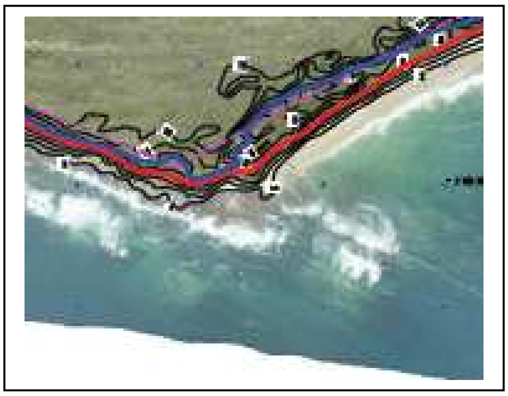
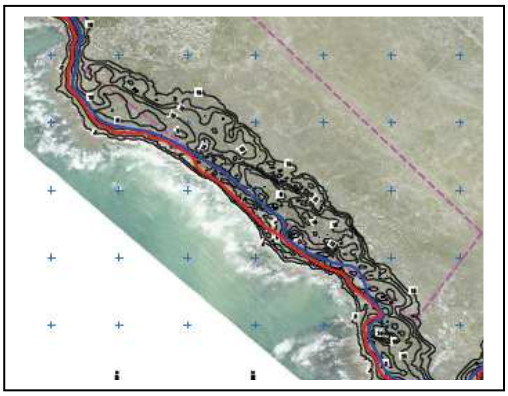
Eskom

Eskom Holdings Limited

ENVIRONMENTAL IMPACT ASSESSMENT FOR THE PROPOSED NUCLEAR POWER STATION ('NUCLEAR-1') AND ASSOCIATED INFRASTRUCTURE





ESTIMATING THE 1:100 YEAR FLOOD LINE FROM THE SEA

J27035

October: 2009

EXECUTIVE SUMMARY

A number of specialists working on the Nuclear-1 EIA have requested that the 1:100 year flood line due to flooding from the sea be estimated. This relates to the width of the coastal corridor and the siting of the nuclear terrace within the defined Nuclear Installation Corridor.

The 1:100 year flood line is a combination of surface elevations caused by a number of coastal processes. Specifically the elevations due to:

- Tides
- Sea level rise (where applicable)
- Storm surge
- Wave run-up

The dominant process is seen to be the maximum elevation calculated for the wave run-up. As the run-up is highly dependant on the slope of the coastal feature, the wave height and water depth, it is necessary to discretize the area under study into a number of regularly spaced beach normal profiles.

The total flood elevation is calculated by summation of the tide, storm surge and wave run-up for each of the profiles and then interpolated onto a digital elevation map of the site topography. The 1:100 year flood line is then the intersection of the calculated surface elevation and the surfaced topography.

For the evaluation of the 1:100 year flood line for 2075 the influence of climate change is calculated on both the hydrographic parameters and the local topography.

The shoreline also undergoes an adjustment based on the increase in sea level. Erosion occurs at progressively higher levels up the beach. The beach, in profile, is expected to translate vertically, an amount equal to the sea level rise and erode into the hinterland a distance proportional to the local beach slope.

In order to calculate a flood line for a future period, it is necessary to apply the above mentioned shoreline changes to the topography before the interpolation of the increased calculated surface elevation onto the modified surface.

The 1:100 year flood lines have been calculated for each site for the present day and 2075. These may be used by other specialists working on the coastal corridor and the siting of the nuclear terrace within the defined Nuclear Installation Corridor.

ENVIRONMENTAL IMPACT ASSESSMENT FOR THE PROPOSED NUCLEAR POWER STATION ('NUCLEAR-1') AND ASSOCIATED INFRASTRUCTURE

CONTENTS

TABLES

FIGURES

APPENDICES

ABBREVIATIONS

CEM	Coastal Engineering Manual
EIA	Environmental Impact Assessment
FEMA	Federal Emergency Management Agency (USA)
HAT	Highest Astronomical Tide
MSL	Mean Sea Level
PRDW	Prestedge Retief Dresner Wijnberg (Pty) Ltd
SSR	Site Safety Reports

GLOSSARY

Closure Depth — The water depth beyond which repetitive profiles or topographic surveys do not detect sea bed changes, generally considered the seaward limit of littoral transport.

HAT — The highest level of water which can be predicted to occur under any combinations of astronomical conditions.

Hydrographic — Of or relating to the science of hydrography, the scientific description and analysis of the physical conditions, boundaries, flow and related characteristics of the earth's surface waters.

Mean Sea Level — A vertical reference level defined by land surveyors, also known as Land Levelling Datum. It is approximately the average height of the surface of the sea for all stages of the tide over a 19-year period, usually determined from hourly height readings.

Return Period — Average period of time between occurrences of a given event.

Run-up — The vertical level reached by a wave on a beach or coastal structure, relative to still-water level.

Significant Wave Height — Approximately equal to the average of the highest one-third of the waves in a given sea state.

Still-water Level — The surface of the water if all wave and wind action were to cease. In deep water this level approximates the midpoint of the wave height.

Storm Surge — A rise above normal water level on the open coast due to the action of wind stress on the water surface. Storm surge also includes rise in level due to atmospheric pressure reduction.

1 INTRODUCTION

1.1 Background

A number of specialists working on the Nuclear-1 EIA have requested that the 1:100 year flood line due to flooding from the sea be estimated. This relates to the width of the coastal corridor and the siting of the nuclear terrace within the defined Nuclear Installation Corridor.

1.2 Study Approach

Prestedge Retief Dresner Wijnberg (Pty) Ltd (PRDW) has extended the work already completed for the Site Safety Report (SSR) study to estimate the 1:100 year flood line as required for the EIA study. The study takes account of the following processes:

- Tide
- Storm surge
- Wave run-up
- Climate change including sea level rise, increased winds and increased waves
- Long-term erosion due to climate change and measured erosion rates (where available)
- Storm erosion

Note that this study concerns only flooding from the sea and does not address flooding due to rainfall or rivers.

Due to the continuing effects of climate change on both the hydrographic parameters used in calculating the 1:100 year flood line and the effects of erosion on the topography of affected coastal areas, the position of the flood line will continually change in position with respect to a specified design life.

For the given Nuclear-1 design life of 60 years, and assuming a completion date for construction of 2015, two 1:100 year flood lines have been calculated for each site. Specifically, a flood line based on existing hydrographic and topographic conditions and a flood line based on estimated climate change modified hydrographic parameters and topographic changes to the year 2075.

The flood lines determined in this study have been provided in electronic format as GIS shape files for use in the other Nuclear-1 specialist studies.

The area considered for each of the sites is determined by the prescribed boundaries of the Nuclear Installation Corridors and the extent of the available topographic information. The Nuclear Installation Corridors used in this study are obtained from the drawings provided by Eskom - refer to Eskom (2008a, 2008b and 2008c). The study area extends approximately 1 to 2 km beyond the Nuclear Installation Corridors (see **Figures 1 to 3**).

1.3 Conventions and Terminology

The 1:100 year flood line is the line that the largest waves will run up to during a storm event that will occur on average once in a hundred years, or alternatively a storm that has a 1% chance of being exceeded in any given year.

The following map projection system has been used for the Thyspunt site:

Map projection:	Gauss Conformal
Datum:	Hartebeesthoek 94
Spheroid:	WGS84
Scale factor:	1
Central meridian:	25 ºE
Reference system:	WG25
Co-ordinates:	Eastings (X, increasing eastwards) Northings (Y, increasing northwards)

The following map projection system has been used for the Bantamsklip and Duynefontein sites:

Map projection:	Gauss Conformal
Datum:	Hartebeesthoek 94
Spheroid:	WGS84
Scale factor:	1
Central meridian:	19 ºE
Reference system:	WG19
Co-ordinates:	Eastings (X, increasing eastwards) Northings (Y, increasing northwards)

The vertical datum used is Mean Sea Level (MSL) otherwise known as Land Levelling Datum (LLD).

2 METHODOLOGY

An overview of the methodology used to determine the 1:100 year flood lines is provided below. The 1:100 year flood line is a combination of surface elevations caused by a number of coastal processes. Specifically the elevations due to:

- Tides
- Sea level rise (where applicable)
- Storm surge
- Wave run-up

The tides and storm surge are localised to a specific area. However, this area of constant elevation occurs over a large geographical domain and can therefore be considered as constant for each site (CEM, 2006).

The dominant process is seen to be the maximum elevation calculated for the wave run-up. As the run-up is highly dependant on the slope of the coastal feature, the wave height and water depth, it is necessary to discretize the area under study into a number of regularly spaced beach normal profiles.

The total flood elevation is calculated by summation of the tide, storm surge and wave run-up for each of the profiles and then interpolated onto a digital elevation map of the site topography. The 1:100 year flood line is then the intersection of the calculated surface elevation and the surfaced topography.

For the evaluation of the 1:100 year flood line for 2075 the influence of climate change is calculated on both the hydrographic parameters and the local topography.

There is an addition to the above mentioned elevations by an amount equal to the expected sea level rise for the year 2075. Further, there is an expected increase in both the storm surge and the extreme waves, thereby influencing the wave conditions used in the calculation for run-up.

The shoreline also undergoes an adjustment based on the increase in sea level. Erosion occurs at progressively higher levels up the beach. The beach, in profile, is expected to translate vertically, an amount equal to the sea level rise and erode into the hinterland a distance proportional to the local beach slope.

In order to calculate a flood line for a future period, it is necessary to apply the above mentioned shoreline changes to the topography before the interpolation of the increased calculated surface elevation onto the modified surface.

The details of the hydrographic parameters and shoreline changes are described below.

3 HYDROGRAPHIC AND BATHYMETRIC PARAMATERS

The hydrographic conditions described in this chapter include all parameters which are required for the calculation of the surface elevation used to calculate the 1:100 year flood line. For each of the hydrographic conditions used, a brief description of the specific parameter and the values used is given. The calculation of the specific conditions has been completed within the scope of the Site Safety Reports for each of the sites and these documents are referenced for further information.

Further, the modifications to the hydrographic conditions due to climate change are tabulated and referenced.

Long term erosion due to increased sea level has been calculated for the 2075 1:100 year flood and details of the coastal adjustments given.

3.1 Bathymetry and Topography

For all of the sites the model bathymetry and topography has been obtained from the following sources:

- MIKE C-MAP electronic hydrographic charts
- Multi-beam bathymetric surveys by the Council for GeoScience
- Multi-beam bathymetric surveys of the inshore zone by Tritan Survey cc
- Beach profiles by Tritan Survey cc
- LIDAR survey by Southern Mapping Company for land

3.2 Hydrographic Conditions

3.2.1 Tides

Tides are driven by deterministic processes and are therefore predictable for any point along the coastline. In the determination of the 1:100 year flood, the Highest Astronomical Tide (HAT) for each of the sites has been used.

HAT is the highest level which can be predicted to occur under average meteorological conditions and under any combination of astronomical conditions (South African Tide Tables, 2009). HAT is not the extreme upper level which can be reached, as storm surges and other meteorological or geological (e.g. tsunami) conditions may cause considerably higher levels to occur.

Table 1: Tidal levels for the three sites

Site	Location of nearest tide gauge	HAT [m MSL]
Thyspunt	Port Elizabeth	1.28
Bantamsklip	Hermanus	1.28
Duynefontein	Cape Town	1.20

HAT will only be reached once every 18.6 years, although levels within approximately 0.10 m of HAT will be reached annually.

3.2.2 Storm surge

Storm surge is, for the purpose of this report, defined as the influence of meteorological effects such as winds and barometric pressure that result in actual sea level being above or below the predicted astronomical tide level.

For the calculations of the 1:100 year flood lines, extreme values for positive storm surge residuals (the difference between the actual water level and the predicted tide) have been calculated from long-term hourly tide gauge measurements for each site.

The values **tabulated below** are based on the best statistical estimate of the extrapolation to extreme values from measured tidal residual data for a 100 year return period.

Table 2: Calculated 1:100 year storm surge levels

Site	Storm surge [m above still water level]	Reference
Thyspunt	0.90	PRDW (2008a)
Bantamsklip	0.94	PRDW (2009c)
Duynefontein	0.74	PRDW (2009a)

3.2.3 Extreme waves

Extreme waves are, for the purpose of this report, defined as sea and swell waves generated by wind and having periods between 4 and 25 seconds. The wave climate at each site was determined by refracting an offshore hindcast dataset to approximately the -31 m MSL depth contour opposite the site and then performing an extreme value analysis on the dataset. The modelling procedure and the results are described in PRDW (2008a, 2009a and 2009c).

For each of the sites, a number of regions along the study area have been defined based on the local bathymetry and coastline orientation.

The maximum and minimum values **tabulated below** are based on the best statistical estimate of the extrapolation to extreme values from the refracted data for a 100 year return period. These are calculated for all regions at each of the sites, whilst only the minimum and maximum heights are reported below.

Table 3: 1:100 year wave conditions at -31 m MSL

Site	Minimum significant wave height [m]	Maximum significant wave height [m]
Thyspunt	9.52	9.84
Bantamsklip	7.82	8.32
Duynefontein	8.10	8.18

3.2.4 Wave transformation across the surf-zone

A numerical model was used to transform each of the extreme wave conditions from the -31 m MSL position inshore to approximately the -6 m MSL position, where the resulting wave conditions are required as input to the wave run-up computations.

Refer to PRDW (2009b) for further details of the wave transformation modelling. The values obtained for each of the regions (refer to **Section 3.2.3**) are given in **Table 4**.

Table 4: Transformed 1:100 year wave conditions at -6 m MSL

Site	Minimum significant wave height [m]	Maximum significant wave height [m]
Thyspunt	4.0	7.8
Bantamsklip	5.1	6.8
Duynefontein	4.8	5.0

3.2.5 Wave run-up

Wave run-up is calculated using the method of Hughes (2004) on a number of beach and coast profiles along each site. The profiles are spaced approximately 100 m apart in order to obtain a high resolution of calculated values for run-up. Approximately 80 profiles have been used for each site.

The final value of vertical wave run-up is seen to be highly dependent on the slope of the profile. In order to maintain consistency of approach for all of the profiles, the slope was taken as the average value between points at -6 m MSL to +9 m MSL.

Table 5: Minimum and maximum calculated wave run-up

Site	Minimum run-up [m]	Maximum run-up [m]
Thyspunt	1.7	7.2
Bantamsklip	1.2	6.7
Duynefontein	2.0	3.9

Note that these run-up levels represent the 98th percentile value, i.e. during a storm event only 2% of the individual wave run-ups will exceed this level. For further details of the calculation of run-up refer to PRDW (2009b).

3.3 Long Term Climate Change

PRDW has formulated a position paper on the consequences of global climate change for coastal engineering design. This is given in full in **Appendix A**. The report describes the changes expected to the year 2050 and 2100 on the following parameters relevant to this report.

- Sea level rise
- Storm surge
- Waves

For the purpose of the calculation of the 1:100 year flood line for the year 2075 a linear approximation of the changes to the relevant parameter has been used.

The final values for changes to the hydrographic parameters described in **Section 3.2** are **tabulated below**. For sea level rise, the value adopted for this study is based on the “Upper end of projections” as given in **Table 2** in **Appendix A**. It is recommended that the “Extreme upper limit” given in the same table be considered in the Nuclear-1 design process, but this extreme limit is not considered appropriate for this flood line assessment.

Table 6: Adopted changes to hydrographic parameters due to climate change

Parameter	Expected changes to the year 2075
Sea level rise	+ 0.6 m
Storm surge	Increase of 15.5%
Waves	Increase of 12.8%

The above values have been used to modify the hydrographic parameters from **Table** 2 for the increase in storm surge and **Table 3** for the increase in extreme waves used in the calculation for run-up.

3.4 Coastline Stability and Erosion

The morphology of the coastline is a result of many individual sediment transport events caused by a succession of waves. In this sense, the shape of the beach and nearshore region may be thought of as representing a form of averaging over time (Reeve *et al.*, 2004). The stability of a length of coastline will depend on the difference between the volumes of sediment entering and leaving this section owing to the net cross-shore and longshore sediment transport due to waves, currents and wind. The coastline will be eroding, accreting or remaining in equilibrium. If equilibrium exists, it is most likely to be a dynamically stable equilibrium, whereby the coastline is evolving continuously in response to varying winds, waves and currents (Reeve *et al.*, 2004). Nevertheless, the typical coastline is relatively constant over a period of months or years, although the position of the coastline at any particular point will vary about this average.

3.4.1 Long term erosion from sea level rise

The effect of increased water levels due to climate change (refer to Section 3.3) needs to be accounted for in the assessment of long term erosion. These effects are shown to be highly complex and inclusive of local geomorphological and sedimentological characteristics (CEM, 2002). However, the majority of coastline response studies to sea level change are based on the simplified fundamental assumption that a beach will maintain an equilibrium profile dependent on the dominant wave climate. As such, provided that the rate of sea level rise is small, the beach profile will translate vertically and horizontally landward such that this equilibrium profile is maintained.

One of the best known shore response models to climate induced sea level change was proposed by Bruun in 1962 (CEM, 2002). This model, though noted as omitting factors other than wave action affecting sediment transport (CEM, 2002), has nonetheless been widely used in predicting long-term sea level change tendencies.

This model has been applied to each of the sites in order to obtain a long term modified topography based on the distance between the calculated depth of closure and the +9 m MSL contour. Refer to PRDW (2008b, 2009b, 2009d) for the calculation procedure and values used.

3.4.2 Long term measured erosion

Beach profile measurements indicate accretion within approximately 1 km of the north breakwater at Koeberg. Erosion is observed further to the north up to the extent of the Nuclear Installation Corridor (PRDW, 2009b). This suggests a re-orientation of the beach north of Koeberg in response to the sheltering caused by the breakwaters, and the rates of accretion and erosion would be expected to reduce over time as the beach approaches a new equilibrium.

However, as there is insufficient data available to ascertain the position of the new equilibrium profile, the maximum calculated erosion rate, 0.59 m/year for the area has been used to ascertain the recession of the topography along the coast for the Duynefontein Nuclear Installation Corridor to the year 2075 (refer to PRDW (2009b) for further details).

Although no equivalent information is available for the Thyspunt and Bantamsklip sites, an analysis of historical and current aerial photographs indicated that the beaches at Thyspunt and Bantamsklip are in dynamic equilibrium. Thus, no addition of long term erosion to the 2075 topographic contours for these sites was made.

3.4.3 Storm erosion

The effect of an individual storm on a sandy beach will be to erode the beach. The transport of sand is offshore, with the beach slope increasing. In severe storms, there exists the possibility of the erosion of the back of dune, with subsequent set back of the vegetation line. This erosion could cause a breach in the dune and allow for extended flooding into the hinterland behind the dune.

As the maximum erosion is constrained to the area below the maximum run-up level, and erosion on the back of dune is seen to be marginal during the 1:100 year storm for beaches at the sites (PRDW 2008b, 2009b, 2009d) a uniform storm erosion term has been used in the 1:100 year flood line calculations. Storm erosion has been included with the addition of a 0.5 m erosion allowance. This allowance has been included in the total surface elevations for all profiles along the coastlines of the respective sites.

4 RESULTS AND CONCLUSIONS

For each profile at each site, the tide, storm surge and run-up were combined for each of the approximately 80 profiles. The minimum and maximum calculated total water surface elevations for each of the 1:100 year lines calculated is given in **Table 7.**

Table 7: Minimum and maximum combined water surface elevations above MSL

	Present day: Excluding climate change		Year 2075: Including climate change	
Site	**Min [m MSL]**	**Max [m MSL]**	**Min [m MSL]**	**Max [m MSL]**
Thyspunt	4.4	9.9	5.7	11.2
Bantamsklip	4.0	9.4	4.8	10.8
Duynefontein	4.4	6.3	5.3	7.4

The final calculated results for the 1:100 year flood line for each of the individual sites is shown in **Figures 1 to 3**. Also shown in the figures are the Nuclear Installation Corridors for each site.

The 1:100 year flood lines have been calculated for each site for the present day and the year 2075. These may be used by other specialists working on the coastal corridor and the siting of the nuclear terrace within the defined Nuclear Installation Corridor.

The flood lines determined in this study have been provided in electronic format as GIS shape files for use in other Nuclear-1 specialist studies.

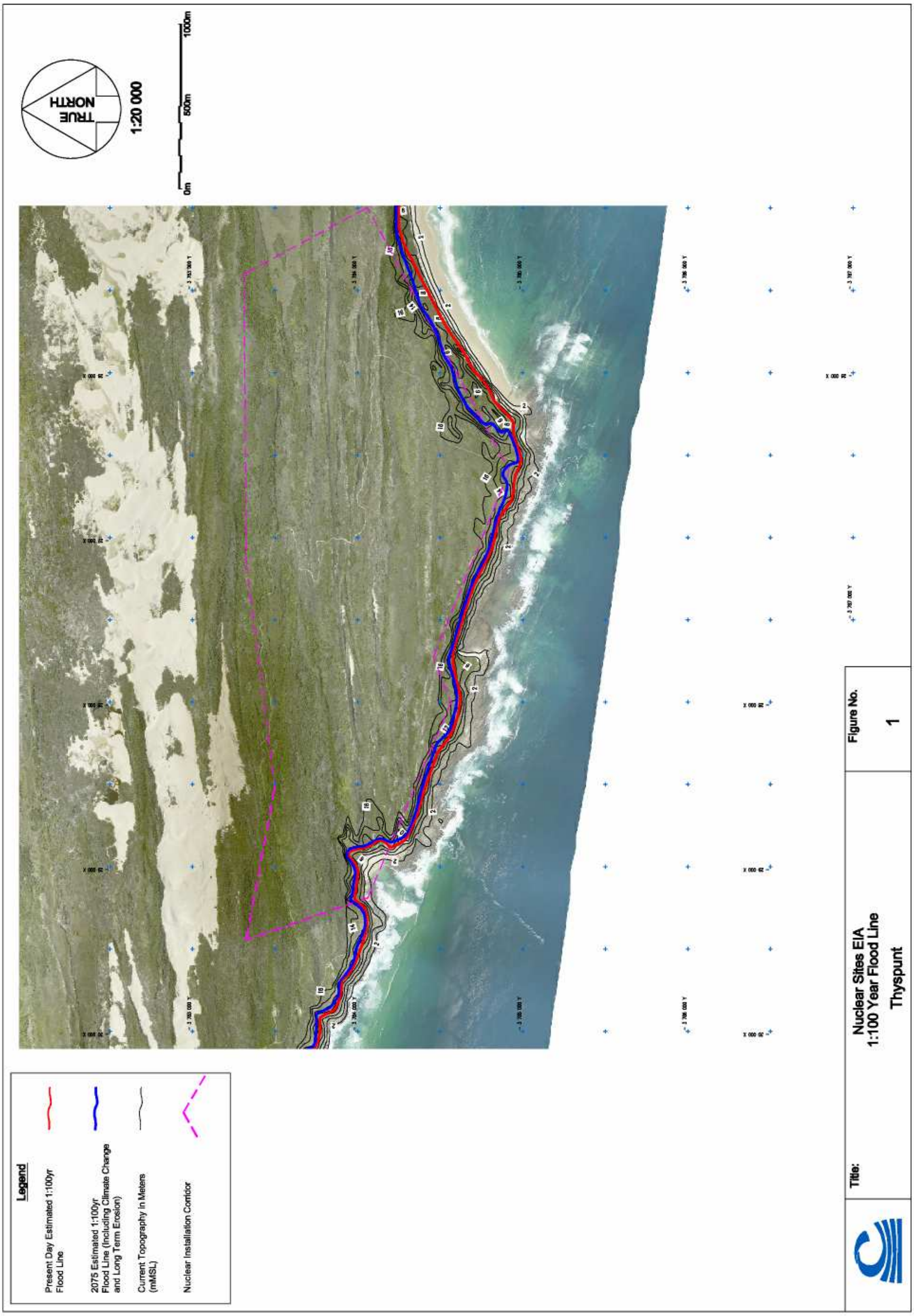


Figure 1: 1:100 Year Flood Line - Thyspunt

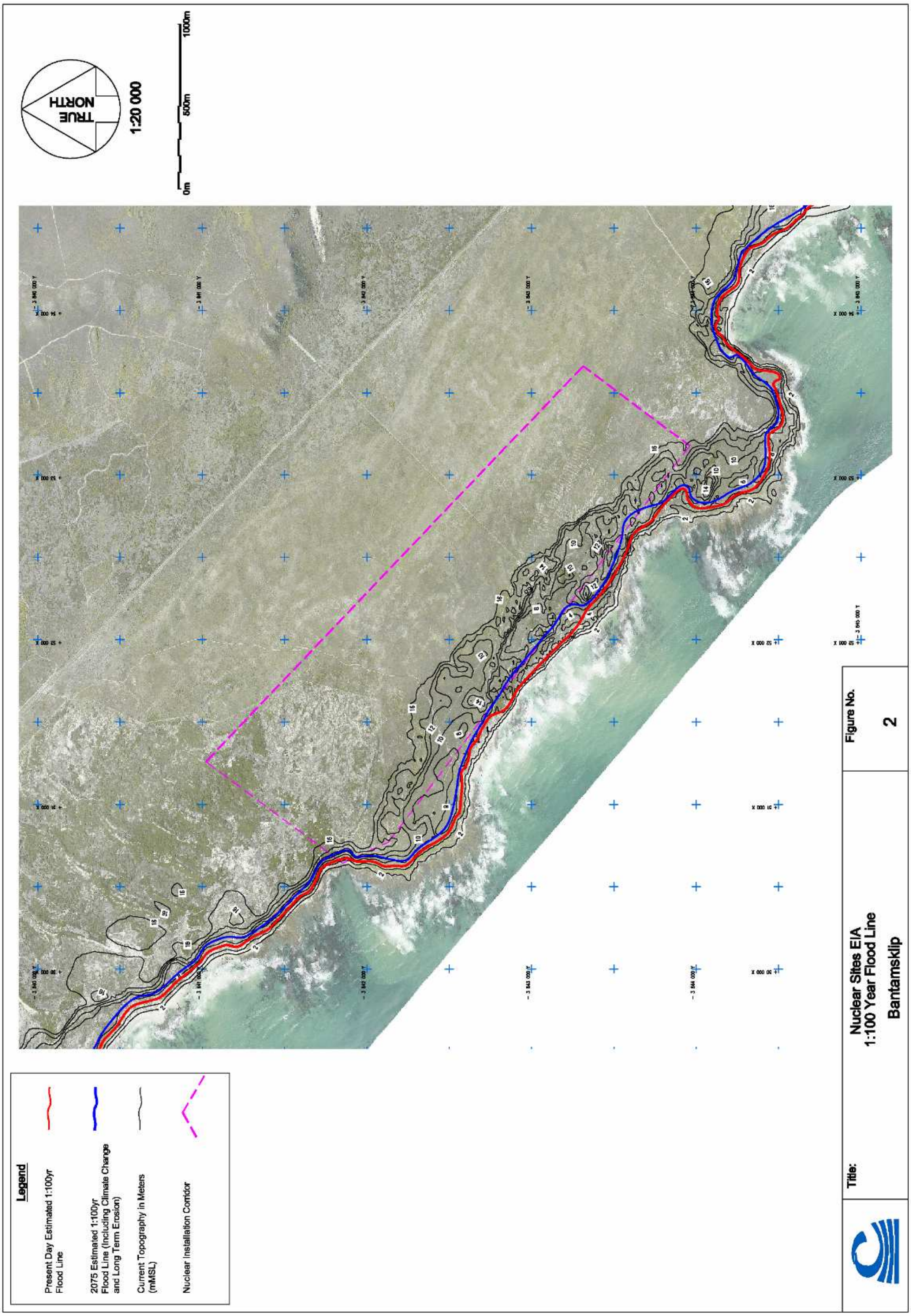


Figure 2: 1:100 Year Flood Line - Bantamsklip

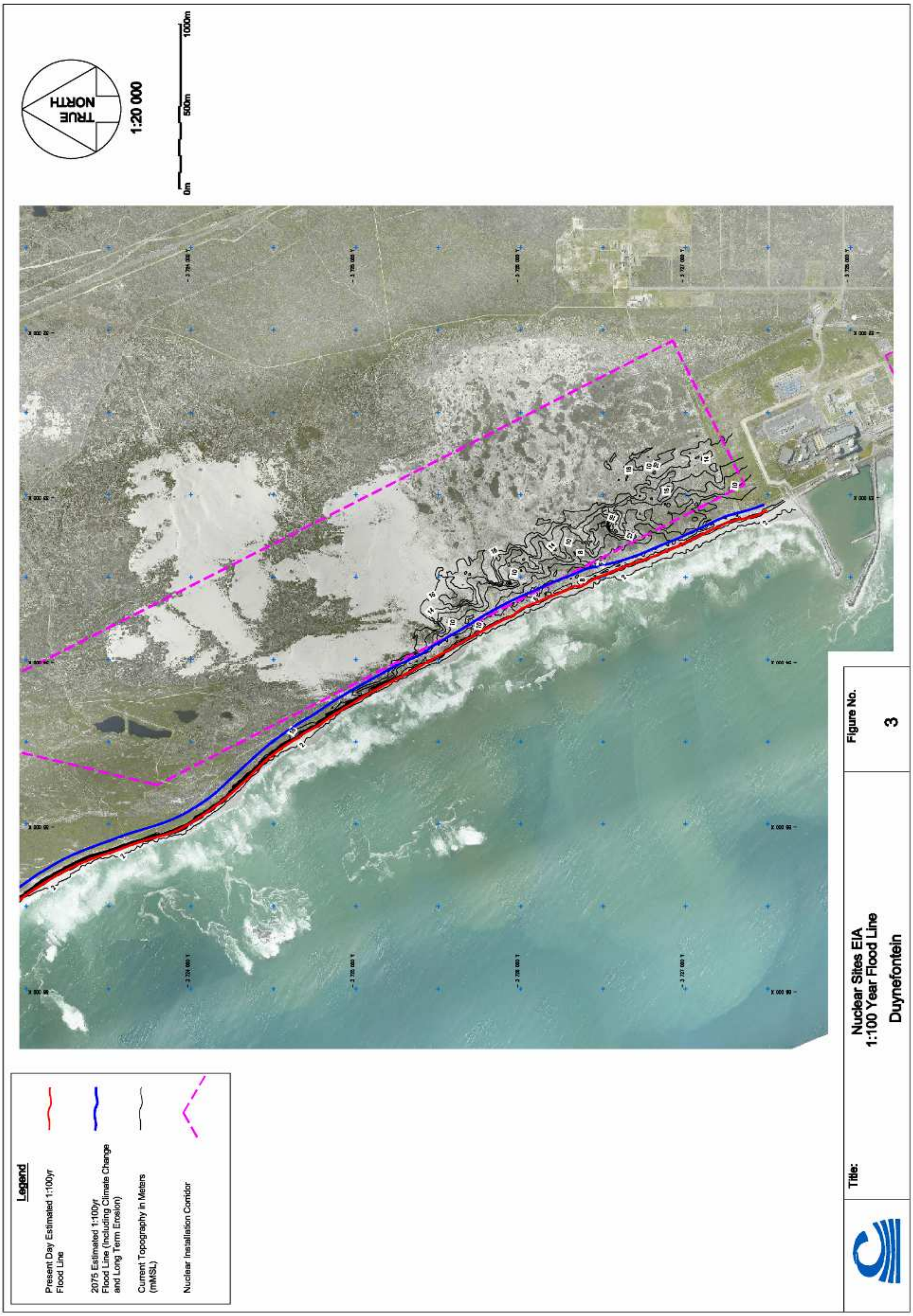


Figure 3: 1:100 Year Flood Line - Duynefontein

5 REFERENCES

CEM (2002) Coastal Morphodynamics. In: US Army Corps of Engineers. **Coastal Engineering Manual.** Part 4. Ch.3, April 2002.

CEM (2006) Water Levels and Long Waves. In: US Army Corps of Engineers. **Coastal Engineering Manual.** Part 2. Ch.5, June 2008.

Eskom (2008a) **EIA Corridor**, Nuclear-1: Thyspunt Site, Infrastructure: Thyspunt Site, CAD Drawing, Drawing number: 0.96/00049 Rev. 07A

Eskom (2008b) **EIA Corridor**, Nuclear-1: Bantamsklip Site, Extent of Plant, CAD Drawing, Drawing number: 0.96/10009 Rev. 07D

Eskom (2008c) **EIA Corridor**, Nuclear-1: Duynefontein Site, Infrastructure: Duynefontein Site, CAD Drawing, Drawing number: 0.96/20007 Rev. 04C

Hughes, S. A. (2004) Estimation of wave run-up on smooth, impermeable slopes using the wave momentum flux parameter. **Coastal Engineering**, 51, October, pp. 1085 - 1104

PRDW (2008a) Numerical Modelling of Coastal Processes - Thyspunt, **Eskom - Nuclear Sites Site Safety Report.** Prestedge Retief Dresner Wijnberg Pty. (Ltd). Report No. 1010/2/101, December 2008.

PRDW (2008b) Coastal Engineering Investigations - Thyspunt, **Eskom - Nuclear Sites Site Safety Report.** Prestedge Retief Dresner Wijnberg Pty. (Ltd). Report No. 1010/2/102, December 2008.

PRDW (2009a) Numerical Modelling of Coastal Processes - Duynefontein, **Eskom - Nuclear Sites Site Safety Report.** Prestedge Retief Dresner Wijnberg Pty. (Ltd). Report No. 1010/4/101, September 2009.

PRDW (2009b) Coastal Engineering Investigations - Duynefontein, **Eskom - Nuclear Sites Site Safety Report.** Prestedge Retief Dresner Wijnberg Pty. (Ltd). Report No. 1010/4/102, October 2009.

PRDW (2009c) Numerical Modelling of Coastal Processes - Bantamsklip, **Eskom - Nuclear Sites Site Safety Report.** Prestedge Retief Dresner Wijnberg Pty. (Ltd). Report No. 1010/3/101, October 2009 (*in print*)

PRDW (2009d) Coastal Engineering Investigations - Bantamsklip, **Eskom - Nuclear Sites Site Safety Report.** Prestedge Retief Dresner Wijnberg Pty. (Ltd). Report No. 1010/3/102, October 2009 (*in print*)

Reeve, D. Chadwick, A & Fleming, C. (2004) **Coastal Engineering: Processes, Theory and Design Practice.** Spon Press, 2004.

South African Tide Tables (2009) SAN HO-2, Published by the Hydrographer, South African Navy, 2009.

Company name	Prestedge Retief Dresner Wijnberg (Pty) Ltd
Specialist signature	
Date	29th October 2009

APPENDIX 1: GLOBAL CLIMATE CHANGE: CONSEQUENCES FOR COASTAL ENGINEERING DESIGN

GLOBAL CLIMATE CHANGE: CONSEQUENCES FOR COASTAL ENGINEERING DESIGN

POSITION PAPER

REPORT NO. 939/1/001

SEPTEMBER 2009

PRESTEDGE RETIEF DRESNER WIJNBERG (PTY) LTD
CONSULTING PORT AND COASTAL ENGINEERS

Global Climate Change: Consequences for Coastal Engineering Design Report No. 939/1/001					
Revision	**Date**	**Author**	**Checked**	**Status**	**Approved**
01	September 2009	SAL	ARW	For Use	
Keywords: Climate change, coastal engineering design					

GLOBAL CLIMATE CHANGE: CONSEQUENCES FOR COASTAL ENGINEERING DESIGN

POSITION PAPER

TABLE OF CONTENTS

PAGE NO.

LIST OF TABLES

LIST OF FIGURES

1. SCOPE

The purpose of this document is to summarize PRDW's position on the effects of climate change on coastal engineering design. The consequences of climate change are the subject of ongoing research work which will require that this paper be reviewed on an annual basis. Specific parameters to be reviewed include sea level rise and wind-generated waves.

The following parameters relevant to coastal engineering design are expected to be affected by climate change and are assessed in this position paper:

- Sea level rise
- Wind
- Storm surge
- Waves
- Currents
- Seawater temperature.

Since sediment transport is a function of water level, waves and currents, any climate-induced changes to sediment transport will require a site-specific analysis based on changes to the primary forcing parameters listed above.

This position paper considers climate changes to the end of this century only. Due to a lack of local data the changes described here are generally global changes rather than local changes.

2. SEA LEVEL RISE

There has been approximately 0.17 m of sea level rise in the 20th century and an accelerating trend is predicted in the 21st century (see Figure 1). The rise is mainly due to thermal expansion of the ocean, decreases in glaciers and ice caps and losses from the polar ice sheets (see Figure 2). The main source of uncertainty is the melting of the Greenland and Antarctic ice sheets (IPCC, 2007).

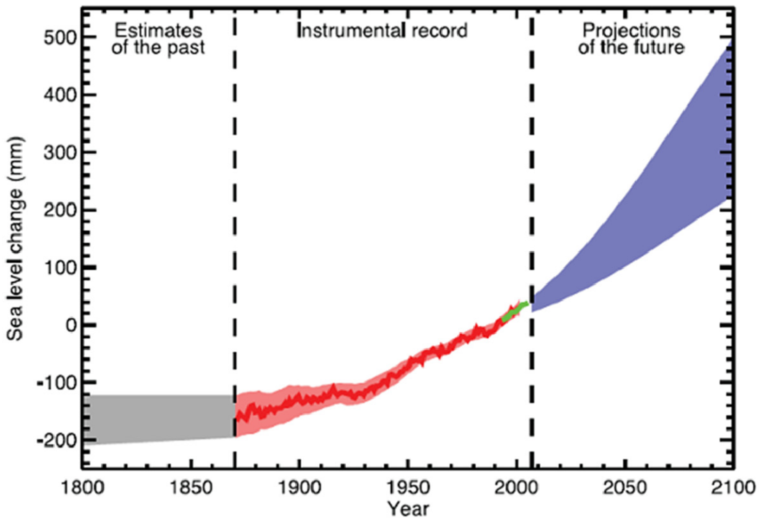


FIGURE 1: HISTORICAL AND PROJECTED FUTURE SEA LEVEL RISE FOR EMISSIONS SCENARIO A1B (IPCC, 2007).

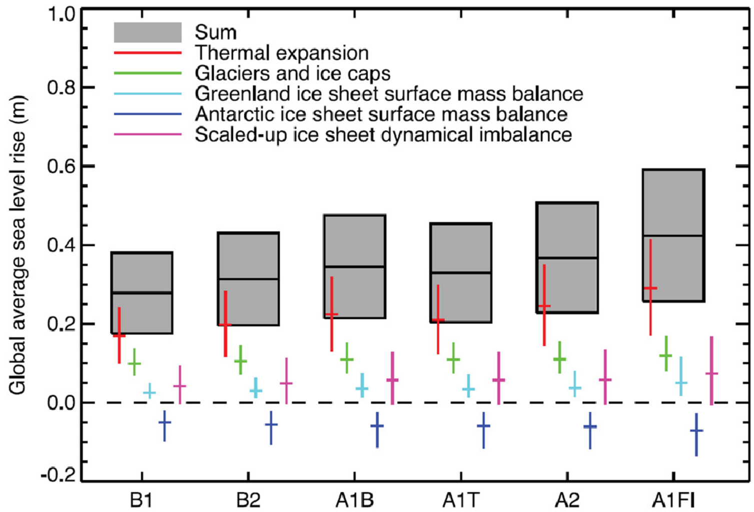


FIGURE 2: PROJECTIONS AND UNCERTAINTIES (5 TO 95% RANGES) OF GLOBAL AVERAGE SEA LEVEL RISE AND ITS COMPONENTS IN 2090 TO 2099 (RELATIVE TO 1980 TO 1999) FOR THE SIX EMISSIONS SCENARIOS (MEEHL *ET AL*, 2007).

Table 1 summarises the projected sea level rise for this century extracted from a number of recent sources and arranged chronologically.

TABLE 1: PROJECTED SEA LEVEL RISE DURING THIS CENTURY (2000 - 2100)*

Sea Level Rise [m]	Source	Comment
0.35 - 0.85	IAEA (2003)	▪ Recommended values for 100 year lifetime of a nuclear power plant by the International Atomic Energy Agency. ▪ Estimate from 2003.
0.86	Defra (2006)	▪ Guidelines from Department for Environment, Food and Rural Affairs, UK Government. ▪ Values given exclude local land subsidence.
0.26 - 0.59	IPCC (2007)	▪ Predictions from the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. ▪ These are model predicted ranges for the worst case future emissions scenario A1F1. ▪ Does not address uncertainties in climate-carbon cycle feedbacks nor include the full effects of changes in ice sheet flow, because a basis in published literature is lacking. ▪ Therefore the upper values given are not to be considered upper bounds for sea level rise.
0.79	IPCC (2007)	▪ The IPCC projections given above include a contribution due to increased ice flow from Greenland and Antarctica at the rates observed for 1993-2003, but these flow rates could increase or decrease in the future. ▪ If this contribution were to grow linearly with global average temperature change, the upper ranges of sea level rise would increase by 0.1 - 0.2 m. ▪ Adding 0.2 m to 0.59 m increases the upper range to 0.79 m.
0.5 - 1.4	Rahmstorf (2007)	▪ A semi-empirical relation is presented that connects global sea-level rise to global mean surface temperature. ▪ When applied to future warming scenarios of the IPCC, this relationship results in a projected sea-level rise in 2100 of 0.5 to 1.4 m above the 1990 level. ▪ Concludes that a rise of over 1 m by 2100 for strong warming scenarios cannot be ruled out.
1.6	Rohling *et al* (2008)	▪ Based on average rise each century during the interglacial period ~120 000 years ago during which sea levels reached 6 m above where they are now. ▪ Data from the Red Sea indicates a rise of 1.6 ±0.8 m per century.
0.79	Pfeffer *et al* (2008)	▪ The study addresses the plausibility of very rapid sea level rise from land ice occurring this century by considering kinematic constraints on glacier contributions. ▪ "Low 1" scenario: a low range estimate based on specific adjustments to dynamic discharge in certain potentially vulnerable locations.
0.83	Pfeffer *et al* (2008)	▪ "Low 2" scenario: in addition to the assumptions made in Low 1, the authors integrated presently observed rates of change in dynamic discharge forward in time.
2.0	Pfeffer *et al* (2008)	▪ "High 1" scenario: combines all eustatic sources taken as high but reasonable values. No firm upper limit can be established so the values chosen represent judged upper limits of likely behaviour on the century timescale. ▪ The Greenland and Antarctic Glacier velocities required for very large increases in sea level (2-5 m) are found to be far beyond the range of observations, and while no physical proof is offered that these velocities cannot be reached, the authors recommend that they should not be adopted as a central working hypothesis.
0.5	PIANC (2008)	▪ Recommendation by The International Navigation Association (PIANC), based on average values in IPCC (2007).

0.55 - 1.2	Deltacommissie (2008)	▪ Commission set up by Dutch government to recommend how to protect the Dutch coast and the low-lying hinterland against the consequences of climate change. ▪ Based on research conducted by 20 leading national and international climate experts, including several IPCC authors. ▪ Supplements the scenarios for 2100 produced by the IPCC (2007). ▪ Regarded as *plausible upper limit scenarios*, which are regarded as possible by the group of sea level experts consulted, based on current scientific knowledge. ▪ Note that the values given exclude land subsidence, which will increase the relative sea level rise locally in the Netherlands by 0.1 m.
2.0	Ananthaswamy (2009)	▪ With climate change modelling being so uncertain, with many ice dynamics not included due to lack of knowledge of those systems, this article states that climate scientists are looking for other ways to predict sea level rise. Some approaches being explored may take a more black box approach, where the rate of sea level rise is proportional to the increase in temperature: the warmer Earth gets, the faster ice melts and the oceans expand. This held true for the last 120 years at least. ▪ A worst case scenario indicated in this article would present up to 2 m sea level rise by 2100.
0.15 - 0.76	Lowe *et al* (2009)	▪ This is from the recent UK Climate Projections Report of June 2009. ▪ Based on a UK regionalisation of the IPCC (2007) projections. ▪ Based on the high emissions scenario including ice melt. ▪ Range represents 5^{th} – 95^{th} confidence intervals (see Figure 3).
0.93 - 1.9	Lowe *et al* (2009)	▪ This is the so-called "High-plus-plus" (H++) scenario from the UK Climate Projections Report of June 2009. ▪ The top of the H++ scenario range is derived from indirect observations of sea level rise in the last interglacial period, at which time the climate bore some similarities to the present day, and from estimates of maximum glacial flow rate. ▪ This is a UK regionalisation of an upper limit global rise from Rohling *et al* (2008) of 2.5 m ≈1.6+0.8 m, taking glacial-isostatic adjustment (GIA) of the earth's crust into account. ▪ This value might be used for contingency planning and to help users thinking about the limits to adaptation. It is **very unlikely** that the upper limit of this scenario will occur during the 21st century, but it cannot yet be ruled out completely given past climate proxy observations and current model limitations.

* The IPCC projections are from 1980-1999 until 2090-2099.

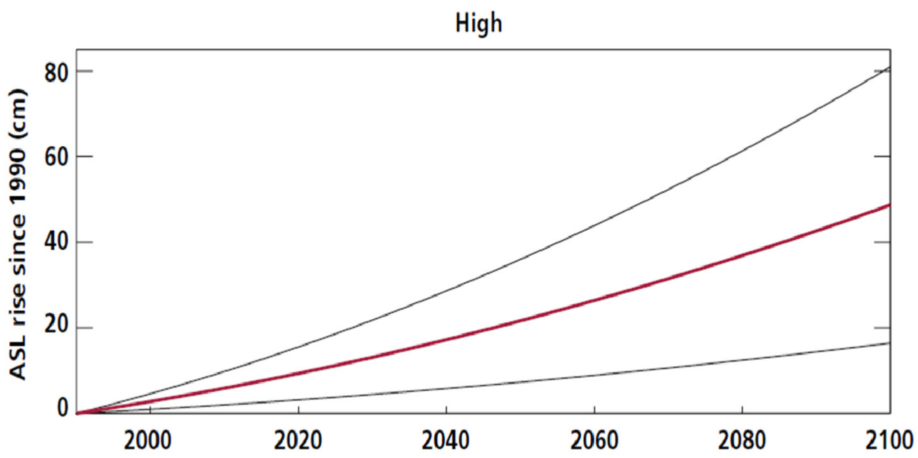


FIGURE 3: ESTIMATED UK ABSOLUTE SEA LEVEL (ASL) RISE TIME-SERIES FOR THE 21ST CENTURY. HIGH EMISSIONS SCENARIO. CENTRAL ESTIMATES (THICK LINES) ARE SHOWN TOGETHER WITH RANGE GIVEN BY 5TH AND 95TH PERCENTILES (THIN LINES). (LOWE *ET AL*, 2009).

The first issue is whether these global sea level rises apply locally to Southern Africa. Mechanisms for local sea level changes include vertical land movement, atmospheric pressure changes, ocean density variations, circulation changes and differential heating. Local sea level change due to ocean density and circulation change relative to the global average have been modelled (Meehl *et al*, 2007). For Southern Africa the predicted changes are approximately 0.05 m above the global average over the 21st century.

The rate of sea level rise measured by tide gauge between 1970 and 2003 at Durban is +2.7±0.05 mm/y, which is similar to recently published results of global sea-level rise calculations over the last ten years derived from worldwide tide gauge and TOPEX/Poseidon altimeter measurements, which range between 2.4 and 3.2 mm/y (Mather, 2007). An analysis of tide gauge records around Southern Africa (Mather *et al*, 2009) indicates that regional sea level trends vary, with the West Coast rising relative to land by +1.87 mm/y (1959–2006), the South Coast by +1.48 mm/y (1957 and 2006) and the East Coast by +2.74 mm/y (1967–2006). Vertical crust movements in Southern Africa are upwards (i.e. the sea level rise relative to land will be reduced compared to the global sea level rise) and increase from approximately +0.3 mm/y on the West Coast to +1.1 mm/y at Richards Bay (Mather *et al*, 2009). Mather *et al* (2009) also identify atmospheric pressure trends as contributing to the measured regional sea level trends given above.

Since the observed regional trends in relative sea level rise described above are relatively small compared to the uncertainties in the long-term global projections, for long-term design purposes it is proposed to apply the global sea level rise projections directly to Southern Africa.

Since the Intergovernmental Panel on Climate Change (IPCC) is the primary consensus reference on this subject, the sea level rise projections from the IPCC's Fourth Assessment Report (IPPC, 2007) are summarised below. Referring to Table 1, the mid-point of the sea level rise projections for the worst emissions scenario is (0.26 + 0.59) / 2 ≈ 0.4 m by 2100. The maximum sea level rise projection is 0.59 + 0.2 ≈ 0.8 m by 2100, which is the upper range modelled under the worst emissions scenario and includes a contribution due to increased ice flow from Greenland and Antarctica.

Since the IPPC's Fourth Assessment Report there has been an increased effort to understand the factors influencing sea-level rise, specifically the melting of the ice caps. The results of this research are summarised in Table 1 and provide an upper limit to sea level rise of 2.0 m by 2100.

Our recommended design approach (see Section 8) is to consider the implications for design of the following three sea level rise scenarios to 2100: the mid-point of the IPPC (2007) projections of 0.4 m, the upper end of the IPPC (2007) projections of 0.8 m, and in specific cases the design should also be evaluated for future design adaptations or contingency planning in the event of an extreme upper limit sea level rise of 2.0 m.

3. WIND

Based on a range of models, it is likely that future tropical cyclones (typhoons and hurricanes) will become more intense, with larger peak wind speeds associated with ongoing increases of tropical sea-surface temperatures. Extra-tropical storm tracks are projected to move poleward, with consequent changes in wind, precipitation and temperature patterns, continuing the broad pattern of observed trends over the last half century (IPCC, 2007).

For Cape Town, the south-east winds, which typically prevail along the Cape coast during the summer months, are projected to become stronger as climate change progresses and may become an increasing feature of the winter months. It is important to note that the north-west winds that prevail in winter do not, as yet, show a statistically discernable change as a result of climate forcing and are not projected in regional climate forecasts to change (MacDeevitt and Hewitson, 2007, cited in LaquaR Consultants, 2008).

The International Atomic Energy Agency (IAEA, 2003) recommends that an increase in wind strength between 5 and 10% be considered over a 100 year lifetime of a nuclear power plant. This is a global estimate from 2003.

The Department for Environment, Food and Rural Affairs of the UK Government (Defra, 2006) recommends that sensitivity testing be performed taking into account a 5% increase in offshore wind speed to the year 2055 and a 10% increase to the year 2115.

Due to the inherent uncertainties in long-term regional climate forecasts and the requirement for a precautionary approach, an increase in wind speed of 10% to the year 2100 is recommended for design, based on IAEA (2003) and Defra (2006). Ongoing research work on regional wind climate projections should be reviewed annually, considering that the Ferrel Westerly winds are the main drivers for winter storm events along the South-Western and Southern Cape coastlines. Changes in wind direction are likely to be localised, with little information currently available.

4. STORM SURGE

Storm-induced surges can produce short-term increases in water level that rise to an elevation considerably above tidal levels. Storm surge is mainly composed of an atmospheric pressure component (low pressure for positive storm surge and high pressure for a negative storm surge) and a wind-induced component.

The gradient in atmospheric pressure and thus the atmospheric pressure component of storm surge is proportional to the wind speed, while the wind set-up component of storm surge is proportional to the square of the wind speed. With a 10% increase in wind speed due to climate change (see Section 3) the total storm surge is thus likely to increase by between 10% and 21%, depending on the relative contribution of the pressure and wind components, respectively.

The UK Climate Projections Report (Lowe *et al*, 2009) applied sophisticated surge models and found that around the United Kingdom the 1:50 year surge is projected to increase by less than 0.09 m by 2100 (not including the mean sea level change). In addition, a "High-plus-plus" (H++) model scenario was also considered (Lowe *et al*, 2009). Whilst the top end of this scenario cannot be ruled out based on current understanding, it is regarded as very unlikely to occur during the 21st century. For the H++ scenario the 1:50 year surge in the Thames Estuary is projected to increase by approximately 0.2 - 0.95 m.

In the absence of downscaled storm surge model data for Southern Africa, it is conservatively recommended to increase the storm surge by 21% to the year 2100, based on a 10% increase in wind speed.

Since shelf waves, edge waves and meteo-tsunamis have similar forcing mechanisms to storm surge, i.e. changes in wind or atmospheric pressure, is recommended to also increase the water level changes caused by these processes by 21%. Note that tsunamis due to geological forcing mechanisms, e.g. earthquakes, are unlikely to be influenced by climate change (IPPC, 2007).

5. WAVES

As part of the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Trenberth (2007) reports on historical trends in significant wave height (H_{m0}) obtained from Voluntary Observing Ships (VOS) data between 1950 and 2002 (see Figure 4). These results show that around Southern Africa the increase in H_s is around 0.4 cm/decade, whilst significantly higher increases up to

1.2 cm/decade are found in the Northern Atlantic and Northern Pacific Oceans. These results suggest that future wave height changes will not be uniform.

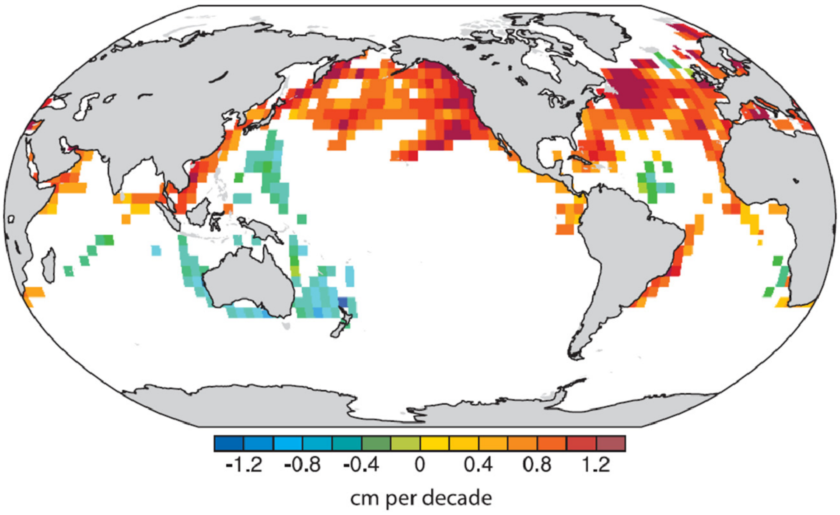


FIGURE 4: ESTIMATES OF LINEAR TRENDS IN SIGNIFICANT WAVE HEIGHT FOR REGIONS ALONG THE MAJOR SHIP ROUTES FOR 1950 TO 2002. TRENDS ARE SHOWN ONLY FOR LOCATIONS WHERE THEY ARE SIGNIFICANT AT THE 5% LEVEL. (TRENBERTH *ET AL*, 2007).

The UK Climate Projections Report (Lowe *et al*, 2009) applied sophisticated wave models and found that around the United Kingdom for the medium emissions scenario, the projected changes to 2100 in the winter mean H_{m0} are between –0.35 and +0.05 m. Changes in the annual maxima are projected to be between –1.5 and +1.0 m. Changes in wave period and direction were found to be rather small and more difficult to interpret.

The Department for Environment, Food and Rural Affairs of the UK Government (Defra, 2006) recommends sensitivity testing taking into account a 5% increase in wave height to the year 2055 and a 10% increase to the year 2115. These increases are the same as Defra recommends for wind.

The methods presented in Coastal Engineering Manual (CEM, 2003) have been used to analyse the impact of an increased wind speed on fetch-limited and duration-limited waves. Duration-limited waves show the largest increase, with a 10% increase in wind speed due to climate change (see Section 3) increasing the wave height by 13% for the lower wind speeds and 17% for the higher wind speeds.

Wave data measured offshore of Cape Town and Richards Bay have been analysed to investigate trends in the peak significant wave height of individual storm events (Guastella and Rossouw, 2009). The Cape Town data suggests an increasing trend during winter of approximately 0.5 m over the 14 year period from 1994 to 2008, and a general decreasing trend during summer. The Richards Bay data do not show any conclusive trends over the 30 year period from 1979 to 2008. The study also identifies cold fronts and their associated low pressure systems as the major cause of extreme wave events along the South-Western Cape coastline. On the East Coast of South Africa tropical cyclones and cut-off lows were identified as being responsible for the extreme wave events.

In the absence of downscaled wave generation model data for Southern Africa, it is conservatively recommended to increase the wave height by 17% to the year 2100, based on a 10% increase in wind speed. The impact on wave period can be estimated from the present day H_{m0}-T_p relationship. We are not aware of data on changes in wave directions for South Africa. Sensitivity testing to wave direction should be considered on a project-specific basis.

6. CURRENTS

Ocean circulations could be affected by climate change, and these effects could be either gradual or sudden. For example, it is very likely that the Atlantic Ocean Meridional Overturning Circulation (MOC), which transports relatively warm upper-ocean waters northward (including the Gulf Stream), and relatively cold deep waters southward, will slow down during the course of the 21st century. It is however very unlikely that the MOC will undergo a large abrupt transition during the 21st century. (IPCC, 2007). No reference to possible changes in the Agulhas Current is made in IPCC (2007).

Coastal hydrodynamics will be affected by changes in wind, wave height, wave direction and sea level. Wind-driven currents will tend to increase linearly with wind speed, while wave-driven currents will depend both on wave height and wave direction. These changes will vary from one location to another and can only be quantified through detailed site-specific modelling.

7. SEAWATER TEMPERATURE

From a coastal engineering design perspective, seawater temperature is relevant for cooling water studies and also has a small effect on sediment settling velocities and thus sediment transport. Impacts on marine ecology are beyond the scope of this position paper.

The UK Climate Projections Report (Lowe *et al*, 2009) applied sophisticated hydrodynamic models and found that the seas around the UK are projected to be 1.5 - 4°C warmer, depending on location, and ~0.2 psu fresher by the end of the 21st century, using the medium emissions scenario. Seasonal stratification strength is projected to increase but not by as much as in the open ocean.

The International Atomic Energy Agency (IAEA, 2003) recommends an increase in sea temperature of 3°C be considered over a 100 year lifetime of a nuclear power plant.

Additional factors to be considered include:

- changes in large ocean currents on temperature, e.g. Agulhas Current

- changes in coastal upwelling due to changes in wind speed or direction.

8. RECOMMENDED DESIGN APPROACH

The recommended design approach is to first calculate the present day design parameters based on historical datasets, e.g. determine the 1:100 year wave height from an Extreme Value Analysis of measured Waverider data or wave hindcast data. The present day parameters should then be increased to account for climate change using the values in Table 2. In some cases a conservative design will be achieved by excluding the effect of climate change, e.g. for entrance channel depths and minimum seawater intake depths it is recommended not to include sea level rise.

Although the rate of change is expected to increase over time (see for example Figures 1 and 3), because of the uncertainty attached to these rates and to be conservative, we have assumed a linear increase over the 21st century, with 50% of the change predicted to the year 2100 occurring by 2050. The recommended increases are given in Table 2; refer to Sections 2 to 7 for the supporting information.

TABLE 2: RECOMMENDED INCREASE IN DESIGN PARAMETERS DUE TO CLIMATE CHANGE

Parameter		**Increase to 2050**	**Increase to 2100**
Sea level rise	Mid-point of projections(1)	+ 0.2 m	+ 0.4 m
	Upper end of projections(2)	+ 0.4 m	+ 0.8 m
	Extreme upper limit(3)	+ 1.0 m	+ 2.0 m
Wind speed		+ 5%	+ 10%
Storm surge (including shelf-waves, edge waves and meteo-tsunami)		+ 10%	+ 21%
Wave height		+ 8.5%	+ 17%
Wave period		Obtain from present day H_{m0} - T_p relationship.	
Wave direction		No data, consider sensitivity testing.	
Seawater temperature		+ 1.5ºC	+ 3ºC
Currents and sediment transport		Use site-specific modelling with the forcing parameters increased by the values given above.	

Notes:

(1) Although engineering judgement is required on a case by case basis, this value would typically be recommended for minor structures with a short design life, or structures that can relatively easily be adapted to accommodate possible accelerated sea level rise in future.

(2) Recommended for the majority of large coastal structures.

(3) In specific cases the design should also be evaluated for future design adaptations or contingency planning in the event of an extreme upper limit sea level rise of 2.0 m by 2100. See below for further details.

In specific cases an extreme upper limit sea level rise of 2.0 m by 2100 should be considered as part of the design process. This will depend inter alia on the type of structure, the design life and the consequences of failure. Examples of the issues that should be considered include:

- The survivability of the structure under the extreme upper limit climate change projections.
- The design should consider making allowance for future adaptations, e.g. increase the breakwater crest width to allow for future raising of the crest level, allow space for future revetments in front of structure.
- Consider the cost implications of an adaptive versus precautionary approach (see Appendix A for more details).
- Consider the impacts of the structure on the adjacent coastline or adjacent structures, and vice versa, e.g. raising the structure levels may increase the flooding risk for adjacent structures.

REFERENCES

1. Ananthaswamy, A (2009) Sea level rise: It is worse than we thought. New Scientist, 2715, 28-33.
2. CEM (2003) CEM Part II Chapter 2 - Meteorology and Wave Climate, US Army Corps of Engineers, July 2003.
3. Defra (2006) Department for Environment, Food and Rural Affairs. Flood and Coastal Defence Appraisal Guidance: FCDPAG3 Economic appraisal: Supplementary note to operating authorities – Climate change impacts October 2006." Defra, UK Government.
4. Deltacommissie (2008) Working together with water, A living land builds for its future, Findings of the Deltacommissie 2008.
5. Guastella, L A and Rossouw M (2009) Coastal Vulnerability: Are Coastal Storms Increasing in Frequency and Intensity along the South African Coast? International Multi-purpose reef conference, Jeffrey's Bay, South Africa, May 2009.
6. IAEA (2003) Flood Hazard for Nuclear Power Plants on Coastal and River Sites. International Atomic Energy Agency. IAEA Safety Standards Series No. NS-G-3.5.
7. IPCC (2007) Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland, 104 pp.
8. LaquaR Consultants (2008) Global Climate Change and Adaptation - A Sea-Level Rise Risk Assessment, prepared by LaquaR Consultants CC for the City of Cape Town, 2008.
9. Lowe, J A, Howard, T P, Pardaens, A, Tinker, J, Holt, J, Wakelin, S, Milne, G, Leake, J, Wolf, J, Horsburgh, K, Reeder, T, Jenkins, G, Ridley, J, Dye, S, Bradley, S (2009). UK Climate Projections science report: Marine and coastal projections. Met Office Hadley Centre, Exeter, UK.
10. MacDeevit, C and Hewitson, B (2007) Sea-level Rise on the Cape Coast. Atmospheric Science Honours Thesis 2007. University of Cape Town.
11. Mather, A A (2007) Linear and nonlinear sea-level changes at Durban, South Africa, South African Journal of Science, 103, November/December 2007, 509-512.
12. Mather, A A, Garland G G and Stretch D D (2009). African Journal of Marine Science 2009, 31(2), in press.
13. Meehl, G.A., T.F. Stocker, W.D. Collins, P. Friedlingstein, A.T. Gaye, J.M. Gregory, A. Kitoh, R. Knutti, J.M. Murphy, A. Noda, S.C.B. Raper, I.G. Watterson, A.J. Weaver and Z.-C. Zhao, 2007: Global Climate Projections. In: Climate Change 2007: The Physical Science Basis. Contribution of Working

Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

14. Rohling, E J, Grant, K, Hemleben, Ch, Siddal, M, Hoogakker, B A A, Bolshaw, M and Kucera, M (2008). High rates of sea-level rise during the last interglacial period, Nature Geoscience, 1, 38-42, 2008.
15. PIANC (2008) Waterborne transport, ports and waterways: A review of climate change drivers, impacts, responses and mitigation. May 2008.
16. Pfeffer, W. T., Harper, J. T. & O'Neel, S (2008). Kinematic constraints on glacier contributions to 21st-Century sea-level rise. Science, 321, 1340-1343.
17. Rahmstorf, S. (2007) A Semi-Empirical Approach to Projecting Future Sea-Level Rise. Science, 315, 368-370.
18. Trenberth, K.E., P.D. Jones, P. Ambenje, R. Bojariu, D. Easterling, A. Klein Tank, D. Parker, F. Rahimzadeh, J.A. Renwick, M. Rusticucci,B. Soden and P. Zhai, (2007). Observations: Surface and Atmospheric Climate Change. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S.,D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

APPENDIX A: ADAPTIVE VERSUS PRECAUTIONARY APPROACH

Our response to climate change requires appropriate decisions on whether to consider a managed adaptive approach or whether to adopt a more precautionary approach. The following (reproduced from Defra, 2006) provides a brief explanation of this.

Managed adaptive approach

A managed approach allows for adaptation in the future, and is wholly appropriate in the majority of cases where ongoing responsibility can be assigned to tracking the change in risk, and managing this through multiple interventions. This approach provides flexibility to manage future uncertainties associated with climate change, during the whole life of a flood risk management system. To consider a precautionary approach only, could lead to greater levels of investment at fewer locations. A managed approach is therefore important to ensure best value for money.

Both structural (e.g. physical changes to structures, upstream storage or a combination thereof) and non-structural solutions (e.g. land use changes, resilience, statutory objections, relocation, public awareness) are necessary to ensure cost effective adaptation can take place in future years. In order to fully explore non-structural options alongside structural options, the sensitivity analysis of these options should become a more important component of appraisal and decision making, with care needed at screening-out stages to avoid discarding non-structural options without strong justification. See Figure A.1 and the saw-tooth line to illustrate.

Precautionary approach

For some circumstances, future adaptation may be technically infeasible or too complex to administer over the long term of up to 100 years. These circumstances may occur where multiple interventions are not possible to manage the changes in risk. Therefore, a precautionary approach, perhaps with one-off intervention, may be the only feasible option, such as in the design capacity of a major culvert or in the span of a road bridge across a flood plain. See Figure A.1 and the dashed line to illustrate.

REFERENCES

Defra (2006) Department for Environment, Food and Rural Affairs. Flood and Coastal Defence Appraisal Guidance: FCDPAG3 Economic appraisal: Supplementary note to operating authorities – Climate change impacts October 2006." Defra, UK Government.

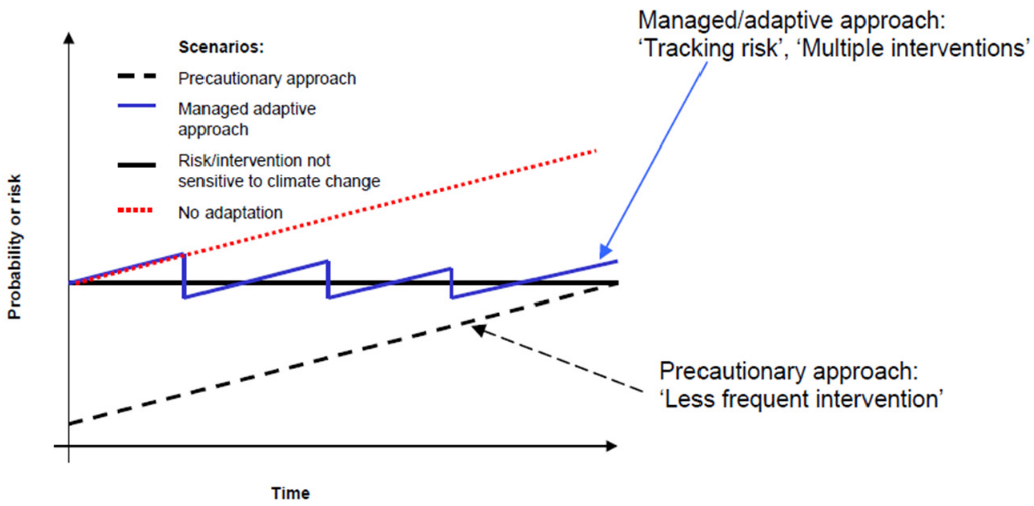


FIGURE A.1: COMPARISON BETWEEN MANAGED ADAPTIVE APPROACH AND PRECAUTIONARY APPROACH RESPONSE TO CLIMATE CHANGE. (DEFRA, 2006).