ESKOM HOLDINGS LIMITED
GENERATION DIVISION

NUCLEAR 1 ENVIRONMENTAL IMPACT ASSESSMENT AND ENVIRONMENTAL MANAGEMENT PROGRAMME

SPECIALIST STUDY FOR SCOPING REPORT

SPECIALIST STUDY: Oceanography

F A Shillington
Department of Oceanography
University of Cape Town
Rondebosch 7701

September 2007

NUCLEAR 1 ENVIRONMENTAL IMPACT ASSESSMENT AND ENVIRONMENTAL MANAGEMENT PROGRAMME

SPECIALIST STUDY FOR SCOPING REPORT

SPECIALIST STUDY: OCEANOGRAPHY

CONTENTS

Chapter	Description	Page

1 EXECUTIVE SUMMARY

The next site for a coastal nuclear power station will be either on the west coast or south coast of South Africa, in close proximity to the coastal ocean. Using present knowledge of the Duinefontein Power Station, it is assumed that there will be a significant exchange of seawater cooling effluent of the order of 100 cubic metres per second.

Background information about the present state of knowledge of a number of marine parameters is considered to be essential to the early planning of where to site the power station. Some of the information is specific to either the west, or the south coasts, while other large scale processes (e.g. sea level rise, which is about 1.8 mm per annum at present) are likely to be more generic to both coasts. The following are some of the processes, and their oceanic responses that will have to be investigated in detail, before a specific site is chosen.

- ***Sea level and sea state*:** If as in the case of Duinefontein, there is a small harbour for the intake basin, detailed information will be required about sea level and sea state at a variety of time scales. This is to ensure that the sea water intake is never flooded or left above the sea level. Short to medium term sea level variability is a function of the coastal ocean response to gravitational and atmosphere forcing: astronomical tides (days to weeks with a maximum variation of about two metres), air pressure (days to months, where a change in air pressure of 1 hecto pascal results in a change in sea level of 1 cm), and weather phenomena (days to weeks, with sea level changes of the order of 50 cm). Added to these external forcings and their oceanic responses, is the slow continued upward trend of sea level rise due to global warming (approximately 1-2 mm per annum), which is in line with global estimates (e.g. IPCC AR4, Chapter 5, 2007).

Sea state refers to the very short period (3-20 second band) surface gravity waves forced by both local and remote wind. These waves eventually break on the beach, and depending on the locality, may also cause transport of sediment both on and off shore and along the shore. Sea level is directly affected by the height of the breaking waves, with larger waves "setting up" the sea ;level more that smaller waves

The recent 2004 tsunami (Merrifield et al 2005) has alerted everyone to the importance of variations in sea level due to remotely forced tsunamis. The impact of the 2004 Indian Ocean tsunami was higher along the south coast than on the west coast. There is anecdotal evidence that the Struis Baai harbour "emptied" during the tsunami. More recently (September 12, 2007) there was another large earthquake off the coast of Indonesia, which generated a tsunami wave which crossed the Indian Ocean and was measured on the Port Elizabeth tide gauge with height of just under a metre, and a period of approximately 36 minutes. Tsunamis generated from the Indian Ocean will have a bigger influence on the south coast sites than the west coast sites.

- ***Seawater temperature:*** is an important variable with regard to the amount of heat that can be extracted by the seawater cooling system of the power station. The local sea temperatures have a climatological annual variation, and along the west coast respond to the wind either by being cooled at the surface due to wind induced upwelling in summer (opposite to the usual seasonal cycle of the highest temperature in summer), or relatively warmed by downwelling in winter. These factors are very site specific, and the variation is very different on the west coast, and southern coasts. Annual average satellite derived sea surface temperatures for the period 2003-2006 have been obtained and reported for the different sites. These vary from 14-15℃ in the nor th west (Brazil and Skulpfontein), to 19-20℃ at Thyspunt on the south coast (see Figure 4.0 a). The annual cycle of monthly mean sea surface temperatures has an amplitude in the range of approximately 5-6℃, and the monthly maximum and minimum sea surface temperatures for the 2003-2006 period have also been reported for the different sites.

It will be important to measure sea temperatures close to the coast, and investigate the shorter time scale temperature variability on a time scale of days to months.

- ***Chlorophyll a concentrations*** are considerably higher along the west coast (> 10 mg m^{-3}), than along the south coast (between 2.5 and 10 mg m^{-3}). High chlorophyll *a* concentrations imply biologically productive seawater, which has implications for enhanced biological growth and bio-fouling of the sea water intake. This is a situation that has to be managed at Koeberg since its inception.

It has been found that the sites along the west coast are exposed to high productivity water, whereas the south coast sites have low production.

- ***Coastal currents*** are important in dispersing the heated seawater from the power station intake. The nature of the forcing of the coastal ocean by wind, waves, tides, hot water from the power station outlet, and temperature gradients of the near shore circulation system has to be established, as has the response of the coastal ocean to this forcing to be established. Again this is a site specific problem and cannot be completely addressed here as it requires specific specialised site specific measurements and associated numerical modelling. These measurements need to carried out in the next phase of the investigations.

- Extensive use should be made of a number of excellent reports by Prestedge, Retief, Dresner and Wijnberg (2001a; 2001b; and 2005). In particular, Table 1 in the Kapp Prestedge and Retief (1991) report is invaluable in drawing together the measurements of coastal information and calculations that are presently available at the various sites under investigation. The table is included as appendix 1.

2 INTRODUCTION

This specialist study for this report uses available literature and a limited new analysis of sea surface temperature (SST) and chlorophyll *a* (chl *a*) data from the Aqua satellite to examine some of the nearshore oceanographic conditions pertinent to constructing a new coastal nuclear power station. It is assumed that the power station will use sea water for cooling and that it will draw approximately 100 m^3s^{-1} from the sea. No further assumptions are made about how this water will be obtained (e.g. at Koeberg there is a small harbour that acts as a "stilling basin", so that the sea water intake is protected from the incident wave climate, and other major sea level fluctuations). It is a possibility that the seawater intake may be via a pipeline out to sea, particularly in the case of a site on a rocky shore, thus obviating the need for a "stilling basin".

The terms of reference for this study are to examine important physical processes for which there is data, that affect the mean sea level, coastal currents, temperatures of the coastal ocean, and chl *a* as a proxy for ocean productivity.

Below is a comprehensive list of factors that should be investigated, and is provided as a guideline. It is not possible to address all of these factors in this initial report, as a lot of the relevant data for the various sites is unavailable. A subset of the factors considered to be most important is addressed as comprehensively as is possible in the limited time. These are taken from the list below:

Engineering design studies will need to consider:
Possibility of flooding from the sea, which requires knowledge of

- Return periods for extreme high water levels (sea level rise) and long period surge
- Wave run-up and storm set-up
- Maximum credible tsunami, run-up, combined with highest astronomical tidal level

Securing of cooling seawater supply, which requires knowledge of

- Exposure of cooling water intake
- Damage to the cooling water intake and the outfall structure from waves
- Sedimentation
- Blockages of cooling water intake, both physical and biological
- Thermal plume dispersion

Data collection and study reports will be required on the following marine effects:
Water level recordings

- Tidal constituents and astronomic predictions\Tidal residuals, long waves, atmospheric effects (set-up and set down), occurrence prediction; and
- Extreme level predictions.

Tsunami risk assessment

- Amplitude, duration, run-up, run-down; and
- Extreme level predictions.

Wave height, period and direction

- Offshore and inshore data sets;
- Wave refraction model sets;
- Wave run-up evaluation; and
- Extreme value prediction.

Currents

- Inshore and offshore, temporal and spatial variation, surface and sub-surface current
- recordings and spatial imagery; and
- Correlation between wind, tide and current patterns.

Water temperature

- Spatial and temporal variation in sea water temperature, salinity and chemistry;
- Extreme value prediction;
- Ambient water temperatures;
- Prediction of extreme values; and
- Thermal plume dispersion model.

- Possible changes of the hydrographic conditions due to climatic changes

Sediment dynamics
- Spatial and temporal variation in sediment characteristics (physical and chemical);
- Beach surveys and coastline stability assessment;
- Gross and net sediment transport rates (Aeolian, alongshore, on-shore, off-shore) and possible bypass requirements;
- Geomorphological model of changes caused by intake and discharge works,
- including effects of discharge plume; and
- Assessment of suspended ingress into intake basin and future maintenance requirements.

Blockage and fouling

Bathymetry

Conditions at the five possible new sites (three along the west coast, and two along the south coast) are discussed in the light of a reduced, but important set of criteria. These are:

Sea Surface Temperature and Chl a
- Spatial and temporal variation in sea surface temperature and Chl a;
- Annual Average and annual cycle of SST;
- Annual Average and annual cycle of Chl a;
- Possible changes of the hydrographic conditions due to climatic changes

A great deal of further useful information is available in three site safety and investigation reports (Prestedge *et al.* 2001a; Prestedge *et al.* 2001b and Prestedge *et al.* 2005). Extensive use has been made of these reports, as well as the Kapp Prestedge and Retief (1991). These reports are referred to here as PRDW (2001a; 2001b; and 2005) and KPR (1991) respectively. Table 1 from KPR (1991) is reproduced in Appendix 1.

2.1 Description of Proposed Project

This is a desktop and literature study and a preliminary data analysis of some of the physical factors affecting the sea level fluctuations on a range of time and space scales along the west and south coasts of South Africa. In particular, sea surface temperatures (SST), and chlorophyll *a* (chl *a*)are analysed from a four year data base of monthly satellite averages for the period 2003-2006, extracted with the online GIOVANNI system from the internet (see http://giovanni.gsfc.nasa.gov).

The KPR (1991) report discusses in detail the effect of the wave climate on the site selection. KPR (1991) raise four aspects that need investigation, viz.

(i) extreme wave and water level events;
(ii) average wave conditions likely to found during normal operating conditions;
(iii) wave driven sediment transport, which will be very site specific; and
(iv) wave driven nearshore circulation which will be important in the discussion of the design and siting of intake and discharge structures.

Table 1 in KPR (1991) (see Appendix 1) summarises a range of measurements and calculations available at sites in the southern, north western and eastern Cape.

3 BACKGROUND

3.1 Legislative Framework

There does not appear to be any the legislative framework referring to the temperature that the cooling water can be returned to the ocean in the South African water quality guidelines. It is assumed that because the seawater cooling will be a closed system, the only change to the cooling water will be a gain in heat. There will be no biological change in the seawater *per se.* From the experience at Koeberg to date, the heated seawater returned to the ocean has very limited impact on the coastal ocean.

3.2 Assumptions & Limitations

As enumerated in the introduction, there is a list of physical variables that need to be measured at the particular chosen site. This is in order to understand the relevant physical processes that will affect both the building of the new coastal power station, and its subsequent operation. From the perspective of this report, most of these pertain to being able to ensure a continuous supply of adequate seawater cooling. Although most of these quantitative measurements are unavailable at present, KPR (1991) report a summary of coastal information as at 1991. This is presented in Appendix 1.

Since the consultant is a physical oceanographer, he uses his best scientific judgement when it comes to deciding what physical variable to analyse and what he is able to confidently report on from the available data and literature. It is not the intention of this report to reproduce previously available reports, but to summarise their content where relevant.

The full list of detailed topics to be measured and/or calculated/modelled presented in the introduction can be used as a basis for drawing up the new terms of reference (TOR) for the next more detailed investigation of any particular site.

4 DESCRIPTION OF THE SITES AND SURROUNDING MARINE ENVIRONMENT

4.0 General Description

With the recent advances in satellite sensor technology, it is now possible to determine the average SST and chlorophyll *a* concentrations around the South African coastal area.

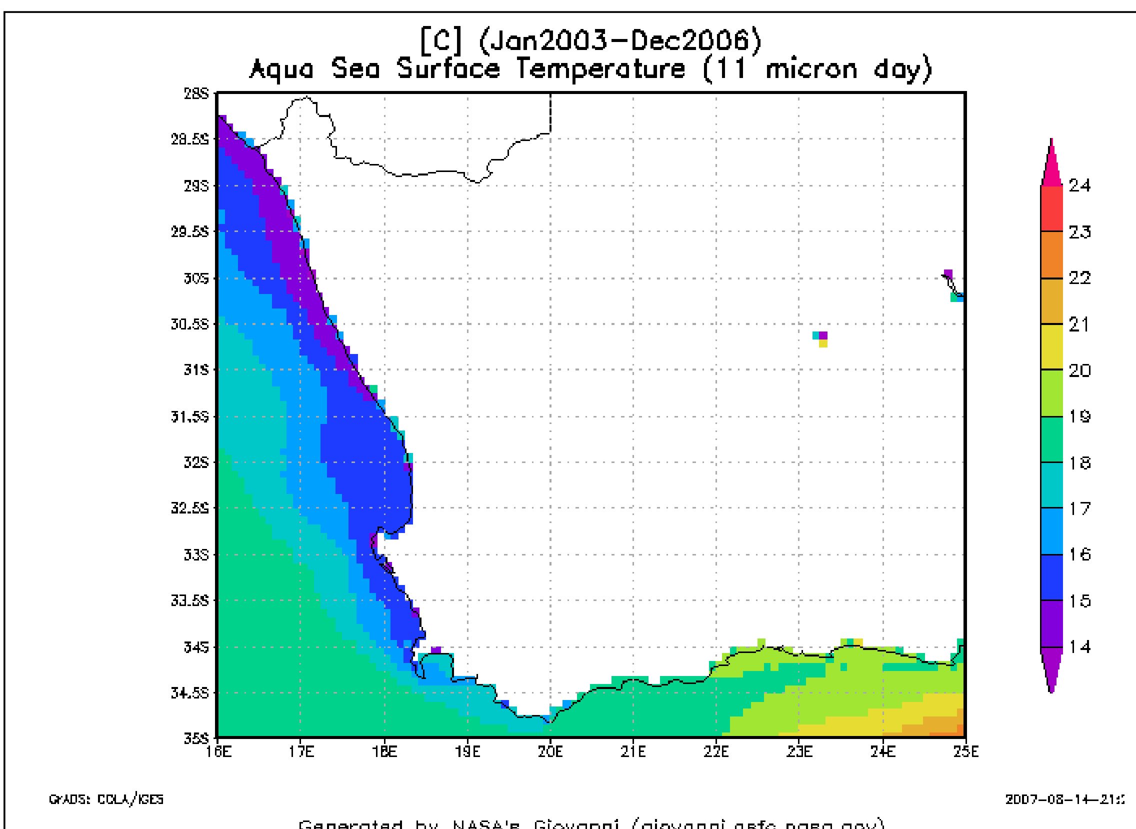


Figure 4.0a Annual average SST (℃) around South A frica, from 36 months of monthly data (2003-2006). Axes are latitude and longitude. The colour bar is SST ℃, from cold (purple 14℃), to warm (red - 24 ℃)

Figure 4.0a shows the spatial variation of the annual average of 36 months between January 2003 and December 2006, of satellite derived SST (Aqua using the MODIS instrument). Fig 4.0b, is the spatial variation of the annual average of chlorophyll *a* pigment concentrations around the South African west and south coasts. The area from 28-31.5℃S latitude along the west coast, has an average SST between 14-15℃. At Koeberg the average is between 15-16℃, at Bantamsklip it is between 16-17℃, and at Thyspunt it is between 19-20℃. At Brazil and Skulpfontein, it is between 14.0-14.5℃. Averag e chlorophyll *a* concentrations are above 10 mg m^{-3} along the west coast and between 2.5-10 mg m^{-3} along the south coast.

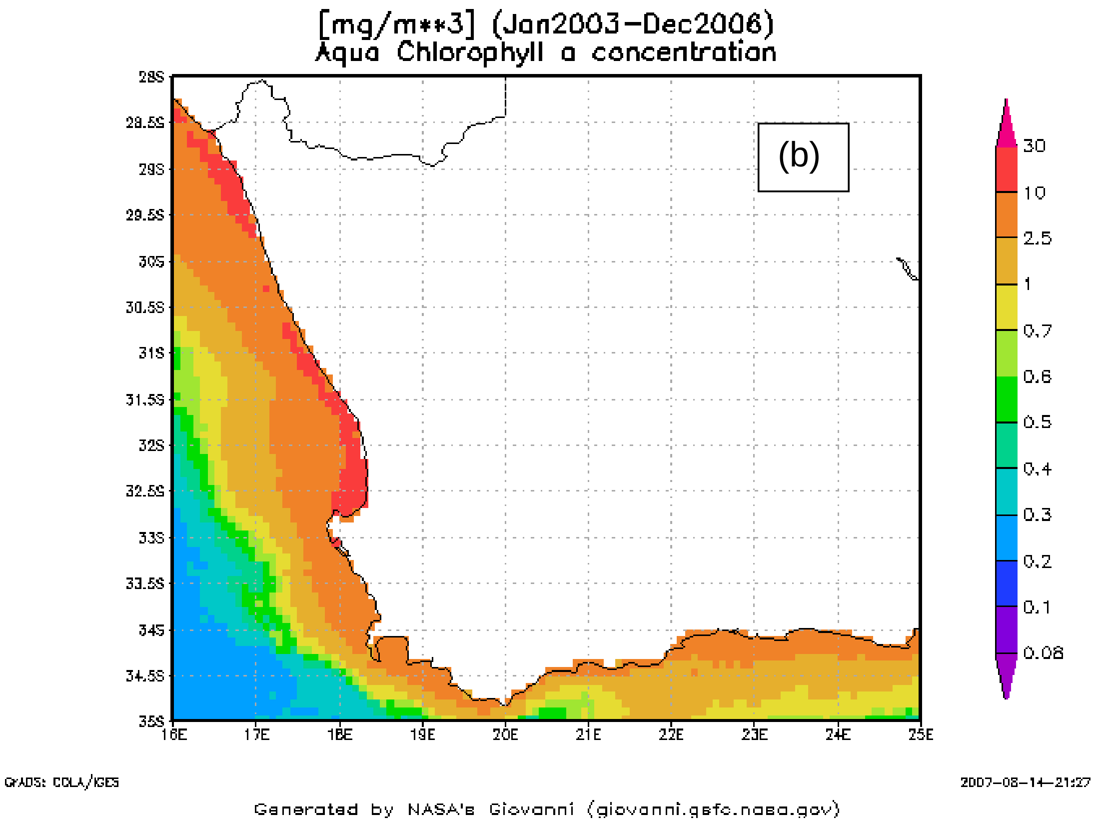
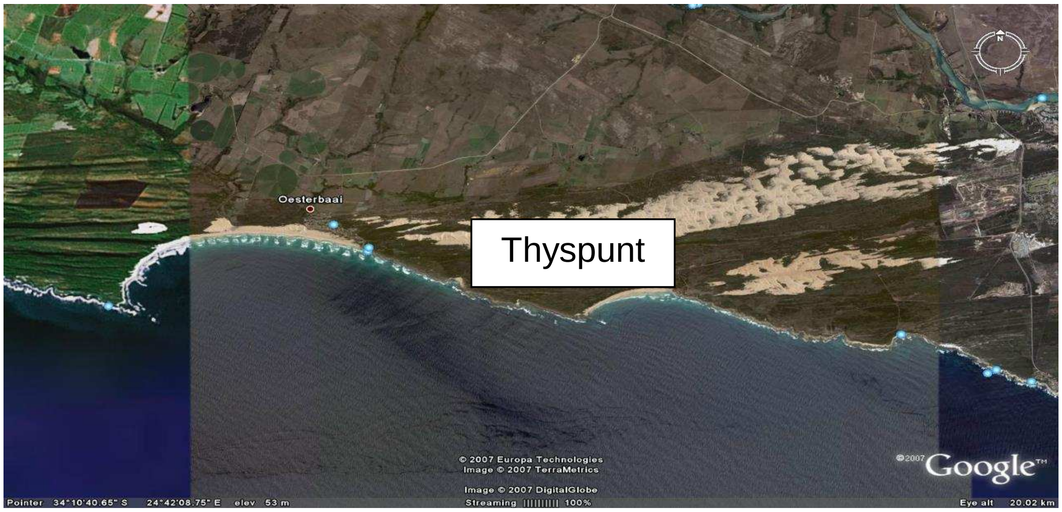


Figure 4.0b Spatial variation of the annual average chlorophyll *a* concentration (mg m^{-3}) around South Africa, from 36 months of monthly data (2003-2006). Axes are latitude and longitude. The colour bar is chl *a* concentration in mg m^{-3} from low (purple 0.08 mg m^{-3}), to very high (red - 30 mg m^{-3}).

4.1 Thyspunt:

The Thyspunt site is located on an exposed section of coastline directly open to waves arriving from a SW direction, with approximate co-ordinates 34° S10'; 24° E25' (KPR, 1991). There are significant headlands at Cape Seal (to the west) and Cape St. Francis (to the east). This is a highly stable section of coastline with respect to marine sediment dynamics, with areas of exposed rocky coastline and a few small beaches protected by rocky headlands. According to PRDW (2001a), there are no areas of international or national priority in terms of marine protected coastal estuary areas near this site.



Further details of the site are presented by PRDW (2001a). The offshore bathymetry that controls incoming wave refraction from the deep sea appears to be reasonably well mapped (PRDW, 2001a) to a level of 10m below mean sea level (MSL), and can be used to construct wave refraction diagrams. Wave refraction by the bottom topography can focus or diffuse the wave energy at a particular site. These effects have to be modelled carefully for the particular sites, and are not generally known.

New measurements of SST, Chl *a* and the diffuse attenuation coefficient (which is measure of how far the sun's radiance penetrates the ocean at a wavelength of 490 nano metres (nm)), have been analysed and are presented using the online NASA GIOVANNI software. The data are from the MODIS spectrometer aboard the AQUA satellite, which orbits the earth once every 100 minutes. The area examined for Thyspunt is from 34.0-34.5°S; 24.0-24.5°E, and the monthly average data are for the 2003-2006 period. The data have a spatial resolution of 9 x 9 km pixels.

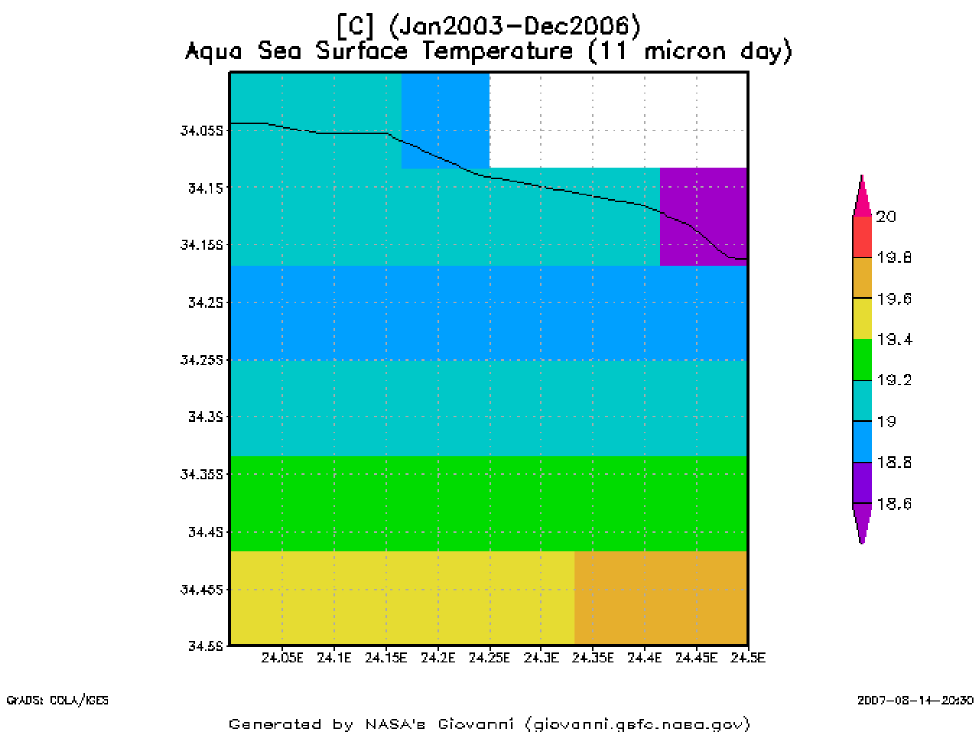


Figure 4.1a Four year average (34.0-34.5°S; 24.0-24 .5°E) of satellite derived sea surface temperature (SST) for Thyspunt

The average SST for Thyspunt for the four-year period 2003-2006 is between 19.0-19.2°C (Fig. 4.1a). The cool pixel (18.6-18.8°C) is consid ered to be spurious as it partly over the land and partly over the sea, and does not accurately represent the SST.

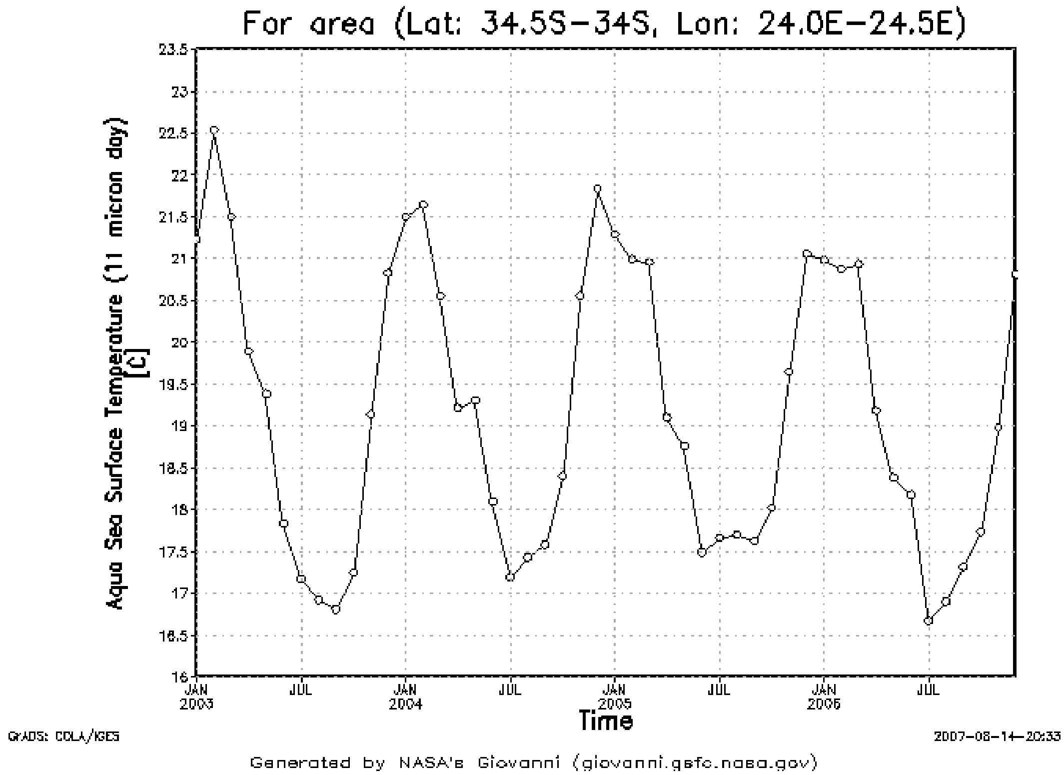


Figure 4.1b Monthly time series of SST over the four years (2003-2006) averaged over 34.0-34.5°S; 24.0-24.5°E

Maximum SST is 22.5°C and minimum SST is 16.6°C ove r the period 2003-2006 (Fig. 4.1b). It should be noted that the maximum occurs in January of the first two years (2003 and 2004), and then in December of the latter two years (2004 and 2005). The annual cycle of SST has a varying amplitude over the four years.

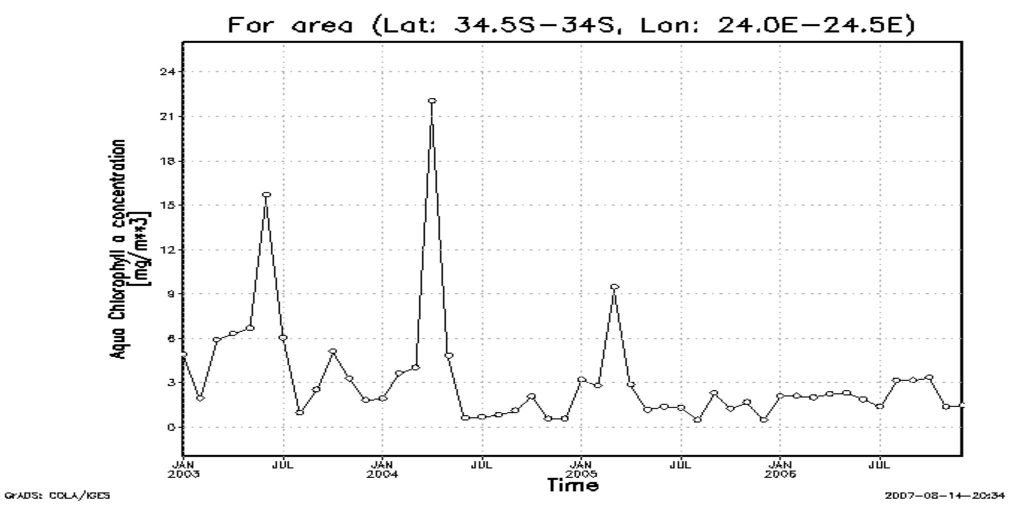


Figure 4.1c Monthly time series of chl *a* for the four years (2003 – 2006) averaged over 34.0-34.5°S; 24.0-24.5°E.

It can be seen from Fig. 4.1c, that the chl *a* has a very irregular cycle, with a maximum in June 2003 of 16 mg m^{-3}, 22 mg m^{-3} in April 2004 and 9 mg m^{-3} in March 2005 In 2006, the value does not exceed 3 mg m^{-3}. The maximum concentration of chl *a* is about 22 mg m^{-3} and the minimum is close to zero. The chl *a* can be used as a proxy for ocean productivity, which in turn will help determine the amount of biological growth at a particular site.

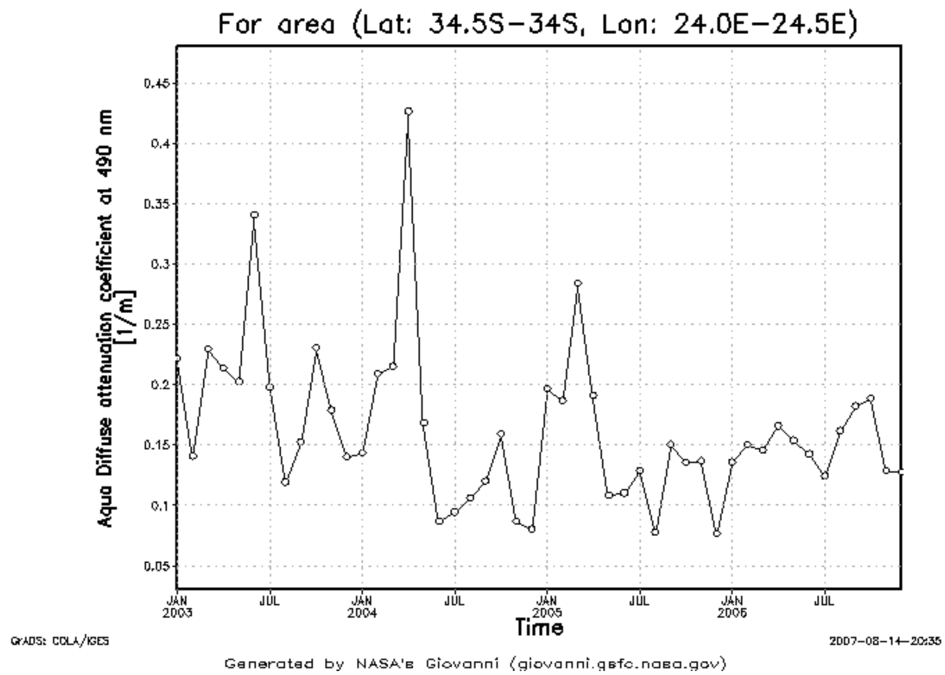


Figure 4.1d Monthly time series of diffuse attenuation coefficient at 490 nm for the four years (2003 – 2006).

The maximum diffuse attenuation coefficient value from Fig. 4.1d, is ~0.4 m^{-1}, and minimum value is about ~0.07 m^{-1}. This gives an idea of the clarity of the water, with light dropping to 1% of its surface value at a depth of 2.5 m, and 14.3 m respectively (theinverse of the diffuse attenuation coefficient). The variation of this water clarity is due to high and low concentrations of phytoplankton. and is seen to co-vary with the concentrations of chl *a* in Fig. 4.1c.

Other detailed oceanographic measurements available for this site are set out in Table 1 in KPR (1991), and are reproduced in Appendix 1.

4.2 Bantamsklip:

This site is located between Danger Point to the northwest and Quoin point to the southeast, at an approximate location of 34^{o} S45'; 19^{o}E30' (KPR, 1991). It is a highly exposed section of rocky coastline and "highly stable with respect to marine sediment dynamics" (PRDW, 2001b). Further details of the site are presented in PRDW (2001b), where it is stated that "…the average wave energy along the study coastline can be expected to be the highest anywhere along the SA coastline due to its southerly latitude and orientation perpendicular to the dominant south westerly swell waves." PRDW (2001b) continue to say that "… a period of three years of data collection should be allowed for prior to the commencement of engineering activities." This should allow for the assessment of extreme values.

Sea surface temperatures (SST), Chlorophyll *a* and diffuse attenuation coefficient (water clarity) at 490 nm have been analysed using the online NASA GIOVANNI software from the MODIS instrument aboard the AQUA satellite, for the BANTAMSKLIP marine area 34.5-35.0°S; 19.1-19.6°E.

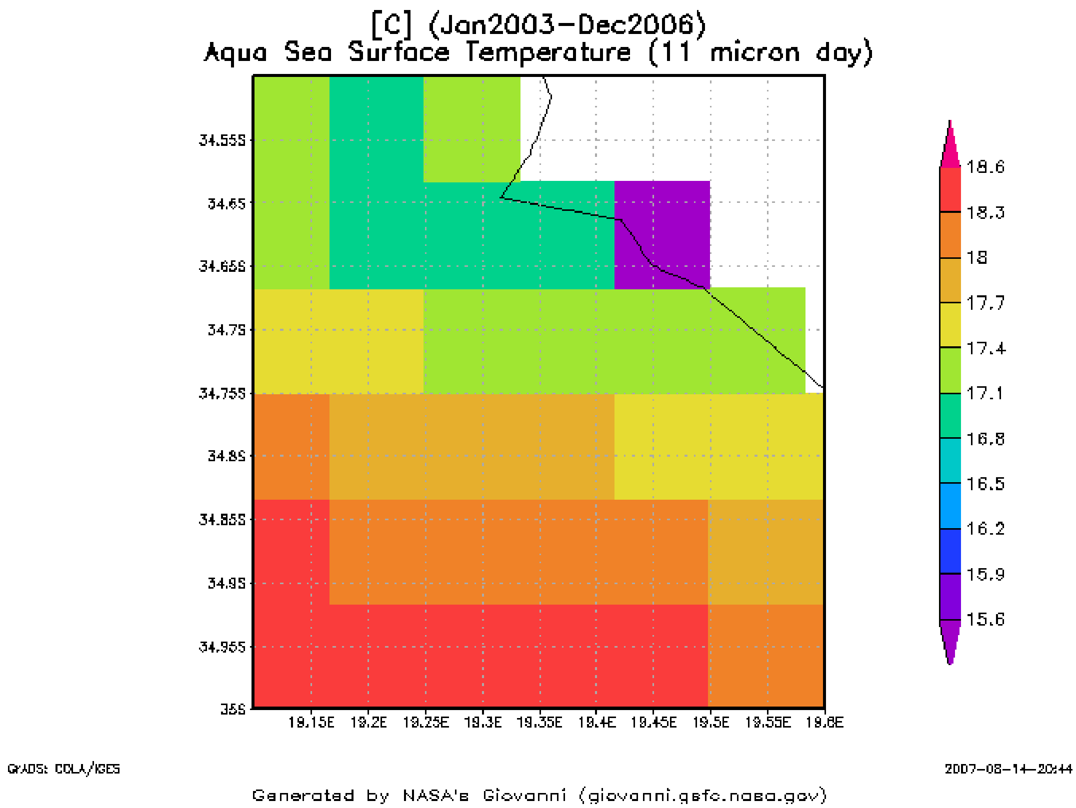


Figure 4.2a Monthly averaged SST for 2003-2006 for 9 x 9 km pixels in the area 34.5-35.0°S 19.1-19.6°E.

The mean SST for Bantamsklip (Fig. 4.2a) is 16.8-17.1℃. The very cold pixel in Figure 4.2a is considered to be spurious as it includes values from the land.

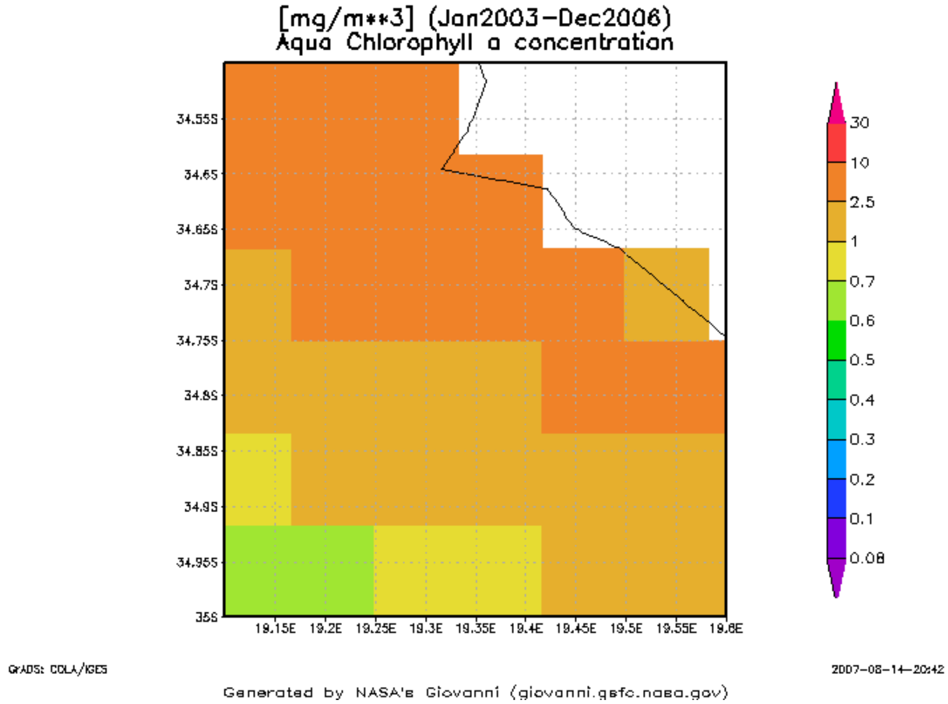


Figure 4.2b Monthly averaged chlorophyll *a* data averaged spatially and time as in Figure 4.2a.

The mean chlorophyll *a* values for Bantamsklip (Fig. 4.2b) are between 2.5-10 mg m^{-3}. Such values of chlorophyll concentration are typical of a moderately productive coastal ocean. It can be seen that the concentrations decrease out to sea away from the coast.

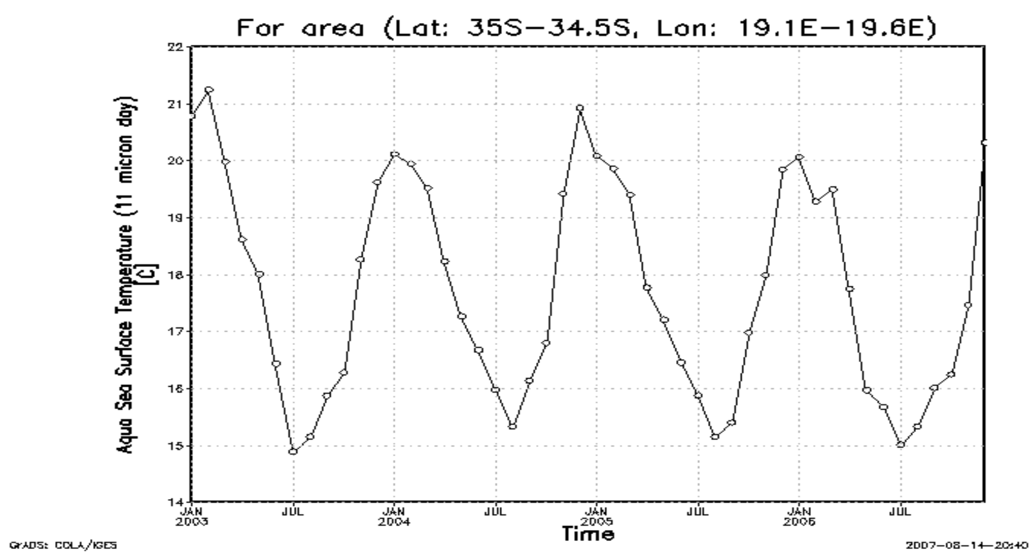


Figure 4.2c Monthly time series of SST over the four years (2003-2006) averaged spatially as in Figure 4.2a.

Fig. 4.2c shows the maximum and minimum SST is ~21.3℃ and 15.0℃ respectively. The amplitude of the seasonal cycle is about 5-6℃, and varies between years.

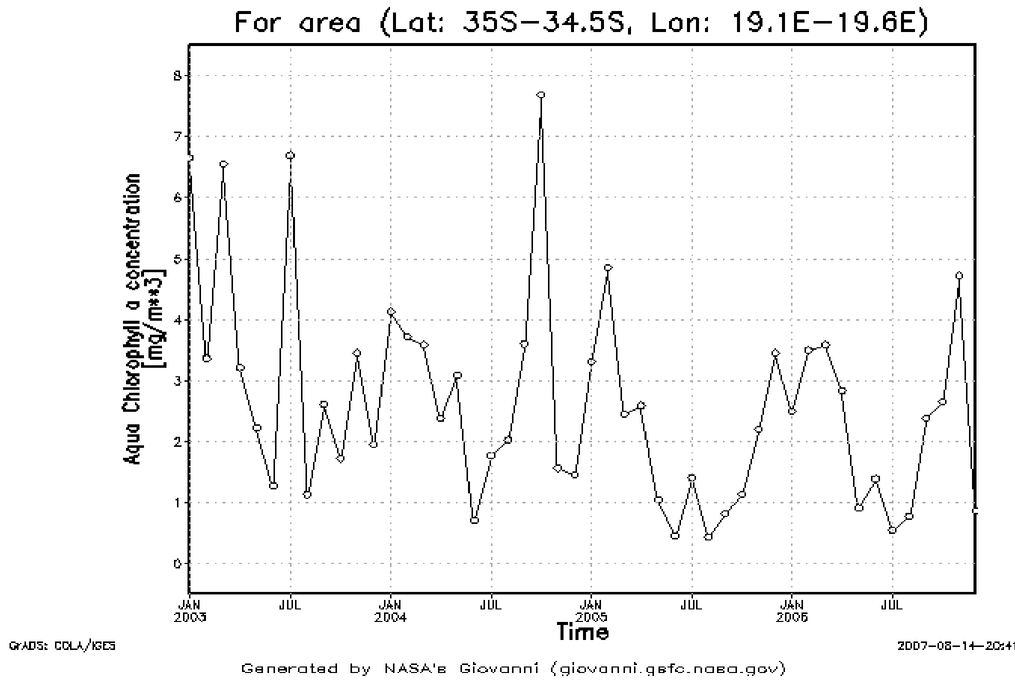


Figure 4.2d Monthly time series of chlorophyll *a* for the four years (2003 – 2006) averaged spatially as in Figure 4.2a.

Maximum and minimum chlorophyll *a* concentration is 8 mg m^{-3} and 0.5 mg m^{-3} (Fig. 4.2d), with a highly irregular annual variation.

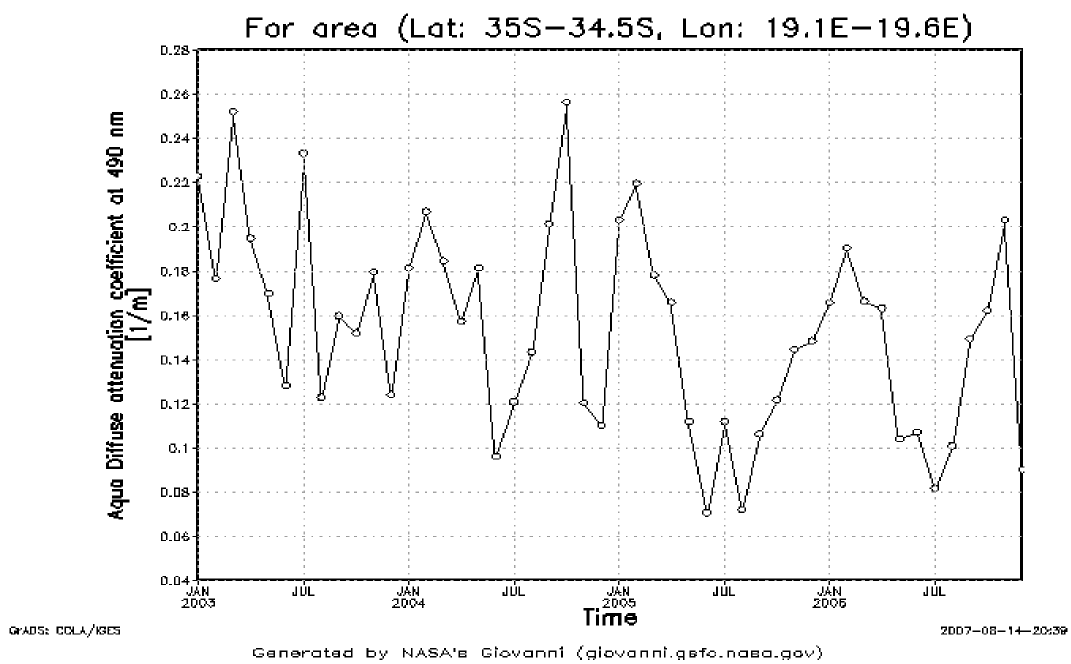


Figure 4.2e Monthly time series of diffuse attenuation coefficient (at 490 nm) for the four years (2003–2006) averaged spatially as in Figure 4.2a.

Fig. 4.2e shows the variation of the diffuse attenuation coefficient. The reciprocal of this gives the depth of the 1% light level. This is very similar to Thyspunt. Further detailed oceanographic measurements are available for this site in Appendix 1.

4.3 Duinefontein (existing Koeberg nuclear power station)

The Koeberg site is located north of Cape Town at an approximate location of 33^{o}S 40’; 18^{o}E 26’ (KPR, 1991 and Google Earth). This is a highly exposed section of sandy coastline and has a reasonably stable sediment transport regime. A large volume of marine data has been collected regularly during the running of the Koeberg nuclear power station over the past 25 years, some of which is discussed in (PRDW 2005). This report should be extensively consulted for details of site safety and details of extreme values of wave heights and temperature measurements.

Sea surface temperatures (SST), Chlorophyll *a* and diffuse attenuation coefficient (water clarity) at 490 nm have also been analysed using the online NASA GIOVANNI software from the MODIS instrument aboard the AQUA satellite, for the Koeberg area between 33.5-34.0°S; 17.8-18.3°E.

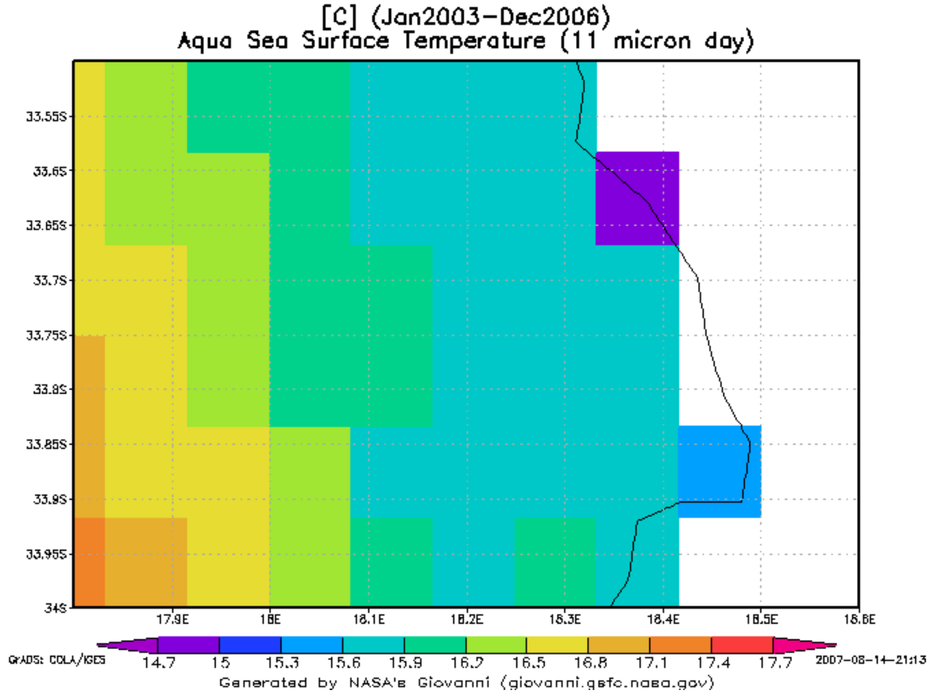


Figure 4.3a Four year average of satellite derived sea surface temperature (SST) for Koeberg area 33.5-34.0°S; 17.8-18.3°E.

The mean SST for the Koeberg area for the four year period 2003-2006 is between 15.6-15.9°C (Fig. 4.3a). The two very cold pixels are co nsidered to be spurious, as they are both over a substantial part of the land as well as the sea, and do not accurately reflect SST.

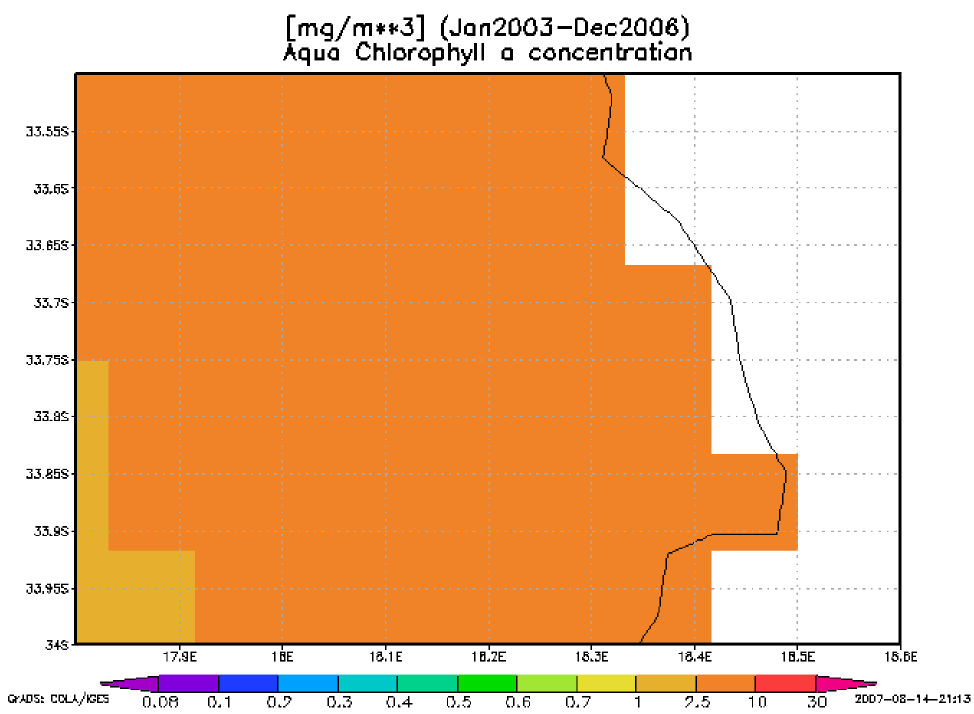


Figure 4.2b Monthly averaged chlorophyll *a* data for the period 2003-2006 averaged spatially and temporally as in Figure 4.2a.

The mean chlorophyll *a* values for Koeberg are between 2.5-10 mg m^{-3} (Fig. 4.2b)

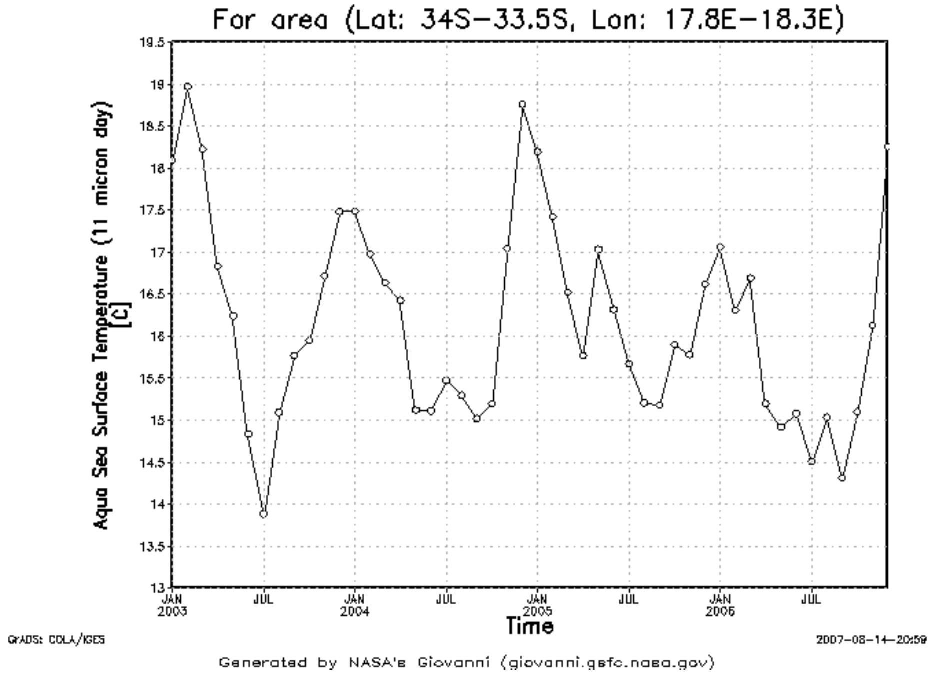


Figure 4.3c Monthly time series of SST over the four years (2003-2006) averaged spatially as in Figure 4.3a.

The monthly maximum and minimum SST for Koeberg is 19.0℃ and 14.0℃ respectively (Fig. 4.3c). Note the very "cool" January 2006, and hence the strong interannual variability. The highest SST of 19.0℃ has a very low probability of exceedance (< 1 %) according to the exceedence curves (Figure 3.3) in PRDW (2005). The significance of this is that high seawater intake temperatures raise the operating costs of the power station.

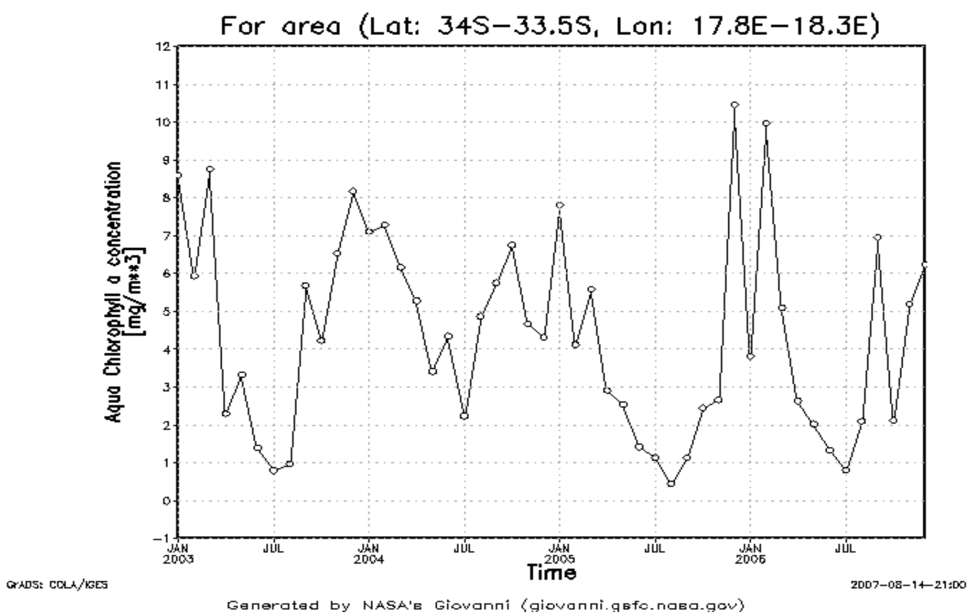


Figure 4.2d Monthly time series of chlorophyll for the four years (2003 – 2006) averaged spatially as in Figure 4.2a.

The time series of chl *a* for Koeberg (Fig. 4.2d) is highly irregular, with a maximum and minimum chlorophyll *a* concentration of 10.5 mg m^{-3} and 0.5 mg m^{-3}. The maxima and minima are reached in summer (due to upwelling of nutrient rich water) and winter respectively.

4.4 Brazil

According to KPR (1991), the Brazil and Skulpfontein sites are within ~100 km of each other, with Brazil lying to the northwest of Skulpfontein. Therefore, all data referring to Skulpfontein below, are assumed to apply to Brazil. This assumption will have to be verified in future studies.

4.5 Skulpfontein

This site is located on the west coast at an approximate location of 29°S 15'; 17°E 00' (KPR, 1991). Little is known to the author about the marine sediment dynamics at this site, so furter detailed studies at the this site and at Brazil are needed to gain quantitative information.

SST, Chl *a* and diffuse attenuation coefficient (water clarity) at 490 nm have been analysed using the online NASA GIOVANNI software from the MODIS instrument aboard the AQUA satellite, for the area 29.0-30.0°S; 16.5-17.0°E.

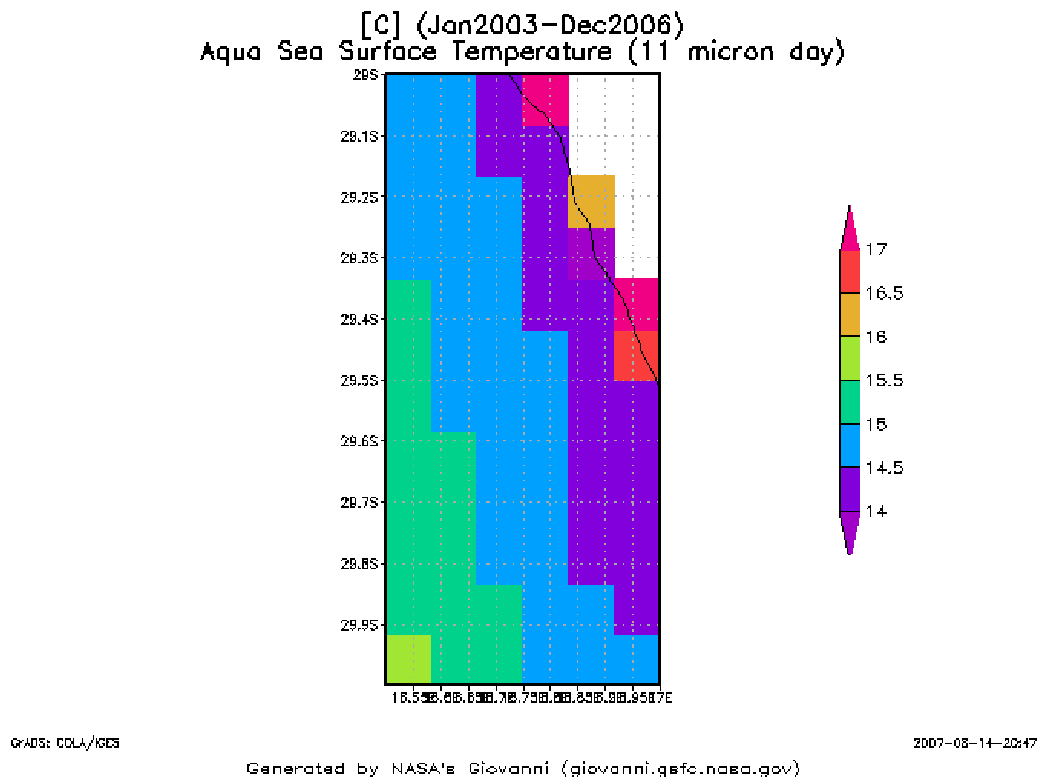


Figure 4.4a Monthly averaged SST for 2003-2006 for 9 x 9 km pixels for the area 29.0-30.0°S; 16.5-17.0°E.

The mean SST is the coldest of the five sites, with a value between 14.0-14.5 °C (Fig. 4.4a). Caution is drawn in interpreting the extremely warm pixels that have a land area in them. These pixels will give spuriously high SST (> 16°C) because the data includes warming from the land.

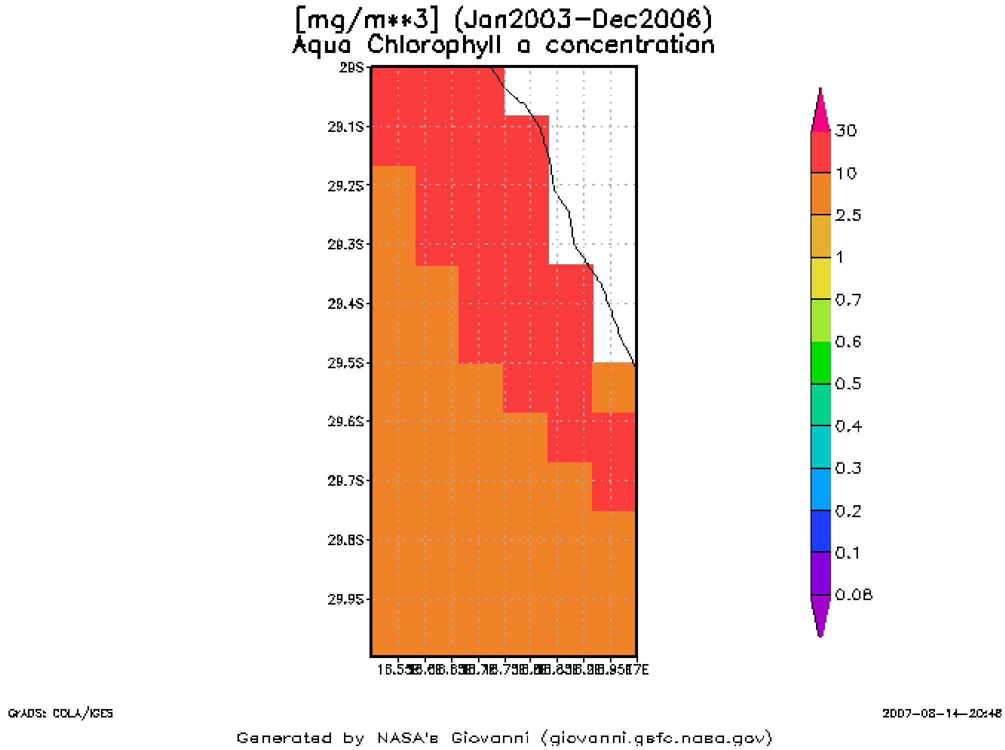


Figure 4.4b Monthly averaged chlorophyll *a* data for the same area and time as in Figure 4.4a.

The mean chl *a* values are high, and above 10 mg m^{-3}(Fig. 4.4b)

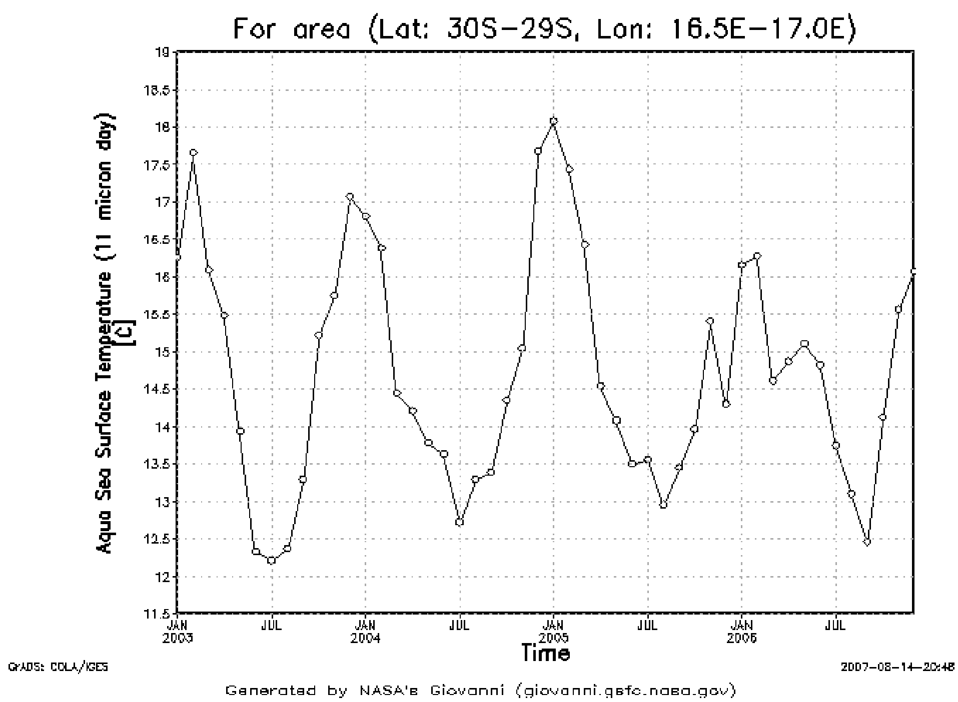


Figure 4.4c Monthly time series of SST over the four years (2003-2006) averaged spatially as in Figure 4.4a.

Maximum and minimum SST is 16.0℃ and 12.3℃ respec tively, with a highly irregular annual cycle (Fig.4.4c).

5 IMPACTS AND MITIGATION MEASURES

The most important impact the ocean has on the coastline is the continued attack by the storm waves; the slow rise of sea level, and the slow transport of sediment either on and offshore, or along parallel to the shore. These main oceanographic processes will continue to affect the sites with their own natural scales of variability. As regards the coastal ocean temperatures, chl *a,* sea level variability, and coastal currents, the new Nuclear facility will have to be designed to cope with the natural variability and its extreme values, which all occur at a large range of space and time scales. This is a task for the design engineers, after suitable measurement, analysis and numerical modelling programmes have been instituted for a particular chosen site.

6 SITE SENSITIVITY ANALYSIS

6.1 Criteria for Site Sensitivity Analysis

Because there is a dearth of measurements fo waves, currents and knowledge of extreme values for all the sites, this report has focussed on SST and chl *a* variability as measured from satellite borne instruments. It is anticipated that the power station intake temperature is an important variable in the design. It is unknown what the maximum seawater temperature value is, beyond which the cooling effect of the seawater intake becomes inefficient. At Koeberg, this is assumed to be near 19°C. Taking this as an upper bound value, it can be seen that at the two south coast sites of Thyspunt and Bantamsklip, this is the same as the annual average SST (19.0-19.2). The maximum value for 2003-2006 is 22.5°C for Thyspunt, and 21. 3°C for Bantamsklip, well above the assumed threshold of 19°C.

By contrast, along the west coast, the annual average SST varies from 15.7°C for Koeberg to 14.2°C for the Skulpfontein-Brazil sites. Clearly if the intake seawater temperature is an important factor for the design of the power station, the Skulpfontein-Brazil sites are the best with the coldest water available.

Conversely, if seawater productivity is an important parameter (more productive water will have higher biological growth of mussels and anemones and other bio-fouling processes), the west coast sites are more vulnerable that the south coast sites. This needs to be taken up further from the biological reports (Griffiths et al.)

It is only possible to give a very broad brush overview of the wave climate. This will be most vigorous along the south coast, including the Koeberg site, where there is the highest wave energy along the South African coast. This wave energy decreases with distance north-wards along the west coast.

Sediment transport will have to be investigated site by site. Clearly the sites with a rocky coastline will be less vulnerable that the sandy beach sites (e.g. Koeberg, where, because of the continual sediment transport by wave and currents, the harbour intake basin has to be dredged on a regular basis). According to KPR (1991), both of the two south coast sites (Thyspunt and Bantamsklip) and the two west coast sites (Skulpfontein and Brazil) are rocky and exposed sites (see also Appendix 1 from KPR, 1991). Only the Koeberg site is on a sandy beach.

6.2 Site Sensitivity

From the criteria discussed above, it is clear that the west coast could be better in terms of power station cooling water, because they would have colder seawater intake. This is offset by the fact that these sites are situated in the productive Benguela Upwelling region. The means that the west coast sites are in a region of high biological productivity. All the rocky sites will have greater ecosystem biodiversity than the sandy beach sites (Koeberg).

6.3 Discussion and Recommendations

The main sensitivity that is likely to arise in connection with the marine aspect of the sites, pertains to the effect the building and operation of the nuclear power station will have on the local marine biology of the site. At this stage, it is not possible to predict where a warm thermal plume will disperse, without a detailed map of the undersea topography, measurements of the coastal currents and local wind. The effects of the waves and currents will be very different for a site that is on a beach area (such as at Koeberg), compared with one that is situated on a rocky shore. Such effects on the coastal currents and incoming wave forces on the site may be influenced by nearby coastal headlands, and undersea topography close to the coast.

Extensive use should be made of the four reports referred to (PRDW 2001a; 2001b; 2005; and KPR 1991). Table 1 in KPR (1991), reproduced in he Appendix 1, is especially relevant, as it contains extensive detail of coastal ocean parameters such as the nature of the coastline, the magnitude of breaking waves, breaker zone width, incident wave energy at wave breaking, alongshore sediment transport, at all of sites that have been investigated.

7 CONCLUSION

This study has identified some of the important physical processes (see in particular Appendix 1) that occur at the five sites that have been identified as candidates for the choice of a new site to build a nuclear power station. The report has concentrated on presenting and interpreting the effects of new measurements (SST and chl a concentration) that have been measured from space over the past 4 years.

While there has been a general discussion of the important physical parameters, attention is drawn to the excellent table of measurements and calculations from KPR (1991), reproduced as Appendix 1.

It is recommended that in the run up phase to the development of a new nuclear power station, the opportunity is taken to update the measurements and knowledge of the physical coastal processes described in this report.

8 GLOSSARY OF TERMS USED

Sea surface temperatures – satellite radiometers measure the sea surface temperature (SST) of a very thin micro layer of the ocean surface.

Chlorophyll *a* – chlorophyll *a* is the amount of pigment in milligrams per cubic metre (mg m^{-3}) measured from the visible spectrum of a spetrometer onboard a satellite.

Diffuse attentuation coefficient – this measures the amount of radient energy emmited from the ocean at a wavelength of 490 nano metres. The units are one over length. It is interpreted as the depth at which the incoming sunlight is attenuated to 1% of the surface value, and so gives a measure of the clarity of the water. Clear water will have low concentrations of phytoplankton present and opague water will have high phytoplankton present.

9 REFERENCES

GIOVANNI online NASA satellite visualisation at http://reason.gsfc.nasa.gov/Giovanni/

(KPR, 1991) Kapp, Prestedge and Retief 1991. ESKOM Nuclear power station site investigations, site selection – interpretation. ESKOM contract No. 25580710

IPCC AR4, Chapter 5, 2007. obtained from http://ipcc-wg1.ucar.edu/wg1/wg1-report.html

MERRIFELD, M. A.,. FIRING, Y. L, BRUNDRIT, G., FARRE, R., KILONSKY, B., KNIGHT, W., KONG, L., MAGORI, C., MANURUNG, P., MCCREERY, C., MITCHELL, W., SHILLINGTON, F., WIJERATNE, E. M.S., CALDWELL, P., JARDIN, J., NAKAHARA, S., PORTER, F.-Y., TURETSKY, N. 2005.
Tide Gauge Observations of the Indian Ocean Tsunami, December 26, 2004. *Geophys. Res. Lett., Vol 32, No 9, L0960310.1029/2005GL022610*

(PRDW, 2001a) Prestedge, Retief, Desner and Wijnberg 2001a. ESKOM Nuclear power station site investigation program, NSIP, coastal engineering Thyspunt site. Report 345/02.

(PRDW, 2001b) Prestedge, Retief, Desner and Wijnberg 2001b. ESKOM Nuclear power station site investigation program, NSIP, coastal engineering Thyspunt site. Report 345/01.

(PRDW, 2005) Prestedge, Retief, Desner and Wijnberg 2005. Koeberg nuclear power station site safety report. Report no. 201/53/001 Rev 00.

10 APPENDIX 1

Table 1 from KPR (1991) giving a summary of coastal information.

NSIP COASTAL ENGINEERING STUDIES

TABLE 1 : SUMMARY OF COASTAL INFORMATION

ITEM	PARAMETERS	SOUTHERN CAPE				NORTH WESTERN CAPE		EASTERN CAPE					KOEBERG
		BK1	BK2	BJ1	BJ2	BZ1	SF1	TB2	TB1	TP1	TP2	TP3	
1.0	COASTLINE												
	(Rocky/Sandy) (Exposed/Sheltered) (Open Coast/Bay)	Rocky Exposed Open Coast	Rocky Exposed Open Coast	Rocky Exposed Open Coast	Rocky Exposed Open Coast	Rocky Exposed Open Coast/ Shallow Bay	Rocky Exposed Open Coast	Rocky Exposed Open Coast	Rocky Exposed Open Coast	Rocky Exposed Open Coast	Rocky Exposed Open Coast	Sandy Sheltered Bay	Sandy Exposed Open Coast
2.0	SIGNIFICANT WAVE HEIGHT AT BREAKING (m)												
	(Hbs) 20%	3.3	4.2	3.9	4.1	3.5	3.5	3.6	3.6	3.7	3.0	2.9	3.0
	(Hbs) 1 yr	6.9	9.1	8.4	9.8	7.9	7.9	7.5	8.1	8.0	6.8	6.8	7.0
	(Hbs) 5 yr	8.0	10.4	9.6	11.4	9.1	9.1	8.5	9.3	9.6	7.9	7.9	8.8
	(Hbs) 100 yr	9.8	13.0	12.0	14.3	*	*	13.9	13.9	13.4	9.8	9.8	12.5
3.0	BREAKER ZONE WIDTH (m)												
	(Wbs)20%	260	320	420	500	**	**	220	140	150	160	220	260
	(Wbs)1 yr	800	800	750	950	**	**	440	220	380	220	450	800
	(Wbs)5 yr	880	1000	800	1050	**	**	500	230	410	270	560	1180
4.0	INCIDENT WAVE ENERGY AT BREAKING												
	Magnitude (GJ/yr/m crest)	997.8	1695.4	1449.1	1550.3	903.8	1007.6	1088.2	1066.9	1147.1	708.7	671.8	1015.2
	Resultant Direction (deg. true)	230	226	245	221	246	242	201	201	205	198	168	248
	Ratio of Nearshore to Deep Ocean Energy	0.64	1.09	0.93	0.99	0.97	1.08	0.83	0.83	0.87	0.54	0.51	0.77
	Beach Normal (deg. true)	235	212	259	226	252	255	202	204	204	198	168	248
	Angle of Incidence (deg. true)	-5	14	-14	-5	-6	-13	-1	-3	1	0	0	0
	Direction relative to normal							E	E	W	-	-	-
5.0	ALONGSHORE SEDIMENT TRANSPORT - TIME SERIES RESULTS												
	Average Net Potential Transport Rate												
	Magnitude (million cu.m/yr)	-0.7	+3.1	-2.6	-1.1	-0.7	-1.7	-2.0	-4.9	1.2	-0.4	-0.1	0.5
	Direction (deg. true)	E-W	W-E	E-W	E-W	S-N	S-N	E-W	E-W	W-E	E-W	E-W	S-N
6.0	SEDIMENT TRANSPORT ZONE WIDTH (m)												
	(Wsed)80%	480	560	540	500	**	**	165	150	150	185	235	620
	(Wsed)90%	560	600	600	530	**	**	300	270	160	205	265	780
7.0	DISTANCE FROM SHORELINE TO -20 m MSL CONTOUR (m)	1900	1300	1200	1200	**	**	900	400	550	750	2200	2000

* Insufficient Bathymetric Data and Limitation Wave Directional Data.

** Insufficient Bathymetric Data.