KOEBERG NUCLEAR POWER STATION MARINE DISCHARGE ASSESSMENT IN SUPPORT OF THE CWDP APPLICATION

MARINE ECOLOGY SPECIALIST STUDY

PREPARED FOR:

ESKOM

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EXECUTIVE SUMMARY

Koeberg Nuclear Power Station (KNPS) primarily discharges heated cooling water into the sea along with co-discharges from the power plant. Effluents that may be added to the discharge in future are those from sea water and brackish water reverse osmosis desalination plants. The existing and future efluents could generate chronic and/ or acute effects on biota in the receiving environment.

Following the promulgation of the Integrated Coastal Management Act 24 of 2008 (ICMA) the KNPS is required to re-apply for authorization to discharge effluent to sea, via the coastal waters discharge permit (CWDP) process, for their existing power plant discharge. In addition they must include the planned desalination plant discharges.

This evaluation has examined the risks to marine ecology in the receiving environment linked to the combined discharges produced at the KNPS. The evaluation relied on detailed hydrodynamic modelling conducted by PRDW, published information on the marine ecology of the receiving environment and region and known toxicity effects of the discharge constituents. All predicted ecological impacts associated with the discharge were graded as being of low to medium significance.

The KNPS is located on a mainly sandy coast with the predominantly sandy seabed of the South West Cape inner shelf ecozone, which is well-studied in terms of marine ecology. Potential kelp habitat was identified at isolated reef formations in the nearshore immediately north of the power plant (designated North Blinder 1 and North Blinder 2) and at the rocky shorelines to the south of the discharge (South Rocks).

The maximum concentrations of the various discharge constituents, at the point of discharge, were compared to guideline and background concentrations where known and applicable. Constituents which were compliant with the general receiving water quality guidelines at the end of the outfall were not modelled. The discharge plume is not compliant with established water quality guidelines in that specified limits of temperature, total residual oxidant (TRO), phosphate and hydrazine were predicted to be transgressed outside of mixing zone boundaries contemplated by DEA (100 m from outfall) and in developing policy (300 m from outfall). Site-specific thresholds were derived for these constituents in order to adequately evaluate the ecological risks associated with their discharge.

Increases in temperature within the receiving water body have potential negative ecological consequences resulting in lethal and sub-lethal effects on marine life. Exceedance of the site-specific chronic effects threshold is limited to within 100 m of the discharge during normal power plant operations and within 1 km of the discharge under abnormal conditions. The acute threshold is constrained to the immediate area of the discharge. Abnormal conditions occur infrequently and last <12 hours.

Chlorine is a biocide and therefore toxic to marine organisms in itself and in its bromine based primary derivatives, grouped as TRO. The TRO plume exceeds the general guideline threshold (0.003 mg/l) beyond provisional and defined mixing zone distances from the discharge. Neither of the north blinder sites are predicted to experience TRO concentrations exceeding the derived site-specific threshold of 0.01 mg/l. The South Rocks site was predicted to experience two events over the calendar year modelled where the site-specific guideline would be marginally exceeded for 24 hours or less. Due to short exposure durations ecological risks to the local kelp bed habitat can be discounted.

Phosphate is only released intermittently and for short periods. Only abnormal conditions were modelled. Elevated phosphate concentrations potentially enhance phytoplankton growth. Effects on phytoplankton production are unlikely due to nitrogen and not phosphorus being the limiting nutrient in the region. Further the batch releases are considerably shorter (<50 hours per year) than the 12-14 day upwelling/relaxation cycle typical of the region that largely controls phytoplankton production and distribution. No measurable effects are predicted.

Under normal operating conditions, hydrazine at concentrations in excess of 0.0025 mg/l (the derived site-specific water quality threshold) may occur for <100 hours in a year and is not expected to extend to either of the north blinder sites. If the South Rocks site is impacted the duration of the exceedance will be ≤2 hours. Under abnormal conditions associated with refuelling, this exposure at the South Rocks site increases to ≤10 hours. As such, it is unlikely to harm the kelp habitat at those locations. Hydrazine chronic level toxicity (EC_{50}) to other taxa such as fish exceeds 3 mg/l, which is greater than the predicted discharge concentration for this compound.

The KNPS discharges heavy metals at concentrations below the DWAF receiving water quality thresholds in the cooling water effluent. Over time sediment heavy metal concentrations in depositional areas can build up, possibly leading to deleterious effects on benthic communities. Measured heavy metal concentrations in the sediments were low being at or near the analytical detection limit in the non-depositional sites but were elevated but variable in the cooling water intake basin. Copper, lead and cadmium concentrations measured at some sites in the intake basin exceeded the respective sediment quality guidelines recommended for the Benguela Current area. However, the mean values for the basin did not and accordingly, the intake basin sediments were not considered to constitute toxicity risks. Samples within the KNPS seawater intake basin show variable heavy metal concentrations with high levels of arsenic, chromium, copper, iron and lead at a location in close proximity to the northern stormwater discharge for the KNPS. It is probable that the observed elevated levels are due to stormwater flows.

The major uncertainties that exist in evaluating the environmental risks of the KNPS discharges are: that there may be unknown synergistic or additive effects on effluent toxicity due to desalination related constituents in the effluent discharge, and uncertainties about whether the predictions of low toxicity levels based on assessments of the risks posed by individual constituents are robust, particularly for inhabitants of the water column.

A monitoring programme encompassing whole effluent toxicity tests, discharge plume behaviour in the field, field based toxicity investigations in the receiving environment and inorganic contaminant build-up in sediments is recommended to reduce these uncertainties. Further, the established intertidal beach monitoring should be continued to identify any effects on this component of the natural environment, should these arise. In addition, the KNPS should investigate whether there are benefits from modifying chlorination procedures and hydrazine discharge practices to in order to comply with the emerging policy and regulations on the extents of effluent mixing zones for marine discharges.

GLOSSARY

Biocide	Products used to destroy, render harmless, prevent the action of, or otherwise exert a controlling effect on any harmful organism by chemical or biological means.
Depauperate	A faunal community having a low number of species.
Ecoregion	A division of an ecozone.
Ecotoxicity	the potential effects of biological, chemical or physical stressors on the ecosystem.
Ecozone	A large geographical region having a distinct biodiversity of flora and fauna.
Environmental quality objective	These are generally broad, narrative statements describing the desired quality levels (or goals) for a particular environment or environmental component.
Epipelagic	Open-ocean wind-mixed and sunlit surface waters.
Epiphytically	A plant growing on another plant as physical support without being harmful.
Eurythermal	Organism able to tolerate a wide range of temperatures.
Intertidal zone	The area between the low tide and high tide shoreline.
Isobaths	Imaginary line indicating points with the same depth below the sea surface.
Mixing zone	Limited area within which the discharge is initially diluted and where water quality criteria can be exceeded.
Nearshore	Area between the low tide shoreline and the low tide breaker zone, where waves start breaking as they approach the shore.
Pelagic	Relating to the open ocean.
Poikilotherm	Organism whose internal temperature varies considerably.
Receiving environment	Water body (river, stream, ocean) into which the effluent is discharged.
Subthermocline	Below the thermocline, thin layer within which temperature changes more rapidly with depth than it does in the layers above or below.
Subtidal zone	The zone below the low-tide level, i.e. it is never exposed at low tide.
Undercurrent	Current that moves below the surface.
Upwelling	Process through which deep, cold water rises toward the surface. This occurs as surface waters are pushed away due to wind action and are replaced by subsurface waters that are cold and nutrient-rich.

ABBREVIATIONS

BOD	Biological oxygen demand
COD	Chemical oxygen demand
CRF	Circulating water system
CWDP	Coastal water discharge permit
LOEC	lowest observed effect concentration
NOEC	No observable effect concentration

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1 INTRODUCTION

The Koeberg Nuclear Power Station (KNPS) uses seawater to cool condensers in the production of electricity for the national grid. The seawater is abstracted from an intake basin, flows through the power station and is returned to sea via a shore-based discharge channel (Figure 1.1). During this process, the incoming seawater is heated to ~11.8 °C above ambient (ΔT = 11.8 °C) and has various co-discharges added to it including biocide and will, in future, have discharges from sea water and brackish water desalination plants added to it. Current discharge flows are high (~86 m^3/s) and the effluent is jetted across the surf zone and then mixes with the offshore inner continental shelf seawater. Additional volume flow from the proposed desalination plants are 1.31 m^3/s and have a marginal influence on the overall discharge rate.

Figure 1.1: Google Earth view of the KNPS and discharge on the Cape west coast. Seawater from the intake basin is pumped through the power plant and discharged into the outlet basin. Discharge jet momentum can be high allowing the discharge plume to cross the surf zone.

In terms of section 69 of National Environmental Management: Integrated Coastal Management Act, 2008 (Act No.24 of 2008) (ICMA), any discharge of effluent that originates from a source on land into coastal waters requires a Coastal Waters Discharge Permit (CWDP) issued under this section by the Minister. Since the promulgation of the ICMA, the Department of Environmental Affairs (DEA) is the competent authority for issuing a CWDP.

Currently KNPS operates under a 'water use license' (Permit 853N) issued by the Department of Water Affairs. Following the promulgation of the ICMA the KNPS is required to re-apply for authorization for their discharge via the CWDP process. The requirements for this are detailed in DEA (2013). KNPS appointed PRDW to assist with the CWDP application by providing technical information on the properties and behavior of the effluent discharge plume in the receiving environment. PRDW subcontracted Lwandle Technologies (Pty) Ltd. (Lwandle) to assist through the provision of advice on receiving water quality guidelines (WQG) for the physical and chemical constituents of the effluent plume and on the impacts on local marine ecology that may be generated.

1.1 The Requirements for a CWDP

The information that DEA requires for the award of a CWDP is set out in DEA (2013). In broad terms, these include:

a) A biophysical description of the receiving environment;
b) Description and analysis of the important marine ecological features of the receiving environment;
c) Information on the discharge design and achievable dilution factors for the discharged effluents;
d) Information on the expected/predicted behaviour of solid phase particles in the discharged effluent specifically on sedimentation and resuspension following discharge;
e) Compliance of the discharge with environmental quality objectives applicable to the host receiving environment;
f) A risk or impact assessment for the overall discharge mainly focused on predicted effects of constituents that may compromise the defined environmental quality objectives;
g) For new discharges details on construction considerations and structural design; and
h) An environmental monitoring plan for the discharge dealing with normal and abnormal discharges.

PRDW (2017) provides detail on items a) (physical aspects), c), d), e) (screening assessment), and g). The balance of the items is addressed in this report. It follows that this document is to be read in conjunction with the PRDW (2017) report.

1.2 Scope of Work

Lwandle's scope of work specified by PRDW is set out below.

Perform a desktop assessment of the impacts on marine ecology in the vicinity of the KNPS discharges associated with or arising from:

- The current releases of thermal and chemical constituents, including desalination plant discharges;

- Abnormal conditions that may arise in terms of chlorine, boron and temperature fluctuations in the discharge and therefore the receiving environment; and
- The discharge of hydrazine.

In addition, Lwandle in conjunction with KNPS, PRDW and the DEA, was required to provide guidance on the development of appropriate environmental quality guidelines for the chemicals discharged by the KNPS according to the relevant international scientific literature. These would be applicable to those chemicals not identified by the DWAF (1995) and/or the draft update of these guidelines commissioned by the DEA (Massie et al, 2017), or for chemical concentrations that are exceeded under normal and/or abnormal conditions.

Further tasks assigned to Lwandle were:

- The collection and biogeochemical analyses of sediment samples from sites in the immediate vicinity of the effluent discharge and in identified potential deposition areas for fine sediments;
- Compilation of an amendment report to that of the March 2013 University of Stellenbosch (Robinson 2013) report (titled: 'The release of warmed cooling water and associated continuous chlorination: impacts on the marine environment') that assessed the impacts on the marine environment of the release of warmed cooling water and continuous chlorination taking account of revised predictions on effluent plume properties and behaviour as revealed by updated modelling; and
- Compilation of a monitoring programme consistent with the requirements set out for coastal water discharges by the DEA (2013).

1.3 Approach to the Study

As specified in the terms of reference the assessments were to be undertaken as desktop studies with inputs from the hydrodynamic modelling conducted by PRDW and the existing marine science literature on the receiving environment and the toxicological literature and data supporting the formulation(s) of water quality guidelines. The exception to this was the collection of sediment samples from the study area.

1.4 Limitations for the Study

The assessments are reliant on the existing scientific literature and the reliability of the modelled effluent plume as the only empirical data collected was that on sediment properties and benthos (Appendix A in this report).

1.5 REPORT STRUCTURE

In this report:

- Section 1 provides the general background to the required work;
- Section 2 provides detail on the receiving environment focussed on the biophysical aspects;
- Section 3 identifies the important discharge/environmental interactions;
- Section 4 analyses the environmental impacts of the discharge;
- Section 5 outlines monitoring that would be required for the discharge to ensure that it operates within the defined limits;
- Section 6 summarises the conclusions and recommendations from the assessments; and
- Appendix A describes the sediment and benthos survey results.

2 OVERVIEW DESCRIPTION OF THE RECEIVING ENVIRONMENT

The overview descriptions given below are drawn from the extensive body of research and environmental assessments that exist for the south-western Cape marine environment. Primary sources at the regional scale include Shannon (1985), Chapman and Shannon (1985), Shannon and Pillar (1986), Branch and Griffiths (1988), Rogers and Bremner (1991), Crawford et al (1987), Shannon and Nelson (1996) etc. Specific details are drawn from Lombard et al. (2004), Griffiths et al. (2010) and Sink et al. (2011) on biodiversity features, Robinson (2013) for features within the region of the discharge and Sink et al (2011) for fisheries and other ecosystem services.

2.1 OCEANOGRAPHY

The KNPS is located on the coast in the centre of the southern Benguela ecosystem. The dominant oceanographic feature of this region is coastal upwelling driven by equatorward winds. These are predominantly seasonal with highest frequency of occurrence in the austral spring and summer, consequently upwelling is mostly restricted to these seasons.

Upwelling is not uniform along the coastline as it is most intense where the continental shelf is narrowest. The upwelling cells that most influence the project area are Cape Point and Oudekraal to the south and Cape Columbine to the north (Shannon and O'Toole 1998). Although not located within one of these cells the KNPS location experiences the effects via invasion of the area by cool water (9-13 °C). When upwelling weakens and stops under declining equatorward wind force the cool dense water transported into the inner continental shelf reverses flow and retreats offshore and is replaced by warmer and previously-mixed upwelled water. Temperatures in this can be >20 °C.

The upwelling process transports high concentrations of nutrients into the euphotic zone. These are sequestrated by phytoplankton and high biomasses develop with associated zooplankton, planktivorous fish (e.g. sardine and anchovy) and their predators. The latter include seabirds such as African penguin and Cape gannet.

Winter temperatures in the region are more uniform than those of summer and fall in the narrow range of 14 – 16 °C. This is a result of no upwelling and strong mixing driven by predominantly north-westerly to westerly winds associated with winter storms.

In general, the southern Benguela region is dominated more by wind-driven upwelling and swell events, than by consistent current flows. The currents follow major topographic features at velocities of 10-50 cm/s. South of Cape Columbine a southward flow of cold water can develop in the nearshore during periods of wind reversals, and during the winter non-upwelling period (Nelson & Hutchings 1983). There is a more persistent poleward flow of sub-thermocline water on the continental shelf and at the shelf break, forming a poleward undercurrent, which is most developed in the south of the region (Boyd & Oberholster 1994).

Measured currents at the KNPS location (PRDW 2017) show that nearshore (10 m water depth) surface current velocities were mostly <53 cm/s while those at the base of the water column were predominantly <28 cm/s. At 30 m water depth surface currents were mostly <35 cm/s and near the seafloor (<14 cm/s). The observed velocity gradient may be due to the enhanced influence of waves in the shallower water. Flow directions at the seabed at both sites oscillated between northward and southward flows. Flow direction at the sea surface at the shallow water site oscillated between north north-west and south south-east but had greater offshore (north-west) and onshore (south east) flows at the deeper site. These currents are consistent with those measured for the region.

2.2 Biodiversity and Biological Communities

The southern Benguela Current ecoregion is biologically productive due to coastal upwelling that provides the inorganic nutrients that drive high plankton productivity at the base of a food chain supporting pelagic and demersal fisheries and associated predator populations. Due to its ecological and socio-economic importance, the ecosystem has received dedicated scientific attention over the years to the point where it is fairly well understood, at least in broad terms. The descriptions given below are focused on the geographic area of the KNPS and the important habitats that occur there.

2.2.1 Biodiversity zonation

The location of the KNPS within the southern Benguela ecoregion and associated ecozones, and the current system of marine protected areas (MPAs) are shown in Figure 2.1. The facility is located on a mainly sandy coast with the predominantly sandy seabed of the South West Cape inner shelf ecozone (zoomed detail from Figure 2.1 shown in Figure 2.2). There are rocky shorelines and shallow subtidal areas to the south at Melkbosstrand and at Bok Punt to the north. Isolated reef formations exist in the nearshore immediately north of the power plant (designated North Blinder 1 and North Blinder 2). The rocky shoreline and subtidal areas surrounding Robben Island lie to the south-west.

The South West Cape inner shelf ecozone is a large feature extending from Table Bay in the south to Cape Columbine in the north and offshore to the 150 m isobath. The transition with the Namaqua Inshore ecozone is situated in the region of Cape Columbine. By definition, taxonomic distributions within ecozones are uniform with gradients being located within the transition zones to adjacent ecozones. The KNPS is located away from such transition zones.

The nearest existing and proposed MPAs to the facility are 16 mile beach to the north, Robben Island and Table Mountain National Park to the south-west and the Benguela Mud MPA to the north-west further offshore.

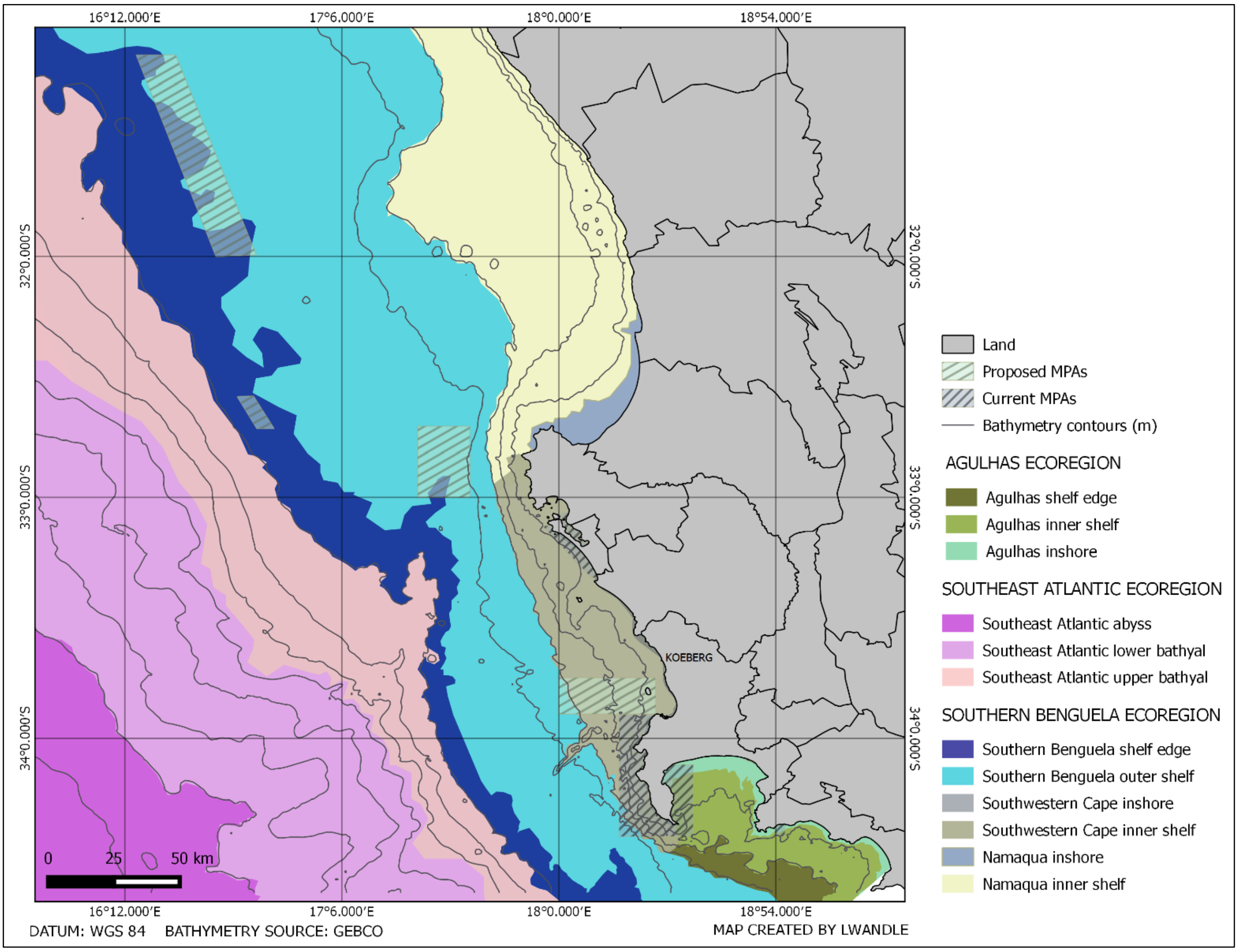

Figure 2.1: The southern Benguela ecoregion, associated ecozones and current and proposed MPAs (redrawn from Sink et al. 2011)

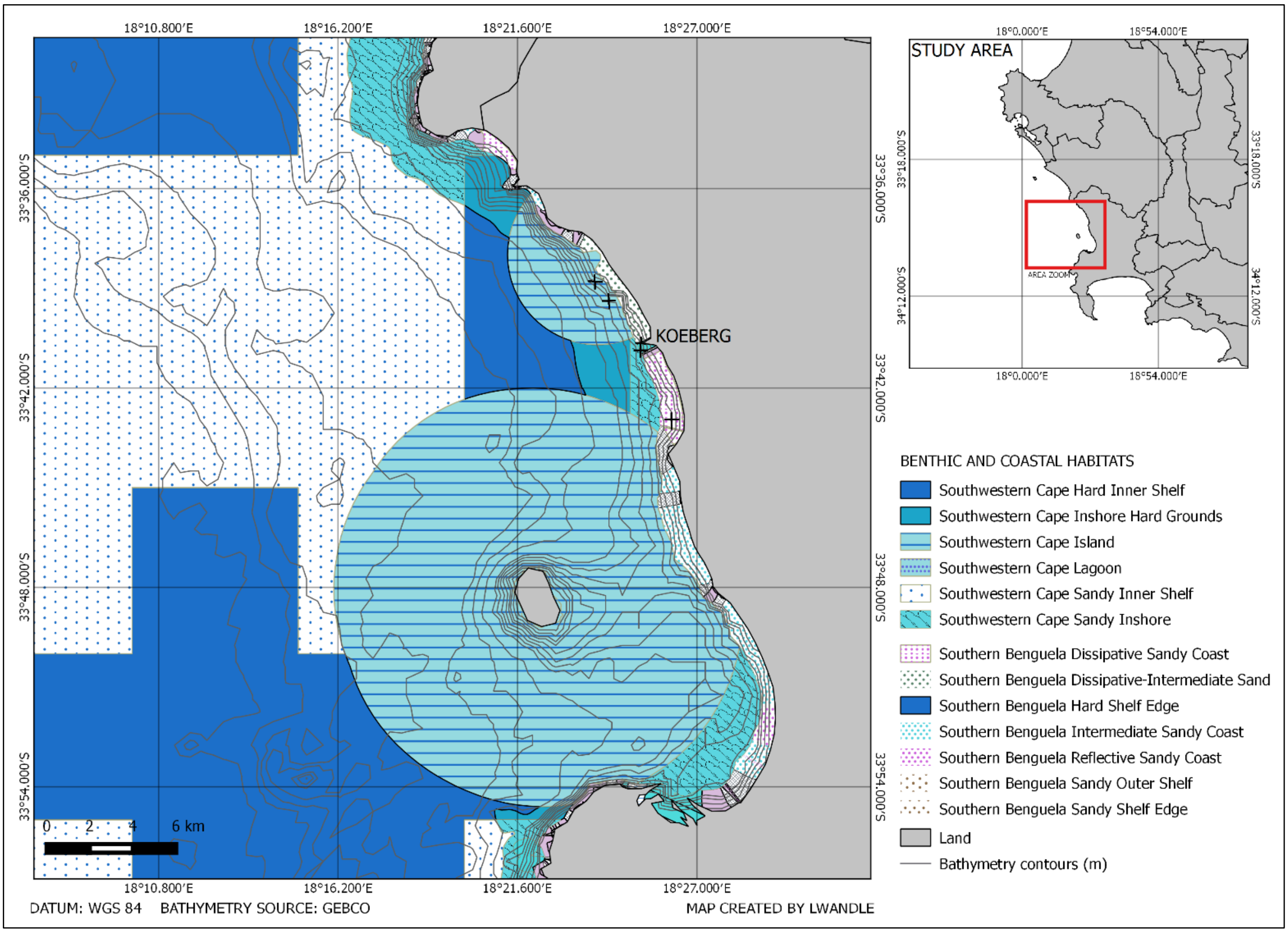

Figure 2.2: Benthic habitats in relation to the KNPS (redrawn from Sink et al. 2011)

The geographical relationship with the pelagic biodiversity zonation is shown in Figure 2.3 with a zoomed version in Figure 2.4. The Aa1 habitat type is extensive encompassing most of the continental shelf water body from Table Bay northwards. The inshore boundary of this zone is set at 30 m depth. The apparent excluded areas around Robben and Dassen Islands are the result of 'buffer' areas set for these (and all) offshore islands in the South African region due to their biodiversity importance (Sink et al. 2011). The Aa1 habitat is characterised by high productivity, high chlorophyll levels (phytoplankton biomass) and cold water (through upwelling). Although not totally uniform in terms of physical processes biological communities are mostly so, especially in respect of the larger fauna.

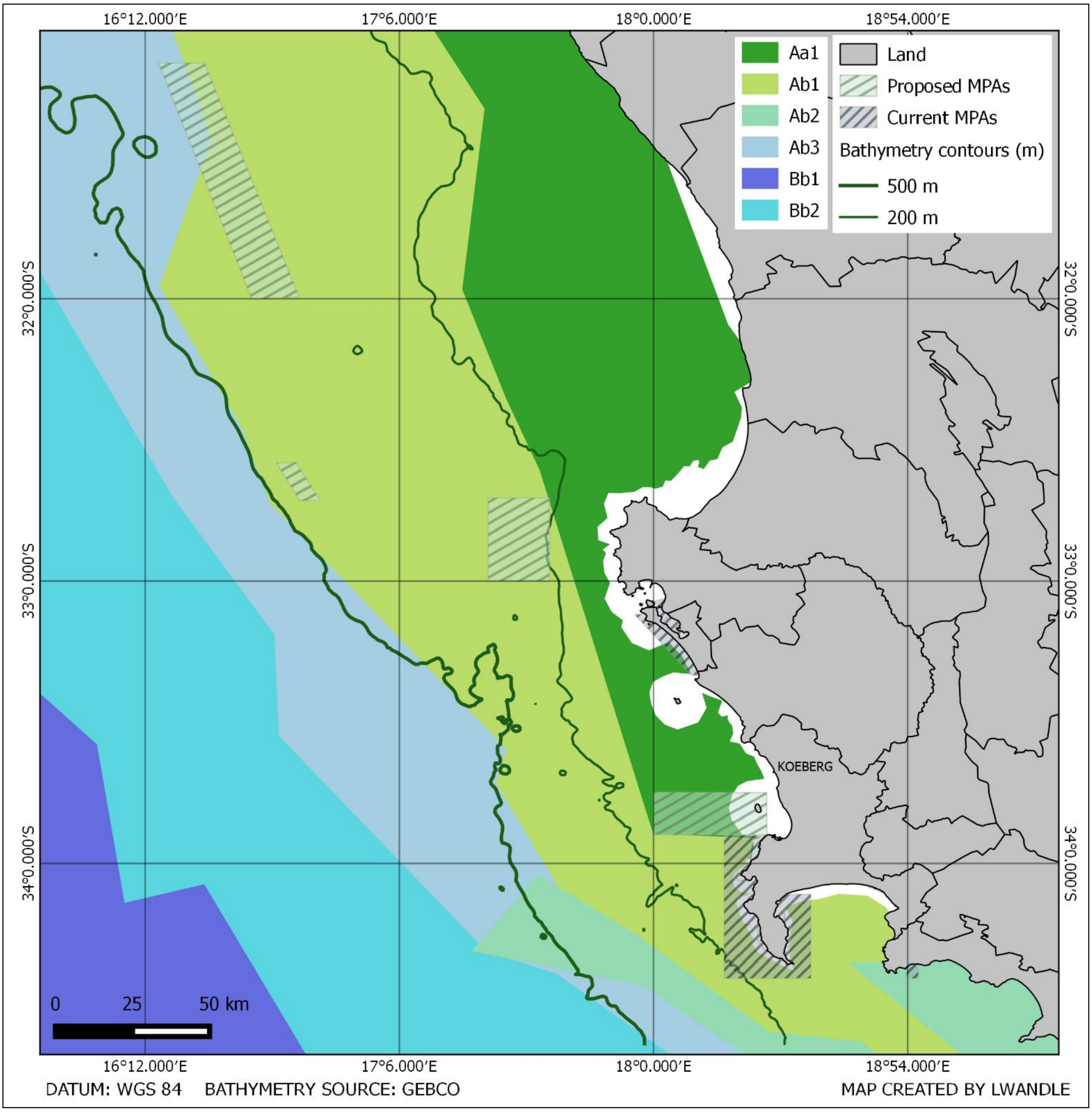

Figure 2.3: Southern Benguela ecoregion pelagic biodiversity zonation in relation to the KNPS (redrawn from Sink et al. 2011)

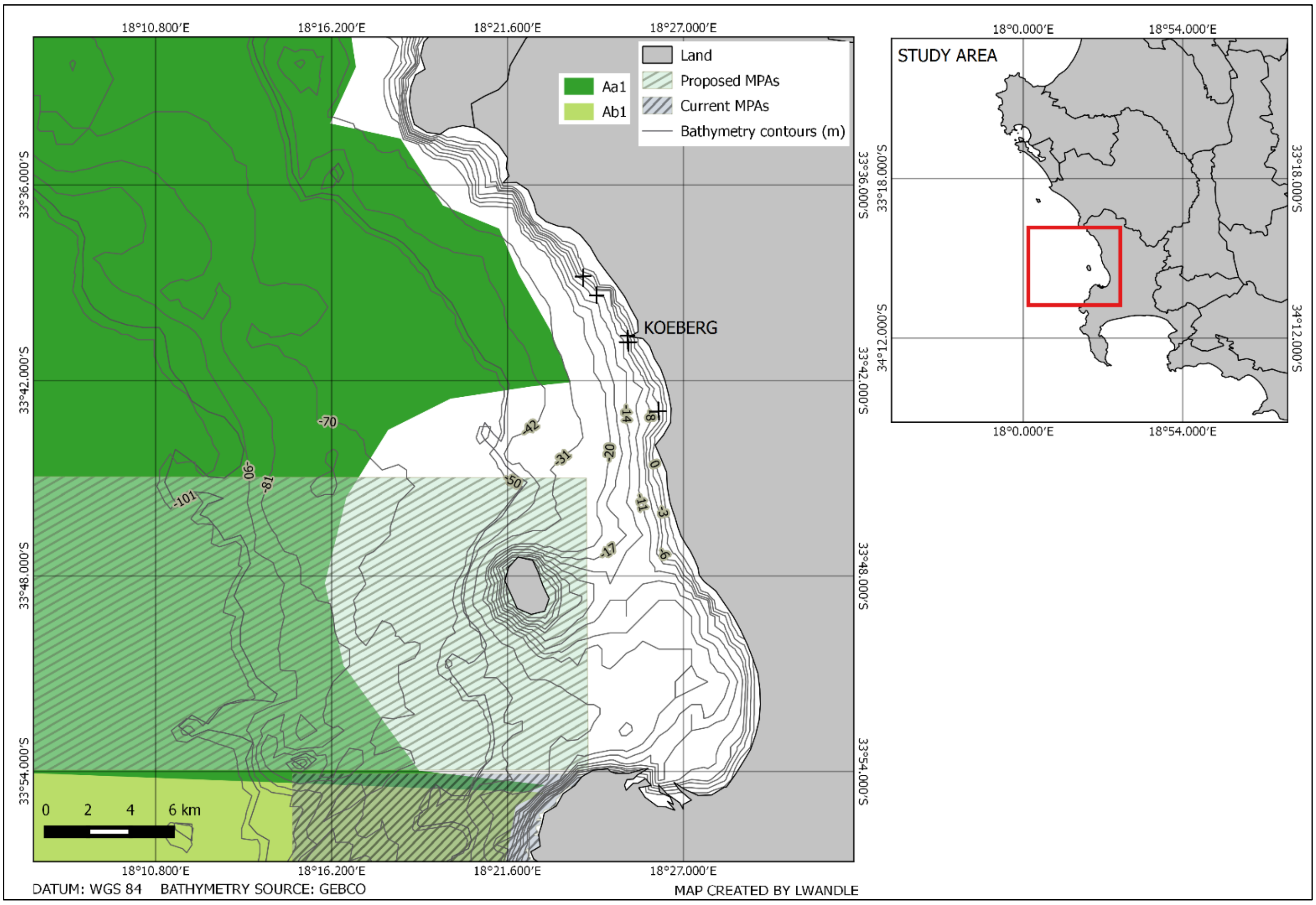

Figure 2.4: Pelagic habitats in relation to the KNPS (redrawn from Sink et al. 2011)

Brief descriptions of the biological communities of the rocky shore and subtidal, sandy shore and subtidal and pelagic zone are provided below.

2.2.2 The intertidal rocky shore community

Intertidal rocky shores on South Africa's south west and west coast can be divided into four zones (Figure 2.5): uppermost is the supralittoral fringe, also called the Littorina zone, followed by the upper midlittoral zone (or 'upper balanoid' zone), the lower midlittoral zone (or 'lower balanoid' zone), and lowermost the sublittoral fringe or Cochlear/Argenvillei zone. These four zones and the actual biomass of species within them can be modified by a number of factors, the most important being wave action (McQuaid & Branch 1984, Branch & Griffiths 1988). The following description of the 'typical' inhabitants of these zones is based on the review by Branch & Branch (1981), Branch & Griffiths (1988) and McQuaid et al. (1985).

***Supralittoral fringe (Littorina zone)* -** Highest on the shore, in the Littorina zone, species diversity is low, and macroscopic life is almost entirely constituted by high densities of the tiny snail *Littorina africana* and variable cover of the red alga *Porphyra* spp.

Upper midlittoral ('upper balanoid') – The upper midlittoral is dominated by animals, with the limpet *Scutellastra* (=*Patella*) *granularis* being the most characteristic species. Other grazers such as the trochid gastropod *Oxystele variegata* and the limpets *Helcion pectunculus* and *Cymbula* (=*Patella*) *granatina*, and the thaid gastropod *Nucella dubia* occur in variable densities. Barnacle cover (*Chthalamus dentatus*, *Tetraclita serrata* and *Octomeris angulosa*) is low. The green alga *Ulva* spp. is usually present.

Lower midlittoral ('lower balanoid') – Towards the lower shore, the biota is determined by the degree of wave exposure. On sheltered and moderately exposed shores, algae become more important, particularly the red algae *Champia lumbricalis*, *Gigartina radula*, *G. stiriata*, *Aeodes orbitosa*, *Iridea capensis*, the green algae *Codium* spp. and the brown algae *Splachnidium rugosum* and *Bifurcaria brassicaeformis*. The limpet *Cymbula granatina* and the whelks *Burnupena* spp. and *Nucella cingulata* are also common, as is the reef building tube-worm (polychaete) *Gunnarea capensis*. Shores experiencing greater wave action can be almost completely covered by the alien invasive mussel *Mytilus galloprovincialis* or at more sand inundated shores by the indigenous black mussel *Choromytilus meridionalis*.

Sublittoral fringe (Cochlear/Argenvillei zone) – Lowermost on the shore is the unique Cochlear/Argenvillei zone, which has no counterpart anywhere else in the world. At shores with moderate to strong wave action, this zone is dominated by dense populations of the limpet *Scutellastra* (=*Patella*) *cochlear*, which can exceed densities of 450/m^2. At such densities, it excludes most other species from this zone. When limpet densities are lower, the flora and fauna composition resembles that of the lower midlittoral zone accompanied by the anemone *Bunodactis reynaudi*, other patellid limpets and numerous whelks. Further north on the West Coast *S. cochlear* is replaced by *S. argenvillei*. Shores with very high exposure are dominated by the Spanish mussel *M. galloprovincialis* which is an exotic species largely replacing the indigenous black mussel *C. meridionalis* (Griffiths et al. 2010) and/or the tunicate *Puyra stolonifera*. The Cochlear/Argenvillei zone is then absent. However, at shores covered by mussel beds, usually all the species normally occurring on the rock surface can be found living on the shells using the mussel bed as substratum. These animals are, however, often smaller than those found on rock (Hockey & Van Erkom Schurink 1992, Steffani & Branch 2002). On very sheltered shores, both limpets and mussels are absent and the shore is dominated by the limpet *C. granatina* and the polychaete *G. capensis*, which can build reefs more than 30 cm thick, thereby excluding most other species from the shore.

2.2.3 The subtidal rock substratum community

Along the West Coast of South Africa, kelp beds are the dominant communities on subtidal rocky reefs (= Sublittoral zone, Figure 2.5). The main species in these beds are the kelps *Ecklonia maxima* and *Laminaria pallida*. The more delicate rope-like *Macrocystis angustifolia* can be found at more sheltered localities (Branch & Griffiths 1988).

Below the sublittoral fringe, the inshore zone is generally dominated by small *E. maxima* plants and supports few animals. At intermediate depths, algal biomass is maximal with large *E. maxima* plants forming a canopy, beneath which *L. pallida* and understorey algae grow. Animal species diversity and biomass are, however, still low. Further offshore the kelp plants thin out and give way to a dense faunal community dominated by sea urchins, filter-feeding mussels, sponges and holothurians (Velimirov et al. 1977, Field et al. 1980, Branch & Griffiths 1988).

Field *et al*. (1980) have surveyed transects across kelp beds at Melkbosstrand. Here the inshore is dominated by *E. maxima*, giving way to *L. pallida* with increasing depth. There is a marked decline in densities with depth which was attributed to relatively high turbidities at this location.

Representative understorey algae include *Bifurcariopsis capensis*, *Botryoglossum platycarpum*, *Desmarestia firma*, *Epymenia obtusa*, *Gigartina radula*, *Neuroglossum binderianum*, *Plocamium corallorhiza*, *P. maxillosum* and *Trematocarpus fragilis*. Epiphytically on kelp growing algae include *Carpoblepharis flaccida*, *Carradoria virgata* and *Suhria vittata*. The fauna are dominated by filter feeders, notably the ribbed mussel *Aulacomya ater*, holothurians (sea cucumbers) *Pentacta doliolum* and *Thyone aurea*, Porifera (sponges) and to a lesser degree tunicates *Puyra stolonifera* and barnacles.

Carnivores, particularly the rock lobster *Jasus lalandii* and anemones, can be abundant and prey almost exclusively upon mussels. Grazers and debris feeders are less common and include the sea urchin *Parechinus angulosus*, some patellid limpets, the giant periwinkle *Turbo cidaris*, the abalone *Haliotis midae* and some isopods and amphipods. Other faunal members include the whelks *Burnupena papyracea* and *Argobuccinum argus*, the starfish *Marthasterias glacialis*, the crab *Plagusia chabrus* and polychaetes. The fish fauna in these systems is dominated by the endemic hottentot (*Pachymetopon blochii*), but also includes twotone fingerfin (*Chirodactylus brachydactylus*), redfinger (*Cheilodactylus fasciatus*), blacktail (*Diplodus sargus capensis*), galjoen (*Dichistius capensis*), maned blennies (*Scartella emarginata*), and various klipfish.

The kelps *Ecklonia maxima* and *Laminaria pallida* are the main primary producers in this system. Few species feed directly on them but the main energy conversion pathway is by means of detritus- and particularly filter-feeders feeding on the detritus derived from the kelp plants. This detritus is also an important food source for filter-feeders in the rocky and sandy intertidal (Bustamante & Branch 1996, Soares et al. 1997). The main filter-feeders in the kelp beds are the mussels *Aulacomya ater*, *Mytilus galloprovincialis and Choromytilus meridionalis* and the top predator on these is the west coast rock lobster *Jasus lalandii*. The kelps, mussels and lobster are thus very important in this system.

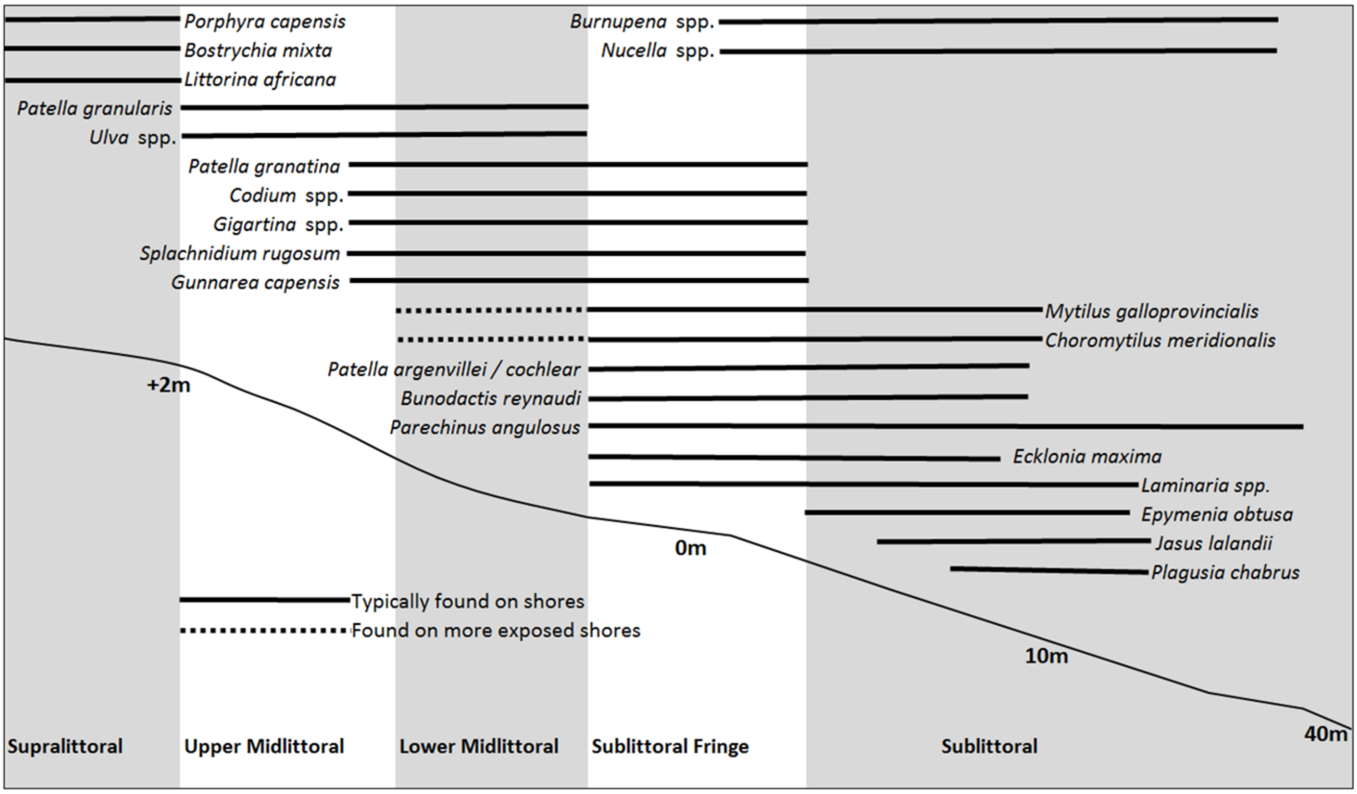

Figure 2.5: Intertidal and subtidal zonation of rocky shores in the southern Benguela Current region (redrawn from Lane & Carter 1999)

2.2.4 Intertidal sandy beach communities

The properties of the intertidal portion of sandy beaches and consequently the composition of their biota are related to the degree of wave energy, sand particle size and beach slope (McLachlan et al. 1993). These factors interact to produce three general beach morphodynamic types: dissipative, reflective, or intermediate beaches. Generally, dissipative beaches are characterised by fine sand and flat intertidal beach gradients. The wave energy is dissipated in the surf zones, so that the conditions experienced in the intertidal are less exposed/turbulent. These beaches are considered benign and harbour the richest intertidal faunal communities. Reflective beaches, on the other extreme, are coarse grained (mean particle size >500 µm) with steep intertidal beach faces. The relative absence of a surf zone causes all the wave energy to travel into the intertidal and the waves to break directly on the shore. This causes a high turnover of sand, which is considered a harsh intertidal climate. The result is depauperate faunal communities. Intermediate beach conditions exist between these extremes and have a very variable species composition (McArdle & McLachlan 1991, McLachlan et al. 1993, Jaramillo et al. 1995). This variability is mainly attributable to the amount and quantity of food available. Beaches with a high input of e.g. kelp wrack have a rich and diverse drift-line fauna, which is sparse or absent at beaches lacking a drift-line (Branch & Griffiths 1988, Field & Griffiths 1991).

The west coast of South Africa is almost linear, and virtually all beaches are exposed to strong wave action, and are thus of the intermediate or reflective type. Typical of exposed beaches, they are usually relatively steep and narrow with well-sorted fine to medium-sized sediments, but some of the steepest beaches can have coarse sands (Branch & Griffiths 1988).

The entire Benguela region from the Cape Peninsula right up the West Coast to northern Namibia has a remarkably consistent sandy beach macrofauna (Field & Griffiths 1991). Lane & Carter (1999) reviewed the composition of the soft-bottomed benthic macrofauna (invertebrate animals >1 mm) communities of the West Coast, and the following description of the beach zones and their invertebrate macrofauna is based on their document, supplemented by data from other studies and reviews (Christie 1976, Bally 1983, 1987, Branch & Griffiths 1988, Jaramillo et al. 1995).

The supralittoral zone of sandy beaches (Figure 2.6) is situated above the high-water spring mark (HWS), and receives water input only from large waves at spring high tides or through sea spray. This zone is characterised by air-breathing Crustaceans, particularly the amphipods *Talorchestia capensis* and *T. quadrispinosa*, the giant isopod *Tylos granulatus* and the terrestrial isopod *Niambia* sp. A diverse array of insect species (Coleoptera and Diptera) can also be found, which are almost all associated with, and feeding on, wrack or other debris deposited along the drift-line. Oligochaetes can also be abundant, again particularly under seaweed debris. Community composition depends on the nature and extent of wrack, in addition to the physical factors structuring beach communities, as described above.

The intertidal or midlittoral zone has a vertical range of about 2 m. This mid-shore region is characterised by the isopods *Pontogeloides latipes*, *Eurydice longicornis* and *Excirolana natalensis* and the polychaete *Scololepis squamata*. The white mussel *Donax serra* may also present in considerable numbers.

2.2.5 Subtidal sand substratum community

Subtidally, three zones are defined in the turbulent depths zone, each with a defined macrofaunistic grouping:

Inner turbulent zone - The inner turbulent zone extends from the low water spring mark (LWS) to a depth of about 2 m. The mysid *Gastrosaccus* spp., the ribbon worm *Cerebratulus fuscus* and the cumacean *Cumopsis robusta* are typical of this zone, although they generally extend partially into the intertidal above. In areas where a suitable swash climate exists the scavenging gastropod *Bullia digitalis* can be present in considerable numbers, 'surfing' up and down the beach in search of carrion. Adults of the white mussel *D. serra* can also be present in this zone.

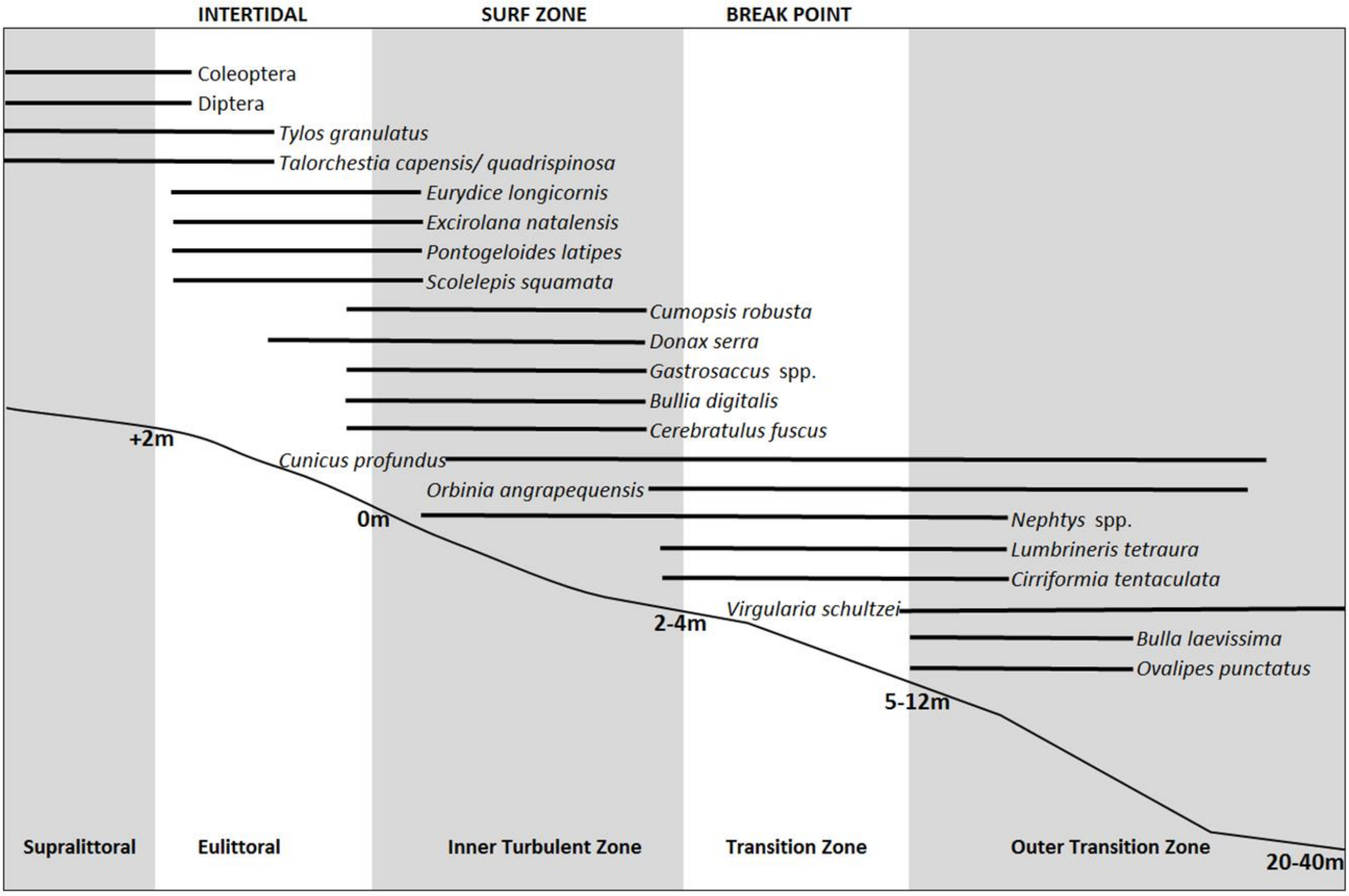

Figure 2.6: Intertidal and subtidal zonation of sandy shores in the southern Benguela Current region (redrawn from Lane & Carter 1999)

Transition zone - The transition zone spans approximately the depth range 2-5 m. Extreme turbulence is experienced in this zone, and as a consequence it typically harbours the lowest diversity. Typical fauna of this zone include amphipods such as *Cunicus profundus* and deep burrowing polychaetes such as *Cirriformia tentaculata* and *Lumbrineris tetraura.*

Outer turbulent zone - Below 5 m depth extends the outer turbulent zone, where turbulence is significantly decreased and species diversity is again much higher. Next to the polychaetes of the transition zone, other polychaetes in this zone include *Pectinaria capensis*, *Sabellides ludertizi*, *Nephtys capensis* and *Orbinia angrapequensis*. The sea pen V*irgularia schultzei* is also common as is the whelk *Bullia laevissima* and a host of amphipod species. Similar to the intertidal portion of the sandy beaches, the most important factors regulating the distribution of species are the degree of turbulence and the sediment texture (Christie 1976).

Benthos survey data from the inner continental shelf off the KNPS are reported in Appendix A. Forty-two taxa were recorded, all considered characteristic of sand seafloors in the region (e.g. Steffani et al 2015). Polychaete worms accounted for ~50 % of the overall abundances while large but rarer bivalves (*Bullia*) and pelecypods (*Dosinia*) were dominant in terms of benthos biomass. The taxa recorded were similar to those reported from multiple surveys conducted on the inner continental shelf south of the KNPS at Milnerton in Table Bay (CSIR, 2015). This similarity in community composition is a feature of the southern Benguela Current region (Steffani et al. 2015) and the fact that both sites are located in the southwestern Cape inner shelf ecozone (Figure 2.1).

2.2.6 Pelagic Communities

The pelagic communities are typically divided into plankton and ichthyoplankton and fish. Brief descriptions are given below, again with emphasis on communities, or components of communities that may be affected by KNPS cooling water discharge.

Plankton and ichthyoplankton

The phytoplankton is generally dominated by large celled organisms. The most common diatom genera are *Chaetoceros*, *Nitschia*, *Thalassiosira*, *Skeletonema*, *Rhizoselenia*, *Coscinodiscus* and *Asterionella* whilst common dinoflagellates are *Prorocentrum*, *Ceratium* and *Peridinium* (Shannon and Pillar, 1985). Harmful algal bloom (HAB) species (e.g. *Ceratium furca*, *C. lineatum*, *Promocentrum micans*, *Dinophysis* sp, *Noctiluca scintillans*, *Gonyaulax tamarensis*, *G polygramma*, *Alexandrium catanella*, *Mesodinium rubrum*) also occur episodically and dense HABs have been observed in the region, especially north of Cape Columbine (Pitcher & Calder, 2000). Mean phytoplankton biomass ranges between 3 and 4 µg chla/litre but varies considerably with phases in the upwelling cycle and in HABs (Brown et al. 1991).

Zooplankton comprises predominantly crustacean copepods of the genera *Centropages, Calanoides, Metridia, Nannocalanus, Paracalanus, Ctenocalanus* and *Oithona* (Shannon and Pillar, 1986). Larger zooplankton commonly occurring in the nearshore area are the two Euphausiid species *Euphausia lucens* and *Nyctiphanes capensis* (Hutchings et al, 1991, Shannon & Pillar, 1986). The zooplankton generally graze phytoplankton and therefore biomass and biomass distributions depend upon this component of the plankton.

Ichthyoplankton comprise fish eggs and larvae. In the southern Benguela area the most significant contributors to this are the epi-pelagic shoaling species anchovy *Engraulis japonicus* and pilchard *Sardinops sagax* (Shannon & Pillar, 1986). Other species including hakes and mackerel are also represented but generally to a far lesser extent. Recruitment areas for these commercially and ecologically important species are located generally north of Cape Columbine but can extend southwards towards Table Bay, therefore including the nearshore region off the KNPS (Crawford et al. 1987). It is therefore likely that relatively high densities of fish eggs and larvae can be episodically present in the plankton.

Fish

In sandy beach nearshore and surf zones of the southern Benguela region the structure of fish communities vary with the degree of wave exposure. Species richness and abundance is generally high in sheltered and semi-exposed areas but typically very low off the more exposed beaches (Clark 1997a, b). Beach seine catches from the shore have resulted in a total of 29 species. Dominant species include harders (*Liza richardsonii*), silverside (*Atherina breviceps*), white stumpnose (*Rhabdosargus globiceps*), False Bay klipfish (*Clinus latipennis*), in rocky areas, and two species of goby (*Psammogobius knysnaensis* and *Caffrogobius nudiceps*) (Clark 1997a, b). Given the coastal morphology at KNPS the area experiences an exposed wave climate with median and 99th percentile significant waves heights of 1.5 m and 4.5 m respectively (PRDW, 2017). Consequently, surf zone fish abundance is expected to be low in the surf zones adjacent to the power plant.

In the offshore environs of the continental shelf all of the commercially important fish species occur. As pointed out above the area is important for the recruitment of the epi-pelagic species (anchovy, pilchard and red eye); it is in the seasonal migration pathway of these fish to spawning grounds south of Cape Point and on the western Agulhas Bank (Crawford et al. 1991), and is mapped by Sink et al. (2011) as being part of the core area for the epipelagic fishery.

Rock lobster (*Jasus lalandii*) occur on rocky grounds around Robben Island and are commercially fished north of the island (Sink et al. 2011). This species is widely distributed on rocky grounds across all of the inner continental shelf of the Benguela Current region with commercial fishing extending from east of Cape Hangklip in the south-east to the Orange River in the north-west.

For both of these fisheries the absolute or relative importance of inner continental shelf area potentially influenced by the KNPS discharge is not known but is probably not significant due to its very small area compared to that of the overall recruitment and foraging habitat of these species.

2.3 Beneficial Uses

The South African water quality guidelines for the coastal zone (DWAF 1995) defines 'beneficial use' as the desired use or uses for a particular marine (or estuarine) water body, and identifies five beneficial uses with associated environmental objectives for the coastal zone water body. These include:

- Suitability as a basic amenity through the environmental objective of prevention of public nuisance from visual degradation and/or odour problems;
- Maintenance of the ecosystem through the environmental objective of ensuring ecological integrity;
- Recreation, including primary and secondary contact, with the environmental objective of protecting human health and aesthetic condition;

- Collection and/or culture of aquatic life for food with the linked environmental objective of maintenance of water quality, and
- Industrial purposes, again with the environmental quality objective of ensuring water quality levels are such that the water body is fit for use.

The concept of beneficial use has an approximate biodiversity equivalent in 'ecosystem services'. These are defined as benefits people derive from functioning ecosystems, including the ecological characteristics, functions, or processes that directly or indirectly benefit human wellbeing (Costanza et al. 2011 in Sink et al. 2011). Broad categories of ecosystem services are:

- Supporting (function) – equivalent to the beneficial use of 'maintenance of ecosystems';
- Provisioning (primarily fishing) – equivalent to the beneficial use of collection and/or culture of aquatic life for food;
- Regulating (function) – no apparent beneficial use equivalent, and
- Cultural (function) – equivalent in part to the recreation beneficial use.

Whichever beneficial use or ecosystem service is assigned or assignable to the receiving water body for the KNPS discharge, the 'maintenance of the ecosystem/supporting function' can be considered as having the strictest environmental quality objectives. As the CWD authorization should be protective of both near and far field ecological integrity (e.g. DEA 2009) this assessment of the risks to marine ecology linked to the KNPS discharge is based on this beneficial use/ecosystem service and associated environmental quality objective of ensuring ecological integrity.

3 CHARACTERISATION OF THE KNPS DISCHARGE

3.1 KNPS DISCHARGE CONSTITUENTS

The KNPS discharge comprises effluent from the essential water service system, circulating water system, conventional island releases, nuclear island releases, wastewater treatment plant and southern stormwater system. Additionally, the cooling water drawn from the intake basin (Figure 1.1) contains effluents from the auxiliary boiler plant, demineraliser plant sumps and filters, the chlorination plant, northern stormwater system and a building ventilation system (PRDW, 2017). Flow from the circulating water system is the largest ranging from 81 972 to 327 888 m^3/h depending on plant operating condition, followed by the essential water system (12 700 m^3/h), with the rest of the effluent sources contributing minor volumes (<400 m^3/h, PRDW, 2017).

Additional discharge constituents are those emanating from proposed sea water and brackish water desalination plants operating on the KNPS precinct. Both will use reverse osmosis technology with the seawater plant (SWRO) supplying potable water to the City of Cape Town and the brackish water plant (BWRO) supplying water to the KNPS. The individual plants are discussed in more detail in section 3.4 of PRDW (2017); brine effluents and intake water pre-treatment constituents are summarised in Tables 3.1-3.3 below for completeness. These constituents are included in Table 3.4 which provides an assessment of the bulk effluent exiting at the KNPS in terms of meeting/exceeding water quality guidelines and requirements for modelling constituent behaviour in the broader receiving environment.

Table 3.1: Characterisation of the brine effluent from the proposed BWRO desalination plant

Parameter	Unit	Value
Produced freshwater	m^3/h	75
Recovery rate	-	0.75 to 0.85
Feed water	m^3/h	100(1)
Discharge	m^3/h	25(1)
Temperature	°C	20
Salinity	psu	15(2)
Nitrite (NO_2)	mg/l	7.33
Nitrate (NO_3)	mg/l	9.33
Silica (SiO_2)	mg/l	66
Sulphates	mg/l	2500
Phosphonate antiscalant	mg/l	31.3(3)
Chlorine	mg/l	0.002 – 0.1 (4)
Sodium metabisulphate(5)	mg/l	3
Peroxyacetic acid	mg/l	1.55
Low pH cleaner	mg/l	4.13
High pH cleaner	mg/l	4.13
Total residual dibromonitrolopropionamide (DBNPA) (6)	mg/l	1.15 - 2.475(7)

Notes:
(1) Maximum value (based on minimum recovery rate of 0.75)
(2) Maximum salinity during discharge of Cleaning In Place (CIP) effluent.
(3) Based on the maximum recovery rate of 0.85 and a dose rate of 4.7 mg/l into the feed water.
(4) Usually low because of reactions with sodium bisulphate (neutralised). A maximum value of 0.1 mg/l was assumed in (Van Ballegooyen, et al., 2007).
(5) For the neutralisation of chlorine. May lead to reduction of dissolved oxygen if overdosed.
(6) Alternative to chlorine.
(7) (Van Ballegooyen, et al., 2007)

Table 3.2: Characterisation of the pre-treatment effluent from the proposed BWRO desalination plant

Parameter	Unit	Value
Discharge(1)	m^3/h	40
Temperature	°C	20
Aluminium	mg/l	32
Iron	mg/l	22
Manganese	mg/l	5.5
Total Suspended Solids (TSS)	mg/l	400
Total Organic Carbon (TOC)	mg/l	150
Coagulant: Ferric Chloride (as Fe)(2)	mg/l	20.6
Ferric Chloride (as $Fe(OH)_3$)	mg/l	39.4
Anionic Polymer(3)	mg/l	3

Notes:
(1) Discharge expected to occur for approximately 6 minutes every hour.
(2 Ferric Chloride ($FeCl_3$) will precipitate into Ferric Hydroxide, which will contribute to the TSS of the discharge. The Ferric Hydroxide may cause a discolouration of the pre-treatment effluent.
(3) Alternative to Ferric Chloride.

Table 3.3: Characterisation of the pre-treatment effluent from the proposed SWRO desalination plant

Parameter	Unit	Value
Produced freshwater	m^3/h	833
Feed water	m^3/h	2 083(1)
Brine discharge	m^3/h	1 250(2)
Salinity	psu	66(3)
Increase in temperature (ΔT)	°C	2
pH	-	7.3-8.2
Suspended Solids	mg/l	11.76
Coagulant: Ferric Chloride (as Fe)(4)	mg/l	3.33
Coagulant: Ferric Chloride (as $Fe(OH)_3$)(4)	mg/l	6.37
Total Suspended Solids	mg/l	18.04(5)
Phosphonate antiscalant	mg/l	4.7(6)
Chlorine	mg/l	0.002 – 0.1 (7)
Sodium metabisulphate(8)	mg/l	3.14
Peroxyacetic acid	mg/l	1.55
Low pH cleaner(9)	mg/l	4.13
High pH cleaner(10)	mg/l	4.13
Total residual dibromonitrolopropionamide (DBNPA) (11)	mg/l	1.15 - 2.475(12)
Anionic polymer (alternative to Ferric Chloride)	mg/l	1.67

Notes:
(1) Assuming 40% of feed water is converted to freshwater.
(2) Assuming 60% of feed water is discharged as brine.
(3) An intake salinity of 35 psu and a freshwater recovery of 40% results in a brine salinity of 58.3 psu. A brine salinity of 66 psu is thus conservative and takes into account variations in the intake salinity and variations in the concentration of the brine.
(4) Ferric Chloride ($FeCl_3$) will precipitate into Ferric Hydroxide, which will contribute to the TSS of the discharge. The concentrations presented here assume that the pre-treatment effluent is blended with the brine. The Ferric Hydroxide may cause a discolouration of the pre-treatment effluent. Options to limit the metal discharges in the filter backwash effluent shall be considered. If found to be necessary, these options may include a Dissolved Air Floatation system or diversion of the primary filter backwash for clarification and sludge disposal.
(5) Including Ferric Hydroxide precipitant.
(6) Typically dosed into feed water at 3 mg/l which results in ~5 mg/l in effluent.
(7) Usually low because of reactions with sodium bisulphate (neutralised). A maximum value of 0.1 mg/l was assumed in (Van Ballegooyen, et al., 2007).
(8) May lead to reduction of dissolved oxygen if overdosed.
(9) Generally sulphuric acid. Effect would be reduction in pH, therefore pH guidelines apply.
(10) Alkaline cleaner. Effect would be on pH, therefore pH guidelines apply.
(11) Alternative to chlorine.
(12) (Van Ballegooyen, et al., 2007)

3.2 Required Dilutions

Table 3.4 lists the constituents in the KNPS discharge as derived from information provided to PRDW (2017) by KNPS, including discharges from proposed desalination plants. The table lists maximum concentrations at the discharge, guideline and background concentrations where known, water quality guideline concentrations where known and applicable, background concentrations and required dilutions to meet the water quality guidelines. The constituents requiring dilution to meet water quality guidelines are those modelled by PRDW (2017) and assessed in Section 4 in terms of their predicted impacts on marine ecology in the receiving water body. Explanatory text is provided for each of the non-screened out constituents in terms of the site-specific guidelines that may be applied or reasons underlying their respective exclusion from modelling and assessments of environmental risks including those for selected desalination plant effluent constituents.

Table 3.4: List of constituents present in the KNPS discharge, guideline and background concentrations. Guideline concentrations are derived from DAFF (1995), DEA (Massie et al. 2017), ANZECC (2000) and the scientific literature on toxicity. This table follows Table 4-6 in PRDW (2017). Orange highlight constituents that require modelling of their behaviour in the receiving environment.

Constituent	Unit	Maximum Concentration at end of Outfall Channel	Background Concentration	General Guideline Concentration	Required Dilutions to meet the General Guideline	Site Specific Guideline Concentration	Required Dilutions to mee the Site Specific Guideline	Comment
Temperature Increase (ΔT)	°C	11.77	0	1	12	1	12	Section 3.2.1
Temperature Increase (ΔT): Accidental Pump Trip	°C	21.18	0	1	21	1	21	Section 3.2.1
Absolute Temperature (chronic effects)	°C					25	0	
Absolute Temperature (acute effects)	°C					30	0	
Free Chlorine	mg/l	0.60	0	0.003	199	0.01	60	Section 3.2.12
Free Chlorine: Shock Chlorination	mg/l	6.597	0	0.003	2199	0.01	660	Section 3.2.12
Total Suspended Sediment (TSS)	mg/l	4.704	4	7	0	7	0	
Hydrazine	mg/l	0.110	0	0.0002	549	0.0025	44	Section 3.2.3
Hydrazine: Exceptional releases during outages	mg/l	0.200	0	0.0002	1002	0.0025	80	Section 3.2.3
Sulphate	mg/l	2,744	2,700	-	Non-toxic	-	0	
Sodium	mg/l	10,829	10,763	-	Non-toxic	-	0	
Aluminium Sulphate	mg/l	0.09	-	-	Precipitates	-	0	
Ammonia	mg/l	0.23	0.015	0.60	0	0.60	0	
Chloride	mg/l	19489.12	19400	-	Screened out based on contribution to salinity	-	0	
Boron	mg/l	5.02	4.5	7	0	7	0	Section 3.2.4
Lithium Hydroxide	mg/l	0.1714	0.17	-	???		0	Section 3.2.5
Phosphate	mg/l	0.87	0.037	0.053	52	0.053	52	Section 3.2.7
Detergents-LAS	mg/l	0.030	0	0.033	0	0.033	0	
Detergent-AES	mg/l	0.610	0	0.65	0	0.650	0	
Detergent-AE	mg/l	0.133	0	0.14	0	0.140	0	
Aluminium	mg/l	0.0053	0.001	0.024	0	0.024	0	
Copper	mg/l	0.0009	0.0008	0.0013	0	0.001	0	
Chromium	mg/l	0.0043	0.00008	0.0144	0	0.014	0	
Iron	mg/l	0.0038	0.003	0.01	0	0.010	0	
Manganese	mg/l	0.0011	0.0007	0.007	0	0.007	0	
Nickel	mg/l	0.0048	0.00056	0.025	0	0.025	0	
Lead	mg/l	0.0033	0.00015	0.012	0	0.012	0	
Zinc	mg/l	0.0033	0.0012	0.025	0	0.025	0	
EDTA	mg/l	0.31	0	500	0	500	0	
Citric Acid	mg/l	0.71	0.1	1	0	1.000	0	
Ethanolamine	mg/l	0.0119	0	0.09	0	0.090	0	
Nitrates	mg/l	0.705	0.67	1.28	0	1.280	0	
Nitrites	mg/l	0.0256	0.017	0.013	-2	0.013	-2	Section 3.2.6
Faecal Coliforms	counts/100ml	0.46	0	20	0	20	0	
BOD	mg/l	1.29	-	5	0	5	0	Section 3.2.8
COD	mg/l	3.62	-	25	0	25	0	Section 3.2.8
Oil/Grease	mg/l	0.33	0	15	0	15	0	Section 3.2.9
Salinity	psu	35.22	35	36	0	36	0	Section 3.2.11
Silica	mg/l	0.66	0.63	-	0	-	0	Section 3.2.10
Phosphonate Antiscalant	mg/l	0.05	0	2	0	2	0	Section 3.2.14
Sodium metabisulphate	mg/l	0.03	0	0.032	0	0.032	0	Section 3.2.12
Peroxyacetic acid	mg/l	0.01	0	0.05	0	0.050	0	Section 3.2.14
Low pH cleaner	mg/l	0.03	0	-	0	-	0	Section 3.2.15
High pH cleaner	mg/l	0.03	0	-	0	-	0	Section 3.2.15
DBNPA	mg/l	0.02	0	0.035	0	0.035	0	
TOC	mg/l	1.18	1.08	-	Screened out as Background approximates discharge	-	0	GL ≈ Discharge
Anionic Polymer	mg/l	0.02	0	-	0	-	0	Section 3.2.13
Ferric Chloride (as Fe)	mg/l	0.04	-	-	Screened out based on contribution to TSS	-	0	Section 3.2.13

3.2.1 Temperature

It is axiomatic that organisms must be able to tolerate the temperature ranges normally encountered in their physical environment and, in poikilotherms, limited temperature elevations within the ranges typical of their habitats should not be harmful to the extent that their persistence in the habitat is compromised. Temperature data for the KNPS region presented in PRDW (2017, Table 2-2) show that in the upper water column (≤10 m depth) minimum temperatures are 8.2-8.7°°C and maximums are 19.2-20.1°°C with the overall temperature ranges being ~11°°C. Temperatures in this location and the southern Benguela Current area in general, vary with the upwelling cycle (above) and temperatures can change by ~7°°C in less than a week (e.g. Figure 2-11, PRDW 2017). Consequently, organisms that inhabit this area classify as being eurythermal and able to accommodate variable temperature increases within this overall range. Therefore, responses of local organisms to temperature elevation limits of +1°°C (DWAF 1995) or +3°°C (World Bank 1998) should only be detectable when ambient temperatures are at the upper end of their natural ranges. A complicating issue here is that a range of temperate eurythermal species have shown the ability to tolerate temperatures a few degrees above the maxima of their respective habitats before the initiation of physiological responses. One of these is the molecular heat shock response (HSR) whereby heat-shock proteins (Hsps) are produced to protect cell proteins from thermally induced degradation (Wickner et al. 1999, and others). In this regard, Buckley et al. (2001) demonstrated that HSR induction occurred at 26-29°°C in mussels (*Mytilus* t*rossulus* and *M. californianus*) collected from lower intertidal and shallow subtidal zones that experience water temperatures ranging between 10°°C and 20°°C. For temperate exclusively subtidal gastropod species exposed to moderately variable (<10°°C range) Tomanek (2013) showed that HSR was initiated at 24°°C and peaked at 27°°C.

Mid-latitude phytoplankton species (*Thalassiosire rotula, T. pseudonana* and *Akashiwo sanguinea*) show similar thermo-plasticity with peak growth rates at ~25°°C and marked declines at 30°°C (Boyd et al. 2013). Comparable responses are apparent in mussel (*Mytilopsis leucophaeta*) larvae that show elevated mortality compared to controls above 24°°C (Verween et al. 2007) and the local sand mussel (*Donax serra*) that demonstrates shell gape at exposure temperatures of 28°°C (Stenton-Dozey & Brown 1994a).

The responses of benthic and pelagic organisms to absolute temperature levels reviewed above indicate that, in temperate environments, temperatures above 25°°C will generate chronic effects in resident populations. This threshold is employed as a site-specific guideline for the lower limit of the temperature range for chronic effects in evaluating the marine ecology risks posed by the KNPS discharge.

The upper limit of the chronic effects temperature range is logically the lower incipient lethal limit. Bamber (1990) defined this as 30-33°°C for zooplankton, indicating that this is general across a wide range of environments. Verween et al (2007) indicate a similar threshold for mussel larvae, BEEMS

(2011a) list 32°°C for juvenile sea bass (*Dicentrarchus labrax*), and Bamber and Seaby (2004) quote an instantaneous lethal temperature of 34°°C for lobster larvae. For the purposes of this assessment, an incipient lethal limit of 30°°C is used as a site-specific guideline to evaluate potential acute effects of the elevated temperature in the KNPS discharge.

3.2.2 Free chlorine/TRO and derivatives

Chlorine and its derivative collectively termed total residual oxidant (TRO) do not occur naturally in the marine environment and the background concentration is thus zero. The specified guideline concentration in the receiving environment outside of the nominal mixing zone is 0.003 mg/l (free chlorine, ANZECC (2000) low reliability trigger/screening level concentration) and the World Bank (1998) limit for discharge is 0.2 mg/l. The United Kingdom environmental quality standard (EQS) is set at 0.01 mg/l with a screening level of 0.001 mg/l (CEFAS 2011).

Table 3.5 summarises TRO no observed effect concentrations (NOEC) and lowest observed effect concentrations (LOEC) for a range of representative marine taxa. Consistent with the precautionary approach these are an order of magnitude greater than the specified screening/trigger levels.

The most sensitive taxon is the brown (phaeophyte) macroalgae *Fucus* with an NOEC for growth of 0.02 mg/l. Kelp and some associated sub-canopy phaeophyte algae are the local equivalent to *Fucus* and, for the purposes of this assessment, the United Kingdom EQS of 0.01 mg/l (50% of the respective phaeophyte NOEC for growth) is used as a site-specific guideline to evaluate environmental risks of TRO in the KNPS cooling water discharge.

Table 3.5: Experimentally derived TRO NOEC (equivalent to EC_{10}) and LOEC for representative marine taxa

Taxon	Environmental Compartment	Test Variable	Metric	TRO mg/l	Source
Tisbe	Plankton: Copepod	Larval survival	NOEC	0.16	CEFAS 2011
Pomatoceros	Benthos: Tube-dwelling Polychaete	Larval development	NOEC	0.30	CEFAS 2011
Ceramium	Benthos: Red Macroalgae	Growth	NOEC	0.14	CEFAS 2011
Fucus	Benthos: Brown Macroalgae	Growth (intermittent exposure)	NOEC	0.06	CEFAS 2011
Fucus	Benthos: Brown Macroalgae	Growth (permanent exposure)	NOEC	0.02	CEFAS 2011
Sabellidae	Benthos: Polychaete	Siphon retraction	LOEC	0.10	Last et al 2016
Donax	Benthos: Sand Mussel	Burrowing	LOEC	0.10	Stenton-Dozey and Brown 1994b
Mysidopsis	Nekton: Mysidacea	Reproduction	NOEC	0.02-0.09	ANZECC 2000
Menidia	Fish: pelagic/neritic	Growth	NOEC	0.09-0.19	ANZECC 2000

Bromoform is the main chlorination by-product (CBP) formed and is therefore the main focus of the following discussion. At KNPS, a chlorine dose of 1.5 mg/l is used and the residual TRO concentration at the outfall is 0.5 mg/l. This implies that 1 mg/l of chlorine is used by the cooling waters. This would result in approximately 0.01- 0.05 mg/l bromoform concentration at the outfall.

This is based on the assumptions that the absolute yield of bromoform resulting from the chlorination of seawater is about 1-5% (Allonier et al. 1999; Abarnou & Miossec 1992). As the cooling waters from the outfall mixes with the receiving waters, the residual chlorine reacts with fresh organic matter and more bromoform is likely to be produced. The ratio of dibromochlomethane (DBCM) + bromodichlormethane (BDCM) to bromoform has been reported to be between 0.03 and 0.07 mg/l (BEEMS, 2011b). Therefore, total production of these trihalomethanes is expected to range between 0.0004 and 0.003 mg/l.

The toxicity data for bromoform and CBPs is very limited (Jenner et al. 1997). The lowest NOEC value for bromoform determined through an EDF study on CBP was 0.5 mg/l (BEEMS, 2011b) for the larvae of the *Crassostrea gigas* oyster. However, an early study by Stewart (1979) reported about 20% mortality in the larvae of the oyster *C. virginica* at bromoform concentrations as low as 0.05 mg/l and an LC_{50} of 1 mg/l. Based on a LC_{50} of 1 mg/l and a safety factor of a 100, a probable NOEC level of 0.01 mg/l, equivalent to the UK marine EQS, is obtained. A higher guideline of 0.05 mg/l would be obtained using the EDF data and a safety factor of 10 (used with more reliable data).

The estimated concentration of bromoform at the outfall is within the range of guideline values. This concentration will be further reduced primarily through volatisation and decay as the cooling waters are discharged into the receiving waters. Additional bromoform will be produced as the residual TRO reacts with fresh organic matter in the receiving environment. However, as noted above, the concentration of residual TRO is simultaneously reduced through mixing and the concentration of bromoform produced will also be lower and hence remain close to the guideline. On the other hand, it is possible to screen out DBCM and BDCM as their total concentration at the outfall is below the reference value by Taylor (2006) being 0.005 mg/l. It is also below a 0.25 mg/l guideline derived from the reported lowest NOEC for DBCM (2.5 mg/l on sea-urchin embryo).

In view of the above trihalomethanes are screened out from further assessment. However, given that the actual amount of trihalomethanes produced at KNPS is not known, further studies would be beneficial to understand the formation and decay of these compounds in the discharged cooling water.

3.2.3 Hydrazine

Hydrazine is a powerful reductant and is likely to degrade through reactions with the oxidants present (e.g. dissolved oxygen, residual chlorine). These lead to a relatively short half-life of hydrazine in seawater of approximately 8 hours (CERI 2007). Hydrazine toxicity in the marine environment is highest (24 hr LOEC = 0.002 mg/l) for phaeophyte gametophyte growth (CERI 2007). Exposures of kelp bed habitat (reef formations) to hydrazine at this concentration may limit sporophyte formation and thus kelp bed development. However, effects on other marine organisms including fish have only been recorded at orders of magnitude higher concentrations (96 hr LC_{50} of 3.4 mg/l, CERI 2007) which exceed the hydrazine concentration in the KNPS discharge.

The general water guideline derived by Government of Canada (2011) is 0.0002 mg/l. The recorded NOEC of 0.0025 mg/l for phaeophyta is employed as a site-specific guideline for assessing risks associated with hydrazine release.

3.2.4 Boron

The average background concentration for boron in seawater is 4.5 mg/l and the guideline of 7 mg/l is based on the UK statutory guidance (Pacey et al. 2011a). ANZECC (2000) indicates 12.2-88.3 mg/l as the LC_{50} toxicity level for fish. Marine toxicity data are limited and they recommend that the background concentration of boron in seawater be used as a low reliability trigger value. The maximum concentration at the end of the outfall, where the waste streams may not be fully mixed (PRDW, 2017), is marginally higher than the background and as the UK toxicity threshold exceeds both boron is screened out from further assessment.

3.2.5 Lithium hydroxide

Lithium hydroxide is known to have low ecotoxicity (Pacey et al. 2011b). In this case, the maximum concentration in the discharge is approximately equal to the background and this compound is therefore screened out from further assessment.

3.2.6 Nitrite-Nitrogen

In the marine environment nitrite is a transient intermediate compound in the oxidation of ammonium to nitrate, a process termed nitrification (Herbert 1999). It typically reaches its highest concentrations in the water column at the base of the euphotic zone where ammonia-oxidising bacteria (e.g. *Nitrosomonas*) are not substrate limited or outcompeted by photosynthesising phytoplankton as occurs at higher light levels. The produced nitrite is then further oxidised to nitrate by e.g. *Nitrobacter*. Reported nitrification rates in Herbert (1999) range from 2 to 112 mg N m^2/day, depending on substrates availability and nitrifying bacterial biomass showing that, in the second step of the nitrifying process, nitrite can be rapidly converted to nitrate.

The specified water quality guideline concentration for nitrite-N of 0.013 mg N/litre is the 80th percentile of the natural distribution in the receiving environment. Measurement data for the Benguela Current, however, show that nitrite-nitrogen can attain 0.042 mg N/litre at 60 m depth in the water column (Chapman and Shannon, 1985). As there are no direct toxicity effects linked to nitrite-nitrogen (it is not listed in ANZECC 2000) and significantly higher concentrations than the derived guideline concentration have been measured in the larger receiving environment this compound is screened from further assessment here.

3.2.7 Phosphate

The mean background and general and site-specific guideline concentrations are calculated from in-situ nutrient concentrations for the South African West coast. The data were obtained from the

SADCO database and from DAFF. All sample points were within 10 km from the nearest shore and shallower than 100 m depth. The guideline value was taken as the 80th percentile of the distribution (*cf* ANZECC 2000, Massie et al. 2017). The phosphate concentration in the discharge is an order of magnitude higher than the specified guideline and can lead to local enrichment in dissolved phosphorus in the receiving water body. The potential consequences are evaluated in the impact assessment below.

3.2.8 BOD & COD

Biological oxygen demand (BOD) and chemical oxygen demand (COD) are essentially oxygen debts placed on the receiving environment by labile organic matter in the KNPS discharges. There are no receiving water quality concentration guidelines for these compounds but discharge limits have been proposed in conditions for general discharge authorisation (special limits) (in Anchor 2015). The BOD limit is ~4 x higher than the maximum levels predicted for the discharge while that for COD is an order of magnitude higher.

Despite there being no specific water quality guideline for either of BOD and COD indirectly the prescription for dissolved oxygen (DO) that it should not fall below 10% of the natural variability (DWAF 1995), or should not depart from the 20^{th}-80^{th} percentile range (Massie et al. 2017) can be considered to apply. Shallow inshore waters in the southern Benguela current area south of Saldanha Bay are generally saturated in terms of oxygen concentration (Chapman and Shannon, 1985, Andrews and Hutchings, 1980). Saturation concentrations at 1 bar at 15 °C and 20 °C respectively are 7.9 mg/l and 7.2 mg/l (www.engineringtoolbax.com/oxygen-solubility-water-d_841.html). The mid-point of this range is 7.55 mg/l. On the assumption that the seawater is consistently saturated application of the 20^{th}-80^{th} percentile range would basically limit the discharge of any oxygen consuming chemicals so the DWAF (1995) is considered to apply here. The consequence is that the oxygen 'debt' placed on the receiving water body should not be significantly greater than 0.76 mg/l.

The maximum COD at the point of discharge is predicted to be 3.62 mg/l (Table 3.1). COD comprises what can be considered to be an instantaneous oxygen demand, linked to the oxidation of reduced substances such as sulphide to sulphate, and a longer term (~5 days) demand linked to aerobic decomposition of organic matter by microorganisms (e.g. CSIR 2017). The latter the BOD fraction. Maximum BOD in the KNPS discharge is estimated to be 1.29 mg/l (Table 3.1) and therefore the maximum instantaneous oxygen demand is 2.33 mg/l. Given the nature of the receiving water body with water column mixing of the flux of oxygen through the sea surface by strong wave action and appreciable oxygen evolution by photosynthesising phytoplankton and macroalgae (kelps, etc.), this level of oxygen demand should not distort ambient oxygen concentrations to a measurable degree.

Consequently, from considerations of discharge limits and potential effects on the receiving environment both COD and BOD are screened out from further assessment here.

3.2.9 Oil and grease

The DWAF (1995) guidance for oil and grease is that there should not be visually obvious concentrations on the water surface but no concentration limits are given. The International Maritime Organisation (MARPOL 73/78, Annex 1, Regulation 15) guidance for the discharge of machinery space drainage water is that it should not form a visible sheen on the water surface and that this can be achieved by limiting oil concentrations to below 15 mg/l. This is adopted here as a general and a site-specific guideline. The estimated maximum oil and grease concentration in the KNPS discharge is far below this limit and these constituents are screened out from further assessment.

3.2.10 Silica

Silica as silicate (SiO_4) is an abundant mineral, making up a large proportion of the earth's crust. In the marine environment silica is structurally important in planktonic diatoms (phytoplankton) and has been shown to limit growth in this class of the phytoplankton where silicate concentrations are low as in the northern Benguela Current region (Chapman and Shannon, 1985, Shannon and Pillar, 1986). Measured silicate concentrations in the southern Benguela current area range between 0.36 and 0.90 mg/l (Andrews and Hutchings, 1980). The predicted maximum concentration in the KNPS discharge is 0.66 mg/l, in the middle of the range; this constituent is screened out from further assessment.

3.2.11 Salinity

The salinity of the SWRO brine effluent is about double that of the feedwater while that of the BWRO is <50% of the receiving seawater body (15 psu vs 35 psu). Dense brines discharged directly into the sea will tend to sink to the seafloor, whilst lower salt concentration brines would be buoyant. At KNPS, the brine from the temporary BWRO plant will be discharged via the Southern Stormwater system (SEO-S) and diluted through mixing with the cooling effluent from KNPS. When the permanent plant is installed, the discharge may be moved to the top of the outfall channel, similar to the SEK, where the SWRO plant discharge will be located. The discharged brines will mix with the KNPS effluents in the discharge channel and, primarily due to volume differences in the respective effluents, should not affect the dispersion of the plume (PRDW, 2017).

3.2.12 Chlorine residual and sodium metabisulphate

The RO plant feedwater is chlorinated to prevent biofouling and, similar to the KNPS cooling waters, a chlorine dose of 1.5 mg/l is to be applied. However, the chlorine (or more appropriately TRO) needs to be removed before the feedwater reaches the RO membranes. The latter, being made of polyamide materials, can be damaged by oxidising chemicals. Sodium metabisulphate is added to react with the TRO and form harmless by-products such as Br^-, Cl^- and sulphate. As a result, the expected concentrations of free chlorine or TRO within the brine is expected to be very low. Sodium metabisulphate is considered non-toxic. However, excess sodium metabisulphate can reduce dissolved oxygen concentrations. This can be remedied by ensuring appropriate dosing or by aerating the effluent before discharge.

Dibromonitrilopropionamide (DBNPA) is a non-oxidising biocide that can be used as an alternative to chlorine. It is also used during the cleaning processes. It degrades rapidly into relatively non-toxic by-products.

3.2.13 Coagulants and total suspended solids

In SWRO and BWRO plants coagulants, such as ferric chloride ($FeCl_3$), are added to the feedwater to coagulate particulate material which can then be filtered in pre-treatment. In SWRO plants at the pH of seawater, $FeCl_3$ precipitates into ferric hydroxide ($Fe(OH)_3$), adding to the particulate load. In BWRO plants the main driver of particle formation is oxidation of the ferric chloride to ferric hydroxide by increased dissolved oxygen concentrations. The pre-treatment filters are backwashed intermittently and the backwash water added to the effluent brine. The amount of particulate matter discharged is dependent on the feedwater quality but can be at relatively high concentrations (Table 3.2 and Table 3.3), contributing to effluent turbidity. Further, the discharge of the red $Fe(OH)_3$ is likely to result in a discolouration in the brine. The estimated particulate $Fe(OH)_3$ that may increase turbidity is included in the total suspended solids (TSS), which should not decrease the euphotic zone depth by more than 10% compared to background levels (DWAF, 1995). However, the degree to which the ferric hydroxide may influence effluent colour is currently unknown due to uncertainties on RO plant intake water pre-treatment filter backwashing frequencies and how the filter backwash will be bled into the larger KNPS effluent stream. Possible effects and their mitigation are assessed in the impact assessment section below.

Either as an alternative to ferric chloride or in conjunction with it an anionic polymer (typically anionic polyacrylamide, Lee et al. 2014) may be employed as a flocculent. The anionic polymer is efficient at combining and stabilising microflocs allowing them to be removed in filtration. Further, there are environmental advantages in their application as they can reduce chemical oxygen demand, through the removal of fine organic matter, obviously further reduce total suspended solids (TSS) in the feed water as well turbidity due to coloured dissolved organic matter CDOM). A further advantage of these flocculants is that characteristically dense sludges are formed due to strengthened bridging between particles (Lee et al. 2014). However, this is only an advantage if the sludge is to be disposed of on-land. Anionic polymers are considered to be weakly toxic, in contrast to cationic polymers (Lee et al. 2014), and on this basis, are screened out from further assessment.

3.2.14 Anti-scalants

The build-up of scale inside the pipes and the RO plant surfaces exposed to feedwater is undesirable for the plant's performance. This is prevented by the addition of antiscalants such as acid and polyphosphates, organic polymers or polyphosphonate. Polyphosphates are used less frequently as they can lead to the formation of orthophosphate, enhancing algal growth and eutrophication. The composition of the antiscalants used depends on the membrane type and can vary according to the manufacturer. The use of polyphosphonates was proposed for the Volwaterbaai desalination plant (Pulfrich & Steffani 2007). Polyphosphonates and organic polymers have low aquatic toxicity. However, they can bind with nutrients and ions required for algal growth. As such, this can have a negative effect on phytoplankton growth but there is no guideline for the concentration of polyphosphonates in the receiving water. They are typically dosed into the feedwater at 3 mg/l which is much lower than levels at which chronic toxic effects have been observed.

3.2.15 CIP solution

The membrane cleaning is often done in two stages. It is first washed with an acidic solution and then with an alkaline one before being rinsed with product water. Silt deposits and biofilms are cleaned using alkaline solutions (pH 11-12) whereas metal oxides and scales are removed using acidic solutions (pH 2-3). While the components used have low toxicity, they affect the effluent's pH. For instance, where sulphuric acid is used, it lowers the pH to about 6-7. This acidity is, however, buffered by the natural alkalinity of seawater. The CIP might also contain additives such as Ethylenediaminetetra-acetic acid (EDTA) and DBNPA, sodium tripolyphosphate (STPP) and Trisodium phosphate (TSP). EDTA is a chelating agent known to bind with metals. At the low concentrations present in the CIP, EDTA in the effluent is expected to be bound to metal ions such manganese and calcium. By itself, EDTA has very low aquatic toxicity. Similarly, STPP has low aquatic toxicity. STPP can be hydrolysed to orthophosphate. The latter is also formed upon dissolution of TSP. Increases in orthophosphate can lead to increases in algal growth. However, the release of CIP additives will be occasional. Furthermore, in the vicinity of the KNPS, phosphate is not a limiting nutrient and therefore increases in phosphate are unlikely to cause significant algal growth.

4 IMPACT ASSESSMENT

4.1 INTRODUCTION

This section evaluates the impacts of the intake and discharge of cooling water on the receiving environment focussing on the constituents of the discharge that are non-compliant with established and/or adopted water quality guidelines in terms of:

- Extents of the non-compliant zones compared to provisional mixing zone dimensions of 300 m radius for deep water discharges (Anchor 2015) and the World Bank (1998) 100 m distance;
- The associated toxicity exposure mediated ecological risks; and
- Heavy metals that, although currently compliant to sediment quality guidelines in terms of average concentrations, are an exception to this due to the possible build-up of their concentrations in deposition areas to the extent that there are possible effects on biota.

The section incorporates and expands on the assessment conducted by Robinson (2013) through inclusions of:

- The results of the updated hydrodynamic modelling (PRDW 2017);
- Additional evaluations of discharge constituents; and
- Considerations of normal and abnormal conditions that may affect discharge characteristics.

The physical effects of the seawater intake and discharge system infrastructure on the coast are not dealt with as they have been in place for >20 years and have been accommodated within the environmental processes characteristic of the KNPS location.

4.1.1 Identification of potential environmental impacts (operational phase only)

The **Activity** that may have negative effects on the marine environment is the discharge of the heated cooling water back into the sea, with co-discharges that may generate chronic and/ or acute effects on biota in the receiving environment.

The **Environmental conditions** that can influence the significance of such effects include ambient water temperatures, current direction and speed, waves and tides. These were incorporated into the PRDW (2017) model runs. Abnormal conditions can arise from routine maintenance or shutdowns. Accordingly, at times, there are abnormal fluctuations in temperature and levels of chemical constituents such chlorine and hydrazine in the discharged water. These were also modelled.

The discharge constituents taken forward for modelling as derived from Table 3.4 are temperature, chlorine/TRO, hydrazine and phosphates

4.1.2 Impact Assessment Method

The impact assessment follows a regular procedure of rating the significance of impacts according to the criteria of duration, geographic extent and intensity/magnitude, refined by consideration of the larger context. Table 4.1 provides the definitions followed.

Table 4.1: Definitions of impact assessment criteria used in this study.

Criterion	Ratings of Impacts
Duration	**Temporary/ event** = less than 24 hours. **Short term** = less than a month **Seasonal** = winter/spring and summer/autumn. **Long term=** the impact will cease after the operational life of the power plant. **Permanent.**
Geographic Extent	**Site** = within 500 metres of discharge. **Local** = within 1 000 m of the discharge **Sub-regional** = The KNPS gazetted marine security zone centred on the KNPS extending 3.2 km alongshore and 2 km offshore **Regional** = extending from Melkbosstrand in the south to Bok Punt in the north and to 5 km offshore in the SW Cape inner continental shelf ecozone that extends from Cape Point in the south to Cape Columbine in the north and to the 150 m isobath offshore (Figure 2.2).
Intensity/ magnitude/ power over receptors	Magnitude <u>in the given area, over the given time:</u> **Low =** negligible alteration of natural systems, patterns or processes. i.e. the disturbance affects the environment in such a way that natural functions and processes continue 'normally'. It affects a localised group within a population for a short time period, and does not interfere with other trophic levels. **Medium =** notable alteration of natural systems, patterns or processes. i.e. where the affected environment is altered but natural functions and processes continue, albeit in a modified way. A portion of a population is affected, but not for more than one generation and without threatening the integrity of that population/system or any species/groups that depend on it. **High =** severe alteration of natural systems, patterns or processes. i.e. where natural functions or processes are altered to the extent that they will temporarily or permanently cease. Affects an entire population/species or system causing a decline in abundance/change in distribution/major disruption that exists for several generations.
Significance	Determines whether the impact will cause a notable alteration of the environment, <u>particularly in the broader context</u>, and how this should influence decision making; ratings are: **Low to very low =** The impact may result in minor alterations of the environment and/or can be easily avoided by implementing appropriate mitigation measures, and should not have an influence on decision-making, or **Medium =** The impact will result in a moderate alteration of the environment and can be reduced or avoided by implementing the appropriate mitigation measures, and should only have an influence on decision-making if not mitigated, or **High =** The impacts will result in a major alteration to the environment even with the implementation of the appropriate mitigation measures and should have an influence on decision-making.
Confidence	Specifies the degree of confidence in predictions based on available information and specialist knowledge as **Low** or **Medium** or **High**, with reasons.

4.1.3 Employment of Modelling Results in the Impact Assessment

The hydrodynamic dispersion modelling for the KNPS discharge conducted by PRDW (2017) predicted the extent of and fluctuations in constituents of the discharges in the receiving water environment. The modelling results are interpreted below to predict impacts in the receiving environment (water column and seabed) according to constituent concentrations and distributions. In addition, time series data are used to identify exposure risks at selected receptor sites. The latter include two subtidal reefs (Blinders), the inter- and sub-tidal zones of the intake basin breakwater, sites at 100 m and 1 000 m from the discharge and inter- and sub-tidal zones to the south of the KNPS at Melkbosstrand. The locations of these six sites, within a 5 km radius of the discharge, are shown in Figure 4.1.

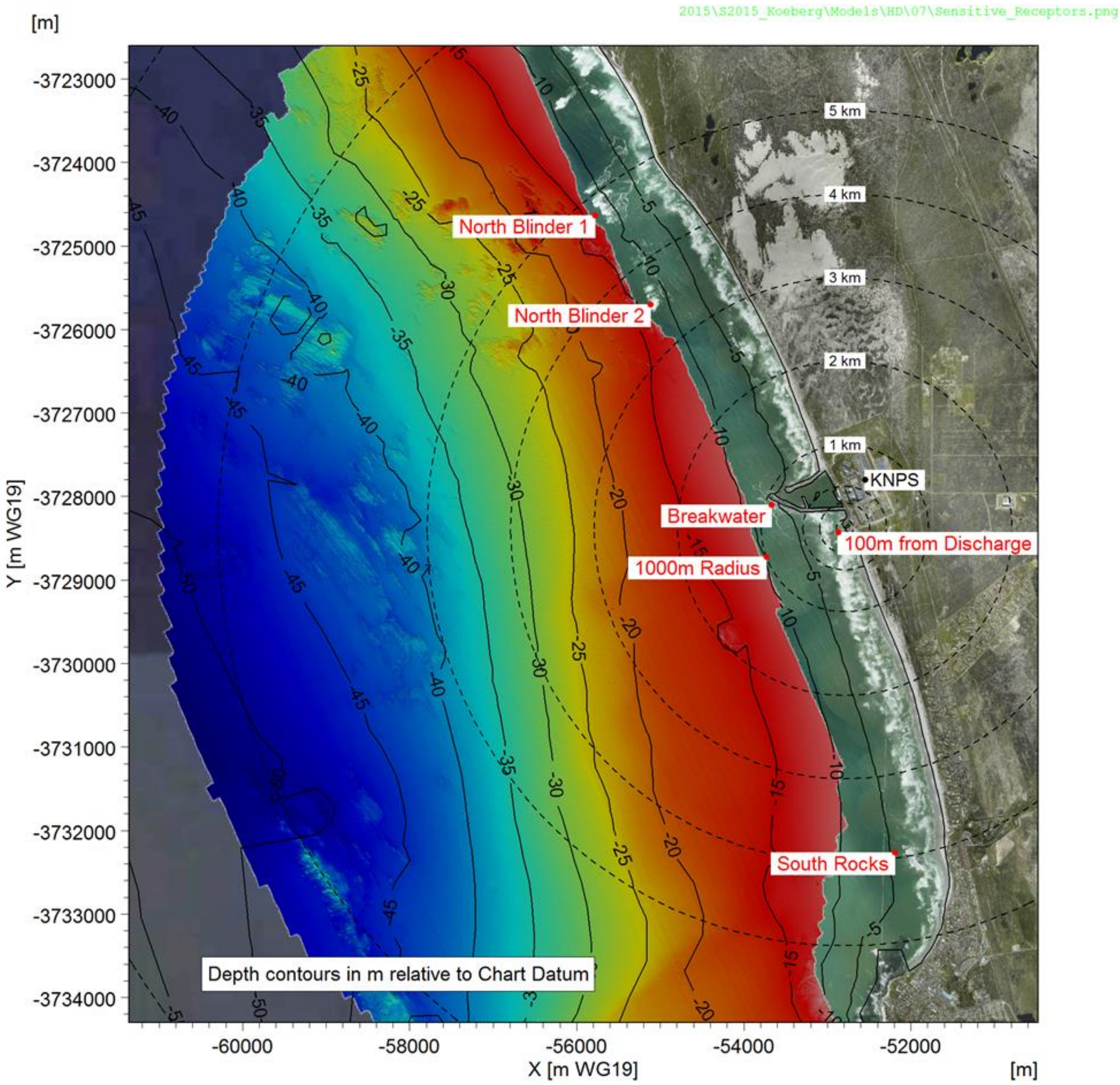

Figure 4.1: Locations of sensitive receptors within a 5 km radius of the discharge (PRDW 2017).

All of the hydrodynamic modelling results and plots are presented in PRDW (2017). For completeness discharge distribution plots in the receiving environment that are pertinent to the assessments of the impacts are provided in the relevant sections below. In each case the specific sources of the plots in the PRDW (2017) report are indicated for ease of reference, should this be required.

4.2 Impact-1. Effects of cooling water discharge on the environment: Temperature

4.2.1 Nature of Impacts

The discharge of cooling water to the marine environment generates chronic level effects on biota such as, alterations in growth, metabolism, reproduction, production, and/ or influence ecosystem level processes through e.g. alterations of the amount of oxygen dissolved in sea water (Robinson, 2013, and authors cited therein).

4.2.2 Applicable Guidelines and Thresholds

Defined water quality guidelines for temperature exceedances are described in Section 3 above. General guidelines are those for South Africa defined as +1 °C above ambient (DWAF 1995), the World Bank (1998) advice on cooling water discharges as +3 °C at the boundary of a nominal mixing zone. Site-specific guidelines based on discernible chronic and acute responses in marine biota derived for this assessment are absolute temperature thresholds of 25 °C as the lower limit of chronic effects and 30 °C as the lower limit of acute effects.

4.2.3 Impact Assessment

4.2.3.1 Compliance with general guidelines

Figure 4.2 and Figure 4.3 show the percentage of time that the DWAF (1995) water quality guideline of +1 °C above ambient is exceeded in the receiving water body at the surface and seabed under normal operating conditions. The area of non-compliance at the 95th percentile level (>5% of the time) near the sea surface extends from 4 km to the north of the KNPS to approaching 6.5 km to the south and 3.2 km offshore. Near the seabed the area of non-compliance is lower, due to the fact that the discharge plume is buoyant (Jury & Bain 1989), extending from 3.8 km in the north to ~5.5 km in the south and 1.2 km offshore. The corresponding non-compliant areas for the +3 °C World Bank (1998) limit (Figure 4.4 and Figure 4.5) near the sea surface extend 1.5 km to the north of the discharge, 3.5 km to the south and 1.5 km offshore. At the sea bed, these dimensions are 0.5 km north. 3.5 km south and 0.8 km offshore.

In both cases the areas of non-compliance are extensive and considerably exceed the provisional mixing zone dimensions put forward by DEA (300 m radius from discharge for offshore locations, (Anchor 2015) and the World Bank (1998) 100 m distance.

The impact significance ratings for compliance with general guidelines is summarised in Table 4.2 below.

Table 4.2: Impact assessment table for temperature exceedances above the general WQG (+1 °C) and World Bank (+3 °C) on the receiving environment under normal operating conditions.

Nature of negative impact	**Compliance with general water quality guidelines**
Extent/ geographical area of impact	**Regional:** The heated effluent plume exceeds defined thresholds beyond provisional and defined mixing zone distances from the discharge and extends into the SW Cape inner continental shelf ecozone.
Duration of impact	**Long term:** Continuously throughout the life of the power plant.
Intensity/ magnitude/ power of impact	**High:** The discharge is non-compliant with existing and developing policy on marine outfalls in South Africa.
Significance before mitigation	**High**.
Mitigation/ management actions	Mitigation would require alternative methods to dissipate the heat produced in nuclear power generation through, e.g. cooling towers or through heated cooling water dispersion through an offshore deep-water discharge with diffusers. The cost benefits of either of the above or other alternatives are moot in terms of the ecological risks posed by the discharge (see below).
Significance with mitigation	**Low** – The discharge would be consistent with policy
Confidence in predictions	**High** – the modelled plume behaviour is robust.

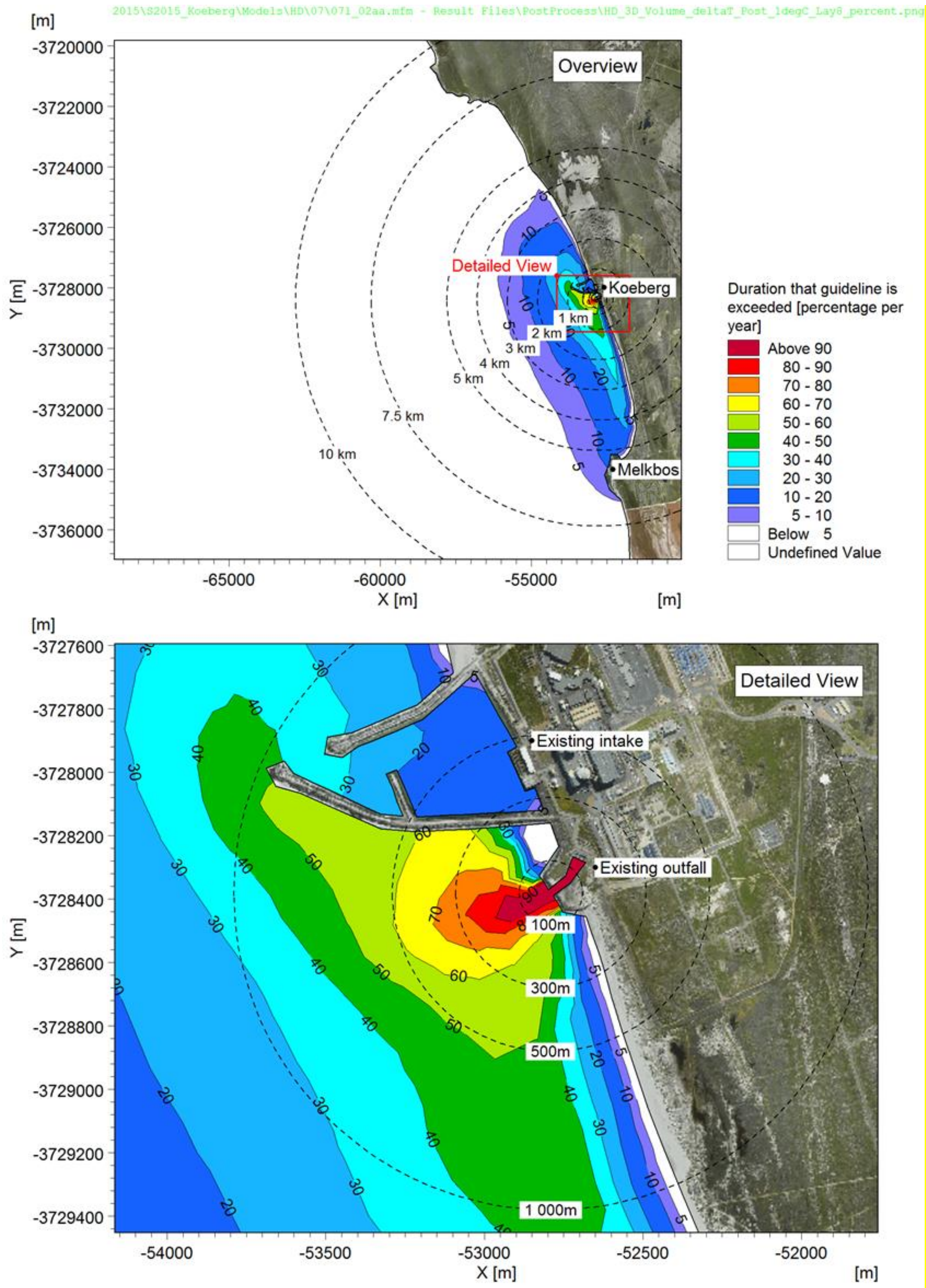

Figure 4.2: Percentage of time during which the DWAF (1995) water quality guideline increase in temperature (+1 °C above ambient) is exceeded near the sea surface with plant operating at full capacity (from PRDW 2017, their Figure B-1).

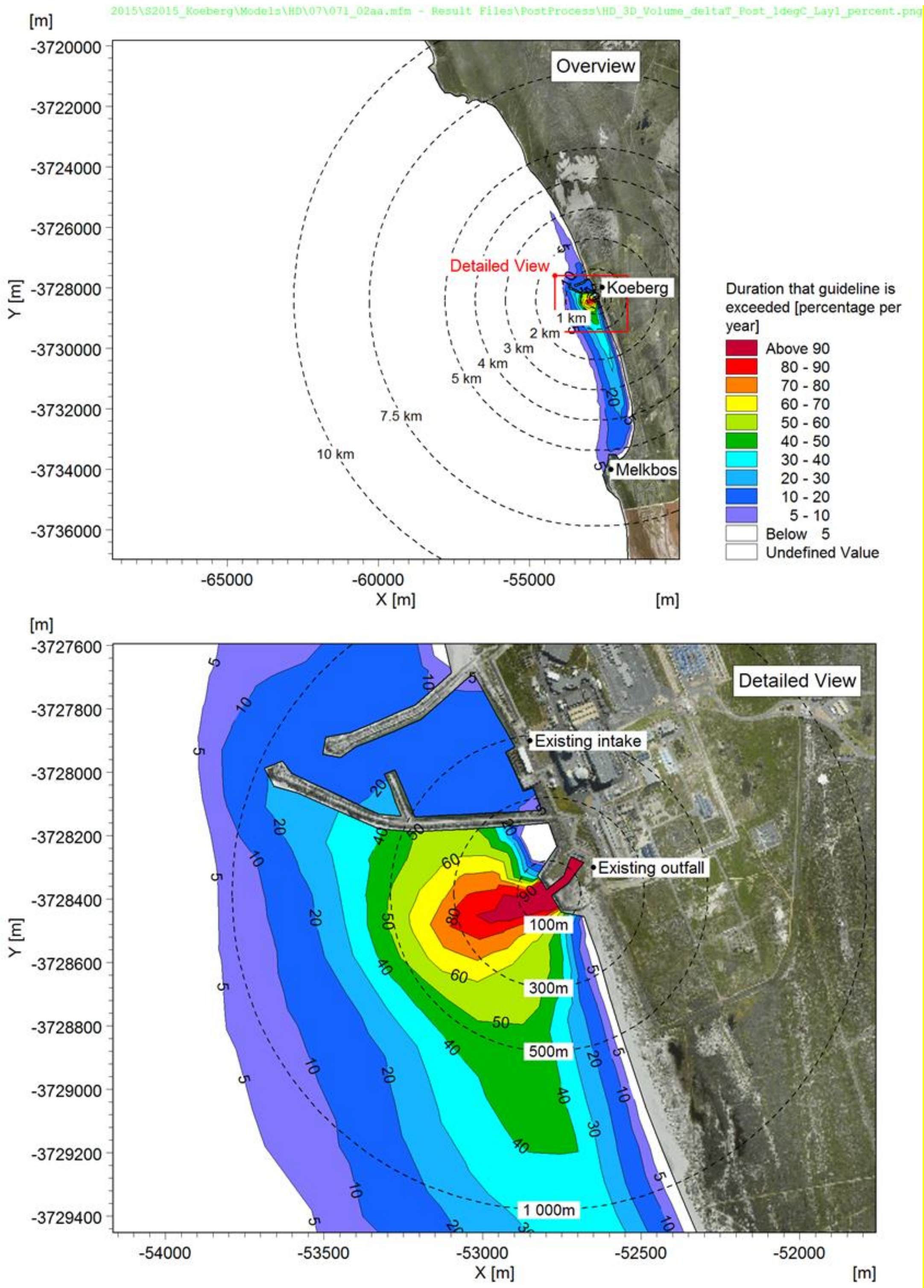

Figure 4.3: Percentage of time during which the DWAF (1995) water quality guideline increase in temperature (+1 °C above ambient) is exceeded near the seabed with plant operating at full capacity (from PRDW 2017, their Figure B-2).

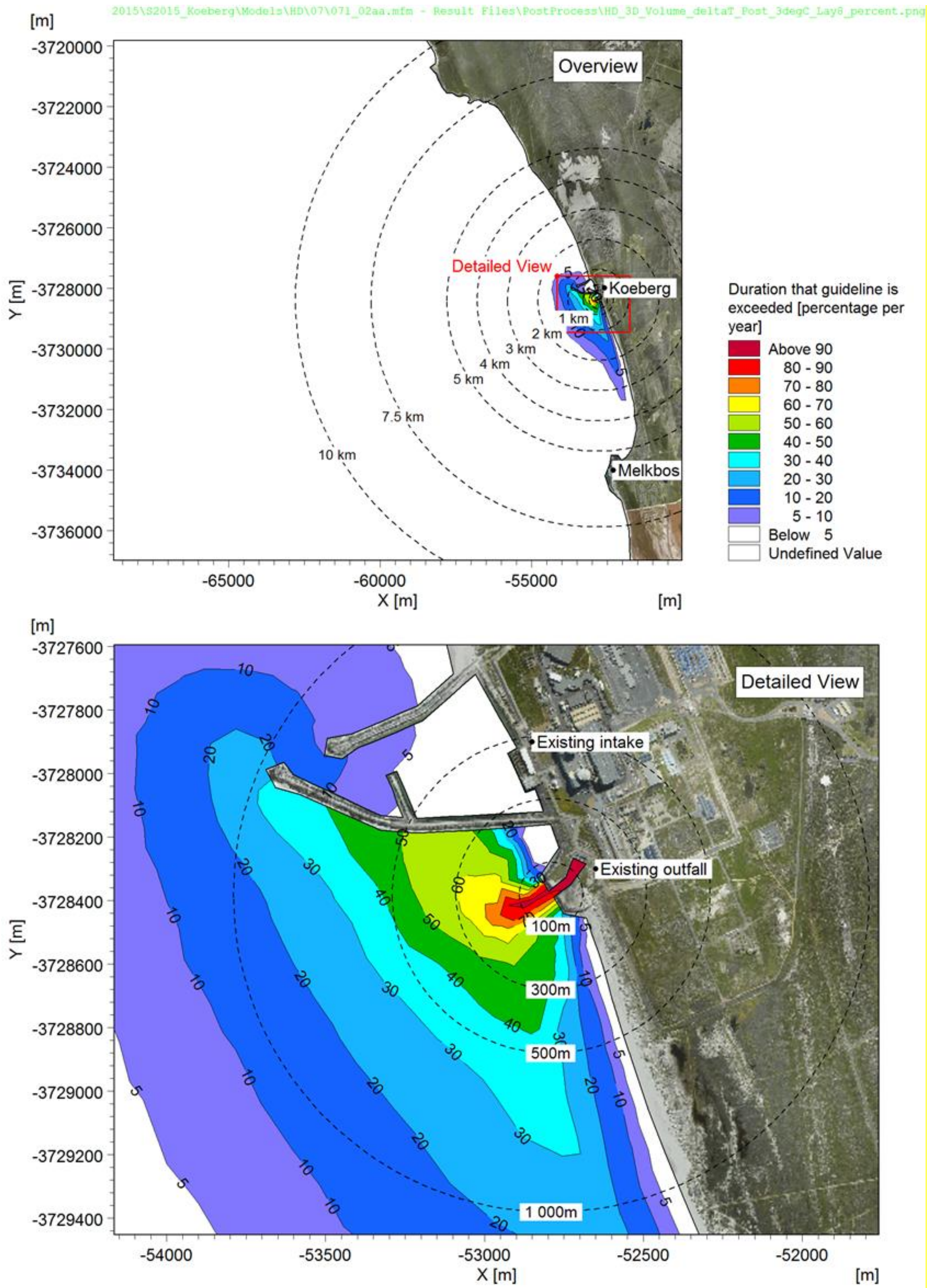

Figure 4.4: Percentage of time during which the World Bank (1998) water quality guideline increase in temperature (+3 °C above ambient) is exceeded near the sea surface with plant operating at full capacity (from PRDW 2017, their Figure B-5).

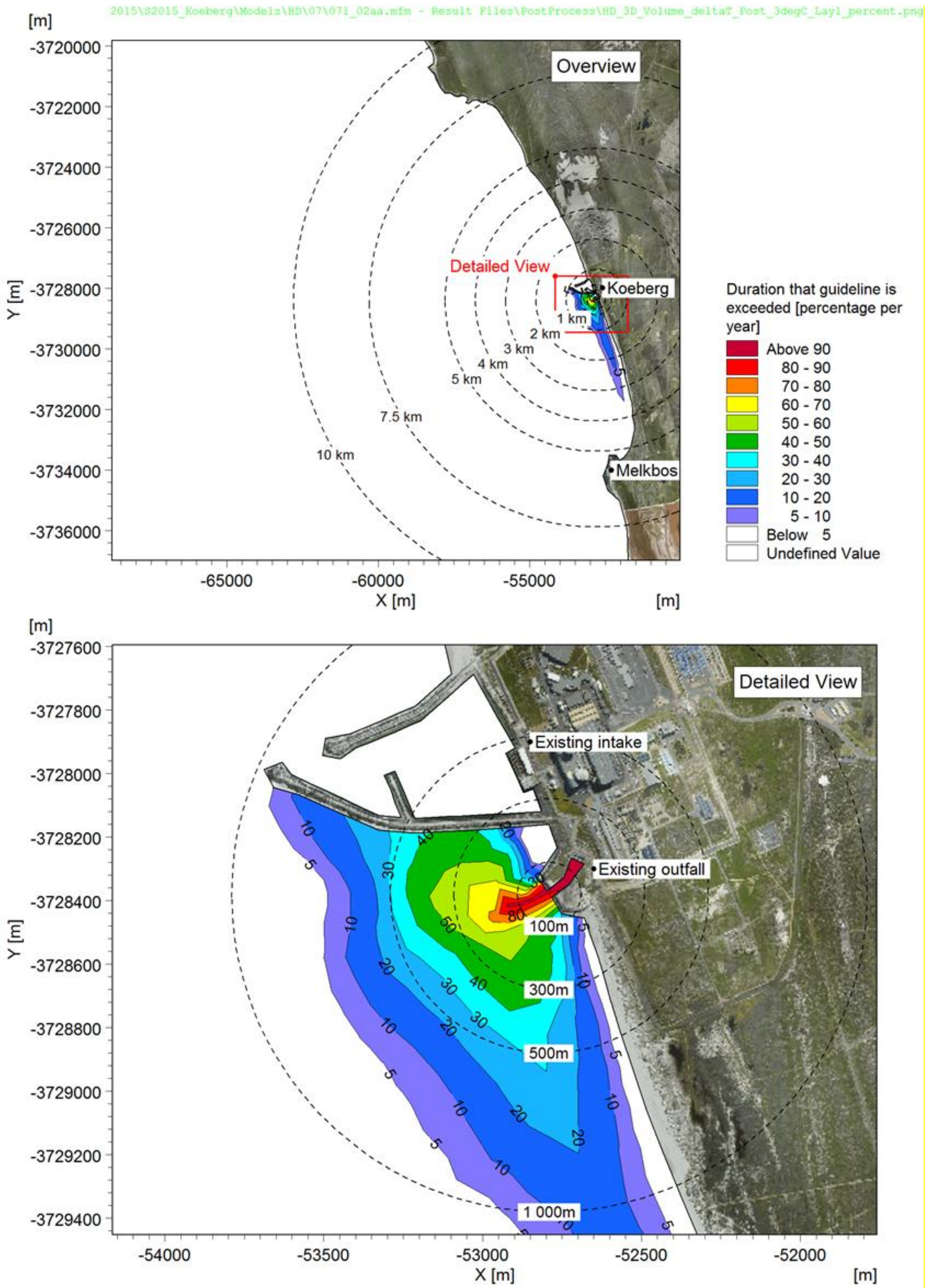

Figure 4.5: Percentage of time during which the World Bank (1998) water quality guideline increase in temperature (+3 °C above ambient) is exceeded near the seabed with plant operating at full capacity (from PRDW 2017, their Figure B-6).

4.2.3.2 Compliance with derived site-specific guidelines and ecological risk

The derived site-specific water quality guidelines (Section 3) set the lower absolute temperature limit for chronic (sub-lethal) effects at 25 °C and that for acute (lethal) effects at 30 °C. Figure 4.6 and Figure 4.7 show predicted extents of the ≥25 °C and ≥30 °C temperatures in the discharge plume under normal plant operating conditions while Figure 4.8 and Figure 4.9 show predicted distributions under the short terms (12 hours) abnormal conditions of breakdown/tripping of one of the CRF pumps.

Under normal operating conditions temperature induced chronic effects in the resident biota will be restricted to the immediate area of the discharge in the longshore and extend 100 m offshore. Temperatures above the acute effects threshold are not predicted under this operating scenario. In the abnormal conditions of a CRF pump stopping operating the extent of the area that will experience temperatures in excess of 25 °C is estimated to be 1.1 km south of the discharge, 0.5 km north and 1.0 km to the west. Temperatures higher than 30 °C are predicted to occur but to be constrained to the immediate area of the discharge in the longshore and extend 0.2 km offshore. All of these predicted extents are smaller at the seabed.

The impact significance ratings for compliance with site-specific guidelines under normal plant operating conditions is summarised in Table 4.3 and Table 4.4 summarises those for abnormal conditions.

Table 4.3: Impact assessment table for the extents of the ecological effects of temperature exceedances above the site-specific chronic (25 °C) and acute (30 °C) effect guidelines on the receiving environment under normal operating conditions.

Nature of negative impact	**Ecological effects due to exceedances of site-specific temperature guidelines**
Extent/ geographical area of impact	**Site:** The chronic effects threshold is limited to within 100 m of the discharge.
Duration of impact	**Long term:** Continuously throughout the life of the power plant.
Intensity/ magnitude/ power of impact	**Low:** Effects are sub-lethal and limited to a negligible area.
Significance before mitigation	**Very Low**.
Mitigation/ management actions	n/a
Significance with mitigation	n/a
Confidence in predictions	**High** – the modelled plume behaviour is robust.

Table 4.4: Impact assessment table for the extents of the ecological effects of temperature exceedances above the site-specific chronic (25 °C) and acute (30 °C) effect guidelines on the receiving environment under abnormal operating conditions.

Nature of negative impact	**Ecological effects due to exceedances of site-specific temperature guidelines**
Extent/ geographical area of impact	**Local:** The chronic effects threshold is limited to within 1000 m of the discharge. The acute threshold is limited to the **Site** extent.
Duration of impact	**Temporary:** Out of commission durations are <12 hours and events are infrequent.
Intensity/ magnitude/ power of impact	**Low:** Non-compliance durations are short (<12 hours) and rare
Significance before mitigation	**Very Low**.
Mitigation/ management actions	n/a
Significance with mitigation	n/a
Confidence in predictions	**High** – the modelled plume behaviour is robust.

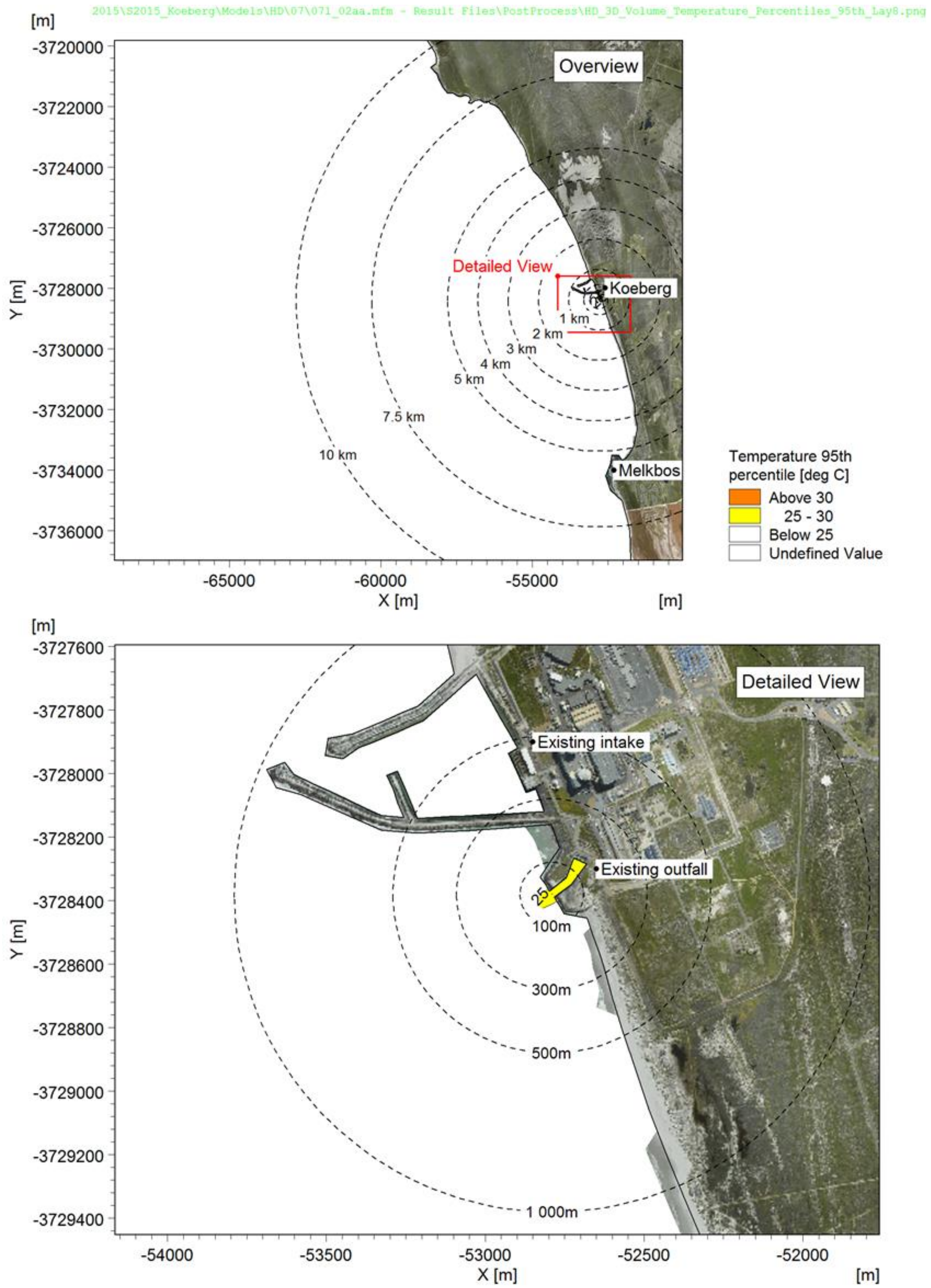

Figure 4.6: 95th percentile near surface absolute temperature distributions for temperatures ≥25 °C and ≥30 °C: plant operation at full capacity (from PRDW 2017, their Figure B-9).

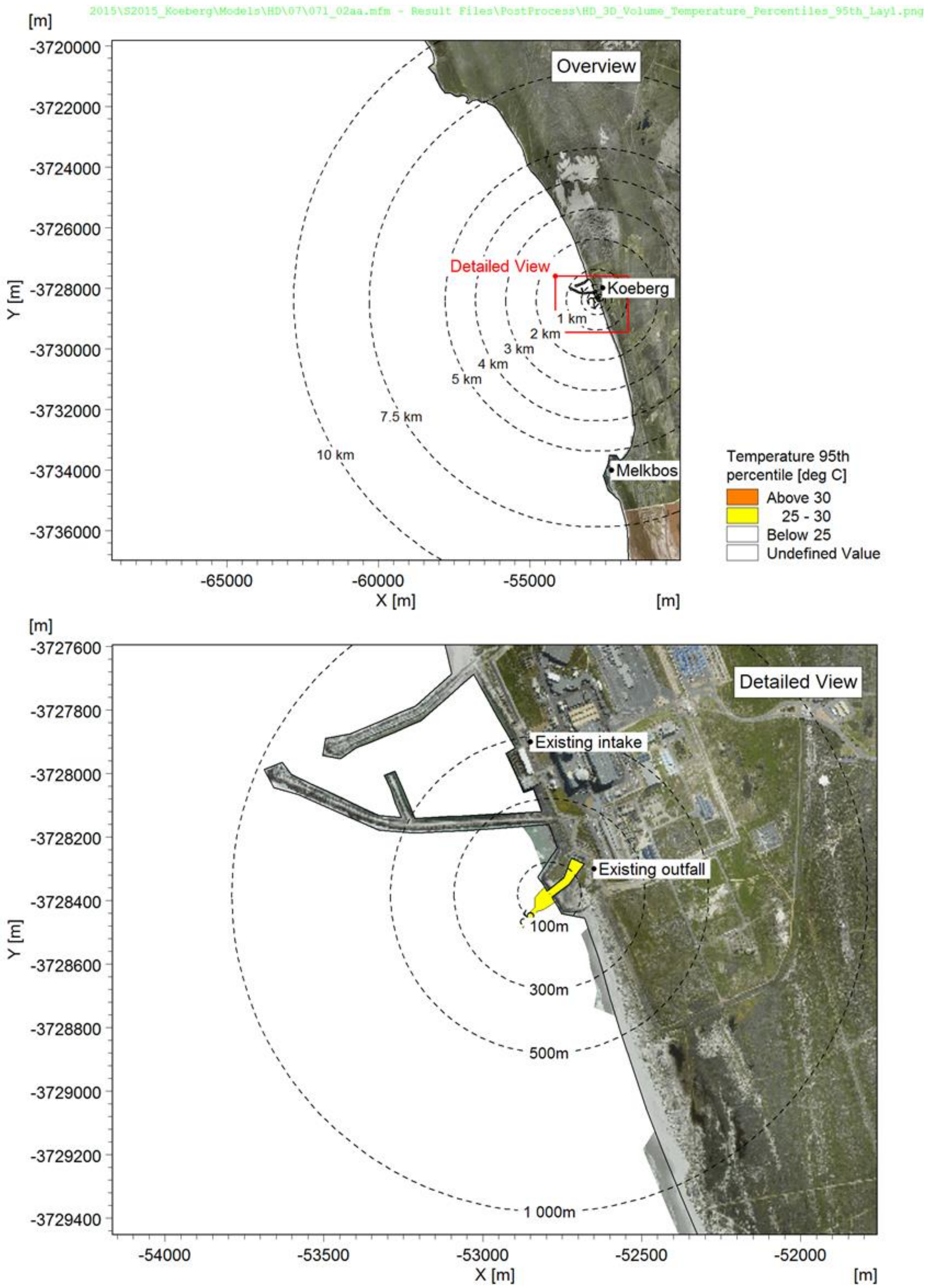

Figure 4.7: 95th percentile near seabed absolute temperature distributions for temperatures ≥25 °C and ≥30 °C: plant operation at full capacity (from PRDW 2017, their Figure B-10).

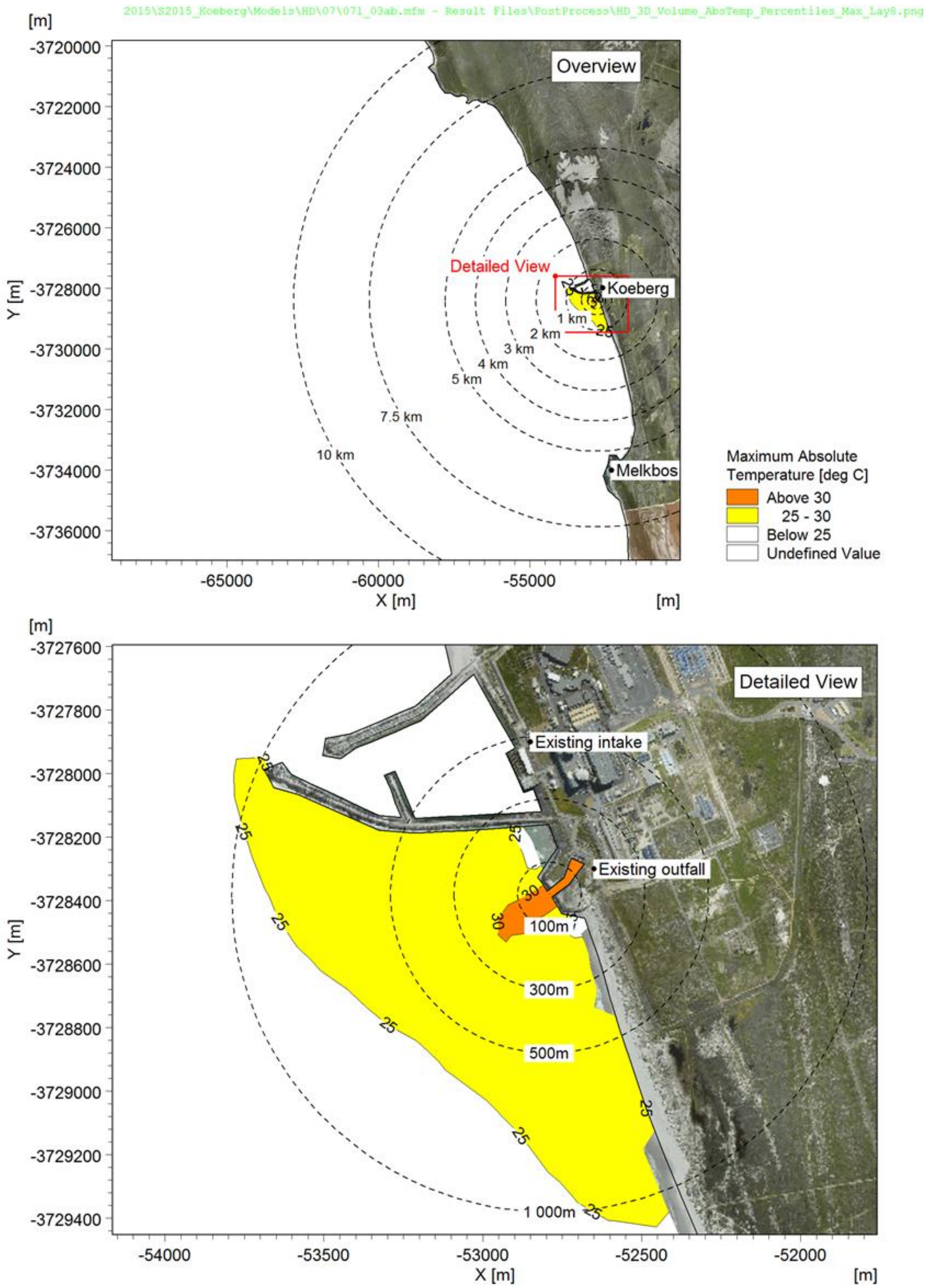

Figure 4.8: Maximum near surface absolute temperature distributions for temperatures ≥25 °C and ≥30 °C: abnormal conditions CRF pump trip scenario (from PRDW 2017, their Figure B-29).

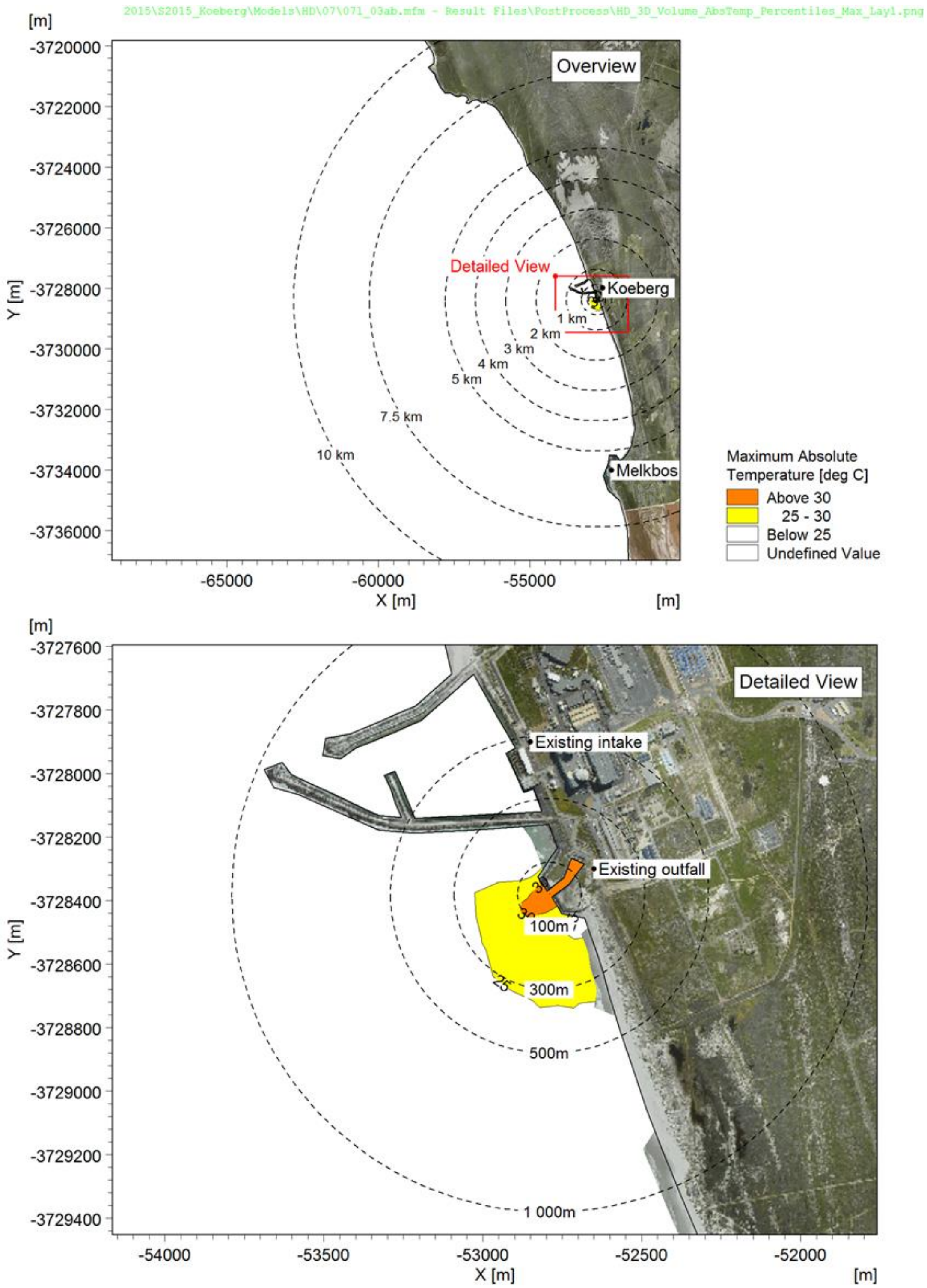

Figure 4.9: Maximum near seabed absolute temperature distributions for temperatures ≥25 °C and ≥30 °C: abnormal conditions CRF pump trip scenario (from PRDW 2017, their Figure B-30).

4.3 Impact-2. Effects of cooling water discharge on the environment: Total residual oxidant (TRO)

4.3.1 Nature of Impacts

Chlorine is a biocide so is naturally toxic to marine organisms in itself and in its bromine based primary derivatives, grouped as TRO. Discharge concentrations of TRO (as chlorine) are predicted to be 0.60 mg/l under normal KNPS operating conditions but an order of magnitude higher at 6.60 mg/l under short duration shock treatment conditions (Table 3.4).

4.3.2 Applicable Guidelines and Thresholds

Defined water quality guidelines for absolute concentrations of chlorine (as proxy for TRO) are described in Section 3 above. The general guideline is derived from ANZECC (2000) who classify it as a low-reliability trigger value due to the lack of sufficiently robust toxicity test data for marine organisms. The guideline concentration is 0.003 mg/l which incorporates a precautionary factor of 10 below the NOEC level assessed. To evaluate actual risks to local biota the United Kingdom EQS of 0.01 mg/l is applied here.

4.3.3 Impact Assessment

4.3.3.1 Compliance with the general guideline

The modelled behaviour of TRO post discharge for normal plant operating conditions shows that, at the sea surface, the DWAF (1995) water quality guideline concentration will be exceeded at the 95th percentile level (5% of the time) in a zone extending 3.25 km north of the KNPS discharge, ~4.5 km south and 2.2 km offshore (Figure 4.10). At the seabed, as expected from discharge plume behaviour, the non-compliant area extends 2 km north, ~4.5 km south and ~1.25 km offshore (Figure 4.11). Due to the very short durations of shock (abnormal) chlorine dosing and appreciable intervals between such treatments (0.5 hours every 14 daysThe areas of non-compliance are extensive and considerably exceed the provisional mixing zone dimensions put forward by DEA (300 m radius from discharge for offshore locations, Anchor 2015) and the World Bank (1998) 100 m distance.

The impact significance ratings for compliance with the general guideline is summarised in Table 4.5 below.

Table 4.5: Impact assessment table for the effects of TRO exceedances above the general WQG on the receiving environment

Nature of negative impact	Compliance with general water quality guidelines

Extent/ geographical area of impact	**Regional:** The TRO plume exceeds the general guideline threshold beyond provisional and defined mixing zone distances from the discharge and extends into the SW Cape inner continental shelf ecozone.
Duration of impact	**Long term:** Continuously throughout the life of the power plant.
Intensity/ magnitude/ power of impact	**High:** The discharge is non-compliant with existing and developing policy on marine outfalls in South Africa.
Significance before mitigation	**High**.
Mitigation/ management actions	Mitigation through altering the chlorine dosing intensity and dosing frequency should be evaluated for application at KNPS
Significance with mitigation	**Medium** – Even with altered chlorine treatment it is questionable whether the discharge would meet the provisional or defined mixing zone dimensions
Confidence in predictions	**High** – the modelled plume behaviour is robust.

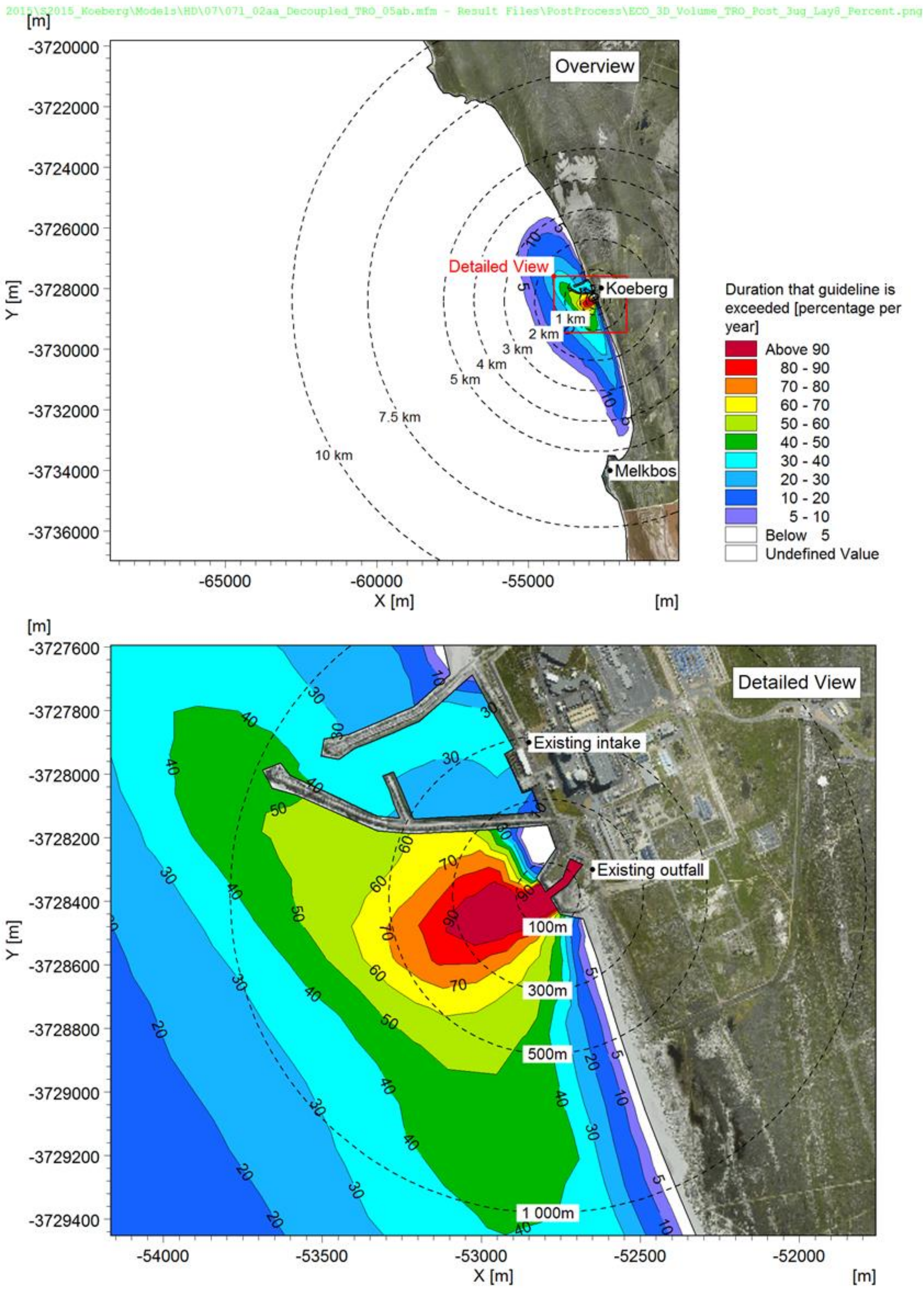

Figure 4.10: The percentage of time during which the general guideline (ANZECC 2000) TRO guideline concentration of 0.003 mg/l is exceeded near the sea surface (from PRDW 2017, their Figure B-31).

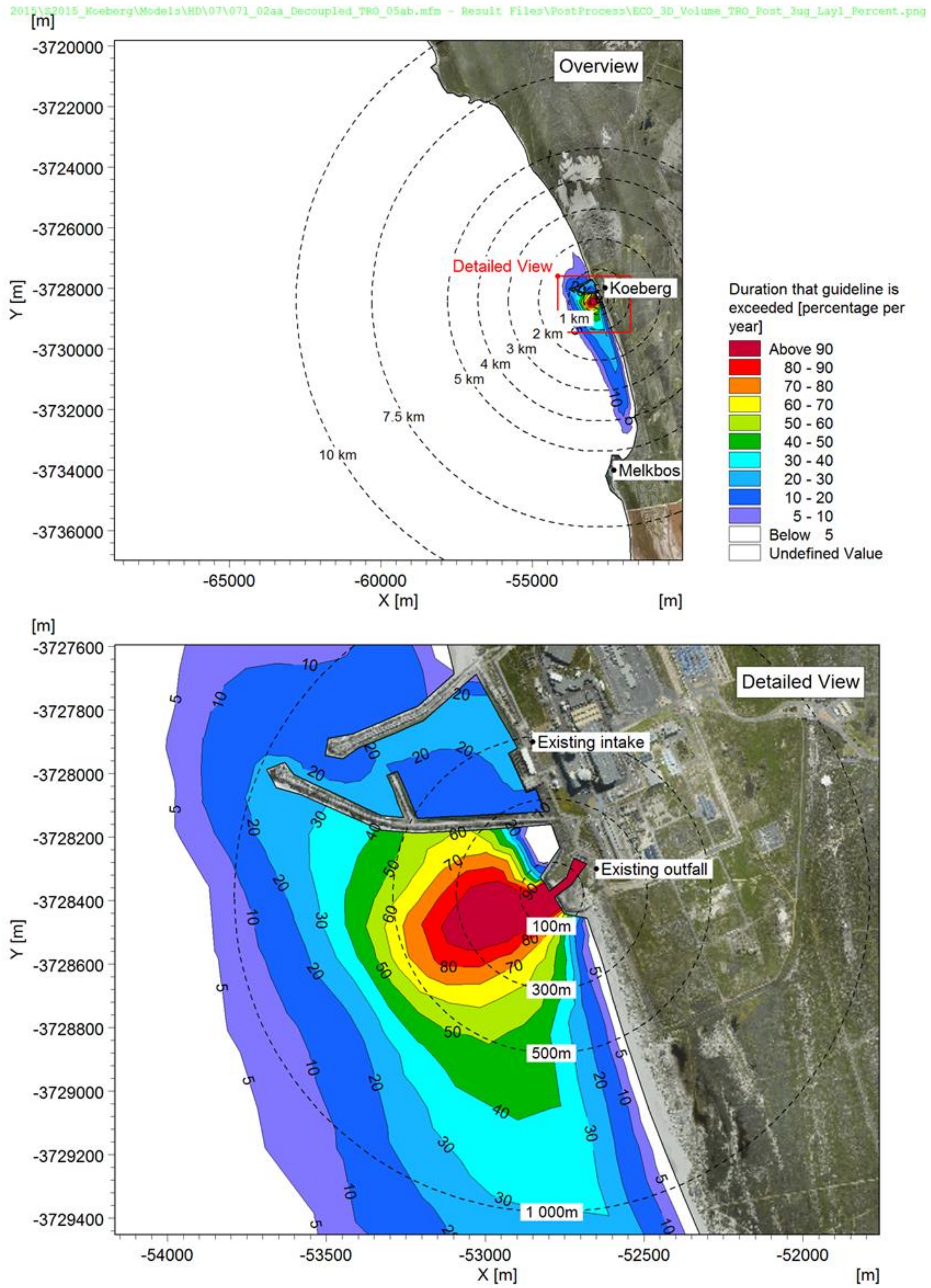

Figure 4.11: The percentage of time during which the general guideline (ANZECC 2000) TRO guideline concentration of 0.003 mg/l is exceeded near the seabed (from PRDW 2017, their Figure B-32).

4.3.3.2 Compliance with derived site-specific guideline and ecological risk

The derived site-specific water quality guidelines (Section 3) set the lower chlorine (TRO proxy) concentration limit for chronic (sub-lethal) effects at 0.01 mg/l. Figure 4.12 and Figure 4.13 show the distribution of the proportion of time that this limit is exceeded in the receiving water body. The spatial extents where the 95th percentile (equivalent to 5% of the time) of the modelled concentrations exceed the site-specific guideline at the sea surface are 1.5 km north of the discharge, 2.8 km south and 1.5 km offshore (west). At the seabed, these dimensions are 0.8 km north, 2.8 km south and 0.8 km offshore. These dimensions exceed provisional (Anchor 2015) and defined (World Bank 1998) mixing zone dimensions.

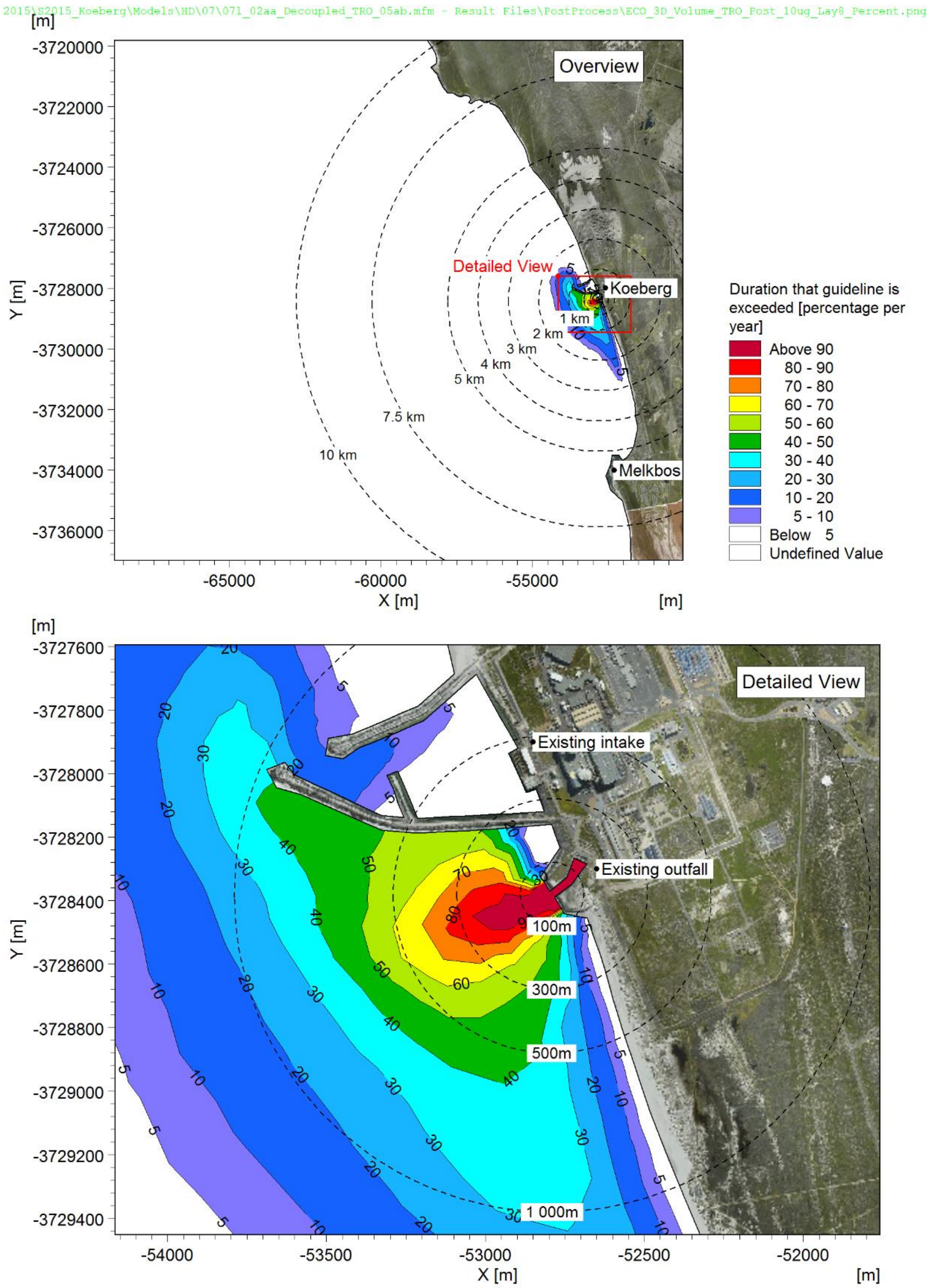

Figure 4.12: The percentage of time during which the site-specific guideline TRO guideline concentration of 0.01 mg/l is exceeded near the sea surface (from PRDW 2017, their Figure B-33).

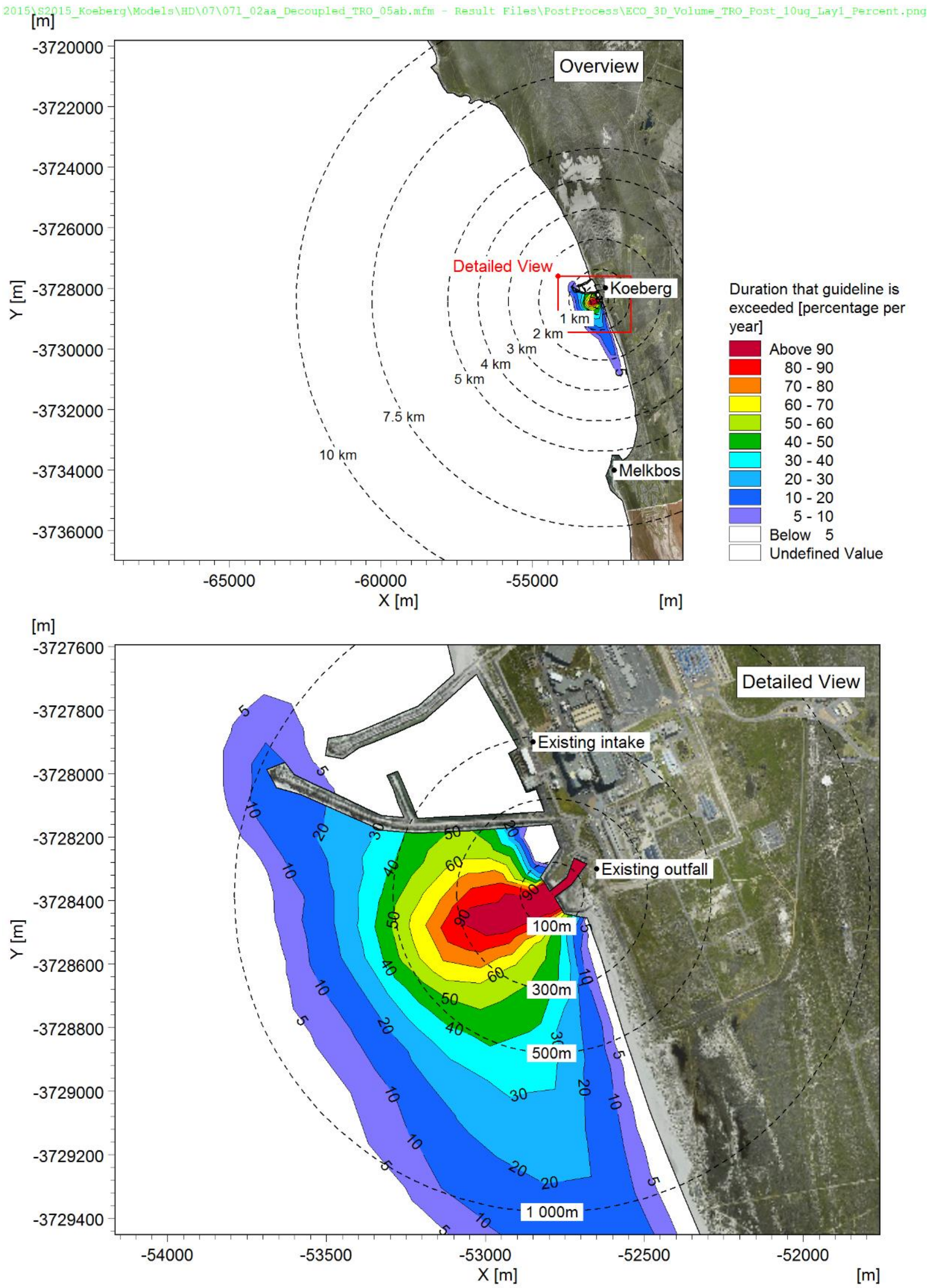

Figure 4.13: The percentage of time during which the site-specific guideline TRO guideline concentration of 0.01 mg/l is exceeded near the seabed (from PRDW 2017, their Figure B-34).

The risks that the site-specific guideline was based on was compromised growth in phaeophyte algae, namely kelp. Potential habitat for kelp in the marine environment are the reef formations at North Blinder 1 & 2, north of the KNPS discharge, and at South Rocks, south of the discharge (Figure 4.1). The predicted variation in TRO concentration with time over the modelled calendar year (2009) at these sites is shown in Figure 4.14, Figure 4.15 and Figure 4.16 (note y-axis scale changes).

Neither of the north blinder sites are predicted to experience TRO concentrations exceeding the site-specific threshold of 0.01 mg/l. As expected North Blinder 2 will be exposed to higher TRO concentrations than the site further north but comparison of the plots indicate that the temporal variations are similar. The South Rocks site is predicted to experience two events over the calendar year where the site-specific guideline will be marginally exceeded; January and November. In both instances exceedances will be very short at 24 hours or less. The January exceedance is concurrent to the periodic shock chlorine dose modelled for early January, but the November event not so, coinciding with a smaller elevation of ~0.5 mg/l observable in the time series for a site 100 m offshore of the discharge (see Figure B-39 in PRDW 2017). Due to short exposure durations, ecological risks to local kelp bed habitat can be discounted.

General risks of chronic effects to organisms in the receiving water body extend over the areas of non-compliance with the site-specific TRO guideline (above). Affected organisms can include plankton and fish in the water column and benthos on the seabed.

The impact significance ratings for compliance with the site-specific guideline is summarised in Table 4.6 below.

Table 4.6: Impact assessment table for the extent of ecological effects of TRO exceedances of the site-specific guideline (0.01 mg/l) on the receiving environment.

Nature of negative impact	**Ecological effects due to exceedances of site-specific TRO guidelines**
Extent/ geographical area of impact	**Sub-Regional:** The chronic effects threshold is limited to within the gazetted KNPS security zone.
Duration of impact	**Long term:** Continuously throughout the life of the power plant.
Intensity/ magnitude/ power of impact	**Low:** Effects on kelp are unlikely and plankton and ichthyoplankton will be exposed to transient effects that diminish in time with dilution of the discharge plume and TRO decay processes. A minor proportion of the benthos regional benthos may be chronically affected.
Significance before mitigation	**Medium:** - The predicted effect area exceeds provisional mixing zone dimensions.
Mitigation/ management actions	Mitigation through altering the chlorine dosing intensity and dosing frequency should be evaluated for application at KNPS
Significance with mitigation	**Low:** - Non-compliances should be restricted to within 500 m of the discharge.
Confidence in predictions	**Medium** – the modelled plume behaviour is robust but the consequences of intermittent dosing (proposed mitigation) have not been modelled yet.

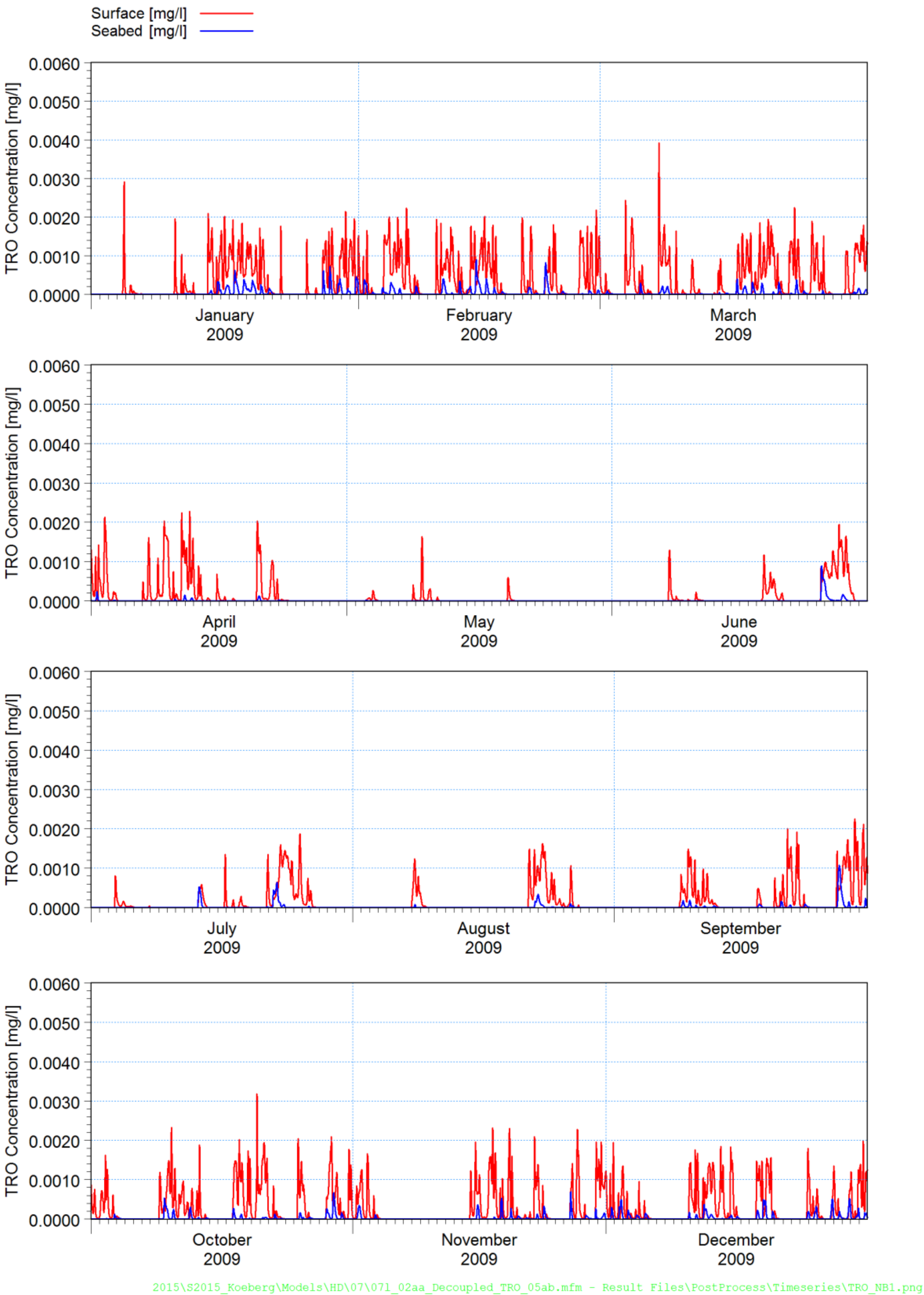

Figure 4.14: Time series of TRO concentrations at the North Blinder 1 site (from PRDW 2017, their Figure B-42).

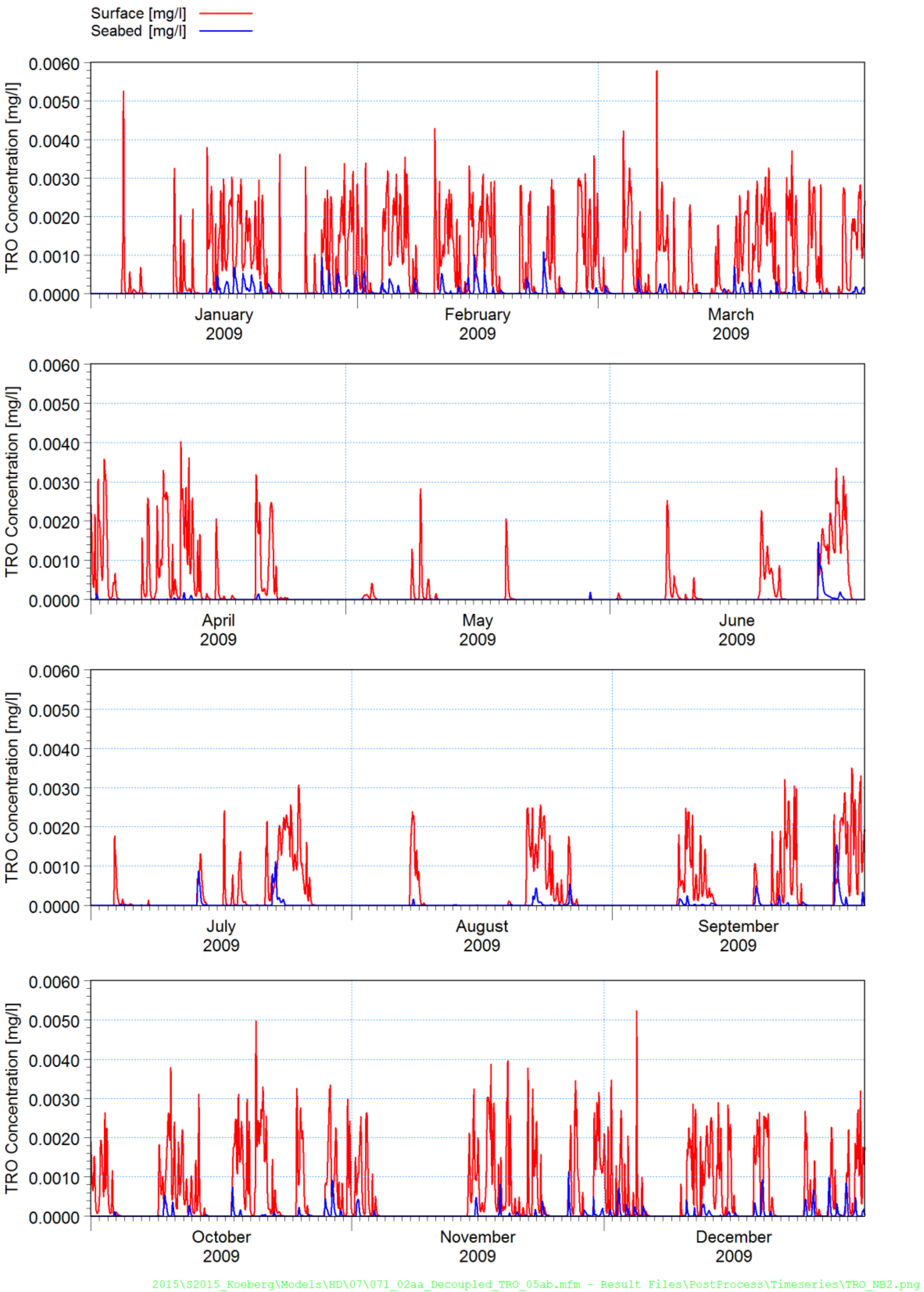

Figure 4.15: Time series of TRO concentrations at the North Blinder 2 site (from PRDW 2017, their Figure B-41).

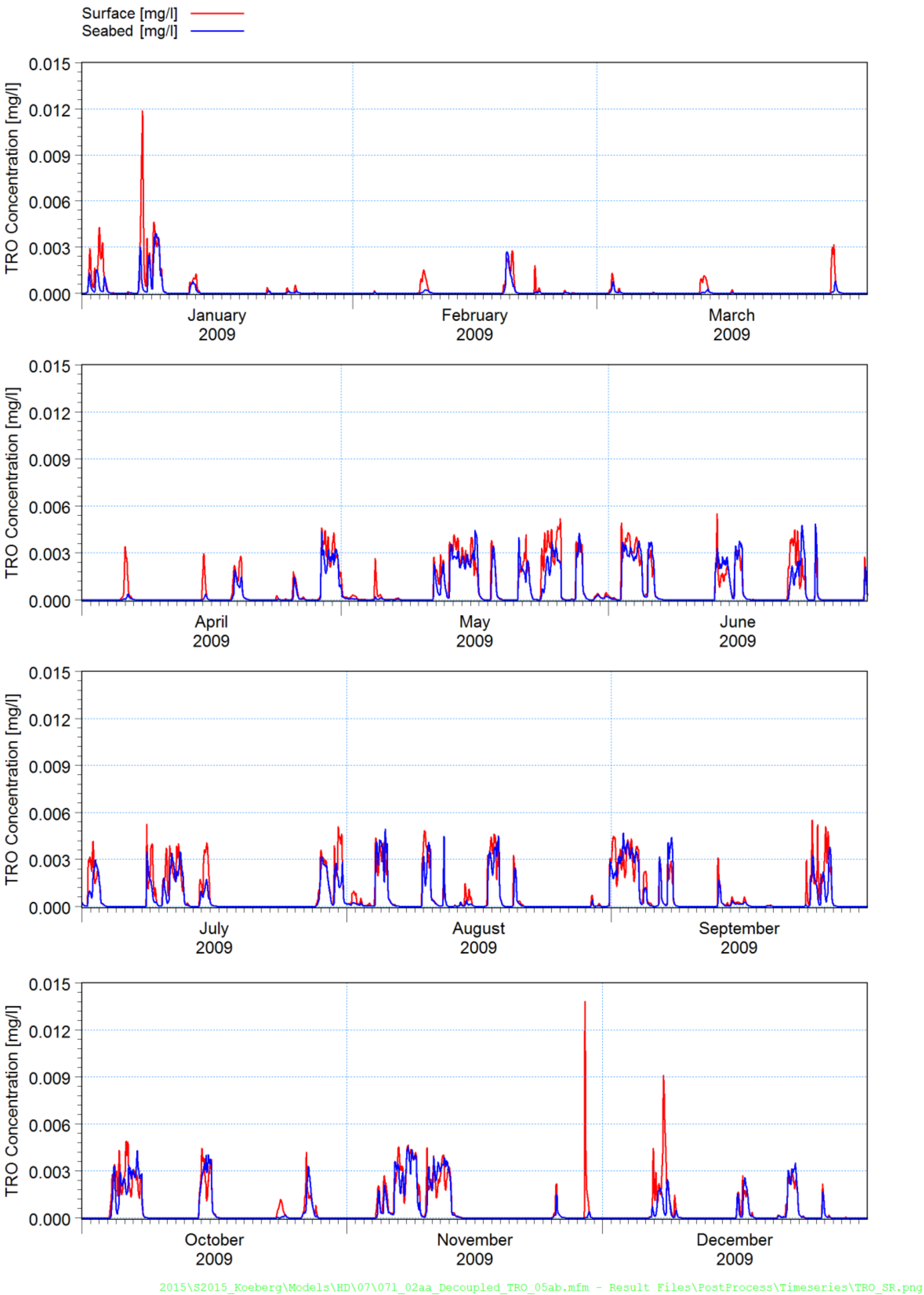

Figure 4.16: Time series of TRO concentrations at the South Rocks site (from PRDW 2017, their Figure B-37).

4.4 Impact-3. Effects of cooling water discharge on the environment: Phosphates

4.4.1 Nature of Impacts

The phosphate concentration in the KNPS discharge peaks at 0.87 mg/l (Table 3.4). Phosphate is discharged from four sources, two of which are from the Electrical Building Ventilation System (DEL) and are considered minor sources as these occur once per year for two-hour periods (Table 5-13, PRDW, 2017). The other sources of phosphate are from the nuclear (KER) and conventional (SEK) island discharges. These sources can supply total annual loads of 625 and 396 kg of phosphate to the discharge but with discharges occurring intermittently over short periods (total durations of 20 and 12 hours respectively (Table 5-13, PRDW 2017). PRDW (2017) modelled abnormal flows.

Predicted distributions of phosphate discharged from the KNPS under abnormal operating conditions are shown in Figure 4.17 (surface) and Figure 4.18 (near seabed). The specified general and site specific receiving water quality guideline concentration is 0.053 mg/l (Table 3.4). Concentrations above the threshold extend from 4.25 km north of the KNPS to 6.5 km south of the plant and 3.0 km offshore at the surface and are more constrained at the seabed extending from 2 km north to the same distance south but are restricted to ~1 km offshore. Peak concentrations >10 mg/l are predicted to occur in the intake basin but will be flushed through the plant with the intake cooling water and discharged at concentrations of 0.5-1.0 mg/l with the cooling water effluent.

Durations of non-compliances with the water quality threshold would be mostly restricted to periods <50 hours per year over all the area of the discharge (PRDW 2017, their B-55 and B-56).

The influence of the elevated phosphorus would be on phytoplankton production. As nitrogen is the limiting nutrient for this in the southern Benguela ecoregion (Chapman and Shannon 1985) the minor elevation in phosphorus concentration in a minute proportion of the pelagic zone (Aa1, Figure 2.3) is therefore not expected to exert any measurable influence in the receiving water body. Consequently, no deleterious effects on marine ecology are predicted.

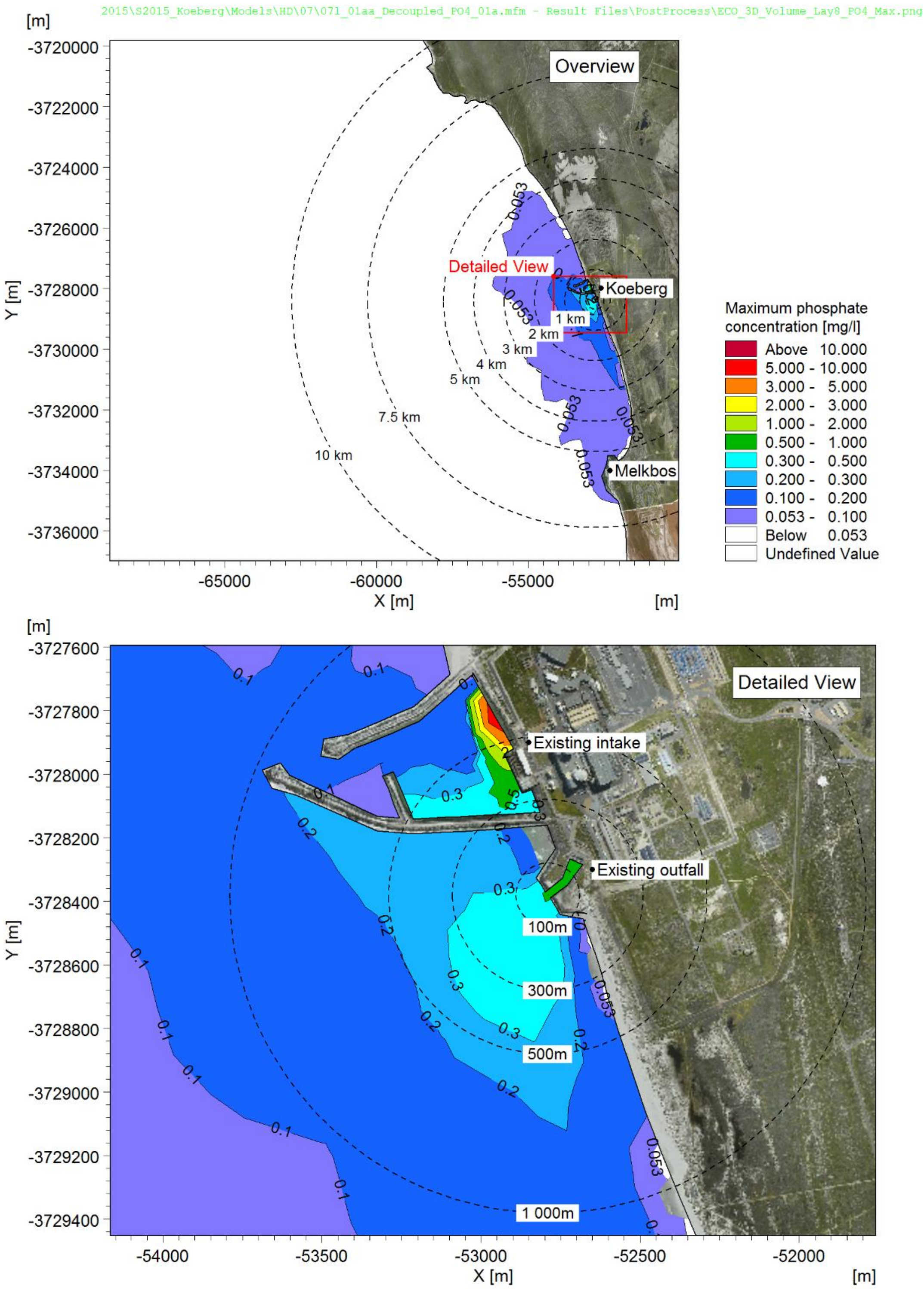

Figure 4.17: The maximum near surface phosphate concentration: exceptional discharges during refuelling outages (one unit operational) (from PRDW 2017, their Figure B-57).

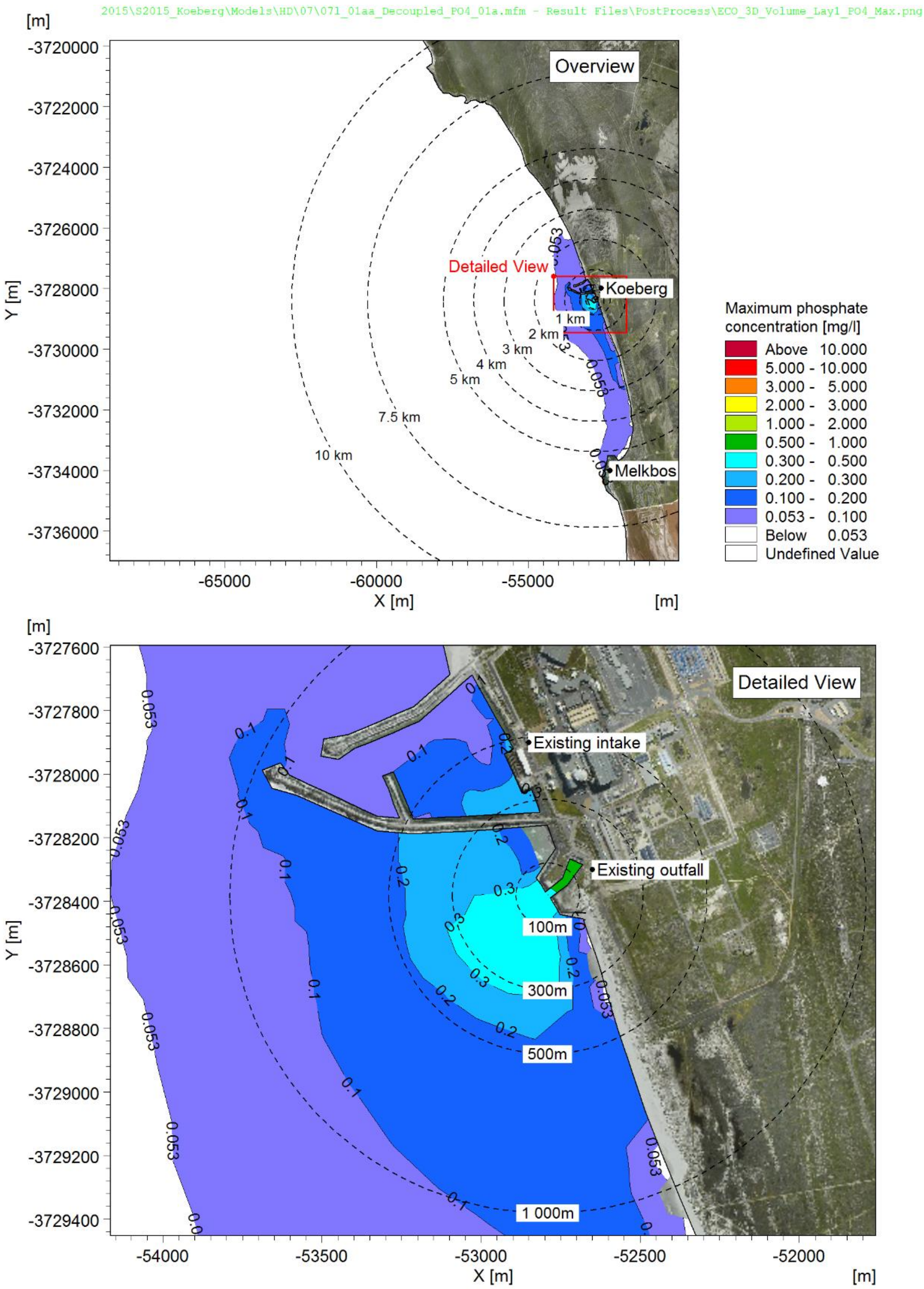

Figure 4.18: The maximum near seabed phosphate concentration: exceptional discharges during refuelling outages (one unit operational) (from PRDW 2017, their Figure B-58).

4.4.2 Impact Assessment

The significance of the impact is summarised in Table 4.7 below.

Table 4.7: Impact assessment table for the effects of elevated phosphate concentrations above the general and site-specific WQG (0.053 mg/l) on the receiving environment.

Nature of negative impact	Ecological effects due to exceedances of site-specific phosphate guidelines
Extent/ geographical area of impact	**Regional:** The chronic effects threshold extends beyond the sub-regional boundary offshore.
Duration of impact	**Long term:** Continuously but intermittently throughout the life of the power plant.
Intensity/ magnitude/ power of impact	**Low:** Effects on phytoplankton production are unlikely due to nitrogen and not phosphorus being the limiting nutrient in the region. Further the batch releases are considerably shorter than the 12-14-day upwelling/relaxation cycle typical of the region that largely controls phytoplankton production and distribution.
Significance before mitigation	**Very Low:** - No measurable effects are predicted.
Mitigation/ management actions	n/a
Significance with mitigation	n/a
Confidence in predictions	**High** – the modelled plume behaviour is robust and the local phytoplankton ecology is relatively well understood.

4.5 IMPACT-4. EFFECTS OF COOLING WATER DISCHARGE ON THE ENVIRONMENT: HYDRAZINE

4.5.1 Nature of Impacts

The nature of the impact of hydrazine is the generation of toxicity effects on specifically kelp gametophytes on rocky/reef substrata in the shallow subtidal zone of in the receiving water body.

Hydrazine in the KNPS discharge varies with annual loads of 263 kg at normal operations and 480 kg in reactor outages. These loads result in estimated concentrations in the discharge of 0.11 mg/l and 0.20 mg/l respectively (Table 3.4).

4.5.2 Applicable Guidelines and Thresholds

The specified general water quality guideline is 0.0002 mg/l and the site specific higher than this at 0.0025 mg/l (Section 3 above). The general guideline is based on a NOEC calculated from observed chronic toxicity effects (gametophyte growth) in *Macrocystis* (giant kelp) and an applied factor of precautionary factor of 10. The site-specific guideline is derived from the calculated NOEC.

4.5.3 Impact Assessment

4.5.3.1 Compliance with the general guideline

The modelled behaviour of hydrazine post discharge for normal plant operating conditions shows that, at the sea surface, the specified water quality guideline concentration will be exceeded in a zone extending 10.0 km north of the KNPS discharge, 9.0 km south and 4.0 km offshore (Figure

4.19). At the seabed, as expected from discharge plume behaviour, the non-compliant area extends 9.0 km north, 9.0 km south and 1.5 km offshore (Figure 4.20). During short-term outages, these dimensions increase to 12.5 km north, 17.5 km south and 5.0 km offshore at the sea surface and 12.5 km north, 17.5 km south and 4.0 km offshore near the seabed (PRDW 2017). Hydrazine release durations under this scenario are very short at <2 hours. The areas of non-compliance in both normal operating and abnormal outage scenarios are extensive and considerably exceed the provisional mixing zone dimensions put forward by DEA (300 m radius from discharge for offshore locations, Anchor 2015) and the World Bank (1998) 100 m distance. However, in all cases the amount of time in any one year that exceedances of the guidelines may occur is ≤100 hours for normal plant operations and ≤300 hours during short-term outages in all affected areas except for the immediate area of the discharge (<100 m) and in the cooling water intake basin.

The impact significance ratings for compliance with the general guideline is summarised in Table 4.8 below.

Table 4.8: Impact assessment table for the effects of hydrazine exceedances on the receiving environment: compliance with general WQG concentration (0.0002 mg/l)

Nature of negative impact	Compliance with general water quality guidelines
Extent/ geographical area of impact	**Regional:** The hydrazine plume exceeds the general guideline threshold beyond provisional and defined mixing zone distances from the discharge and extends into the SW Cape inner continental shelf ecozone.
Duration of impact	**Long term:** Continuously but intermittent short-duration exceedances throughout the life of the power plant.
Intensity/ magnitude/ power of impact	**High:** The discharge is non-compliant with existing and developing policy on marine outfalls in South Africa.
Significance before mitigation	**Medium** – The short non-compliant durations reduce the significance of non-compliance with policy.
Mitigation/ management actions	Mitigation through altering the hydrazine release practices from semi-batch discharge to more frequent blending of the constituent into the combined discharge from the KNPS
Significance with mitigation	**Low - Medium** – The required mixing zone will reduce but may not comply with existing and developing policy on marine outfalls in South Africa.
Confidence in predictions	**Medium** – the modelled plume behaviour is robust but factors that should reduce hydrazine in the effluent (residual BOD demand and oxidation by TRO) may not have been adequately addressed.

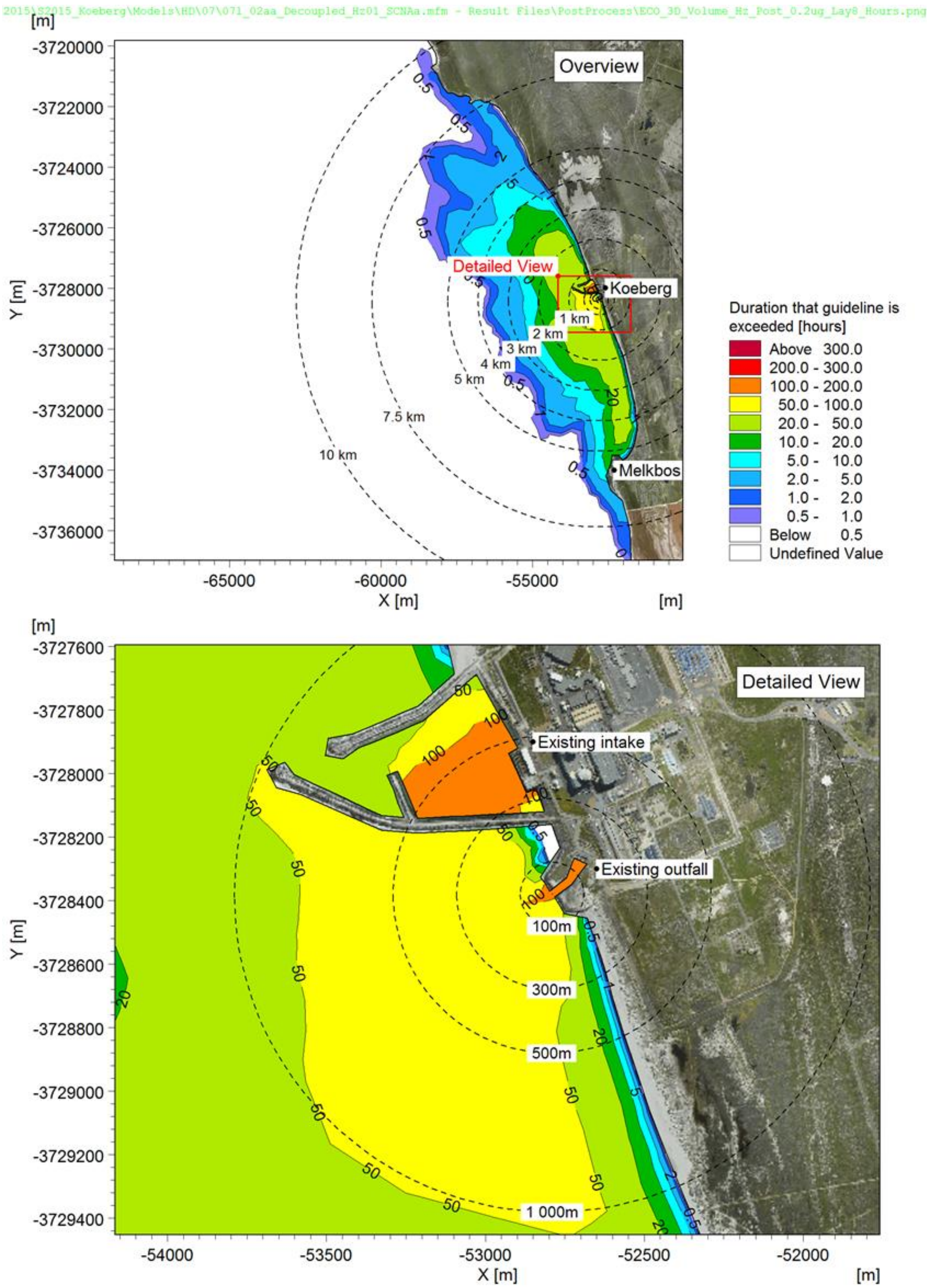

Figure 4.19: Maximum annual duration that the specified water quality guideline for hydrazine of 0.0002 mg/l would be exceeded in near surface waters under normal plant operations (from PRDW 2017, their Figure B-43).

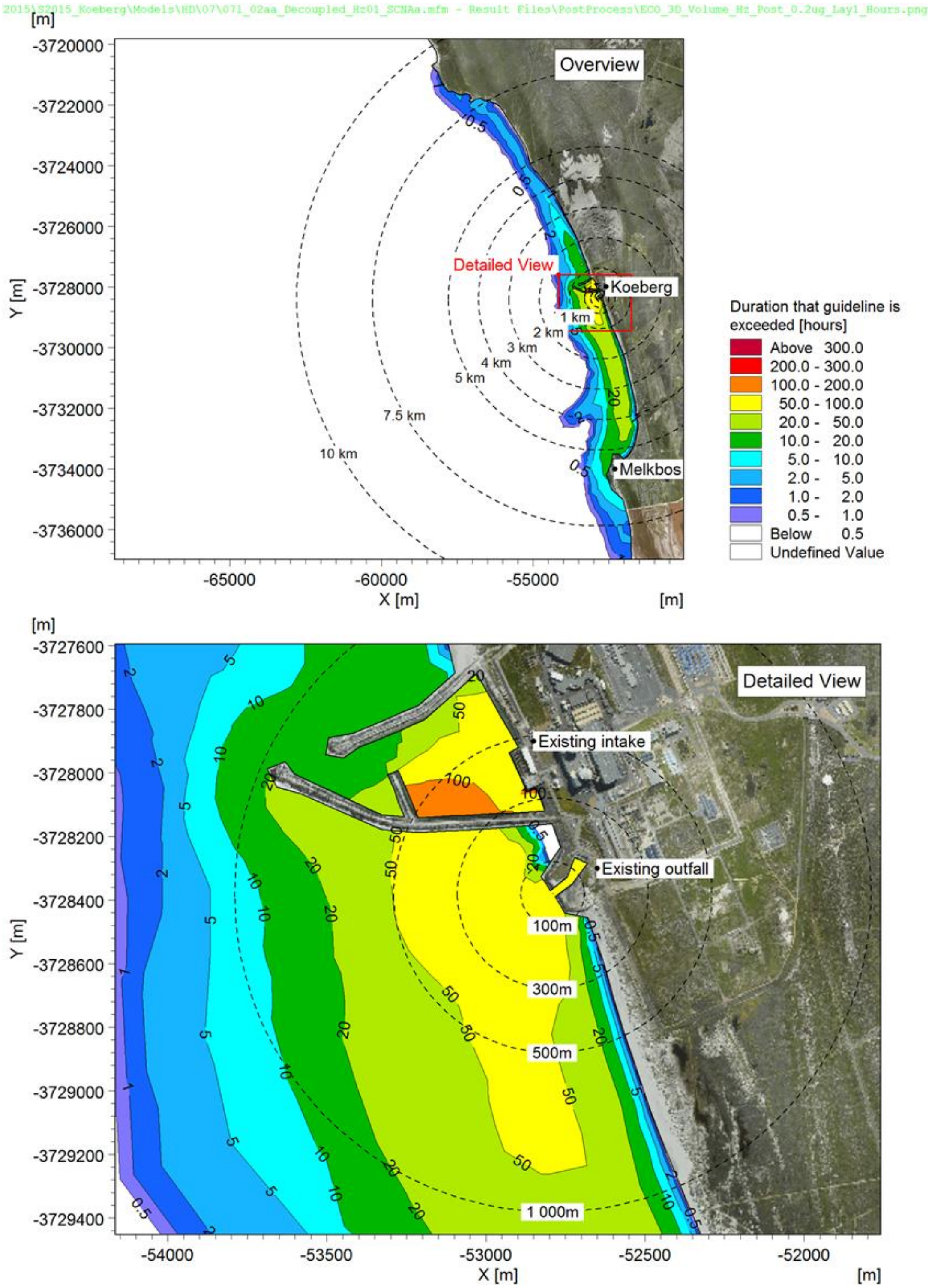

Figure 4.20: Maximum annual duration that the specified water quality guideline for hydrazine of 0.0002 mg/l would be exceeded near the seabed under normal plant operations (from PRDW 2017, their Figure B-44).

4.5.3.2 Compliance with derived site-specific guideline and ecological risk

The derived site-specific water quality guidelines (Section 3) set the hydrazine chronic effect threshold at 0.0025 mg/l. Figure 4.21 and Figure 4.22 show the distribution of the proportion of time that this limit is exceeded in the receiving water body. The spatial extents where the modelled concentrations exceed the site-specific guideline at the sea surface are 2.5 km north of the discharge, 4.5 km south and 1.5 km offshore (west). At the seabed, these dimensions are 0.8 km north, 2.5 km south and 1.0 km offshore. These dimensions exceed provisional (Anchor 2015) and defined (World Bank 1998) mixing zone dimensions but the overall durations of exceedance over a calendar year are ≤100 hours.

The specified water quality guideline is the NOEC of 0.0025 mg/l for chronic effects (growth) on *Macrocystis* gametophytes. As stated above potential kelp habitat near the KNPS is at North Blinder 1 and 2, and at South Rocks, south of the discharge. These sites could be affected by hydrazine contained in bottom waters. Figure 4.22 shows that, under normal operating conditions, hydrazine at concentrations in excess of 0.0025 mg/l is not expected to extend to either of the north blinder sites and that if the South Rocks site is impacted the duration of the exceedance will be ≤2 hours. Under abnormal conditions associated with refuelling this exposure increases to ≤10 hours (PRDW 2017, Figure B-52).

Kelp gametophytes can delay sporophyte generation by seven months or longer in unfavourable conditions such as low nutrient concentrations or unfavourable light conditions (Carney, 2009). In the southern Benguela Current region such conditions may develop in the relaxation phase of the upwelling cycle when inorganic nutrient specifically may be reduced in the upper water column due to uptake by phytoplankton. Upwelling replenishes these so the duration of dormancy controlled primarily by unfavourable nutrient conditions is that of the local upwelling cycle (12-14 days in late spring through summer). The annual duration of exposure to possible growth inhibiting concentrations of hydrazine at the South Rocks site is less than half that of a single upwelling cycle. It is unlikely that such exposures can cause any measurable ecological effect in kelp gametophyte growth at this site.

Hydrazine chronic level toxicity (EC_{50}) to other taxa such as fish exceed 3 mg/l (CERI 2007), which is greater than the predicted discharge concentration for this compound.

The impact significance ratings for compliance with the site-specific guideline is summarised in Table 4.9 below.

Table 4.9: Impact assessment table for the extent of ecological effects of hydrazine exceedances of the site-specific WQG (0.0025 mg/l) on the receiving environment.

Nature of negative impact	**Ecological effects due to exceedances of site-specific hydrazine guidelines**
Extent/ geographical area of impact	**Regional:** The chronic effects threshold may affect the South Rocks site outside of the gazetted KNPS security zone.
Duration of impact	**Long term:** Continuously but intermittent throughout the life of the power plant.
Intensity/ magnitude/ power of impact	**Low:** Effects on kelp are unlikely as are effects on other biota in the receiving water body.
Significance before mitigation	**Very Low** for ecological effects-but **medium** for area of exceedance non-compliance with defined mixing zone limits
Mitigation/ management actions	Mitigation of the mixing zone apparent non-compliance can be through altering the hydrazine release practices from semi-batch discharge to more frequent blending of the constituent into the combined discharge from the KNPS
Significance with mitigation	**Very Low** for ecological effects & **Low-Medium** for mixing zone extent which although probably restricted to within 500 m of the discharge still exceeds contemplated limits.
Confidence in predictions	**Medium** – the modelled plume behaviour is robust but the consequences of intermittent dosing have not been modelled yet.

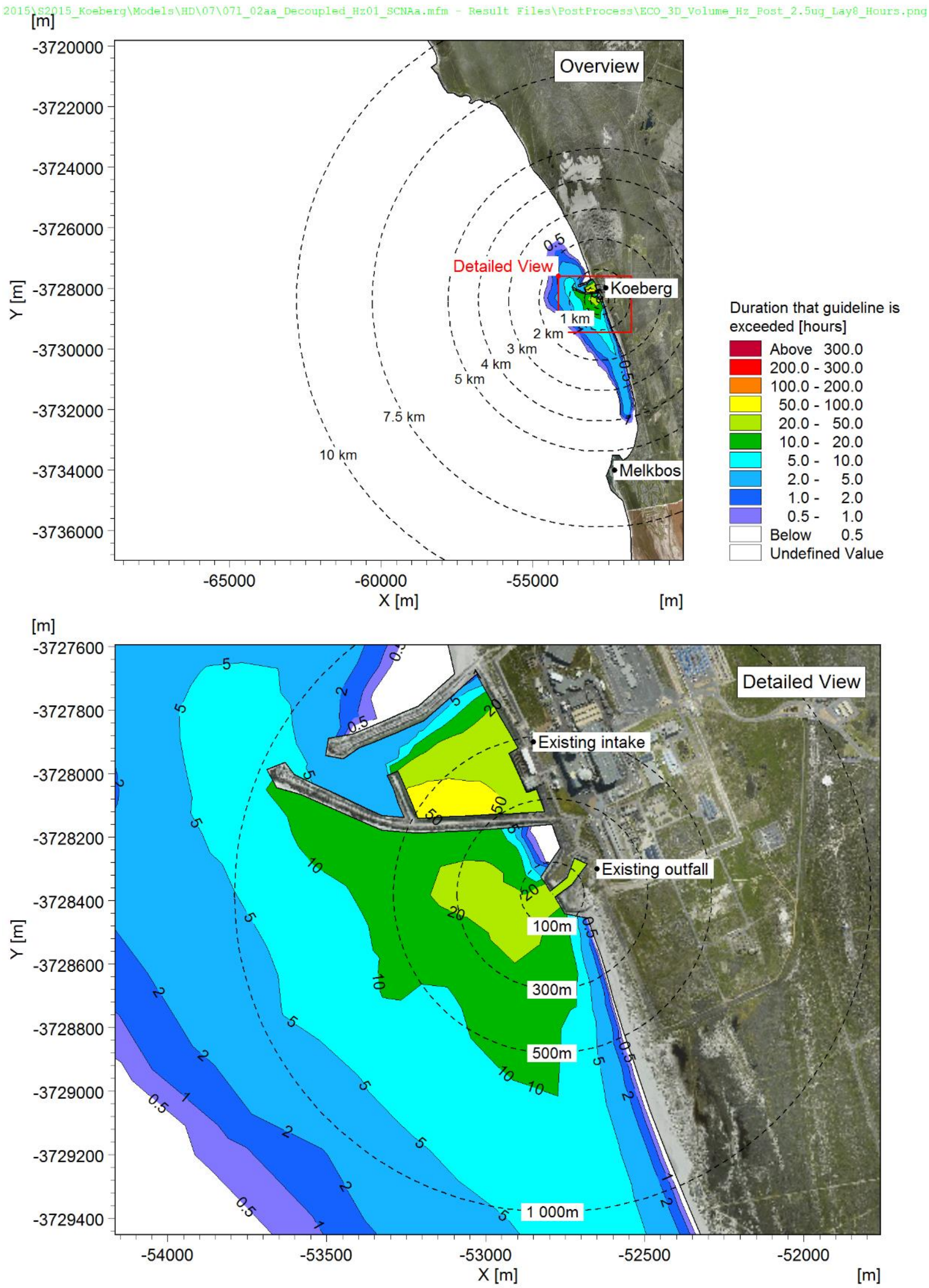

Figure 4.21: Maximum annual duration that the specified site-specific water quality guideline for hydrazine of 0.0025 mg/l would be exceeded near the sea surface under normal plant operations (from PRDW 2017, their Figure B-45).

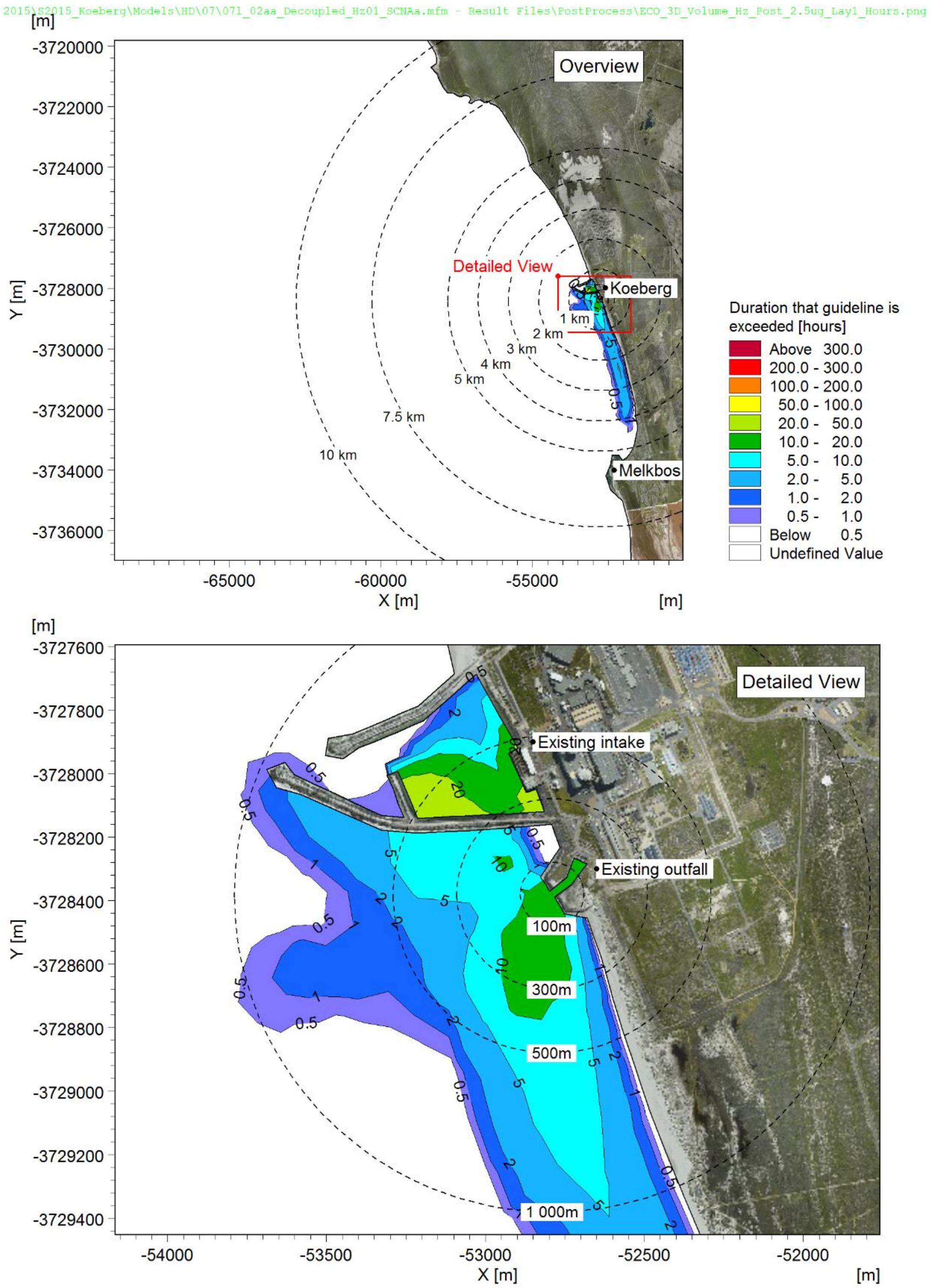

Figure 4.22: Maximum annual duration that the specified site-specific water quality guideline for hydrazine of 0.0025 mg/l would be exceeded near the seabed under normal plant operations (from PRDW 2017, their Figure B-46).

4.6 Impact-5. Effects of cooling water discharge on the environment: Discolouration of discharged effluent by Ferric Hydroxide

4.6.1 Nature of Impacts

Effects of ferric hydroxide ($Fe(OH)_3$) (rust particles) in the discharged effluent from the KNPS could include imparting a red colour to it. Figure 4.23 shows an extreme case of this for a SWRO desalination plant, which operated without any dilution of its discharge. Unlike the situation applicable to the combined KNPS and SWRO discharges, where the former is a factor of 149 x greater than the latter, and that for the BWRO plant 7 118x greater. Discolouration of the bulk effluent exiting at the KNPS is therefore considered to be improbable. However, even if entering the receiving environment at very dilute concentrations (~0.04 mg/l, Table 3.4), the fine particulate ferric hydroxide particles can be scavenged from the water column by micro bubbles generated by wave action (e.g. Walls and Bird 2017) and concentrated in sea surface foams. It is possible that this can imbue the foams, which are relatively long lived due to stabilisation by dissolved organic matter, with a pinkish hue. This can lead to negative perceptions of the KNPS discharge and plant operations in the local community and wider public body.

Figure 4.23: Brine discharge from a reverse osmosis desalination plant employing ferrous sulphate as a coagulant in intake water pre-treatment. The red colour is due to particulate ferric hydroxide discharged in the brine effluent (from UNEP 2008).

4.6.2 Applicable Guidelines and Thresholds

There are none available; the general effect would be aesthetic, i.e. sense of place.

4.6.3 Impact Assessment

The sea area possibly affected by foam discolouration would be the shallow nearshore extending north and south of the KNPS discharge. The spatial and temporal extent of this is unknown. The impact significance ratings for the possible aesthetic effects are summarised in Table 4.10 below.

Table 4.10: Impact assessment table for sea foam discolouration by ferric hydroxide discharged from SWRO plant.)

Nature of negative impact	**Sea surface foam discolouration**
Extent/ geographical area of impact	**Local**: it is expected that affected foams would be restricted to the nearshore in the immediate locality of the KNPS discharge.
Duration of impact	**Long term:** Continuously but intermittent short-duration exceedances throughout the life of the power plant.
Intensity/ magnitude/ power of impact	**Low:** Effects will be limited to public perception only; no adverse ecological effects are anticipated.
Significance before mitigation	**Low**
Mitigation/ management actions	Exclude ferric hydroxide coagulant from the discharge by rerouting to settlement ponds and ultimately land fill or employ an alternative particle removal process such as dissolved air flotation
Significance with mitigation	**Very low**.
Confidence in predictions	**Medium** – there is no local experience indicating that the impact will be realised.

4.7 Impact-6. Effects of cooling water discharge on the environment: Build-up of heavy metal concentrations in deposition areas

4.7.1 Nature of Impacts

The KNPS discharges heavy metals at very low concentrations in the cooling water effluent (Table 3.4). These do not pose any toxicity risk to pelagic organisms as their concentrations are below the respective DWAF (1995) and DEA (Massie et al. 2017) updated receiving water quality thresholds. Dissolved heavy metals can adsorb to suspended inorganic and organic particles in the water column and find their way to the seabed through sedimentation (e.g. Libes 2011). This preferentially occurs in quiet water areas in wave and current affected inner continental shelf zones, or in deeper water off the continental shelf edge. Over time sediment heavy metal concentrations in these depositional areas can build up through continued supply, such as may occur from a continuously operating discharge, e.g. the KNPS, and local remineralisation of organic matter and associated biogeochemical processes. This can generate heavy metal concentrations approaching those considered to cause toxicity effects in benthos with ecological consequences of modification to benthic communities (e.g. Gray & Elliot 2009).

Candidate depositional areas that may be influenced by the KNPS discharge have been identified by PRDW (2017) as the KNPS seawater intake basin, within Murray's harbour at Robben Island and the entrance to the port of Cape Town.

Heavy metal distributions in these environments and the open sandy seafloor in the vicinity of the KNPS were measured in 2015 and the sediment properties and concentrations are listed in Appendix A. Table 4.11 lists the data for the non-depositional open inner continental shelf samples and that from the KNPS seawater intake basin, considered to be a depositional environment, along with the sediment quality guidelines (SQG) recommended for the Benguela Current area (BCLME 2006). Heavy metal concentrations were low being at or near the analytical detection limit in the non-depositional sites but were elevated but variable in the intake basin. This is linked to elevated aluminium (proxy for clay minerals) concentrations in this location. Copper and lead concentrations measured at intake basin site IB 1 and cadmium at site IB 3 exceeded the respective SQGs but the mean values for the basin did not. Accordingly, intake basin sediments do not classify as being contaminated to the extent that they constitute toxicity risks.

Samples within the KNPS seawater intake basin show variable heavy metal concentrations with high levels of arsenic, chromium, copper, iron and lead at site IB 1 relative to the other three sites within the basin (Table 4.11). The observed heavy metal concentration gradients may be ascribable to the proximity of site IB 1 to the northern stormwater discharge for the KNPS (Figure 4.24).

Table 4.11: Heavy metal concentrations in sediments on the continental shelf adjacent to the KNPS and in the KNPS cooling water intake basin. The BCLME (2006) sediment quality guidelines (SQG) and probable (toxicity) effect (concentration) (PEL) are shown, and highlighted cells indicate exceedances of the relevant SQG concentrations.

Location	Stn	Heavy Metal (mg/kg)										
		Al	Cd	Ni	Hg	As	Cr	Cu	Fe	Pb	Mn	Zn
Inner Continental Shelf	1	675	0.11	0.50	0.01	1.00	8.00	0.60	468	11.00	12.00	3.50
	2	721	0.09	0.50	0.01	1.00	7.70	0.50	446	2.80	9.70	1.90
	3	829	0.08	0.50	0.01	2.00	8.10	0.50	500	2.50	6.50	1.90
	4	759	0.08	0.50	0.01	1.00	7.20	0.50	452	2.50	5.80	2.20
	5	746	0.08	0.50	0.01	1.00	6.80	0.50	430	2.50	6.20	2.70
	6	751	0.07	0.50	0.01	1.00	6.90	0.50	397	2.90	5.10	1.50
	7	925	0.08	0.50	0.01	1.00	7.50	0.50	531	3.10	7.00	2.70
	8	717	0.07	0.50	0.01	1.00	7.70	0.50	479	2.50	8.90	1.80
	9	722	0.08	0.50	0.01	1.00	8.60	0.50	490	3.00	12.00	2.40
	10	842	0.10	0.50	0.01	2.00	8.40	0.50	549	2.50	11.00	2.20
	11	1087	0.20	0.50	0.01	2.00	7.90	1.90	93	4.80	13.00	0.50
	12	1342	0.15	0.50	0.01	4.00	8.30	1.80	112	4.90	13.00	1.90
	13	2102	0.09	0.50	0.01	1.00	8.20	1.80	301	4.40	11.00	4.60
	Mean	940	0.10	0.50	0.01	1.46	7.79	0.82	404	3.80	9.32	2.29
KNPS Intake Basin	IB 1	6322	0.32	2.90	0.02	6.00	41.00	41.00	13961	42.00	30.00	17.00
	IB 2	3392	0.29	0.50	0.01	1.00	17.00	6.80	2981	9.10	17.00	6.70
	IB 3	6982	0.75	4.50	0.02	1.00	11.00	3.50	1201	5.90	31.00	19.00
	IB 5	8272	0.60	6.20	0.03	3.00	20.00	6.80	3431	9.30	36.00	22.00
	Mean	6242	0.49	3.53	0.02	2.75	22.25	14.53	5394	16.58	28.50	16.18
Guidelines	SQG		0.68	15.90	0.13	7.24	52.30	18.70		30.20		124.00
	PEL		4.21	42.80	0.70	41.6	160.00	108.00		112.00		271.00

Figure 4.24: Distribution of sediment sample sites relative to the stormwater discharge in the KNPS cooling water intake basin.

The source(s) of the heavy metals in the intake basin can be the KNPS cooling water discharge, the stormwater discharge to the basin and/or natural accumulation due to fine particle scavenging of heavy metals from the dissolved phase and their deposition and incorporation in intake basin sediments. The apparent build-up in the concentration of iron in intake basin sediments over the ~33 years of KNPS operation estimated from the differences between mean concentrations in the basin (5 364 mg/kg) and that for the adjacent continental shelf sediments (404 mg/kg) (Table 4.11) is 4 960 mg/kg. The estimated mass of surficial sediment (to 10 cm depth) in the basin is 17 225 000 kg (PRDW 2017, Table 4-7) indicating a net flux of iron into the basin of 85 436 kg; approximately 2 589 kg/year. To date the average annual release of dissolved iron through the cooling water discharge has been 22 kg (PRDW 2017, Table 4-8). It is clear that, even if all of the discharged dissolved iron was oxidised to particulate ferric hydroxide and deposited in the intake basin this could not account for the apparent increase in iron. The alternative source is the stormwater discharge which, as noted above, appears to support a concentration gradient from sample site IB1 to the balance of the basin (Table 4.11 and Figure 4.24), However, this gradient may be an artefact of the maintenance dredging; site IB1 being less disturbed than the other sites and therefore having a longer deposition history allowing the higher concentrations to develop.

The stormwater source being the apparent historical source of iron in the intake basin sediments notwithstanding, high particulate ferric hydroxide discharges from the proposed SWRO and BWRO plants combined of 38 200 kg/year (PRDW 2017, Table 4-8) may appreciably increase the flux of iron into these sediments. The ecological consequences of this are moot as iron may accumulate but probably be biologically inert as it should be bound up in insoluble poly-metallic hydroxides and, if left undisturbed by maintenance dredging as it gets buried, transformed to insoluble sulphides. Dredging, of course would remove the iron enriched sediments from the basin and enable them to be diluted by inner continental shelf low iron content sediments before possibly being re-incorporated into the seawater intake basin sediments.

4.7.2 Impact Assessment

The significance of the impacts of discharges of heavy metals, including iron discharged from the SWRO and BWRO plants, in the KNPS effluent are summarised in the table below.

Table 4.12: Impact assessment table for the build-up of heavy metals including iron discharged from the proposed SWRO and BWRO plants in the receiving environment

Nature of negative impact	**Compromised sediment quality**
Extent/ geographical area of impact	**Local** – Heavy metal build-up does not extend beyond the KNPS cooling water intake basin.
Duration of impact	**Long term**
Intensity/ magnitude/ power of impact	**Low** for most metals as average heavy metal concentrations fall within sediment quality guideline even within the depositional environment of the KNPS cooling seawater intake basin, but **Medium** for iron due to potentially increased build-up from the high annual loads generated by the RO plants.
Significance before mitigation	**Medium** for seawater intake basin sediments; **Very Low** for non-depositional areas
Mitigation/ management actions	If monitoring shows build up in sediment iron concentrations in the seawater intake basin, exclude ferric hydroxide coagulant from the discharge by rerouting to settlement ponds and ultimately land fill or employ an alternative particle removal process such as dissolved air flotation.
Significance with mitigation	**Low**
Confidence in predictions	**High** – for the adjacent open inner continental shelf area but **Medium** for the intake basin sediments due to uncertainty on the sources of the heavy metals in this location.

To gain more confidence in the spatial and temporal variations (including possible build-up over time) of the heavy metals in the intake basin, further monitoring is recommended, as discussed in Section 5.1.

5 MARINE ENVIRONMENTAL MONITORING & INVESTIGATIONS

5.1 MONITORING

The KNPS discharges a complex mix of constituents to the marine environment. Due to the dominance of warm water the effluent plume is buoyant with apparently reducing influence on the seabed with distance from the immediate area of the discharge. Further, the trajectory of the effluent plume varies with metocean conditions and the axis of flow can be southerly, westerly or north-westerly. These characteristics add complexity to monitoring of the effects or even presence of the discharged effluent in the receiving environment within realistic time and resource constraints that a monitoring programme will have to face. The programme outlined below takes account of these issues while aiming to obtain scientifically defensible information on the plume and associated environmental effects.

The monitoring programme addresses the following:

- Effluent toxicity – The evaluation of the possible effects of the plume set out above has focused on the individual constituents in the discharge. The combined or possible synergistic effects have not been quantified primarily due to a lack of robust information for such plumes;
- Build-up of contaminants in sediments in the receiving environment – The inorganic constituents, primarily heavy metals, can influence sediment biogeochemistry in depositional areas in the adjacent receiving environment to the point of generating adverse effects on benthos;
- Distributions and gradients in primarily temperature, as a proxy for other constituents, in the receiving environment; and
- Actual, as opposed to predicted, toxicity effects in the receiving environment.

5.1.1 Whole Effluent Toxicity

- Purpose: Determine the toxicity risk to the receiving environment of the dissolved constituents of the discharged effluent and the required dilutions to reduce these to acceptable levels. Match these dilutions to those predicted for the effluent plume (PRDW hydrodynamic modelling results) to determine the water body actually at risk from the discharge.
- Sampling: Obtain multiple grab samples of effluent from the discharge channel twice yearly to compile a whole effluent toxicity profile over time to constrain the variation of the toxicity risks in the receiving environment.
- Analysis: Conduct sea urchin fertilization success tests on the dissolved constituents. Include other tests suitable for determining toxicity levels if required (e.g. microtox).

- Reporting: Compile effluent toxicity tests reports for each period and a composite report on the time series focused on determining variability in toxicity levels and the areas predicted to be at risk in the receiving water body.

5.1.2 Sediment Contamination

- Purpose: Determine whether there is a consistent build-up of inorganic contaminant concentrations in seabed sediments in the receiving water body and the seawater intake basin (identified deposition area), to the point where these represent an ecological risk.
- Sampling: Obtain and analyse sediment samples from the station locations occupied in the 2015 sediment and benthos survey (see Appendix A) at annual intervals.
- Analysis: Test samples for particle size distributions, organic content and heavy metal concentrations and macrobenthos distributions. Predict sediment heavy metal build-up rates in the sediments in the depositional areas and identify levels of disturbance, if any, on benthos community structure.
- Reporting: Compile full, stand-alone scientific reports on each of the surveys and a synthesis of the results when appropriate.

5.1.3 Effluent Plume Distributions in the Receiving Environment

- Purpose: Using primarily temperature distributions quantify the actual distribution of the discharged effluent plume in the receiving environment to validate the hydrodynamic model results. This is required to add confidence to assessments of actual as opposed to predicted effects of effluent toxicity.
- Sampling: Conduct multi-parameter CTD surveys of the effluent plume area twice yearly to obtain synoptic 3D distributions of the plume extent. These should be conducted concurrently to the whole effluent toxicity testing and logistically coordinated with the measurements required under section 5.14.
- Analysis: Analyse the CTD data to obtain representations of the distribution of the effluent plume at the time of sampling. Determine whether there are concurrent distortions to distributions of specifically dissolved oxygen and phytoplankton biomass. Use these variables to place the results of the whole effluent toxicity tests in the environmental context.
- Reporting: Produce monitoring reports at each survey interval and a composite report on the time series for the distributions.

5.1.4 Toxicity Effects of the Discharge Plume

- Purpose: Determine the existence, or not, of toxicity effects attributable to the discharge effluent plume in the receiving water body by monitoring biofouling rates on artificial substrates suspended in (test) and outside (reference) of the effluent plume to complement the whole effluent toxicity test results.

- Sampling: Suspend settlement plates at 3-5 m depth in the water column at five locations within the discharge plume within 1 000 m of the end of the discharge channel and match these with five locations approximately 1 000 m offshore 5 km north and south of the KNPS. Exposure periods should be <90 days and tests should be conducted in upwelling and non-upwelling periods over a multi-year cycle. Temperature sensors will be deployed at all plate positions to measure the exposure of each site to the thermal plume and to validate the hydrodynamic model results.
- Analysis: toxicity effects are to be determined on a comparative basis between test and the reference sites. If differences are detected the presence or absence of the responsible organisms are to be determined to identify a) varying sensitivity levels within the biofouling community, and b) assist in isolating the causative constituents, if possible. Time series temperature records will be evaluated against temperature distributions as currently predicted from the PRDW (2017) hydrodynamic modelling.
- Reporting: Report on each deployment and provide a synthesis of the results at the conclusion of the monitoring period.

5.1.5 Effects of the Effluent Discharge on Intertidal Organisms

The KNPS has been conducting regular surveys of sandy beach fauna in the vicinity of its discharge. This programme should be continued to add to the long-term data set that has been established.

5.2 Investigations

Chlorine (TRO) and hydrazine discharges were determined to be non-compliant with both general and site-specific guidelines in terms of the spatial extents of their respective plumes in the receiving environment. KNPS has indicated that the chlorine dosing regime and the hydrazine discharge practices can be modified to extents that do not compromise power plant operations. The implications for TRO and hydrazine distributions in the receiving environment should be determined by hydrodynamic modelling of the available options to determine whether there are benefits for the receiving environment and evaluate these against the costs that could be generated by altered management practices.

6 CONCLUSIONS & RECOMMENDATIONS

This evaluation has examined the risks to marine ecology in the receiving environment linked to the combined discharge of cooling water and effluents from power plant operations at the KNPS. The evaluation relied on detailed hydrodynamic modelling, conducted by PRDW that described the behaviour of the discharge plume and constituents, published information on the marine ecology characteristics of the receiving environment and region, and known toxicity effects of the discharge constituents. The main conclusions of the evaluation, summarised in Table 6.1, are that:

- The discharge plume is not compliant with established water quality guidelines in that specified limits for temperature, total residual oxidant (TRO), phosphate and hydrazine were predicted to be transgressed outside of mixing zone boundaries contemplated by DEA (2013) and in developing policy;
- Risks to organisms within ~2 km of the discharge are limited to chronic effects;
- All predicted <u>ecological</u> impacts associated with the discharge were graded as being of very low to medium significance;
- All predicted <u>exceedances of water quality guideline</u> concentrations were rated as high significance due to large mixing zones indicated by the simulation modelling; and
- Identified mitigation options for reducing the medium to high significance impacts should be subject to feasibility assessments, including simulation modelling, and cost/benefit analyses as the associated ecological risks are not rated as highly significant.

The results of the environmental impact assessment conducted for the purposes of this evaluation of the KNPS discharge are summarised in Table 6.1.

The major uncertainties that exist are:

- The possible existence of synergistic or additive effects on effluent toxicity due to constituents in the effluent discharge; and
- Whether the predictions of low toxicity levels based on assessments of the risks posed by individual constituents are robust, particularly for inhabitants of the water column.

A monitoring programme encompassing whole effluent toxicity tests, discharge plume behaviour in the field, field based toxicity investigations in the receiving environment and inorganic contaminant build-up in sediments is recommended to reduce these uncertainties. Further, the established intertidal beach monitoring should be continued to identify any effects on this component of the natural environment, should these arise. In addition, the KNPS should investigate whether there are benefits from modifying chlorination procedures and hydrazine discharge practices to reduce their level of non-compliance with the emerging policy and regulations on the extents of effluent mixing zones for marine discharges.

Table 6.1: Impact summary table

#	Impact type	Extent	Duration	Intensity/ magnitude	Significance before mitigation	Mitigation	Significance post mitigation	Confidence in prediction
1	Temperature guideline exceedances - normal operations	Regional	Long-term	High	High	Alternative Cooling	Low	High
2	Temperature elevation: Ecological rist - normal operations	Site	Long-term	Low	Very Low	n/a	n/a	High
2	Temperature elevation: Ecological risk - abnormal operations	Local	Temporary	Low	Very Low	n/a	n/a	High
3	TRO guideline exceedances	Regional	Long-term	High	High	Modify Cl dosing	Medium	High
4	TRO discharge: Ecological risk	Sub-Regional	Long-term	Low	Medium	Modify Cl dosing	Low	Medium
5	Phosphate discharge: Ecological risk	Regional	Long-term	Low	Very Low	n/a	n/a	High
6	Hydrazine discharge: Guideline exceedances	Regional	Long-term	High	Medium	Modify Discharges	Low-Medium	Medium
7	Hydrazine discharges: Ecological risk	Regional	Long-term	Low	Very Low & Medium	Modify Discharges	Very Low & Low-Medium	Medium
8	Discolouration of sea surface foams by $Fe(OH)_3$	Local	Long-term	Low	Low	Divert flows	Very Low	Medium
9	Heavy metal build-up including iron in deposition areas	Local	Long-term	Low & Medium	Medium & Very Low	Divert flows to reduce iron	Low	High & Medium

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APPENDIX A. SEDIMENT AND BENTHOS SURVEY

INTRODUCTION

The sediment size distribution, the metals and organic concentrations and the macrobenthic fauna was examined in the vicinity of the Koeberg Nuclear Power Station outfall in order to establish the required baseline for a Coastal water discharge permit.

METHODS

Sampling for sediment properties and benthic macrofauna distributions was conducted on the 4th November, and the 1st and 4th December 2015. Table 1 lists the geographic coordinates of each of the sampling points and indicates the variables measured while Figure A.7.1 shows a map of the sample locations.

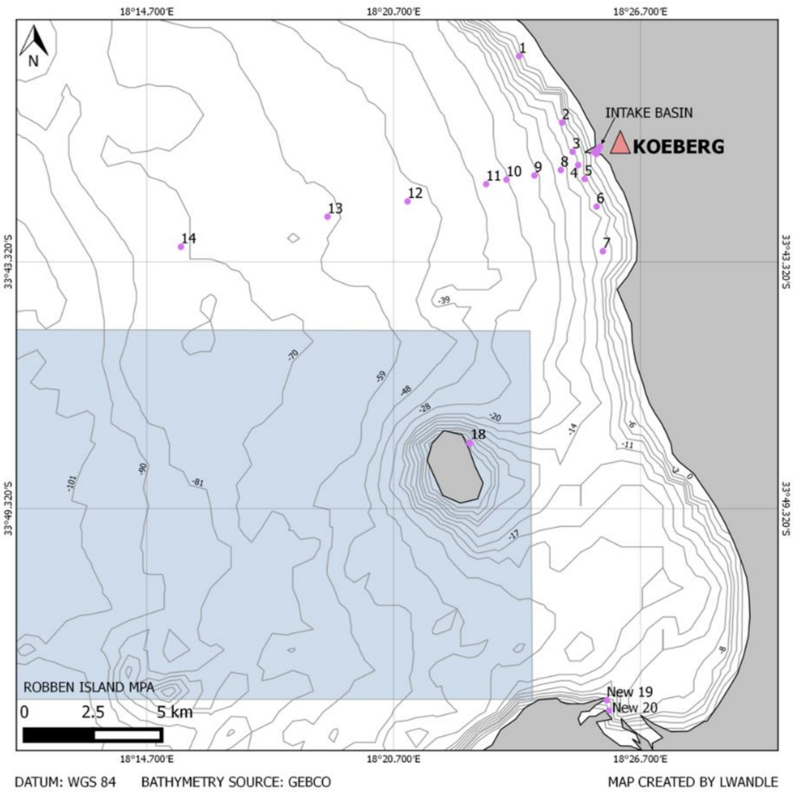

Figure A.7.1: Map of the sampling locations for sediment and macrobenthos samples. Four replicate samples were taken in the intake basin. The bathymetry is also shown with the contours showing the depths. The blue rectangle represents the proposed marine protected area surrounding Robben Island.

Table A.7.1: Site locations and variables analysed at each site.

Site	Longitude (°E)	Latitude (°N)	PSA	Metal	Org	Macro-fauna
1	18.3958	-33.6387	Y	Y	Y	Y
2	18.4133	-33.6656	Y	Y	Y	Y
3	18.4176	-33.6774	Y	Y	Y	-
4	18.4198	-33.6828	Y	Y	Y	Y
5	18.4225	-33.6884	Y	Y	Y	-
6	18.4273	-33.6996	Y	Y	Y	Y
7	18.4298	-33.7177	Y	Y	Y	Y
8	18.4128	-33.6848	Y	Y	Y	Y
9	18.4021	-33.6870	Y	Y	Y	Y
10	18.3908	-33.6887	Y	Y	Y	Y
11	18.3825	-33.6905	Y	Y	Y	Y
12	18.3507	-33.6975	Y	Y	Y	Y
13	18.3183	-33.7037	Y	Y	Y	-
14	18.2588	-33.7159	N	N	N	-
IB 1	18.4285	-33.6754	Y	Y	Y	-
IB 2	18.4262	-33.6776	Y	Y	Y	-
IB 3	18.4272	-33.6783	Y	Y	Y	-
IB 4	18.4270	-33.6768	N	N	N	-
IB 5	18.4278	-33.6770	Y	Y	Y	-
18	18.3761	-33.7976	Y	Y	Y	-
19	18.4314	-33.8996	Y	Y	Y	-
20	18.4323	-33.9038	Y	Y	Y	-

At each sampling site, a van Veen grab samples of the sea floor surficial sediments were taken. The grab dimensions were 0.33 x 0.33 m resulting in a sampled area of 0.1 m^2/grab. The penetration depth of the grab into the sediment was typically 5-10 cm yielding a sample volume of ~5-10 litres. At each sampling site one van Veen grab sample of the sea floor surficial sediment was taken. At 20 sites, both sediment grain size distribution and, organic and inorganic subsamples were obtained from the single grab-sample. At ten sites (indicated in Table A.1) a subsample for macrobenthic community structure was also collected. To obtain these samples the remaining sediment was rinsed through a 1 mm aperture stainless steel sieve. The benthic macrofauna retained on the sieve was washed into labelled sample bottles and fixed in buffered ~4% formaldehyde solution.

The PSA samples were frozen prior to being handed to the Council for Geoscience laboratories in Cape Town where they were analysed further. The samples for chemical analysis were frozen and analysed by the CSIR in Stellenbosch.

The macrofauna samples were freighted to the laboratory of KZN Coastal Impact Consultants, located in Durban, for analysis. The fauna was extracted from the sediments by sequential sieving and elutriation through stainless steel sieves. All residues were carefully scanned under a binocular microscope to ensure that the heavier and more cryptic animals were secured. The extracted fauna was transferred to plastic screw-cap jars containing 70% ethanol for permanent preservation. Identifications were made using a scanning binocular microscope with a zoom capability. Finer details, when required, were obtained with a more powerful compound microscope. The fauna was identified to the lowest practically possible taxonomic level.

The numbers for each taxon were recorded before the material was blot-dried and weighed to the nearest milligram. Literature used for identification of the fauna included Barnard (1950), Day, (1967), Kensley (1972,1973, 1978), Griffiths (1976), and Branch (2008). Univariate indices - Shannon-Wiener Diversity (H’) and Pielou’s Evenness (J’) - were calculated using the R software and the vegan package (Oksanen et al., 2007). These measures allow the evaluation of community structure assuming that healthy communities are normally rich in numbers, display high species diversity and have an even spread of numbers amongst species.

A principal component analysis was performed in R on the chemical composition of the sediments for all sites except those at the Intake basin and sites 18, 19 and 20. The PCA was based on the Euclidean distance between the sites. The chemical concentrations were log-transformed and scaled before analysis. A type I scaling was applied in order to consider in the differences between the sites.

RESULTS

Particle Size Distributions

Benthic organisms are highly dependent on the nature of the sea-bed for their survival. Species will tend to settle and thrive mostly in those areas with sedimentary characteristics that match their needs in terms of feeding, reproduction and obtaining shelter from predators. It is, therefore, important that benthic ecological surveys incorporate sedimentary conditions within their suite of measurements. It allows clearer recognition of the relative roles played by anthropogenic, rather than natural, factors in driving structural changes within benthic communities.

The sediments across the sampling sites were composed mostly of fine sand (particle size between 125 and 250 µm). The particle size distribution for all the sites is shown in Figure A.7.2, which highlights the uniformity of the sediment across the sampling sites. The sediments at site 13, which was the furthest site from the shore, showed slightly larger grain size and were mostly composed of medium sand (between 250 - 500 µm). The sediment size in the KNPS intake basin were largely similar to those of the adjacent inner continental shelf. Given the similarity between the sites, the sediment composition can be discounted as a driver of community structure.

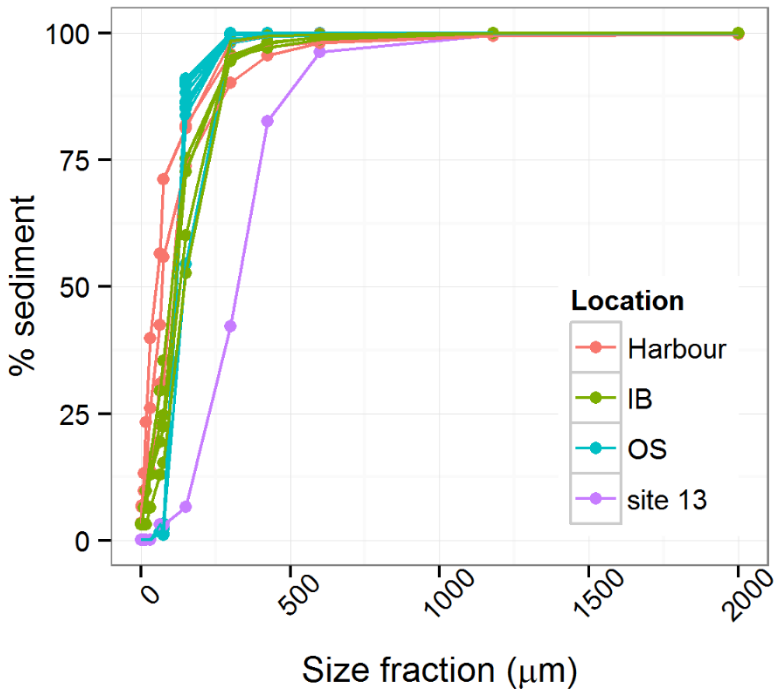

Figure A.7.2: Sediment size distribution at sites located in the vicinity of the KNPS outfall on the open shelf (OS), in the KNPS seawater intake basin (IB), Murray's Harbour and the Port of Cape Town (Harbour). Site 13 is highlighted due to its significant difference from the other sites.

SEDIMENT CHEMICAL COMPOSITION

The chemical composition of the sediments was analysed. Table A.7.2 and Table A.7.3 show the concentration of metals and phosphorus as well as the organic contents at all sites. The stations located in Murray's Harbour (site 18), the Port of Cape Town (sites 19 & 20) and those within the intake basin (sites denoted IB) contained higher metal concentrations than the open shelf sites. The intake basin, Murray's Harbour and the Port of Cape Town are depositional areas. Figure A.3 shows the concentration of selected metals against that of aluminium for all stations. It indicates a linear increase and clearly shows highest metal concentrations at the Port of Cape Town and Murray's harbour, followed by the intake basin and the open shelf samples. For example, nickel concentrations were below <0.5 mg/L at all other stations but ranged between 2.90 – 19 for the intake basin and the stations 18, 19 and 20. Concentrations of heavy metals in the intake basin were generally higher than on the open shelf but were variable. This is linked to elevated aluminium (proxy for clay minerals) concentrations in these locations (Figure A3). Copper and lead concentrations measured at intake basin site IB 1 and cadmium at site IB 3 exceeded the respective

SQGs but the mean values for the basin did not. Accordingly, intake basin sediments do not classify as being contaminated to the extent that they constitute toxicity risks.

Samples within the KNPS seawater intake basin show variable heavy metal concentrations with high levels of arsenic, chromium, copper, iron and lead at site IB 1 relative to the other three sites within the basin (Table 4.10). The observed heavy metal concentration gradients may be ascribable to the proximity of site IB 1 to the northern stormwater discharge for the KNPS (Figure 4.23).

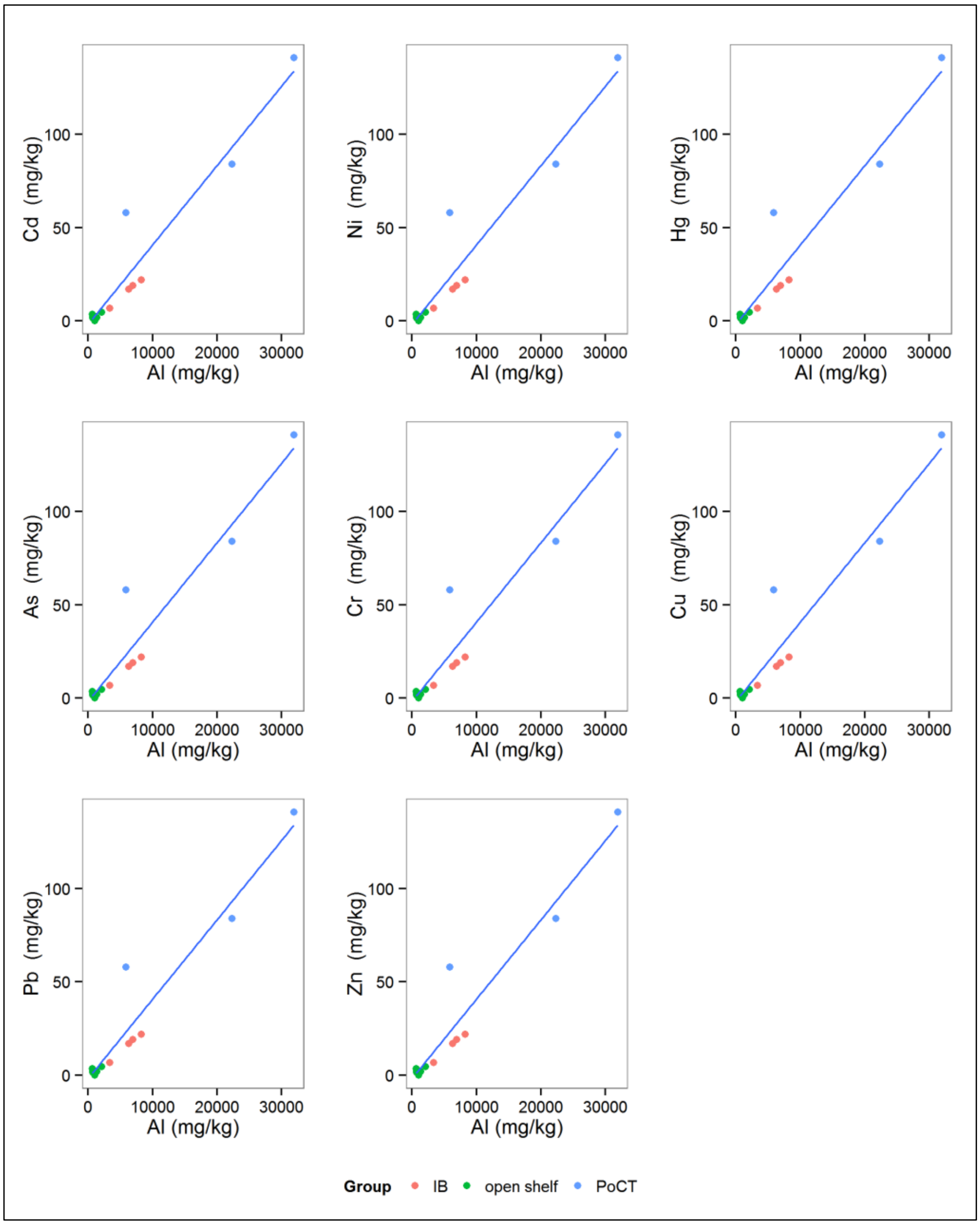

Figure A.7.3: Plots of the concentration of selected metals against that of aluminium at open shelf sites (OS), in the intake basin (IB) at KNPS and at the port of Cape Town (PoCT).

The variation between the open shelf sites was explored using PCA. A PCA determines the differences between the sites (the Euclidean distance) based all the variables measured and similar sites are plotted close to each other. The PCA plot (Figure A.4) shows the Euclidean distances between the stations at KNPS (excluding the intake basin). The PCA plot highlights the differences between Site 13 and the other sites on the inner shelf. Site 13 appeared to have a higher total organic and moisture content as well as a higher concentration of aluminium and magnesium.

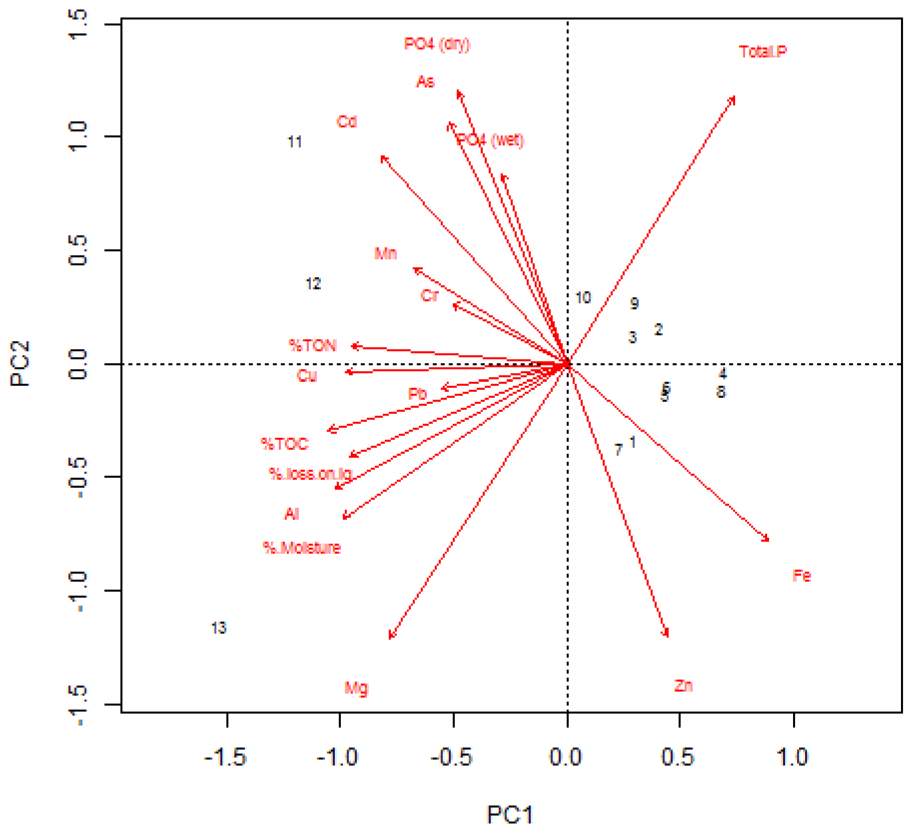

Figure A.7.4: PCA showing the chemical composition of the sediments at sites within the vicinity of the KNPS outfall excluding the intake basin and stations 18, 19 and 20. A type I scaling was applied whereby the differences between the sites was considered. The perpendicular projection of the site onto a variable vector indicates the relative value of the variable at this particular site (Buttigie & Ramette, 2014). The two axes shown explain 72% of the variation amongst these sites.

Table A.7.2: Sediment properties for all sites. The % loss on ignition, Total organic carbon (%TOC) and Total organic nitrogen (%TON) are measures of the sediment organic content.

Stn	PO4 -wet (mg/kg)	Total P (mg/kg)	PO4-dry (mg/kg)	% Moisture	% loss on ignition	%TOC	%TON
1	<1.00	2414	1	19	1	0.11	0.01
2	6	2346	7	18	1	0.11	0.01
3	5	2146	6	20	1.2	0.11	0.02
4	4	2112	5	19	0.8	0.09	0.01
5	3	2038	4	19	1.3	0.1	0.02
6	6	1863	7	19	1.3	0.1	0.02
7	2	1914	2	20	1.6	0.12	0.02
8	1	2533	1	18	1.1	0.08	0.02
9	11	2619	13	18	1.6	0.07	0.02
10	5	2589	6	19	1.3	0.14	0.02
11	21	2203	27	21	1.8	0.23	0.03
12	13	1785	17	22	1.9	0.19	0.03
13	2	617	3	26	3.1	0.37	0.03
18	14	2434	25	43	7	2.74	0.4
19	2	1216	5	57	15.2	4.03	0.42
20	3	1046	6	48	9.9	3.09	0.29
IB 1	8	1726	15	45	6.8	1.58	0.21
IB 2	4	1794	6	31	4.8	0.7	0.08
IB 3	3	1951	5	39	7.4	1.93	0.27
IB 5	2	1672	4	50	9.7	3.38	0.51

Table A.7.3: Concentration of metals in the sediments in the vicinity of KNPS, at Murray harbour and of the Port of Cape Town. The highlighted cells show exceedances of the BCLME (2006) sediment quality guideline concentrations (SQL). PEL denotes probable effect levels for toxicity.

Stn	Heavy Metal (mg/kg)										
	Al	Cd	Ni	Hg	As	Cr	Cu	Fe	Pb	Mn	Zn
1	675	0.11	0.50	0.01	1.00	8.00	0.60	468	11.00	12.00	3.50
2	721	0.09	0.50	0.01	1.00	7.70	0.50	446	2.80	9.70	1.90
3	829	0.08	0.50	0.01	2.00	8.10	0.50	500	2.50	6.50	1.90
4	759	0.08	0.50	0.01	1.00	7.20	0.50	452	2.50	5.80	2.20
5	746	0.08	0.50	0.01	1.00	6.80	0.50	430	2.50	6.20	2.70
6	751	0.07	0.50	0.01	1.00	6.90	0.50	397	2.90	5.10	1.50
7	925	0.08	0.50	0.01	1.00	7.50	0.50	531	3.10	7.00	2.70
8	717	0.07	0.50	0.01	1.00	7.70	0.50	479	2.50	8.90	1.80
9	722	0.08	0.50	0.01	1.00	8.60	0.50	490	3.00	12.00	2.40
10	842	0.10	0.50	0.01	2.00	8.40	0.50	549	2.50	11.00	2.20
11	1087	0.20	0.50	0.01	2.00	7.90	1.90	93	4.80	13.00	0.50
12	1342	0.15	0.50	0.01	4.00	8.30	1.80	112	4.90	13.00	1.90
13	2102	0.09	0.50	0.01	1.00	8.20	1.80	301	4.40	11.00	4.60
18	5912	1.00	3.60	0.06	1.00	15.00	2.80	1651	5.90	35.00	58.00
19	31892	0.47	19.00	0.30	6.00	15.00	12.00	3271	18.00	142.00	141.00
20	22292	0.23	13.00	0.31	7.00	61.00	74.00	19061	62.00	111.00	84.00
IB 1	6322	0.32	2.90	0.02	6.00	41.00	41.00	13961	42.00	30.00	17.00
IB 2	3392	0.29	0.50	0.01	1.00	17.00	6.80	2981	9.10	17.00	6.70
IB 3	6982	0.75	4.50	0.02	1.00	11.00	3.50	1201	5.90	31.00	19.00
IB 5	8272	0.60	6.20	0.03	3.00	20.00	6.80	3431	9.30	36.00	22.00
SQG		0.68	15.90	0.13	7.24	52.30	18.70		30.20		124.00
PEL		4.21	42.80	0.70	41.6	160.00	108.00		112.00		271.00

BENTHIC MACROFAUNA COMMUNITY STRUCTURE

The results of the macrobenthos analysis are listed in Table A.7.8 (identities and abundances) and Table A.7.9 (identities and biomass). 42 taxa were present in total. The taxa present is characteristic of the region, the South West Cape inner shelf ecozone (see section 2.2). Table A.7.4 and Table A.7.5 list the 10 most important contributors in terms of abundance and biomass respectively. Polychaete worms accounted for about 50% of the abundance counts. This category was dominated by a Sabellid species which was found in large numbers at station 12. Rare, large taxa were more significant in terms of biomass. *Bullia laevissima* contributed to 48% of the biomass but this was due to two individuals found at station 7. Similarly, six individuals of *Dosinia lupinus* were counted at station 12 where this species accounted for 28% of the total biomass.

Table A.7.4: Relative contributions made by individual taxa to the total faunal count at 10 macrofauna sampling sites at the KNPS outfall. The sampling site locations are listed in Table A.1

Taxon	Classification	Rank	Count	Contribution (%)
Sabellidae sp A	Polychaete worm	1	168	24.10
Urothoe pinnata	Amphipod Crustacean	2	64	9.18
Urothoe grimaldi	Amphipod Crustacean	3	54	7.75
Actinaria sp A (small)	Cnidarian sea anemone	4	53	7.60
Prionospio sp A	Polychaete worm	5	39	5.60
Virgularia schultzei	Cnidarian Sea-Pen	6	37	5.31
Nephtys capensis	Polychaete Worm	7	36	5.16
Magelona cincta	Polychaete Worm	8	29	4.16
Phylo capensis	Polychaete Worm	9	28	4.02
Tellinidae sp A	Bivalve Mollusc	10	23	3.30

Table A.7.5: Relative contributions made by individual taxa to the total biomass at 10 sites at the KNPS outfall

Taxon	Classification	Rank	Mass (g)	Contribution (%)
Bullia laevissima	Gastropod Mollusc	1	48.51	47.58
Dosinia lupinus	Bivalve Mollusc	2	28.63	28.08
Virgularia schultzei	Cnidarian Sea-Pen	3	6.53	6.41
Nassarius sp A	Gastropod Mollusc	4	5.86	5.75
Actinaria sp A (small)	Cnidarian sea anemone	5	3.95	3.87
Actinaria sp B (large)	Cnidarian sea anemone	6	2.14	2.09
Nephtys capensis	Polychaete Worm	7	1.41	1.39
Glycera convoluta	Polychaete Worm	8	1.41	1.38
Diopatra neapolitana	Polychaete Worm	9	0.86	0.84
Nephtys hombergi	Polychaete Worm	10	0.60	0.59

A survey of the macrobenthic community at the Chevron outfall located in Milnerton was conducted in December 2015 (Lwandle, 2016). The proximity of this site to the KNPS areas and the fact that sampling was conducted at a similar time allows for comparison between the two studies. While a number of species are present at both the Chevron and KNPS sites, the relative contribution both in terms of biomass and counts vary. Table A.7.6 and Table A.7.7 show the 10 most significant contributors to abundance count and biomass at Chevron outfall for surveys conducted in 2015 for comparison. *Bullia laevissima*, *Virgularia schultzei*, *Nephtys capensis*, *Glycera convolute* and *Diopatra neapolitana* are major contributors to biomass at both sites. *Urothoe grimaldi*, *Virgularia schultzei*, *Nephtys capensis*, *Tellinidae* and *Nermertea* were amongst the most important contributors to abundance counts at both sites.

Table A.7.6: Relative contributions made by individual taxa to the total faunal count in the 2015 survey at the Chevron outfall

Taxon	Classification	Rank	Count	Contribution (%)
Nephtys capensis	Polychaete Worm	1	151	18.48
Orbinia angrapequensis	Polychaete Worm	2	126	15.42
Caullierella acicula	Polychaete Worm	3	114	13.95
Nemertea sp 1	Nemertean Ribbon Worm	4	114	13.95
Tellina	Bivalve Mollusc	5	68	8.32
Urothoe grimaldi	Amphipod Crustacean	6	59	7.22
Paramoera capensis	Amphipod Crustacean	7	54	6.61
Virgularia schultzei	Cnidarian Sea-Pen	8	41	5.02
Amaryllis macrophthalma	Amphipod Crustacean	9	14	1.71
Glycera convoluta	Polychaete Worm	10	13	1.59

Table A.7.7: Relative contributions made by individual taxa to the total biomass in the 2015 survey at the Chevron outfall

Taxon	Classification	Rank	Mass (mg)	Contribution (%)
Virgularia schultzei	Cnidarian Sea-Pen	1	15885	49.26
Bullia laevissima	Gastropod Mollusc	2	10389	32,22
Nephtys capensis	Polychaete Worm	3	1493	4,63
Orbinia angrapequensis	Polychaete Worm	4	1095	3,39
Tellina	Bivalve Mollusc	5	551	1,71
Nemertea sp 1	Nemertean Ribbon Worm	6	414	1,28
Caulleriella acicula	Polychaete Worm	7	379	1,18
Glycera convoluta	Polychaete Worm	8	296	0,92
Scolelepis squamata	Polychaete Worm	9	286	0,89
Diopatra neapolitana	Polychaete Worm	10	156	0,48

Table A.7.8: Identities and counts of macrobenthos sampled in the vicinity of the KNPS

Site	**1**	**2**	**4**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
AMPHIPODA										
Ampelisca									1	
Bathyporeia	1							1	4	
Corophiidae sp A	2							2		
Cunicus profundus			1		1	1				
Indischnopus herdmani	1	3		1	11	4				
Paramoera capensis	1					2		1		
Perioculodes longimanus	1		1						12	
Urothoe grimaldi	6	21	20		3	4				
Urothoe pinnata		34	22	1	5	2				
Urothoe sp A										1
CARIDEA										
Ogyrides saldanha			1							
CNIDARIA										
Actinaria sp A (small)							12	17	11	13
Actinaria sp B (large)								1		1
CUMACEA										
Cumacea cf *Bodotria*					1					
Cumacea cf *Iphinoe*								1		
Cumacea sp A										1
GASTROPODA										
Bullia laevissima					2					
Nassarius sp A										15
ISOPODA										
Microarcturus							1			
NEMERTEA										
Nemertea sp A	1	2	2		3	4	3	3		2
OSTRACODA										
Ostracoda sp A		1	1							
Ostracoda sp B			1							
PELECYPODA										
Dosinia lupinus										6
Tellinidae sp A			5		14	3		1		
PENNATULACEA										
Virgularia schultzei		6		6		22	1	1		1
POLYCHAETA										
Capitellidae sp A						1				
Caulleriella acicula			1					17		
Centranthus caeca	2	2	4	3	2					3
Diopatra neapolitana	2	2	1		1					
Glycera sp A										2
Glycera convoluta						1		1		
Lumbrineris albidentata										1
Lumbrineris meteorana										1
Magelona cincta								12	11	6
Nephtys capensis	8	8	4	5	3	1	1	2	2	2
Nephtys hombergi										1
Nephtys sp A										5
Orbinia cuvieri										6
Phylo capensis					1		2	20	1	4
Prionospio sp A					6	1		13	13	6
Sabellidae sp A									5	163
Sigalion capense					1					
No. of Taxa	**10**	**9**	**13**	**5**	**14**	**12**	**6**	**15**	**9**	**20**
Total Abundance	**25**	**79**	**64**	**16**	**54**	**46**	**20**	**93**	**60**	**240**

Table A.7.9: Identities and weights (mg) for macrobenthos sampled in the vicinity of the KNPS

Site	1	2	4	6	7	8	9	10	11	12
AMPHIPODA										
Ampelisca									2	
Bathyporeia	2							5	8	
Corophiidae sp A	7							12		
Cunicus profundus			3		1	2				
Indischnopus herdmani	3	6		8	34	9				
Paramoera capensis	6					11		3		
Perioculodes longimanus	4		5						32	
Urothoe grimaldi	12	42	39		2	6				
Urothoe pinnata		73	48	2	4	3				
Urothoe sp A										2
CARIDEA										
Ogyrides saldanha			180							
CNIDARIA										
Actinaria sp A (small)							960	17	1361	1609
Actinaria sp B (large)								1		2134
CUMACEA										
Cumacea cf *Bodotria*					3					
Cumacea cf *Iphinoe*								1		
Cumacea sp A										5
GASTROPODA										
Bullia laevissima					48511					
Nassarius sp A										5860
ISOPODA										
Microarcturus							3			
NEMERTEA										
Nemertea sp A	10	11	9		30	33	27	3		18
OSTRACODA										
Ostracoda sp A		3	4							
Ostracoda sp B			3							
PELECYPODA										
Dosinia lupinus										28636
Tellinidae sp A			9		42	13		5		
PENNATULACEA										
Virgularia schultzei		1531		1157		3382	171	51		242
POLYCHAETA										
Capitellidae sp A						11				
Caulleriella acicula			3					67		
Centranthus caeca	6	15	41	38	3					14
Diopatra neapolitana	208	366	130		160					
Glycera sp A										43
Glycera convoluta						105		1304		
Lumbrineris albidentata										312
Lumbrineris meteorana										12
Magelona cincta								18	21	18
Nephtys capensis	129	129	24	73	98	42	35	280	535	68
Nephtys hombergi										601
Nephtys sp A										12
Orbinia cuvieri										86
Phylo capensis					18		9	118	12	15
Prionospio sp A					8	12		24	18	14
Sabellidae sp A									6	193
Sigalion capense					82					
No. of Taxa	**10**	**9**	**13**	**5**	**14**	**12**	**6**	**15**	**9**	**20**
Total biomass (mg)	**387**	**2176**	**498**	**1278**	**48996**	**3629**	**1205**	**1909**	**1995**	**39894**

THE DISTRIBUTION OF UNIVARIATE INDICES

Univariate analysis deals with single indices that are derived from numerical features of a community. They provide insight into community structure and are amenable to standard statistical analysis and comparisons. Table A.7.10 presents the univariate measures calculated for the 12 sites at KNPS. These univariate measures of diversity were generally similar across the sites and comparable with those calculated at the Chevron outfall. However, the Pielou's Evenness factor (J) was much lower at site 12. This was due to the dominance of the *Sabellidae* polychaete.

Table A.7.10: Indices of macrobenthic community structure for the sites sampled in the 2015 survey.

Site	No of Species (S)	Total counts (N)	Biomass (g)	Pielou's Evenness (J)	Shannon Wiener Diversity (H')
1	10	25	0.387	0.850	1.957
2	9	79	2.176	0.729	1.601
4	13	64	0.498	0.717	1.839
6	5	16	1.278	0.865	1.392
7	14	54	48.996	0.846	2.234
8	12	46	3.629	0.747	1.857
9	6	20	1.205	0.709	1.271
10	15	93	1.909	0.778	2.108
11	9	60	1.995	0.871	1.913
12	20	240	39.894	0.483	1.446

CONCLUSIONS

Sediment size distribution, heavy metal concentrations and benthic macrofauna were analysed within the vicinity of the KNPS outfall. Sediment particle size distribution was fairly uniform across all of the sites sampled. These included sites in the immediate vicinity of the outfall and in depositional areas within Table Bay (Port of Cape Town and Murray's harbour). Heavy metal concentrations in the sediments were low being at or near the analytical detection limit in the non-depositional sites but were elevated but variable in the intake basin (and the Port of Cape Town and Murray Harbour). However, within the KNPS intake basin, the mean concentrations did not exceed established sediment quality guidelines for the region (BCLME 2006). The macrofauna community structure at the 10 sites on the open shelf was typical of the the South West Cape inner shelf ecozone. Given the low heavy metal concentrations and the benthic community structure, there is no evidence of impacted sediments at the 10 locations measured.

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