APPENDIX 1B

NAMIBIAN MARINE PHOSPHATE (PTY) LTD

WATER COLUMN

Sandpiper Project

Proposed recovery of phosphate enriched sediments from the Marine Mining Licence Area No.170 off Walvis Bay Namibia.

Environmental Impact Assessment Report for the Marine Component

Prepared by:
Mr. Jeremy Midgley (Pr.Sci.Nat)
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In association with:
Enviro Dynamics
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ENVIRO DYNAMICS

March 2012

Dr. R Carter: Water Column

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South Africa

SPECIALIST STUDY NO. 1B:

Water Column
Assessment of Potential Impacts on Marine Life arising from
Changes to Marine Water Quality

Project:

The Dredging of marine phosphate enriched sediments from Mining Licence Area No. 170

Date:

March 2012

Prepared for:

Namibian Marine Phosphate (Pty) Ltd.

Prepared by:

Lwandle Technologies (Pty) Ltd

Declaration:

I, *Robin Carter* of Lwandle Technologies (Pty) Ltd, do not have and will not have any vested interest (either business, financial, personal or other) in the proposed activity proceeding other than remuneration for work performed in terms of the South African Environmental Impact Assessment Regulations, 2010

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Report compiled by Robin Carter, Sue Lane & Erich Koch

Date	Version	Revised	Reviewed
02/12/2011	1	Erich Koch	R Carter
04/12/2011	2	R Carter	S Lane
19/12/2011	3	S Lane	R. Carter

summary

APPROACH TO THE STUDY

The risks to marine life in the water column arising from dredging for phosphates at depths of between 190-300 m on Namibia's continental shelf are assessed in this study. The study is to be integrated into a multidisciplinary assessment of effects of the proposed mining.

Information about ecosystem functioning in the mining licence area was obtained from consulting local experts and extrapolated from reports on other surveys done in Namibian and southern African waters. Additionally the scientific literature topical to dredging was drawn on. No fieldwork was done for the project.

A standard impact assessment methodology is used to predict the severity of impacts arising from the following typical dredging activities:

- disposal of wastes from regular vessel operations;
- exchange of ballast water;
- discharge of overspill from dredge hoppers, and
- excavation of the seabed.

Where possible measures to prevent or otherwise minimise negative effects are given.

OUTCOMES OF THE STUDY

Based on the specific environmental conditions which exist in the project area, and the proposed mining/dredging method and schedule, eleven potential impacts are assessed. These are:

- Pollution from discharged vessel wastes;
- Ecosystem disruption by alien species discharged with ballast water;
- Organisms adversely affected by suspended sediments in the water column;
- Toxicity from released hydrogen sulphide in the water column;
- Reduction in dissolved oxygen in the upper water column from introduced anoxic bottom waters;
- Increased nutrients promote phytoplankton growth and ultimately reduce dissolved oxygen concentrations;
- Trace metals (cadmium and nickel) discharged with the overspill affect organisms in the water column;
- Benthic organisms are exposed to remobilised cadmium and nickel in the dredge areas on the seabed;
- Benthic and/or demersal organisms are exposed to an increased flux of dissolved H_2S into the lower water column;
- Benthic and/or demersal organisms are exposed to anoxic sediments and lowered oxygen levels on the seabed; and
- Removal of thio-bacteria mats by dredging increases the flux of H_2S to the lower water column.

The results of the impact assessment are summarised in the table below. Ten of the eleven identified impacts are rated to be of low significance, at most, both before and after mitigation; the exception being the possibility of importing alien species in ballast water, which could be serious. However, the level of risk posed by the dredger releasing ballast water taken up from ports outside of the BCLME region is miniscule compared to the other shipping that may be discharging ballast water in Walvis Bay. Accordingly, this assessment does not identify any unique or significant environmental risks that may be generated by the proposed mining project.

Also, it is clear from other specialist studies that considerable areas of the seabed are disturbed by industrial fishing. However, until the effects of fishing are quantified, specifically the area of seabed disturbed by demersal trawling, neither cumulative nor additive effects can be assessed.
Finally, the confidence levels awarded to the impact assessments show that there is some uncertainty about the biogeochemical properties of the sediments in the proposed mining areas. This should be resolved by investigations specific to the mining areas either prior to commencement of mining or in its early/initial stages. The proposed dredging tracks (approximately 4 km long by 3.0 m wide) are unique in terms of monitoring investigations on overspill plume characteristics and behaviour. Therefore field investigations into these using combinations of ADCP (backscatter) coverage, multi-parameter CTD profiling and water sampling need to be conducted at intervals over at least the first years of mining operations. If these investigations show that the impacts are more severe than predicted herein, then real-time controls on, for example, exceeding established thresholds for turbidity, dissolved oxygen, H_2S etc. should be used to manage the dredging operations.

IMPACT ASSESSMENT SUMMARY TABLE

Table No.	4-3	4-4	4-5	4-6	4-7	4-8	4-9	4-10	4-11	4-12	4-13
Risk Area	**Vessel operation**		**Overspill discharge**					**Seabed dredging**			
Nature of the impact	**Pollution from wastes**	**Alien spp. in ballast water**	**Turbid plume**	**H_2S toxicity at surface**	**Oxygen deficient water at surface**	**Nutrients added at surface**	**Trace-metal toxicity at surface**	**Trace-metal toxicity on seabed**	**H_2S toxicity on seabed**	**Lowered oxygen levels on seabed**	**Increase of H_2S flux.**
Extent	Dredge area	National	Dredge area	Dredge area	Dredge area	Dredge area	Dredge area	Annual Mining Area	Dredge area	Annual Mining Area	Dredge area
Duration	Very short term	Short term to permanent	Very short term	Short term	Very short term	Short term	Short term	Short term	Medium term	Medium term	Long term.
Intensity	No lasting effect	None to serious	No lasting effect	Minor effects	No lasting effect	No lasting effect	Minor effects	Minor effects	Moderate effects	Minor effects	Minor effects
Probability	Possible	Possible	Possible	Possible	Improbable	Possible	Possible	Possible	Possible	Possible	Improbable
Status	Negative	Negative	Negative	Negative	Negative	Neutral	Negative	Negative	Negative	Negative	Negative
Significance (no mitigation)	None	Can be high	Low	Low	None	None	Low	Low	Low	Low	None
Mitigation	System maintenance	IMO guidelines	Built-in	None possible	n/a	None possible	None possible	None possible	None possible	Not possible	n/a
Significance (with mitigation)	None	None	Low	Low	None	None	Low	Low	Low	Low	None
Confidence level	High	High	High	Medium	High	Medium	Medium	Medium	Medium	High	Medium

glossary of terms and abbreviations

< - less than
> - greater than
°E – degrees east
°S – degrees south
µg/ℓ – micrograms per litre
µm – micro-metre
µMol - micro-mole
AAIW - Antarctic Intermediate Water
ADCP – acoustic doppler current profiler
BCLME – Benguela Current Large Marine Ecosystem
BNL - bottom nepheloid layer
cm/s - centimetres per second
Contaminant – foreign matter
EIA – Environmental Impact Assessment
EMMP – Environmental Monitoring & Management Programme
EPL - Exclusive Prospecting Licences
ESACW - Eastern South Atlantic Central Water
ESD – equivalent spherical diameter
g C/m^2/yr – grams of carbon per metre squared per year
H_2S - hydrogen sulphide
INL – intermediate nepheloid layer
km – kilometre
m – metre
m^3 – cubic metre
MFMR – Ministry of Fisheries and Marine Resources
ml/ℓ – millilitres per litre
MLA – Mining Licence Area
MV – Motor Vessel
NADW - North Atlantic Deep Water
NH_4^+ - ammonium
Nitrate (NO_3^-)
NMP - Namibian Marine Phosphate (PTY) Ltd
NO_2^- - nitrite
$^{o}/_{oo}$ - parts per thousand or per 'mille'

PO_4^{3-} - phosphate
POC - particulate organic carbon
Pollution – The introduction of contaminants into natural environment that may affect organisms or ecological processes.
POM – particulate organic matter
PON - particulate organic nitrogen
psu – practical salinity unit
SACW - South Atlantic Central Water
SiO_3 – silicate
SNL – surface nepheloid layer
SPM - suspended particulate matter
TSHD - Trailing Suction Hopper Dredge

contents

Tables and Figures

1 INTRODUCTION

Lwandle Technologies (Pty) Ltd. (Lwandle) has been commissioned by Namibian Marine Phosphate (Pty) Ltd to assess potential impacts of dredging for phosphates on the continental shelf off the central Namibian coast (called the Sandpiper Phosphate project).

The proposed mining and mining method *inter alia* will:

- Directly modify the seafloor in the mined area;
- Redistribute fine sediments to the adjacent seabed;
- Modify benthos community structure in the mined area;
- Affect seawater quality through re-suspension of sediments at the dredge head and discharge of lean water from the dredger's hoppers, possibly modifying dissolved oxygen distributions through either relocating hypoxic water in the water column or exposing anoxic pore water in the sediments. This can also apply to methane, hydrogen sulphides and contaminants that may be held within the dredge area sediments;
- Import alien and/or noxious organisms into the region via ballast water discharges from the dredger on first entry to the project area;
- Possibly affect fish and fisheries;
- Possibly disturb marine mammals and seabirds; and
- Possibly compromise other ecological services such as eco-tourism etc.

This specialist study is part of a suite of investigations into the various environmental risks posed by the proposed phosphate ore mining and is solely focused on potential water quality effects of dredging and risks associated with ballast water discharges (boxed text above).

1.1 APPROACH

The assessment into possible water quality effects was conducted as a desktop study based on the scientific literature topical to the proposed mining project. In addition local experts were consulted on the anticipated biogeochemical implications of dredging the identified ore body. No primary data were acquired for the project or project area.

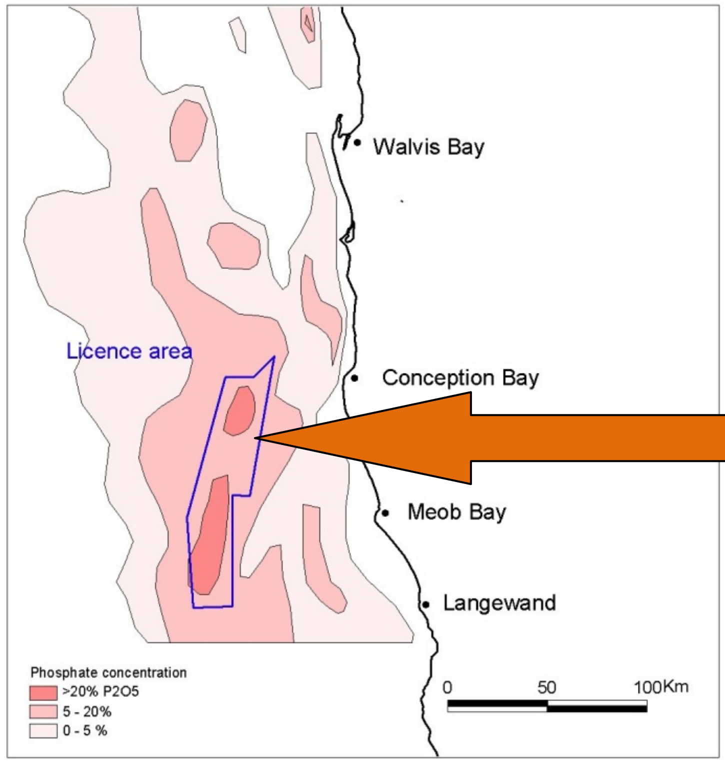
These data were analysed to assess environmental risks and potential impacts and to formulate recommendations for use in an environmental management and monitoring programme. The assessment has the following goals:

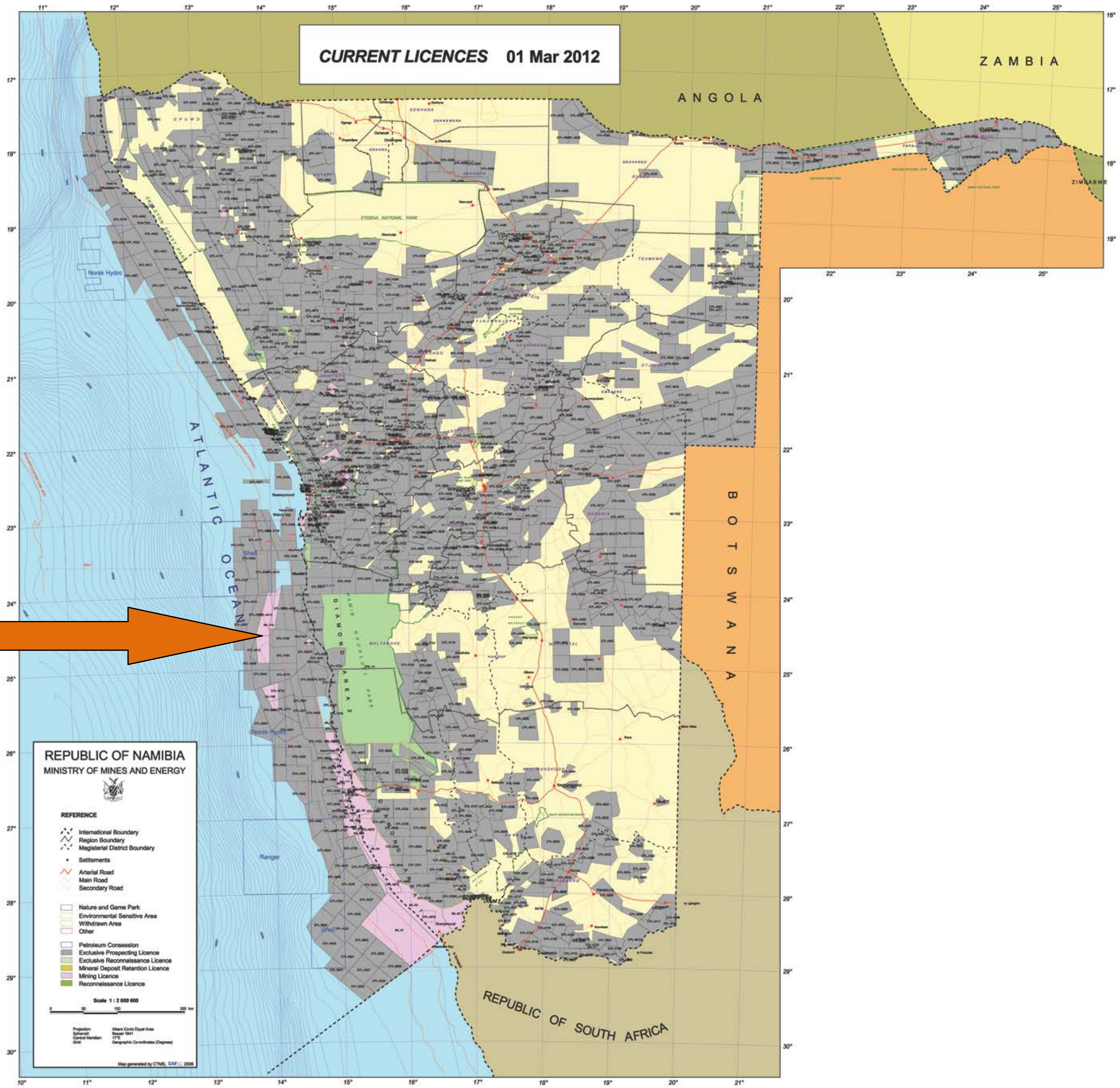
- first to prevent impacts;
- second to minimise the impacts that cannot be entirely prevented; and
- third to mitigate the residual minimal impacts.

1.2 STUDY AREA

The proposed mining area is located on the Namibian central continental shelf offshore of the region between Conception Bay and Langewand (**Figure 1-1**). Water depths in the mine area range between 190-300 m. The map on the right in **Figure 1-1** shows the Ministry of Mines and Energy's licence areas as at 1st March 2012; areas shaded pink are Mining Licence Areas (MLAs), grey are Exclusive Prospecting Licences (EPLs).

Figure 1-1: Location of Mining Licence Area (MLA) 170 offshore central Namibia.
MLA 170 is a consolidation of EPLs 3414, 3323 & 3415





1.3 ASSUMPTIONS AND LIMITATIONS

This assessment is based on a number of assumptions and is subject to certain limitations, which should be borne in mind when considering information presented in this report, i.e.

- It is assumed that the project information provided was correct at the time of writing of this report. In the event that project design changes significantly, further assessment may be warranted;
- The data gaps are unlikely to have a significant bearing on the results of the assessment and the mitigation measures recommended in this report take account of any potential risks associated with any data gaps; and
- The assessment of potential impacts assumes that NMP and all subcontractors will adhere to best practice Health, Safety and Environment (HSE) policies.

2 PROJECT DESCRIPTION

A detailed project description with all technical data tabulated is provided in the general EIA. Below is a brief summary of the proposed project.

The export target for the Sandpiper phosphate project is 3 million tonnes of 'rock phosphate' per annum, which requires the mining of 5.5 million tonnes of marine sediments. The mining licence is issued for a period of 20 years. In order to accommodate product supplies to the market place, as well as building a stockpile of exportable phosphate material, a three-year ramp up of production, is envisaged.

Within the mineral resource of the Mining Licence Area 170 , there are two initial target areas, SP-1 in the north and SP-2 south of this and slightly further offshore (**Figure 2-1**). A further candidate area has been identified (SP-3), this is 11 km long and 8 km wide (88 km^2) in water depths of 235-270 m. SP-1 is 22 km long and 8 km wide (176 km^2) in water depths of 190-235 m. This is the primary target site where dredging will commence. SP-2 has the same size but is in deeper water ranging from 245 m to 285 m.

The phosphate ore will be recovered by standard dredging techniques using a Trailing Suction Hopper Dredge (TSHD) operating in discontinuous mode; **Figure 2-2** shows a schematic view of a TSHD and suction pipes. During dredging the dredge arm and drag head will be lowered to the sea floor and then the dredger will sail along a defined dredge path removing a 3.0 m wide (width of drag head) by 0.75 m deep swath of sediment. It is proposed that the largest available TSHD will be used in the mining. This has a fill capacity of 46 000 m^3 which will produce approximately 70 000 tonne of sediment (saturated wet bulk density). It is anticipated that approximately 15% of the mass of the dredged material, equivalent to about 9 000 tonnes, will be fine sediments (<125 µm) and will be discharged overboard with the excess (lean) water through a discharge point in the dredger's hull located 10-15 m below the sea surface.

Once the dredger hopper is filled, the TSHD will sail to a single point mooring to pump the slurry ashore to a holding pond. It is assumed that it will take 16-17 hours to fill the hopper, and on average 20 hours to sail to shore for unloading and sail back to the operational location to initiate dredging again. The vessel will continue to dredge within the particular 'cut' zone terminating dredging just above the footwall clays. Depending on the resource this may be 2-3 m deep. It is expected that there will be 43 weeks of dredging per year during full operations (year 3).

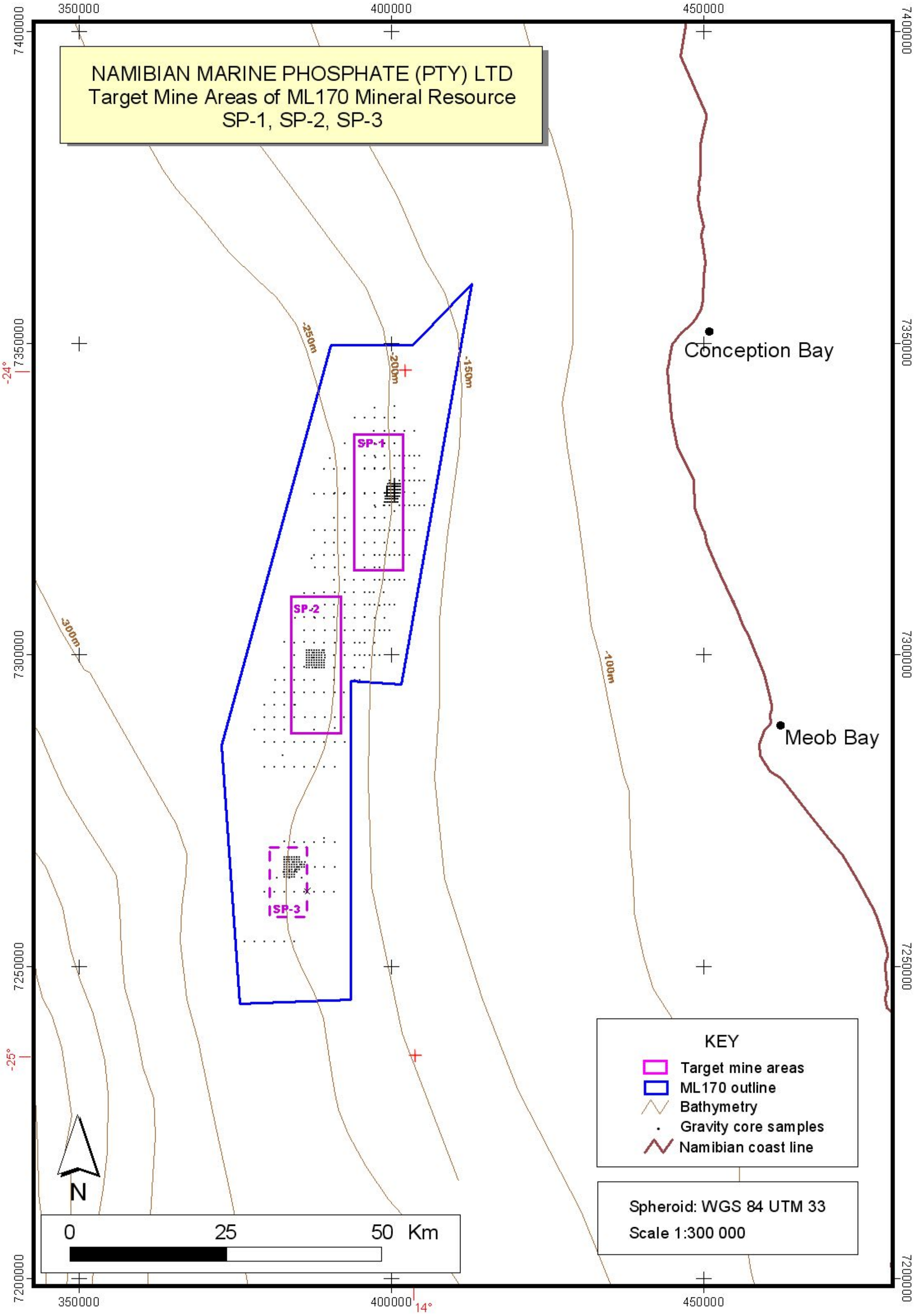


***Figure 2-1: Location of the proposed target sites* SP-1, SP-3 *and* SP-3**
within the three resource areas of the Sandpiper Phosphate licence area.

Figure 2-2: Schematic of a TSHD operating in relatively shallow water.

2.1 RISK FACTORS IDENTIFIED

Activities which need to be managed to reduce negative effects, as they are typically sources of potentially significant impacts on water quality, are:

- exchange of ballast water at commencement of dredging campaigns;
- excavation of the seabed in the mine area(s) potentially releasing hydrogen sulphide, exposing anoxic sediments with associated modifications to dissolved oxygen distributions, mobilisation of trace metals and possibly nutrient enrichment;
- discharge of fines and water from the dredger hopper (=plumes) in dredger overspill; and
- disposal of wastes from regular vessel operations.

Potential impacts will be assessed in **Section 4** below in relation to the specific environmental conditions which exist in the project area as described in **Section 3** below.

3 ENVIRONMENTAL DESCRIPTION

3.1 REGIONAL OVERVIEW

The Namibian coastline is about 1500 km in length and runs in a general SSE - NNW direction with a continental shelf between 100 and 160 km wide. The shelf is widest off the Orange River and off Walvis Bay and the main shelf break is at 300-450 m depth with a secondary 'minor' break at 130 - 180 m (e.g. Inthorn *et al*. 2006). Namibia and the west coast of South Africa is the eastern boundary of the Benguela Current Large Marine Ecosystem (BCLME), which lies between 15 - 37°S and 0 - 26°E (Shillington *et al*. 2006). The cool Benguela current is the only eastern boundary current to be bounded at both ends by warm water of tropical origin, the Angola Current on the north and Agulhas current in the south (**Figure 3-1**). The surface currents of the Benguela are generally equatorward, with vigorous coastal upwelling cells and strong equatorward shelf edge jets. Subsurface currents on the continental shelf especially below 100 m depth are consistently poleward (Shillington *et al*. 2006). Upwelling of cool nutrient rich water occurs throughout the Namibian continental shelf water and is generated by Ekman transport forced by the equatorward wind stress pattern of the Benguela system. A significant feature of the Namibian continental shelf is the presence of a mud belt about 740 km long in the inner and mid-shelf between Cape Frio and Conception Bay. The sediments are biogenic in origin, resulting from the high primary productivity of the region.

Seasonal intrusions of tropical, warm and saline waters from the Angola Current into the northern Benguela region occur in late summer or early autumn, while in winter and spring the front is then pushed northwards into the Angola gyre (Boyd 1987). The Angola front is a permanent feature at the sea surface maintained throughout the year in a narrow latitudinal band between 14 - 16°S (Hardman-Mountford *et al*. 2003). In years where the intrusion of the Angolan front is stronger and maintained during the summer/ autumn months, it is often referred to as a Benguela Niño year. At the southern end of the BCLME is the warm Agulhas Current (34 - 37°S), which is the western boundary of the southern Indian Ocean. Occasionally this retroflexes around the southern tip of Africa, intermittently producing Agulhas rings which may interact with the southern Benguela upwelling frontal system.

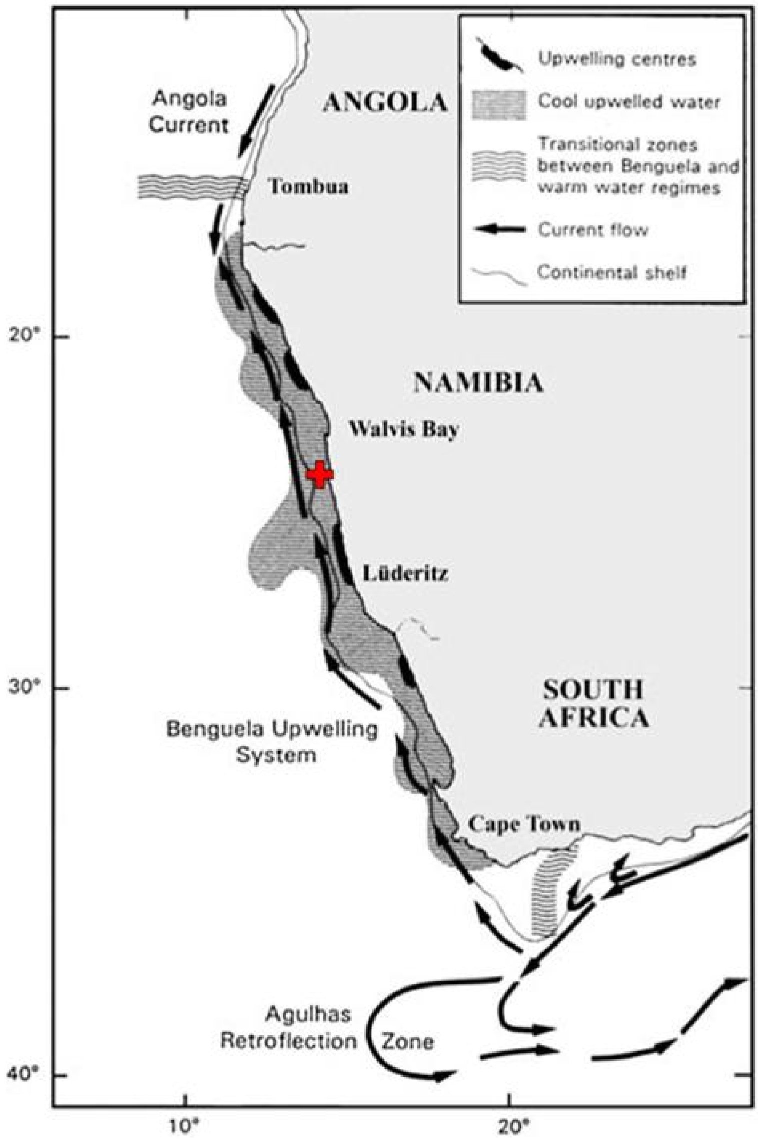


Figure 3-1: Main oceanographic surface features of the Benguela upwelling system
(from Bianchi *et.al*. 1999). The cross shows the location of the prospective phosphate dredge area.

Upwelling intensity is not uniform over the coastal area due to short term and seasonal differences in the wind regime and coastal topography. The major upwelling cell in the Benguela is located at Lüderitz. This may possibly be the strongest sustained, locally wind-driven coastal upwelling region of the world oceans (Hardman-Mountford *et al*. 2003). It is believed to effectively divide the Benguela system into two regions, acting as an environmental barrier for a number of species. Upwelling cells of lower intensity also occur northwards to Cape Frio, but observations have been made of upwelling occurring as far north as 15°S (Parrish *et al*. 1983). A number of generally weaker upwelling cells are located along the northern Namibian coast around 20°S and near Walvis Bay (23°S) in central Namibia. In the Southern Benguela additional cells are found near Hondeklip Bay (30°S) and at Cape Columbine (32°S) (Hardman-Mountford *et al*. 2003).

The Benguela ecosystem is highly productive and supports large fish stocks and associated commercial fisheries. The fishing industry in Namibia is the second largest contributor to the country's GDP and is therefore of great importance to the economy. Changes in distribution of demersal fauna occur mainly along depth gradients and latitude, with the central shelf area north of Lüderitz mainly being dominated by Cape hake *Merluccius capensis* and the pelagic goby *Sufflogobius bibarbatus* and has a low overall species diversity, consistent with the generally hypoxic waters in the area (Bianchi *et al*. 1999.). Higher species diversity is found south of the Lüderitz upwelling cell, with a number of species reaching their northernmost limit having their distribution off South Africa. Even though the oxygen content is also low, it is not as extreme as in the northern shelf region allowing for a larger number and diversity of fish species and invertebrates.

3.2 CENTRAL NAMIBIAN CONTINENTAL SHELF

3.2.1 Water Circulation and Currents

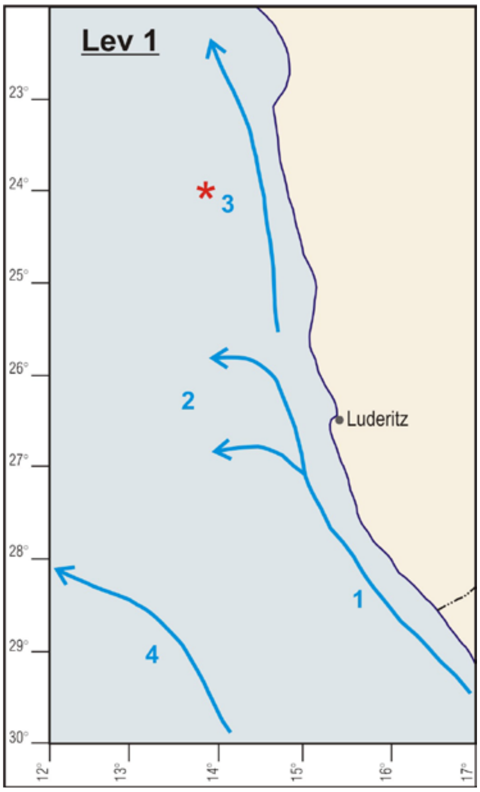
In the area of the proposed dredge site, waters shallower than 40 m have an overall northward flow, with maximum velocities occurring in austral summer. Poleward flow starts dominating as the water depth increases (Shillington *et al*. 2006). Shillington *et al*. (2006) used the CLIPPER numerical model to simulate and represent graphically current and coastal circulation around the shelf areas of Namibia (http://www.ifremer.fr/lpo/clipper/ present.html). The prevailing currents and circulation at various depths are shown in **Figures 3-2** to **3-4.**

3.2.1.1 Surface layers (0-30 m)

Circulation in the surface waters along the Namibian coast and mining licence area are shown in **Figure 3-2** – LEV01. The surface circulation appears to be dominated by a perennial northward coastal current (1), with intensity peaking during austral summer (25 cm/s). The current (1) is seen to be stronger south of Lüderitz before it bifurcates partly westwards (2 and 3). The current in the coastal area between 22 - 26°S is less intense at about 15 cm/s and exhibits a lower seasonal effect. The westward circulation (4) does not seem to interact with coastal circulation.

3.2.1.2 Circulation at 40 m

The circulation at 40 m (**Figure 3-2** - Lev04) is almost identical to the surface waters, with two main exceptions. Firstly, the maximum current speeds are lower, the northward coastal current (1) is only about 20 cm/s in summer and the current north of 26°S is still present but less intense so that the branching current (3) is not always easily defined. Secondly, the main change at 40 m is the development of a poleward current (red dotted arrow 4) centred at 14°E just off the Walvis Bay area which reaches to about 25 - 26°S. The poleward circulation at this depth is not a permanent feature and occurs twice a year, in February-March and again in October. Dotted arrows indicate that the current is intermittent and shows seasonal variability.



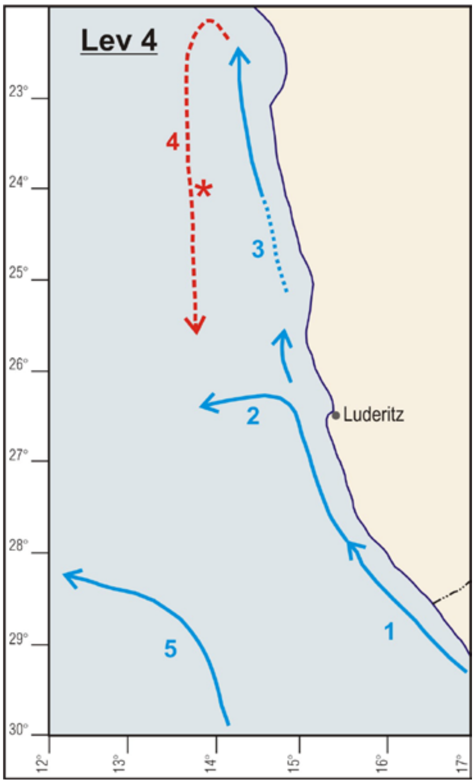


Figure 3-2: Modelled circulation at the surface (Lev 01) and 40 m depth (Lev 04), *representative of the perennial modelled coastal circulation. The northward coastal current (1 and 3) is weaker during austral winter (modified from Shillington et al. 2006). The red star represent the location of the proposed mining site.*

3.2.1.3 Circulation at 80 m and 130 m

Figure 3-3 shows model output diagrams based on the circulation at 80 m (Lev07) and 130 m (Lev10) depths for the same stretch of coastline. At 80 m the southward current (4) intensifies in comparison with the northward current (3), and becomes especially prevalent in September through to April. The northward flowing coastal current becomes much weaker at 80 m and is not as clearly identifiable with maximum current speeds of about 10 cm/s. At 130 m all flow is poleward and there is no evidence of any northward (equatorward) flow. The branches feeding the northward current south of Lüderitz are unstable and also become less defined.

3.2.1.4 Circulation at 230 m and 350 m

Figure 3-4 depicts model output diagrams based on the circulation at 230 m (Lev13) and 350 m (Lev15) depths. The currents flow poleward with maximum speeds, occurring in February and October, in the order of a few centimetres per second. The northward current south of Lüderitz along the shelf (1) only develops in winter at very low speeds and does not penetrate north of 27°S.

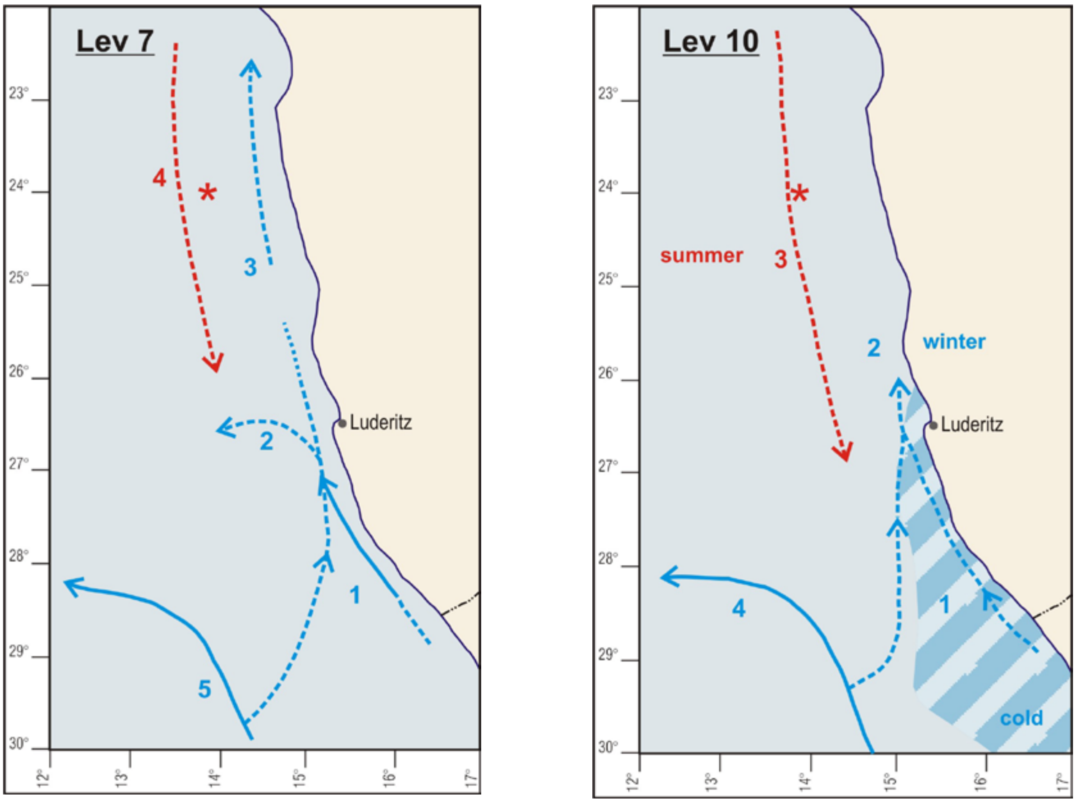


Figure 3-3: Modelled circulation at 80 m (Lev07) and 130 m depth (Lev10)
(from Shillington et al. 2006). The red star represent the proposed mining site.

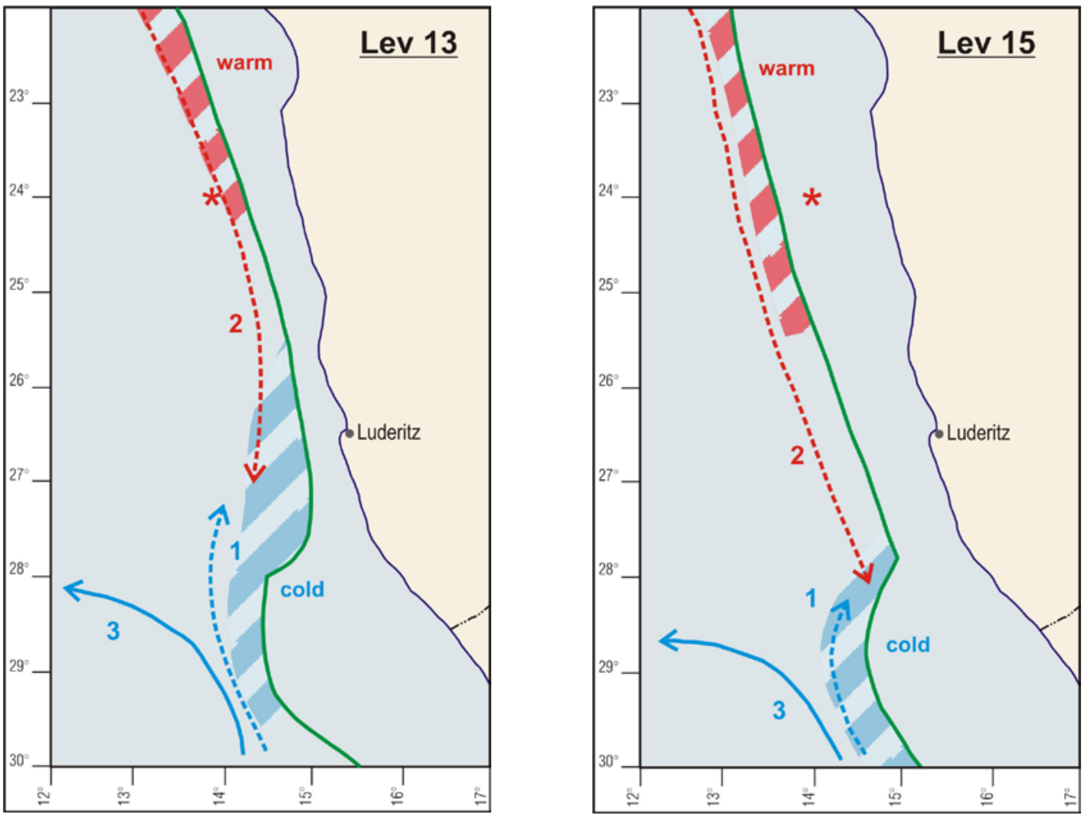


Figure 3-4: Modelled circulation at 230 m (Lev 13) and 350 m depth (Lev 15)
(from Shillington et al. 2006). The red star represent the proposed mining site.

3.2.2 Temperature and Salinity

Water column temperatures in the region of the proposed mining site show seasonal signatures with the surface waters warming above 20°C in summer, largely due to solar heating. According to Bartholomae and van der Plas (2007), the 14°C isotherm is generally located at 30-40 m in summer, and during years of more intense and sustained intrusion of the Angolan front, such as Benguela Niño years, this deepens to 90-100 m.

Figure 3-5 shows the general vertical stratification and characteristic properties of the different water masses which make up the water column just north of the Lüderitz upwelling cell (Inthorn *et al*. 2006). Below the thermocline, two central water masses can be identified, the oxygen depleted, nutrient rich SACW flowing south in the poleward undercurrent from the Angola gyre, and the less saline, relatively nutrient-poor ESACW from the Cape Basin (Shillington *et al*. 2006; Inthorn *et al*. 2006). In both these water bodies there is generally a significant oxygen deficit with the oxygen minimum zone intensifying closer to the shelf where the influence of the poleward flowing SACW is strongest. At depths below this, along the continental slope, AAIW, which is formed at the surface in sub-polar and polar-regions, enters the northern Benguela through the Angola Basin in the poleward undercurrent along the shelf edge (Shillington *et al*. 2006). At depths greater than ~800 m NADW would be encountered (Inthorn *et al*. 2006). Neither AAIW nor NADW appear to extend onto the continental shelf, being confined to the continental shelf slope and deeper.

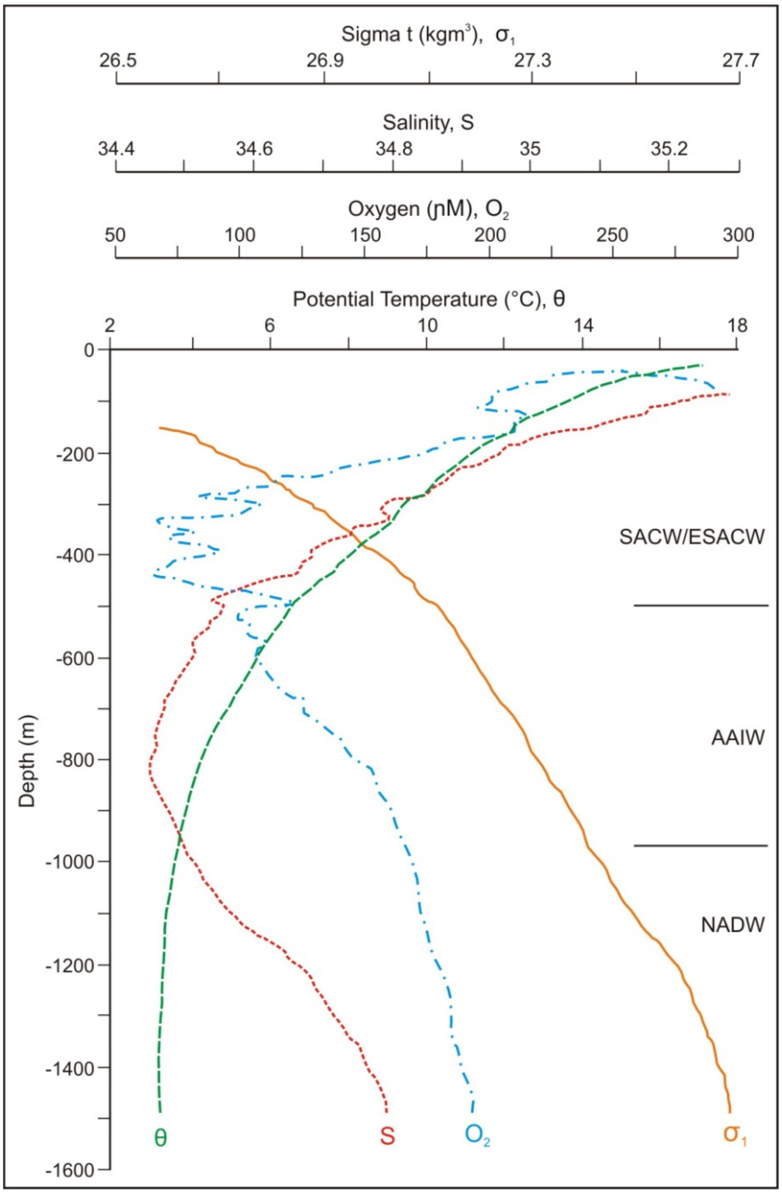


Figure 3-5: Water mass distributions off Namibia
at the northern edge of the Lüderitz upwelling cell at about 25°S. SACW: South Atlantic Central Water, ESACW: Eastern South Atlantic Central Water, AAIW: Antarctic Intermediate Water, NADW: North Atlantic Deep Water (taken from Inthorn et al. 2006).

Figure 3-6 shows a time series distribution of the water conditions at the outer shelf, at 320 m water depth, off Walvis Bay for the decade between 1994 and 2004. It can be seen that in the summer the surface water temperatures can reach up to 20 - 21°C towards the end of summer and cool to about 12 - 14°C during the winter. At the base of the water column the temperature ranges between 8 °C and 11 °C.

Salinities range between 34.7 and 35.1 psu with the higher salinities occurring in the near surface waters (above 200 m depth). Below this depth salinity co-varies with temperature (**Figure 3.6**).

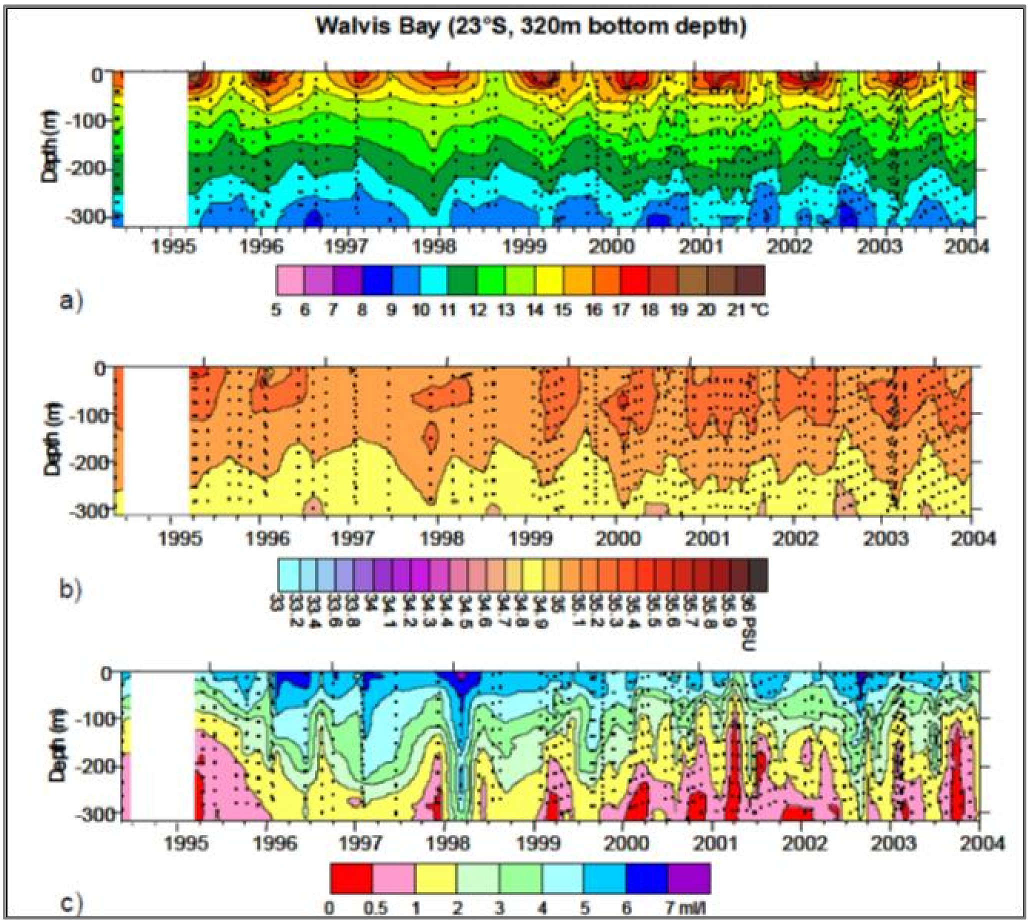


Figure 3-6: Variability of temperature (a), salinity (b) and oxygen (c) at the outer shelf
at 23°S in the Central Benguela between 1994 and 2004. The oxygen variability is modulated by both seasonal (summer/late summer) and interannual (1996-1999 vs 2000-2002) scales (taken from Monteiro and van der Plas (2006)).

3.2.3 Upwelling and Thermoclines

3.2.3.1 Upwelling

The South Atlantic high pressure system is a permanent feature of the region and is subject to seasonal shifts of its centre. The anti-clockwise flow runs almost parallel to the Namibian coast with winds present throughout the year, strongest in winter and spring. The resulting Ekman offshore transport induced by the Southeast trade winds is the primary driving force for the upwelling of the subsurface water mass between Conception Bay at about 23°S and southwards to about 27°S (Hardman-Mountford *et al*. 2003). High primary production off Namibia is supported by the resulting upwelling of cold, nutrient rich, oxygen depleted SACW that penetrates the area from the Angola gyre in austral summer and mainly from the ESACW in winter. Strong upwelling is perennial, with the main seasonal change being noticed in the increased temperature gradient between the offshore ocean water and the upwelled water inshore. The intensity and longevity of the Lüderitz upwelling cell divides the Benguela system into northern and southern sub-systems.

The prospective dredge area is situated on the northern edge of the main Lüderitz upwelling cell and south of the Walvis Bay upwelling cell which is situated at about 22 - 23°S. Due to the intensity of the Lüderitz cell, there is very little primary production in the near shelf area at Lüderitz, but very rich productivity occurs on the upwelling cells boundaries (Bartholomae and van der Plas 2007). The northward flowing surface current feeds the cold, nutrient rich and highly productive water from the upwelling cell over and northwards of the Walvis Bay shelf. This high productivity becomes a major source of biogenic material for the mud belts in the northern Benguela and contributes to the hypoxic and anoxic water conditions characteristic of the central continental shelf in this region (as discussed below).

An extreme intrusion event of the Angola Current into the northern Benguela, likely in autumn, would cause a southward migration of the Angola-Benguela front and bring in warm, nutrient poor water along the northern Namibian coast, possibly as far south as Meob Bay, at about 24°S (Hardman-Mountford *et al*. 2003). Such an intrusion would be associated with decreases in primary productivity in the northern Benguela due to the deepening of the thermocline stabilising the water column and thereby preventing upwelling in the areas of the warm water intrusion with the associated low nutrient concentrations inhibiting phytoplankton production (Hardman-Mountford *et al*. 2003).

3.2.3.2 Thermoclines

According to Boyd (1987), the thermocline off Namibia, between 22°S and 24°S is generally found between 15 - 25 m water depth in both winter and summer, while further south in the centre of the Lüderitz upwelling cell no thermocline exists over the shelf-edge at any time of the year. **Figure 3-6** shows the temperature distributions (top panel) at the edge of the continental shelf at 23 °S with clear evidence of the periodic development of thermoclines in the upper water column. These relax in late winter/spring. In autumn, southward intrusions of the Angola Current into the northern Benguela can also deepen thermoclines and restrict upwelling. This is dependent on the strength of the intrusion, which may reach down to Meob Bay in extreme years (Shillington *et al* 2006; Hardman-Mountford *et al*. 2003).

3.2.4 Nutrients

The shelf waters of the Benguela are characterised by elevated concentrations of nutrients in comparison with those in the surface mixed layer of the adjacent oceanic waters, and also in comparison with concentrations from source waters (**Table 3.1**). For example, SACW water at the thermocline contains about 0.8 - 1.5 µMol (micro-moles) phosphate, but continental shelf waters have phosphate concentrations typically between 1.5 and 2.5 µMol, with values as high as 8 µMol having been recorded off Namibia. This indicates that local regeneration processes within the water column are important throughout the Benguela, but particularly off Namibia (Shannon and O'Toole 1999).

Table 3-1: Nutrient concentrations (µMol) in offshore upwelling source water,

taken to be 11 °C 12 °C, continental shelf and oceanic surface waters in Namibia (Chapman and Shannon 1985, Shannon and O'Toole 1999).

Water Body	Nitrate	Phosphate	Silicate
Offshore upwelling source water	15-25	1.5-2.5	5-20
Continental Shelf	10-30	2-3	20-50
Oceanic Surface	<5	<2	<1

Surface water outside of the upwelling zones may be depleted in silicate which may become the growth limiting nutrient for diatoms (siliceous phytoplankton). In these waters phosphorus is sufficient to support phytoplankton production which is based on ammonium as a nitrogen source (Dittmar and Birkicht 2001).

3.2.5 Dissolved Oxygen

The subsurface waters for much of the Benguela Current system , in particular off Namibia, are naturally hypoxic (<3 ml/l), even anoxic at depth, partly as a consequence of the southward subsurface flow of SACW from the highly saline and hypoxic Angola Basin (Shillington *et al* 2006; Monteiro and van der Plas 2006). The strength of the thermocline contributes to the formation and maintenance of the low oxygen waters as it inversely dictates the downward flux of oxygen to levels below that of the biogeochemical demand in the deeper waters (Monteiro and van der Plas 2006). **Figure 3-6(c)** shows the oxygen variability at the continental shelf edge off Walvis Bay from 1994 – 2004. Surface waters are generally normoxic with concentrations >5 ml/l, but there is a substantial decrease in oxygen concentrations to hypoxic conditions below 100 m water depth.

These low oxygen concentrations extend over a large proportion of the Namibian continental shelf and are particularly evident over the mud belts as shown by comparing **Figure 3-7** with **Figure 3-9**.

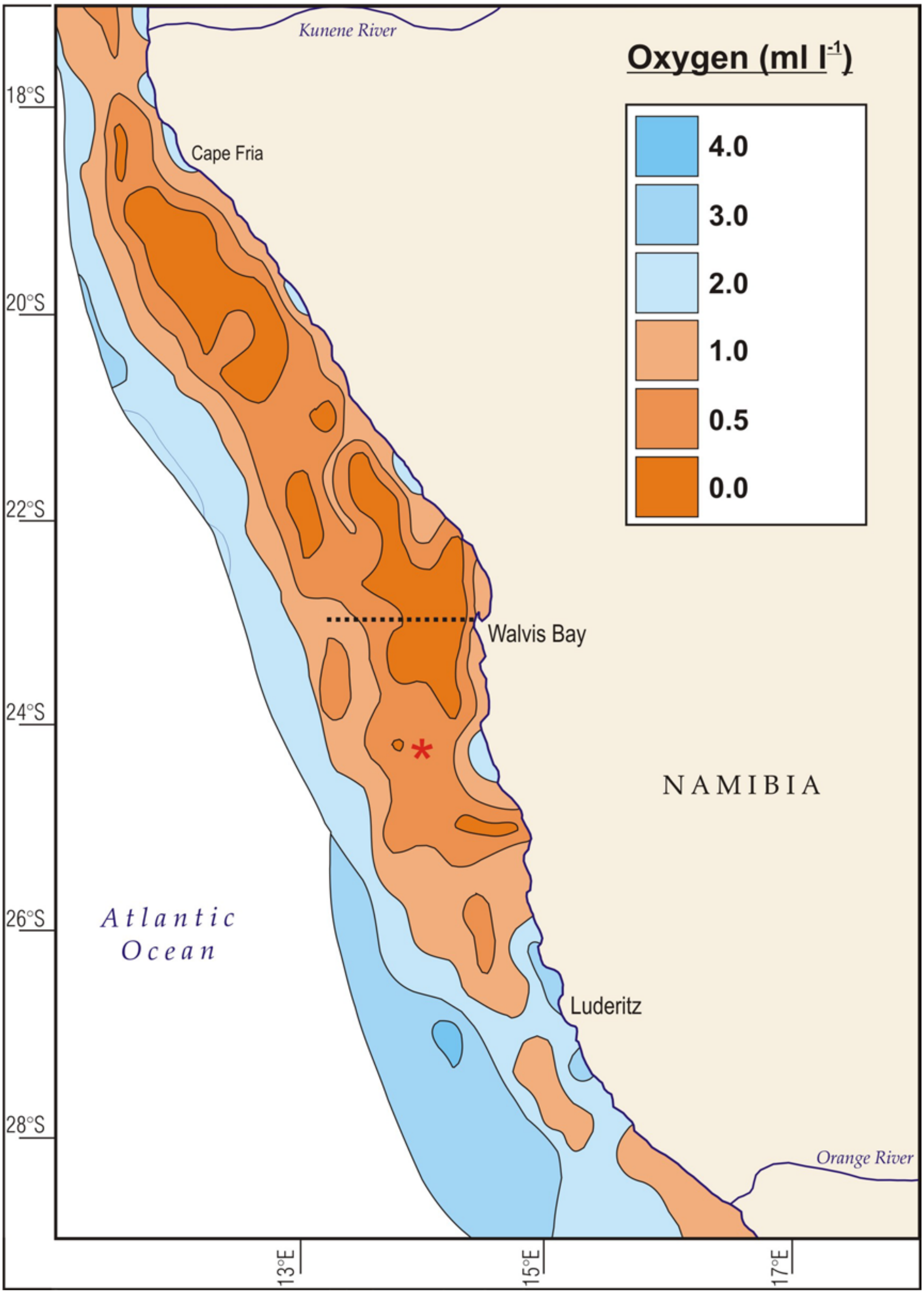


Figure 3-7: Spatial distribution of dissolved oxygen concentrations
along the central Namibian shelf (Taken from Bartholomae and van der Plas 2007). The red star shows the location of the proposed mining site and the black dots the Walvis Bay monitoring line.

Low oxygen conditions are temporally persistent both at the shelf edge (**Figure 3-6**) and on the mud belt itself (**Figure 3-8**). The latter figure indicates that anoxic (<20 µmol = < 0.5 ml/l) conditions at the base of the water column may persist for as much as a year. Time series data from the Walvis Bay monitoring line (location shown in **Figure 3-7**) indicate that 10-30% of the central Namibian continental shelf waters may have dissolved oxygen concentrations below 0.5 ml/ℓ (Barthomolae and van der Plas 2007). This confirms the contention of Chapman and Shannon (1985) that the continental shelf waters off central Namibia are typically oxygen stressed.

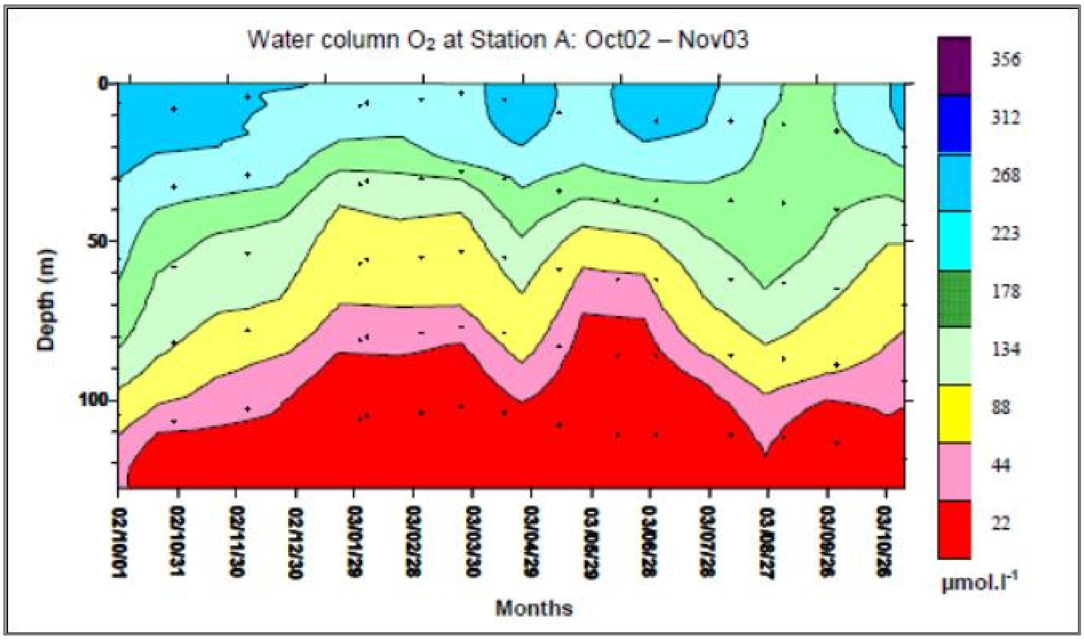


Figure 3-8: Time series measurements of dissolved oxygen concentrations
in the water column overlying the inner continental shelf mud belt off Walvis Bay (from Joubert 2006).

3.2.6 Seabed Sediment Properties

A major feature of the seabed sediments on the Namibian continental shelf is the longshore bands of high and low POM (**Figure 3-9**). These are considered to be mediated by sedimentation of the products of high surface productivity in the inner, richer mud belt and then resuspension and offshore transport of relict material in nepheloid layers (Inthorn *et al*. 2006). The banded structure is thought to be the result of distributions of turbulence associated with internal tides (Monteiro *et al*. 2005).

Van der Plas *et al*. (2007) present data showing that the inshore high POM belt has a high percentage of particulate organic carbon and nitrogen, carbon/nitrogen ratios of 7-8, high percentage mud texture and is comparatively unconsolidated with a high water content. In contrast, low POM sediments have the expected low particulate organic carbon and nitrogen concentrations, carbon/nitrogen ratios of 9-10, a muddy sand texture and are relatively well consolidated with lower water content. Sediment pore water distributions mostly follow those of the sediment properties. The inshore high POM belt has pore water with elevated hydrogen sulphide (H_2S), ammonium (NH_4^+), phosphate (PO_4^{3-}) and silicate (SiO_3) but low nitrite (NO_2^- and nitrate (NO_3^-) concentrations. Reverse distributions were recorded for low POM sediments except that nitrites were similarly low and nitrates marginally higher.

Pore water ammonium and hydrogen sulphide ion concentrations were related to carbon/nitrogen ratios; the former being elevated below a threshold value of 10 while the latter was more restricted to sediments with ratios <8.

Van der Plas *et al*. (2007) applied a simplified steady state simulation model to their data to identify biogeochemical conditions controlling the release of hydrogen sulphide from sediments into the bottom boundary layer. This showed that, below dissolved oxygen concentrations of 1.4 ml/l, hydrogen sulphide flux was high and related to particulate organic carbon concentration and flux within the sediments. At higher dissolved oxygen concentrations the hydrogen sulphide flux to the bottom boundary layer was low and insensitive to the particulate organic carbon flux.

The important conclusions from the above derived by the authors is that the spatial extent of the benthic-pelagic coupling link for the formation of low oxygen bottom waters and associated fluxes of ammonium and hydrogen sulphide ions to the benthic boundary layer (and potentially higher in the water column) is limited to the inshore high POM mud belt at depths between 80 m and 140 m.

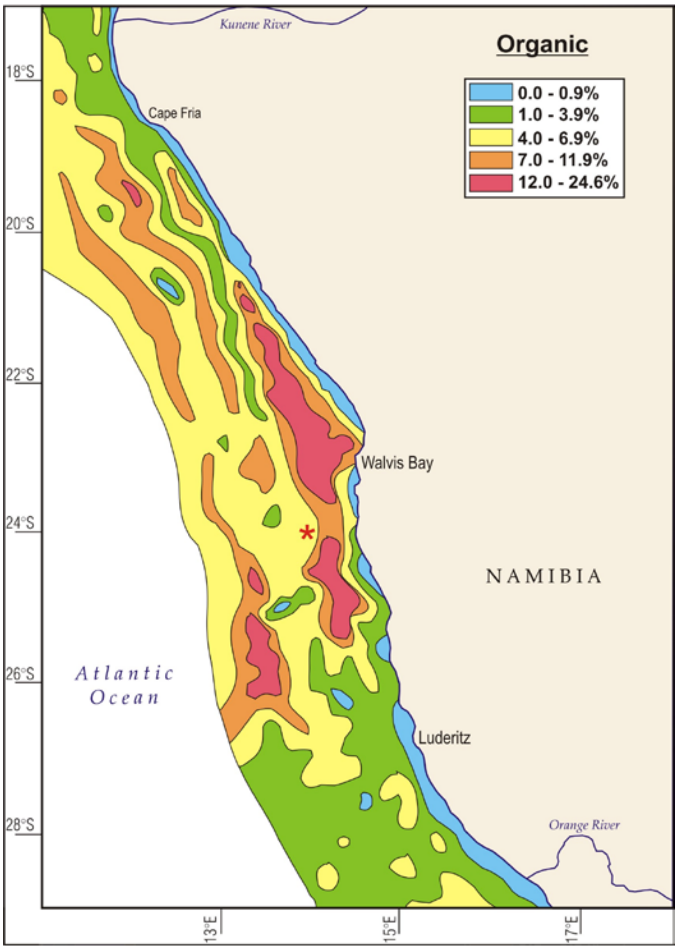


Figure 3-9: Spatial distribution of particulate organic matter (POM),
representing the mud belt along the central Namibian shelf showing the longshore bands of high and low POM (Taken from van der Plas et al. 2007). The red star shows the location of the proposed mining site in deeper water (190-230 m) outside of the inshore mud belt.

Details on surficial sediment properties in the actual mine areas are derived from shallow gravity core logs compiled during prospecting (NMP data) a survey of sediment properties in the approximate centre of the mining licence area (Rogers 2008), the Bremner (1978) regional sediment texture data and observations on sediment texture from benthos grab samples (Steffani 2011).

Gravity core logs indicate that the upper portions of the cores, taken across the centres of the proposed mine areas, were typically muddy sand with abundant shell material. The sand contains phosphorite pellets usually in the fine (125 µm) to medium (250 µm) particle size range. In a series of eight grab samples extending from 44-58 km offshore at 24.44° S the two inshore samples (44 & 46 km offshore) had sandy mud textures whilst the balance further offshore were characteristically muddy sand with shell material. Benthos grab samples were classed as fine/medium sand with shell; the mud fraction appeared to be absent in these samples. It is possible that, due to the high shell content, the jaws of the grab used for sampling did not completely close and whatever mud that may have been sampled washed out of the grab. It appears to be improbable that this would have occurred for all of the grab samples and therefore it is considered to be likely that mud comprised a very minor proportion of the sampled sediments, if it was at all present. These observations accord with the sediment properties listed by van der Plas *et al*. (2007) for their station 2 immediately offshore of the inshore mud belt off Walvis Bay. Further, the location of the mining area immediately offshore of the inner continental shelf break (~180 m depth) coincides with the depth band where there is elevated turbulence associated with internal tides. This is probably sufficient to prevent retention of sedimenting organic matter from surface productivity and advection from the inshore mud belts (Monteiro et al. 2005).

The differences in sediment textures between the sediments in the proposed mine areas and those recorded for the inshore mud belt to the north are illustrated in **Figure 3-10**.

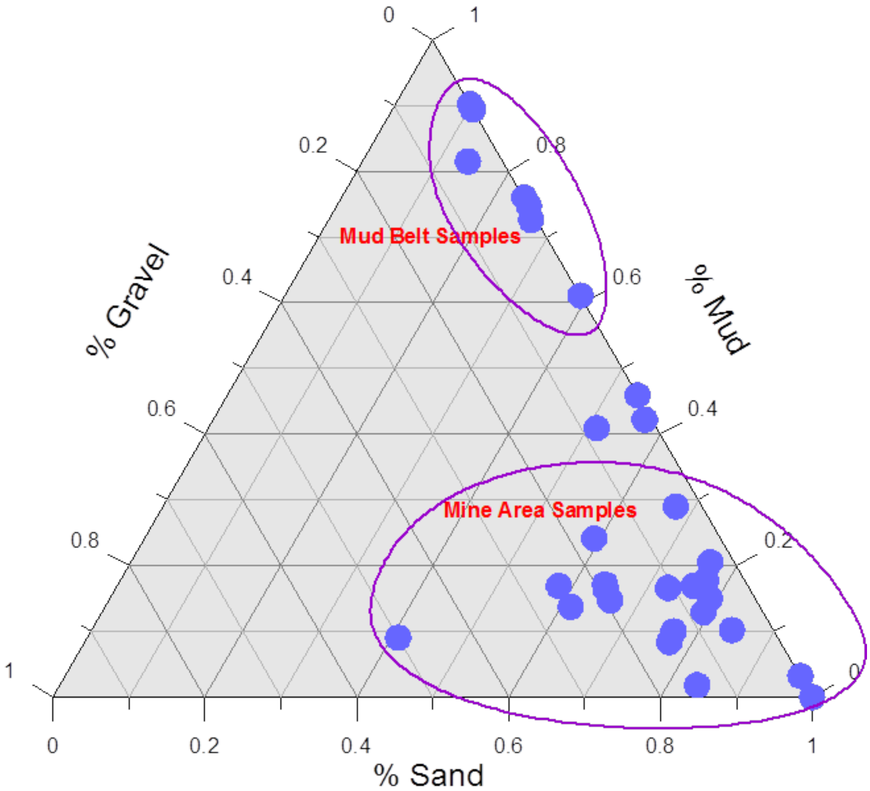


Figure 3-10: Ternary diagram showing sediment textures
in the proposed mine areas and the inshore mudbelt.
Data extracted from Bremner (1978) and Rogers (2008)
Station data used in the plot are listed in Appendix A.

Regional scale information on trace metals on the Namibian continental shelf appears to be restricted to the distributions derived by Calvert and Price (1970, cited in Chapman and Shannon 1985) which are depicted in **Figure 3-11**. These show a consistent relationship between trace metal concentrations and elevated organic carbon concentrations. From this it can be inferred that the distribution of trace metal concentrations will follow that of the high POC mud belts and that concentrations outside of these will be relatively low. This is consistent with general and widespread observations on sediment trace metals in that they are largely associated with silt and clay sized particles and generally have lower concentrations in coarser sediments (e.g. ANZECC 2000).

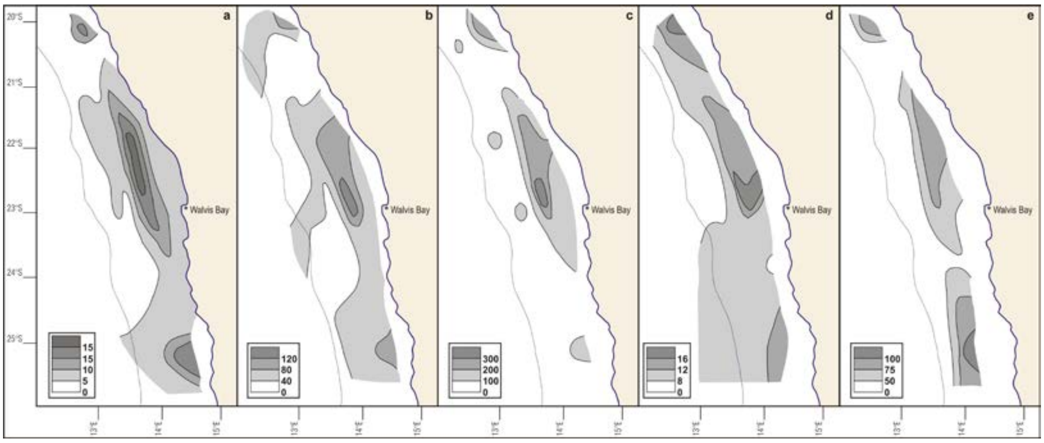


Figure 3-11: Distributions of a) organic carbon, b) copper, c) nickel, d) lead and e) zinc
on the Namibian continental shelf. Units are mg/kg except for organic carbon which is % weight. Plots taken from Calvert and Price (1970) as presented in Chapman and Shannon (1985)

Trace metal concentrations from shallow sediment cores (40-65 cm) taken from within the inshore high POM mud belt immediately north of Walvis Bay are listed in **Table 3.2** and compared against the sediment quality guideline concentrations for the BCLME region (CSIR 2006a).

Table 3-2: Comparisons of trace metal concentrations

in the inshore mud belt immediately north of Walvis Bay against the BCLME sediment quality guidelines (CSIR 2006a). Concentrations are mg/kg sediment.

Trace metal	Inshore mud belt (POM>90%)		BCLME Guideline level	BCLME Probable Effects level
	Borchers et al 2005	*Chapman & Shannon 1985*		
As	13	-	7.24	41.6
Hg	-	-	0.13	0.7
Cr	83	-	52.3	160
Zn	35	81	124	271
Cd	29	-	0.68	4.21
Pb	-	8	30.2	112
Ni	46	116	15.9	42.8
Co	4	-	-	-
Al	-	-	-	-
Mn	45	-	-	-
Fe	-	-	-	-
Cu	37	75	18.7	108

These data imply that arsenic, chromium, cadmium, nickel and copper concentrations in the high POM mud belt may exceed the BCLME sediment quality guideline values and that cadmium and nickel exceed the defined probable effect level for toxicity to marine organisms. Unpublished trace metal data for the region held by MFMR confirm this but also show that although cadmium and nickel may also exceed the BCLME guideline concentration thresholds in muddy sand sediments offshore of the inshore mud belt the measured concentrations are well within the probable effect level concentrations. Borchers *et al*. (2005) point out that the elevated concentrations observed are attributable to cycles of H_2S outgassing and sulphidation of the lower water column. This triggers precipitation of some trace metal species and sedimentation along with POM from phytoplankton. These are then sequestered in the sediments leading to the observed concentrations. The trace metal distributions are therefore a consequence of natural processes as opposed to contamination from an anthropogenic source or sources.

3.2.7 Suspended Particulate Matter

Information on suspended particulate matter (SPM) on the Namibian central continental shelf is sparse. Emery *et al*. (1973, cited in Chapman and Shannon 1985) show a negative gradient with distance offshore in particulate matter concentration ranging from 1.0 to 0.12 mg/ℓ. Most of this is biogenic with 60-90% organic matter. In a more recent study of nepheloid layers Inthorn *et al*. (2006) reported peak SPM concentrations of 2.1 mg/ℓ near the seafloor in the bottom nepheloid layer (BNL). These authors also detected surface (SNL) and intermediate (depth) nepheloid layers (INL). Peak SPM concentrations in the former attain ~3.4 mg/ℓ nearshore whilst the latter are more typically 0.5 mg/ℓ or less (calculated from Figure 5 and Table 2 in Inthorn *et al*. 2006). Particle properties vary between the various nepheloid layers; in the SNL they are 'fresh, large, biogenic particles' whilst in the INL and BNL they are considered to be finer and contain more refractory material (Inthorn *et al*. 2006).

The nepheloid layers are the main vectors for SPM transporting surface produced material to deposition areas in the nearshore mud belt and offshore of the continental shelf break. A schematic representation of these distributions in relation to the proposed mining area is shown in **Figure 3-12**.

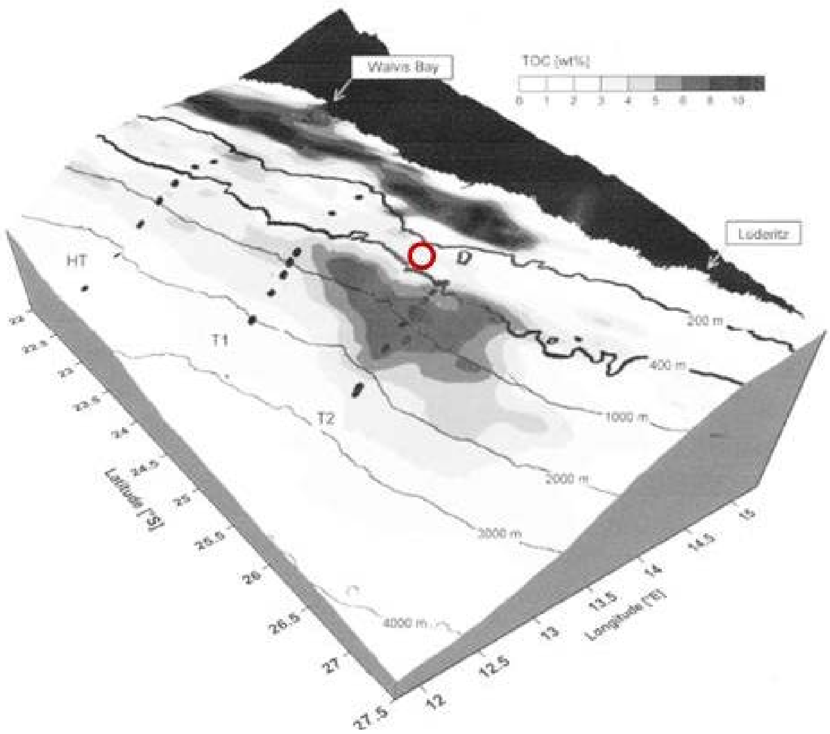


Figure 3-12: Organic carbon distribution on the Namibian continental margin.
Particulate organic carbon (POC) is transported to the depocentre on the upper to intermediate shelf slope by BNL flows affected by Ekman veering (from Inthorn et al. 2006). The red circle shows the proposed mining area in relation to the POC distributions.

Monteiro *et al*. (2005) report considerably higher SPM concentrations in the BNL for inner and outer continental shelf locations on the central Namibian continental shelf measured by moored instrumentation (optical backscatter sensors calibrated against filtered surface water samples). At their outer continental shelf break station (450 m depth) they recorded 34 turbidity events where SPM was in excess of 20 mg/ℓ and five events where SPM exceeded 100 mg/ℓ over a 180 day measurement period. At their inner continental shelf station located in the inshore high POM mud belt most of the measurements exceeded 20 mg/ℓ and for 56 days of the 180 day measurement period SPM concentrations exceeded 100 mg/ℓ. The highest concentrations measured at this site were 400-500 mg/ℓ. The elevations in SPM concentrations were attributed to physical forcing (internal tides) at the outer, deep water site and (methane) gas bubble fluxes in the inshore mud belt. These distributions are likely to extend over the length of the mud belt features making them a major source of SPM in the region.

The fate of the re-suspended material is probably specifically linked to the behaviour of the BNL (above) and it is possible that the generally low SPM concentrations reported by Inthorn *et al*. (2006) were measured outside of a period of elevated turbidity in the inshore mud belt.

3.2.8 Plankton

The BCLME supports primary production rates > 300 g C/m^2/yr, making it one of the most productive marine areas in the world (Shannon & O'Toole 1998). The phytoplankton form the base of the pelagic trophic structure, while the heterotrophic zooplankton supply the dietary requirements for most of the small pelagic fish in the ecosystem such as sardines, anchovy and red-eye, and so in turn provide the energy needed to sustain larger fish, bird and mammal predator species.

3.2.8.1 Phytoplankton

Phytoplankton growth in off Namibia is driven by inorganic nutrients (nitrogen, phosphorus and silica) supplied to the continental shelf by upwelling. The dominant upwelling cell in the region is that at Luderitz where sustained equatorward winds drive perennial upwelling (Shannon, 1985). Cold, nutrient rich water from this area is carried northwards towards Walvis Bay, warming and stabilising through thermocline development as it does so. The high light, high nutrient conditions in the upper water column downstream of the upwelling cell allow the development of dense blooms of phytoplankton (e.g. Shannon and Pillar, 1986). Chlorophyll-*a* concentrations on the inner continental shelf in the Walvis Bay region attain 3->10 µg/ℓ with peak concentrations generally within 30-40 km of the coast. Offshore of this phytoplankton biomass declines with cell counts <25% of values inshore (Kruger 1983, cited in Shannon and Pillar 1986).

Namibian continental shelf phytoplankton biomass varies in space and time depending on the state of upwelling, season and episodic invasions of the region by relatively oligotrophic Angola current water (section 3.2.3). **Figure 3-13** shows such variability for the overall region. The low biomasses in the Luderitz upwelling cell (~26.5° S) are clearly evident as are the increased biomasses in the downstream Walvis Bay region. The proposed mine area is located on the southern end of the region with these elevated phytoplankton levels and at 40 km offshore, is also probably on the outer edge of the inshore band of high phytoplankton biomass.

The Benguela is generally regarded as a diatom-dominated system. Diatoms are characteristic of turbulent, nutrient-rich upwelled water such as that found along the eastern edge of the Benguela current. Both the northern and southern Benguela share many similar species assemblages, with *Chaetoceros, Nitzschia, Thalassiosira, Rhizosolenia* being distributed throughout the region (Shannon and O'Toole 1999). There are, however, essential differences between the north and the south, some of which are linked to the atmosphere/ocean dynamics (e.g. nutrient supply, turbulence and stratification). The diatom *Delphineis karstenii* (*Fragilaria karstenii*) is restricted to the north, while *Skeletonema costatum* is found predominantly in the southern Benguela (Shannon and O'Toole 1999). Dinoflagellates are also common in the central area of the northern Benguela e.g. *Gymnodinium* and *Peridinium* spp (Shannon and O'Toole 1999).

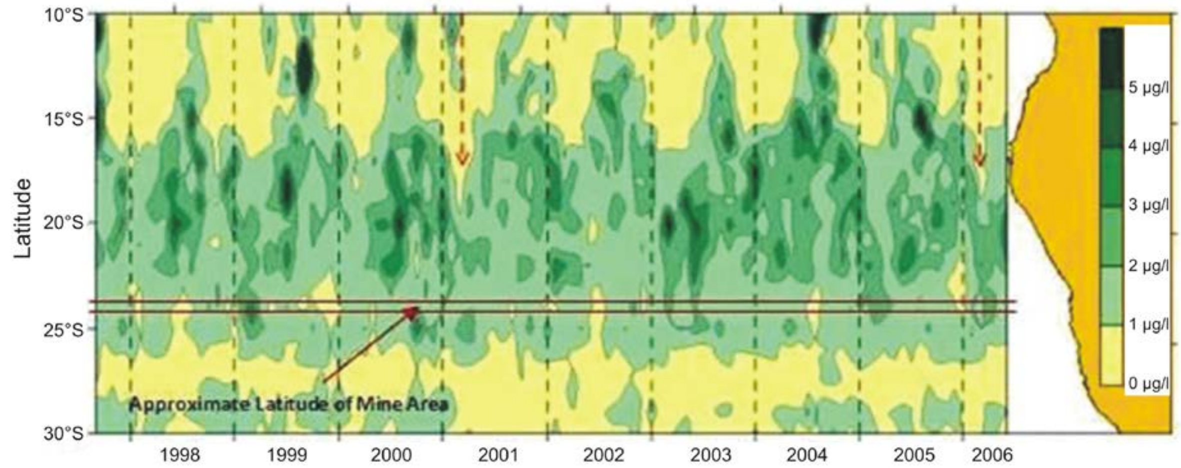


Figure 3-13: Satellite derived chlorophyll-a distribution on the Namibian continental shelf.
over the period 1997-2005. The plot shows average concentrations across a 60 km swath (Barthomolae and van der Plas 2007). The latitude of the proposed mine area is shown (modified from GeoTask 2006).

3.2.8.2 Zooplankton

Zooplankton in the Benguela ecosystem is dominated by small crustaceans, with copepods and euphausiids being the most important groups for the remainder of the trophic structure in the BCLME. Copepods are numerically the most abundant and diverse group. Of the euphausiids in the Benguela ecosystem, *Nyctiphanes capensis* is dominant in the northern Benguela and *Euphausia lucens* in the south. These two species generally do not occur together except near Lüderitz (Shannon and O'Toole 1999). Thaliaceans (gelatinous zooplankton) are common throughout the Benguela. The impact of thaliaceans on zooplankton and ichthyoplankton (fish eggs and larvae) has not been quantified, but it could be significant at times. In the northern Benguela peak abundances of zooplankton appear to coincide with periods of maximum phytoplankton abundance viz. November - December and March - May, the former following the main upwelling season and the latter during moderate upwelling when summer stratification weakens.

4 ENVIRONMENTAL IMPACT ASSESSMENT

The risks of impacts on marine life arising from changes to water quality from proposed dredging at sea are assessed in this section. It focuses on the dredge site/s and adjacent areas as spillage and/or leakage of material from the dredge vessel during transit to the offloading point is considered to be negligible. Mitigation measures are presented to avoid or reduce negative effects. The monitoring required to assess the accuracy of predictions made herein, and so improve future predictions, and success of mitigation measures is outlined in **Section 5**.

Components of the natural environment in the mining area offshore central Namibia which may be sensitive to disturbance by the envisaged activities are drawn from the Description of the Environment in **Section 3** of this report.

Activities associated with the planned dredging which could cause negative impacts are drawn from information provided by NMP's Sandpiper project engineers and assumptions drawn from experience about dredging. Details are presented in **Section 2,** the Project Description chapter of this report.

4.1 IMPACT ASSESSMENT CRITERIA

The impact analysis is based on the criteria given in **Table 4-1** below.

Table 4-1: Impact ranking criteria.

Impact Criteria:						
Extent	**Dredge Area** Per vessel cycle i.e. ~66,000m^2 or 6.6 ha	**Annual Mining Area** Up to 3 km^2	**Specific Mine Site** (SP1 or SP2) each is 22x8 km or 176km^2	**Local** 25-50 km or 2,000km^2-8,000km^2	**Regional** 50-100 km or 8,000km^2 – 30,000km^2	**National** 100 km to EEZ (200 nautical miles)[1] 100 to 370 km, or >30,000km^2

Duration	**Very Short Term** 3 days	**Short term** 3 days – 1 year	**Medium term** 1 - 5 years	**Long term** 5 – 20 years	**Permanent** > 20 years (life of mine)

Intensity/ Magnitude	**No lasting effect** No environmental functions and processes are affected	**Minor effects** The environment functions, but in a modified manner	**Moderate effects** Environmental functions and processes are altered to such extent that they temporarily cease	**Serious effects** Environmental functions and processes are altered to such extent that they permanently cease

[1] 1 nautical mile = 1,85 kilometres

Probability	**Improbable**	**Possible**	**Probable**	**Highly Probable/ Definite**

Evaluation of the **significance** of impacts uses a balanced combination of extent, duration and magnitude/ intensity, and modified by probability, risk, irreversibility, cumulative effects. Significance is evaluated before and after mitigation (unless mitigation is built into the dredging proposal, and is guaranteed). The significance is given in **Table 4-2** below:

Table 4-2: Significance ratings.

	None	**Low**	**Medium**	**High**
Impact Significance	A concern or potential impact that, upon evaluation, is found to have no significant impact at all.	Any magnitude, impacts will be localised and temporary Accordingly the impact is not expected to require amendment to the project design	Impacts of moderate magnitude locally to regionally in the short term Accordingly the impact is expected to require modification of the project design or alternative mitigation	Impacts of high magnitude locally and in the long term and/or regionally and beyond Accordingly the impact could have a 'no go' implication for the project unless mitigation or re-design is practically achievable

As stated in the summary Project Description, **activities** which need to be managed to prevent significant negative effects on life in the water column, are:

- disposal of wastes from regular vessel operations;
- exchange of ballast water;
- discharge of overspill from dredge hoppers (=plumes); and
- excavation of seabed.

Risks of impacts typically arising from these activities are illustrated in **Figure 4-1** below:

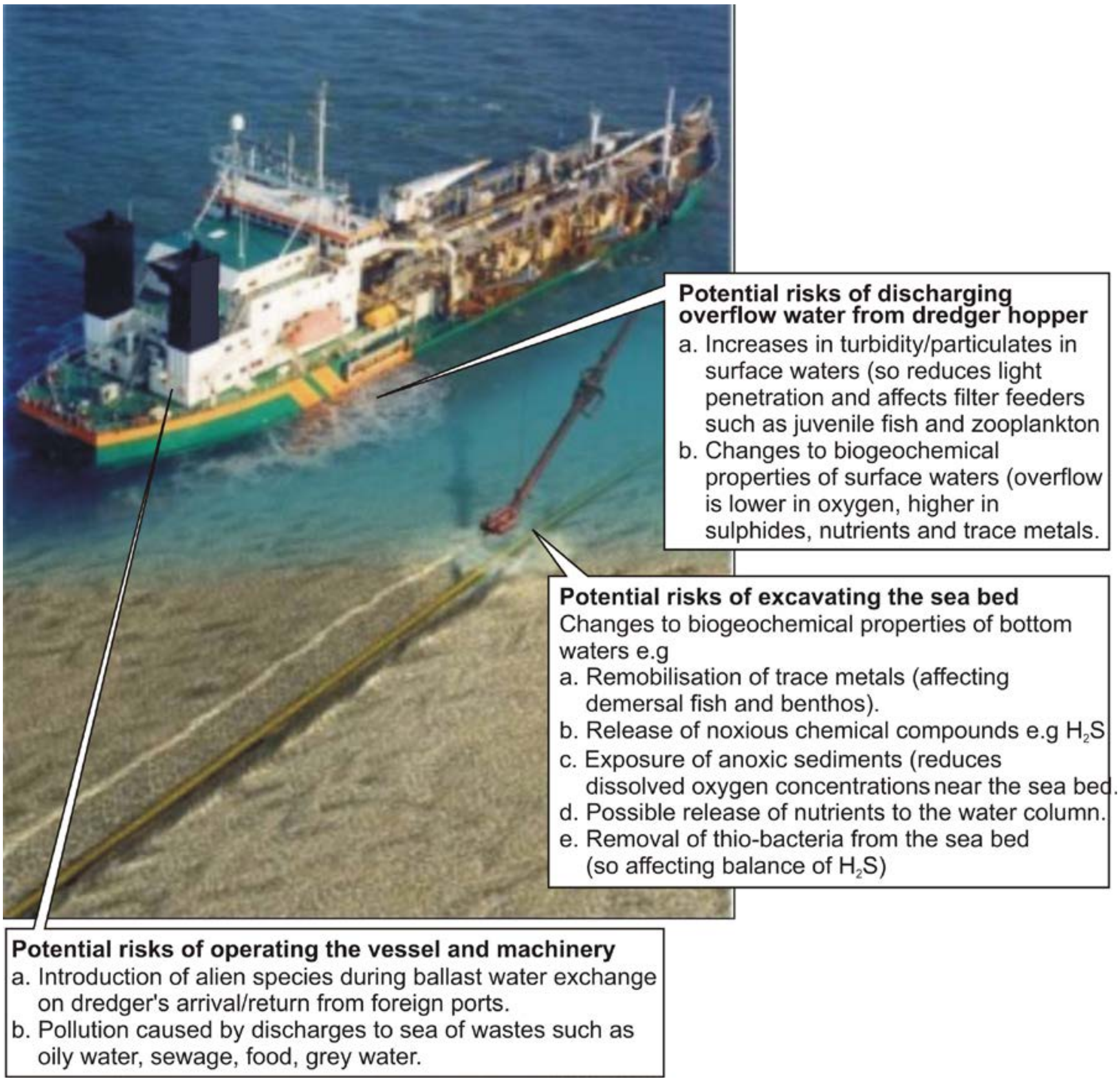


Figure 4-1: Risks to water quality
from operation of a Trailer Suction Hopper Dredger at sea.

The Sandpiper project is predicted to result in eleven potentially negative impacts on the water column from dredging operations; these are individually assessed below.

4.2 IMPACTS OF DISCHARGE TO SEA OF SHIP WASTES

Discharges to sea from the dredger of wastes such as oily water, sewage, food and grey water occur under normal ship operations. These wastes are controlled in terms of MARPOL 73/78, to which convention Namibia is a signatory. This limits what can be disposed of to sea, and specifies the monitoring and record keeping required. Therefore compliance with these regulations will, under normal operating conditions, limit pollution effects in the water column.

Table 4-3: Potential impact of releasing vessel wastes into the sea.

Nature of the impact	Potential deterioration in water quality from discharges to sea of wastes such as oily water, sewage, food, grey water, from the dredger.
Extent	Within the actual dredge area per event (~6.6ha)
Duration	The effects of the event are "very short" because normal mixing would rapidly dilute the discharge material
Intensity	No lasting effect, because effects will not be measurable.
Probability (of pollution)	Possible
Status	Negative
Significance (no mitigation)	None
Mitigation	Ensure vessel discharge systems are in good working order and do not malfunction.
Significance (with mitigation)	None
Confidence level	High

4.3 IMPACTS OF EXCHANGE OF BALLAST WATER

The dredger to be used will probably be travelling into the mining area from a foreign port, unladen. For safe navigation it will have taken on ballast water which will be gradually discharged during the initial dredging cycle. Uncontrolled ballast water discharges have been identified as important vectors for alien and/or noxious species (IMO, http://www.imo.org).

Table 4-4: Potential impact of releasing alien species with ballast water.

Nature of the impact	Alien marine species may displace indigenous species and reduce indigenous biodiversity and/or affect aquaculture and/or aquaculture products.
Extent	National: introduced aliens can spread throughout central and northern Namibia (from Luderitz upwelling cell to the Angola Benguela front).
Duration	Unknown, depends on the introduced organisms but likely to be very long term or permanent when an introduced alien becomes invasive
Intensity	None to serious. Unknown, depends on behavior of the introduced organisms.
Probability	Possible (i.e. it can occur)
Status	Negative
Significance (no mitigation)	Can be high – ecosystem changing
Mitigation	Follow IMO guidelines on ballast water management
Significance (with mitigation)	None. (Alien introductions would become "improbable" but if introductions were to occur the consequences (significance) would still be high).
Confidence level	High

4.4 IMPACTS OF DISCHARGE OF OVERSPILL WATER FROM DREDGE HOPPERS

Plumes of suspended sediments are caused by the discharge of overspill water from the dredger. Overspill discharge removes fine sediments (generally <125 µm ESD) and concentrates the material retained in the dredge hopper improving dredging efficiency (e.g. Vlasblom 2003). Suspended sediment concentrations in these discharges are generally dependent on the type of sediments being dredged and overall turbulence within the hopper from which the overspill water is being produced. CSIR (2006b) show that overspill from dredging for diamond mining in 100 m+ water depth has suspended sediment concentrations ranging from 168 g/ℓ for mud to 18 g/ℓ for muddy sand. Sand sized sediments generally produce very low suspended sediment concentration overspill water (~3 g/ℓ). Overspill rates are dependent on the dredger pump rate which is estimated to be 10-12 m^3/s for the proposed Sandpiper project. The target dredge sediments are classed as muddy sand (**Figure 3-10**) and therefore from the above the rate of suspended sediment discharge is calculated as ~713 tonnes/hr. As an independent check on this it has been estimated that 9 000 tonnes of sediment will be discharged with the overspill during a 16-17 hour dredge cycle in the proposed project (see section 2). For a 16 hour cycle the discharge rate is 562 tonnes/hr, very close to that calculated from the discharge characteristics for a muddy sand sediment as measured by CSIR (2006b).

The overspill discharge is located in the bottom of the dredger's hull 10-15 m below the sea surface depending on sediment load in the dredge hoppers. There will be some jet momentum added to the discharge because of elevation differences between the discharge collection point and the sea surface but the main variable affecting the discharge behaviour will be the concentration of fine sediments in the overspill water (Winterwerp 2002). In concentrated mixtures, e.g. that typical of overspill water when dredging mud, the discharge will act as a negatively buoyant plume and flow directly downwards in convective descent through the receiving water column until the density difference between it and the receiving water is reduced by mixing through entrainment or as it encounters the seabed; at this point the density flow will undergo dynamic collapse and mix laterally with the adjacent waters and be subject to advection by ambient currents. In this discharge behaviour scenario, therefore, the bulk of the sediment in the overspill water will rapidly return to the base of the water column, either to be held in the BNL or to redeposit on the seabed. Conversely, if sediment concentrations in the discharged overspill water are relatively low, e.g. that quoted for sandy sediments above, there will be minimal density differences between the overflow and the receiving water, the jet momentum will rapidly dissipate and mixing will occur. Under the latter scenario the receiving water body will be the upper mixed layer (i.e. surface to the top of the thermocline) and most of the effects of the plume will be exerted there. These are expected to be short-lived however as sedimentation rates for fine sand sized particles are relatively high (~4 mm/s, CSIR 2006b) and most of the particulate material should sink out of the upper mixed layer (mean depth when present of 25 m, Boyd 1987) within a few hours. Suspended sediment that remains in the upper mixed layer should be carried north-west by the Benguela Coastal Current (BCC) (**Figure 3-2)** and be advected away from the proposed mining areas and the coast. Conversely, fine sediments that sink to the seabed will be entrained in the BBL and carried southwards and offshore and probably be deposited in the depocentre southwest of the mine site (**Figure 3-12**). Muddy sand sediment mixtures at intermediate concentrations in the overspill are expected to behave in 'transition mode'; defined by Winterwerp (2002) as the discharged plume being subject to both density currents and mixing.

Therefore in this scenario there can be effects both in the upper mixed layer and in the sub-thermocline waters.

Given the target dredge sediment texture (muddy sand) and calculated sediment concentrations in the overspill discharge it is expected that overspill plumes generated by dredging during the proposed phosphate mining will behave in the 'transition mode'.

CSIR (2006b), on the basis of hydrodynamic modelling, estimated suspended sediment plume dimensions from dredger overspill for mud, muddy sand and sand substrates in 100-130 m depth off southern Namibia. Modelled plumes generated during dredging of mud extended for >7 km in the upper mixed layer and up to 10 km from source at the base of the water column. Suspended sediment concentrations exceeded 100 mg/ℓ up to 1.5 km from source and were >20 mg/ℓ 3-5 km away. Concentrations were variable over time, however, with levels >100 mg/ℓ occurring for <10% of the time simulated in their model (up to 3 months simulation periods). At the base of the water column suspended sediment concentrations >1 000 mg/ℓ occurred in the immediate vicinity of dredging. Concentrations of 100 mg/ℓ were predicted to extend as far as 10 km from the dredge area but exceedances for >50% of the time were limited to within 2 km of dredging. Concentrations >20 mg/ℓ could extend over an area of ~10 km^2.

In muddy sand sediments plume dimensions were constrained to within 4 km^2 around the dredge area. Suspended sediment concentrations >100 mg/ℓ were predicted to be limited to the area of active dredging and to be limited in terms of occurrence to 1% of the three month period simulated. i.e. <1 day. Concentrations of 20 mg/l did extend over the entire plume area but were limited in terms of occurrence to 1-10% of the time (<1-9 days).

As pointed out above the sediments in the Sandpiper project's targeted dredging areas are predominantly muddy sand and it is therefore expected that dredge plumes generated will behave similarly to that described by CSIR (2006b) for this class of sediment. For the impact assessment it is assumed that plume dimensions will be 1 500 m long by 800 m wide and that suspended sediment concentrations within this plume will be >20 mg/ℓ but <100 mg/ℓ. These dimensions are estimated from measured and modelled sediment plumes in Newell et al. (1998) and measurements of plumes from a dredger with an overspill discharge rate of 3 017 tonnes/hr in southern Namibia by CSIR (2006b). This discharge rate is ~4x higher than that estimated for the Sandpiper project. The sediment concentration limits approximate the effects thresholds for suspended sediments defined by EMBECOM (2004). For the lower limit, chronic effects on marine biota can be expected after 3 day exposures whereas acute effects may be generated in concentrations above 100 mg/ℓ.

Plumes are dynamic three dimensional structures and decay over time through mixing with the receiving water body and through the particles sinking to the seabed. **Figure 4-2** provides an example of the vertical structure of an overspill discharge plume generated by dredging muddy sand sediments. In this example the average speed of the dredger was 1 m/s (= ~2 kts) so the distance on the x-axis approximates elapsed time from discharge in seconds.

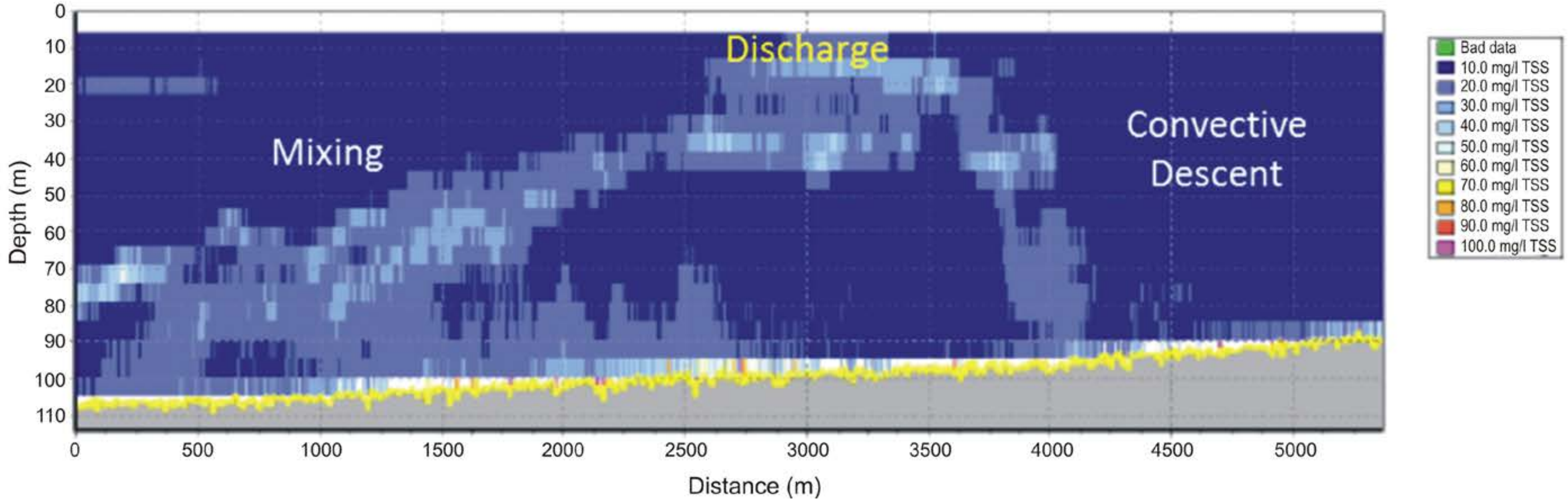


Figure 4-2: An example of the vertical structure of an overspill discharge plume
generated by dredging muddy sand sediments (from CSIR 2006b).

Maximum suspended sediment concentrations for the plumes shown in **Figure 4-2** estimated by calibration of ADCP backscatter intensity against measured turbidity and filtered water samples are 40-50 mg/ℓ, with most of the concentrations in the sediment plume falling into the 20-30 mg/ℓ range.

The two modes of plume behaviour are evident in **Figure 4-2**; on the right of the discharge point the sediment is falling rapidly to the base of the water column in what is interpreted as the density driven convective descent mode. Elapsed time from discharge to sea floor is approximately 1 000 seconds (~17 minutes). To the left of the discharge the sediment is behaving in the mixing mode but is still sinking to the seafloor with the maximum duration of suspension in the water column of ~3 000 seconds (~1 hour). This plume is therefore short-lived. Other examples of measured plumes in CSIR (2006b) indicate longevities of 1-2 hours. All of these observed sedimentation rates are higher than those calculated from sediment particle sedimentation rates. The average settling rate for muddy sand sediments measured by CSIR (2006b) is 1.6 mm/s. This indicates equivalent plume longevities of ~16 hours. The differences are probably especially due to the cohesive behaviour of the finer silt and clay particles in the discharged sediment mix, which would accelerate sedimentation, and/or a higher prevalence of the convective descent mode of discharged sediment behaviour (e.g. Winterwerp 2002).

For the assessment of dredger plumes generated in the proposed Sandpiper Project mining area the lower sedimentation rate of 1.6 mm/s is applied. This indicates durations of ~3 hours being required to transit the upper mixed layer and ~33 hours to sink to the base of the water column. Consistent with the CSIR (2006b) measurements and hydrodynamic modeling, sediment concentrations within the plumes are predicted to be <100 mg/ℓ.

The overspill water discharged during dredging may also contain dissolved compounds such as hydrogen sulphide (H_2S), inorganic nutrients including phosphorus and ammonium/ammonia and possibly trace metals liberated from the sediments by the dredging process and associated turbulence. As the dredged sediments are transported into the dredge hopper as a slurry of sediment and seawater, hypoxic or anoxic bottom water may also be withdrawn from near the sea floor and released into surface waters with the overflow water. Each of these may affect water quality in the area of dredge operations.

The main factor controlling possible deleterious effects on water quality is mixing, and therefore dilution, in the receiving waters. The dredger will be pumping an approximately 40% sediment/sea water slurry at ~11 m^3/s into the dredger hopper. Assuming that there is no sea water retention in the hopper this will result in a sea water overflow rate of 6.6 m^3/s. This will be discharged along the length of the dredger track (~16 km) from the bottom of the dredger's hull (10-15 m depth). The receiving water body will be the upper mixed layer which has a mean depth of 25 m (Boyd 1987). A major source of turbulence to enhance mixing will be the motion of the dredger itself through propeller wash and water displacement. This is estimated to affect an area extending 5 m either side of the 40 m beam width operating dredger i.e. a swath approximately 50 m in width.

From the above it is calculated that the volume of the receiving water body for each 4 km pass of the dredger is ~5 000 000 m^3 and the volume of sea water discharged over the 1.33 hour dredge cycle is ~31 680 m^3. Given these circumstances if it is assumed that the sea water discharged is totally anoxic, an unlikely scenario given turbulent mixing in the dredger hopper and exposure to air, the effect of the dilution process would be to decrease the oxygen concentration in the receiving water body by <1%. Upper mixed layer oxygen concentrations are approximately 6 ml/l, although they can reach super saturation levels in phytoplankton blooms (Chapman and Shannon 1985). The corresponding decrease in oxygen concentrations would therefore be <0.06 ml/ℓ which is probably not observable within the natural diurnal variation (balance of photosynthesis and respiration) in the region.

Similar dynamics would apply to the other potentially biogeochemical transforming chemicals that may be translocated from the base of the water column to the surface layers.

4.4.1 Increased suspended sediment concentrations to levels and persistence where deleterious effects on biota are predicted

Table 4-5: Potential impact of the suspended sediment / plume

Nature of the impact	**Dredging generates plumes of suspended sediments that adversely affect organisms in the water column**
Extent	Dredge Area - >20mg/ℓ suspended sediment concentration
Duration	Very short term – plume disperses within 1-2 days
Intensity	No lasting effect – within water quality guidelines for suspended sediment (chronic effects ensue after 3 days exposure to >20 mg/ℓ)
Probability	Possible
Status	Negative
Significance (no mitigation)	Low
Mitigation	Built in, with discharge below dredger's hull (10-15 m below sea surface)
Significance (with mitigation)	Low
Confidence level	High

4.4.2 Changed biogeochemical properties of near surface waters (overflow is higher in sulphides)

Table 4-6: Potential impact of sulphides in overflow water.

Nature of the impact	**Sulphidic sediment pore-water entrained in the dredged sediment is discharged with the over-spill water thereby affecting organisms in the water column**
Extent	Dredge area – the amount of H_2S entrained will be minimal due to predicted low concentrations in the target dredge sediments.
Duration	Short term – because entrained H_2S will de-gas in the dredger hopper (turbulence) and rapidly dilute if released to the upper water column; however if toxicity effects do occur recovery periods can be longer than 3 days but definitely less than 1 year.
Intensity	Minor effects – there may be short term toxicity effects on plankton (regeneration rates for plankton are days to weeks)
Probability	Possible
Status	Negative
Significance (no mitigation)	Low
Mitigation	None possible
Significance (with mitigation)	Low
Confidence level	Medium – the assessment relies on a prediction of a low H_2S concentration in the target dredge area sediments.

4.4.3 Changed biogeochemical properties of surface waters (overflow is lower in oxygen)

Table 4-7: Potential impact of lower oxygen levels in overflow water.

Nature of the impact	**Hypoxic/ anoxic bottom water is entrained in the discharged overflow water so reducing dissolved oxygen concentrations in the upper water column where it can affect organisms.**
Extent	Dredge area
Duration	Very short – as mixing will reduce the oxygen debt.
Intensity	No lasting effect – in a worst case scenario approximately 31 680m^3 of anoxic water may be discharged along a 4 km long dredge path during dredging. This will be mixed into approximately $5x10^6$ m^3 of normal oxic water. Mixing factors are therefore <1%; and dissolved oxygen concentration reductions will be negligible (<0.1ml/ℓ). Such levels are not generally measurable at sea.
Probability	Improbable
Status	Negative
Significance (no mitigation)	None
Mitigation	N/a
Significance (with mitigation)	None
Confidence level	High

4.4.4 Changed biogeochemical properties of surface waters (overflow is higher in nutrients)

Table 4-8: Potential impact of higher nutrient levels in overflow water.

Nature of the impact	**Increased availability of nutrients (ammonium and phosphorus) promote phytoplankton growth. Following senescence, the phytoplankton will add to the POM flux to the seabed eventually further reducing dissolved oxygen concentrations through remineralisation**
Extent	Dredge area
Duration	Short term
Intensity	No lasting effect (silicate is probably the limiting nutrient for diatoms)
Probability	Possible
Status	Neutral
Significance (no mitigation)	None
Mitigation	None possible
Significance (with mitigation)	None
Confidence level	Medium – due to there being no nutrient data specific to the proposed mining areas

4.4.5 Changed biogeochemical properties of surface waters (overflow is higher in trace metals)

Table 4-9: Potential impact of higher levels of trace metals in overflow water.

Nature of the impact	**Trace metals (cadmium and nickel) bound in the dredged sediment are discharged with the over spill water thereby affecting organisms in the water column.**
Extent	Dredge area – the affected area would be that of the suspended sediment plume.
Duration	Short term – equivalent to the life of the plume.
Intensity	Minor effects – there may be short term chronic toxicity effects on plankton specifically from cadmium. Regeneration rates for plankton are days to weeks.
Probability	Possible but unlikely due to required exposure periods being much longer than the predicted plume durations (< 40 hours) as the 240 hr EC_{50} concentration is >1000 µg/l).
Status	Negative
Significance (no mitigation)	Low
Mitigation	None possible
Significance (with mitigation)	Low
Confidence level	Medium – due to there being no trace metal data specific to the proposed mining areas

4.5 IMPACTS OF EXCAVATION OF THE SEABED

By definition dredging excavates sediments from the seabed. For the proposed marine pelletal phosphate mining this will remove sediments to 1-3 m depth down to just above the clay footwall horizon. This will probably occur through a series of 0.75 m deep cuts in a series of 4 km long dredging lanes in the specified mining areas. The dredging will therefore expose various sediment layers to the overlying water body as it proceeds to recover phosphate ore.

The biogeochemical properties of Namibian continental shelf sediments varies with the amount of pelagically produced POM that sediments out onto the sea floor and is held in the seabed sediments. On the inner continental shelf mud belt the downward flux of POM is high, as is the retention, and consequently the sediments have high POC concentrations; are generally anoxic and may be sulphidic and contain methane gas (van der Plas *et al*. 2007). Fluxes of ammonium and H_2S to the water column are appreciable as is oxygen demand due to links with organic matter remineralisation (e.g. Joubert 2006). The H_2S flux allows the establishment of thio-bacteria on, or just above, the sediment surface. These bacteria take up sulphur and therefore provide natural controls over the amount of noxious H_2S that is released to the water column through diffusion processes (Lavik *et al*. 2008). The bacterial maps therefore play an important ecological role in reducing specifically H_2S toxicity in the lower water column allowing fish, e.g. pelagic goby, occupy these areas. These bacteria do not however limit 'bulk' releases of H_2S to the water column mediated by methane bubble fluxes (van der Plas *et al*. 2007). The sulphidation process in the sediments and overlying water sequestrates dissolved trace metals leading to elevated concentrations within the seabed sediments.

In contrast coarser muddy sand sediments immediately seaward of the offshore flank of the mud belt show very much reduced pore water concentrations of H_2S and silicate, moderately reduced ammonium and phosphate but broadly similar nitrate-nitrogen levels (van der Plas *et al*. 2007). This is consistent with the strongly reduced POM concentrations as shown by POC and particulate organic nitrogen (PON) concentrations being ~20% of those in the inshore mud belt. The low POM here is due to the location outside of the inshore highly productive upwelled water and to the removal of POM that falls to the seabed by turbulence associated with internal tides (Monteiro *et al*. 2005). Therefore conditions required for *inter alia* H_2S production, i.e. high POM fluxes, possibly extending to burial of POM, and anaerobic bacterial sulphate reduction, are not generally met. Consequently the reservoirs and fluxes of this compound along with nutrients are expected to be low as is the potential oxygen take-up by sediments due to the absence of significant amounts of fresh, labile POM in the sediments. However, thio-bacterial mats have been observed in water depth ranges similar to those of the proposed mining areas (Nat-Mirc *in litt.*, 2012) indicating that the H_2S flux at these depths is at least sufficient to allow their establishment. Obviously if bacterial mats are present in the mine area mining will disrupt them with possibly increased H_2S fluxes to the over lying lower water column with associated toxicity effects on marine organisms.

Sediments in the target dredge areas are predominantly muddy sand (**Figure 3-10**) and are expected to be biogeochemically similar to the muddy sand sediments located offshore of the inshore mud belt described above.

4.5.1 Changes to biogeochemical properties of bottom waters: Remobilised trace metals (affecting demersal fish and benthos).

Table 4-10: Potential impact of exposing trace metals on the seabed.

Nature of the impact	**Trace metals held within the target dredge area sediments are remobilized; they become bio-available through exposure to the overlying water during dredging with deleterious effects on filter and/or deposit feeding benthos.**
Extent	Annual Mining Area
Duration	Short term – bio-availability will reduce with time as trace metals become bound into the sediments again.
Intensity	Minor effect - the toxicity risk is from cadmium and /or nickel. Concentrations are below the probable effects level and therefore the risks of toxicity effects are considered to be low as is the potential for bio-magnification in the food chain.
Probability	Possible
Status	Negative
Significance (no mitigation)	Low
Mitigation	None possible
Significance (with mitigation)	Low
Confidence level	Medium – due to there being no trace metal data specific to the proposed mining areas

4.5.2 Changes to biogeochemical properties of bottom waters: Release of hydrogen sulphide into the water column

Table 4-11: Potential impact of releasing hydrogen sulphide from the seabed.

Nature of the impact	**Sulphidic sediment pore-water is exposed by dredging, and the flux of dissolved H_2S into the lower water column is increased, so affecting benthos.**
Extent	Dredge area –the amount of H_2S released will be minimal due to predicted low concentrations in the target dredge sediments.
Duration	Medium term –pulses of H_2S escaping from the trench walls should be extremely short term with toxicity effects on benthos being experienced over benthos life cycles.
Intensity	Moderate effects
Probability	Possible
Status	Negative
Significance (no mitigation)	Low
Mitigation	None possible
Significance (with mitigation)	Low
Confidence level	Medium – the assessment relies on a prediction of low H_2S in the target dredge area sediments.

4.5.3 Changes to biogeochemical properties of bottom waters: Anoxic sediments exposed (reduces dissolved oxygen concentrations in the lower water column)

Table 4-12: Potential impact of exposing anoxic sediment surfaces on the seabed.

Nature of the impact	**Exposure of anoxic sediments by dredging reduces the already low concentrations of oxygen that occur in the lower water column so affecting resident biota, primarily benthos.**
Extent	Annual mining area – it is expected that oxygen distributions that existed prior to dredging would re-establish themselves with time, and the effects on benthos will diminish.
Duration	Medium term
Intensity	Minor effects – The area is already identified as being hypoxic and therefore any additional effects from dredging will be relatively small.
Probability	Possible
Status	Negative
Significance (no mitigation)	Low
Mitigation	Not possible
Significance (with mitigation)	Low
Confidence level	High - the supporting evidence about sediment properties in the target dredge areas is robust.

4.5.4 Changes to biogeochemical properties of bottom waters: Thio-bacteria layer removed from the seabed

Table 4-13: Potential impact of removing the thio-bacteria mat.

Nature of the impact	**Removal of thio-bacteria mats by dredging increases the flux of H_2S to the lower water column.**
Extent	Dredge area – the footprint of physical disturbance.
Duration	Long term – the overall amount of H_2S in the dredge furrow sediments has been reduced and requires significant POM flux re-establish itself; only then could the thio-bacteria return.
Intensity	Minor effects
Probability	Possible – Thio-bacterial mats have been observed at similar depth ranges to the proposed mining areas so despite predicted low H_2S flux rates there can be a net supply of this compound to the lower water column until re-establishment.
Status	Negative
Significance (no mitigation)	Low
Mitigation	n/a
Significance (with mitigation)	Low
Confidence level	Medium – the assessment relies on a prediction of low H_2S in the target dredge area sediments.

4.6 CUMULATIVE EFFECTS

It is clear that considerable areas of the seabed are disturbed by industrial fishing (see Appendix 1A). However, until the effects of fishing are quantified, i.e. specifically the area of seabed disturbed by demersal trawling, neither cumulative nor additive effects can be assessed.

5 MONITORING

The confidence levels in the impact assessments show that there is some uncertainty about the biogeochemical properties of the sediments in the proposed mining areas. This should be resolved by investigations specific to the mining areas either prior to commencement of mining or in its early/initial stages.

The proposed 4 km long dredging tracks in ~200 m water depths are unique in terms of monitoring investigations on overspill plume characteristics and behaviour. Therefore field investigations into these using combinations of ADCP (backscatter) coverage, multi-parameter CTD profiling and water sampling need to be conducted at intervals over at least the first years of mining operations. If these investigations show that these impacts are more severe than predicted herein, then real-time controls on e.g. exceedances of turbidity, dissolved oxygen, H_2S thresholds etc., should be established to manage the dredging phase.

Finally, as required in terms of the International Convention for the Prevention of Pollution from Ships 73/78 (MARPOL), monitoring and systematic record-keeping of all waste streams on the dredger shall be done and ballast record books kept.

6 SYNTHESIS

As is evident in **Table 6.1** below, ten of the eleven impacts assessed are rated low (at the highest), both before and after mitigation; the exception to this is the potential consequences of the possible import of alien species which could be serious if one or more should become invasive. However the risk presented by the infrequent import and release of ballast water taken up from ports outside of the BCLME region by the dredger is miniscule compared to the other shipping that may be discharging ballast water in Walvis Bay. Accordingly this assessment does not identify any unique or significant environmental risks that may be generated by the proposed mining project.

Table 6-1: Impact assessment summary table.

Table No.	4-3	4-4	4-5	4-6	4-7	4-8	4-9	4-10	4-11	4-12	4-13
Risk Area	**Vessel operation**		**Overspill discharge**					**Seabed dredging**			
Nature of the impact	**Pollution from wastes**	**Alien spp. in ballast water**	**Turbid plume**	**H_2S toxicity at surface**	**Oxygen deficient water at surface**	**Nutrients added at surface**	**Trace-metal toxicity at surface**	**Trace-metal toxicity on seabed**	**H_2S toxicity on seabed**	**Lowered oxygen levels on seabed**	**Increase of H_2S flux.**
Extent	Dredge area	National	Dredge area	Dredge area	Dredge area	Dredge area	Dredge area	Annual Mining Area	Dredge area	Annual Mining Area	Dredge area
Duration	Very short term	Short term to permanent	Very short term	Short term	Very short term	Short term	Short term	Short term	Medium term	Medium term	Long term.
Intensity	No lasting effect	None to serious	No lasting effect	Minor effects	No lasting effect	No lasting effect	Minor effects	Minor effects	Moderate effects	Minor effects	Minor effects
Probability	Possible	Possible	Possible	Possible	Improbable	Possible	Possible	Possible	Possible	Possible	Improbable
Status	Negative	Negative	Negative	Negative	Negative	Neutral	Negative	Negative	Negative	Negative	Negative
Significance (no mitigation)	None	Can be high	Low	Low	None	None	Low	Low	Low	Low	Low
Mitigation	System maintenance	IMO guidelines	Built-in	None possible	n/a	None possible	None possible	None possible	None possible	Not possible	n/a
Significance (with mitigation)	None	None	Low	Low	None	None	Low	Low	Low	Low	Low
Confidence level	High	High	High	Medium	High	Medium	Medium	Medium	Medium	High	Medium

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