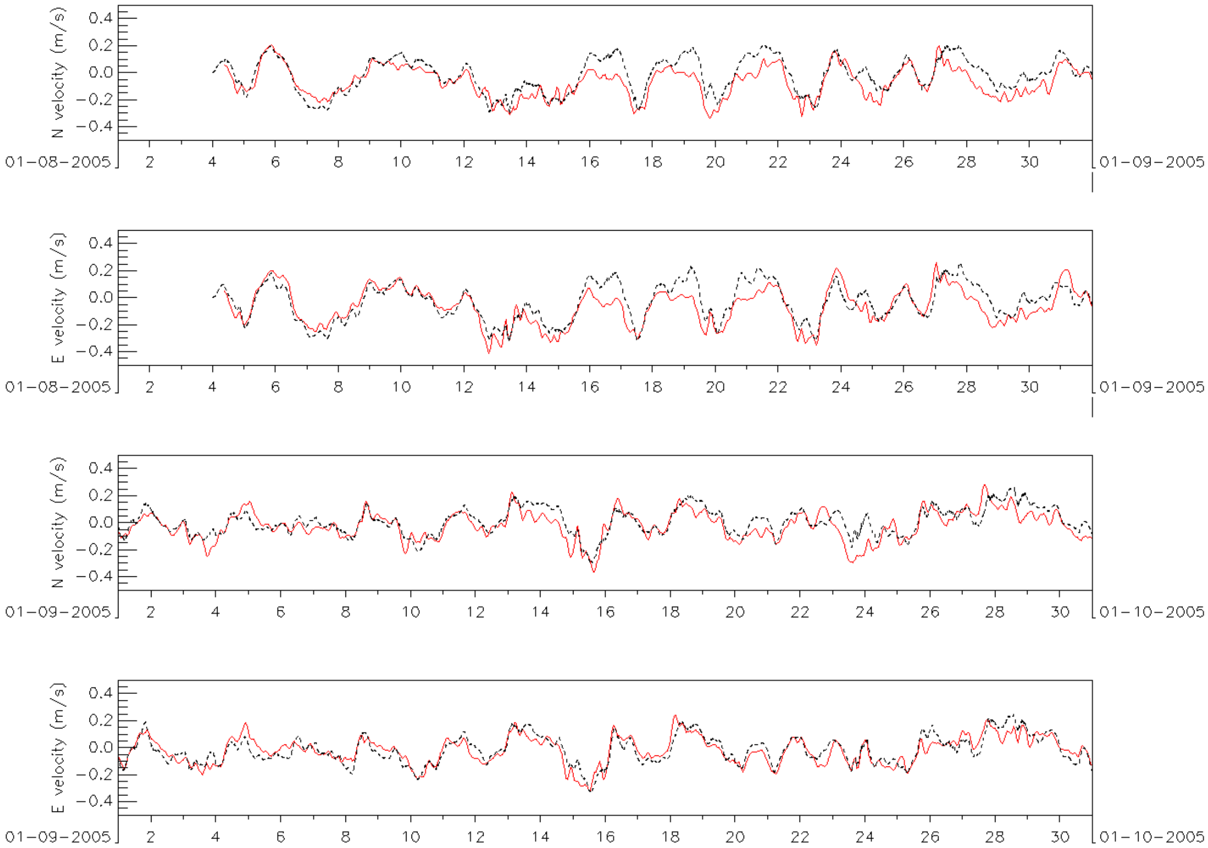

Figure 5.12: Comparison of the measured (red line) and modelled (dotted black line) at a 13m water depth at the ADCP location for the months of August and September 2005.

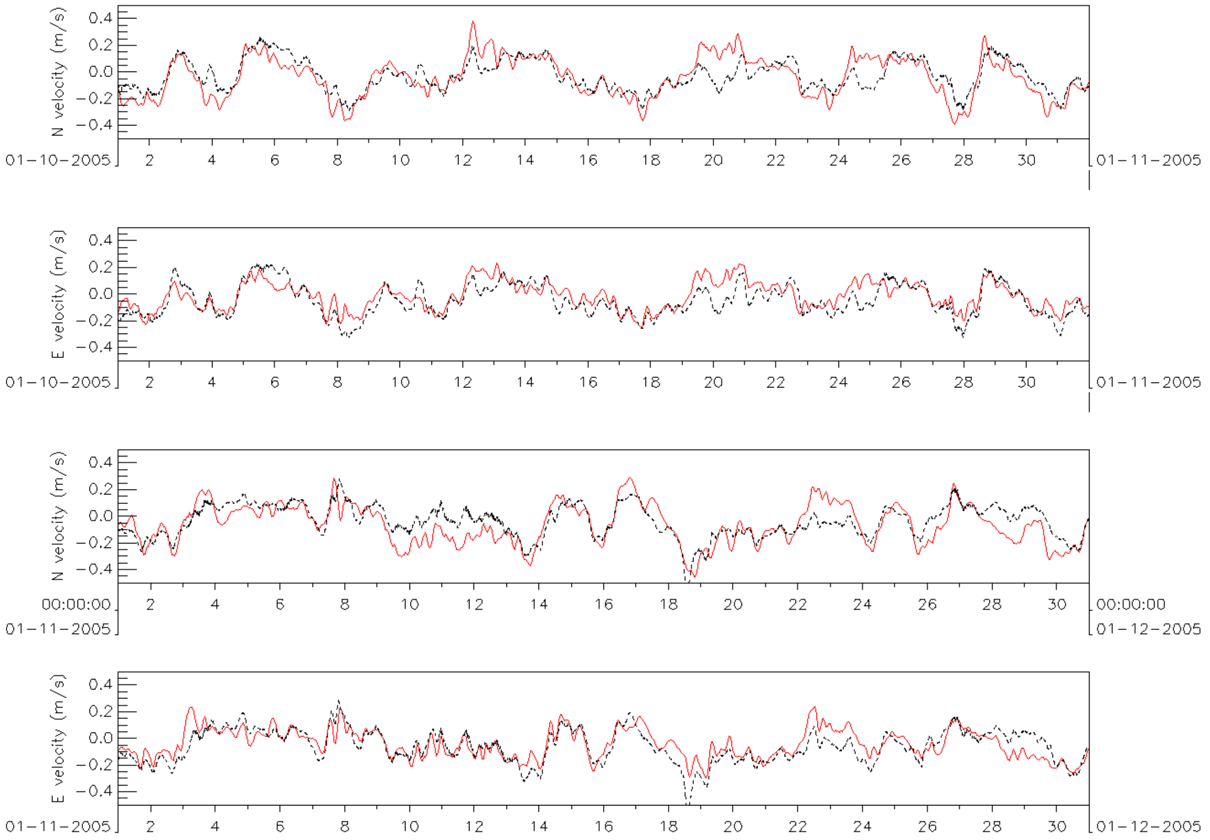

Figure 5.13: Comparison of the measured (red line) and modelled (dotted black line) at a 13m water depth at the ADCP location for the months of October and November 2005.

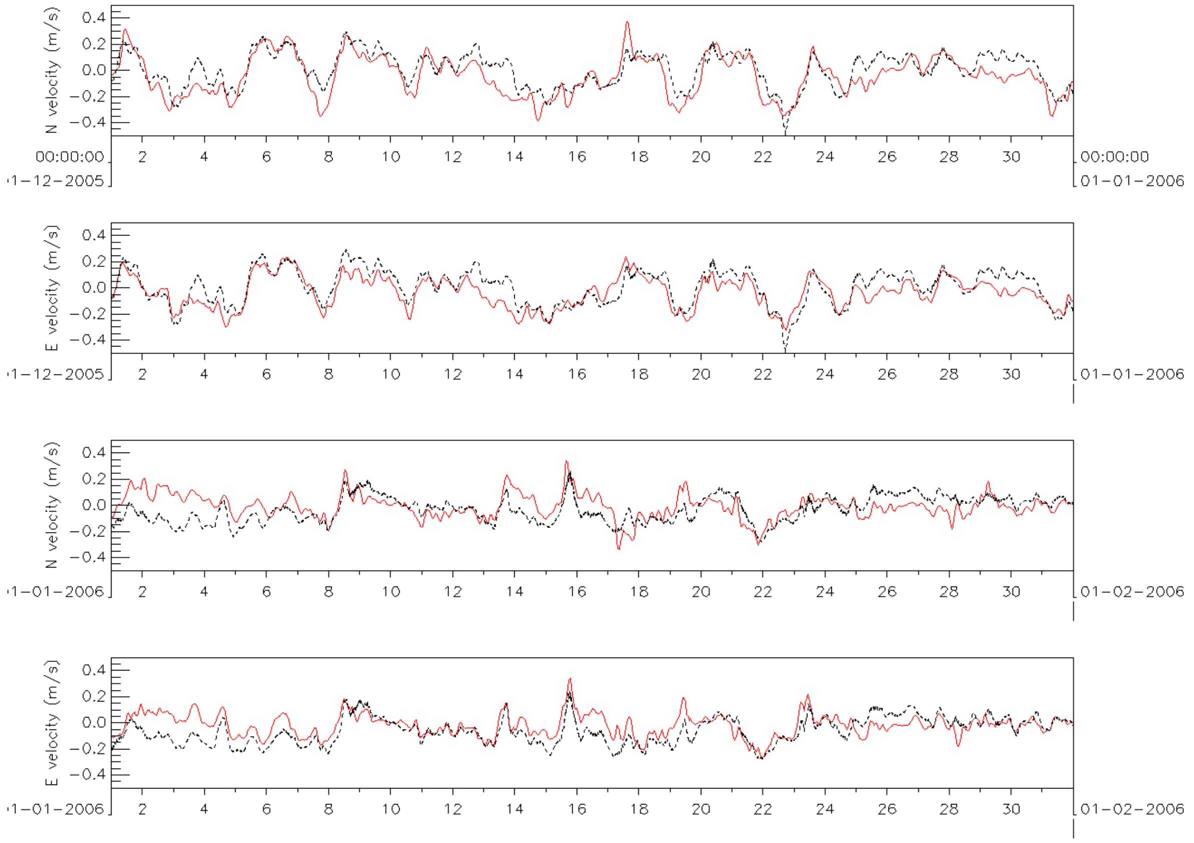

Figure 5.14: Comparison of the measured (red line) and modelled (dotted black line) at a 13m water depth at the ADCP location for the months of December 2005 and January 2006.

The measured and modelled currents compare well except for a few occasions were the modelled over-predicted the magnitude of the northeasterly wind-driven flows and a couple of occasions where the modelled currents underpredicted the southwesterly flows most probably due to the influence of the Agulhas Current.

There exists no bias in representing eth more extreme flows which are the most likely to affect sediment re-suspension and subsequent advection. The model therefore is deemed adequate for the purposes of simulation water column turbidity and the movement of dredge spoil in the offshore environment.

5.5 Sediment Transport Simulations

The Delft3D morphological capability of DELFT3D-FLOW (Deltares, 2011b) integrates the results of the Delft3D-WAVE and Delft3D-FLOW hydrodynamic models to determine sediment concentrations, sediment transport rates (suspended and bedload) and morphology of cohesive and non-cohesive sediments. In the present study the model was applied in fully three-dimensional-horizontal mode, but the feature to dynamically update the bed during simulation was not used.

5.5.1 Description of the Sediment Transport Model

A very clear and logical discussion of Delft3D-Online-SED is presented by Lesser *et al*. (2004). Additional information regarding the transport of cohesive sediments is presented by Van Ledden *et al.* (2004). The Delft3D-Online-SED morphological model forms part of the Delft3D-FLOW model and the local velocities and eddy diffusivities are based on the results of the hydrodynamic computations. Computationally, the three-dimensional transport of sediments is computed in a similar manner as the transport of any other conservative constituent such as heat and salinity. However, there are some critical differences between sediment and other constituents such as the exchange of sediment between the bed and the flow and the settling velocity of sediment under the action of gravity. The sediment also has an effect on the local mixture density and may cause turbulence damping. In the Delft3D-Online-SED module these processes are described by different formulations depending on whether one is modelling cohesive or non-cohesive fractions.

Some of the processes and features of the Delft3D-Online-SED are:

- Cohesive and non-cohesive sediment fractions may be modelled separately and/or simultaneously;
- Suspended and bed load transport of non-cohesive sediments are computed using Van Rijn's (1993) approach;
- The standard Delft3D-FLOW advection-diffusion solver is used for the transport of the suspended sediment;
- The bed-load is adjusted for bed slope effects;
- For cohesive sediment fractions (*e.g.* mud) the fluxes between the water phase and the bed are calculated from the well-known Partheniades-Krone formulations (Partheniades, 1965);
- Settling velocities are adapted due to hindered settling;
- The effect of flocculation of the cohesive sediment on the settling velocity is taken into account; and
- The effect of sediments concentrations on fluid density are included in the formulations.

A limitations of the present model implementation is that for the calculation of the deposited sediment thickness, the contribution from each fraction is considered independently from the other fractions.

5.5.2 Model set-up

The model grid for the calculation is the same as the three-dimensional hydrodynamic grid. The non-cohesive sediments that were considered consisted of rock and sand as non-cohesive sediments and mud as a cohesive fraction. The relevant input parameters used in the model are presented in Tables 5.2 and 5.3.

Table 5.2: Input parameters for non-cohesive fractions.

Parameters for sediment model	Gravel	Sand
Median grain size (D50)	2 000 µm (maximum)	15 µm
Van Rijn's reference height factor	1.0	1.0
Ripple height factor	2.0	2.0
Longshore bed gradient factor	1.0	1.0
Transverse bed gradient factor	1.5	1.5
Current-related reference concentration factor	0.8	0.8
Current-related transport vector magnitude factor	0.8	0.8
Wave-related suspended transport vector	1.0	1.0
Wave-related bedload transport factor	1.0	1.0
Minimum depth for sediment calculations	1.0 m	1.0 m
Dry cell erosion factor	0.0	0.0

The settling, deposition and re-suspension behaviour of the material is characterised by the settling velocity, the critical shear stress for deposition, the critical shear stress for re-suspension, and the re-suspension rate. While settling velocities can be measured relatively easily, the remaining parameters are significantly more difficult to measure experimentally.

In determining the sediment parameters listed in Table 5.3, provision was made for the different influences of silt and clay on the behaviour of the mud. The critical shear stress for erosion of muds increases (up to a factor of 2) with the addition of sand and reaches a maximum for approximately 50% sand (Mitchener and Torfs, 1996; Dankers, 2000). The addition of sand to muds also may dramatically reduce the erosion rate from the seabed (Mitchener and Torfs, 1996). However here the sand fraction (4%) in the material to be dredged is very small. If only sand and muds are considered (i.e. rock is excluded), the sand fraction increases to approximately 10% of the material to be dredged.

During disposal of large volumes of dredge material, the bottom layers of the cohesive sediments may initially settle on the bed and will only be suspended after the surface mud has eroded. To simulate this process the critical shear stress for sedimentation selected is high.

The remainder of the sediment parameters have been based on those reported in the literature (Van Ledden *et al*., 2004; Dankers, 2000; Torfs *et al.*,1996; Mitchener and Torfs, 1996; Deltares, 2011; CSIR, 1995a,b, 2000). Specifically, the critical bed shear stress for erosion used in the modelling is based on the work of Van Ledden *et al.* (2004) and the concept that the dumped mud is unconsolidated and relatively loosely packed.

The erosion parameter has been calculated by considering the shear stresses where the erosion rate exactly balances the deposition rate for various sediment fall rates and critical bed shear stress for erosion parameters. This balance occurs when the shear stress is given by $\tau = \tau_{crit} + w_s C / M_E$

where

τ is the shear stress at the seabed (Pa)
τ_{crit} is the critical shear stress for erosion (Pa)
w_s is the settling velocity (m/s)
C is the sediment concentration (kg/m^3) and
M_E is the erosion rate.

By using the specified value of the settling velocity and critical shear stress for erosion selected above and by considering different sediment concentrations near the seabed, the erosion parameter has been selected so that net erosion from the seabed occurs for bottom shear stresses of 0.3-0.7 Pa for low suspended sediment concentrations near the seabed (~ 10 mg/ℓ) and >2.5 Pa for suspended concentrations of approximately 50 mg/ℓ at the seabed.

Table 5.4: Input parameters for cohesive sediment fractions.

Parameter for sediment model	Value
Settling velocity	0.5 mm/s
Critical bed shear stress for sedimentation	1000 Pa
Critical bed shear stress for erosion	0.25 Pa
Erosion parameter	0.00001 kg/m^2/s
Initial sediment thickness	0.0 m

Preliminary sensitivity tests based on one month model simulations indicated that the model results are relatively sensitive to the selected M_E values. The relevant model parameters selected are tabulated below. These parameters lie within those generally accepted for model studies such as this one (*i.e.* M_E = 10^{-6} to 10^{-4} kg/m^2/s and T_{crit} (erosion) = 0.1 to 0.3 Pa for unconsolidated and relatively loose muds in sand/mud mixtures).

The material that is deposited on the bottom will begin to consolidate, which is the process whereby the deposited grains are compacted under the influence of gravity, leading to the expulsion of the pore water and the increase in density of the material and a reduction in the deposition thickness. In order to compute the deposition thickness in the model, a typical consolidation condition after one month has been assumed. This is characterised by a porosity of 80%, a wet density of ~1350 kg/m^3 and a dry density of 530 kg/m^3 (Van Rijn, 1989). The sand and mud fractions were assumed to have dry weights of 1 460 and 465 kg/m^3 and porosities of 45% and 82%, respectively.

5.6 Dredging Scenarios

The dredging scenario assumed in the modelling is as follows:

- All dredging to be undertaken by a CSD and occurs at an effective dredging rate of 263 4 000 m^3 per week for a total duration of 18.7 weeks (131 days);
- Lean mixture overboard operations are allowed, resulting in a sediment loading rate of the dredging location of 13 kg dry material per m^3 of material dredged;
- A hopper barge size of ~3 700 m^3, resulting in approximately 21 hopper discharges at the dredge spoil disposal site per day for the duration of the dredging. Each hopper barge load contains 30% sediments, suggesting a dry density of sediments of 795 kg/m^3 in the hopper.

As motivated in Section 2.4.4, only the CSD dredging operation has been simulated as it constitutes a worst case dredging scenario. The model data can therefore be utilised to assess any other scenario that may come under consideration.

5.7 Assumptions and Limitations of the Modelling Study

The assumptions made in the modelling study and the limitations of the modelling study are as follows:

- The project description is as provided at the commencement of the study. Should this change significantly this may affect the model outcomes. An attempt has been made to keep the study sufficiently generic to ensure its validity should aspects of the project description change (i.e. the worst case scenario in terms of turbidity loading namely a CSD dredging operation has been assumed);
- There exists a degree of uncertainty around the exact quantity and nature of the material to be dredged. The quantities to be dredged have been calculated based on the areas to be dredged and both the existing digital terrain model for the terrestrial areas and the bathymetry of the marine areas. The size distribution and nature of the material to be dredged is based the FEL-2 Marine engineering report and subsequent communications with project team. The assumed size distribution and type of material to be dredged are summarised in Table 2.3. It has been assumed that 48% of the material to be dredged comprises fines. Should the fines in the material to be dredged exceed 4835% then the results may not be appropriately conservative.
- The model calibration is adequate for the purposes of this study. To the extent that there exist discrepancies between measured data and modelled result, the discrepancies, in general, result in a more conservative assessment (i.e. flows are over-predicted leading to greater potential for –re-suspension of sediments and therefore elevated water column turbidity.
- The assumed behaviour of sediment in the model is based on a number of parameterisations that have associated with them a degree of uncertainty. These parameters have been selected based on observed water column turbidity measurements of a previous capital dredging operation in the region (Berth 306 development in 2005 to 2006) that suggested a much lower rate of re-suspension of sediments and re-distribution of dredge spoil from the offshore dredge spoil disposal site. Model sensitivity studies indicate that changes in the modelling outcomes using a range of probable parameterisations are of a nature that they are unlikely to affect significantly the conclusions drawn from the analyses of the model results.

6 MODEL RESULTS

The model results have been analysed and presented in a manner suitable to inform the impact assessment undertaken in the Marine Ecology specialist studies (MER, 2013, Cyrus 2014a,b), as well as additional impacts considered in this report.

6.1 Visual Impacts

In terms of aesthetic or visual impacts it is the visibility of sediment plumes that are of concern. The plumes may be visible at the dredge spoil disposal site and will be visible around the dredger in the port.

In Section 4 a conservative guideline of 10 mg/ℓ elevation in suspended sediments in the upper water column has been assumed for a threshold above which plumes are likely to be visible in the marine environment. Extending the conservative approach we have assessed the number of days that the suspended solid concentration in the surface waters exceeds 10 mg/ℓ. As the model results do not include background turbidity, in reality it is assumed that plumes become visible when the suspended sediment concentrations are increased by 10 mg/ℓ or more above background levels. The same threshold is assumed for both offshore waters and the Port of Richards Bay and surrounds. The model results are presented as contours of the number of days per season that the suspended sediment concentrations in the surface waters are increased by 10 mg/ℓ or more above background. A season is considered to have a duration of approximately 3 months (or 90 days). Given that the model simulations for CSD dredging operations have a duration of approximately 5 months, the total number of days of exceedance of the thresholds indicated will therefore be approximately twice that reported in the figures contained in this report when the full 6 month period is considered. One of the reasons for reporting the results as days of exceedance of a threshold is that this enables impacts to be assessed should the dredging durations be different to those simulated in this modelling study.

The days of exceedance of a 10 mg/ℓ threshold at the sea surface in the Port of Richards Bay, reported in Figures 6.1, indicate that visual impacts from the dredging activities will be limited to the confines of the port, and then mostly to the area being dredged. This is somewhat of an unexpected result. However, the dredging activities are confined to the inner recesses of the port, where tidal and other wind-driven flows are minimal providing limited opportunity for the spread of turbid waters. The visual impacts in the port, although not continuous, will persist on and off for at least the duration of dredging activities.

It is likely that it will be difficult to discern the visual plumes due to the dredging from other high turbidity in the port due to activities such as berthing activities. However what may occur is that the accumulation of fines on the seabed within the port may provide reservoir of fine material that would be easily re-suspended by shipping activities. Thus the normal elevations in turbidity due to shipping and berthing activities may be exacerbated by the dredging activities. Weerts (2008) provides evidence of such elevated water column turbidity due to shipping activities at the Richards Bay Coal terminal (Figure 6.2). These observations were made approximately two years after the capital dredging that was undertaken for the Berth 306 development. While it is tempting to attribute the severity of these elevated turbidity events to a legacy of the fines accumulated in the Richards Bay Coal Terminal basin during the capital dredging activities for the Berth 306 development, it should be noted that similar visual observations of elevated turbidity have been noted more recently (2014 and 2015) which are more difficult to attribute to previous capital dredging activities (Figure 6.3). Observations in other South African ports environments (Saldanha Bay), have suggested that the benthic sediments “recover“ from the elevated fines observed in the benthic sediments after capital dredging events typically over a period of approximately 5 years. This may not be the case in a more sheltered environment such as Richards Bay.

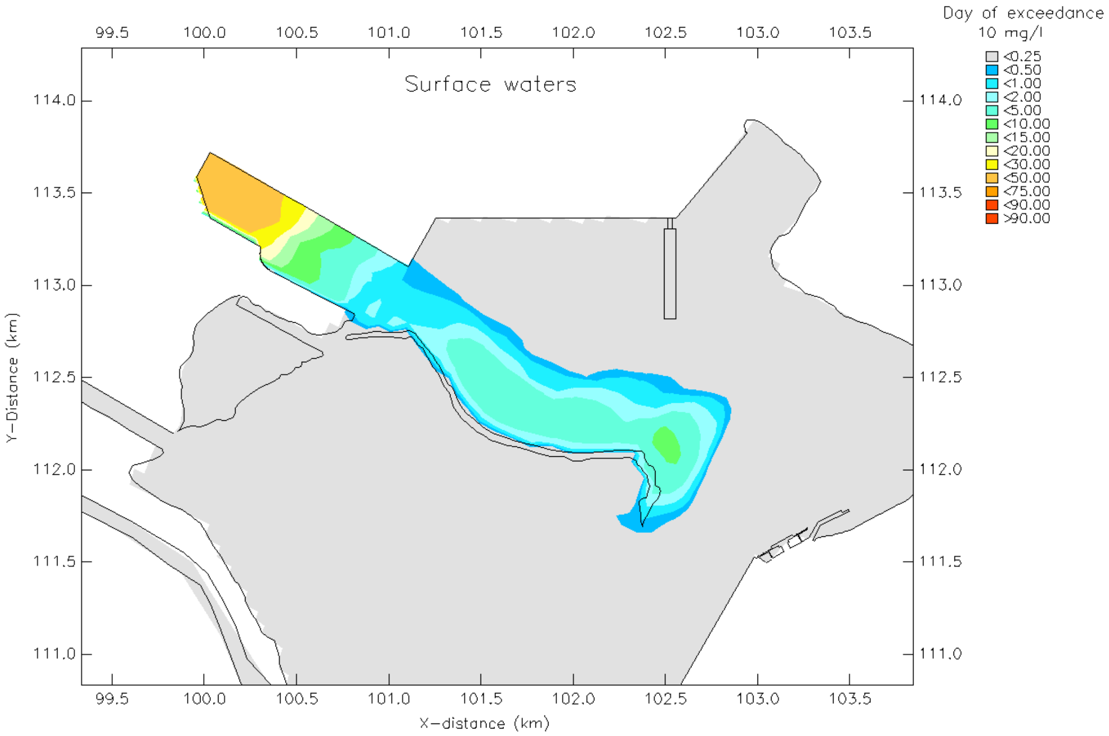

Figure 6.1: **Day of exceedance of a suspended sediment concentration of 10 mg/ℓ in the surface waters of the port.**

Figure 6.2: **Sediment driven into suspension by ship berthing activities in the coal basin in the Port of Richards Bay (photo taken 24th April 2008) (Source: Weerts (2008)).**

Figure 6.3: **Sediment driven into suspension by ship berthing activities in the coal basin (upper panel) in the Port of Richards Bay (GoogleEarth image: 3 May 2014) and in the entrance channel (lower panel) of the Port of Richards Bay (GoogleEarth image: 5 May 2015).**

Further offshore there is predicted to be discoloration of the surface waters over a fairly extensive region (Figure 6.4), the duration being up to approximately 50% of the time both in the immediate vicinity of the dredge spoil disposal site and extending 2 km or more both to the SW and NE. It is however expected that the discoloration of the surface waters will decrease significantly when dredge spoil disposal operations cease. Significantly elevated turbidity in the surface layers would only be expected during storm conditions. The discoloration of nearshore waters due to the dredging operations is predicted not too exceed 30 days in a season except for the nearshore and surf-zone waters of the Central Beach. The discoloration (> 10 mg/ℓ) of the surface waters at the entrance to the Mhlatuze estuary and the port entrance is predicted to be minimal and not exceed 5 days per season.

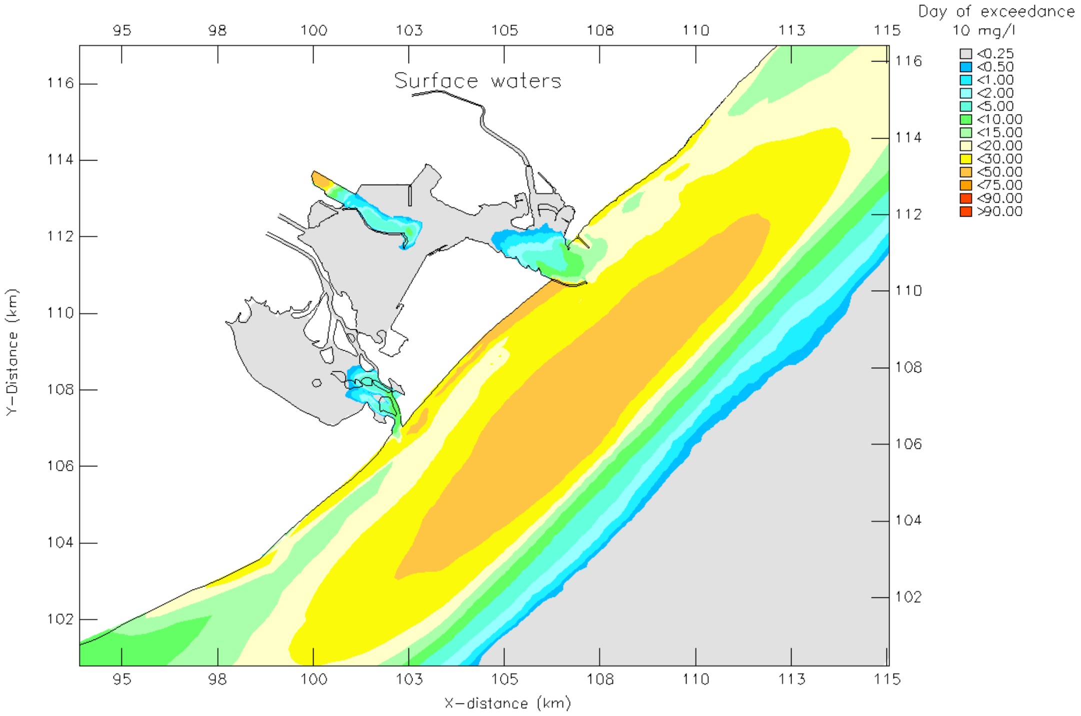

Figure 6.2: **Day of exceedance of a suspended sediment concentration of 10 mg/ℓ in the surface waters offshore of the Port of Richards Bay.**

Figure 6.3: **Elevated water column turbidity due to dredging activities at the port entrance and re-suspension of sediments in the nearshore environment (Photo courtesy of Mr C.J. Ward as reported in Weerts (2008)).**

In terms of visual impacts, most of the time it will not be able to easily discern these predicted impacts from the already high turbidity events occurring in the region, *i.e.* the turbid inflows into the Mhlatuze Estuary (Figure 6.4), the nearshore turbidity from shoreline erosion to the north of the port, as well as the turbidity associated with ongoing maintenance dredging (Figures 6.3 and 6.5).

Figure 6.3: Elevated water column turbidity in the Mhlatuze Estuary in November 2011 due to sediment-laden river inflows to the estuary.

Figure 6.5: Elevated water column turbidity in the offshore environment observed on 28 August 2014.

6.2 Ecological impacts associated with elevated turbidity

A number of environmental thresholds exist (see Section 4.1) for assessing ecological impacts. The three selected for presentation are:

- A <20 mg/ℓ suspended sediment concentration guideline suggested by Steffani *et al*. (2003) that represents a conservative lower threshold below which impacts are not expected to occur in ecologically sensitive areas in and around Algoa Bay. This <20 mg/ℓ threshold is a low risk, monthly average goal for these regions;
- A >80 mg/ℓ suspended sediment concentration guideline suggested by Steffani *et al*. (2003) that they considered to represent a high risk that requires mitigation action;
- A <100 mg/ℓ target value for suspended sediment concentrations in the water column that, based on a literature review (EMBECON, 2004), represents limited risks for biota. This represents an alternative view to the Steffani *et al*. (2003) threshold of > 80 mg/ℓ of suspended sediment concentrations beyond which impacts are considered likely to occur.

In recognition of the suspended sediment thresholds suggested for the mudflats and Bhizolo Canal, model results for an additional threshold of 150 mg/ℓ are also presented.

For the assessment of potential ecological impacts, the model results are presented as contours of the number of days that the 20 mg/ℓ guideline is exceeded in the surface layer (Figure 6.6) and near the bottom (Figure 6.8). The exceedance of this guideline in the surface waters represents potential impacts of concern in terms of light in the water column and associated effects on primary productivity, while in the deeper waters this indicates the lower threshold for effects should this exceedance occur for a continuous 2-3 days or more. It should be noted here that the results are plotted as total days of exceedance of the relevant threshold per season. An exceedance of 3 days in the plots typically does not indicate that the guideline has been exceeded for 3 continuous days. Rather it indicates that the threshold is exceeded on a number of occasions the Richards Bay Capacity Expansion Option 3A capital dredging during the season but for a much shorter duration, typically a day at most. However the total duration of all of these exceedances will be 3 days or more.

The exceedance of 80 mg/ℓ in surface waters (Figure 6.10) and near the seabed (Figure 6.11 and 6.12) and 100 mg/ℓ in surface waters (Figure 6.6) and near the seabed (Figure 6.7) for even short periods of time indicates that ecological impacts are likely where this occurs.

A plot of the days of exceedance of the 20 mg/ℓ threshold indicate that this value is exceeded in the surface layers over a fairly extensive region extending 2 to 3 km beyond the confines of the dredge spoil disposal site for between 20 and 30 days per season (Figure 6.6). Near the seabed the days of exceedance range between 30 and 50 days per season over a similar extent (Figure 6.8). In the port the extent of the area over which this threshold is exceeded in the surface layers spatially co-incide approximately with the dredging footprint (Figure 6.7), the number of days of exceedance of the threshold (a maximum of 30 days per season) closely mirroring the duration of dredging at the relevant locations. The days of exceedance of the 20 mg/ℓ threshold near the seabed increases to a maximum of between 50 and 75 days at the far recesses of the area being dredged (Figure 6.9). Furthermore, the area over which there is exceedance of this guideline is somewhat larger near the seabed with evidence of the area of exceedance extending beyond the actively dredged areas. However in these areas the guideline is only exceed at most between 2 and 5 days per season.

The days for which a 80 mg/ℓ threshold is exceeded in the surface layers is minimal both offshore and within the port (Figures 6.10 and 6.11). However near the seabed this threshold is exceeded over a more extensive area. The threshold can be exceeded up to 5 days total duration per season at distances of up to 2 km beyond the confines of the dredge spoil disposal site (Figure 6.12). It is expected that these observations represent a limited number of major resuspension events having a duration of one or two days at most.

The exceedance of higher suspended sediment concentration thresholds is not observed in the surface layers. At depth however these thresholds are exceed beyond the confines of the dredge spoil disposal site. The 100 mg/ℓ is exceeded near the seabed up to 4 km beyond the dredge spoil disposal site (Figure 6.13); however the total duration of this exceedance is typically less than 2 days per season. The area over which suspended sediment concentrations above 150 mg/ℓ are observed is predicted to extend beyond the confines of the dredge spoil disposal site (Figure 6.14); however exceedances of this threshold having with a total duration of greater than 5 days per season do not extend more than 500 m beyond the confines of the dredge spoil disposal site. Exceedances of this guideline with a total duration greater than one day do not extend beyond approximately 1 km of the confines of the dredge spoil disposal site.

These results are consistent with the OBS mooring data from sites located both to the north and south of the dredge spoil disposal site measured during the Berth 306 capital dredging (see Figure 6.12 for the approximate locations of the moorings), however the days of exceedance for particular the lower thresholds are significantly higher in the modelling results than were observed. This could partially be due to the fact that the dredging and dredge spoil disposal rates assessed here are significantly higher in the modelling study than occurred during the Berth 306 capital dredging programme. It may also however simply be that the model simulations in this study tend to overestimate water column turbidity in this offshore domain.

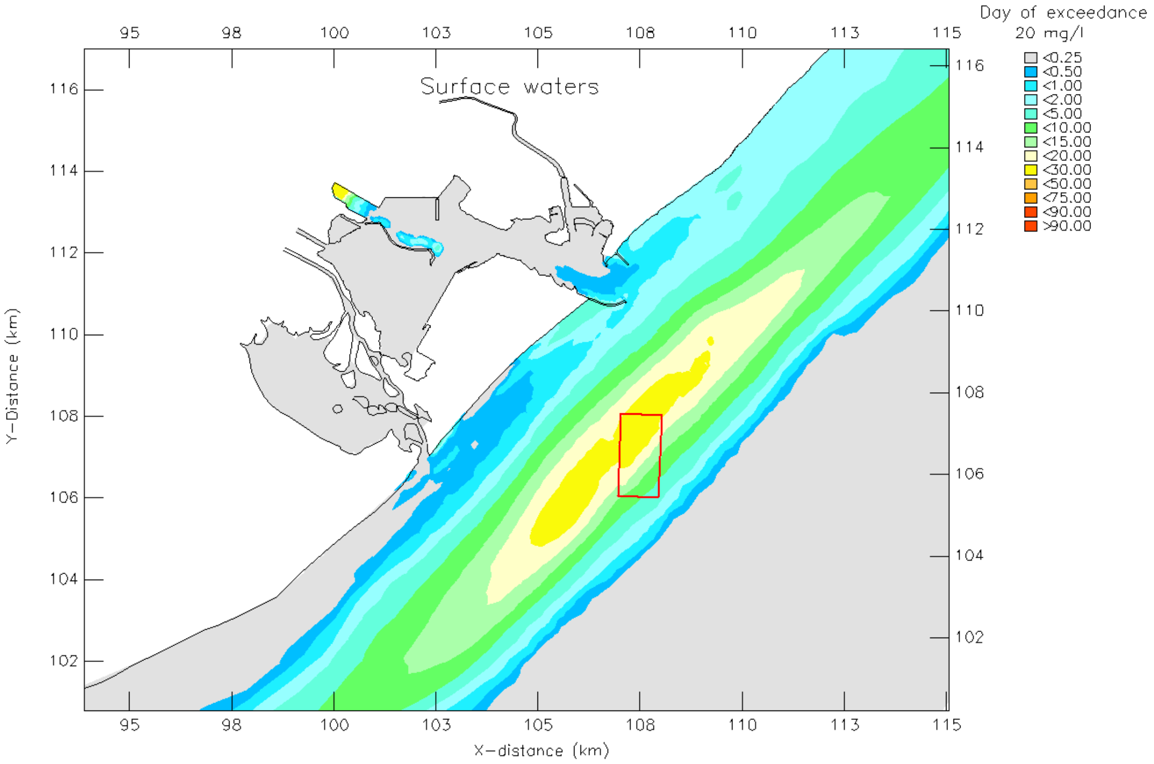

Figure 6.6: **Number of days per season that a suspended sediment concentration threshold of 20 mg/ℓ is exceeded at the seas surface.**

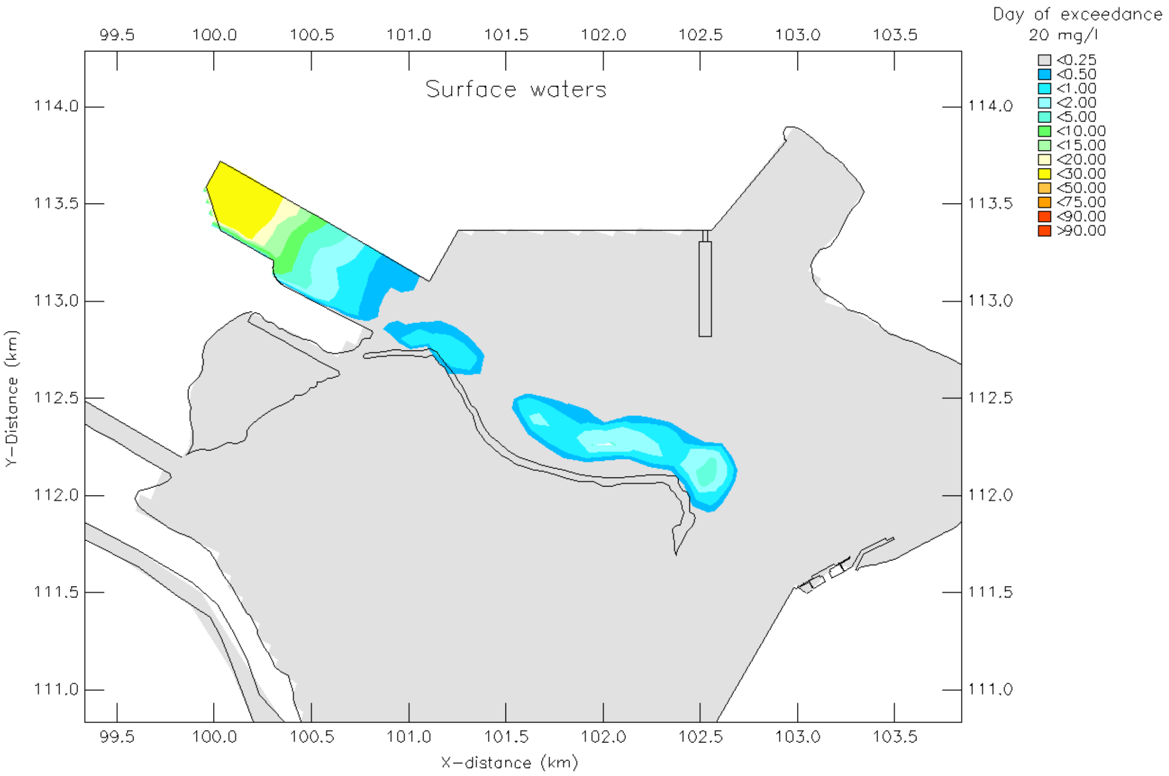

Figure 6.7: Number of days per season that a suspended sediment concentration threshold of 20 mg/ℓ is exceeded at the sea surface within the Port of Richards Bay.

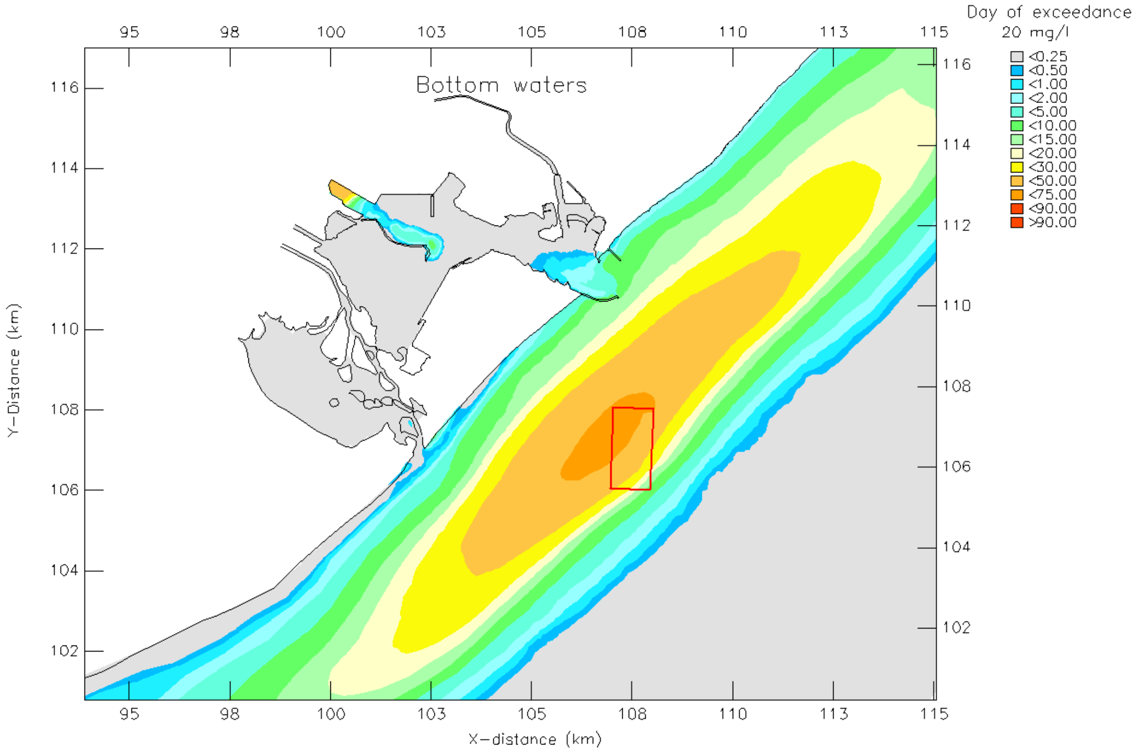

Figure 6.8: Number of days per season that a suspended sediment concentration threshold of 20 mg/ℓ is exceeded near the seabed.

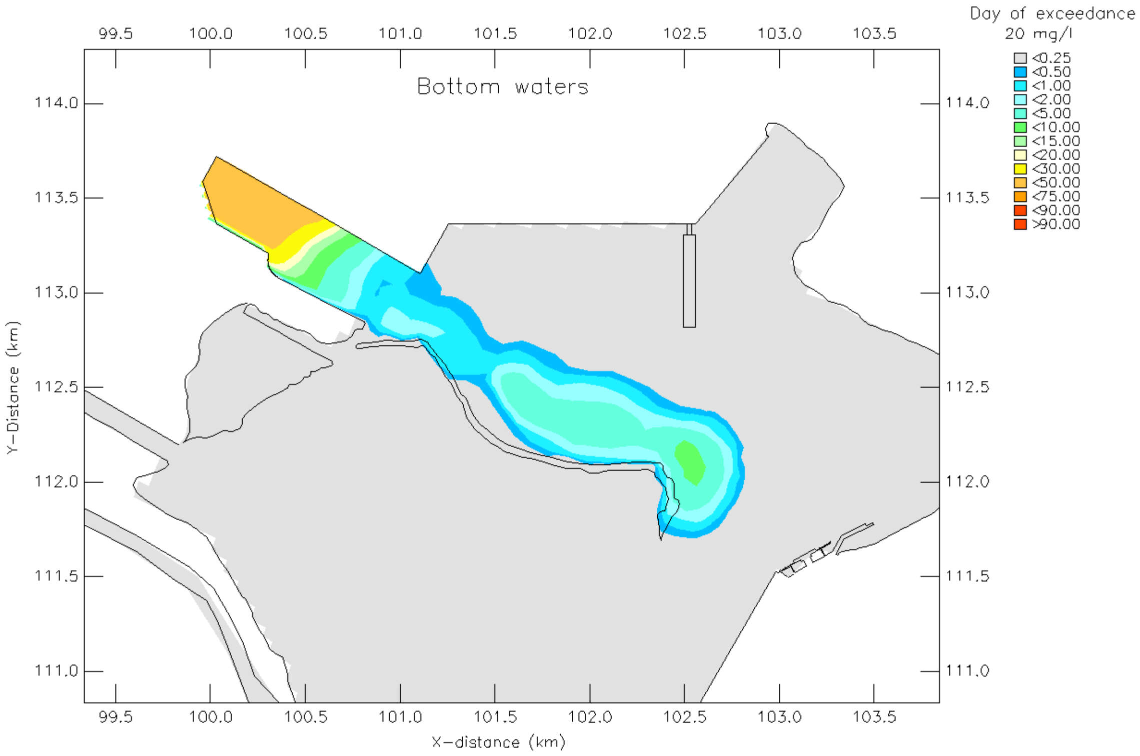

Figure 6.9: Number of days per season that a suspended sediment concentration threshold of 20 mg/ℓ is exceeded near the seabed within the Port of Richards Bay.

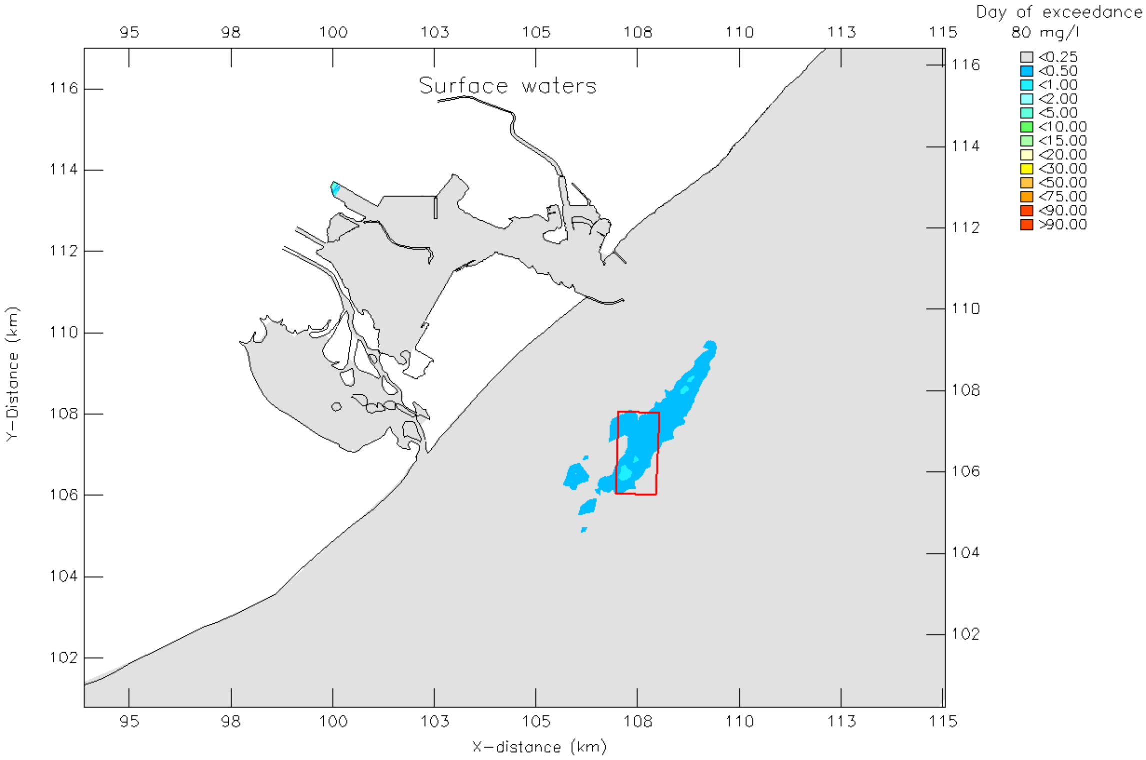

Figure 6.10: Number of days per season that a suspended sediment concentration threshold of 80 mg/ℓ is exceeded at the sea surface.

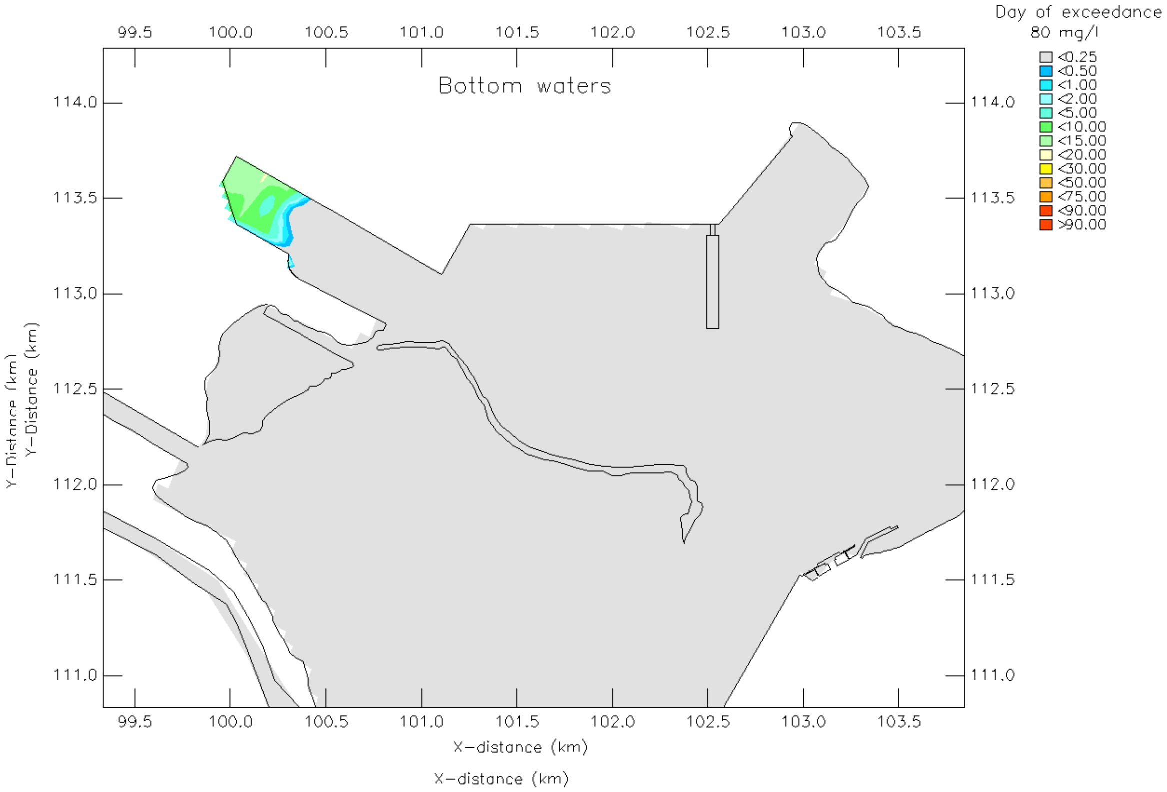

Figure 6.11: Number of days per season that a suspended sediment concentration threshold of 80 mg/ℓ is exceeded at the sea surface within the Port of Richards Bay.

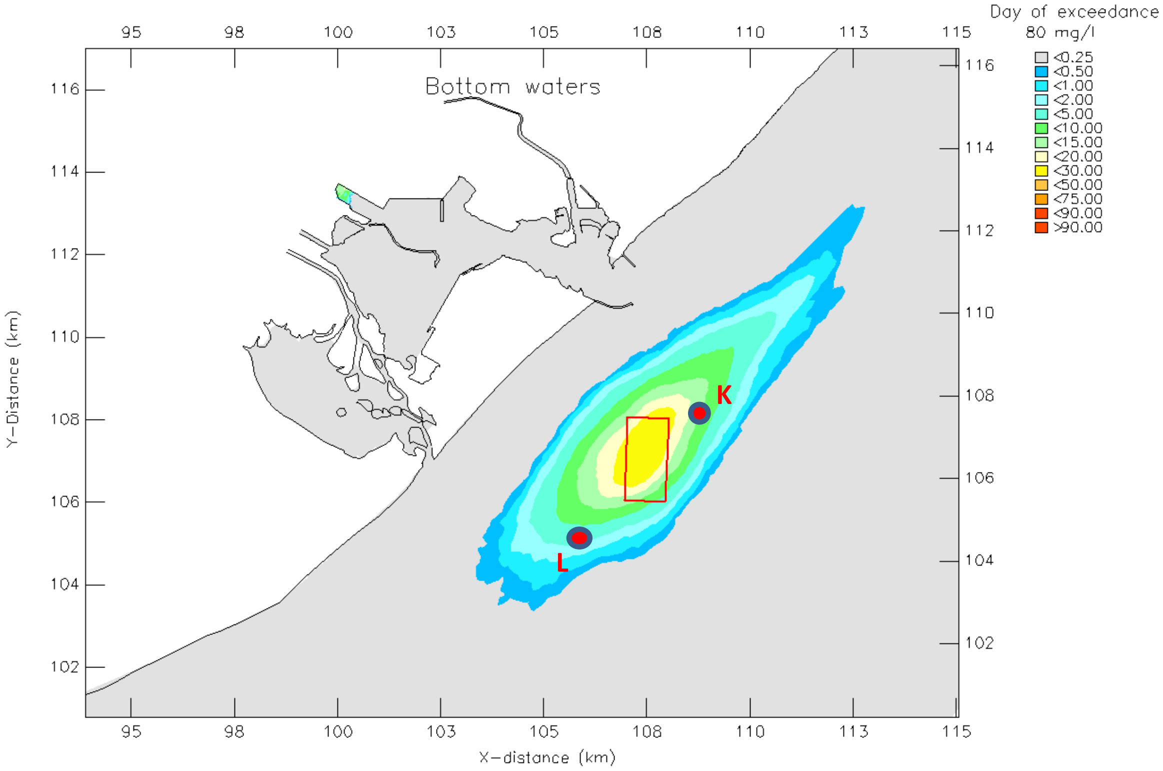

Figure 6.12: Number of days per season that a suspended sediment concentration threshold of 80 mg/ℓ is exceeded near the seabed.

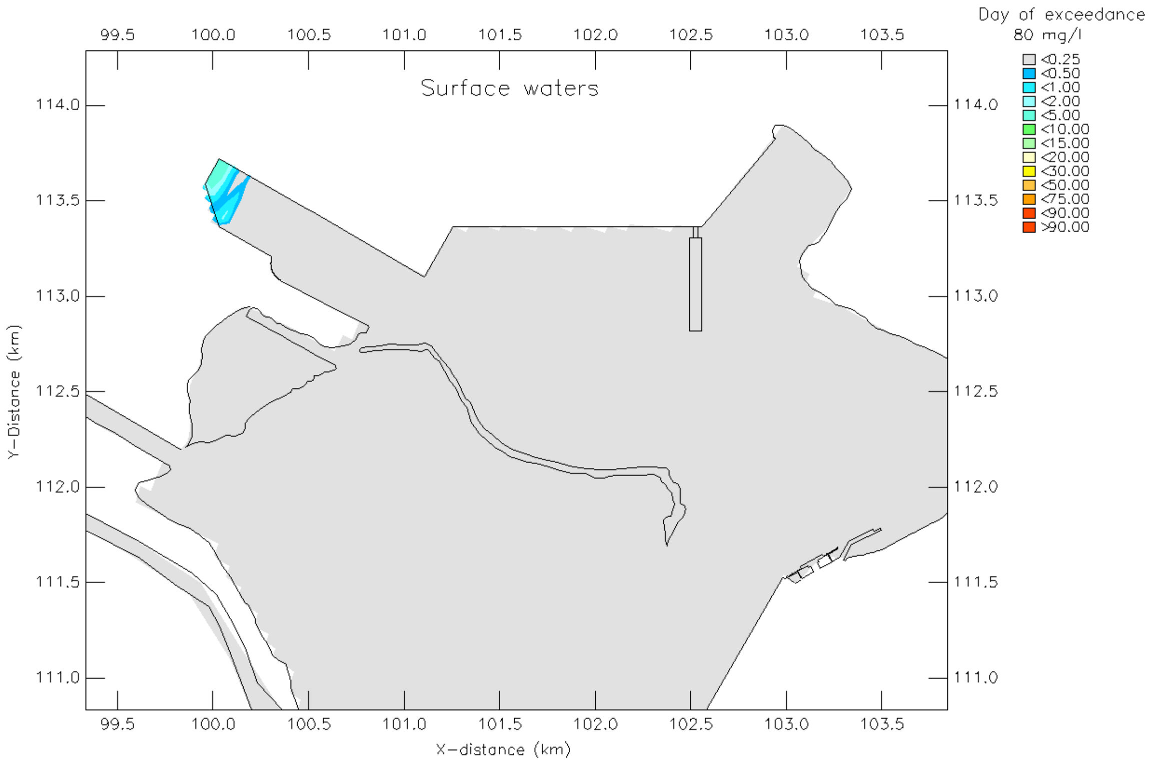

Figure 6.13: **Number of days per season that a suspended sediment concentration threshold of 80 mg/ℓ is exceeded near the seabed within the Port of Richards Bay.**

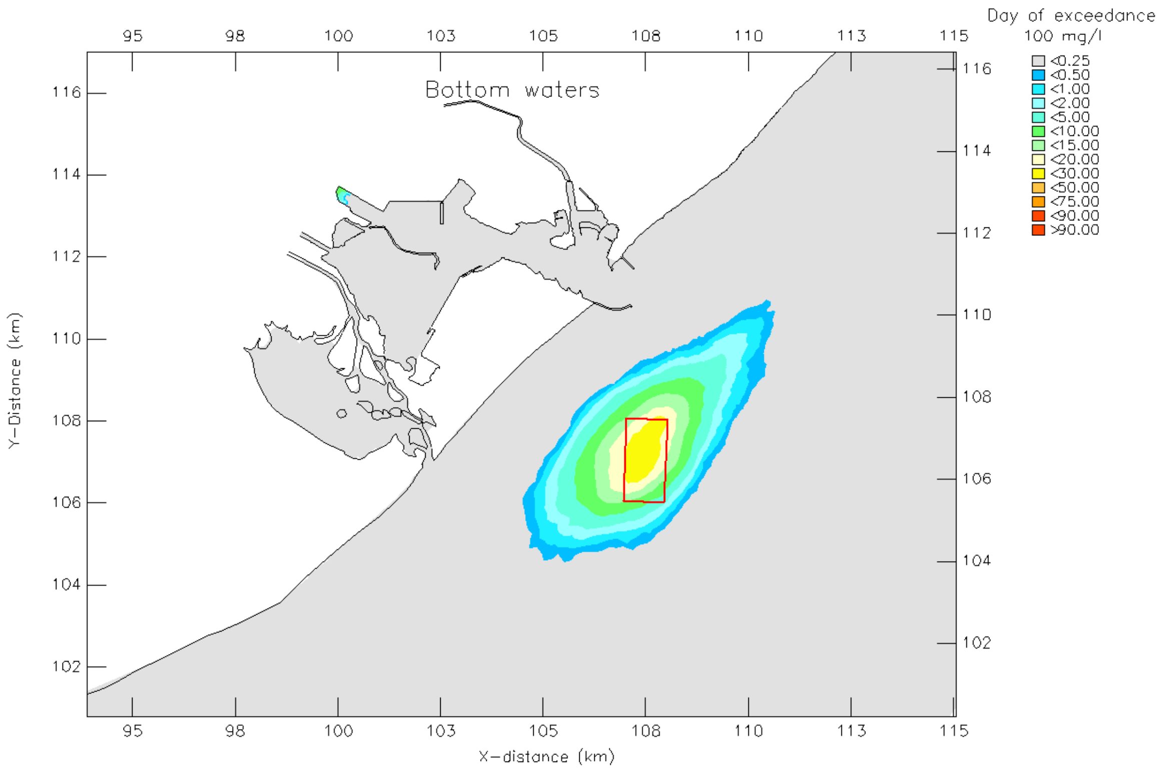

Figure 6.14: **Number of days per season that a suspended sediment concentration threshold of 100 mg/ℓ is exceeded near the seabed.**

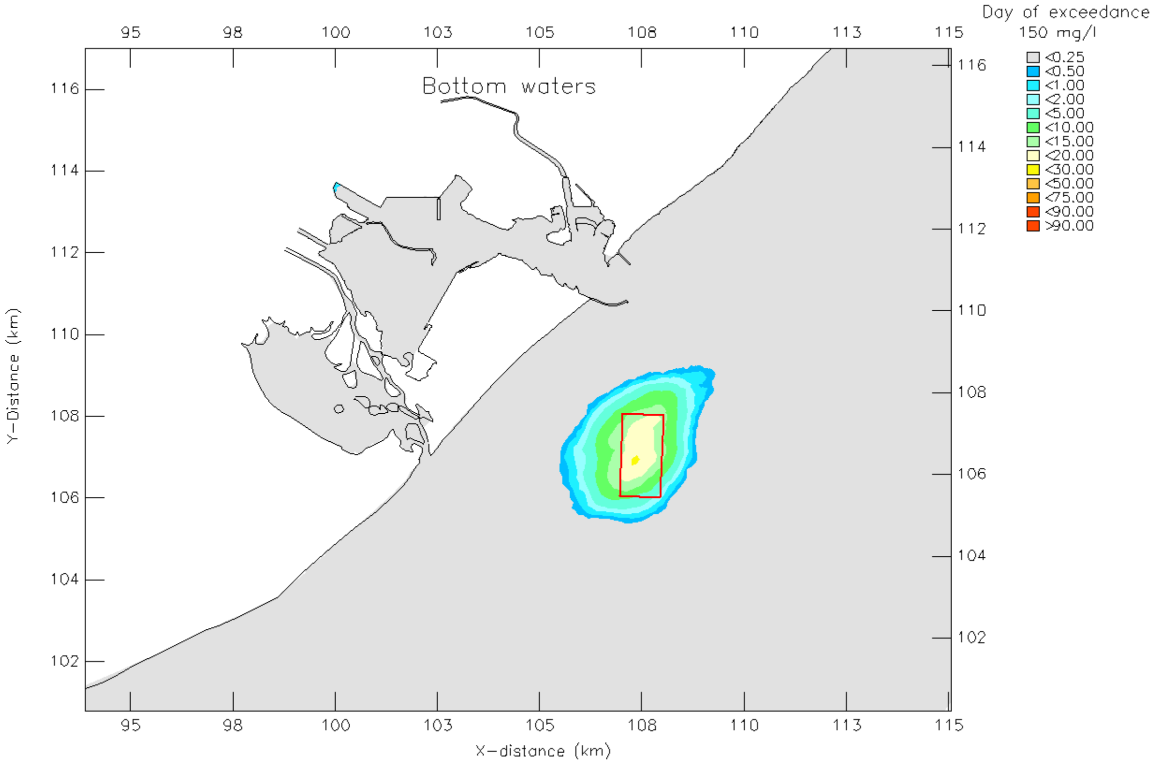

Figure 6.15: **Number of days per season that a suspended sediment concentration threshold of 150 mg/ℓ is exceeded near the seabed**

The contours of 99th percentile suspended sediment distributions (not presented here) suggest that the maximum suspended sediment concentrations occurring near the seabed exceed 500 mg/ℓ at a limited number of locations on the dredge spoil disposal site, however suspended sediment concentrations near the seabed over the dredge spoil disposal site mostly do not exceed 350 mg/ℓ.

Time series plot of suspended sediment concentration are possible for selected locations (at a 2 hour temporal resolution should they be required).

In summary, the turbidity levels expected within the Port of Richards Bay are quite modest compared to those observed during the Berth 306 capital dredging programme. The model predictions suggest that there will be little potential impact beyond the actual areas being dredged. In contrast, the model predictions in the offshore zone indicate higher levels of turbidity than were measured during the Berth306 dredge spoil disposal operations. As noted above this could be partially due to the fact that the dredging rates assumed in the modelling study or could simply be that the model simulations tend to overestimate water column turbidity in this offshore domain. One of the reasons for this could be the fact that the actual critical shear stresses for re-suspension for the dredge spoil are significantly higher than those assumed in the modelling. Samples from the dredge spoil disposal site during the Berth306 monitoring indicated that the sediments were more cohesive (Weerts, pers. Comm.) than on would have anticipated from physical properties alone. Underestimating the critical shear stresses of re-suspension in the model would lead to an overestimate of water column turbidity in the offshore domain.

6.3 Ecological impacts associated with distribution of contaminated sediments and smothering effects

To assess the potential marine ecological impacts associated with distribution of contaminated sediments and smothering effects the model results are presented as the near maximum (99th percentile value) thickness of sediments deposited at the seabed (Figure 6.16), the 95th percentile thickness of sediments deposited at the seabed (Figure 6.17) and the mean thickness of sediment deposited at the seabed (Figure 6.18). The 99th percentile and 95th percentile values indicate the maximum and near maximum "footprint" of sediment re-mobilised from the dredge spoil disposal site, while the mean sediment thickness represent the more persistent "footprint" of the sediments re-mobilised from the dredge spoil disposal site (*i.e*. excludes more temporary deposition of sediments around the dredge spoil disposal site). The limitation of the latter metric (*i.e*. the mean) is that, should deposition occur during the latter half of the simulation, it will largely be discounted.

6.3.1 Maximum change in depth at the dredge spoil disposal site

The maximum change in water depth at the dredge spoil disposal site has relevance to potential shoreline stability effects. The 95% and 99% exceedance contours of these depth changes (*i.e*. sediment thickness) in principle can inform the assessment of potential shoreline impacts if required.

The bulk of the changes in the seabed are due to the muds, a consequence of the assumption of relatively high porosities (>80%) for muds when disposed at the dredge spoil disposal site. This also implies that as the muds are re-suspended from the site (to the extent that this occurs), the sediment deposition thickness at the dredge disposal site will decrease relatively rapidly compared to the mass of sediments removed from the dredge spoil disposal site. The modelling results indicate limited re-distribution of sediments from the dredge spoil disposal site over the period of the model simulations. For the model simulations to inform the long-term changes (*i.e.* reduction in height of the dredge mound) would require very long duration model runs. While such long-term model simulations are well-suited to describing the long-term redistribution of sediments beyond the confines of the dredge spoil disposal site, the best means of estimating the likely long-term changes in the dredge mound would be to interpret the measured changes occurring at the dredge spoil disposal site between the various capital dredging projects that have taken place (*i.e.* undertake a comparison of the various "in"- and "out"-surveys of the dredge mound). Unfortunately, only the Berth306 data are available to this study and, to the best of our knowledge, no further bathymetric surveys of the dredge spoil disposal site so the long-term rehabilitation (*i.e.* reduction) in the dredge disposal mound could not be assessed. However, the Berth306 bathymetric survey data for the dredge spoil mound generated during the Berth306 capital dredging do provide some insight into the long-term rehabilitation of the dredge spoil mound. Two previous studies commented on the long-term bathymetric changes on the dredge spoil disposal site (van den Bossche *et al*., 2007 and Weerts, 2008). Based on these studies comments are made here on the expected long-term changes expected for the dredge spoil disposal site at the end of this section of the report.

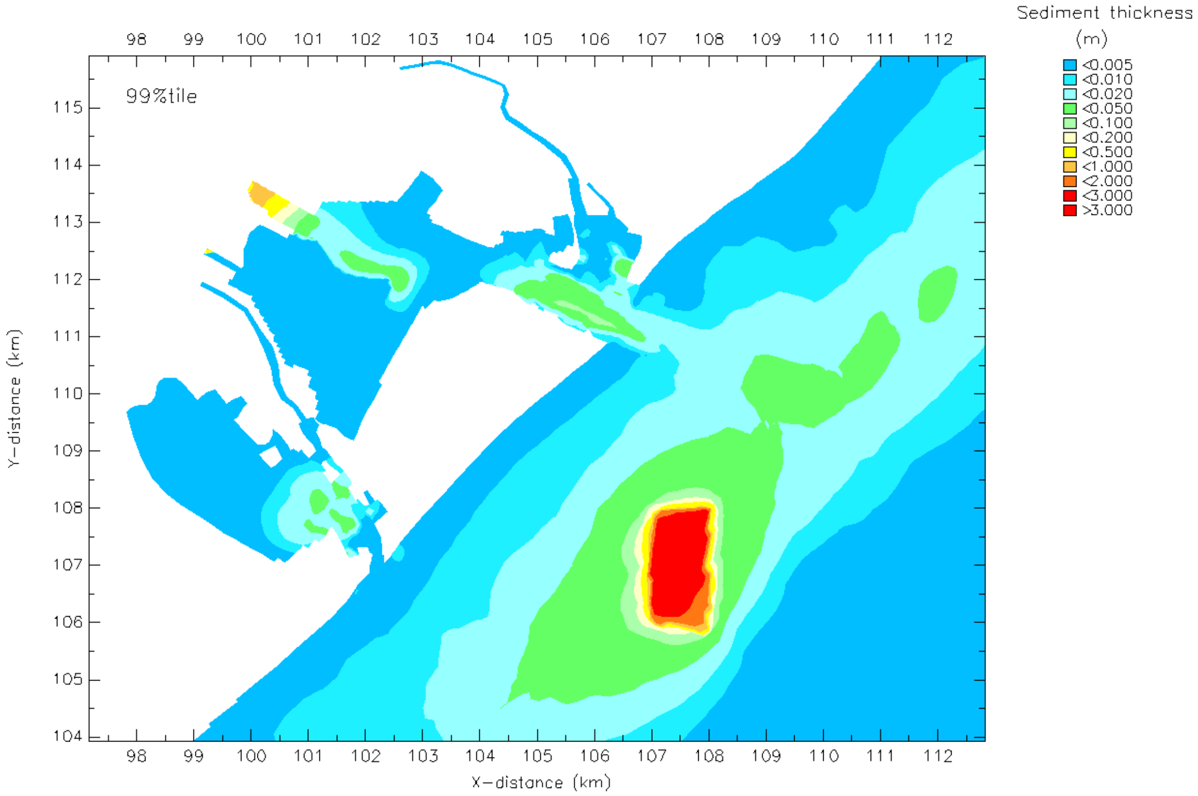

Figure 6.16: **99th percentile deposition thickness of sediments (in m).**

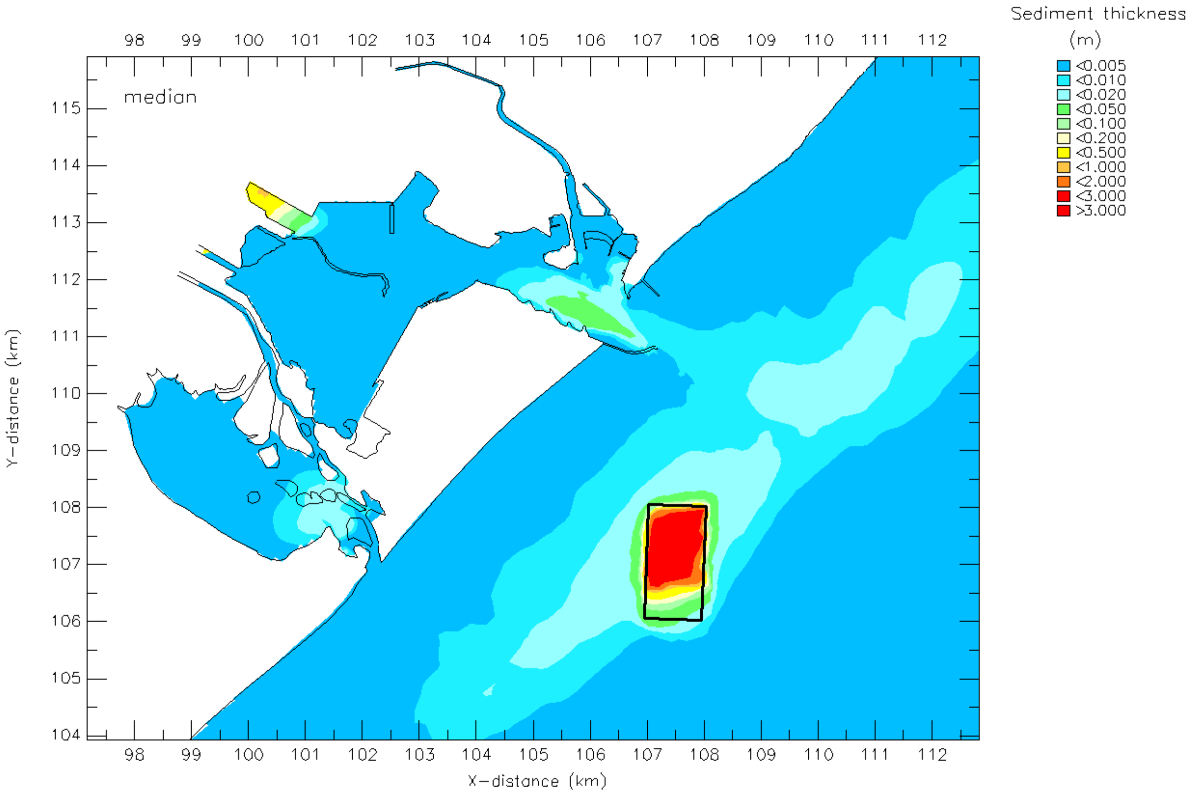

Figure 6.17: **95th percentile deposition thickness of sediments (in m).**

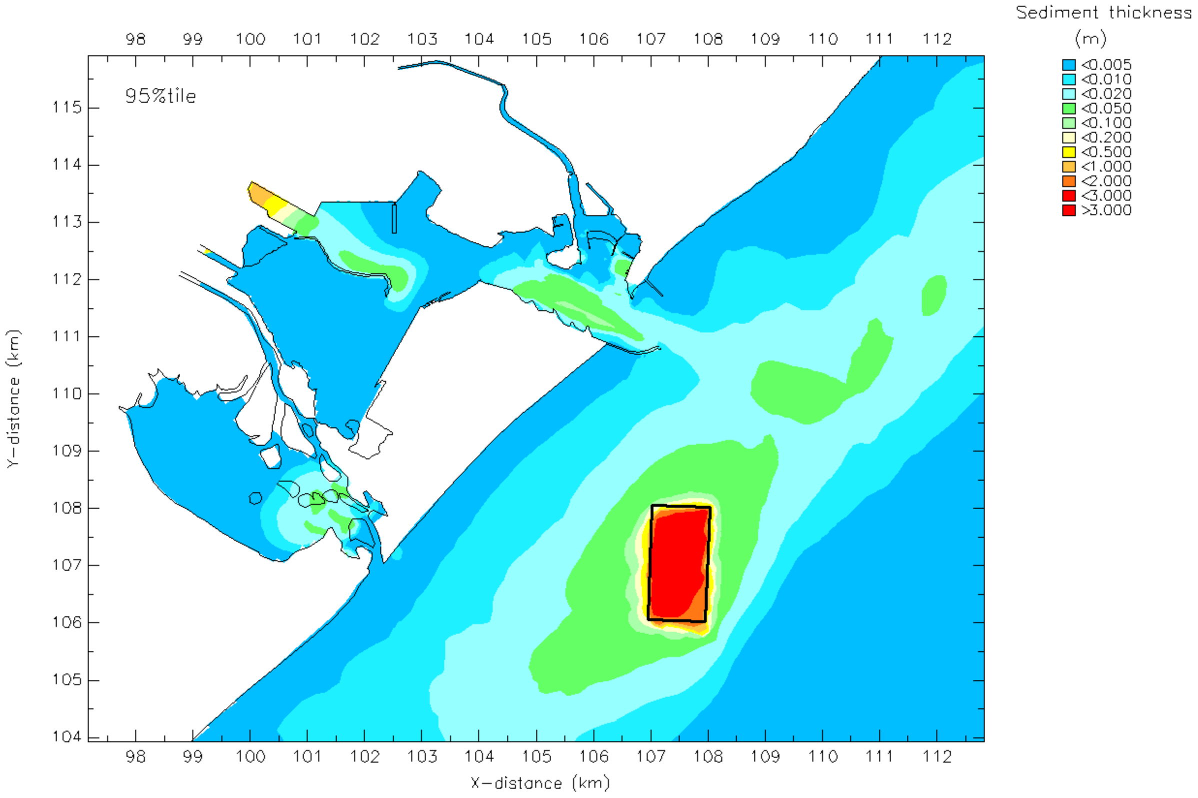

Figure 6.18: **Mean deposition thickness of sediments (in m).**

Both the sediment deposited within the confines of the port or at the dredge spoil disposal site and tend largely to remain either within the immediate area of dredging within the port or within the demarcation of the dredge spoil disposal site.

The model results indicate that the dredged material will be deposited within immediate vicinity of the dredging during the dredging activities to a depth of between 0.5 m and 1.0 m. These relatively high values are consistent with the finding that elevated suspended sediment concentrations will remain confined largely to the area where dredging is taking place (Figure 6.16, 6.17 and 6.18).

There exists evidence that some of the sediments will be deposited just inside the Mhlatuze Estuary mouth, however in the short-term the thickness of sediment deposited will be less than 3 cm in the short-term but < 1 cm in the medium term and beyond. This is trivial compared to the sediment movements and deposition of sediments expected during normal tidal exchange or floods.

The only other areas where significant deposition occurs is in the harbour entrance where the maximum depth changes predicted are in the order of 5 cm but certainly less than 10 cm. Deposition of dredge sediments from dredging activities is expected to range between 2 cm and 3 cm towards the eastern extremity of the sandspit, however this in unlikely to be of great concern in the medium to long term.

The maximum sediment thickness of dredge spoil on the dredge spoil disposal site is < 3 m. However this includes rock which, in reality, is unlikely to be disposed of at the offshore dredge spoil disposal site. Should the rock not be disposed of at the offshore dredge spoil disposal site, it is expected that the sediment thickness on the disposal site will be of the order of 2 m. Of course the above assumes that the dredge spoil will be spread more or less uniformly over the dredge spoil disposal site. Previous experience (*i.e.* the Berth 306 capital dredging project) has indicated that this is highly unlikely to occur in practise. During the Berth306 dredging programme, the dredge spoil was disposed of at two locations (Figure 6.19), resulting in substantial mounds of dredge spoil, namely a northern mound and southern mound (Figure 6.20). The central mound in Figure 6.20 was a pre-existing mound of dredge spoil that existed prior to the commencement of the Berth306 dredging activities.

The model simulations, having been run for only 6 weeks post-dredging are not able to inform the long term rehabilitation of the dredge spoil disposal site. Van den Bossche *et al*. (2007) have however evaluated the changes that occurred between the immediate post-dredging bathymetric survey in January 2006 and a further post-dredging survey undertaken in July 2007.

The results seem to indicate no major loss of sediments from the dredge spoil site over this period. Rather there was erosion (- 6 m) of one of the two dredge spoil disposal mounds generated during the Berth306 capital dredging. The eroded material however largely was re-distributed to be deposited in close proximity of the original dredge spoil mound rather than moved far away from the site. Most of the eroded material accumulated offshore(+2m) closer to the existing reefs in the area (Figure 6.21).The changes occurred over an 18 month period. One could assume a similar continued rate of change in the intervening period between July 2007 and the present, however as the dredge spoil mounds decreases in size the likely rate of re-distribution of the sediments is likely to decrease and the “erosion” of the dredge spoil mound will slow.

One should be careful in making assumption around the rate of “erosion” of the dredge spoil mound as the period between January 2006 and July 2007 included the occurrence of one of the largest storms (accompanied by very high waves and spring tides) ever experienced in the region. It may therefore have been that the changes observed between the January 2008 and July 2007 surveys occurred in a single event of a magnitude that is unlikely to re-occur soon. Furthermore the redistribution of sediments seem to suggest a “slumping” of the dredge spoil mound as an event rather than an ongoing erosion of sediments from the dredge spoil mound.

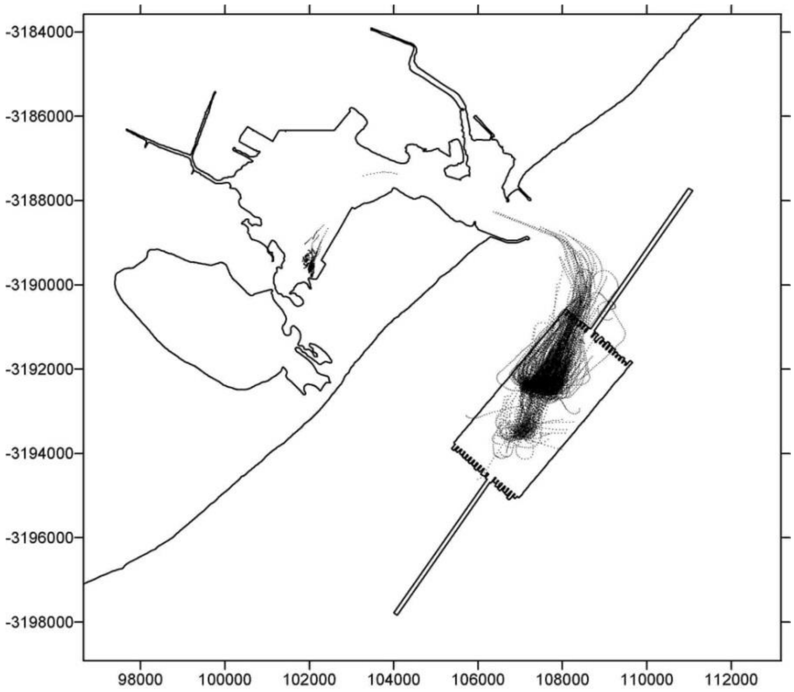

Fig. 6.19: **Plot of dredger dumping positions based on van Oord data for August 2005 to January 2006 (after Ramsay and MacHutchon, 2006).**

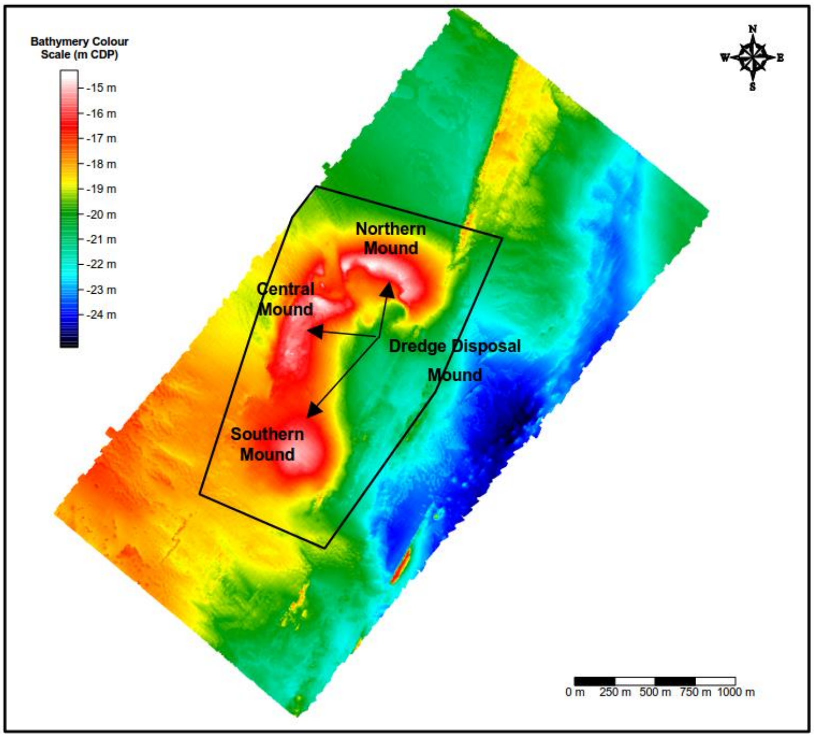

Fig. 6.20: **Multibeam bathymetry map showing dredge spoil mounds that existed immediately after the completion of the Berth306 capital dredging (Source: van den Bossche *et al*., 2007)**

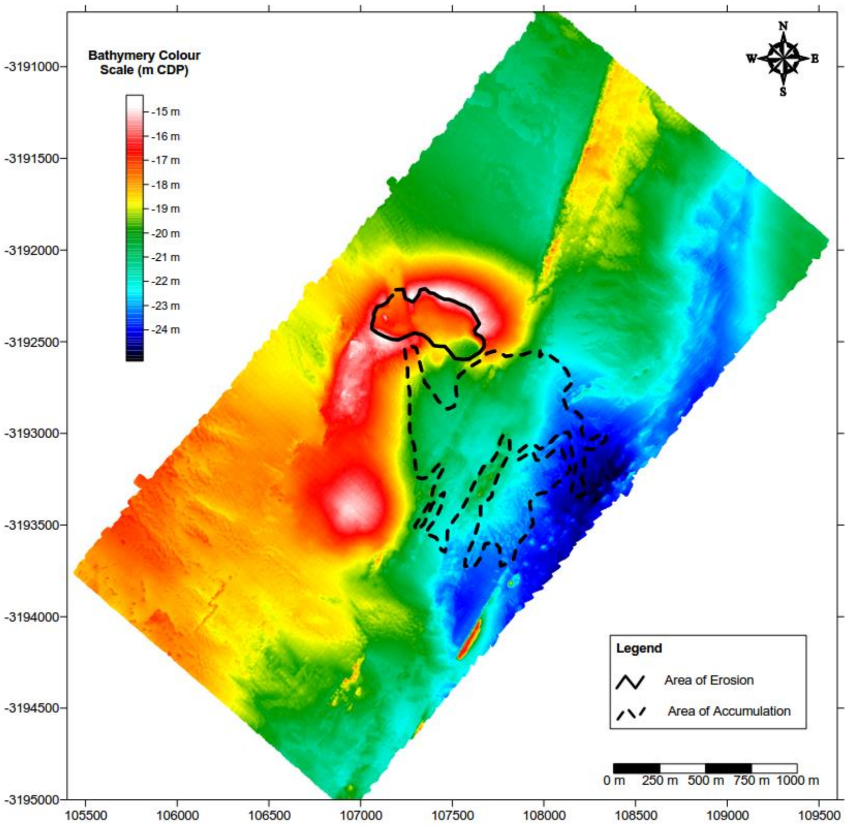

Fig. 6.20: **Multibeam bathymetry map showing the location of maximum erosion and accumulation of material on the offshore dredge spoil disposal site between January 2006 and July 2007 (Source: van den Bossche *et al.*, 2007)**

6.3.2 Toxicity effects of contaminants released from the sediments

The toxicity effects from potential contaminants released into the water column were simulated using appropriate loads (*i.e.* as determined from the metals concentrations in the surficial sediments in CSIR (2013a) and modelling these as a conservative tracer in the model. However, given the low levels of contamination of the sediments and the fact that previous elutriation studies have indicated that only 0.2% of the trace metal concentrations in the sediments enter the water column (van Ballegooyen *et al.*, 2006), presently the model results have not been assessed for potential toxicological effects of trace metals. If necessary, the model results could be assessed in terms of achievable dilutions of trace metals and the extent to which there would be compliance with the South African water quality guidelines. However, for the reasons stated above presently this is considered superfluous to this study. As noted earlier, it would be more sensible to better understand the risks posed by the contaminated sediments as suggested in CSIR (2013a), should it be deemed necessary, before undertaking a detailed analysis of the model results on contaminated sediments that are based on assumptions (assumed percentages of metals entering the water column) around which there remains some uncertainty.

6.4 Summary of model results

The aesthetic impacts of elevated suspended sediment concentrations in the water column are unlikely to extend beyond the confines of the port. Further offshore the discoloration of surface waters may be quite extensive and, although occurring quite often, will typically be of a short duration (*i.e.* associated with specific weather events).

The elevation in suspended sediment concentrations above thresholds of concern occur mainly within the confines of the dredge spoil disposal site. However, the lower thresholds (20 mg/ℓ and 80 mg/ℓ) may be exceeded up to 2-4 km beyond the confines of the dredge spoil disposal site.

The re-distribution of sediments during the model simulation period is limited and typically comprises mostly muds. As noted above, the limited duration of the model simulations will result in an underestimation of the true extent of the re-distribution of sediments that will occur over the long-term. However, the more widespread the distribution of sediments the greater will be their mobility. The implication is that the sediments that have been widely distributed beyond the immediate vicinity of the dredge spoil are those having the greatest mobility and consequently are unlikely to form long-term accumulations of sediments at locations significantly distant from the dredge spoil disposal site.

6.5 Climate Change Effects on Model Outcomes

Climate change is expected to have significant consequences for coastal ecosystems as a result of sea level rise, increased storminess, changes in ocean temperatures, ocean acidification, *etc*. However of relevance to this study are primarily the effects of sea level rise, changes in storminess (*e.g*. winds and waves) and possible long-term changes in circulation patterns.

The simulations are relevant to the period of the proposed dredging activities, extending to approximately 5 years following the dredging activities when the remobilisation of sediments from the offshore disposal site is likely to be of a magnitude that would significantly affect water column turbidity and/or benthic habitats in the vicinity of the dredge spoil disposal site. On such time scales the anticipated effects of sea levels rise and/or changes in storminess on the model outcomes will be very limited, and more than likely negligible. Any anticipated changes in ocean circulation, at this stage would be speculative at best

Were sea level rise effects to be taken into account they would in all likelihood reduce the mobility of sediments from the offshore disposal site due to the increase in water depth. Conversely, increased storminess would serve to increase the number of occasions and extent to which sediments would be remobilised at the offshore dredge disposal site. However as noted above, the anticipated changes in sea level and storminess will be limited over the short to medium term when dredging impacts are likely to be observed.

7 ENVIRONMENTAL MONITORING PROGRAMME

Monitoring associated with dredging needs to be integrated into the full project cycle and includes:

- the development of an appropriate *environmental baseline* against which to assess potential impacts;
- measurements in support of *impact assessment and any associated modelling;*
- *compliance monitoring*; and
- monitoring to *validate and/or verify impact assessment and associated modelling*.

Abiotic monitoring programs required to develop an appropriate environmental baseline and to support robust impact assessment include:

- monitoring of *water quality (primarily turbidity and total suspended solids)* in the environment(s) likely to be affected by dredging and dredge spoil disposal activities;
- *pre-dredging bathymetric surveys* of the dredge site(s) and dredge spoil disposal site;
- *sediment quality (biogeochemical) characterisation* of the dredge site(s) and dredged spoil disposal site prior to dredging; and
- *measurements to support modelling studies* undertaken as part of the assessment of environmental impacts.

Such monitoring typically needs to be (and mostly will have been) executed prior to the completion of the impact assessment for the EIA.

Sufficient water quality data are available to provide the requisite baselines for turbidity and total suspended solids concentrations (CSIR, 2013b,c) in the water column for use in the dredging and dredge spoil disposal specialist studies in the Port of Richards Bay. However, the environmental baseline for turbidity and suspended solids developed for the offshore region has associated with it a degree of uncertainty due to observational biases in the historical data used to develop the baseline (see Section 3.8.2). The sediment quality of the material to be dredged has been characterised in CSIR (2013a). These data indicate a degree of metal contamination in the proposed dredge location, albeit only for the surficial sediments. Recommendations have been made in CSIR (2013a) one how to address any residual concerns in this regard. No recent biogeochemical characterisation of the offshore dredge spoil disposal site could be located. Were such a characterisation to exist it is not clear how representative it would be of present condition as the dredge spoil disposal site is used for ongoing disposal of limited quantities maintenance dredging spoil.

The focus here is on the monitoring requirements associated with:

- *Compliance monitoring* (Section 7.1) to ensure the proposed environmental objectives for dredging activities are met during dredging operations;
- *Monitoring for impact verification* (Sections 7.2 and 7.3), which comprises biophysical measurements characterising stressors (drivers of impact) and associated direct ecological impacts, but could also include data to support the verification of modelling studies that typically are used to characterise the drivers of ecological impacts (*e.g.* high turbidity, low oxygen concentrations, *etc.*) in dredging impact assessment studies. Here only the abiotic monitoring requirements are addressed.

Accordingly an Environmental Monitoring Programme has been developed for monitoring for compliance and verification of impact assessments associated with dredging and dredge spoil disposal activities. This includes:

- Compliance monitoring based on total suspended solids concentration thresholds of concern;
- Monitoring of physical changes in benthic habitats;
- Monitoring of potential shoreline changes;
- Monitoring to verify impact assessments and associated modelling activities.

The detail of ecological and ecosystem monitoring will need to be provided by the Marine Ecology specialists.

7.1 Monitoring for compliance and verification of impact assessments associated with dredging and dredge spoil disposal activities

7.1.1 Dredge spoil disposal

The designated dredge spoil disposal site in offshore of Richards Bay can be conceived as a sacrificial zone for receiving dredge spoil and any contaminants it may hold. However, it is essential that all spoil disposal occurs within the confines of the specified area and preferably is spread as uniformly as possible of the site. Therefore, all navigation tracks for spoil disposal round trips and locations of spoil release must be supplied by the dredge operator to the designated Environmental Control Officer on at least a weekly basis. This officer should then check that spoil is being released within the confines of the designated spoil disposal site and advise the dredge operator(s) when apparently uneven disposal patterns are developing. These data are to be reported to an Environmental Monitoring Committee or similar entity auditing the dredge monitoring. Should there be any impacts of the dredging and/or validation of the predicted impacts this will require detailed knowledge of dredge spoil disposal activities. Records thus need to be kept for each dredge disposal event. The information to be reported should include start of the disposal (*i.e.* “doors open”), the conclusion of the disposal (*i.e.* “doors closed”), and whether the hopper was full or not. These records need to be stored for safe-keeping after dredging operations have ceased (i.e. preferably indefinitely but at least for a minimum of 2 to 3 years).

7.1.2 Turbidity and suspended solids compliance monitoring programme

Reference is often made to both pre-cautionary and compliance monitoring. Here, pre-cautionary and compliance monitoring are assumed to be one and the same since in both cases the intention is to identify and avoid situations where adverse dredging impacts are likely to occur. As the most pervasive and definite environmental risks during dredging operations are associated with increases in turbidity and total suspended solids concentrations in the water column, these variables are well-suited for compliance monitoring.

The imposition of a limit on the concentration of total suspended solids in the water column at specified locations near dredging operations or openwater dredge disposal sites rather than a turbidity limit is common for dredging projects in most parts of the world. This is because total suspended solids concentrations correlate well with environmental impact and are broadly comparable from site to site and sediment to sediment. This is not the case for turbidity. However, the major problem with imposing a limit on the concentration of total suspended solids in the water column for dredging compliance monitoring is that total suspended solids concentrations cannot be determined quickly. This is because the water samples require transport to and subsequent analysis in a specialised laboratory. Depending on the location of the laboratory relative to the dredging operation, it can take anywhere between 12 - 72 hours to receive the results. In the meantime the total suspended solids concentration in the water body of interest will have changed. Total suspended solids concentrations cannot, therefore, be easily used to detect and correct short-term problems or dredging permit violations. It also becomes difficult to regulate a dredging operation because the economic ramifications are significant when a dredging contractor is required to cease operations based on the potential violation of a total suspended solids concentration limit, but which has to be verified based on results that may only be forthcoming several days later (Earheart, 1984). Due to these problems a turbidity limit is often substituted for a total suspended solids concentration limit in dredging permits. This is because turbidity can be measured quickly (within a few minutes) using any one of numerous *in situ* or onsite laboratory/vessel-based turbidimeters by dredging personnel, and importantly because there is often a strong relationship (usually linear) between these variables (CSIR, 2013c). Thus, if the relationship between turbidity and total suspended solids concentration is defined (as has been done in CSIR, 2013c) then turbidity measurements can be used to estimate the total suspended solids concentration to determine if there is compliance with permit limits.

Unfortunately there exists no universal relationship between turbidity and total suspended solids concentrations. Rather, this varies from place to place because the relationship is determined by the particle size of sediment, the particle composition, and water colour amongst other variables (Gippel, 1995). There is also no universal relationship among turbidity measurements made on the same sample with different instruments. For this reason a study has been undertaken to develop the requisite relationships for dredging activities in and near the Port of Richards Bay (CSIR, 2013c). The relationship is both needed to simplify total suspended solids concentration compliance monitoring for capital and maintenance dredging operations in and near the port as well as to provide the variables for programming new generation *in situ* water quality monitoring instruments that use turbidity measurements to calculate total suspended solids concentrations based on a user programmed relationship between these variables. The relationship developed and recommended for use in compliance monitoring is

$$\text{Total suspended solid concentration (mg/}\ell\text{)} = 1.525 \times \text{Turbidity (NTU)}$$

The relationship can be used to calculate total suspended solids concentrations in the water column for dredging compliance monitoring, based on the measurement of turbidity. However, care should be taken when using this relationship as factors such as the change in sediments being dredged could influence the slope of the relationship. For this reason the relationship needs to be verified by analysing water samples collected in close proximity to dredging operations for turbidity and total suspended solid concentrations. A more detailed account of this relationship and associated caveats in its application is given in CSIR (201c).

Purpose of the Monitoring

The purpose of the compliance monitoring is to determine whether dredging and dredge spoil disposal activities associated with the Port of Richards Bay marine infrastructure development are causing unacceptably high turbidity and total suspended solids concentrations in the water column, both in the Port of Richards Bay and the marine environment offshore of Richards Bay. As noted above, only turbidity and total suspended solids concentrations are referred to in the compliance modelling as these are good proxies for other environmental impacts.

The data collected during the compliance monitoring will also have the dual purpose of supporting the assessment of dredging-related environmental impacts upon completion of dredging activities. This may, however, require an extension of the duration of the proposed compliance monitoring.

Monitoring parameters

The parameters that need to be monitored are turbidity (as NTU) and total suspended solids (as mg/ℓ). While turbidity will be used as the primary measure to ensure compliance of dredging activities with environmental limits imposed by regulatory authorities, the opportunity should be taken whenever possible to obtain concurrent turbidity and suspended solids concentration measurements.

Given the quality of the sediments being dredged, the measurement of contaminants in the water column (*i.e.* dissolved metals, hydrocarbons) is not considered necessary except perhaps on the few occasions where know contaminated sediments are being dredged. A better approach would be to assess and manage the risk based on the recommendations contained CSIR (2013a) as this would avoid the requirement for measuring such contaminants in the field during dredging, particularly should the risk be determined to be low.

However, other parameters such as temperature, salinity, dissolved oxygen concentration and pH should be measured at the same time that turbidity and total suspended solids concentrations are measured. These data, while not required for compliance monitoring, typically provide context for observed ecological effects that may be due to natural variability in water quality rather than the effects of dredging. While the measurement of dissolved inorganic nutrient concentrations may aid the interpretation of these data, such measurements are not deemed necessary.

Environmental Thresholds

Suggestions have been made for dredging at other locations in South Africa (Lwandle, 2013) that “pre-cautionary” monitoring be undertaken based on the control thresholds defined by Probyn (2000). However, it was stated that these control thresholds should be applied only for the upper portion of the water column (*i.e.* if suspended sediment concentration exceeds 20 mg/ℓ for three consecutive days the dredging should be halted or management interventions made to allow the concentration to decrease below the threshold 20 mg/ℓ level). If turbidity exceeds 80 mg/ℓ for more than 6 hours continuously then dredging should either be halted or other management interventions, such as the emplacement of silt screens, should be implemented to allow concentrations to decrease below the set level.

It is however better that site-specific thresholds be developed for compliance monitoring. In this regard the environmental thresholds suggested for this project (CSIR, 2013c) are possibly the most appropriate for application within the Port of Richards Bay. These thresholds, if exceeded, would require immediate high level intervention to reduce the turbidity and suspended sediment concentrations to below relevant thresholds. The relevant thresholds proposed are:

- a turbidity of 93 NTU and suspended solids concentration of 142 mg/ℓ for stations situated on the Mudflats and in Bhizolo Canal,
- a turbidity of 66 NTU and suspended solids concentration of 100 mg/ℓ for stations situated elsewhere in Richards Bay.

Greater care needs to be taken when specifying compliance monitoring at the offshore dredge spoil disposal site. Unlike the situation at the location of dredging, the stopping of dredging activities will not necessarily immediately result in lower turbidity at the dredge spoil disposal site. This is due to the fact that the dredge spoil that has already been disposed of at the dredge spoil disposal site constitutes a “reservoir” of sediments that are available for re-suspension should environmental conditions occur that generate enough turbulence and bottom stress to re-suspend the material.

A more pragmatic approach to management of disposal activities at the offshore dredge spoil disposal site therefore seemed appropriate. It is suggested in (2013c) that compliance monitoring at the offshore dredge spoil disposal site be performed by profiling turbidity through the water column at distances of 500, 1000 and 1500 m to the north-northeast and south-southwest of the spoil disposal ground as these are the likely predominant current and hence also suspended sediment dispersion directions. This approach assumes that a sacrificial zone extending 500 m in any direction from the margin of the spoil disposal ground is appropriate. However the hydrodynamic modelling results and OBS mooring results from the previous Berth306 dredge monitoring suggest that spatial extent of 1 000m would be more appropriate. It is therefore proposed that the relevant thresholds be applied to this greater distance. It is suggested in CSIR (2013c) that, should the turbidity in any part of the water column at the compliance monitoring stations exceed 10.2 NTU or 16.4 mg/ℓ, that this should precipitate a sequence of more detailed monitoring until either the turbidity decreases to below this threshold value or is proven to remain sufficiently high to precipitate management intervention. There however exist some concerns around the validity of this threshold due to the limited temporal resolution of the profiling data used to derive this threshold and a likely resultant bias in the data (see Section 3.8.2 of this report). The OBS mooring measurements (made at least 1 000 m beyond the dredge spoil disposal site) suggest that this threshold should be substantially higher. CSIR (2013c) states that should a turbidity of 66 NTU be exceeded at any point further than 500 m from the spoil disposal ground this should be taken as a signal of the need for immediate management intervention. This threshold of 66 NTU corresponds to a suspended solids concentration of 100 mg/ℓ, which corresponds to the 10th percentile of the Acute Sub-lethal endpoint for suspended solids concentration defined by Anchor Environmental (2003). The exceedance of this threshold (but at an increased distance of 1 000 m) seems the most appropriate criterion upon which to base the need for management intervention with respect to dredge spoil disposal activities. It should however be noted that the modelling predicts that this threshold of 100 mg/ℓ will be exceed up to a total duration of approximately 5 days per season (*i.e*. roughly 5% of the time) near the seabed but very rarely, if at all, in the upper water column.

All compliance monitoring must be done under the direct supervision of an independent environmental control officer and the results audited episodically by a supervisory committee.

Monitoring protocol

It is proposed that the monitoring commence approximately one month prior to the commencement of dredging activities. Upon commencement of dredging activities it is proposed that the profiling within the port be executed daily for approximately 5 - 7 days, such monitoring commencing after approximately 10 days of dredging and disposal activities. Thereafter the monitoring can take place once every two weeks; reducing to monthly or even a less regular basis should the results of the initial monitoring indicate this is acceptable. A similar approach should be taken at the offshore dredge spoil disposal monitoring sites; however the initial daily monitoring at the offshore sites is not required.

Collection and analysis of samples

Sampling to determine total suspended solids concentrations should be undertaken when executing profiling measurements, preferably near the surface and near the seabed. If possible such sampling should be supplemented by water samples obtained in the vicinity of the dredgers during dredging activities. These data will be help develop a more robust relationship between turbidity measurements and total suspended solids concentrations. The samples should be kept cool (preferably on ice) until return to the laboratory, where the turbidity should be measured and the total suspended solids concentration determined. Given the sampling is for compliance monitoring purposes analysis of the results should occur as rapidly as possible.

7.1.3 Turbidity and suspended solids monitoring to support the assessment of impacts in the marine environment

Should ecological effects be observed in the marine environment that are considered deleterious, certain minimum information will be required to determine whether such effects are attributable to dredging activities or not. This information will include wind, wave and current data that is both representative of the likely source of high turbidity or total suspended solids concentrations as well the potential impact locations, as well as turbidity or total suspended solids measurements at or near the site of impact.

The locations of potential impact within the Port of Richards Bay that will need to be monitored will need to be specified in collaboration with the marine ecology specialist. The focus here is on specifying the monitoring to occur in the offshore region. In addition to the profiling stations to be set up to monitor the consequences of dredge spoil disposal, it is proposed that:

- an Acoustic Doppler Current Profiler (ADCP) mooring (or equivalent instrumentation) be deployed offshore to measure waves, currents and bottom temperatures at a similar location to that used for the Berth306 study.
- two moorings measuring near bottom turbidity be set up at the same locations as the K and L mooring sites of the Berth306 monitoring (or at a location 1 000m distant from the dredge spoil disposal site boundary in both a NE and SW direction). Ideally these moorings need to be maintained for a one month period prior to dredging through to one month after dredging has ceased. However, given that dredging can occur over a long period and that the maintenance and servicing of such moorings may be onerous and costly, it is recommended that the mooring duration be limited to possibly the first 2 - 6 months of dredging (or the most intensive period of dredging). Based on an analysis of the data such monitoring may be rationalised or discontinued. Such a mooring duration should be sufficient to characterise physical and water quality parameters that could be drivers of any ecological changes of concern. Water column profiling and water sampling to determine total suspended solid concentrations for calibration purposes should be measured at the time of deployment, servicing and retrieval of the moorings. An alternative to such moorings would be more regular water quality profiling in the offshore region than indicated for compliance monitoring alone. However, such boat-based water column profiling of turbidity can be is costly and difficult to implement should it be required at a high temporal resolution. Furthermore, due to practicalities, such profiling is often biased towards calmer conditions when the water column turbidity is likely to be low. This implies that the full range of turbidity variability, particularly the temporal variability, may not be successfully sampled without the use of moorings.

7.2 Monitoring physical changes in benthic habitats

There are two aspects to monitoring change in benthic habitats, namely potential smothering impacts and changes in the morphology and sediments constituting those habitats (*e.g.* changes in grain size). For example, there could be significant (even medium-term or progressive) changes/impacts in the sea-floor in the areas surrounding the dredge spoil disposal site.

Bathymetric surveys

Generally pre- and immediate post-dredging bathymetric surveys are recommended for dredge disposal sites to monitor sediment erosion and deposition at and in the vicinity of these sites as these provide a good proxy for a number of potential impacts. Such pre-dredging surveys are required for engineering design and planning. Often the post-dredging survey is also required for verification of dredged and dumped volumes. These pre- and immediate post-dredging surveys should, therefore, not be considered as an additional cost attributable to environmental monitoring requirements alone. Such “in-“ and “out-surveys” have been undertaken for previous dredging programmes for developments within the Port of Richards Bay.

Thus, it is recommended here that immediate post-dredging bathymetric surveys be undertaken of the dredge disposal sites, including an area within 1 km surrounding the areas where disposal and sand sourcing has actually taken place. Ideally a second post-dredging survey needs to be undertaken to assess the sediment mobility and associated bathymetric changes. This survey should take place approximately 12 months after the completion of the immediate post-dredging survey.

Characterising changes in habitat

It is expected that the grain size distribution and organic content of the sediments at and surrounding the dredge spoil disposal site will change. To assess the nature and duration of these changes it is recommended that surficial ***sediment grab samples of the seafloor*** within the bathymetric survey areas should be collected on an approximate 0.5 by 0.5 km grid spacing (or spacing of similar nature informed by knowledge of the ecosystem at these sites), and analysed for sand/silt/mud/organic content. (Given the limited quantity of sediments containing toxicants (metals) it is not anticipated that these surficial sediments will need to be analysed for metals. However, following the Precautionary Principle, initial surveys should perhaps measure metal concentrations in the sediments identified as being of potential concern). This sampling should be conducted in conjunction with the bathymetric surveys, including the pre- and post-dredging surveys.

7.3 Monitoring of potential shoreline change impacts

Monitoring also need to be taken to assess potential shoreline change impacts associated the dredge spoil disposal mound and its effect on the local wave climate. Included in this monitoring should be:

- Beach topographic surveys extend from the back-shore as deep as possible into the surf zone, i.e. from approximately 120 m inland of the high water mark to -2 m MSL. Vertical accuracy should be better than 10 cm (ideally ~ 1 cm). Horizontal accuracy should be better than 1 m. The surveys should commence months, if not seasons, prior to the commencement of the capital dredging activities.
- Shoreline/beach sediment sampling and characterisation (grading analyses). Initially this should be conducted quarterly for the first two years from the start of construction, then every semester thereafter. The alongshore spacing should match the beach profile survey lines.

7.4 Monitoring to validate impact assessments and associated modelling activities

The monitoring suggested in Sections 7.1. - 7.3 should be sufficient to assess the extent of physical changes leading to impacts of concern, provided that the proposed monitoring using moorings is implemented.

Whilst not strictly an environmental monitoring activity, if any impact assessment is going to be made and validated the exact nature of the dredging operations needs to be recorded. This includes the nature and duration of dredging (*i.e.* dredging technology used, hopper size, down-time, number of dumps, location of dumps, *etc.*). Typically it is the absence of these data that makes it difficult if not impossible to robustly interpret the monitoring data. *The need to ensure a comprehensive record of the dredging operations cannot be overemphasized.* The recording of such information is considered essential.

8 CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

The modelling results suggest that the extent and duration of elevated suspended sediment concentrations in the water column as well as the extent of the re-distribution of disposed dredge spoil will be limited. The model does not predict any major impacts at recognised sensitive sites within the port as the effects are largely confined to the areas to be dredge. The model does not predict significant impacts at recognised sensitive sites beyond the port (*i.e.* mouth of the Umhlatuze Estuary). However, at times and for certain guidelines the extent (if not the duration) of elevated suspended sediment concentrations and thickness of sediments on the seabed is relatively extensive (extending up to 4 km from the dredge spoil disposal site).

In many respect the impacts are expected to mirror those of the Berth 306 dredging in the offshore domain. The key difference between the capital dredging proposed here and that which occurred during the Berth 306 capital dredging is that:

- the rates of dredge spoil disposal assumed here is approximately 0% greater than that for the Berth 306 capital dredging;
- it is also proposed that the dredge spoil be more evenly distributed over the offshore disposal site that occurred during the Berth 306 capital dredging;
- the mud content in the material to be dredged for the Richards Bay Capacity Expansion Option 3A capital dredging (48%) is comparable but slightly lower than that for the Berth 306 capital dredging (56%).

all suggesting that the elevation of turbidity due to the Richards Bay Capacity Expansion Option 3A capital dredging and dredge spoil operations may be greater in the offshore region than was observed for the Berth 306 capital dredging. Conversely, due to the location and nature of the dredging, the elevation of turbidity within the port itself due to the Richards Bay Capacity Expansion Option 3A capital dredging is expected to be much more confined and lower than that observed for the Berth 306 project.

8.2 Recommended Mitigation Measures

The Port of Richards Bay is a working port. Therefore, any mitigation measures proposed require careful consideration and should be practically achievable within this constraint. Within the port the only mitigations suggested are lean mixture overboard discharges be limited or that silt curtains or a similar measure be deployed (if necessary) to limit the spread of fine of fine sediments through the port. However, the model results suggest that such measures will not be required. Furthermore the practicality and/or viability of such measures is uncertain. Therefore, such a mitigation measure should only be considered to the extent that it is required and is practical, and it if provides cost-effective environmental protection.

The only other mitigation measures are to follow compliance monitoring procedures and management options (see Section 7) diligently and to follow the normal due diligence measures associated with dredging (*e.g*. minimisation of lean mixture overboard *etc.*).

There are no obvious mitigation measures for the offshore environment, since elevated turbidity and so on is largely determined by previous disposal of dredge material and prevailing environmental conditions, neither of which can be managed/controlled.

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