A PRELIMINARY CONCEPT FOR AN LNG IMPORT TERMINAL FOR SALDANHA BAY

by
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Abstract

South Africa presently faces a serious and much-acknowledged energy capacity deficit. The Department of Energy are determined to address this capacity crisis by creating several new power plants between 2010 and 2030, as stipulated in the "Integrated Resource Plan 2010". A Combined Cycle Gas Turbine (CCGT) power plant is proposed to add 2370 MW of capacity to the national grid.

The "new-build" CCGT plant will use natural gas as a feedstock for energy generation. The plant is destined to begin energy generation by 2019, and will ramp up to full capacity by 2030. Following a review of the existing natural gas sources and the nascent gas network in South Africa, Liquefied Natural Gas (LNG) has been identified as the most suitable immediate source of natural gas feedstock for the CCGT. LNG fuel must be imported into South Africa aboard large, special purpose LNG Carrier (LNGC) vessels. LNGC vessels require a designated marine import terminal in order to offload the super-cooled and potentially flammable cargo. Saldanha Bay, located on the South West coast of South Africa, has been selected by Transnet as a preferred location for LNG terminal development.

A review of LNG technology reveals the need for mandatory onshore LNG storage and regasification facilities, land area requirements, demands of different LNGC types and the characteristics of dedicated LNG jetties and terminals. Floating, offshore and traditional LNG terminals are discussed.

The objective of this thesis is to review potential terminal sites and conceptual layouts in Saldanha Bay, and via a Multi Criteria Analysis, to present three distinct LNG terminal layout options for further consideration. The conceptual layouts will address technical concerns such as berth orientation and layout, safe navigational access to the terminal, mandatory onshore infrastructure and optimisation of berth operations.

Saldanha Bay as a port location is studied and the importance of local environmental features is highlighted. Potential terminal development sites are identified following a review of nautical and terrestrial restrictions. Four *conceptual site layouts* are proposed, providing jetty locations and orientations in the Bay. The sites are located in North Bay, Hoedjiespunt, and two in Big Bay.

Several Key Design Parameters (KDP's) are identified as having a critical bearing on the ultimate layout, operation and feasibility of an LNG terminal in Saldanha Bay. The sensitivity and influence of the KDP's at each of the four conceptual sites is investigated. Analysis of KDP effects leads to the development of design variation options at the sites. Twelve *terminal layout schemes* are ultimately derived.

A Multi Criteria Analysis (MCA) is performed to rank the 12 terminal layout schemes in terms of technical efficacy. A sensitivity study is conducted to justify the selection of MCA parameter weights. The three top-scoring schemes are recommended for more detailed pre-feasibility investigation. The three terminal layout schemes, located in Big Bay and Hoedjiespunt, make use of both standard trestle jetties and floating LNG technologies.

The thesis has shown that a number of viable sites and layouts for LNG terminals exist in Saldanha Bay and demonstrates a systematic analysis of design issues leading to preferred options. The thesis concludes by outlining the next steps in the process towards a final terminal scheme selection.

Opsomming

Suid-Afrika ervaar huidig ‘n drastiese energie kapasiteit verlies. Die Departement van Energie is vasbeslote om die energie krisis aan te spreek deur verskeie nuwe kragstasies tussen 2010 en 2030 op te rig, soos beskryf in die “Integrated Resource Plan 2010”. ‘n Gekombineerde Siklus Gas Turbine (GSGT) kragstasie is voorgestel om ‘n verdere 2370 MW by te voeg tot die nasionale krag netwerk.

Die “nuut-geboude” GSGT kragstasie sal natuurlike gas as brandstof vir kragopwekking gebruik. Die kragstasie is beplan om teen 2019 krag op te wek, en sal teen 2030 volle kapasiteit loop. Na ‘n ondersoek van die bestaande natuurlike gas bronne en gas netwerke in Suid Afrika, is Vloeibare Natuurlike Gas (VNG) geïdentifiseer as die huidiglike beskikbare bron van brandstof vir die GSGT. VNG moet ingevoer word aanboord spesiaal geboude VNG vaartuie. VNG vaartuie benodig ‘n spesifieke mariene invoer terminaal om die vlambare vloeistof mee af te laai. Saldanhabaai, aan die Suid-Westerlike kus van Suid Afrika, is as verkose area vir die VNG terminaal ontwikkeling geïdentifiseer deur Transnet.

‘n Oorsig van VNG tegnologie bevind dat VNG stoorplek en vergassings fasiliteite, land area, verskeie VNG vaartuie en karakteristieke van VNG terminale benodig word. Verskeie VNG terminale word bespreek in hierdie studie.

The doel van hierdie tesis is om die potensiële terminaal bou-terrein en konseptuele ontwerpe in Saldanhabaai, deur middel van ‘n multi-kriteria analise (MKA), in drie verskillende ontwerp moontlikhede voor te stel.

Saldanhabaai, as hawe, is bestudeer en belangrike omgewings aspekte is geïdentifiseer. Potensiële terminaal bou-terrein is geïdentifiseer na aanleiding van seevaart en land beperkings. Vier konseptuele bou-terreine is voorgestel wat jetty posisies en orientasies aandui. Die bou-terreine is in Noordbaai, Hoedjiespunt, en twee in Big Bay.

Verskeie Sleutel Ontwerp Parameters (SOP’s), wat ‘n kritieke rol speel in die uiteindelike orientasie, werking en effektiwiteit van die VNG terminaal in Saldanhabaai, is geïdentifiseer. Die sensitiwiteit van die SOP’s by elk van die vier voorgestelde moontlikhede, is ondersoek. ‘n Ontleding van die effek van die SOP’s het variasie in die ontwerp moontlikhede by die verskillende bouterrein tot gevolg. Twaalf terminaal orientasie skemas is voorgestel.

‘n MKA is uitgevoer om ‘n ranglys van opsies te produseer in terme van tegniese effektiwiteit. Dit is voorgestel dat die top drie opsies verder ondersoek moet word. Die drie terminaal orientasie skemas, wat voorgestel word vir die Big Bay en Hoedjiespunt areas, maak gebruik van standaard jetties en drywende VNG tegnologie.

Hierdie tesis bevind dat ‘n aantal uitvoerbare bouterreine en orientasies in Saldanhabaai moontlik is. ‘n Sistematiese analise van ontwerps kwessies wat na verkose opsies lei, word ook in die tesis ge-adresser. Die voorgestelde stappe in die besluitneming van ‘n finale terminaal skema vorm die slot van die tesis.

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Padhraic O’ Connor

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List of Abbreviations and Acronyms

BCM	Billion Cubic Metres
BOG	Boil Off Gas
CBA	Critical Biodiversity Area
CCGT	Combined Cycle Gas Turbine
CD	Chart Datum
CHP	Combined Heat and Power
CSIR	Council for Scientific and Industrial Research
CSP	Concentrated Solar Power
DOE	Department of Environment
EIA	Environmental Impact Assessment
ERC	Energy Research Centre
ERS	Emergency Release System
ESD	Emergency Shut Down
FLNG	Floating Liquefied Natural Gas
FPSO	Floating, Production, Storage and Offloading
FRU	Floating Regasification Unit
FSRU	Floating, Storage & Regasification Unit
GBS	Gravity Based Structure terminal
GUI	Graphical User Interface
GW	GigaWatt
GWhr	GigaWatt hour
IAP	Interested and Affected Party
IDZ	Industrial Development Zone
IGU	International Gas Union
IOC	International Oil Company
IRP	Integrated Resource Plan
LAR	Land Area Requirement
LLD	Land Levelling Datum
LNG	Liquefied Natural Gas
MCA	Multi Criteria Analysis
MMTA	Million Metric Tonnes per Annum
MHWN	Mean High Water Neap
MHWS	Mean High Water Spring
MLWN	Mean Low Water Neap
MLWS	Mean Low Water Spring
MSL	Mean Sea Level
NG	Natural Gas
MW	MegaWatt
NPA	National Ports Authority
NPC	National Planning Commission
NPP	New Power Plan
OCGT	Open Cycle Gas Turbine
ORV	Open Rack Vapourisers
PV	Photovoltaics

SANDF	South African National Defence Force
SANHO	South African Navy Hydrographic Office
SBIDZ	Saldanha Bay Industrial Development Zone
SCV	Submerged Combustion Vapourisers
SDF	Spatial Development Framework
SEA	Strategic Environmental Assessment
STL	Submerged Turret Loading
STS	Ship To Ship
STV	Shell and Tube type Vapourisers
SWAN	Simulating WAves Nearshore
SWL	Still Water Level
TNPA	Transnet National Ports Authority
WL	Water Level
YMS	Yoke Mooring System
ZVI	Zone of Visual Influence

List of Symbols

A	Area of vessel exposed to wind [m^2]
B	Breadth [m]
B_p	Bollard pull force [kN]
C_w	Wind drag force coefficient
d	Draught [m]
D	Depth [m]
F	Fetch length [m]
F_g	Gust factor
F_w	Wind drag force [kN]
F_{Xw}	Longitudinal wind drag force [kN]
F_{Yw}	Lateral wind drag force [kN]
H_s	Statistically significant wave height [m]
L_{OA}	Length Over All [m]
L_{PP}	Length Between Perpendiculars [m]
S_f	Safety factor
U	Wind velocity [m/s]
U_A	Wind stress factor [m/s]
V	Wind velocity striking vessel [m/s]
W_{Bg}	Bank clearance width starboard [m]
W_{BM}	Basic manoeuvring width [m]
W_{Br}	Bank clearance width port [m]
W_i	Channel width parameter [m]
Z_n	Channel depth parameter [m]
ρ_a	Density of air [kg/m^3]

1 INTRODUCTION

1.1 Introduction to Research Topic

At the time of writing, South Africa faces a blatant and much-acknowledged energy capacity deficit. The demand for power is particularly high for a country of its size – a detail that can be attributed to the energy intensive mining operations that float the economy. The Department of Energy (DOE) recognises this and has vowed to double the existing grid capacity by 2030 with the introduction of several "new-build" power plants (DOE, 2011a).

One such proposed new power plant, earmarked to deliver 2370 MW of power by 2030 is a Combined Cycle Gas Turbine (CCGT) plant, fuelled by natural gas. The CCGT plant demands a constant and reliable feedstock of natural gas to guarantee energy production. However, the natural gas network in South Africa is poorly developed, and the country does not produce substantial volumes of this clean fossil fuel. Natural gas will therefore have to be imported to ensure success of the DOE's proposed scheme.

Liquefied Natural Gas (LNG) has been identified as a practical means of importing natural gas into South Africa (ERC, 2013). LNG, simply put, is super-cooled methane that has reduced in volume by a factor of 585 due to the vapourisation process. This feature of the fuel makes it ideal for transport by sea, as enormous volumes of natural gas can be carried as a relatively compact liquid cargo.

LNG is transported in its liquid state at a temperature of -162°C in insulated containment tanks, aboard specially built liquid bulk vessels. These Liquefied Natural Gas Carriers (LNGC's) transfer cargoes of LNG from the gas extraction site to the import site, which are typically separated by thousands of kilometres. At the point of import, the LNG will be unloaded from the vessel, regasified into natural gas and supplied to the end user – in this case a CCGT power plant.

The import site requires a dedicated marine terminal to receive the laden LNG vessel. The terminal must be sufficiently deep to accommodate the LNGC, should boast adjacent land space for terminal development and expansion and should be distant from other port users and residential areas to allow for a mandatory safety exclusion zone.

Saldanha Bay is identified as a potential harbour for the development of a dedicated LNG terminal, its related storage and regasification facilities and its downstream industries.

The objective of this study is to develop conceptual LNG terminal solutions for Saldanha Bay. This will be achieved through an understanding of the metocean conditions specific to the Bay, a review of LNG technologies and implementation of port design guidelines acquired through an in-depth literature study.

1.2 Objective of Study

The objective of this thesis is to review multiple sites and layouts in Saldanha Bay, and via a Multi Criteria Analysis, to present three distinct LNG terminal layout options for further consideration. The conceptual layouts will address technical concerns such as berth orientation and layout, safe navigational access to the terminal, mandatory onshore infrastructure and optimisation of berth operations.

1.3 Rationale

South African Energy Demand

Rationale for a new LNG import terminal stems from an increasing and urgent demand for energy in South Africa. The additional capacity required will be provided by several new-build power plants. The DOE's "Integrated Resource Plan", (reviewed in Chapter 2), indicates the break-up of proposed plants. The majority of base load supply is to be provided by renewable, coal and nuclear plants. A moderate 2.4 GW is to be provided by a Combined Cycle Gas Turbine facility, which uses natural gas as a feedstock.

A new-build CCGT will require a steady and substantial supply of natural gas fuel if it is to serve as a base load energy plant. South Africa's gas network is, however, poorly developed. The DOE's National Gas Plan (DOE, 2005) indicates that although there are substantial gas reserves offshore the Western Cape and in the Kudu field in southern Namibia, neither of these sources will be able to deliver gas to consumers in the short to mid-term future. Liquefied Natural Gas, regasified to its gaseous state, is therefore the logical source of feedstock for the new CCGT.

Rationale for LNG Terminal at Saldanha Bay

LNG is imported aboard large insulated liquid bulk carriers. These vessels necessitate a dedicated LNG terminal due to the specific dockside facilities required to unload the cargo, and to maintain a safety zone between the potentially flammable cargo and other port activities. Saldanha Bay, approximately 60 Nm north of Cape Town, is proposed as a suitable location for the LNG terminal and CCGT power plant. Growing energy demands from the city of Cape Town and power requirements of the proposed mid and heavy-industry based Industrial Development Zone in Saldanha are impetus for the CCGT. Saldanha Bay is an ideal port for a new LNG terminal due to its natural water depth and protection, and the terrestrial space available for expansion, much of it earmarked for industrial use (DTI, 2013).

Terminal Throughput and Dimensions

In addition to a marine terminal in Saldanha, an LNG storage facility and a regasification plant will be necessary adjacent to the terminal in order to convert LNG to a useable gas fuel. These three facilities are the final components of the larger LNG "Value Chain" that describe the process of gas extraction from the field, liquefaction into LNG, transport, and regasification into gas before delivery to the end user.

1.4 Report Outline

Following a review of the rationale, the specifics of an LNG facility in Saldanha are discussed. The LNG value chain is studied, with particular focus on the terminal and regasification components. Design practices at existing LNG terminals are considered. The CCGT power plant will be the major end-user of the LNG chain.

The annual throughput of the import facility must be determined in order to configure the marine terminal dimensions, LNG storage tank size and the capacity of the regasification facility. Terminal throughput is described by the number of metric tonnes unloaded through the facility (MMTA – *million metric tonnes per annum* of LNG) or by the volume of regasified natural gas the imported LNG could produce (BCM – *billion cubic metres* of natural gas). The throughput necessary to supply an uninterrupted feedstock to the CCGT is determined following a technical analysis. This figure will dictate the ultimate capacity and dimension of the terminal. The subsequent terminal size is compared to modern import terminals. In most international examples an LNG facility will supply a number of energy plants or an existing natural gas network. The Saldanha terminal throughput is reviewed and adjusted.

Technology Review

The marine elements of the import facility such as dredging demands, diameter of turning circle and width of entrance channel will be directly related to the dimensions of the LNG Carrier vessel used to import the cargo. The characteristics and key elements of modern LNGC's are discussed. The size of the design vessel for the Saldanha terminal is decided following a review of the existing LNGC fleet and trends within the industry. The LNG throughput expected at the port, discussed in the previous Chapter, will play a role in the size and frequency of call of the design vessel. The minimum, average and design vessel sizes are selected.

A traditional LNG import terminal consists of a piled trestle jetty with an unloading platform abreast of midships where cryogenic hoses offload cargo. The cargo is pumped towards land in raised insulated pipelines and stored in large LNG storage tanks. A recent trend however is to move towards floating facilities, where the LNGC, storage tanks and regasification plant are based offshore. The different forms of import terminal are introduced and their potential application in Saldanha discussed.

Development Areas and Conceptual Site Layouts

Saldanha Bay as a port location is introduced to the reader. The existing port layout is described, and the importance of nearby environmental features is highlighted. Prospective LNG terminal sites in the Bay are narrowed by both nautical and terrestrial restrictions. These restrictions are identified and a map of Saldanha Bay is developed which presents both nautical and terrestrial zones that may be suitable for terminal design. Potential sites take the necessary land area requirements and hinterland access into account.

Once potential development sites have been identified, a handful of "Conceptual Site Layouts" are proposed. These initial layouts incorporate distinct jetty orientations following a *preliminary* study of marine design parameters such as entrance channel alignment, turning circles, reclamation/dredging works, prevailing wind and wave direction and wave protection options.

Downtime Analysis and other Key Design Parameters

A number of Key Design Parameters (KDP) are identified as having a critical technical bearing on the design and performance of the terminal. These technical parameters are examined in detail in the context of Saldanha Bay, and the variability and implication of the parameters at each conceptual site is noted. Wind and wave induced downtime is a critical KDP and is discussed initially in a separate chapter. Other parameters shall include terminal type, land area requirement, dredge volumes, choice of tugs, safety exclusion zones, navigation and environmental impact. Some KDP's will require numerical modelling to determine their effect at the selected sites, while others will involve extensive literature review or probabilistic analysis.

Analysis of the KDP's will present different design and layout options for the selected conceptual site layouts. The initial four conceptual layouts are thus developed into several potential "terminal layout schemes" following KDP analysis.

Multi Criteria Analysis of Terminal Layout Schemes

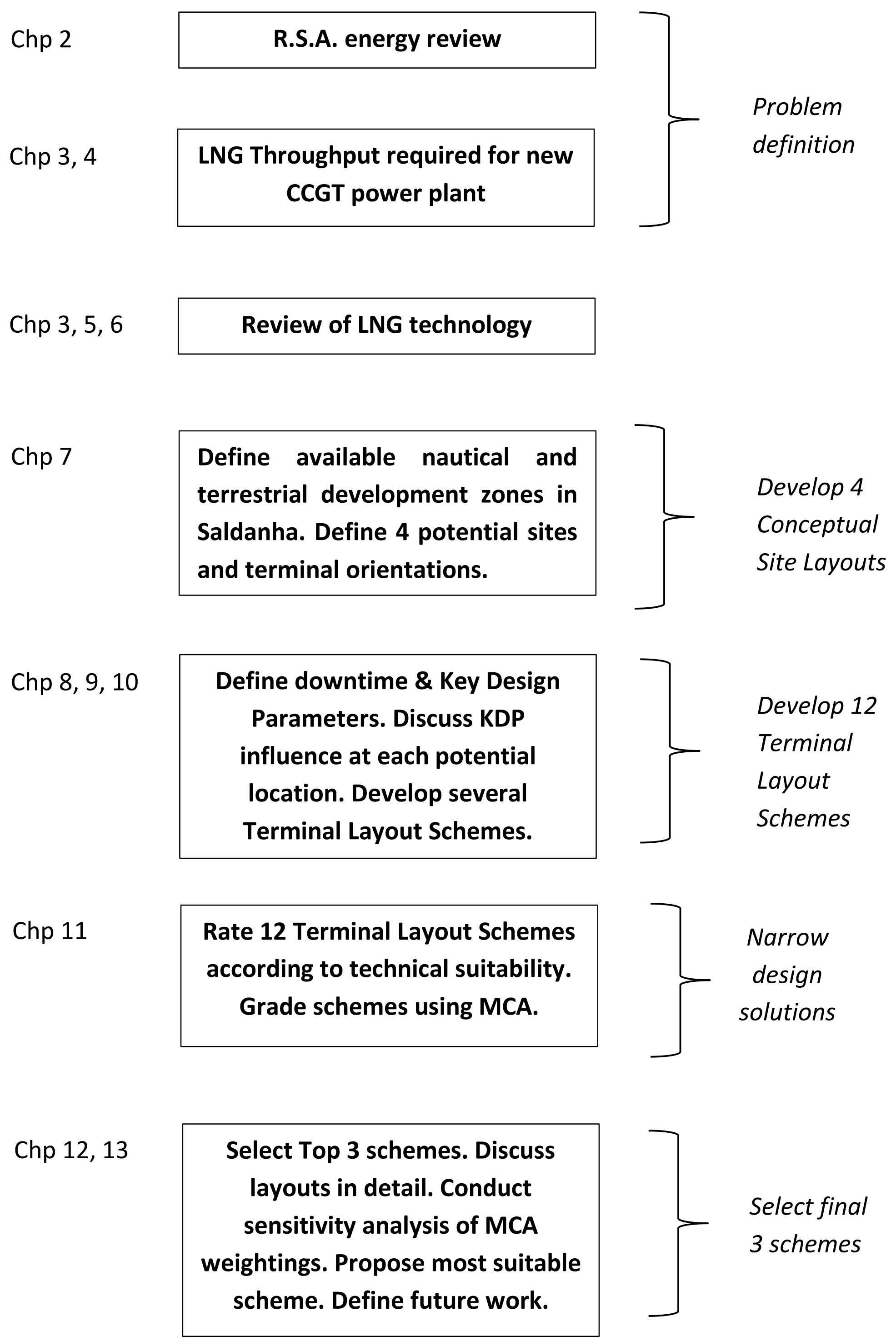
The *terminal layout schemes* resulting from the KDP discussion will be considered as plausible solutions to the design problem. A Multi Criteria Analysis (MCA) is performed to rank the dozen or so layout schemes in order of technical efficacy. The schemes are rated using the prescribed KDP's as parameters, which are assigned individual weightings. A scoring matrix is developed which compares the relative strengths and weaknesses of each layout scheme. Following the MCA process, the three highest scoring layout schemes will be considered for the "detailed pre-feasibility" stage of the design process.

It is likely that the specific weights allocated to the Key Design Parameters (KDP's) in the MCA process will strongly influence the selection of the three final layout schemes. The assigned weights are explained and a sensitivity exercise is undertaken to illustrate the effects of variability of the weights.

The detailed pre-feasibility investigation – narrowing the top three schemes to one conclusive terminal design – does not form part of the scope of study. This time and resource intensive step typically involves a number of external specialists, incorporating environmental advisors, economists, financial planners, civil/structural engineers and port designers. The steps involved in finalising the ultimate layout are outlined, and recommendations for future work are proposed. A final terminal layout, favoured by the author, is suggested nonetheless and briefly discussed.

References and Appendices sections follow the body of the report.

1.5 Schematic of Methodology



1.6 Reader's Guide

The first Chapter of this document provides an introduction to the thesis topic and includes a more detailed review of the rationale and report layout. A synopsis of current energy usage in South Africa and demand forecast up to the year 2030 is presented in **Chapter 2**. The severe energy shortage is the impetus for building new gas fuelled power plants and importation of natural gas or LNG feedstock. The reader is introduced to Liquefied Natural Gas and to the "LNG value chain" in **Chapter 3**. The process of gas extraction at the well, liquefaction, transport, re-gasification and delivery to the customer is described, with a specific focus on the elements of import terminal layout. The annual amount of LNG required to fuel the proposed new-build South African power plant is calculated in **Chapter 4**. The LNG will be imported at a single gas import terminal, to be located at Saldanha Bay. The annual LNG throughput will determine the terminal size, which will be in line with modern terminal dimensions.

Modern Liquefied Natural Gas Carriers (LNGC's) – specially constructed insulated liquid bulk tankers – are described in **Chapter 5**. Dimensions and characteristics of the LNGC vessels to be used at the proposed Saldanha LNG terminal are outlined in this Chapter. A technical review of LNG import terminal types, namely trestle jetty, floating terminal and gravity based structure, is conducted in **Chapter 6**.

The aim of **Chapter 7** is to determine conceptual site layouts for the proposed LNG terminal. The reader will be familiarised with the Saldanha Bay area and the nautical and terrestrial features within. Restricted development areas will be identified and mandatory safety zones will be applied to potential terminal sites. Ultimately four conceptual site layouts will be chosen, taking marine design aspects, jetty orientation, land area requirements, exclusion zones and restricted areas into account. The schemes will apply high-level technical design, allowing scope for flexibility at each site.

A downtime analysis is conducted at each of the potential sites in **Chapter 8**. Wind and wave induced downtime will be estimated following statistical analysis and a series of numerical wave propagation models. The downtime study will identify any sites that could be deemed non-runners due to excessive wave action.

The Key Design Parameters (KDP's) of the LNG terminal are scrutinised in **Chapter 9**. Eleven critical technical parameters are discussed in relation to each of the conceptual site layouts proposed in Chapter 7. KDP's include terminal type, tug selection, land area requirements, dredging and environmental effects, among others. This discussion will result in an expansion of the previous conceptual layouts. Twelve plausible terminal layout schemes will be considered for review. The schemes are briefly described in **Chapter 10** and ranked in **Chapter 11** using a Multi Criteria Analysis (MCA). Schemes are scored using the KDP's which are assigned individual weightings. The MCA process will result in three favourable terminal layouts. A sensitivity analysis will justify the winning schemes.

The three selected sites are discussed in detail in **Chapter 13**, and their individual merits and drawbacks are highlighted. A single layout scheme is recommended, though a detailed technical evaluation of the three preferred sites is not conducted. Necessary steps to develop a detailed technical layout are outlined. Suggestions for future studies on the theme are proposed.

2 SOUTH AFRICAN ENERGY DEMAND

South African energy demand has been running close to maximum generation capacity over the past decade, and resulted in load shedding and blackouts in 2008. This Chapter reviews the Department of Energy's plans to increase capacity by constructing several new power plants before 2030, including natural gas fuelled stations. Sources of natural gas feedstock are discussed, and LNG is proposed as an ideal gas fuel.

2.1 IRP 2010

In 2010 the Department of Energy (DOE) initiated a process that would ultimately produce a plan outlining South Africa's energy demands, generation capacity and energy mix for 2010-2030 and beyond. Following public participation exercises and two subsequent revisions, the Integrated Resource Plan ("IRP 2010") was published as a Government Gazette in May 2011 (DOE, 2011a). The IRP is considered a "living plan", which is to be updated by the DOE every two years[i].

The primary focus of the IRP is to diversify the power generation mix, in effect reducing the country's reliance on coal burning power plants. Several reasons can be cited for the release of such a plan. At a glance, the more influential catalysts include:

- Frequent energy blackouts in 2007/2008 due to load shedding exercises implemented by Eskom, aimed at reducing strain on the grid
- South Africa's commitment to the Copenhagen Accord in 2009, whereby a carbon emission reduction of 34% by 2020 was pledged, increased to a 42% reduction by 2025 (UN, 2011)
- Necessary replacement of the ageing fleet of coal-based and nuclear power stations
- Questionable economic viability of coal plants following predicted increase in coal prices, which are set to match global prices in the near future (DOE, 2011a)
- Overwhelming increase in cost of new-build nuclear plants
- The potential of local and global niche market creation if a strong focus on Renewable Energy is instigated

The most pressing concern is certainly to ensure security of supply of energy to the national grid. The bout of blackouts in 2008 reportedly cost the economy R50m, and following a press release by Eskom in 2012 threatening further load shedding, the problem clearly has not been resolved (KZN Energy, 2012). Medupi and Kusile coal stations, due to come on line in 2018 (Eskom, 2012), will each add 4800 MW of power to the grid when complete. Until that time the demand is due to run dangerously close to the grid's potential capacity. Construction of additional power plants with short lead times will be necessary to contain the peak load, in addition to firing up the expensive, inefficient but effective 2400MW diesel burning Open Cycle Gas Turbine (OCGT) plants installed as emergency measures in 2008.

South Africa's commitment to the Copenhagen Accord will be an additional incentive to adhere to the proposed IRP. The country is under the international spotlight and may draw criticism from external funders or potential investors should the pledged figures not be met. CO_2 emissions will be constrained from 2025 onwards at a level of 275 Mton/yr. Emission levels should plateau at this value before declining to 225 Mton/yr in 2040 and again to 150 Mton/yr in 2050. Tremendous

[i] The first revision of the IRP, expected in 2012, had not been published at the time of writing (November 2013)

efforts will be required by Eskom, Transnet, Sasol and private mining companies to achieve this target. Eskom, producing 45% of the country's carbon emissions, will need to cut back drastically on carbon-heavy power generation and shift towards greener energies such as wind and solar farms, or cleaner fossil fuel generation such as natural gas.

Taking these matters into account, the Department of Energy proposed a detailed energy supply mix for the years 2010 to 2030 in the IRP 2010 (DOE, 2011a). The proposed total system capacity will comprise "New Build" power generation options starting 2012 and "Committed Build" projects that had been committed to prior to 2010 – namely the Medupi and Kusile coal stations. The decommissioning of 10,900 MW of power stations is included in the IRP 2010 forecast, the majority between 2022 and 2029. The IRP capacity breakdown was determined following two rounds of public interaction. Initially based on a cost-optimal model, it has since developed to take governmental policies on economic growth, job creation, water usage, security of supply and sustainable development into account.

Table 2-1 The Policy Adjusted IRP (DOE, 2011a)

	Committed build											New build options										
	RTS Capacity (coal)	Medupi (coal)	Kusile (coal)	Ingula (pumped storage)	DOE OCGT IPP (diesel)	Co-generation, own build	Wind	CSP	Landfill, hydro	Sere (wind)	Decommissioning	Coal (PF, FBC, Imports)	Gas CCGT (natural gas)	OCGT (diesel)	Import Hydro	Wind	Solar PV	CSP	Nuclear	Total new build	Total system capacity	Peak demand (net sent-out) forecast
	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW
2010	380	0	0	0	0	260	0	0	0	0	0	0	0	0	0	0	0	0	0	640	44535	38885
2011	679	0	0	0	0	130	0	0	0	0	0	0	0	0	0	0	0	0	0	809	45344	39956
2012	303	0	0	0	0	0	300	0	100	100	0	0	0	0	0	0	300	0	0	1103	46447	40995
2013	101	722	0	333	1020	0	400	0	25	0	0	0	0	0	0	0	300	0	0	2901	49348	42416
2014	0	722	0	999	0	0	0	100	0	0	0	500	0	0	0	400	300	0	0	3021	52369	43436
2015	0	1444	0	0	0	0	0	100	0	0	-180	500	0	0	0	400	300	0	0	2564	54933	44865
2016	0	722	0	0	0	0	0	0	0	0	-90	0	0	0	0	400	300	100	0	1432	56365	45786
2017	0	722	1446	0	0	0	0	0	0	0	0	0	0	0	0	400	300	100	0	2968	59333	47870
2018	0	0	723	0	0	0	0	0	0	0	0	0	0	0	0	400	300	100	0	1523	60856	49516
2019	0	0	1446	0	0	0	0	0	0	0	0	250	237	0	0	400	300	100	0	2733	63589	51233
2020	0	0	723	0	0	0	0	0	0	0	0	250	237	0	0	400	300	100	0	2010	65599	52719
2021	0	0	0	0	0	0	0	0	0	0	-75	250	237	0	0	400	300	100	0	1212	66811	54326
2022	0	0	0	0	0	0	0	0	0	0	-1870	250	0	805	1143	400	300	100	0	1128	67939	55734
2023	0	0	0	0	0	0	0	0	0	0	-2280	250	0	805	1183	400	300	100	1600	2358	70297	57097
2024	0	0	0	0	0	0	0	0	0	0	-909	250	0	0	283	800	300	100	1600	2424	72721	58340
2025	0	0	0	0	0	0	0	0	0	0	-1520	250	0	805	0	1600	1000	100	1600	3835	76556	60150
2026	0	0	0	0	0	0	0	0	0	0	0	1000	0	0	0	400	500	0	1600	3500	80056	61770
2027	0	0	0	0	0	0	0	0	0	0	0	250	0	0	0	1600	500	0	0	2350	82406	63404
2028	0	0	0	0	0	0	0	0	0	0	-2850	1000	474	690	0	0	500	0	1600	1414	83820	64867
2029	0	0	0	0	0	0	0	0	0	0	-1128	250	237	805	0	0	1000	0	1600	2764	86584	66460
2030	0	0	0	0	0	0	0	0	0	0	0	1000	948	0	0	0	1000	0	0	2948	89532	67809
TOTAL	1463	4332	4338	1332	1020	390	700	200	125	100	-10902	6250	2370	3910	2609	8400	8400	1000	9600	45637		

The year-by-year energy mix as stated in the "Policy Adjusted IRP" is shown in Table 2-1. Total system capacity in 2010 was 44,535 MW and the proposed capacity in 2030 is 89,532 MW.

Though the capacity is set to double, the expected peak demand will only increase from 38,885 MW to 67,809 MW. These figures propose a capacity buffer of 32% by 2030, while the narrowest predicted margin was 13% in 2012 (assuming all stations running at full capacity). It should be noted that in 2008 Eskom began load shedding when the grid demand was just 8% below total operating capacity.

Renewable energy sources will make up the lion's share of additional capacity, with a proposed added capacity of 18,800 MW (33% of the 56,539 MW proposed). Coal will still be highly valued, delivering 29% of the added capacity over the next 20 years, and new nuclear build will represent 12.7% of added capacity. It is remarkable that such emphasis has been placed on new renewable energy sources, since both DOE and Eskom have little experience with such technologies to date. Table 2-2 summarises the new-build and total capacity options proposed in the IRP 2010.

Table 2-2 Policy Adjusted IRP Capacity (DOE, 2011a)

	Total Capacity		Capacity added (including committed) from 2010 to 2030		New (uncommitted) capacity options from 2010 to 2030	
	MW	%	MW	%	MW	%
Coal	41071	45.9	16383	29	6250	14.7
OCGT	7330	8.2	4930	8.7	3910	9.2
CCGT	2370	2.6	2730	4.2	2370	5.6
Pumped Storage	2912	3.3	1332	2.4	0	0
Nuclear	11400	12.7	9600	17	3600	22.6
Hydro	4759	5.3	2659	4.7	2609	6.1
Wind	9200	10.3	9200	16.3	8400	19.7
CSP	1200	1.3	1200	2.1	1000	2.4
PV	8400	9.4	8400	14.9	8400	19.7
Other	890	1	465	0.8	0	0
Total	89532	-	56539	-	42539	-

Open Cycle Gas Turbine power will make up a significant 4930 MW (8.7%) of added capacity, but these low-efficiency diesel fuelled OCGT plants will only be utilised in the case of peak-shaving when the grid demand is unusually high. Combined Cycle Gas Turbines (CCGT), suitable as a base load source, only account for 4.2% of the additional capacity and will make up a low 2.6% of the total national capacity by 2030.

2.2 Energy Demand Forecasts

An accurate energy demand forecast is the most critical element in capacity planning, utility infrastructure development and ultimately power generation and delivery. Long term energy planning is, by its nature, a tricky process as it is based on predicted global and local economic growth and market fluctuations. The energy demand for 2030 forecast in IRP 2010 may not reflect the situation in 20 years' time. It is for this reason the IRP needs to be updated on a regular basis.

When compiling IRP 2010, energy forecasts were provided by Eskom's Systems Operations and Planning team (SO) and independently by CSIR, resulting in six growth forecasts. CSIR developed three projections (Low, Moderate, High) which predict a 49% energy demand increase (based on the

Moderate model) whereas Systems Operations predict a 72% increase over the 2012-2030 period. The variation around the Moderate CSIR forecast for the year 2030 is -5% (Low) to +8% (High) while the band is far wider for the Moderate SO forecast, varying -22% to + 17%. The expected annual energy demand modelled by CSIR and SO for the IRP 2010 is shown in Figure 2-1.

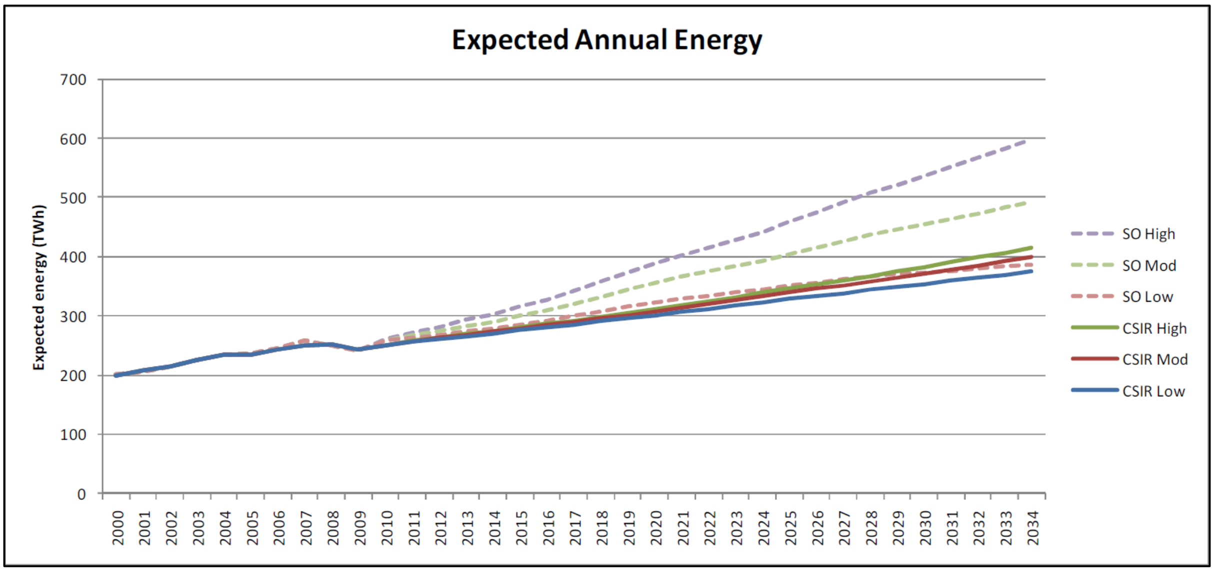


Figure 2-1 Energy demand forecasts input into IRP 2010 (DOE, 2011b)

The final IRP 2010 forecast as shown in Table 2-1 is founded on the SO Moderate prediction. The DOE are satisfied it represents the "least regret approach" where the impact of over-estimation (i.e. over-investment) is less than that of under-estimation (i.e. security of supply jeopardised) (DOE, 2011a).

2.3 IRP Review – National Planning Commission

The Department of Energy did not publish an IRP revision in 2012. An independent review of the IRP was compiled by the Energy Research Centre (ERC) for the National Planning Commission in April 2013 highlighting the lack of anticipated economic growth and subsequently energy demand in South Africa. The ERC report revealed revised curves that predict far lower demands than published in the IRP 2010. By 2030 the predicted peak demand is 50 GW as opposed to the IRP demand of 67.8 GW. The suggested installed capacity is a modest 61 GW as opposed to the 89 GW suggested in the IRP (Figure 2-2).

Such gross variations in installed capacity cannot be ignored. This New Power Plan (NPP) is based on the observation that the demand by the end of 2012 was far lower than predicted by the IRP (and still lower than the 2007 level) and will continue to grow at a slow rate (ERC, 2013). Other inputs include higher nuclear and renewable costs and a change in gas prices.

Aside from the substantial reduction in predicted energy demand, the New Power Plan varies from the IRP in its proposed energy mix. Both Plans consider coal to be a suitable base load source and both emphasise the inclusion of renewables in the mix. The NPP however shies away from the IRP's reliance on nuclear energy as a base supply, preferring natural gas powered CCGTs as a base supply instead. The recent and severe escalation of nuclear power costs[ii] is partly the reason for this. Nuclear plant construction costs were estimated at $3200/kW when the IRP draft was released in 2010. This was raised to $5000/kW when the Policy Adjusted IRP was published by the DOE in 2011. The ERC reported construction costs of a modern plant to be $7000/kW in 2013, which is in line with the Hinkley Point C plant in UK, whose cost was estimated at $7,100/kW in October 2013. The capital cost of a new natural gas power plant, by contrast, is between $720/kW and $1500/kW[iii] on average (NETL, 2013).

Furthermore, gas can provide both base and mid-merit power to the grid, and the generation facilities have a short lead time of 3 – 4 years. Its flexibility is key, particularly in an already stretched national grid.

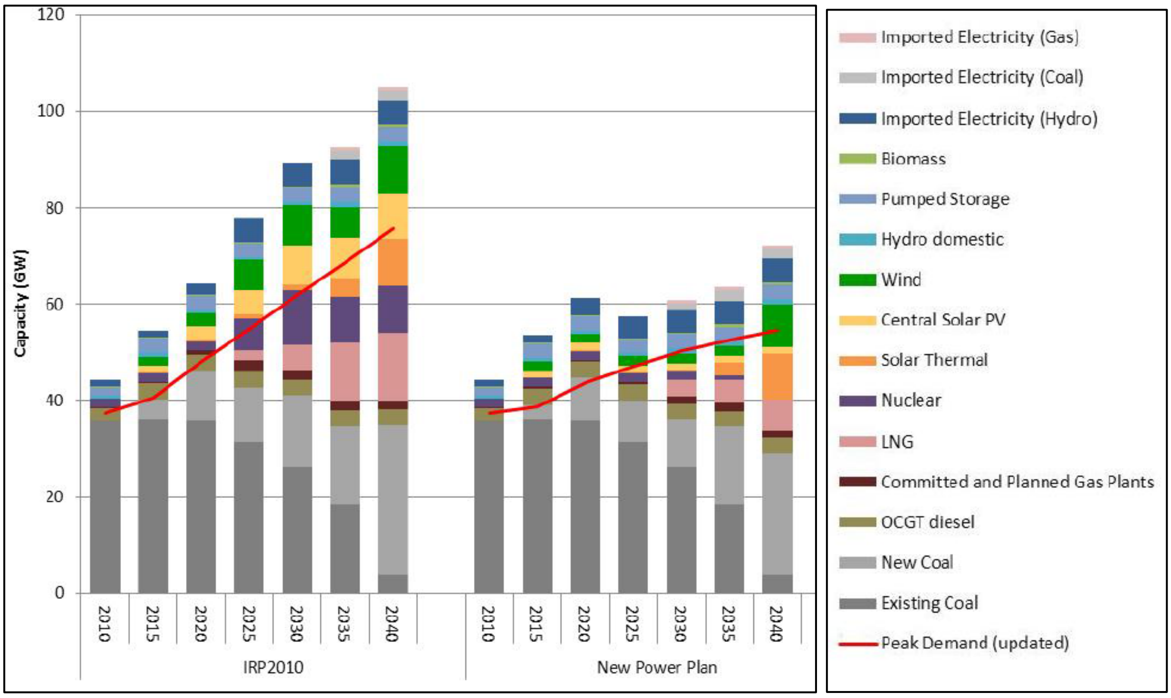


Figure 2-2 Total installed capacity predictions for IRP (2010) and NPP (2013) (ERC, 2013)

2.4 Natural Gas in the Western Cape

In 2005 the Department of Energy released a Gas Infrastructure Plan extolling the benefits of a nationwide gas network (DOE, 2005). Four conceptual gas networks were proposed to complement the existing, if limited, network in Gauteng and the Lilly line in KwaZulu Natal. These networks are 1) Mozambique to South Africa, 2) Western Cape, 3) West Coast to Gauteng and 4) Coastal Transmission Line. Of these four networks only one has been constructed (Mozambique to South Africa). The Western Cape has been earmarked as the most suitable province for a gas network

[ii] Primarily due to the Fukushima disaster in 2011, which has resulted in more stringent construction regulations in the nuclear industry.
[iii] $720/kW without Carbon Capture technology and $1500/kW with Carbon Capture & Storage (CCS)

(DOE, 2005). Its energy demand is relatively high yet the province imports the majority of its electricity from Mpumalanga and Limpopo, resulting in high transmission losses for Eskom. A natural gas powered plant in the Cape would be a far more efficient option.

DOE (2005) has declared the Western Cape a “gas province” due to the presence of the Ibhubesi gas field 105 km offshore of the West Coast. The Gas Infrastructure Plan proposes a short (273 km) subsea and onshore gas pipeline from the offshore field to Saldanha to feed a potential CCGT plant. An alternative gas supply is proposed, sourcing gas from the Kudu gas field in Namibia and delivering to Saldanha via a 633 km pipeline from Oranjemund. When the Gas Infrastructure Plan was released in 2005, neither of the proven reserves was large enough to warrant a pipeline network. To date neither project has been developed to deliver gas in the short to medium term future. It is very unlikely either of these sources will be able to deliver stock to a new build CCGT by 2019, as proposed in the IRP. Consequently natural gas will have to come from LNG imports or possibly shale gas reserves, which also require considerable development before delivery is possible.

It appears that due to its short lead time, ready availability and localised infrastructure requirements, LNG is the most suitable source of natural gas for the Western Cape.

2.5 Saldanha as a Location for LNG Imports & Gas Power Plant

Saldanha has been highlighted time and again as an ideal location for a new gas power plant. Since the development of the iron ore export terminal in the mid-1970s, and the subsequent expansion of the port facilities, the town has attracted both heavy and light industry firms. The most significant consumer of electricity is certainly AccelorMittal Saldanha Works, which requires 160 MW of power.

An Industrial Development Zone (IDZ) to be based in Saldanha has been mooted for some time, though the scheme has advanced considerably in recent years. The Department of Trade and Industry initiated a pre-feasibility study in 2007 to examine the potential for an IDZ. Pleased with the findings, a Saldanha IDZ feasibility investigation was compiled and published in 2011 (Wesgro, 2011). The proposed IDZ will cover an area of 650 ha and will count an Offshore Supply Base, Marine Repair Industry, Renewable Energy Industry, Wind Turbine Blade Manufacturing Industry, Titanium and Zirconium Complex and a Hot Briquetting Iron Plant as its key industries.

The IDZ will be power-thirsty due to the nature of the heavy industries and the immense cooling water requirements which will be supplied by desalination plants. The expected energy demand of the proposed IDZ varies between 192 MW (pessimistic scenario) and 616 MW (optimistic scenario). The projections span 25 years (Wesgro, 2011).

It is clear that an energy demand increase of this magnitude will require the output of at least one new-build plant. The advantages of gas as a base load plant (as opposed to coal or nuclear) have been described previously. Saldanha, with its proposed energy demands, proximity to Cape Town, and existing transmission network is an ideal location for a new build plant. A Combined Cycle Gas Turbine (CCGT) power plant is the most efficient and “greenest” of modern gas plants, and will be considered for this study.

LNG-derived natural gas (methane) is perhaps the most suitable feedstock for the proposed CCGT. LNG must be imported through a custom built and segregated liquid bulk terminal. Saldanha Bay is naturally the optimum location for an import terminal to reduce the distance from terminal to CCGT. There are several other reasons to support the development of an LNG terminal at Saldanha. Some key arguments include:

- Saldanha is an excellent natural deepwater port which can easily accommodate large bulk carriers without the need for extensive dredging
- Saldanha offers room for port expansion which other large ports (Durban, Cape Town) may not
- Mandatory exclusion zones around the terminal and tanker can be readily implemented in Saldanha Bay, whereas other South African ports are congested and heavily populated (Richard's Bay, Durban, Cape Town) and cannot guarantee these zones
- The LNG terminal, its re-gasification facilities and the downstream CCGT power plant are complementary installations and benefit from adjacent installation

The inauguration of South Africa's first CCGT plant may instigate a gas network in the Western Cape. Once a pipeline network is established, future power plant construction and generation becomes more financially attractive.

3 INTRODUCTION TO LNG

Technical properties of Liquefied Natural Gas are introduced in this Chapter. The LNG Value Chain that describes the process of gas extraction from the field, liquefaction into LNG, transport, and re-gasification into gas is described. The LNG import and re-gasification elements of the value chain are proposed at Saldanha Bay, and these facilities are studied in detail.

3.1 Liquefied Natural Gas

Liquefied Natural Gas (LNG) is natural gas, primarily methane (CH_4), which has been cooled to the point of condensation. Liquefaction of the gas occurs at -162°C under atmospheric pressure. Once liquefied, the volume of LNG is approximately 0.17% the volume of natural gas. This property enables enormous volumes of natural gas to be transported as LNG in single bulk cargoes. The density of LNG is relatively low, varying between 410-500 kg/m^3, making its transportation by sea particularly efficient (Foss, 2012).

3.2 LNG as a CCGT Feedstock

Approximately 21% of the world's electricity is produced by natural gas fuelled Open Cycle Gas Turbines (OCGT) or Combined Cycle Gas Turbines (CCGT). CCGT plants, which have been in large scale operation since the early 1990's, are potentially the "greenest" form of fossil fuel power and have consequently become the preferred new-build type of power plant globally (OECD/IEA, 2008).

In comparison with coal-fired power plants, CCGT plants emit far lower levels of SO_2 and NO_x, and approximately 50% CO_2 per kWh. Construction time is far shorter (industry maximum of 30-36 months), investment costs are far lower and delivery service is far more flexible. In most cases CCGT plants incur greater fuel costs, however in cases where coal transport distance to a plant is significant, relative CCGT fuel costs are lowered.

A CCGT consists of an air compressor and a gas turbine aligned on a single shaft connected to an electricity generator. Filtered air, compressed by the compressor, is used to fire the natural gas fuel in the combustion chamber of the gas turbine. Rotation of the turbines blades and shaft drives both the air compressor and the electricity generator. The hot exhaust gas from the turbine is recovered and used to drive a stream turbine electricity generator, producing additional power. The CCGT is thus composed of two energy generators: a gas turbine generator and a steam turbine generator. The gas turbine typically delivers twice as much energy as the steam turbine. This process is schematised in Figure 3-1.

Most CCGT plants consist of one gas turbine and one steam turbine. Many new plants are composed of modular units, with individual units capable of delivering approximately 50MW to 300MW, depending on the model. The CCGT capacity can therefore be readily customised, with additional units installed if greater capacity is required.

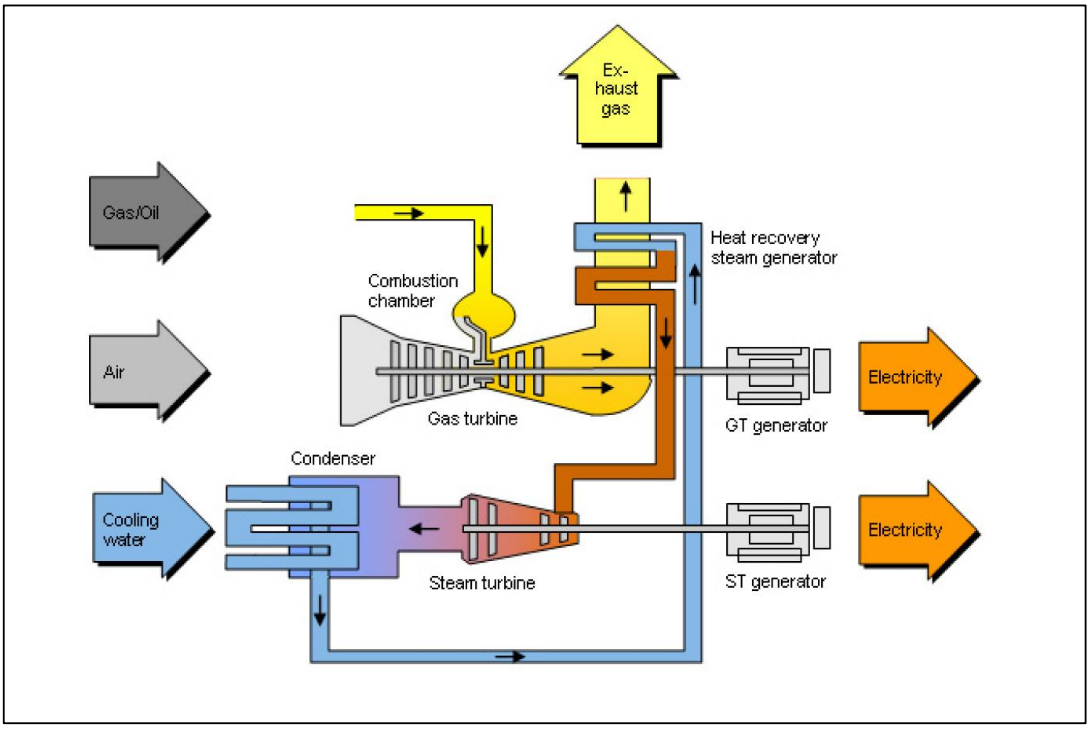


Figure 3-1 Principle of operation of natural gas fuelled CCGT (IEA-ETSAP, 2010)

South Africa does not have an established natural gas network, and the challenges of importing natural gas from the Namibian *Kudu* gas field or the West Coast *Ibhubesi* gas field in the short to medium future are noted in *Section 2.4*. LNG is an obvious choice as a natural gas feedstock for a new build CCGT.

3.3 LNG Value Chain

3.3.1 Introduction to LNG Value Chain

The practice of extracting natural gas from producer gas fields to the delivery of natural gas to the consumer entails a complex *LNG Value Chain* comprising several distinct and costly processes. It is for this reason that the LNG market remains dominated by the main International Oil Companies (IOCs) who have experience in enormous oil production projects and who have initial capital at their disposal. The value chain incorporates four key stages: 1) extraction of natural gas, usually offshore, 2) liquefaction of the gas into LNG, 3) transportation of LNG by liquid bulk carrier and 4) re-gasification of LNG into natural gas. These stages, expanded below, are schematised in Figure 3-2.

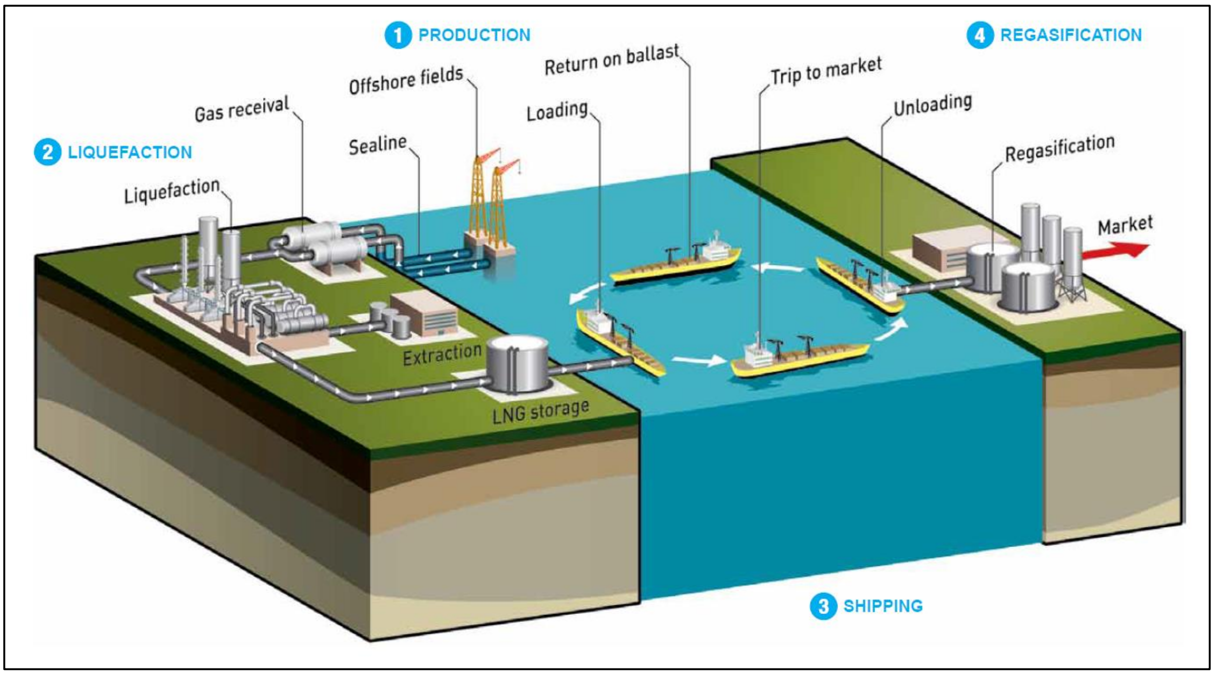


Figure 3-2 Schematic of LNG value chain (TOTAL, 2011)

3.3.2 Exploration and Production

Large natural gas fields are often discovered when exploring for oil. In some cases oil discoveries will be accompanied by large natural gas pockets. In the past this gas used to be flared off to relieve pressure at the well head. In recent years the large IOCs have begun to capture this gas and pipe it ashore for sale as a commodity.

Russia, which holds the majority of the worlds *proved gas* reserves, distributes the gas by pipeline to customers in Europe and mainland Asia via an enormous gas network spanning 164,700 km (GAZPROM, 2013). It is one of few countries that export the product by pipeline however. Many of the large gas fields are in isolated areas far from any potential gas markets, the majority of current fields being offshore. In these cases it is more profitable to convert the natural gas to LNG at the wellhead (or at the nearest point of land) and export the product via LNG carrier to the ultimate gas consumer. Once the distance from gas wellhead to customer exceeds approximately 3500 km (or 1100 km subsea), delivery by LNG becomes feasible (Foss, 2012).

3.3.3 Liquefaction

Natural gas predominantly consists of methane, making up approximately 90% by weight. Small amounts of propane, ethane, butane and nitrogen typically form part of the makeup. Natural gas is treated before liquefaction to remove undesirable elements such as dust, water, benzene, hydrogen sulphide and carbon dioxide, many of which will freeze as solids and can damage the liquefaction plant. This purification process can produce a gas that is nearly 100% methane, and the final level of purity will dictate the LNG selling price (Bramoullé, et al., 2004).

Once purified the temperature of the natural gas is reduced to -162°C using a complex refrigeration process, often involving large heat exchangers, gas fractioning and mixed refrigerant cycles (Linde, 2010). The gas liquefies and condenses into LNG, occupying a volume 1/585th of its original gaseous volume. The cryogenic liquid is kept at condensation point in large insulated storage tanks designed to withstand such extreme temperatures. Liquefaction is a land based process, though the first Floating LNG (FLNG) liquefaction vessel, the Royal Dutch Shell "Prelude FLNG" is expected to be in operation by 2016 (Offshore-Technology, 2013).

The *LNG Liquefaction Train* is the facility that receives gas from the wellhead, removes impurities, refrigerates into LNG and stores the LNG in cryogenic tanks to await export. At the end of 2012 there were 89 liquefaction trains in operation, based in just 18 exporting countries. These liquefaction trains represent an aggregate *nominal* capacity of 282 MMTA, whereas the global LNG consumption was 236 MMTA in 2012 (GIIGNL, 2013). The liquefaction process was typically the most expensive part of the LNG value chain, though the commissioning of large LNG trains and vessels, particularly in Qatar, have reduced production costs in recent years. Table 3-1 presents figures for world LNG export in 2012.

Table 3-1 Global LNG exports in 2012 (GIIGNL, 2013)

SOURCE OF IMPORTS

	10^6 m³ liquid	10^6 t	10^9 m³ (n) gaseous	Share (%)	Var. 2011 / 2012 (%)
Algeria	24.76	11.21	14.18	4.7	-10.2%
Egypt	10.94	4.74	6.35	2.0	-25.1%
Equatorial Guinea	8.23	3.62	4.76	1.5	-8.3%
Nigeria	43.34	19.58	24.75	8.3	3.5%
Norway	7.38	3.31	4.24	1.4	31.7%
Trinidad & Tobago	31.27	13.48	18.19	5.7	3.8%
Atlantic Basin	**125.92**	**55.93**	**72.47**	**23.7**	**-2.2%**
Abu Dhabi	12.13	5.66	6.86	2.4	-2.7%
Oman	17.82	8.15	10.12	3.4	0.7%
Qatar	168.48	76.39	96.15	32.3	1.4%
Yemen	11.06	4.89	6.38	2.1	-23.0%
Middle East	**209.49**	**95.09**	**119.51**	**40.2**	**-0.6%**
Australia	44.99	20.88	25.43	8.8	6.9%
Brunei	14.76	6.82	8.33	2.9	-3.8%
USA (Alaska)	0.41	0.17	0.24	0.1	-45.6%
Indonesia	42.38	18.97	24.27	8.0	-13.3%
Malaysia	51.45	23.72	29.28	10.0	-4.8%
Peru	8.56	3.86	4.92	1.6	4.3%
Russia	24.11	10.86	13.77	4.6	2.8%
Pacific Basin	**186.67**	**85.29**	**106.24**	**36.1**	**-3.1%**
Total	***522.08***	***236.31***	***298.22***	***100.0***	***-1.9%***

It should be noted that the distance between LNG exporting and importing countries has little bearing on the cost of the product to the importer. In general LNG suppliers confirm sales to downstream buyers, agreeing strict pricing structures in a Sale and Purchase Agreement (Farmer & Sullivan, 2012). The contract of sale usually lasts 20 years, assuring security of supply to the receiving terminal over this period. Demand volumes, frequency of delivery, duration of contract and quality of product will determine LNG price. Short term sales (<4 years) and spot-purchases account for just 25% of LNG trade (GIIGNL, 2013). Spot purchases are growing in popularity however.

3.3.4 Transportation by Liquefied Natural Gas Carrier

LNG Carriers (LNGC's) are liquid bulk vessels that are designed specifically for the transportation of LNG. LNGC's transport liquefied gas from the production site to an import terminal at the site of regasification. In most cases the route is direct from exporter to importer, though transhipment is becoming more commonplace. The LNGC vessels, like most other large bulk or ore carriers, are double hulled to prevent hull rupture during grounding or collision. LNG is carried aboard the ship in four or five self-contained compartments. These storage tanks are double walled for rigidity and insulated to maintain the LNG temperature of -162°C (McGuire & White, 2000). The containment tanks, which protrude through the deck, are very distinctive and are usually one of two types: the spherical Moss type and the Membrane type as visible in Figure 3-3. The containment tanks are kept near atmospheric pressure.

Figure 3-3 LNGC vessels: Moss type (l) and Membrane type (r) (GIIGNL, 2013)

A modern LNGC carries roughly 145,000 m^3 of LNG cargo, and has a length of 290 m, breadth of 49 m and laden draught of 12.5 m.

A more detailed investigation of LNG Carrier design and shipping trends is conducted in *Section 5 – LNGC Characteristics.*

3.3.5 LNG receiving terminals

LNG import ports or sites require a dedicated, sheltered and isolated LNG receiving terminal (SIGTTO, 1997). The terminal operator usually imposes a strict safety exclusion zone around the jetty inside which no other vessels can operate. The jetty is typically a piled trestle type structure against which the laden LNGC berths. The cryogenic cargo is unloaded from the vessel using insulated hoses that can withstand the severe temperatures of the liquid payload. The LNG is pumped ashore in raised, insulated pipelines at atmospheric pressure.

3.3.6 Cryogenic Storage and Re-gasification

Large insulated storage tanks, located ashore of the import jetty, are constructed to store the LNG shipment. Individual tanks typically contain 100,000 m^3 to 150,000 m^3. The combined tank volume should be large enough to contain the total import shipment, the total LNG due to be regasified before the next shipment, and a buffer volume to account for shipment delay.

LNG from the LNGC is pumped directly into the shoreside storage tanks. From here the LNG is pumped to the regasification facility where the LNG is gradually heated up using a system of vaporisers. The LNG reaches boiling point, expands and vaporises into its natural gaseous state. The LNG is heated until it reaches ambient temperature, at which point it occupies a volume 585 times that of its liquefied state. Hereafter the gas is quality tested for impurities and percentage methane, is odourised and pressure regulated before being delivered to the end user.

3.4 Layout of an LNG Import Terminal

3.4.1 Standard Import Terminal Layout

The LNG import terminal is defined as the total nautical (wet) and terrestrial (dry) infrastructure necessary to receive LNG by bulk carrier, store and process the LNG and finally deliver NG to the consumer.

The "wet" infrastructure includes measures to create a sheltered berthing environment (i.e. a breakwater structure) and dredging of the seabed to accommodate the draught of a laden LNGC vessel. The key element of the import terminal is the jetty where the LNGC berths and offloads the liquid product. The most common jetty design is a piled trestle jetty, connected to the shore by an elevated causeway. Floating terminal technologies have become popular in recent years however, and both wet and dry terminal elements vary somewhat from the standard trestle jetty. This is a very young technology and accounts for about 12% of world import terminals. Offshore terminal types are discussed in *Section 6 –Import Terminal Types.* The example of a traditional trestle jetty will be used hereafter to illustrate the various elements of the integrated terminal layout.

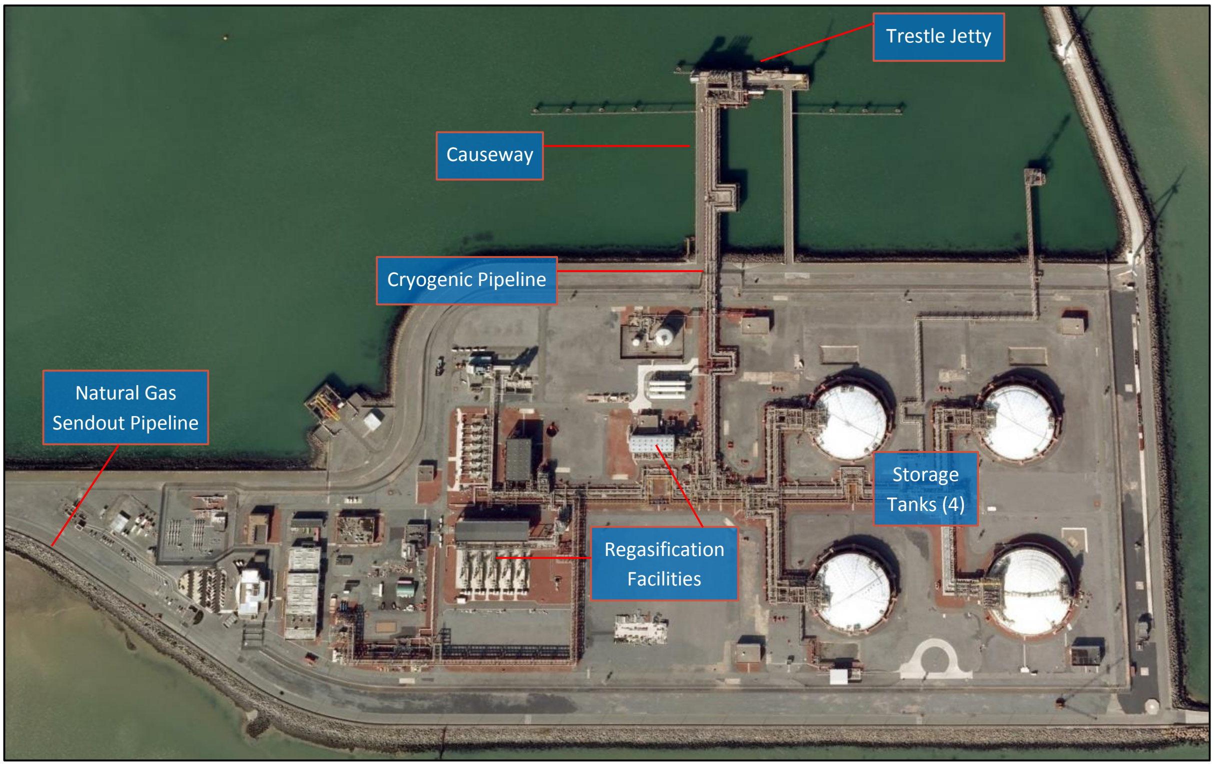


Figure 3-4 LNG import terminal layout in Zeebrugge (Google Earth, 2013a)

The "dry" infrastructure includes LNG storage tanks, insulated cryogenic pipelines and standard natural gas pipelines, a regasification facility, a natural gas regulation facility and ancillary buildings.

The critical components of an import terminal facility are highlighted in Figure 3-4, which shows an aerial image of a reclaimed terminal area in Zeebrugge, Belgium.

Traditional Trestle Jetty

The majority of import terminals comprise a single import jetty, and consequently the L-Jetty arrangement is enlisted. This layout allows for sufficient room for manoeuvring and berthing, and tug vessels have the luxury of operating alongside or behind the mooring dolphins to assist mooring (Ligteringen & Velsink, 2012). The key technical components of a trestle jetty are highlighted in Figure 3-5.

The mooring arrangement generally consists of 4 to 6 mooring dolphins and 2 to 4 breasting dolphins, which may double as spring line mooring dolphins. Breasting dolphins differ from mooring dolphins in that they are flexible, and designed to absorb the kinetic impact of the berthing LNGC. Breasting dolphins are typically designed to withstand up to 300kN/m^2 of force, whereas LNGC hulls are rated to 200kN/m^2 (Ligteringen & Velsink, 2012). The mooring bollards are equipped with quick release hooks, programmed to release the mooring lines when the line load on the bollard exceeds a percentage of the rated Minimum Breaking Load (MBL). A catwalk, suspended between the dolphins, allows access to the bollards. The choice of berthing and mooring dolphin strength, fender strength, line MBL and mooring line arrangement are aspects of the detailed design stage of terminal development, and will not be addressed in this study.

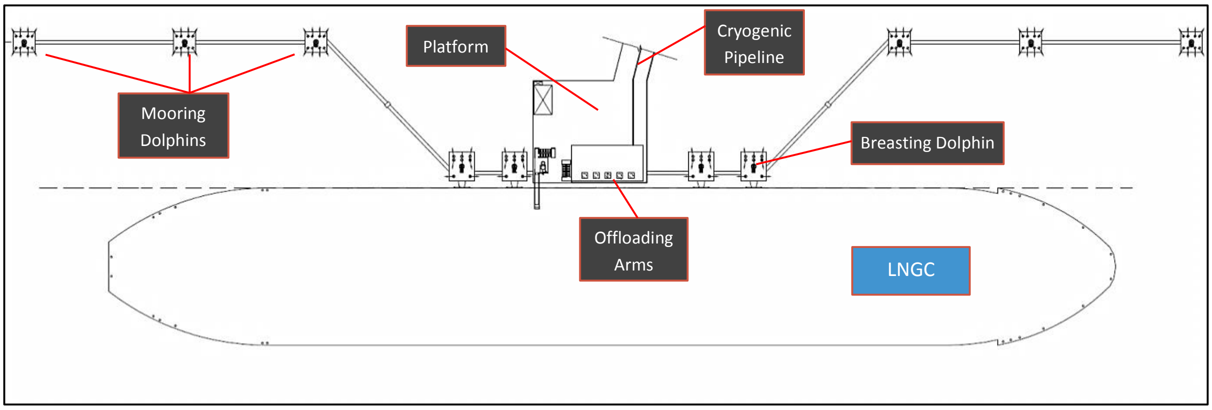


Figure 3-5 Quayside features of an LNG jetty (Shannon LNG, 2007)

Offloading Operation

An offloading platform is situated at the head of the jetty. The platform, comprising a 35 m x 40 m concrete slab supported by steel piles, houses the LNG offloading equipment. The LNG offloading arms are situated at the seaward face of the platform and are positioned to connect to the offloading manifold on the LNGC, usually at midships[iv]. Modern terminals utilise 4 or 5 Chicksan offloading arms; 2 or 3 to transfer the cargo, one to return vapour to the containment tank and one spare that can act as an offload or vapour return arm. Figure 3-6 shows cargo transfer via three offloading arms using FMC Technologies Chicksan arms.

[iv] The offloading manifold tends to be at midships on Membrane and Prismatic vessels. Due to the geometry of Moss vessels, the manifold can be between 32 m forward or 10 m aft (astern) of midships (Legoe & Imrie, 2007).

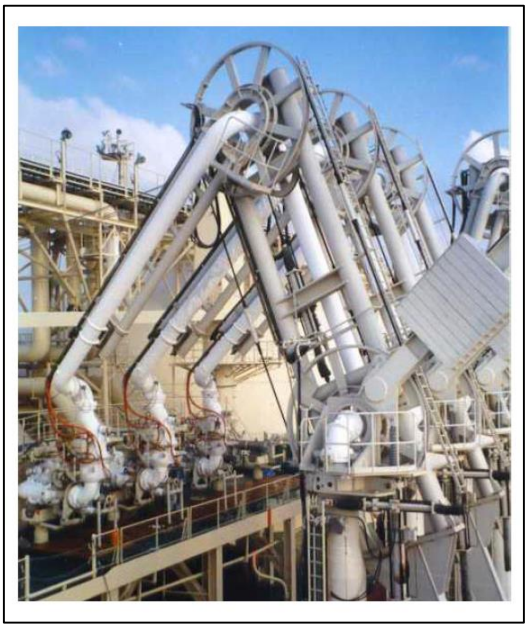


Figure 3-6 Chicksan LNG offloading arms by FMC (Leick, 2005)

Each arm can offload up to 5,000 m^3 of LNG per hour (Levitan & Associates Inc., 2007). When calculating total offloading rates at an LNG terminal, the industry benchmark of 10,000 m^3 LNG per hour is often used.

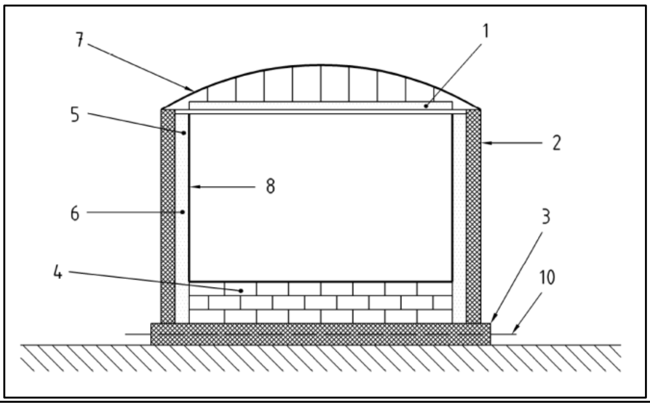
LNG offloaded at the jetty head is pumped ashore in one or two cryogenic pipelines, while an additional pipeline returns vapour to LNGC from the shore facilities (Legoe & Imrie, 2007). The insulated pipes run above the suspended trestle deck or causeway until they reach the LNG storage tanks. The heavily insulated pipelines are particularly expensive, so the distance between jetty head and storage tank should be kept to a minimum.

LNG Storage Tanks

LNG is pumped directly from the LNGC vessel to insulated storage tanks on shore. Most terminal storage tanks are located above ground and are double walled full containment tanks. The inner tank walls are made of a 9% nickel-steel alloy and are heavily insulated to withstand the operating temperature of -162°C. The outer walls, which act as a secondary containment barrier in the (unlikely) event of the inner wall leaking, are made of pre-stressed concrete, often with a carbon steel inner lining. The foundation is a heavily reinforced concrete slab. Figure 3-7 describes the storage tank design elements.

Full containment tanks and membrane type tanks do not require bund walls, as their secondary walls can withhold the cryogenic stock. If single or double containment tanks are installed, a bund wall must be able to hold 110% of the volume of biggest tank (CEN, 2007). There has not been a reported incident of crack failure of 9% nickel-steel tank walls in 35 years of their use (Foss, 2012).

The average capacity of new-build tanks installed in the past decade is 150,000 m^3, though tanks capable of containing 200,000 m^3 of LNG are not uncommon (GIIGNL, 2013). The storage volume of the terminal's tanks should be sufficient to contain the total import shipment, the total LNG due to be regasified before the next shipment, and a buffer volume to account for shipment delay. It is ideal to utilise at least 2 storage tanks as opposed to a single large one for redundancy purposes (repairs, scheduled maintenance etc.). For reference, a 200,000 m^3 tank could have a diameter of 100 m and height of 50 m approx. (Shannon LNG, 2007).



Key

1	suspended deck (insulated)	6	loose fill insulation
2	pre-stressed concrete secondary container	7	outer steel roof
3	concrete raft	8	primary container
4	base insulation	9	reinforced concrete roof
5	insulation on inside of secondary container	10	bottom heating

Figure 3-7 Components of a full containment LNG storage tank (CEN, 2007)

Boil Off

The phenomenon of “boil-off” is inherent in LNG storage, both in LNGC containment tanks and in land based LNG storage tanks. Despite the effects of insulation between the inner and outer tank walls, it is not possible to contain all the LNG at -162°C. Some amount of LNG, generally that touching the inner walls of the tank, heats beyond this boiling point and vaporises. The vapour within the tank is monitored and released in order to maintain constant pressure within the tank. In fact LNG is intentionally stored at its boiling temperature (at atmospheric pressure) to encourage “cryogenic boiling”. The heat extracted during the phase change from liquid to gas results in a cooling of the remainder of the LNG in the tank (Glomski & Michalski, 2011).

Boil Off Gas (BOG) can be re-liquefied on site to form LNG or can be used to fuel generators, such as a CHP plant. During ship to shore LNG transfer, the BOG is sent back to the vessel’s holds in the vapour return pipeline, and occupies the void in the containment tanks left during the LNG transfer process. During periods of storage of LNG in landside tanks, approximately 0.05% boil off is expected per day (Shannon LNG, 2007).

Regasification

The regasification process converts LNG from a cryogenic liquid state to NG in its natural gaseous state at ambient temperature. LNG is pumped out of the storage tanks using low pressure in-tank pumps. It is combined with any re-liquefied BOG gas and propelled through high pressure pumps to the regasification plant at 90 bar. Pump capacities are between 400 m^3/hr and 500 m^3/hr, often with two pumps per LNG tank.

There a number of vapouriser technologies used to regasify LNG, though the more common applications are Open Rack Vapourisers (ORV) and Submerged Combustion Vapourisers (SCV), which make up up 70% and 25% of installed vapourisers respectively (Patel, et al., 2013). Others include

Shell and Tube Vapourisers (STV), Ambient Air Vapourisers (AAV), Combined Heat and Power (CHP) SCVs and Intermediate Fluid Vapourisers (IFV).

Open Rack Vapourisers (OCV's) are perhaps the most simple vapouriser technology, as they use seawater to heat up the LNG. LNG flows through finned aluminium tubes while the seawater counterflows on the outside of the pipes, heating up the LNG. The saltwater is discharged to the ocean at a lower temperature than the inlet water temperature (approx. -5°C temperature drop). A simplified schematic of the ORV process is shown in Figure 3-8.

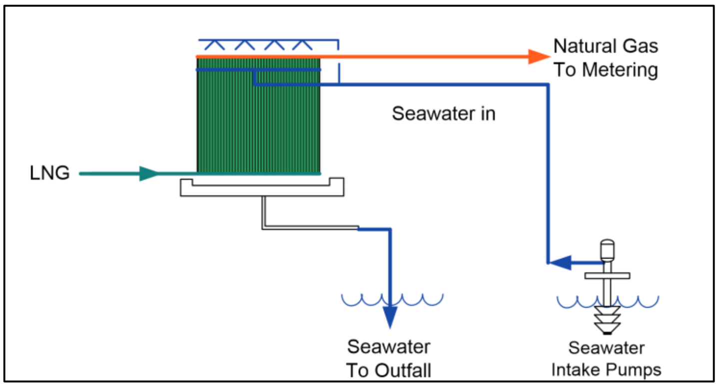


Figure 3-8 Schematic of Open Rack Vapouriser operation (Patel, et al., 2013)

The installation costs of this technology are quite high however, as marine works such as intakes and outfalls must be developed as well as pre-cycle water treatment plant. Running costs are far lower than any other vapourisation technology however. Depending on location, the ORV process may raise local environmental concern due to the discharge temperature differential.

Submerged Combustion Vapourisers (SCV's) use a fresh water basin at constant temperature to heat up the LNG product. LNG passes through a network of stainless steel pipes immersed in the warm water, which is heated using a series of submerged combustion burners. The burners require diesel or natural gas as a feedstock however, so running costs are quite high. Where vapourised natural gas is used as the combustion burner fuel, the SCV process consumes between 1% to 2% of the total LNG sendout rate (Levitan & Associates Inc., 2007). Environmental emissions are therefore far higher with a SCV vapouriser, although they do not discharge any brine into the nearshore marine area. A simplified schematic of the SCV process is shown in Figure 3-9.

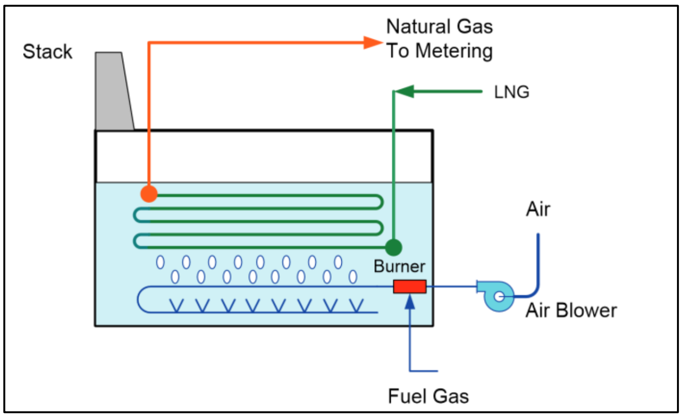


Figure 3-9 Schematic of Submerged Combustion Vapouriser operation (Patel, et al., 2013)

Modern vapourisers process between 150T/hr and 180 T/hr of LNG into natural gas, with a maximum rate of 300T/hr, achieved by OVR vapourisers operating at 100% (Patel, et al., 2013). Assuming no losses[v], the corresponding NG output rate is 195,000 m^3/hr to 235,000 m^3/hr, and a maximum of 390,000 m^3/hr (IGU, 2012b).

Once the LNG has been vapourised, the NG is pressure regulated and odourised before delivery to the consumer.

3.4.2 Considerations for CCGT

Production of pipeline natural gas is essentially the final step in the LNG Value Chain. In many countries the NG will feed directly into the national natural gas grid, and will be boosted and redistributed as necessary. In mainland Europe, where a substantial NG network prevails, regasified natural gas is traded across borders as a commodity.

Natural gas can also be sold in parcels to private users who may have high power demands. These buyers, often medium or heavy industries, will use the gas as fuel in their own small scale generators. Such a concept should be considered in the context of the proposed Saldanha IDZ.

The primary consumers of imported and regasified LNG are Combined Cycle Gas Turbines. Indeed, the concept of a CCGT in the Western Cape, particularly in Saldanha Bay, was the initial onus for the study of a conceptual LNG import terminal in the Bay.

In the case where a CCGT utility is the key consumer of imported LNG, the design of many elements of the LNG import terminal will be dependent on the input demands of the utility. The vapourisation rate of LNG in particular will be dictated by the NG combustion rate of the CCGT. Other design elements, such as the size of LNG storage buffer to guarantee CCGT operation during port downtime, must be considered and are discussed in *Section 4 - LNG Terminal Throughput*.

3.4.3 Practical Design Factors and Assumptions

Following from the introduction to LNG terminal layout (*Section 3.4.1*), a number of general design practices can be deduced. These are summarised as follows:

- Locate the terminal in a sheltered environment, where wind and wave related downtime will not be a problem. Security of supply of natural gas to a CCGT is paramount.
- The distance between the LNG offloading point at the jetty head and the LNG storage tanks should be minimal. The length of insulated cryogenic pipelines and piled jetty infrastructure has massive bearing on the cost of the terminal.
- Sufficient space should be provided ashore for LNG tanks, regasification facilities and the mandatory exclusion zones that surround them.
- The terminal should be located away from other port operations and landside facilities should be distant from populated areas.
- The distance between regasification plant and CCGT is not critical, as natural gas pipelines are affordable and easy to install when contrasted with insulated LNG pipelines.

[v] Losses are bound to be incurred during every stage of the LNG Value Chain, including storage, pumping and regasification. The values printed are the *rated* pump or vapouriser performance values, which will never be achieved in practice (Yang & Huang, 2004).

3.4.4 Complementary CCGT & Vapouriser Siting

There exists a strong technical argument for the side-by-side construction of the regasification facility and the CCGT plant. During the production of electrical energy in a CCGT, exhaust gas exits the gas turbine and enters the atmosphere at 90°C. Similarly, cooling water from the steam turbine is discharged at a higher temperature than the cool intake water. These processes are schematised in Figure 3-1.

Conversely, the heating water used in the LNG regasification process is discharged from the vapouriser at a lower temperature than the intake seawater. This concept applies solely of course to the Open Rack Vapouriser process (refer to Figure 3-8).

In recent years, a handful of utilities have taken the initiative to combine a new-build CCGT with an LNG terminal development. Built adjacent one another, the two facilities share the same open loop heating/cooling seawater. Intake seawater enters the regasification plant and exits the vapouriser approximately 5°C lower after heating up the LNG. This "cooled" seawater then enters the cooling network of the CCGT plant. Upon discharge from the CCGT the "heated" seawater is discharged back to the ocean.

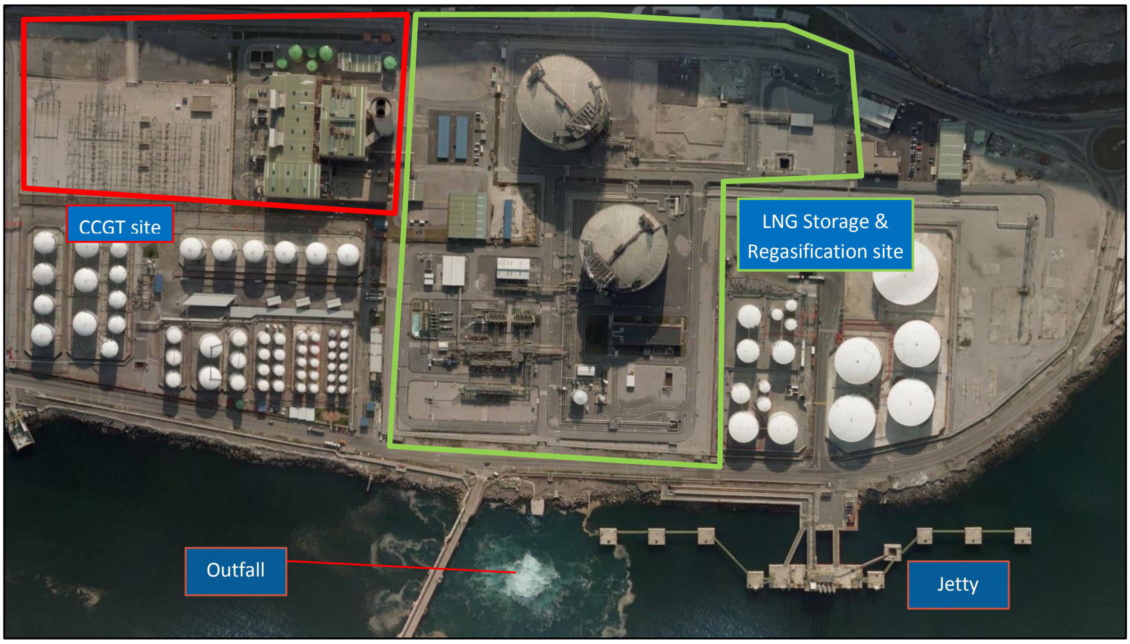


Figure 3-10 Site layout at Port of Bilbao (Google Earth, 2013b)

One such complementary facility was commissioned at the port of Bilbao in 2003 (Goiri, 2005). It is reported that following the -5°C drop in seawater temperature after LNG regasification, the same water was heated by 3°C in the CCGT turbines before discharge. The net temperature difference at discharge was subsequently ΔT= -2°C (A Barrel Full, 2012). This minor temperature differential between intake and discharge brine may prove to be an important mitigation factor in the case of LNG terminal construction in an environmentally sensitive area. The layout at the Port of Bilbao is shown in Figure 3-10.

It should lastly be noted that an LNG terminal is rarely developed solely to serve a singular CCGT facility. The CCGT may be the major consumer, but surplus LNG is usually imported to supply the regional natural gas network. The economies of scale of LNG transport by LNGC dictate that in order to be profitable, substantial volumes of LNG need be shipped at one time. It may not be feasible to import small or infrequent volumes of LNG with the sole goal of fuelling a CCGT power plant.

4 LNG TERMINAL THROUGHPUT

A feasible annual throughput of LNG at the import terminal is estimated in this Chapter. The total LNG volume – quoted in Million Metric Tonnes per Annum (MMTA) – is derived following a study of planned energy generation, storage and buffer volumes and cargo sizes. The throughput will determine the overall import facility dimensions.

4.1 Introduction to Terminal Throughput

South Africa's predicted energy demand has been published in the Department of Energy's IRP 2010. This document clearly stipulates the amount of energy to be created by a Combined Cycle Gas Turbine facility between 2019 and 2030, when the utility will run at maximum capacity. The energy output of the proposed CCGT plant at Saldanha should cater to the demands of the IRP 2010 – specifically 2370MW.

The necessary annual import volume of LNG required to fuel the CCGT can be calculated using the 2030 power output as a benchmark. The LNG value chain – components of which are described in *Section 3.3* – is reverse engineered to derive the total annual and individual LNG shipment volumes. Steps necessary to configure terminal throughput are listed in Table 4-1.

Table 4-1 Procedure to configure import facility throughput

Step	Description	Unit	Notes & Additional Deliverable
1	Define CCGT power output	GW	Calculate no. & size of CCGT turbines to deliver power
2	Determine energy output/yr	GWh/yr	-
3a	Calculate NG input into CCGT turbines	BCM/yr	-
3b	Calculate NG output from vaporisers	BCM/yr	-
4	Calculate LNG input into vaporisers	m^3/yr	Account for Boil Off losses
5a	Determine rate of vapourisation of LNG	T/hr	Calculate no. & size of vapourisers to regasify LNG at determined rate
5b	Determine LNG output rate from storage tanks	m^3/hr	-
6	Calculate storage tank volume	m^3	-
7	Define design LNGC volume per shipment	m^3	-
8	Calculate buffer volume in storage tank	m^3	-
9	Calculate frequency of vessel delivery	days	-
10	Conduct sensitivity analysis	-	Alter cargo bundle, frequency of call & storage tank volume
11	Define import facility size	MMTA	-

4.2 CCGT Energy Generation

The proposed 2370 MW of new build CCGT energy is to be delivered in two Phases. Phase 1 will deliver 711 MW by 2021 while Phase 2 plans on delivering an additional 1659 MW by 2030 (DOE, 2011a). The IRP 2010 further disseminates the Phases into year by year deliverables. The proposed power generation increments are presented on a yearly basis in Table 4-2.

Table 4-2 CCGT power delivery on year-by-year basis (DOE, 2011a)

Phase	Year	Added Power (MW)	Total Power (MW)
1	2019	237	237
	2020	237	474
	2021	237	711
2	2028	474	1185
	2029	237	1422
	2030	948	2370

A CCGT plant comprises two turbines: a gas turbine, fuelled by natural gas from LNG and a steam turbine, propelled by steam generated from the exhaust gases of the gas turbine. This principle is explained in *Section 3.2*. The stated total CCGT power output is a combination of a number of individual turbines of varying sizes. It is likely the incremental power increases of 237 MW were calculated with a specific turbine in mind, i.e. one new 237 MW turbine each year between 2019 - 2021, and so on. It is sensible to work on a redundancy principle of (n+1) units of hardware to ensure full operation during repair or maintenance on an individual turbine. Using the forecast in Table 4-2, ten turbines each delivering 237 MW of power will be necessary, with one additional unit installed as backup.

Combined power delivery by 2030 will be 2.37GW. This equates to 20,761 GWh of energy per year, considering 8760 hours per year. However, base load power plants typically operate 7000 hr/yr, inferring that in order to deliver 2.37GWh of energy per year, the installed CCGT turbine capacity needs to increase by a factor of 1.25 (IGU, 2012a). The CCGT power capacity is thus revised to 2963 MW.

The revised turbine unit capacities are shown in Table 4-3. Seven CCGT turbines[vi] have been selected, each delivering either 467 MW or 565 MW. The year of commission of each turbine is suggested. The total plant capacity is 3465 MW to account for one spare 467 MW turbine. The turbine sizes were selected following a review of CCGT gas turbines manufactured by Alstom (Alstom, 2012) and Siemens (Siemens, 2008), who are industry leaders. The selected models for this study were Alstom turbines (KA26-1 & KA13 E2-2), simply because their power rating better matched the revised power output requirements described in Table 4-3.

Table 4-3 Revised CCGT turbine capacities

Phase	Year	Revised Additional Power Required (MW)	CCGT Turbine Size (MW)
1	2019	297	467
	2020	297	467
	2021	297	467 (spare)
2	2028	593	467
	2029	297	467
	2030	1183	2 x 565
Total	**2030**	**2963**	**3465**

[vi] i.e. a combined Gas/Steam turbine unit

- ***Total Power Output: 2370 MW***
- ***Total Energy Output: 20,761 GWh per year.***

4.3 Natural Gas Feedstock

The CCGT will deliver 20,761 GWh of energy per year, using regasified LNG as a fuel feedstock. The volume of natural gas necessary to provide such an output will depend on several parameters, including altitude, ambient air temperature, relative humidity and calorific value of the gas. The International Gas Union (IGU, 2012b) provides a simplistic ratio that relates natural gas input to energy output from a CCGT, where:

1BCM natural gas = 5,800 GWh electricity

This implies 1GWh of energy requires an input of 172,414 m^3 of LNG. Therefore 20,761 GWh of energy per year will require an input of 3.58 BCM[vii] natural gas per year. A value in BCM natural gas per year, which identifies the natural gas *output capacity* of an LNG terminal, is often used to describe the size of a facility.

- ***Annual capacity required: 3.58 BCM natural gas***

4.4 LNG Input to Vapourisers

The regasification process should deliver 3.58 BCM of natural gas to the CCGT. The relationship

$$1\ m^3\ LNG = 585\ m^3\ natural\ gas$$

is used to determine the LNG necessary for regasification (IGU, 2012b). Therefore 6,118,840 m^3 (=$3.58x10^6/585$) of LNG per year is required as input to the vapourisers.

LNG will be regasified using either an Open Rack Vapouriser (ORV) or a Submerged Combustion Vapouriser (SCV). While the ORV process is very light on power, the SCV process may burn up to 2% of the regasified LNG as heating fuel. The SCV process will thus be used as a more conservative approach to estimate the LNG input requirement. Additional LNG will therefore be necessary to achieve the desired natural gas output. LNG input to the vapourisers is revised as 6,241,217 m^3 per year. Considering the relationship

$$1\ m^3\ LNG = 0.45\ Tonne,$$

the net mass of LNG required for regasification is 2.81 MMTA[viii]. A value in MMTA, which identifies the total amount of LNG regasified at an LNG terminal per year, is also used to describe the size of a facility.

- ***Annual LNG throughput required: 2.81 MMTA***

[vii] BCM = Billion Cubic Metres
[viii] MMTA = Million Metric Tonnes per Annum

4.5 Vapouriser Selection

The natural gas output following the regasification process is 3.58 BCM per year. However, taking the 2% loss of LNG due to SCV vapourisation into account, the *LNG input equivalent* value is 3.65 BCM per year, or 416,749 m^3 natural gas per hour. To achieve this, the vapourisers will need to process 712 m^3/hr of LNG, or 321 T/hr of LNG.

LNG vapourisers are usually rated according to the Tonnes per hour of LNG they regasify. As noted in *Section 3.4.1*, modern vapourisers are capable of regasifying 150 T/hr to 180 T/hr. It is therefore suggested that 2 x 180 T/hr capacity vapourisers are utilised, with an additional vapouriser of the same rating as a spare.

- ***Vapouriser Output: 417,000 m^3 natural gas per hour***
- ***Vapouriser Throughput: 321 T/hr LNG*** (2 x 180 T/hr vapourisers + 1 x 180 T/hr spare)

4.6 Size of Storage Tanks

The average capacity of new-build tanks installed in the past decade is 150,000 m^3, though tanks capable of containing 200,000 m^3 of LNG are not uncommon (GIIGNL, 2013). It has been mentioned that it is sensible design practice to install at least two moderately sized tanks as opposed to a single, large tank for redundancy reasons.

Due to the rigid design standards and elevated costs associated with the construction of cryogenic tanks (CEN, 2006), developers are reluctant to over-size the tank dimensions despite the obvious buffer capacity benefits of doing so.

The combined storage tank volume should be substantial enough to contain the following:

- The LNG bundle[ix] of the largest vessel for which the terminal is designed[x]
- The LNG volume regasified between LNGC cargo deliveries
- A buffer volume of LNG to guarantee NG supply to the CCGT in the case of port downtime

It should be evident that an under-sized tank will lead to critical problems such as minimal or no buffer volume, inability to cater for large LNGC's and a high cargo delivery frequency.

Tank size

The design of the storage tank capacity is an iterative process. Initially, a design vessel is selected. It is accepted that a 145,000 m^3 carrier is the "standard" size vessel plying the LNG routes. A review of the existing international LNG fleet is conducted in *Section 5*, and this assumption will be verified. Secondly, storage tank capacity is assumed. An estimate of 2 x 150,000 m^3 tanks is made, giving a total capacity of 300,000 m^3. Using these starting assumptions the buffer and delivery frequency can be derived.

[ix] An LNG "bundle" is the single volume of cargo aboard an LNGC that will be offloaded at the receiving terminal. A bundle is described in m^3 of LNG.

[x] This is known as the "Design Vessel", and will be described in *Section 5 – LNGC Characteristics*.

LNG Flow Rate

It has been shown that the terminal LNG throughput is 6.24 million m^3/yr. Consequently the daily LNG throughput to feed the vapourisers is 17,100 m^3/day. Therefore each delivery of the standard vessel will last 8.5 days of CCGT operation. Furthermore it will take 17.5 days of steady regasification to empty the storage tanks when completely full.

Delivery Frequency

Assuming all deliveries are 145,000 m^3, 43 deliveries will be made per year, with a frequency of 8.5 days. This compares well to the delivery frequency at many modern terminals, where an interval of 7-10 days is common (Levitan & Associates Inc., 2007) & (Leick, 2005).

LNG Buffer

The terminal will consume the same volume of LNG as delivered by the standard vessel during the period between shipments, i.e. 145,000 m^3. Considering a storage capacity of 300,000 m^3, this leaves a buffer of 155,000 m^3, or 9.1 days of throughput.

A buffer volume equal to 9.1 days of LNG throughput implies that the CCGT power plant can operate as normal for this period. It is unlikely that wind or weather related downtime at the delivery port will account for 9.1 days delivery downtime. Delays at the loading port and during shipment must also be taken into account however. A buffer LNG supply period of 1 to 2 weeks is considered acceptable. The relationship between port downtime in Saldanha and the buffer volume will be better understood following a study of wind and wave induced downtime in Chapter 8.

4.7 Sensitivity Check

Variation of the parameters *storage tank volume*, Vol_{Tank} and *LNGC cargo volume*, Vol_{LNGC} will affect the delivery frequency, buffer volume and therefore buffer period of the terminal. The assumption of Vol_{Tank} = 300,000 m^3 and Vol_{LNGC} = 145,000 m^3 delivered satisfactory values of delivery frequency = 8.5 days and buffer period = 9.1 days.

Nonetheless a simple sensitivity analysis is conducted to visualise the effects of varying these parameters.

<u>Check 1</u>: If Vol_{LNGC} is lowered to 137,000[xi] m^3, the buffer period increases to 9.5 days and the delivery interval drops to 8 days, considering Vol_{Tank} remains 300,000 m^3. These values are still acceptable. If Vol_{Tank} is lowered to 250,000 m^3 however, the buffer period is reduced to a risky 6.6 days.

<u>Check 2</u>: If Vol_{LNGC} is increased to 160,000 m^3, the buffer period reduces to 8.2 days and the delivery interval increases to 9.4 days, considering Vol_{Tank} remains 300,000 m^3. These values are also desirable. If Vol_{Tank} is lowered to 250,000 m^3 however, the buffer period is further reduced to 5.3 days.

[xi] It can be noted that a 137,000 m^3 LNGC will be the smallest average and regular shipment on which the design will be based, following from a review of the existing LNGC fleet. This does not imply that larger or smaller spot deliveries will not be made during terminal operation.

It appears that the initial volumetric assumptions present a suitable balance between delivery period and period of storage buffer. These parameters, listed below, will be used to estimate terminal dimensions for the purpose of this study.

- ***Storage tank size: 2 x 150,000 m^3***
- ***Standard Delivery Bundle: 145,000 m^3***
- ***Days Between Delivery: 8.5 days***
- ***Buffer Volume: 155,000 m^3***
- ***Buffer Period: 9.1 days consumption***

5 LNG CARRIER CHARACTERISTICS

The characteristics and key elements of modern LNG Carriers (LNGC) are discussed. The size of the design vessel for the Saldanha terminal is decided following a review of the existing LNGC fleet and trends within the industry. The LNG throughput expected at the port, determined in the previous Chapter, also plays a role in the size and frequency of call of the design vessel. The minimum, average and design vessel sizes are selected.

5.1 LNGC Design

5.1.1 Introduction to LNGC Vessel Design

Liquefied Natural Gas Carriers are described by the format of their LNG containment system and by the total volume of LNG the containment tanks can hold. There are three distinct types of containment approaches and a number of sub-variations thereof. Two formats dominate the market however: the spherical *Moss* and the *membrane* containment systems.

5.1.2 Moss LNGC Vessels

Tank design

LNGC vessels employing the Moss tank design are the more familiar and recognisable carrier type due to the protrusion of four or five enormous spherical tanks above the deck (see Figure 5-1).

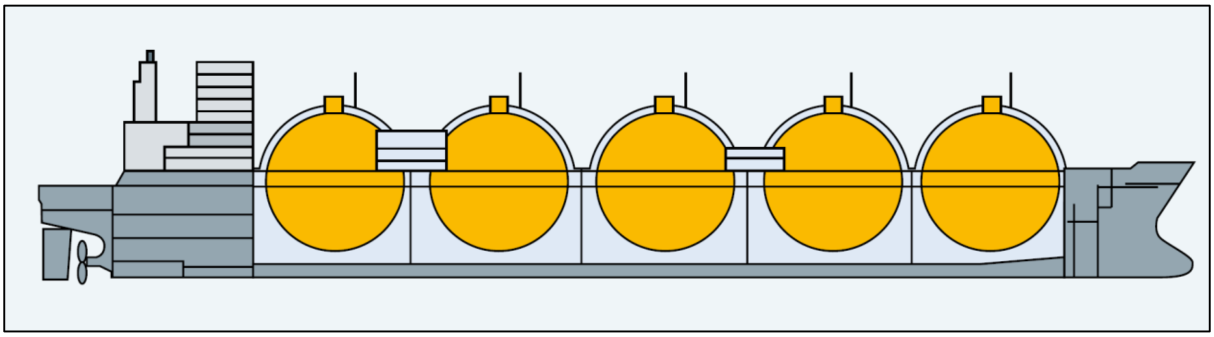


Figure 5-1 Cross section of LNGC with Moss containment system (McGuire & White, 2000)

The Moss design is the oldest and most established of LNGC formats presently in operation. The spherical tanks are self-supporting when fully loaded and do not rely on the ship hull structure for integrity. Due to their spherical geometry, the tanks are able to withstand relatively high pressures. The inner tank is constructed of 9% nickel steel or aluminium, insulated by a layer of polyurethane foam. Figure 5-2 illustrates the cross section of the spherical tank. The Moss design is employed on 30 % of the LNGC's currently in operation.

Windage

Moss type LNGC's are particularly sensitive to wind loading in ports due to the excessive freeboard of the spherical tanks, which may have an air-draft of greater than 60 m[xii] while in ballast condition (Roche, 2004). Furthermore, LNG is not a particularly dense cargo (1 m^3 = 450 kg) so the payload when laden is relatively light. This results in a laden draught of approximately 9 m to 13 m. The effects of wind loading in Saldanha Bay will be studied in *Section 9.5.*

[xii] 138,000 m^3 vessel with 5 spherical tanks

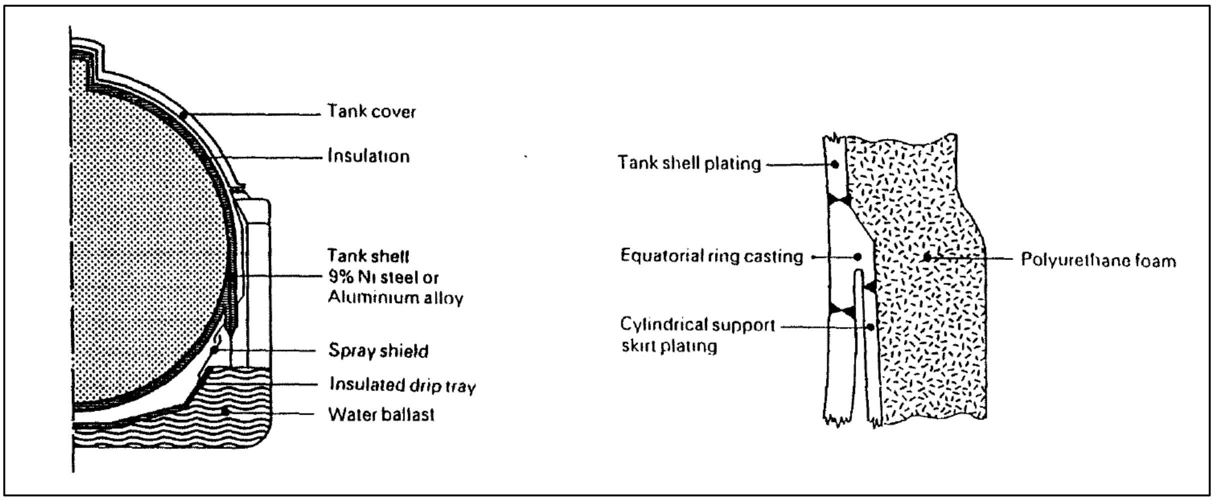


Figure 5-2 Details of tank construction on Moss containment tanks (Zuidgeest, 2002)

Aesthetics

The public perception of the safety of LNG terminals is quite negative and this ill-informed view often leads to mass local opposition to LNG development. The design of a Moss type tanker does not assuage the concerns of the general public, as the sight of large spherical tanks under a network of pipes can impress the view of a highly pressurised and therefore explosive cargo, which is not the case. This unfortunate trivia may have significant repercussions when selecting a vessel type for an import terminal near a populated area.

Manifold Location

It is not uncommon for the LNG manifold to be located between -10 m aft of midships up to + 32 m forwards of midships (Legoe & Imrie, 2007). The manifold location is dictated by the Moss tank positions on board, and generally sits on deck at the recess between the second and third tank. The choice of four or five tanks will greatly affect the lateral manifold placement.

The parallel sides of an LNGC span a short distance relative to the L_{OA} of the vessel. Under ballast conditions the effective berthing length (i.e. the length of parallel sides at fender elevation) may be just 35% to 50% of the vessel's L_{OA}. When this factor is combined with the off-centre location of the manifold, difficulties may be encountered when manoeuvring against berthing dolphins. Additionally fender contact may be reduced to just three points, which is not ideal for such a large carrier (Legoe & Imrie, 2007).

Sloshing

LNG "Sloshing" occurs when the liquid cargo moves inside the containment tank due to natural pitching and rolling of the LNGC while at sea. Sloshing may result in impact forces on the inner walls of the tanks, potentially leading to structural damage. Sloshing is not a concern in the Moss type tank system, as there are no vertical walls for the LNG to reflect off or resonate between. The curved walls of the spherical tanks prevent any significant sloshing, making Moss type vessels suitable for use in areas with a large wave climate. Consequently Moss vessels can sail with partially filled tanks, making them suitable for spot purchases or carrying undersized cargoes, should the trade demand.

Design Variations

Mitsubishi Heavy Industries have recently developed an evolutionary LNGC based on the Moss template. The "Sayaendo" LNGC is essentially a Moss type vessel that incorporates a continuous weather cover for the spherical tanks, integrated into the ship's hull. The new configuration benefits from greater structural efficiency, enabling weight reductions (Sato & Chung, 2013). The reinforced above-deck containment structure and the integration of spherical tanks make the Sayaendo design suitable for harsh weather climates. Five such vessels are due to be delivered before 2020, destined to ply the North Atlantic and Arctic trading routes. A secondary but important benefit of the Sayaendo design is the concealment of the "*ubiquitous hemispherical covers found on conventional Moss LNGC's*", as hinted by Sato & Chung. Figure 5-3 illustrates the conceptual difference between the Sayaendo and Moss designs.

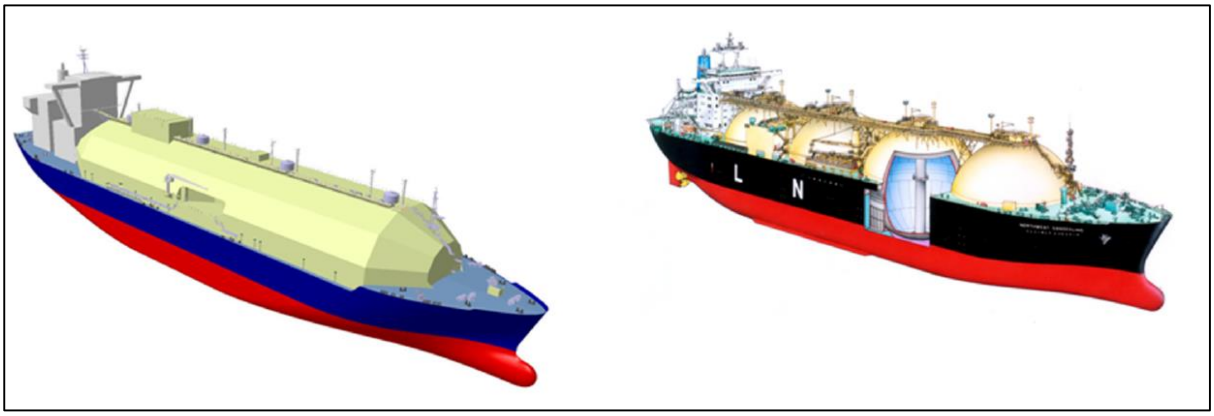


Figure 5-3 Comparison of Sayaendo and Moss LNGC vessels (Hiramatsu, et al., 2010)

5.1.3 Membrane LNGC Vessels

Tank Design

The concept of the membrane tank system is based on a very thin inner wall (0.7 mm to 1.5 mm thick) that is reinforced by an insulation layer that surrounds it. The primary barrier contains the LNG cargo, and its construction varies depending on the manufacturer. The primary insulation layer is surrounded by a rigid inner hull that ultimately forms the load bearing structure for the tank. This secondary barrier acts as a backup containment hold in the unlikely case of inner tank leakage. A secondary insulation layer separates this inner hull from the vessel's main hull. Figure 5-4 shows a simplified cross-section of a membrane LNGC.

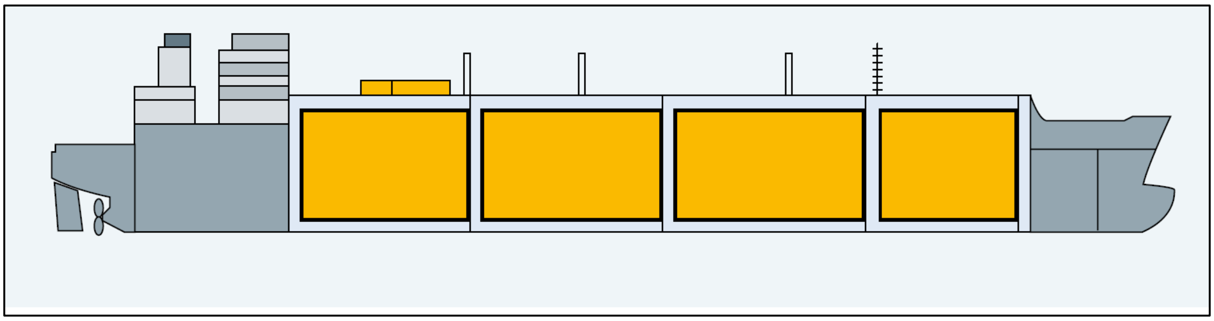


Figure 5-4 Cross section of LNGC with membrane containment system (McGuire & White, 2000)

Membrane tanks are rectangular in cross section with chamfered upper edges, as portrayed in Figure 5-5. The tanks are located below deck, with only the manifold protruding. The deck level and ship freeboard are consequently quite high.

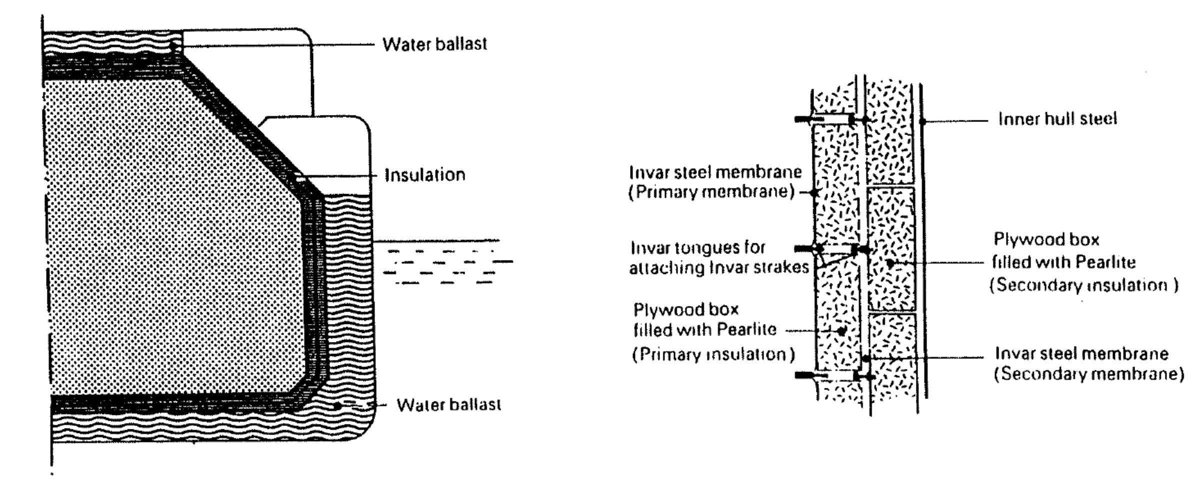


Figure 5-5 Details of tank construction on membrane containment tanks (Zuidgeest, 2002)

Windage

Despite boasting a far lower air draft than Moss carriers, membrane vessels are still subjected to high levels of wind loading in areas with a high wind climate. An air draft of up to 45 m can be expected for a 138,000 m^3 LNGC (Roche, 2004). The design elements of shallow draught and low relative payload similarly apply to membrane vessels.

Aesthetics

The lower freeboard, flat deck and sleeker lines of the membrane vessels appeal more to the public eye and seem to inhibit imagination. The total concealment of the LNG containment tanks appears to arouse less suspicion among local interested and affected parties. Furthermore the lower above-water area of the ship reduces visual impact in areas of natural beauty in comparison with the Moss design.

Manifold Location

The LNG offloading manifold aboard membrane type vessels is generally located at or near midships and near the centre of the parallel sides section (Legoe & Imrie, 2007). Few problems with fender contact and berthing dolphin use are encountered.

Sloshing

Sloshing is a chief concern for membrane type vessels. In the case of severe vessel motions the LNG fluid motion becomes violent, causing breaking waves and high impact loads in the containment tank. Different levels of LNG volumes within the tank will result in different loading phenomena on the tank walls. In the high filling range (H_{fill} = 60% to 90%) the majority of the impact forces are inflicted on the roof of the tank or in the upper corners and knuckles of the chamfer due to run-up (DNV, 2006). In the low filling range (H_{fill} = 20% to 40%) the largest impacts occur at both longitudinal and transverse bulkheads due to breaking waves or a bore effect caused by a large hydraulic jump. These effects are illustrated in Figure 5-6.

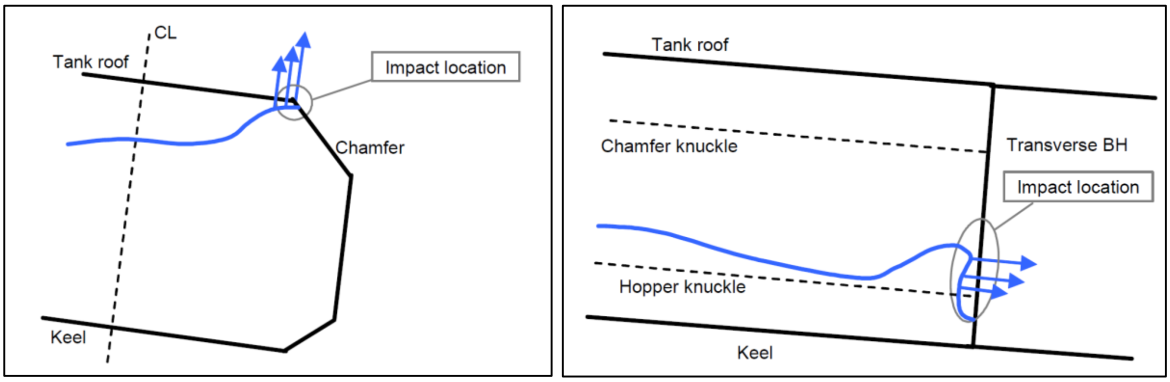


Figure 5-6 Impact forces due to sloshing in membrane tanks (DNV, 2006)

Due to the inherent structural risks associated with sloshing in membrane tanks, most terminal operators forbid the departure of an LNG vessel with partially full membrane containment tanks. Tanks filled above 85% or below 10% are usually safe to depart. This idiosyncrasy of membrane tanks may be of vital importance when planning an LNG offloading operation prior to an imminent storm front for example.

Design Variations

Two vessel designs dominate the membrane LNGC market: the Technigaz *TGZ Mark III* and the Gaz Transport *GT96*. The TGZ Mk III and the GT96 respectively account for 30% and 32% of all LNG Carriers in operation worldwide (Ship Building History , 2013). The key difference between the two vessel designs is the material choice for the containment tanks.

The TGZ system utilises a corrugated/waffled 1.2 mm aluminium membrane that allows for thermal expansion. The secondary barrier is made using Triplex - a fibreglass cloth/aluminium laminate. Both barriers are insulated with reinforced cellular foam. The GT system utilises a stainless steel alloy (36% nickel, 0.2% carbon) called Invar for the primary and secondary barrier. Invar has a very low co-efficient of thermal expansion and is ideal for cryogenic applications. The Invar membrane is just 0.7 mm thick, and is insulated using perlite encased in cellular plywood boxes.

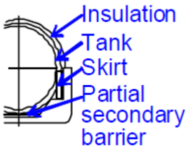
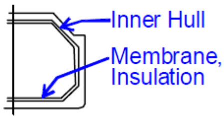
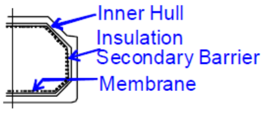
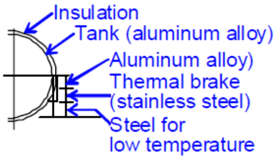
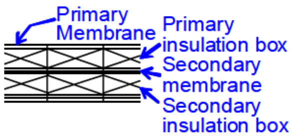
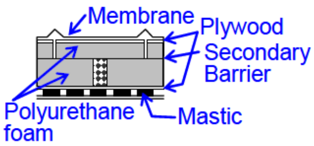
TGZ and GT merged to form a single entity, and subsequently developed the "CS1" containment system, an amalgamation of both membrane designs. Only three vessels have been built so far however, as shipyards were content to continue building the original GT96 and Mk III models they were familiar with.

5.1.4 Summary of Containment Systems

Irrespective of the containment system employed to transport LNG, the remainder of the LNGC vessel design remains much the same. Figure 5-1 and Figure 5-4 clarify this. Both systems will carry a residual heel[xiii] volume when departing the import terminal under ballast and both will usually be fuelled using a combination of oil and Boil Off Gas to power the on-board turbines. Boil Off Gas can account for 0.1% to 0.15% of the LNG cargo per day. A summary of the spherical Moss and the membrane GT and TGZ containment systems is given in Table 5-1.

[xiii] A "heel" volume of 5% to 10% of the cargo is intentionally left on board for journeys sailed under ballast. This LNG is constantly sprayed onto the internal walls of the tanks in order to maintain a tank temperature of - 162°C so that the cooled containment tanks will be prepared for the next cargo.

Table 5-1 Comparison of spherical and membrane containment system parameters (Levitan & Associates Inc., 2007)

	Spherical Tank	Membrane Tank	
		Gaz Transport	Technigaz
Cross section			
Insulation structure			
Tank material	Aluminum alloy of 9% nickel steel	36% nickel steel (Invar)	Stainless steel
Measures for thermal expansion and contraction	By thermal expansion and contraction of tank and skirt 	Measures are not required due to very low coefficient of thermal expansion of membrane	By expansion and contraction of membrane 
Insulation material	Plastic foam	Insulation boxes filled with perlite	Plastic foam
Insulation thickness	220 mm	530 mm	250 mm
Secondary barrier	Drip pan (partial secondary barrier)	Same as primary barrier	Triplex

5.2 Global LNGC Fleet

5.2.1 LNGC Order Book

A study of the existing fleet of LNG Carriers is necessary to understand the market trends regarding vessel designs, cargo sizes and age of vessels. Each year GIIGNL publishes a report that presents the key figures pertaining to the LNG industry. *The LNG Industry 2012* states that the average LNG delivery volume was 130,000 m^3 among 378 active vessels (GIIGNL, 2013). Only 2 new LNGC's were delivered in 2012 compared with 16 in 2011. The order book comprised a significant 78 vessels by the end of 2012 however, highlighting the enormous growth in the industry. Of these, 27 new orders were placed during 2012, with capacities ranging from 150,000 m^3 to 172,000 m^3.

Many of the vessels in operation belong to the 1st Generation of LNG carriers, and are due to be phased out in the coming decade. At least 40 such vessels are older than 30 years, and their cargo capacity is between 18,000 m^3 and 133,000 m^3. The decommissioning of this ageing fleet will significantly raise the average volume of LNG delivered per cargo.

5.2.2 "Standard" LNGC vessel

An updated list of operational LNG vessels was published online in September 2013 (Ship Building History , 2013). This list is reproduced in Appendix E. The updated fleet size is revised to 358 vessels. Of these, 107 are Moss vessels (30%), 115 are GT96 vessels (32%) and 106 are GTZ Mk III vessels (30%). The average volume of the operational fleet is 147,700 m^3, and the mode is 145,000 m^3 (33 vessels).

This "average" vessel size is contestable. At the lower end of the scale are ageing vessels facing retirement, whose cargo capacities may no longer be profitable for long distance deliveries, and at the top of the scale are the beefy Q-Flex and Q-Max vessels, built specifically for use at the Qatargas and Rasgas export terminals in Qatar. Excluding the Q-Series vessels (210,100 m^3 to 266,000 m^3) and the relatively small pre-2000 fleet (all under 133,000 m^3), a more realistic modern "average" vessel range is described. Incidentally, the average volume of this revised range is 146,600 m^3, and the mode remains 145,000 m^3.

It is therefore assumed that the current "standard" vessel boasts a cargo capacity of approximately 145,000 m^3.

5.2.3 Future Trends

The inclusion of 32 Q-Flex vessels (210,100 m^3 to 217,000 m^3) and 13 Q-Max vessels (261,700 m^3 to 266,000 m^3) to the LNGC fleet between November 2007 and August 2010 completely altered the format and outlook of global LNG shipping. Almost overnight the industry realised the vast economies of scale at hand. Prior to the introduction of these behemoths, the largest vessel carried 155,000 m^3. Since 2008 however, the average LNGC size has been growing steadily. Since the inclusion of the Q-Series fleet, the average vessel size post-2000 is elevated to 160,000 m^3.

Analysts are not convinced that the LNG market will sustain another mega-fleet injection for many years to come. Due to economic factors as well as a myriad of technical issues (lack of existing terminal facilities, shipbuilding restrictions, material cost and availability, increased sloshing and inefficient propulsion power), carriers are not expected to surpass the 300,000 m^3 milestone in the near future. It has been proposed that the "next generation" of LNGC vessels will settle down at 225,000 m^3, but for the moment the standard LNGC range will be 135,000 m^3 to 170,000 m^3 (Noble, 2007). The existing order book, running up to 2017, verifies this prediction in the short term (Ship Building History , 2013).

5.3 Operational and Design Ship for Saldanha

5.3.1 The "Standard" Delivery Vessel for Saldanha Bay

An LNGC vessel with a cargo capacity of 145,000 m^3 will be considered the "standard" size vessel to be accommodated at the Saldanha LNG terminal. The fleet review in the previous Section has shown that a vessel of this capacity is the most common currently in operation, and that it represents the average LNG payload volume of the combined fleet.

A *standard vessel* of this capacity was pre-emptively used in *Section 4.6* to estimate the size of the storage tanks in Saldanha. An iterative approach was taken to determine a storage tank size of 300,000 m^3 (i.e. 2 x 150,000 m^3 LNG storage tanks). The use of this standard vessel to regularly import LNG fuel affords the CCGT a maximum operating buffer of 9.1 days in the case of delayed delivery[xiv], with an average interval of 8.5 days between regular deliveries.

[xiv] This model assumes a scenario where the previous shipment fills the storage tanks to capacity.

In the case where the LNG supplier cannot guarantee a standard vessel size of 145,000 m^3, larger or smaller LNGC's may be employed. Considering a fixed storage tank volume of 300,000 m^3, the smallest ideal regular shipment would be a 130,000 m^3 cargo, which will necessitate a delivery frequency of 7 days, and will provide a 10.5 day buffer in the case of non-delivery[xv]. The inherent risk in using smaller vessels is a high delivery frequency demand.

Similarly, a sensitivity study using a storage volume of 300,000 m^3 reveals the largest regular LNG shipment to be 180,000 m^3. This scenario will necessitate a lenient delivery interval of 10.5 days, and a risky buffer period of 7 days of CCGT supply fuel.

The standard vessel for Saldanha Bay will be an LNGC with a delivery capacity of 145,000 m^3.

5.3.2 The "Design" Delivery Vessel for Saldanha Bay

The *design vessel* is generally regarded as the vessel with the greatest dimensions a terminal can receive. In many terminals the predominant limiting dimension is the vessel's draught, particularly at solid bulk terminals where some bulk carriers may draw up to 24 m. Under-keel clearance is generally not a primary concern at LNG terminals however, as the largest Q-Max vessels draw just 13.72 m when fully laden.

Parameters such as air-draft and L_{OA} may have more of an influence on LNGC suitability in Saldanha Bay. The West Coast is renowned for its high wind climate, and air-draft should therefore be kept to a minimum. **A membrane type containment system is thus recommended for the standard vessel and the design vessel in Saldanha**. The wind climate in Saldanha is discussed in *Section 7.3.4* and the influence of wind loading on LNGC's in the port is examined in *Section 9.5.* The vessel L_{OA} may dictate turning circle dimensions and swing radii, should a mooring buoy be employed.

The key factor in selecting a design vessel for a deepwater port such as Saldanha Bay may therefore be the maximum desirable cargo delivery at the terminal. It has been illustrated in the previous Section that the terminal could comfortably receive an 180,000 m^3 carrier in conjunction with a storage facility of 300,000 m^3. A review of the present day LNGC fleet reveals the largest vessel size in this category is 177,000 m^3 (Ship Building History , 2013). The Q-Flex and Q-Max fleets will not be considered, as these vessels are contracted to trade select RasGas and Qatargas routes. Furthermore analysts do not expect the manufacture of a similar vessel in the short to mid-term future (Noble, 2007).

The design vessel for Saldanha Bay will be an LNGC with a delivery capacity of 177,000 m^3.

[xv] Of the existing fleet, the 137,000 m^3 class of vessel matches this idealised vessel size.

A summary of the standard and design vessel key dimensions is stated in Table 5-2.

Table 5-2 Vessel Dimensions to be used for LNG terminal design in Saldanha Bay

Vessel	Capacity [m³]	DWT [T]	Displacement [T]	L_{OA} [m]	L_{PP} [m]	Beam [m]	Moulded Depth [m]	Draught max. [m]
Minimum[xvi]	75,500	39,520	53,000	220	212	35	22.5	10
Min. ideal	130,000	44,600	100,400	274	263	43.4	25.4	12
Standard	145,000	74,400	110,000	288	274	46	26.8	12.3
Design	177,000	87,000	114,000	298.5	285	49	26.8	13

[xvi] The minimum vessel is the smallest post-2000 LNGC in the modern fleet. The dimensions are modelled on the "*Cheikh El Mokrani*" TZ Mk. III membrane carrier, built in 2007.

6 IMPORT TERMINAL TYPES

Dedicated LNG import terminals have been constructed for the past 40 years. This Chapter comprises a technical review of the traditional trestle jetty design that is common to the majority of import terminals, and examines the new floating and offshore technologies that have become popular over the past decade.

6.1 Introduction to LNG Import Terminal Designs

Three Basic Import Terminal Designs

LNG import terminals fall into three distinct categories. The most universal design is the pile driven **trestle jetty**, which has been the standard template for solid and liquid bulk import terminals for over 50 years. The concept of a **floating LNG terminal** has gained in popularity over the past 10 years, and this design has recently been employed in ten different ports. Finally the Gravity Based Structure, or **GBS terminal**, is a free-standing caisson design that sits on the seabed in shallow waters.

Current Trends in Terminal Design

Each year GIIGNL publishes a report that presents the key figures pertaining to the LNG industry. *The LNG Industry 2012* states that by the end of 2012, 93 LNG regasification terminals were in operation across 26 countries. Of these, 82 (88%) are trestle jetties, 10 (11%) are floating terminals and just one (1%) employs the GBS design (GIIGNL, 2013). A total of 236 MMTA of LNG was imported via these regasification terminals in 2012.

The trend in recent years has been leaning towards the construction of floating facilities. No floating terminals were in operation in 2007. By 2008 this had risen to 3% of the total terminal count and reached 11% by 2011. Of the 18 terminals presently under construction, 3 are floating facilities, accounting for 17% of the order book (Global LNG Info, 2013). These figures signify a clear and significant shift towards the use of floating facilities in the future.

Traditional trestle jetties are still the most common terminal format however, as there are no technological restraints restricting the design. The efficacy of the design has been proven, and due to the sheer number of trestle jetties globally, the cost prediction of the terminal will be relatively accurate. By contrast, many floating facilities are implementing technologies for the first time. These technologies are often over-designed to guarantee survivability, and may be costly as a consequence. These developments will be refined as more are terminals are implemented, and should become a legitimate and reliable alternative to trestle jetties in oncoming years.

6.2 Trestle Jetty Terminal

The primary distinction between trestle jetty terminals[xvii] and floating or GBS terminals is that in the case of a trestle jetty, LNG is pumped ashore from the vessel, stored as LNG in cryogenic tanks, and regasified ashore before sendout. This process is described at length in *Section 3.4.1*.

[xvii] This description applies to all *onshore import terminals*. In rare cases the import jetty may be of the caisson or quay wall type.

Advantages

The primary benefit of the trestle jetty terminal is the wealth of existing knowledge and experience that accompanies it. Terminal designers and operators alike are familiar with the scope of the terminal, and layout and systems rarely change between terminals.

A typical onshore import terminal consists of mooring facilities, an LNG offloading platform, a raised causeway linking the jetty to the shore, LNG pipelines delivering cryogenic cargo to onshore LNG storage tanks and a regasification plant. Figure 6-1 shows an image of a standard shore-connected trestle jetty.

Figure 6-1 Standard layout of a trestle jetty import terminal in New Brunswick, Canada (Canaport, 2009)

Another benefit of the nearshore location is the relative ease of access to the site for construction and operation.

Disadvantages

The downside of siting the storage and regasification facilities onshore is the large footprint they occupy, as made evident in Figure 6-1. In areas of unfavourable topography or limited available land, construction of an onshore jetty may not be suitable.

In recent years the public have become far more vocal in opposition to large scale developments. The LNG industry in particular suffers from the NIMBY[xviii] attitude of the general public, who wrongly cite explosive risks as a chief concern. Nonetheless, it has become increasingly difficult to locate LNG terminals near residential areas despite the relatively small safety exclusion zone that is imposed around a terminal perimeter (Somma, 2010).

The operation, and in particular construction, of a nearshore terminal may result in negative environmental effects. Due to the limited draft of LNGC's however, dredging is not usually a critical design element of nearshore terminal projects.

[xviii] Not in my back yard

6.3 Floating Terminals

6.3.1 Introduction to Floating Terminals

The oil industry has used floating loading/unloading technologies for decades. Oil is a far more stable product than LNG. However, it is stored at ambient temperature and is not pressurised or super-cooled. The LNG industry has recently begun using floating technology with liquefaction loading facilities, which are often located in benign maritime environments. The delay in using floating facilities for imports is a technological one: flexible cryogenic hose technology is not yet advanced enough to withstand the degree of flexibility required in large wave conditions. To date, no floating import terminal is capable of pumping LNG cargo directly ashore from the import vessel.

All floating LNG terminals (as of 2013) operate on the same principle: LNG is received at the floating terminal, pumped into incorporated storage tanks, regasified at the point of import and piped ashore as market-ready natural gas. This differs from the traditional jetty setup in that all LNG processing facilities are stationed offshore.

FSRU

The floating terminal philosophy makes use of one critical, dedicated import facility: the FSRU. A *Floating, Storage and Regasification Unit* (FSRU) is a purpose built vessel that can, as its name implies, store and regasify LNG before delivery ashore.

An FSRU is a standard LNG carrier that has been retrofitted to act as a multi-use import facility. Storage tanks are generally reinforced and a highly compact regasification plant is fitted to the top of the deck. The mooring system is altered to adapt to the specific layout of the final terminal location. In many cases the engine and drivetrain are removed from the vessel to create room for regasification plant. Each FSRU is designed to perform in the local environmental and operational conditions at the terminal location, and as such no two units are the same (Blackwell & Skaar, 2009).

Floating terminals can be located in two marine environments: *offshore*, where the FSRU is moored to a Single Point Mooring (SPM[xix]), or *nearshore*, where the FSRU is berthed alongside a jetty.

6.3.2 FSRU moored to an SPM: Weathervaning Tower or SBM

The exact layout of an offshore floating terminal depends on the depth of water at the terminal. Where the water depth is between 16 m and 40 m, the FSRU is moored to a weathervaning tower that is anchored to the seabed. A pivoting mooring yoke, free to rotate about the tower, connects to the bow of the FSRU holding it in place.

Tower mooring

During the offloading process, an LNG carrier berths alongside the FSRU and discharges its cargo into the storage tanks of the FSRU. Once offloading is complete the LNGC is free to depart. Regasification, carried out aboard the FSRU, is a slower process than LNG pumping. As the cargo is vapourised, the resultant natural gas product is offloaded via a riser that runs to the seabed. A

[xix] An **SPM** is a Single Point Mooring, where a vessel is moored to and offloads at a single point. This point may be fixed (i.e. a tower) or floating (i.e. a buoy). An **SBM** is a Single Buoy Mooring, which is strictly defined as a floating buoy type SPM.

natural gas pipeline carries the regasified product ashore. The above-water element of the tower structure and mooring yoke is illustrated in Figure 6-2.

Bow-to-stern mooring of the LNGC to the FSRU is proposed for the near future, modelled on a proven technique used in the oil industry (van der Valk & Watson, 2005).

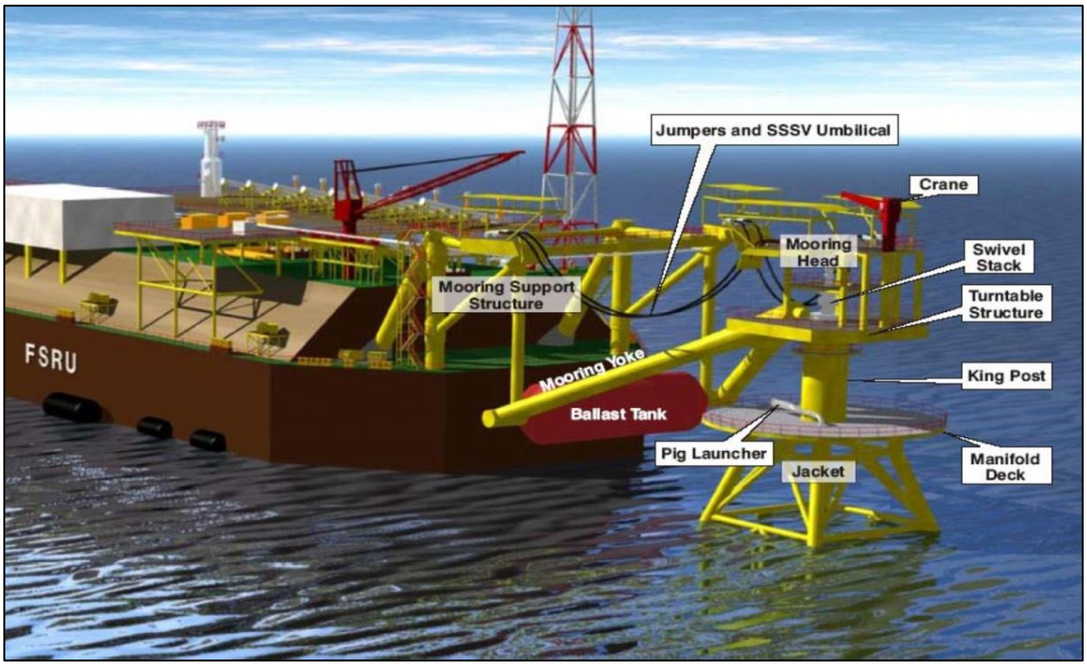


Figure 6-2 Weathervaning FSRU tower mooring system (Levitan & Associates Inc., 2007)

SBM

It is not feasible to build mooring towers in depths greater than 40 m. In this case a Single Buoy Mooring (SBM) type SPM is used to hold the FSRU in position. The buoy is anchored to the seabed by catenary lines, while a natural gas riser runs to the bottom. The SBM may be moored in water depths of several thousand metres. A mooring turret is incorporated into the bow of the LNGC, enabling the vessel to weathervane about the fixed SBM.

Figure 6-3 Turret mooring system used to connect to SBM (LMC, 2013)

Only one turret mooring system has been developed for use at an offshore LNG terminal to date. The terminal in Livorno, Italy, is due to come online by the end of 2013. Figure 6-3 shows the turret system in use aboard an FPSO[xx] in Malaysia.

6.3.3 FSRU Alongside Jetty

Most floating LNG terminals are in fact nearshore terminals, berthed alongside modified existing jetties or purpose built jetties. The fundamental difference between floating and fixed nearshore terminals is the fact that all LNG is offloaded, stored and vapourised while afloat, and only the regasified natural gas piped ashore.

At present two mooring configurations are used. In the *side-by-side system* the FSRU is berthed alongside a standard shore-connected L-jetty. The incoming LNGC moors alongside the seaward hull of the FSRU in order to discharge the LNG cargo. This practice is illustrated in Figure 6-4.

Figure 6-4 Side by side offloading at a dockside FSRU facility in Escobar, Argentina (Excelerate Energy, 2013)

The *cross-jetty* system employs a finger jetty, with the FSRU and LNG carrier stationed on opposite sides of the jetty head. The cargo is offloaded directly from one vessel to the other using two sets of unloading arms located on the jetty, as shown in Figure 6-5. The LNGC is free to berth and moor in a more conventional manner using this design, as opposed to the side-by-side berthing method.

[xx] FPSO: Floating, Production, Storage and Offloading vessel used in the oil and gas industry for processing of hydrocarbons and storage of oil.

Figure 6-5 Cross-jetty offloading from LNGC to FSRU in Guanabara Bay, Brazil (Blackwell & Skaar, 2009)

Advantages

There are a number of reasons for the recent shift towards floating terminals, the primary motivator being cost. Although nautical infrastructure such as breakwaters, dredging and jetty construction must be considered, landside construction is kept to just a natural gas sendout pipe. The cost of purchasing (or leasing) an FSRU tends to be far lower than constructing a permanent shoreside regasification facility. FSRUs are often developed using older LNG carriers, further reducing the capital costs of the technology (Blackwell & Skaar, 2009).

Vessel turnaround time may be reduced if a tower/SBM facility is used. The berthing procedure of mooring to a single upwind point tends to be faster than berthing alongside a jetty in shallow water. In addition, fewer tugs are required to berth alongside a weathervaning FSRU, resulting in an enormous capital cost saving for the terminal. Four tugs are typically required for shallow water jetty berthing, whereas a single tug is required for connection to a tower/SBM FSRU (van Wijngaarden & Oomen, 2004).

There exists enormous potential for flexibility using floating terminal technology. A prime example of this is the LNG import industry in Brazil. Two FSRUs, based in Pecém and Rio de Janeiro, are employed to provide 7.5 BCM of gas per year to the national grid. The FSRUs and LNG import vessels moor alongside a dedicated finger pier and transfer cargo across the jetty. The Guanabara Bay facility at Rio de Janeiro is shown in Figure 6-5. LNG demand in Brazil is seasonal however and in the rainy season much of the country's power is provided by hydroelectric plants. During these months the FSRUs depart and are leased for use overseas either as FSRU's or LNG cargo carriers. Furthermore the finger terminals have been adapted to receive either of the two FSRU's to further diversify LNG receiving options for the country.

Disadvantages

Floating LNG systems are still a largely unproven technology and developers are consequently hesitant to roll out such terminals. Of the 10 floating terminals (operational in mid-2013), two employ propriety SBM attachments, while the remaining eight accommodate FSRU vessels alongside jetties. The SBM solutions use FSRU's that regasify their own cargo i.e. the design does not accommodate either side-by-side or bow-to-stern berthing of LNGC's. One tower mooring FSRU is due to come online in 2014 in Lampung, Indonesia (LNG World News, 2013), and a turret SBM FSRU should also be in operation in Livorno, Italy by early 2014 (Offshore Magazine, 2013).

Access to SBM or tower FSRUs is difficult due to their offshore nature. Additionally a crew of 30 is expected to be housed aboard the regasification vessel at all times, adding to resource expenses not usually associated with nearshore terminals (van Wijngaarden & Oomen, 2004).

6.4 Gravity Based Structure

A Gravity Based Structure (GBS) terminal is a pre-stressed concrete caisson that sits on a level seabed in shallow water. The caisson is heavily ballasted at the base to prevent shifting or overturning. LNG cargo is contained inside the caisson in insulated tanks, while a regasification plant is installed on top of the deck. The caisson is located in open-water depths between 14 m and 20 m, and the solid freeboard of the structure acts as a breakwater for the berthing LNGC. To date only one GBS system has been successfully installed and operated. Figure 6-6 shows an LNGC berthing at the Adriatic LNG GBS type terminal in Rovigo, Italy. The berthing procedure is the same as for a standard jetty terminal, typically using four or five tugs to aid manoeuvrability. Natural gas is piped ashore from the caisson structure.

Figure 6-6 LNG carrier berthing at an offshore GBS terminal in Rovigo, Italy(Exxon Mobil, 2009)

Advantages

As with the offshore SBM/tower solution, the GBS terminal is far removed from the public eye and therefore subject to less opposition on safety, environmental and aesthetic grounds. Environmental effects during operation should be reduced if the terminal is located a suitable distance from the sensitive nearshore area.

Vessel turnaround time will become faster as limiting water depth and in-port navigation will not play a role, thus accelerating berthing operations.

Disadvantages
GBS terminals incur substantial construction and installation costs, and lead time tends to be greater than other floating LNG technologies. A mandatory process in GBS manufacture is the construction of a dedicated graving dock or caisson casting yard onshore in which the concrete terminal is constructed. The graving dock must be large enough to cast the caisson (approximately 180 m x 90 m x 40 m) and float it into open water once complete. The construction of the graving dock alone is an enormous civil works project, and will naturally raise many planning and environmental issues. The cost, lead time and planning issues associated with the graving dock may overshadow the construction of the GBS caisson itself (van Wijngaarden & Oomen, 2004).

The decommissioning of a GBS terminal will be costly and time consuming when compared with a SBM buoy or a steel frame tower. Jetty terminals may be adapted to receive other cargoes should LNG import no longer be deemed necessary. GBS terminals however can serve no other purpose when they reach the end of their lifespan, and will have to be dismantled.

7 CONCEPTUAL SITE LAYOUTS

The aim of this Chapter is to identify areas within Saldanha Bay that may be suitable for LNG terminal development, and generate conceptual site layouts that suggest initial terminal locations and orientations. A basic planning methodology is implemented to achieve this, as described in Figure 7-1.

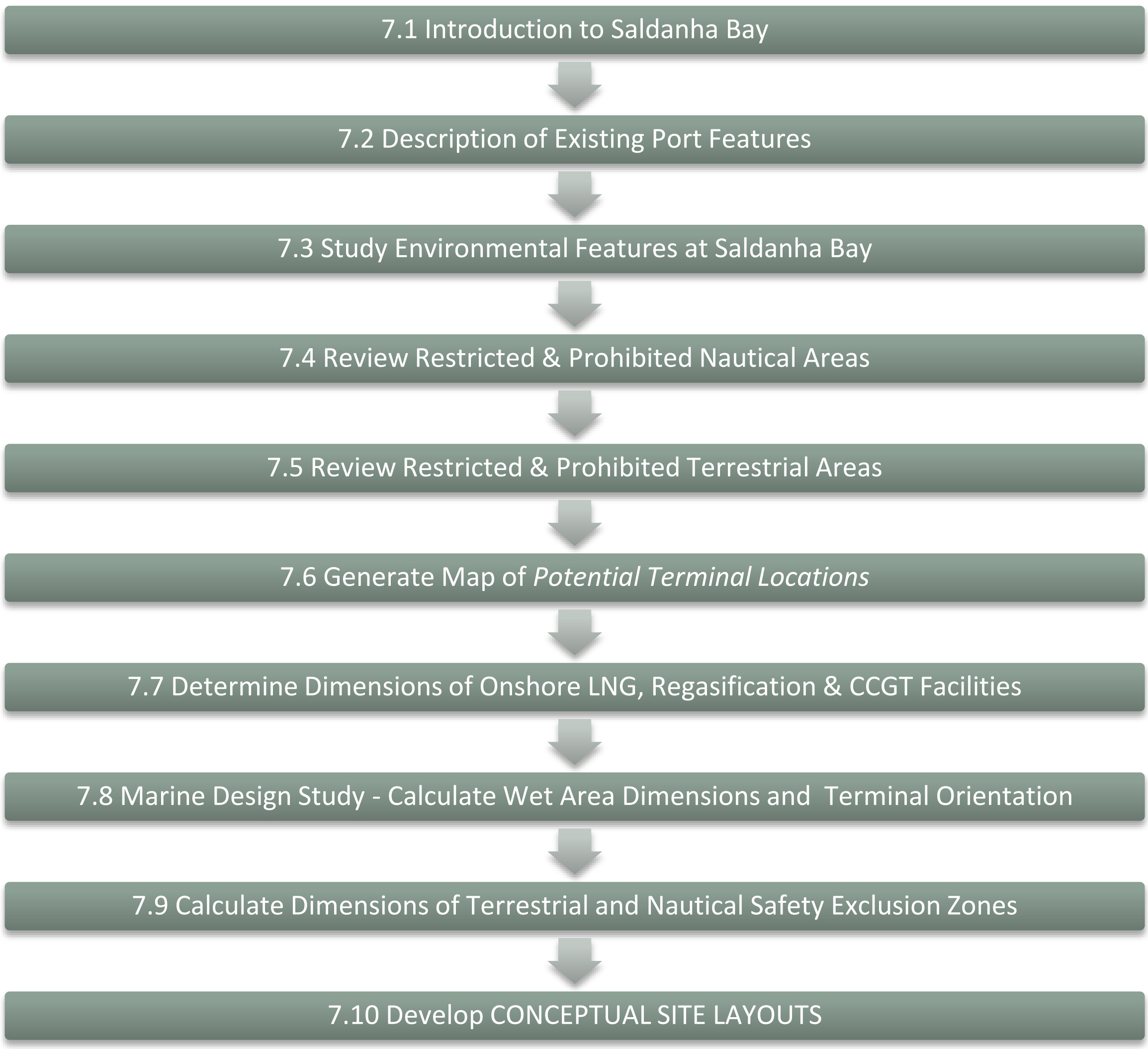


Figure 7-1 Planning flowchart for conceptual site layout development

The structure of this Chapter follows the planning hierarchy outlined above.

7.1 Features of Saldanha Bay

Saldanha Bay is a deepwater natural port on South Africa's west coast. It is located in the Western Cape province, approximately 110 km NNW of the city of Cape Town (Figure 7-2). It is one of few natural ports on the South African coastline, and due to its narrow mouth, is only vulnerable to offshore swell approaching from the SW quadrant. It is likely that Saldanha Bay would have been selected as South Africa's primary port by initial European colonialists and settlers, had it not been for the distinct lack of freshwater near the harbour area (Fair & Jones, 1991).

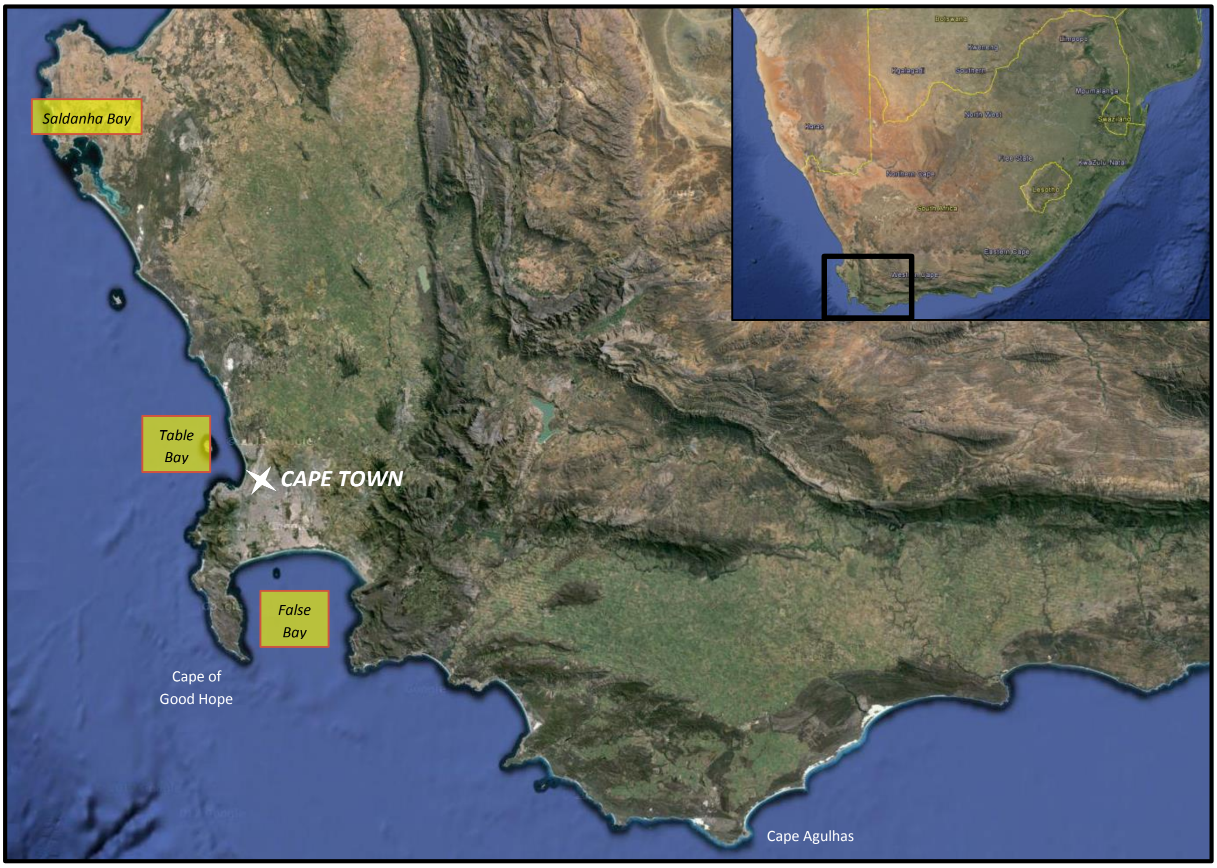


Figure 7-2 - Location of Saldanha Bay on the South African coast (Google Earth, 2013c)[xxi]

Despite many attempts at industrialisation (sealing, whaling, fishing, guano harvesting, mineral mining) since the 1700's, the Bay remained underutilised until the latter half of the 20th Century. The onset of WWII led to a boom in the region resulting from surplus ships redirected round the Cape. A reliable freshwater source was secured, and the area began to develop with a focus on fishing and naval/military enterprise (Burman & Levin, 1974). An iron ore export jetty was constructed in 1976, and a number of downstream industries have developed since then.

The greater Bay area is open to the SW, its outer entrance spanning approximately 6.5 km between North Head and Jutten Point. The mouth of the inner Bay area is defined by the southernmost tip of Marcus Island and Elandspunt, the most northerly point on the Donkergat peninsula. The inner mouth is more exposed to WSW swells and spans 2.3 km at its narrowest point (Figure 7-3).

[xxi] It should be noted that all satellite images, photographs, maps and graphic visualisations of Saldanha Bay in this report are orientated such that North faces **up** on the page, unless explicitly indicated otherwise.

The construction of the iron ore jetty in the early 1970's resulted in substantial changes to the Bay's geography. In 1973 a spending beach type breakwater was developed, linking Marcus Island to the mainland at Hoedjiespunt. The 2 km long arced breakwater now forms an integral manmade feature of the harbour, preventing a substantial amount of wave energy from entering the Bay. Under its shelter, the construction of the iron ore causeway and export jetty was completed in 1976. The impermeable causeway, protruding 3.3 km from the shoreline, effectively splits Saldanha Bay into two smaller bays known as Small Bay and Big Bay. Small Bay, hemmed in by the spending beach breakwater and the causeway, is well protected from swell elements and hosts the local fishing fleet. Big Bay is relatively exposed in comparison, and is consequently undeveloped along its 11 km coastline, save for the small craft harbour at Club Mykonos.

Figure 7-3 Natural features of Saldanha Bay (Google Earth, 2013d)

To the southeast of Saldanha Bay lies Langebaan Lagoon. Unusually, Langebaan Lagoon is a purely saltwater lagoon, and is a critical habitat area for juvenile fish, birdlife, molluscs, macrofauna and crustaceans. The 16 km long lagoon is unique in that it boasts a number of distinct inter-tidal habitats (Anchor Environmental, 2011). The lagoon area was designated a Ramsar wetland conservation site in 1988, and as such the conservation and "wise use" of the sensitive ecological habitat is promoted (Ramsar, 2009). Commercial development in the Lagoon area is prohibited.

For the purposes of this study, "Saldanha Bay" is defined to the west by the entrance between North Head and Jutten Point, and is separated from Langebaan Lagoon by the South Eastern Port Limits, defined in SANHO Chart SAN SC2, "Saldanha Bay and Langebaan Lagoon" (SANHO, 2004) by a line between Salamander Point and Leentjiesklip No.2. These limits are illustrated in Figure 7-3. Chart SAN SC2 is shown in Appendix A.

7.2 Port of Saldanha

Facilities

The primary feature of the Port of Saldanha is the iron ore export terminal. The terminal was developed in 1976 to facilitate the export of iron ore from the mine at Sishen in the Northern Cape. Ore is delivered to the port via an 860 km long railway line which terminates at the port area. The iron ore is stockpiled just ashore of the causeway, where it is transported to the receiving bulk carrier on covered conveyer belts. Two iron ore bulk carrier berths are in use, one at either side of a 990 m piled trestle and caisson jetty that protrudes from the end of the causeway (Figure 7-4). The terminal exports approximately 45 mT of iron ore per annum. A single crude oil import terminal is located at the southernmost end of the jetty (Transnet, 2009).

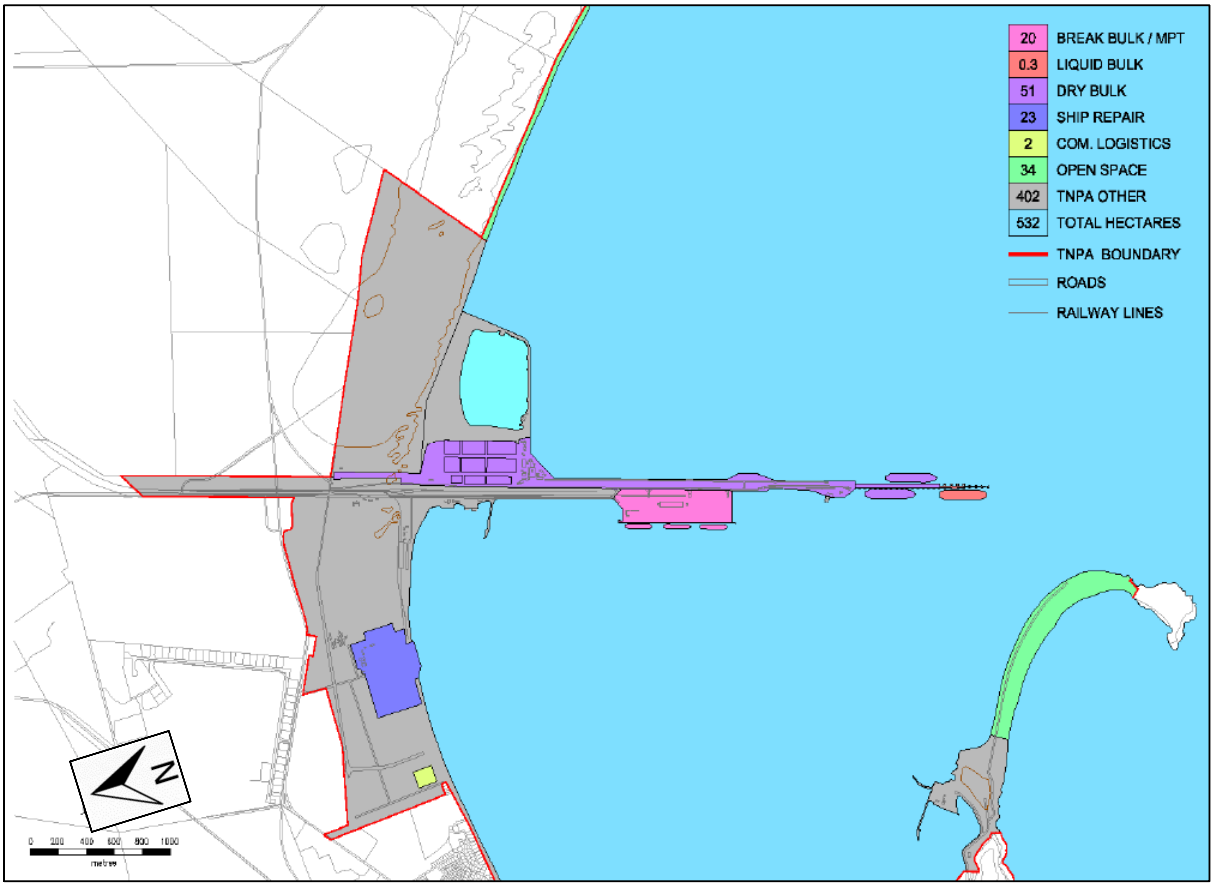


Figure 7-4 Existing operational layout at the Port of Saldanha (Transnet, 2009)

An 874 m Multi-Purpose Terminal (MPT) was developed in 1980, providing three additional berths (#201, #202 & #203) to the Port, as detailed in SANHO Chart SAN 1012, "Saldanha Bay Harbour", (SANHO, 1999). The quay facilitates breakbulk handling, typically imports of steel pellets and coal and exports of zinc, lead, copper, steel coils and zircon. The terminal is situated in shallower water within Small Bay and is maintained to a depth of -14.9 mCD. A number of other shallow water jetties, quays and slipways are dotted along the shores of Small Bay, typically for small craft use.

Nautical Features

In order to accommodate the significant draught of the design iron ore vessel, the iron ore berth pockets are dredged to a depth of -22.9 mCD. The oil berth and outer approach channel are dredged to depths of –23.1 mCD and -23.6 mCD, respectively. A vessel turning circle, 580 m in diameter, is located directly off the southern tip of the oil jetty, maintained to a depth of -23.1 mCD. The existing approach channel is 380 m wide and allows for unidirectional vessel traffic. Maintained depths within the port area are described by chart SANHO Chart SAN 1012, "Saldanha Bay Harbour", which is presented in Appendix A (SANHO, 1999).

The area surrounding the port is characterised by gently undulating coastal plain with low hills (PDNA/SKM JV, 2006). The highest points in the area include Malgaskop (112 m) to the west, Karringberg (175 m) to the east, and Postberg on the Donkergat Peninsula (193 m) to the south. Several smaller hills and outcrops of granite boulders are also evident in the surrounding area.

Saldanha Bay Industrial Development Zone

The concept of the Saldanha Bay Industrial Development Zone (SBIDZ) has been discussed for some decades, and Phase 1 of the initiative was launched in October 2013 by the Department of Trade and Industry (DTI, 2013). The first Phase places focus on developments in the offshore oil and gas industry, and site of 164 ha has been identified for initial development to the west of the existing port causeway, ashore of the Mossgas quay, shown in Figure 7-5.

Long term expansion of the IDZ has been examined in recent years. A pre-feasibility study for a specific IDZ concept was published in 2007 and a subsequent feasibility study was published in 2011 (Wesgro, 2011). A larger "Industrial Corridor" development area has been identified in the Saldanha-Vredenburg area, and its proposed boundaries have been relatively well defined. The corridor sprawls inland from the existing port area and is bound by the local road network: the R27 to the east and the R45 to the north. The corridor envelops the Saldanha-Sishen railway line, and is bound to the west by the local topography (Besaansklip Hill, 114 m) and residential/urban areas.

Figure 7-5 Proposed Industrial Corridor and Port Expansion Area (Google Earth, 2013d)

The extents of the proposed Industrial Corridor are visible in Figure 7-5. Also shown are the recently launched Phase 1 of SBIDZ, and the potential port expansion area, as proposed by the National Ports Authority. Though these industrial areas would be operated by different entities, synergy between them is critical for mutual success of Saldanha Bay IDZ and the port area. It is assumed that IDZ development will stem from the port area and stretch to the interior as the region develops.

It should be mentioned that although the Industrial Corridor covers a significant area of land, an operational IDZ would not necessarily be established across the full length of the corridor. The relatively flat topography of the area may prompt concern regarding visual impact of an extensive IDZ. Furthermore the proposed Corridor may encompass a number of Critical Biodiversity Areas (CBA's) which may be prevalent in the region. Any CBA's identified during a detailed botanical and faunal impact assessment will require a buffer zone around it. A preliminary investigation of the corridor area highlights potential conservation areas (Urban Dynamics Western Cape, 2011). Refer to "*APPENDIX B – Spatial Development Framework Plans*" for detailed plans regarding the proposed Industrial Corridor.

7.3 Environmental Conditions in Saldanha Bay

7.3.1 General Atmospheric Conditions

The Saldanha Bay area is characterised by a semi-arid Mediterranean, mild air climate. The general atmospheric conditions in the Saldanha Bay area are stated in Table 7-1 (CSIR, 2006), (Luger, et al., 1998).

Table 7-1 General atmospheric conditions in Saldanha Bay

Atmospheric Condition	Value
Maximum ambient air temperature	37° C [November]
Minimum ambient air temperature	1° C [July]
Maximum relative humidity	100 %
Minimum relative humidity	15 %
Average annual relative humidity	70 % [at 14:00] to 80 % [at 08:00]
Average air pressure	1013 mb
Highest daily rainfall	20 mm [estimated]
Highest monthly rainfall	60 mm [estimated]
Mean annual rainfall	220 mm
Rain days per annum	50 days [estimated]
Annual 90-percentile rainfall	300 days [estimated]
Wettest month	July/August
Fog days per annum	80 to 111 days[xxii]

7.3.2 Tides

The tides in Saldanha Bay are semi-diurnal, implying that two high and two low tides occur per tidal lunar day. On average a tide will occur every 12 hours and 25.2 minutes, though this may vary by a few minutes due to the phase of the moon and tidal lag. Tidal predictions in South Africa are published annually by SANHO – the South African Navy Hydrographic Office (SANHO, 2013). The SA Navy operates a tide gauge in Saldanha, the historical data from which is used to calibrate and revise the Tide Tables.

Tidal water levels in Saldanha Bay are presented in Table 7-2. The levels are stated relative to Chart Datum (CD) which is based on LAT – the lowest predicted astronomical tide over the 18.61 year lunar nodal cycle.

Table 7-2 Tidal levels in Saldanha Bay (SANHO, 2013)

Tide Description	Acronym	Water Level (above CD)
Highest Astronomical Tide	HAT	+ 2.03 mCD
Mean High Water Spring	MHWS	+ 1.75 mCD
Mean High Water Neap	MHWS	+ 1.27 mCD
Mean Level	ML	+ 0.99 mCD
Mean Low Water Neap	MLWN	+ 0.7 mCD
Mean Low Water Spring	MLWS	+ 0.24 mCD
Lowest Astronomical Tide	LAT	0.0 mCD

The datum used by the Surveyor General to describe topographic heights, the *Land Levelling Datum (LLD)*[xxiii], is offset from Chart Datum by +0.865 mCD in the Saldanha Bay area. **In this report all bathymetric depths are stated relative to Chart Datum (CD).**

It is important to note that the tidal levels stated in the SA Navy Tide Tables strictly refer to ocean tides. There are however a number of other factors that can affect local water levels. Extreme

[xxii] Fog cover in Saldanha typically descends overnight and burns off in the early morning, usually before 10:00.
[xxiii] LLD is referred to as Mean Sea Level (MSL) by oceanographers. Thus LLD = MSL = +0.865 mCD.

atmospheric high pressure or low pressure systems will tend to decrease or increase local water levels respectively. High pressure systems often accompany mild wave conditions, so the combined risk of an extreme wave height and extreme low water level is quite low. The phenomenon of storm surge will conversely result in increased water levels. This may pose a challenge when designing coastal structures for overtopping and survivability, but will also result in greater under keel clearance for deep draught vessels when navigating the port entrance.

7.3.3 Currents

The Saldanha Bay area is subject to very low current velocities. The primary ocean current on the west coast, the Benguela Current, is formed by the prevailing south easterly trade winds, forcing cold, nutrient rich water up the African coastline from the South Atlantic. Current velocities vary between 0.1 m/s to 0.3 m/s along the shore (CSIR, 2006). Inshore of the Benguela Current proper, the Benguela Upwelling System is instigated by local south easterly winds, which invoke moderate currents along the coastline, up to velocities of 0.5 m/s. Due to the disjointed geography of Saldanha Bay, particularly the outer islands, protruding headlands and narrow harbour mouth, the Benguela has little effect within the Bay area.

It has been calculated that the peak tidal flow velocity across the entrance to the Bay (Elands Point to Marcus Island) during a mean spring high tide is 0.17 m/s (CSIR, 2006). This is calculated on the basis of the combined spring tide tidal prism of Langebaan Lagoon and Saldanha Bay discharging through the harbour mouth. The velocity is averaged across the depth of the water column, whereas in reality the flow velocities will be far greater near the water surface. CSIR estimate the maximum discharge velocity to be 0.3 m/s across the entrance to the harbour. This value corresponds with velocities reported by PDNA/SKM (PDNA/SKM JV, 2006) and CSIR numerical model results (CSIR, 1996). Luger et al report that typical current speeds in Big Bay are far lower on average, with 80% of surface currents less than 0.12 m/s (Luger, et al., 1998).

7.3.4 Wind

Wind conditions at Saldanha Bay are recorded for the National Port Authority by CSIR. Wind speed and direction are recorded at the Transnet port control tower on Hoedjiespunt (33°0.70’S, 17°57.76’E). The anemometer is mounted on top of an antenna at an elevation of 50 mCD.

The wind data are recorded in 1-minute intervals over a 20-minute period. At the end of every 20-minute cycle the data are analysed and the averaged 20-minute wind speed, the highest 1-minute wind speed and the 20-minute vector averaged wind direction are logged. The wind records have been logged in this manner from October 1995 to April 2012[xxiv], providing a 17 year unbroken series of data.

Correction for sampling period

The 20-minute averaged wind speed format is suitable to determine the effects of wind loading on large vessels. However, in order to better represent the wind climate, and in keeping with industry practice, the wind speed is converted to a 1-hour averaged wind speed. The ratio of recorded wind

[xxiv] The wind recording instrument was upgraded over a period of days in April 2012, thus breaking the data series. Data from May 2012 to present was not considered in this study.

speed to hourly wind speed is described in the Coastal Engineering Manual (Figure II-2-1, pg II-2-4), (U.S. Army Corps of Engineers, 2006). It is reproduced below as Equation (7.1).

$$\frac{U_t}{U_{3600}} = 1.277 + 0.296 \tanh\left\{0.9 \log_{10}\left(\frac{45}{t}\right)\right\} \qquad (7.1)$$

for t<3600, where *t* = sampling period (in seconds), and *Ut* is the windspeed in m/s averaged over *t* seconds.

Therefore, for *t* = 20 min = 1200 s,

$$U_{3600} = 0.98U_{1200}$$

A correction factor of 0.98 is thus applied to all wind velocities within the dataset.

Correction for instrument elevation

The altitude of the anemometer has a substantial effect on the interpretation of wind speed. In marine and coastal zone wind monitoring, the standard reference level is 10 m above sea level (MSL). To transform the higher altitude wind speed into 10-metre wind speed (U_{10}), the "1/7" Rule is usually applied, shown as Equation (7.2).

$$U_{10} = U_z\left(\frac{10}{z}\right)^{\frac{1}{7}} \qquad (7.2)$$

where *z* is the height of the anemometer in metres above MSL, and *Uz* is the recorded windspeed in m/s at height *z*.

The "1/7" Rule is applicable for data captured in near neutral conditions, within a range of 8-12 m above MSL. The Coastal Engineering Manual (Figure II-2-6, pg II-2-12) provides a more comprehensive method of transformation to the 10-metre wind speed, considering the instrument height is 50 m above sea level. This method, reproduced in Figure 7-6, illustrates the variance of the transformation ratio with regard to the recorded wind speed. The "1/7 Rule" is represented graphically, and can be seen to underestimate the corrected wind speed for all recorded values above 10 m/s. The U/U_{10} ratios derived from the graph are 1.26, 1.24 and 1.19 for the "1/7 Rule", 10 m/s and 25 m/s respectively.

The correction factor U_{10} = U/1.19 is therefore used for all recorded wind speeds above 10 m/s, as velocities between 15 m/s and 30 m/s yield a similar ratio. U_{10} = U/1.24 is applied to wind speeds below 10 m/s, as the "1/7" Rule is shown to underestimate wind speed.

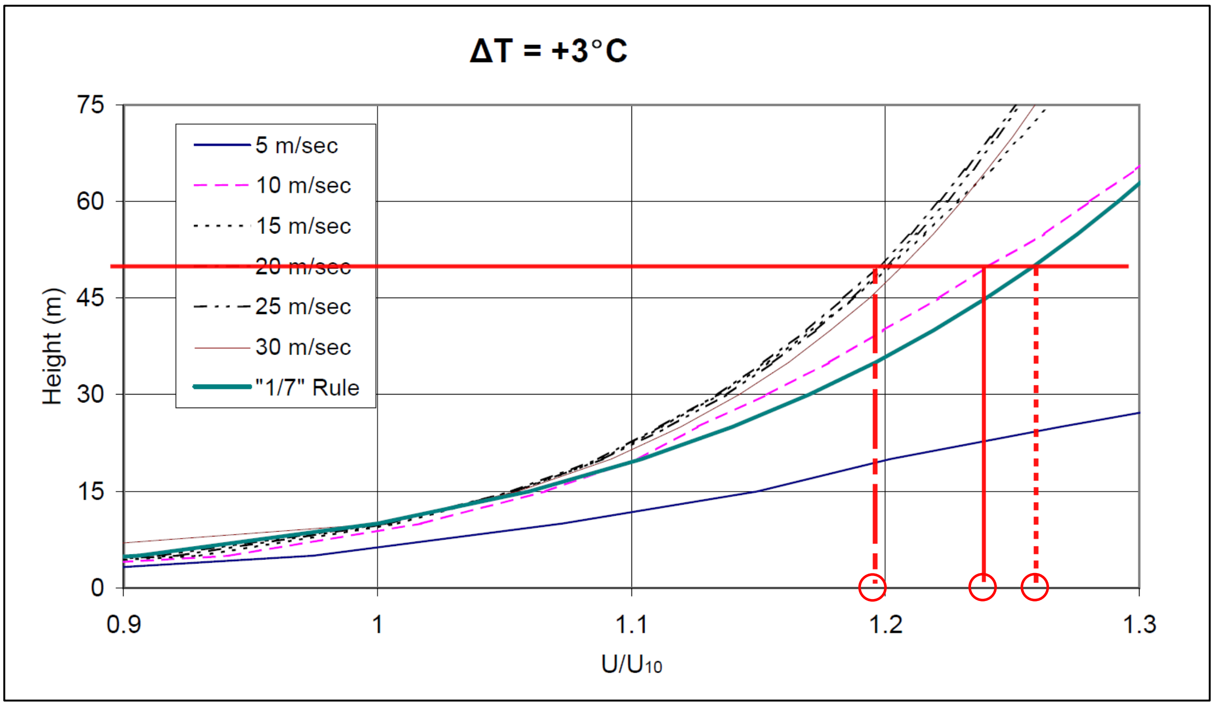


Figure 7-6 Ratio of wind speed at any height to the 10 m wind speed for a temperature difference of +3°C (U.S. Army Corps of Engineers, 2006)

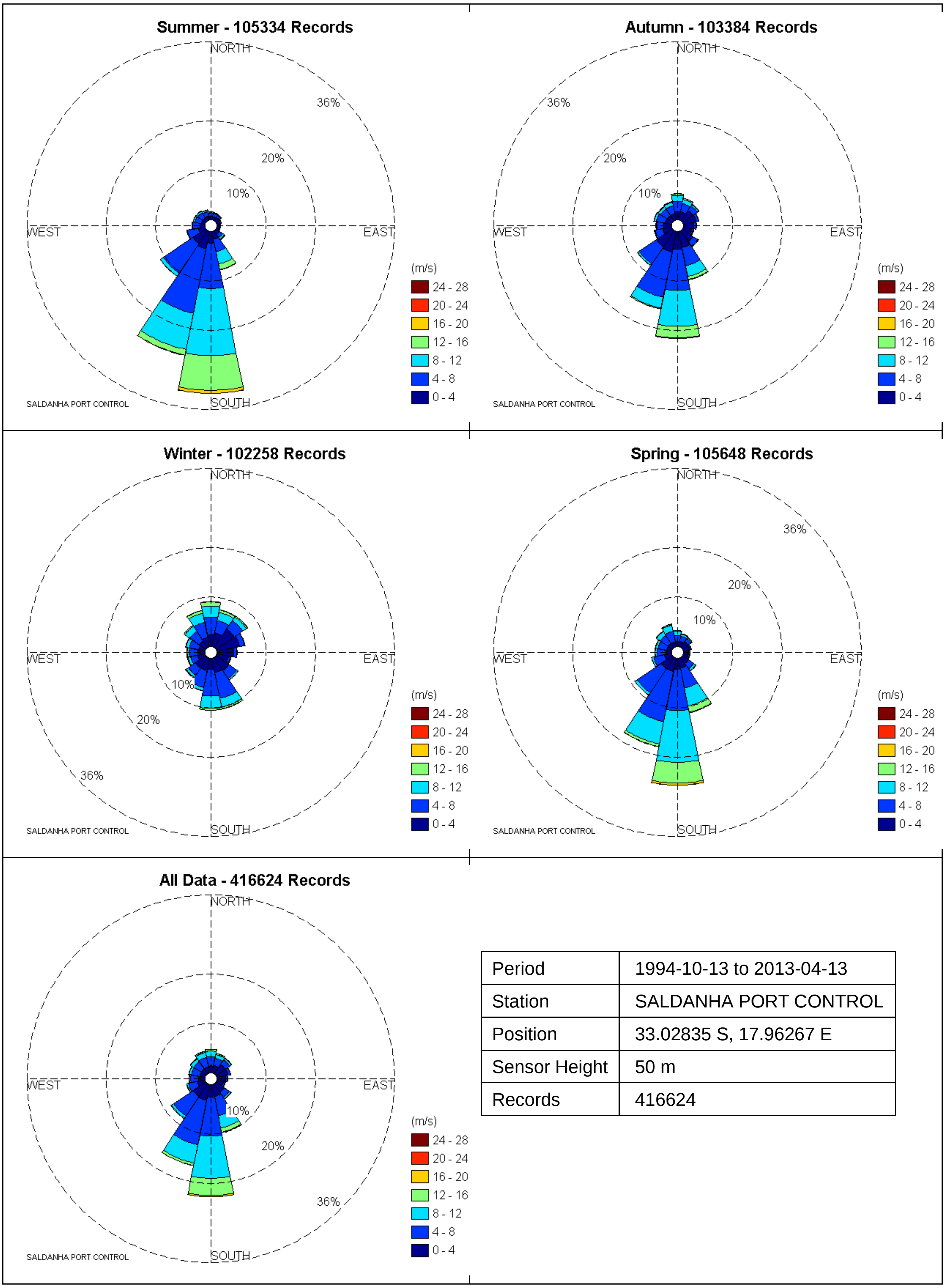
Wind speed directional distribution

Correction factors for both sampling period and elevation above sea level were applied to the raw data series. Using the transformed time series, a joint occurrence distribution table of hourly-averaged wind speed versus direction was produced, shown as Table 7-3. Wind direction is binned into 16 secondary inter-cardinal directions, each 22.5° wide. Southerly winds are the most prominent, accounting for 23% of the wind record, and 58% of winds originate from the 90° quadrant between SSE and SW. The remainder of directional wind occurrences are very evenly distributed, with 2%-4% of logged wind directions allocated to each of the remaining 12 directional bins between WSW and SE.

Table 7-3 Joint occurrence distribution of wind speed and wind direction (CSIR, 2012)

Wind Speed (m/s)	Wind Direction (degrees TN)																
	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Total
0.0 - 2.0	0.51	0.57	0.84	0.89	0.80	0.74	0.73	0.69	0.72	0.73	0.65	0.41	0.35	0.30	0.34	0.42	9.70
2.0 - 4.0	0.89	0.99	1.47	1.46	1.00	0.71	1.33	1.76	1.86	2.53	2.44	1.15	0.94	0.81	0.81	0.81	20.96
4.0 - 6.0	0.99	0.78	0.67	0.42	0.26	0.19	0.87	2.14	3.30	4.39	3.16	1.23	1.04	1.01	0.95	1.01	22.42
6.0 - 8.0	0.91	0.70	0.43	0.09	0.08	0.08	0.39	1.82	4.54	4.78	1.62	0.64	0.56	0.71	0.83	0.93	19.11
8.0 - 10.0	0.68	0.47	0.24	0.02	0.03	0.05	0.24	1.53	4.75	2.72	0.40	0.24	0.21	0.35	0.52	0.66	13.13
10.0 - 12.0	0.42	0.29	0.14	0.01	0.01	0.03	0.12	1.03	3.76	1.06	0.14	0.08	0.07	0.14	0.25	0.38	7.92
12.0 - 14.0	0.23	0.15	0.06	0.01	0.01	0.01	0.05	0.60	2.40	0.39	0.07	0.03	0.03	0.06	0.08	0.17	4.34
14.0 - 16.0	0.10	0.07	0.02	0.00	0.00	0.00	0.02	0.25	1.09	0.11	0.02	0.02	0.01	0.01	0.03	0.06	1.83
16.0 - 18.0	0.03	0.02	0.01	0.00	0.00		0.00	0.08	0.27	0.03	0.00	0.00	0.00	0.00	0.01	0.02	0.48
18.0 - 20.0	0.01	0.00	0.00		0.00		0.00	0.01	0.04	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.08
20.0 - 22.0	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	0.00					0.00	0.00	0.01
22.0 - 24.0	0.00					0.00	0.00	0.00	0.00	0.00							0.00
24.0 - 26.0									0.00								0.00
Total	4.78	4.05	3.89	2.91	2.20	1.82	3.76	9.91	22.73	16.73	8.51	3.81	3.20	3.39	3.82	4.49	100.

Note: a value of "0.00" denotes a positive occurrence of less than 0.005%.

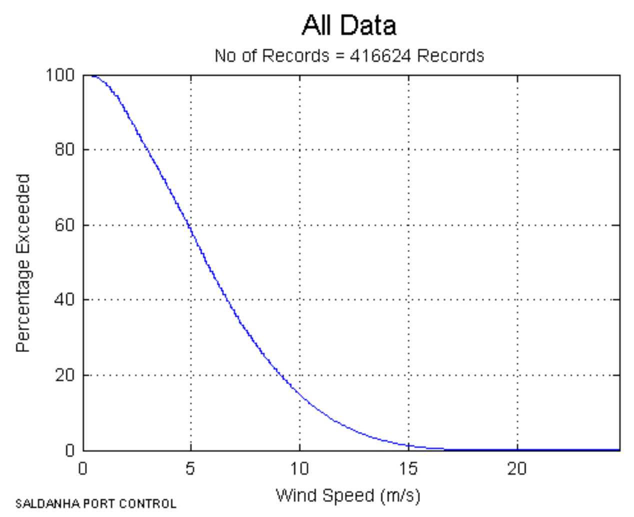


Period	1994-10-13 to 2013-04-13
Station	SALDANHA PORT CONTROL
Position	33.02835 S, 17.96267 E
Sensor Height	50 m
Records	416624

Figure 7-7 Directional wind roses for Saldanha Bay (CSIR, 2012)

Directional wind roses produced from the elevation adjusted time series show the significant seasonal variation in wind direction and strength (see Figure 7-7). The southerly element of the wind climate appears to be dominant throughout the year, while the northerly element becomes a concern only during the winter months.

The percentage wind exceedance table and corresponding exceedance graph are presented in Figure 7-8. The average annual 1% exceedance hourly-averaged wind speed is 15.29 m/s. During the summer period this threshold increases to 15.8 m/s. Wind speeds have been known to reach 24 m/s (for a 20-minute averaged sample), though velocities above 20 m/s are quite rare. The percentage exceedance wind speeds are further discussed in *Section 8.4 - Wind Induced Downtime.*



Wind Speed Exceeded (m/s)					
	1.0%	5%	10%	25%	50%
All Data	15.29	12.61	11.09	8.40	5.71
Summer	15.80	13.53	12.10	9.50	6.72
Autumn	14.79	11.85	10.25	7.56	5.04
Winter	14.62	11.51	9.92	7.23	4.71
Spring	15.46	12.86	11.34	8.91	6.30

Figure 7-8 Seasonal wind speed exceedance curve and percentages at Saldanha Bay (CSIR, 2012)

7.3.5 Offshore Wave Conditions

Offshore wave conditions are monitored by CSIR using a Waverider buoy, moored approximately 5.4 km west of the town of Kommetjie on the Cape peninsula, and 130 km south of Saldanha Bay. The Waverider buoy, hereafter referred to as the Cape Point buoy, is moored in approximately 70 m of water depth, at position 34°12'14.40"S, 18°17'12.01"E. The buoy continuously calculates the significant wave height (H_s), maximum wave height (H_{max}), spectral peak wave period (T_p), average zero down-crossing wave period (T_z), spectral crest period (T_c), average spectral period (T_b), mean wave direction (θ) and spreading factor (*s*) and transmits 30-minute averaged data to a shore station every half hour. The approximate position of the buoy is shown in Figure 7-10.

Wave height distribution

A 3-hourly time series[xxv] has been created from the logged data for the period January 1998 to August 2013. The significant wave height, peak period, wave direction and directional spreading are the four parameters that contribute to this study. A joint occurrence distribution of H_s and T_p has been tabulated for the 15 year time series (Table 7-4).

[xxv] Wave parameters derived from a 20 minute record logged every 3 hours.

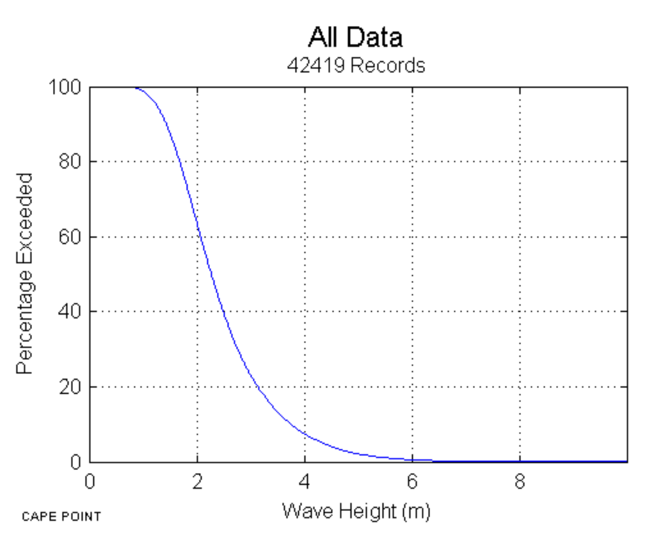
Table 7-4 Joint occurrence distribution of H_s and T_p at Cape Point (CSIR, 2013a)

	Cape Point Waverider Buoy (CP01) – Joint occurrence distribution of H_s and T_p																
H_s (m)	Period (T_p) (s)																
	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20	20-22	22-24	24-26	26-28	28-30	30-32	Total
0.0 - 0.5	0.01			0.00													0.01
0.5 - 1.0	0.00		0.02	0.07	0.37	0.53	0.10	0.06	0.03	0.01							1.19
1.0 - 1.5			0.29	0.45	1.92	6.89	1.36	0.50	0.10	0.04	0.02	0.01					11.56
1.5 - 2.0		0.00	0.38	1.17	2.01	14.67	4.12	1.12	0.25	0.12	0.04	0.01					23.89
2.0 - 2.5			0.10	1.26	1.35	12.87	6.45	1.71	0.22	0.13	0.01	0.02					24.11
2.5 - 3.0			0.01	0.49	0.91	6.98	5.62	2.01	0.21	0.07	0.01	0.05					16.36
3.0 - 3.5				0.10	0.46	3.61	3.50	1.74	0.14	0.04	0.01	0.02					9.62
3.5 - 4.0				0.04	0.18	1.91	2.11	1.38	0.15	0.04	0.00						5.82
4.0 - 4.5				0.01	0.08	1.05	1.18	0.89	0.12	0.02							3.35
4.5 - 5.0				0.00	0.03	0.52	0.69	0.59	0.11	0.02	0.01						1.97
5.0 - 5.5					0.01	0.17	0.32	0.36	0.08	0.02							0.96
5.5 - 6.0						0.08	0.20	0.24	0.05	0.02							0.59
6.0 - 6.5						0.03	0.08	0.11	0.04	0.00							0.26
6.5 - 7.0						0.01	0.03	0.04	0.04	0.01							0.13
7.0 - 7.5						0.00	0.01	0.02	0.02	0.01							0.06
7.5 - 8.0							0.00	0.02	0.00	0.00							0.03
8.0 - 8.5							0.00	0.01	0.01	0.01	0.00						0.04
8.5 - 9.0							0.00	0.01	0.01	0.00							0.03
9.0 - 9.5								0.00	0.01								0.01
9.5 - 10.0										0.00	0.00						0.01
Total	0.01	0.00	0.80	3.59	7.31	49.29	25.79	10.82	1.60	0.58	0.10	0.10					100.

Note: a value of "0.00" denotes a positive occurrence of less than 0.005.

It can be seen that 90% of recorded wave heights are below H_s=3.75 m, while only 7.5% of the wave record is greater than H_s=4 m in height. Offshore significant wave heights of 8 m or greater are not uncommon however, with at least 150 such events occurring over the 15 year record. Maximum individual wave heights (H_{max}) at the buoy have been known to reach 16 m to 18 m (CSIR, 2013a).

Seasonal wave height exceedance values are presented in Figure 7-9. It is evident that the largest wave heights at Cape Point occur during the winter months. The average annual 1% exceedance wave height is H_s=5.6 m, whereas during the winter months the threshold increases to H_s=6.2 m.



Wave Height H_s Exceeded (m)					
	1.0%	5%	10%	25%	50%
All Data	5.6	4.4	3.8	2.9	2.3
Summer	4.3	3.4	3.1	2.5	2.1
Autumn	5.5	4.2	3.6	2.8	2.2
Winter	6.2	5.0	4.4	3.5	2.6
Spring	5.2	4.2	3.7	2.9	2.3

Figure 7-9 Percentage wave height exceedance curve and seasonal values at Cape Point (CSIR, 2013a)

Wave direction

The joint occurrence distribution of wave direction and significant wave height is shown in Table 7-5. Over 50% of waves approach from the southwest (214° to 236°) and over 90% of waves approach from the 68° sector between SSW and WSW (191° to 259°). Waves approaching from the prevailing SW sector are typically swell waves caused by low pressure systems travelling east to west across the South Atlantic. Wind waves from the southeast to the southwest are superimposed on the prevalent swell component and contribute to the prevailing wave direction.

A minor (3%) wave climate component is attributed to waves approaching from west through to north east. This is clearly a wind wave element as the wave heights fall primarily within a narrow band between 1 m to 3 m. These events will typically occur when the wind wave element from west to northeast exceeds the swell height component from the southwest.

Table 7-5 Joint occurrence distribution of H_s and Wave Direction at Cape Point (CSIR, 2013a)

	Cape Point Waverider Buoy (CP01) – Joint occurrence distribution of H_s and Direction																
H_s (m)	Wave Direction (degrees TN)																
	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Total
0.0 - 0.5																	0.00
0.5 - 1.0			0.00					0.01	0.12	0.38	0.39	0.19	0.03	0.05	0.01		1.18
1.0 - 1.5	0.00	0.00	0.03	0.00				0.19	0.98	3.13	5.12	1.91	0.21	0.08	0.01	0.02	11.68
1.5 - 2.0	0.00	0.01	0.03					0.55	1.40	5.00	12.04	4.46	0.24	0.08	0.07	0.03	23.90
2.0 - 2.5		0.01	0.01					0.46	0.95	4.13	13.06	4.70	0.37	0.10	0.09	0.03	23.91
2.5 - 3.0		0.00	0.00					0.10	0.43	1.92	9.07	3.95	0.31	0.10	0.05	0.00	15.93
3.0 - 3.5	0.00							0.00	0.09	1.06	5.37	2.72	0.28	0.05	0.02	0.01	9.60
3.5 - 4.0									0.02	0.59	3.20	1.86	0.22	0.06	0.02		5.97
4.0 - 4.5									0.01	0.25	1.88	1.19	0.10	0.05	0.01		3.48
4.5 - 5.0									0.00	0.14	1.06	0.77	0.06	0.01	0.01		2.04
5.0 - 5.5										0.08	0.54	0.38	0.02				1.02
5.5 - 6.0										0.05	0.35	0.23	0.02	0.01			0.65
6.0 - 6.5										0.03	0.12	0.12	0.01				0.28
6.5 - 7.0											0.08	0.07	0.00				0.15
7.0 - 7.5											0.04	0.03		0.00			0.07
7.5 - 8.0										0.00	0.01	0.02					0.03
8.0 - 8.5										0.00	0.03	0.01	0.00				0.04
8.5 - 9.0											0.01	0.02					0.03
9.0 - 9.5											0.01	0.01					0.02
9.5 - 10.0											0.01		0.00				0.01
Total	0.01	0.03	0.07	0.00	0.00	0.00	0.00	1.30	4.00	16.76	52.38	22.62	1.88	0.59	0.28	0.10	100.

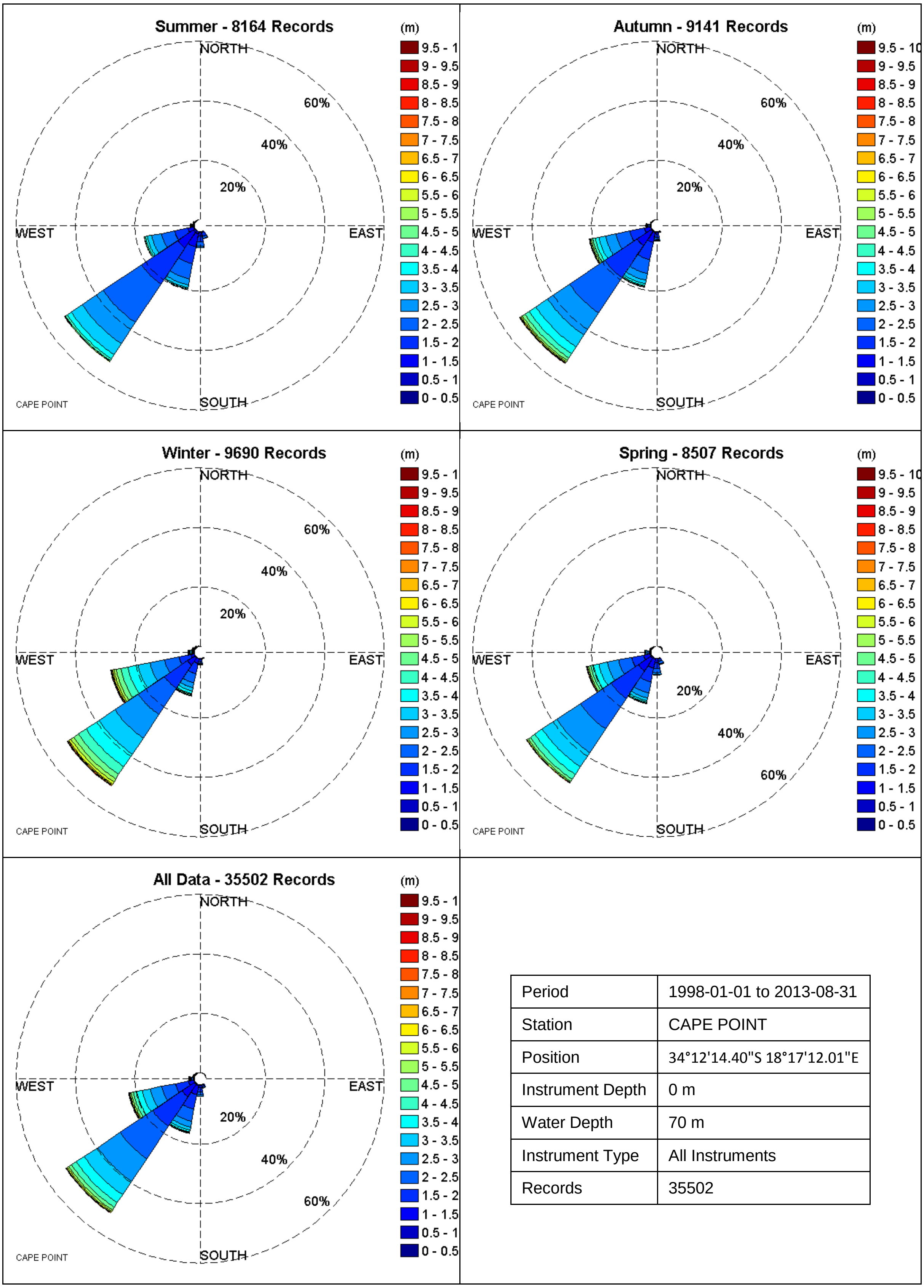
Note: a value of "0.00" denotes a positive occurrence of less than 0.005.

Directional wave roses have been derived from the 3-hourly wave data over the 15 year logging period (Figure 7-11).

It is important to consider the offshore wave environment when studying the wave climate inside Saldanha Bay. The offshore wave direction plays a significant role on the level of wave penetration inside the harbour. Due to the orientation of the harbour mouth (between Elands Point and Marcus Island), Saldanha Bay is particularly vulnerable to wave penetration from 210° to 280°. Wave approach between 240° to 260° will let a substantial amount of wave energy into the harbour as waves from this direction are not impeded by headlands or islands. Waves approaching from 215° to 225° however may cause greater agitation at the existing port area.

The use of refractive wave models allow further insight into directional wave propagation in the harbour. At present there is no wave monitoring device in Saldanha Bay that is capable of recording wave direction.

Figure 7-10 Positions of Saldanha Bay and Cape Point Waverider Buoys (Google Earth, 2013c)



Period	1998-01-01 to 2013-08-31
Station	CAPE POINT
Position	34°12'14.40"S 18°17'12.01"E
Instrument Depth	0 m
Water Depth	70 m
Instrument Type	All Instruments
Records	35502

Figure 7-11 Directional wave roses for Cape Point (CSIR, 2013a)

7.3.6 Nearshore Wave Conditions

A Waverider buoy located at the entrance to Saldanha Bay is used to record significant wave height and peak period. The buoy is located in 23 m of water, at position 33° 03'00"S, 17°58'24"E. Positioned 900 m southeast of Marcus Island and immediately adjacent the outer marker buoy of the approach channel to the Port of Saldanha, the Waverider is in an ideal location to provide representative nearshore wave data. The approximate position of the buoy is shown in Figure 7-10.

The nearshore buoy, hereafter referred to as the Saldanha Bay buoy, does not acquire directional wave data. It is reported (CSIR, 2006) that this particular mooring location was selected since the variation in swell wave direction at this point is expected to be less than 10°. This statistic is verified during a numerical model study in *Section 8.2,* with the mean direction determined to be approximately 242°.

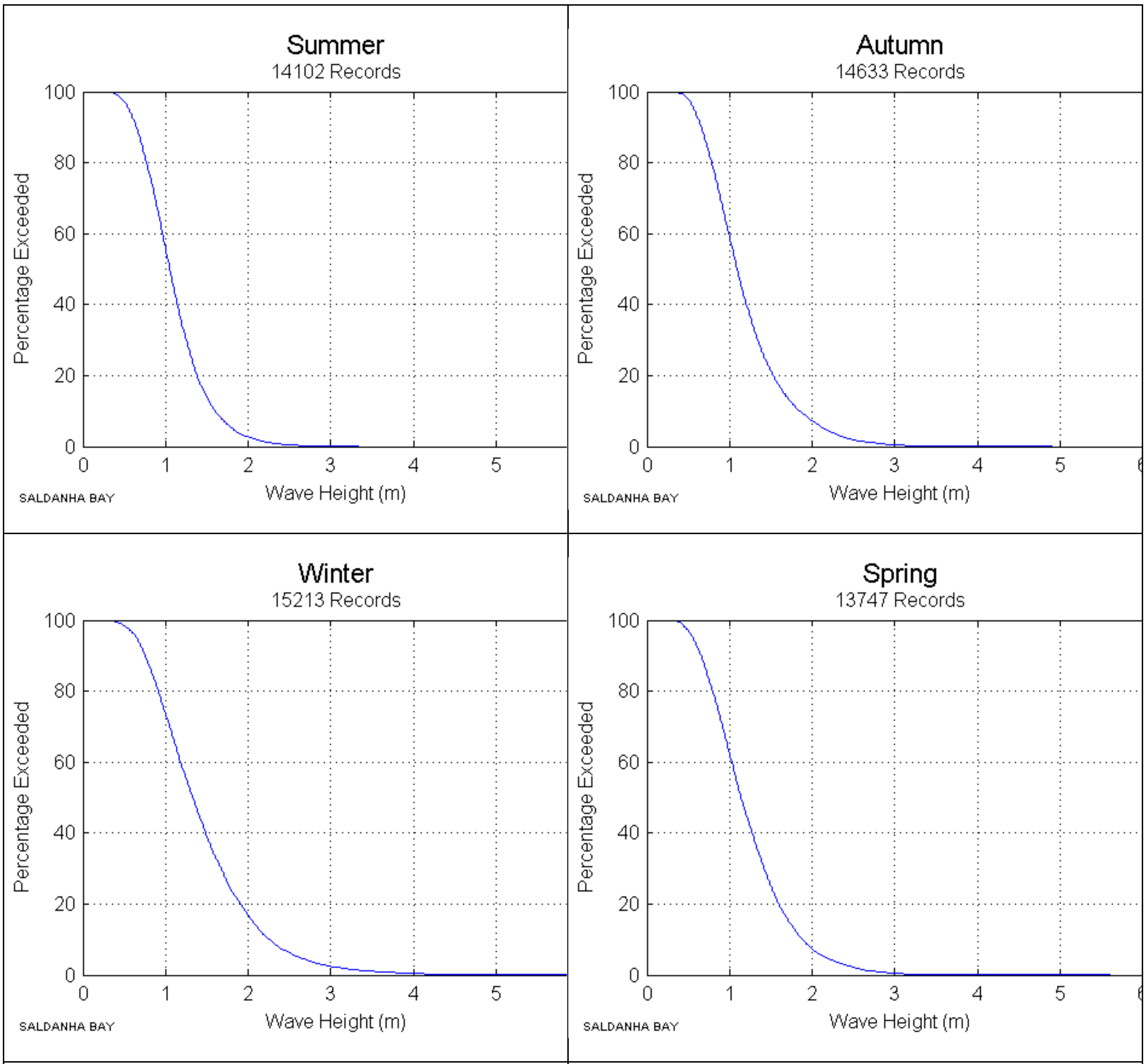
Table 7-6 Joint occurrence distribution of H_s and T_p at Saldanha Bay (CSIR, 2013b)

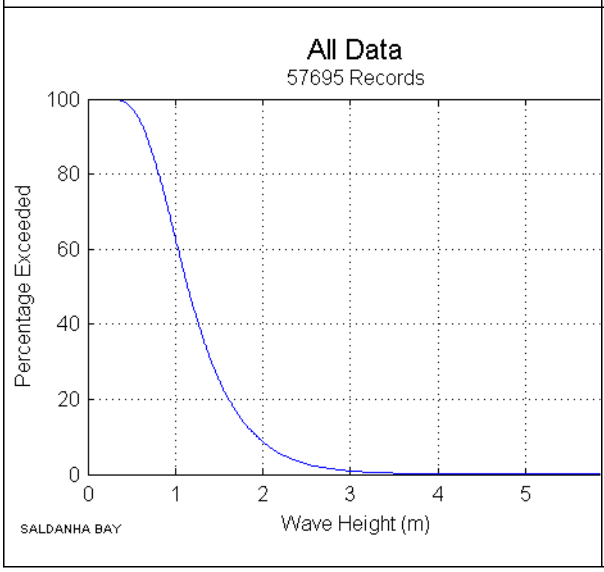
	Saldanha Bay Waverider Buoy (SB01) – Joint occurrence distribution of H_s and T_p																
H_s (m)	Period (T_p) (s)																
	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20	20-22	22-24	24-26	26-28	28-30	30-32	Total
0.0 - 0.5	0.01	0.01	0.04	0.08	0.70	1.23	0.24	0.15	0.01	0.06	0.01	0.00					2.54
0.5 - 1.0	0.03	0.05	0.40	1.15	6.44	19.79	5.25	1.63	0.14	0.34	0.03	0.11					35.37
1.0 - 1.5	0.01	0.02	0.06	0.80	3.77	20.31	9.50	2.30	0.15	0.36	0.02	0.12					37.41
1.5 - 2.0	0.01	0.01	0.01	0.14	1.02	6.60	5.71	2.30	0.11	0.20	0.01	0.05					16.15
2.0 - 2.5			0.00	0.03	0.23	1.81	2.23	1.27	0.07	0.14	0.00	0.04					5.83
2.5 - 3.0			0.00	0.01	0.05	0.37	0.66	0.58	0.07	0.07	0.00	0.00					1.83
3.0 - 3.5					0.01	0.05	0.19	0.23	0.02	0.05	0.01						0.54
3.5 - 4.0						0.02	0.05	0.10	0.02	0.01							0.20
4.0 - 4.5						0.01	0.02	0.04	0.01	0.01	0.00						0.07
4.5 - 5.0							0.01	0.02	0.01	0.01							0.04
5.0 - 5.5								0.01	0.00	0.00							0.01
5.5 - 6.0								0.00	0.00	0.00							0.01
6.0 - 6.5									0.00								0.00
Total	0.05	0.09	0.51	2.21	12.22	50.19	23.86	8.62	0.60	1.25	0.07	0.33	0.00	0.00	0.00	0.00	100.

Note: a value of "0.00" denotes a positive occurrence of less than 0.005.

A 3-hourly time series has been created from the recorded data for the period January 1992 to August 2013. A joint occurrence distribution of H_s and T_p has been tabulated for the 21 year time series, as shown in Table 7-6. More than 90% of significant wave heights are below 2.0 m. On rare occasions a wave height greater than H_s=5 m has been recorded, and only a single storm has resulted in a significant wave height greater than 6 m. Maximum individual wave heights approaching H_{max}=8.5 m have been documented during the 21 year sampling period.

A wave height (H_s) exceedance table has been developed from the waverider time series. The exceedance percentages are presented in Figure 7-12. Seasonal wave height exceedance curves are additionally displayed. A distinct correlation exists between the Cape Point and the Saldanha Bay wave distribution data and seasonal influences are prominent.





Wave Height H_s Exceeded (m)					
	1.0%	5%	10%	25%	50%
All Data	3.0	2.2	1.9	1.5	1.1
Summer	2.3	1.8	1.6	1.3	1.1
Autumn	2.8	2.1	1.9	1.4	1.1
Winter	3.5	2.6	2.3	1.8	1.3
Spring	2.8	2.2	1.9	1.5	1.1

Figure 7-12 Seasonal wave height exceedance curves and percentages at Saldanha Bay (CSIR, 2013b)

7.4 Nautical Restricted Areas

The SANHO Chart SAN SC2, “Saldanha Bay and Langebaan Lagoon”, as shown in Appendix A, identifies nautical zones that are forbidden to motorised craft (SANHO, 2000). Within Langebaan Lagoon there are a number of regions of varying restriction to watercraft users. However for the purpose of this study “Saldanha Bay” will be defined by the southern port limits, illustrated in Figure 7-3.

Donkergat Peninsula Prohibited Area

A nautical exclusion zone is enforced around the Donkergat peninsula, which is under the jurisdiction of the South African National Defence Force. The prohibited area incorporates (from west to east): Plankiesbaai, South Head, Juttenpunt, Juttenbaai, Elandspunt, Salamanderpunt, Meeueiland and Rietbaai. Terminal development will not under any circumstances be considered on this prohibited peninsula.

Marine Protected Areas

Malgas Island, Jutten Island and Marcus Island have been declared Marine Protected Areas under the Marine Living Resources Act (DEAT, 1998). These islands, and the waters immediately surrounding them, will not be considered for development.

Navigation Areas

The navigation channels and turning basins at the port of Saldanha are identified on SANHO Chart SAN 1012, “Saldanha Bay Harbour” (SANHO, 1999). Channel markers designating the entrance to the navigational channel are located immediately south of Marcus Island. Construction, anchoring or mooring in these navigation zones is strictly prohibited. Similarly, LNG terminal development or operations in the entrance channel in the outer port area between North Head and South Head will be prohibited, as defined on SANHO Chart SAN SC2, “Saldanha Bay and Langebaan Lagoon”, (SANHO, 2000).

Mariculture Areas

Four distinct mussel culture areas have been allocated for mussel culture and harvesting in Saldanha Bay. These areas are identified SANHO Chart SAN SC2, “Saldanha Bay and Langebaan Lagoon”, (SANHO, 2000). Navigation within these areas is permitted, though interference with rafts, buoys, floats or culture lines within the boundaries is strictly prohibited. These areas are highlighted as purple polygons in Figure 7-13. It can be seen that the mussel culture areas occupy the vast majority of navigable water in the Saldanha Bay area. It is possible the boundaries of these areas may be flexible should terminal developments impinge on the culture zones. Mitigative actions will necessarily have to be implemented should this scenario arise.

Map of Nautical Restricted Areas

The four prohibited and restricted areas defined above are superimposed on an aerial image of the Bay in Figure 7-13. Of these only the mussel culture areas may consider redefining their boundaries for the purpose of terminal development. The islands (green) fall under the jurisdiction of the West Coast National Park.

Figure 7-13 Nautical restricted areas in Saldanha Bay (Google Earth, 2013d)

7.5 Terrestrial Restricted Areas

The land area around Saldanha Bay has been fastidiously demarcated into zones of land use. Saldanha Bay Municipality has categorised the land within its jurisdiction into 24 types of land use, including residential, resort, business, industrial, open space, agriculture and transport usage.

Saldanha Bay Municipality Zoning Scheme

Land use zones have been designated in the Municipality's Spatial Development Framework (SDF) and are illustrated as a series of maps of varying detail (Urban Dynamics Western Cape, 2011). The SDF includes commentary and maps on proposed future land usage such as the future port area, the conceptual industrial corridor and various spatial management concepts. A selection of relevant maps pertaining to the Saldanha Bay and Port areas are included as *APPENDIX B – Spatial Development Framework Plans*.

A map highlighting the zoning schemes around the Saldanha Bay area has been extracted from the SDF and is presented as Figure 7-14. This Figure serves as an indication of areas that may be suitable or unsuitable for further port development (i.e. an LNG terminal). For clarity, detailed zoning of the port area and Saldanha town area are presented in *APPENDIX B – Spatial Development Framework Plans*.

Zones Suitable for Terrestrial Port Development

For the purpose of this study, only areas demarcated as “Industry”, “Agriculture” and “Transport” will be considered as suitable for port development. In the case where a zone designated as “Authority” refers to Transnet National Ports Authority property, this plot will also be considered suitable. Although an LNG terminal is not an agricultural or transport facility, there may be room for development in these zones under the “special use” clause described in the SDF (Urban Dynamics Western Cape, 2011).

Restricted and Prohibited Areas for Terrestrial Port Development

The southern half of the Malgaskop headland, stretching from North Bay Point to North Head, is designated as a Nature Reserve, the *SAS Saldanha Contractual Nature Reserve*, and is out of bounds as regards terminal development.

The northern half of the headland, stretching from Malgaskop to the southern limits of Saldanha town and Diazville, is owned by the South African National Defence Force (SANDF). This land, primarily used for military training, will be considered as a prohibited development area.

The northern section of Donkergat Peninsula is also under the jurisdiction of SANDF, and development on the peninsula is similarly prohibited. The West Coast National Park occupies the remainder of the Donkergat peninsula, as well as land south of Langebaan town, and development will not be considered here. Malgas Island, Jutten Island and Marcus Island, under the trust of the West Coast National Park, are additionally out of bounds.

Map of Terrestrial Restricted Areas

The prohibited and restricted areas defined above are superimposed on an aerial image of Saldanha Bay in Figure 7-15. Significant among these is the Saldanha residential area, which has been encroaching on the Port area in recent years, and counts most of Small Bay as its eastern boundary.

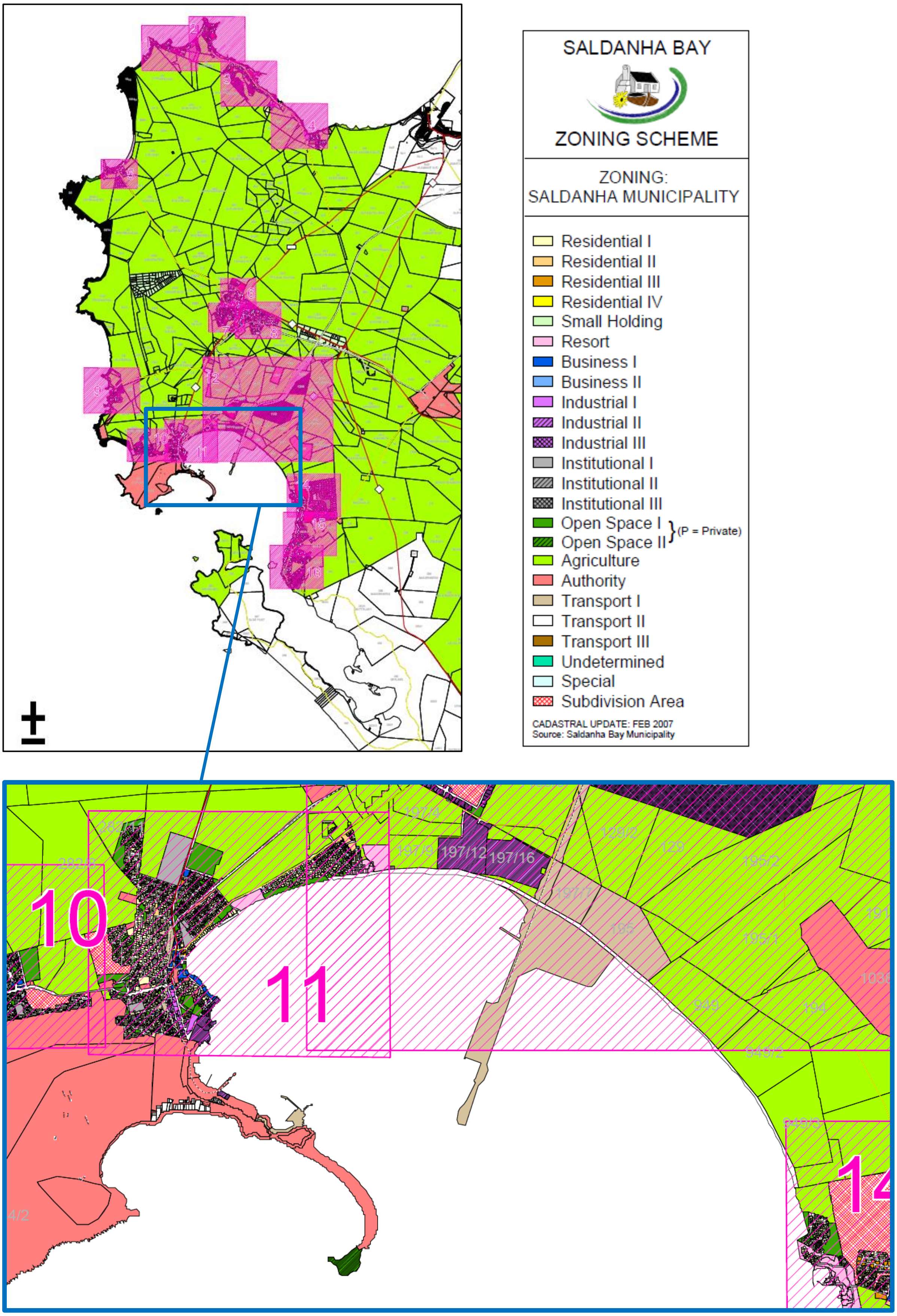


Figure 7-14 Saldanha Bay Municipality zoning scheme (Urban Dynamics Western Cape, 2011)

Figure 7-15 Terrestrial restricted areas in Saldanha Bay (Google Earth, 2013d)

7.6 Map of Potential Terminal Locations

7.6.1 Potential Terminal Locations in Saldanha Bay

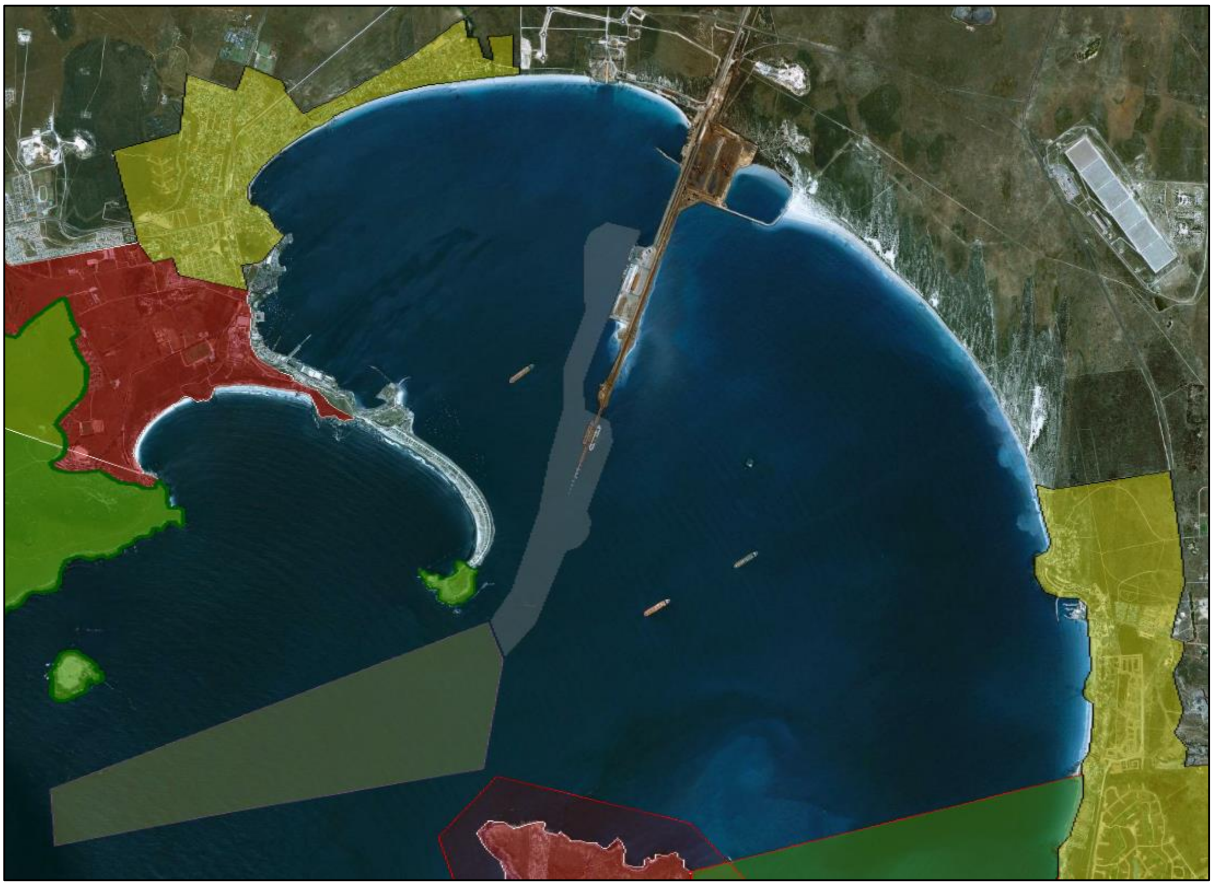


Figure 7-16 Map of combined prohibited areas in Saldanha Bay (Google Earth, 2013d)[xxvi]

The previously identified zones that prohibit nautical and terrestrial development are merged to create a map of combined prohibited areas (Figure 7-16). It should be noted that for the purpose of this study the mussel culture zones defined in Figure 7-13 have been omitted. The boundaries defining the designated mussel culture areas on SANHO Chart SAN SC2, "Saldanha Bay and Langebaan Lagoon" (SANHO, 2000) may be re-defined following negotiation with the Department of Agriculture, Forestry and Fisheries. It should be noted that these areas are not Marine Protected Areas.

A map of potential nautical and terrestrial development areas has been generated, shown in Figure 7-17.

Three distinct nautical development areas have been defined: North Bay, Big Bay and Hoedjiespunt. Four terrestrial areas have similarly been identified: Big Bay foreshore, the existing port causeway, Hoedjiespunt and the future port expansion area as proposed in Saldanha Municipality's Spatial Development Framework (Urban Dynamics Western Cape, 2011).

[xxvi] From this point forth all Google Earth images describe Saldanha Bay, and therefore share the same source (Google Earth, 2013d)

It should be noted at this point that conceptual terminal layouts described in this study will use the **existing port layout** as the base-case scenario. Several hypothetical port developments and extensions in Saldanha Bay have been proposed in the past (Transnet, 2009) and the feasibility or likelihood of promulgation of these developments will not be speculated on here. Needless to say, any legitimate port development considered by the port authority will consider all proposed future extensions in the Masterplanning phase of the design project.

7.6.2 Potential Development Areas (Nautical)

North Bay

The North Bay area includes the entirety of North Bay, stretching south to the entrance channel (300 m buffer) and west to Malgas Island. Water depth ranges between -20 m and -30 m. The site is particularly exposed to swells from 180° to 240°.

Hoedjiespunt

The Hoedjiespunt area is restricted to the east by the existing approach channel and berth pockets of the TNPA port. A buffer is incorporated to allow access to the fishing harbours, Navy jetty and Mossgas slipway. The western boundary is the leeward side of the spending beach breakwater, and the southern limit tapers to meet the breakwater to accommodate the narrow Small Bay entrance. Northerly development into Small Bay[xxvii] is not encouraged. Small Bay hosts an active fishing fleet, a small recreational marina and a Navy jetty, whose access cannot be impeded. Furthermore there are known water circulation problems in the Bay and construction may lead to sediment suspension and water quality issues (Luger, et al., 1998). Lastly, a large residential community along the Small Bay foreshore may be very vocal in opposition to such a large development inside the Bay. Water depths at the demarcated Hoedjiespunt area are generally between -12.1 mCD and -14.7 mCD. Some degree of dredging should therefore be anticipated.

Big Bay

The Big Bay area is a far more spacious zone, with potentially fewer water quality concerns than Small Bay due to a more active wave and current climate. The southern boundary is defined to allow direct access to the Club Mykonos harbour from the main entrance channel to the Bay. The eastern boundary is defined by the -10 m contour as the active breaker zone lies shoreward of this. Development at depths less than -10 m is possible, but dredging costs will become a major concern. Western limits are described by the existing approach channel and turning circle, and by the unused western flank of the TNPA causeway. Depths vary between -8 m (against causeway) and -21 m (at port entrance).

[xxvii] For this study, Small Bay is defined as the body of water north of the dog-leg breakwater on the Hoedjiespunt headland.

Figure 7-17 Map of potential nautical (blue) and terrestrial (green) development areas

7.6.3 Potential Development Areas (Terrestrial)

Hoedjiespunt

Not much land is free for development on the Hoedjiespunt side of the Bay, as attested by Figure 7-15 and Figure 7-16. Immediately north of Hoedjiespunt the land area is occupied by fisheries and light industry which merge into residential areas moving clockwise around the inner Bay. Minimal land is available just south of the TNPA port control tower on Hoedjiespunt. In order to house LNG facilities in this part of the Bay, land may need to be reclaimed leeward of the breakwater, reaching as far north as the dog-leg breakwater on Hoedjiespunt headland. Navigational buoys S1, S2 & S3 that run alongside the breakwater may need to be relocated should reclamation be necessary (SANHO, 1999).

Port Causeway

The eastern side of the Port of Saldanha causeway is entirely unused, as most port facilities are located on the western (Small Bay) side due to superior wave protection. However, one iron ore berth is located at the end of the trestle jetty on the eastern side. Development may be possible along the causeway, particularly towards the shallower end where lower volumes of reclamation material will be required. Should this option be pursued, a balance of cut and fill should be maintained.

Big Bay Foreshore

This land has been designated for agricultural use according to the municipality's SDF. Though some patches of this area have been reported to contain sensitive vegetation (Urban Dynamics Western Cape, 2011), conservation of the area should not be regarded as a critical showstopper for LNG terminal development.

Future Port Expansion Area

As expounded in *Section 7.2*, plans are afoot for an industrial corridor between Saldanha and Vredenburg, which comprises a shore-linked Industrial Development Zone. This corridor is set to merge with the port development area, stemming from the existing port facility. The probable future port expansion area is outlined by the municipality's SDF, and has previously been identified in Figure 7-5. Road, rail and power access already exists in this area, and heavy industry has been the staple for decades. Furthermore, this area has been identified as an "industrial" zone in the SDF, and as such, planning issues for LNG facilities are not expected to be problematic.

7.7 Land Area Requirements

7.7.1 Introduction to Land Area Requirements

In order to develop terminal layout schemes for an LNG import terminal in Saldanha Bay, the total Land Area Requirement (LAR) of the import and regasification facility must be quantified.

The land area will be wholly dependent on the type of import terminal used to offload cargo. For this purpose, the terminal technologies can be divided into two categories: *onshore regasification facilities* and *offshore regasification facilities*. The specific terminal styles are detailed in *Section 6 – Import Terminal Types*.

7.7.2 Offshore Regasification Terminals

Offshore regasification terminals comprise GBS terminals, SPM/Tower terminals and dockside FSRU terminals. Such terminals require minimal land area. A natural gas pipeline, usually 32” OD (outer diameter), will pipe the product to the shore based CCGT. This pipeline will necessitate a 10 m wide tract for pipe laying, adjacent access track and security fence if necessary (Helme, 2012). The footprint of the pipe will depend on the distance to the CCGT from the shoreside.

7.7.3 Onshore Regasification Terminals

The main components of an onshore terminal have been described in *Section 3.4 – Layout of an LNG Import Terminal*. LNG storage tanks occupy the majority of the onshore terminal area, followed by the vapouriser plant. Natural gas and LNG pipelines must be considered, as well as ancillary facilities such as security, workshops, office space etc. The total site will be surrounded by a perimeter fence.

The majority of LNG terminals are located far from residential or commercial zones and are privileged to have dedicated greenfield sites to construct shoreside LNG storage and regasification plants (Cork & Bentiba, 2008). However, some import terminals such as Mugardos and Bilbao in Spain are restricted by the extreme topography of the area, and developers have utilised the limited terrain to its maximum safe potential. Figure 7-18 illustrates how a steep rocky headland was cut away to provide space for oil storage (*right of image)* and LNG storage, regasification and CCGT facilities (*left of image*) in Bilbao.

Regasification, storage and piping components are well integrated at most terminals, so it is difficult to disseminate the overall facility into individual component footprints. In order to estimate the total LAR necessary in Saldanha, a review of seven different Spanish[xxviii] and Portuguese terminals was conducted with a focus on the necessary landside footprint in relation to facility throughput. Findings are presented in Table 7-7. Throughput volumes and LAR have been compiled using data from the Global Energy Observatory (2013) and GIIGNL (2013).

Table 7-7 Ratio of land use to storage capacity in Iberian LNG terminals (Global Energy Observatory, 2013) & (GIIGNL, 2013)

Terminal	Year	LAR	LNG Tanks	NG send out	Ratio of sendout: storage	Ratio of LNG Storage:LAR	Nominal NG Sendout
		[m2]	*[m3]*	*[m3/hr]*	*[m3/hr : m3]*	*[m3/m2]*	*[BCM]*
Barcelona	1969	380000	840000	1950000	2.32	2.21	17.10
Bilbao	2003	230000	300000	800000	2.67	1.30	7.00
Cartagena	1989	290000	587000	1350000	2.30	2.02	11.80
Sagunto	2006	290000	600000	1150000	1.92	2.07	8.80
Huelva	1988	330000	619500	1350000	2.18	1.88	11.80
Sines	2004	130000	380000	1350000	3.55	2.92	7.60
Mugardos	2007	90000	300000	413000	1.38	3.33	3.60
Saldanha	2030	unknown	300000	416794	1.39	unknown	3.58

[xxviii] Spain has the best-developed LNG industry in Europe, with a total annual sendout of 60.1 BCM across six terminals in 2012. Statistical information is relatively easy to acquire, particularly for the three facilities constructed between 2003 – 2007.

This survey reveals the average ratio of LNG storage tank volume to total terminal land usage is 2.25. If this average ratio is applied in the Saldanha scenario which supposes a storage tank volume of 300,000 m^3, the required land area is 133,330 m^2 or 13.3 ha.

Attention should be paid to the dimensions of the Mugardos terminal in Galicia. The site earmarked for development was just 9 ha, demanding a compact terminal design to deliver a 3.6 BCM sendout facility (Kaspar & Hambücker, 2007). Incidentally, the sendout capacity at Mugardos and that proposed at Saldanha are near-identical, as are their sendout rate and storage capacity. Using the Mugardos terminal as a model for a "restricted" design, the minimum LAR at the Saldanha site is 9 ha.

The predicted Land Area Requirement (LAR) for the landside storage, regasification, piping and ancillary facilities in Saldanha Bay is estimated to be 9 ha to 13 ha.

Figure 7-18 A Moss LNGC berthed at the Bilbao LNG terminal (Sofregaz, 2010)

7.7.4 CCGT Site

There exists several reasons to locate the Combined Cycle Gas Turbine (CCGT) plant adjacent to the regasification plant, as highlighted in *Section 3.4.4*. Key amongst these is the dual use of heating/cooling water in the vapouriser/gas turbine plants that ultimately minimises the temperature drop of discharged brine into the Bay. Reduction in NG pipeline length and space-saving co-habitation of secure land are additional arguments.

In many cases the CCGT does not occupy port land, possibly because the CCGT pre-dates the LNG import terminal, or land space in the port is limited (or too costly). In fact the CCGT, national natural gas grid or gas booster station may be located tens of kilometres from the vapouriser send-out point (Leick, 2005). Since the utility is not bound to the port area, its required footprint will be calculated separately.

A review of six different CCGT plants in Spain shows the typical footprint to be between 5 ha and 8 ha, with an average size of 6.8 ha (Global Energy Observatory, 2013). The CCGT planned for Saldanha, set to produce 2370 MW of power, is quite large for a single facility. The upper end of the range will therefore be selected to represent the plant's footprint.

The predicted Land Area Requirement (LAR) for the CCGT facility in Saldanha Bay is estimated to be 8 ha.

7.8 Marine Design Aspects

7.8.1 Introduction to Marine Design Aspects

The planning of the "wet area" of a new port facility should be addressed at the early stages of design. Rudimentary layouts can be proposed early on, and must be frequently developed and revised as the design process progresses. The significance of the dimensions and layout cannot be underestimated, as the wet area tends to be the most costly and time consuming element of port construction, and is extremely difficult to modify once installed (Ligteringen & Velsink, 2012). Design elements will usually consist of approach channel alignment, width and depth, manoeuvring areas and berthing areas.

This Section provides initial estimates of the wet area dimensions as well as suggestions on terminal orientation. These design parameters will be revised at each successive stage of terminal planning.

7.8.2 Initial design assumptions

Saldanha, being a natural deepwater port, boasts a deep and wide *entrance channel* that maintains a depth of at least -25 m up to the inner harbour mouth (i.e. the opening between Elandspunt and Marcus Island). The *approach channel* to the Port begins just south of Marcus Island and is dredged at different stages between -23.1 m and -23.6 m. The present channel width is approximately 380 m.

According to Port Instructions issued by Transnet National Ports Authority, liquid bulk carriers entering the port must be assisted by tugboats, and have a pilot on board (TNPA, 2010). Tug tie-up takes place 1 Nm offshore (i.e. SW) of the port approach channel. This location is approximately half the distance between Elandspunt and North Bay Point. Since the laden LNGC will be under tug assistance from this point onwards, one can assume a higher manoeuvrability and lower approach speed than an unassisted vessel. This navigational assistance greatly influences the design of the approach channel dimensions.

The size of many of the marine design elements are based on the dimensions of the *Design Vessel* for the terminal. The size of this vessel was determined in *Section 5.3.2*, and key dimensions are re-printed below in Table 7-8.

Table 7-8 Key dimensions of Standard and Design LNGC vessel

Vessel	Capacity [m^3]	DWT [T]	Displacement [T]	L_{OA} [m]	L_{PP} [m]	Beam [m]	Moulded Depth [m]	Draught max. [m]
Standard	145,000	74,400	110,000	288	274	46	26.8	12.3
Design	177,000	87,000	114,000	298.5	285	49	26.8	13

7.8.3 Orientation of approach channel

In general the port's entrance channel should be aligned (Thoresen, 2010) such that;

1. The shortest possible (dredged) length is used, taking wave, wind and current conditions into account
2. Cross-currents and cross-winds are kept to a minimum
3. The channel makes a small angle with the dominant wave direction
4. The number (and radii) of bends are minimised or avoided altogether

An adequate approach channel exists running from south of Marcus Island to the tip of the oil import terminal, where a turning circle dredged to -23.1 m is located. The channel runs in a SSW/NNE direction, as visible in SANHO Chart SAN SC2, “Saldanha Bay and Langebaan Lagoon” (SANHO, 2000), shown in Appendix A.

A future LNG terminal site may need a new approach channel, depending on the water depth at its location. Should the terminal be situated in the vicinity of the existing port, it may share use of the current approach channel and turning circle, or elements thereof. The extent of dredging will not be known until a final terminal layout scheme is chosen. Dimensions and layout of a generic approach channel in Saldanha are therefore calculated below to provide an indication of the civil works required. Cautionary measures are taken to ensure the resultant dimensions are conservative and can be applied to any of the conceptual site layouts presented at the end of this Chapter.

With reference to the four design criteria above, the channel should aim to be oriented NNE/SSW to SW/NE to correspond with the prevailing S/SSW wind in the Bay, as described in *Section 7.3.4 – Wind Conditions*. The dominant offshore wave direction, recorded at the Cape Point buoy, is from the SW. Waves will begin to refract once they enter the shallow waters of the Bay, and wave direction will be altered depending on local bathymetric features at the site of interest. At the entrance to the inner harbour it is predicted the waves will assume a direction of approximately 240° or WSW.

An approach channel orientated SSW to SW will therefore minimise cross channel waves and help reduce quartering waves upon vessel approach. Winds will be astern or just off the port stern quarter.

7.8.4 Channel Width

Considering the infrequent delivery interval of LNG to the terminal (one LNGC every 7 – 10 days) and the low call frequency of iron ore, oil and multi-purpose vessels, a one-way channel will be deemed appropriate for Saldanha Bay.

PIANC (1997) have produced a set of guidelines to assist with the high level design of approach channels. The “concept design methodology” is suitable for early design studies and should result in an adequate level of navigational safety. Channel depth and width are addressed in particular detail.

For unidirectional channels, the recommended channel width, *W*, is defined by Equation (7.3) as

$$W = W_{BM} + \sum_{i=1}^{n} W_i + W_{Br} + W_{Bg} \tag{7.3}$$

where W_{BM} is the width of the basic manoeuvring lane, W_{Br} and W_{Bg} are bank clearance widths, and ΣW_i is the sum of additional widths based on environmental and navigational factors. The individual parameters are based on the beam dimension (*B*) of the design ship. The ship’s velocity is assumed to be “Slow: 4 kn to 8 kn” in all cases as the LNGC will be under tug assistance at all times. Channel width, as defined by Equation (7.3), is determined using the individual width parameters listed in Table 7-9.

Table 7-9 Channel width parameters (PIANC, 1997)

W	Description	Value (B)	Width (m)	Notes
W_{BM}	Basic manoeuvrability	1.5 B	73.5	Due to high freeboard, manoeuvrability is only “moderate” despite tug assistance
W_{Br}	Bank clearance width	0.3 B	14.7	Low risk. Slow speed, sloping channel edges
W_{Bg}	Bank clearance width	0.3 B	14.7	Low risk. Slow speed, sloping channel edges
W_i (a)	Vessel speed	0 B	0	Slow. 4 kn – 8 kn.
W_i (b)	Prevailing cross wind	0.5 B	24.5	15 kn – 33 kn cross channel. Conservative value as winds may by longitudinal.
W_i (c)	Prevailing cross current	0.5 B	24.5	0.2 kn – 0.5 kn. Low/Moderate.
W_i (d)	Prevailing longitudinal current	0 B	0	Less than 0.5 kn. Negligible.
W_i (e)	H_s & L	0.5 B	24.5	0 m<H_s<3 m. L<L_{OA}. Hs = 3 m exceeded less than 1% of time.
W_i (f)	Navigational aids	0.2 B	9.8	Infrequent poor visibility (fog).
W_i (g)	Bottom surface	0.1 B	4.9	Channel depth<1.5D. Smooth & soft bottom.
W_i (h)	Depth of channel	0.4 B	19.6	Assumes final depth<1.25D. Conservative assumption.
W_i (i)	Cargo hazard level	0.8 B	39.2	LNG cargo assumes high hazard rating
W	**TOTAL WIDTH**	**5.1 B**	**249.9**	Assume **W = 250 m** for sake of simplicity

The necessary channel width for a unidirectional approach channel is calculated to be ***W* = 250 m**, or a total of 5.1 x Beam (*B*) of the Design Vessel. This estimation of channel width corresponds well with the approximation given by Thoresen, who suggests a bottom width of 5 times the beam of the design ship for gas and oil tankers (Thoresen, 2010).

7.8.5 Channel depth

The necessary depth of an approach channel to ensure safe navigation is primarily based on the draught of the design vessel, with secondary parameters such as squat, atmospheric pressure, movement due to waves and dredging accuracy playing influential roles. These parameters are illustrated in Figure 7-19 (Thoresen, 2010).

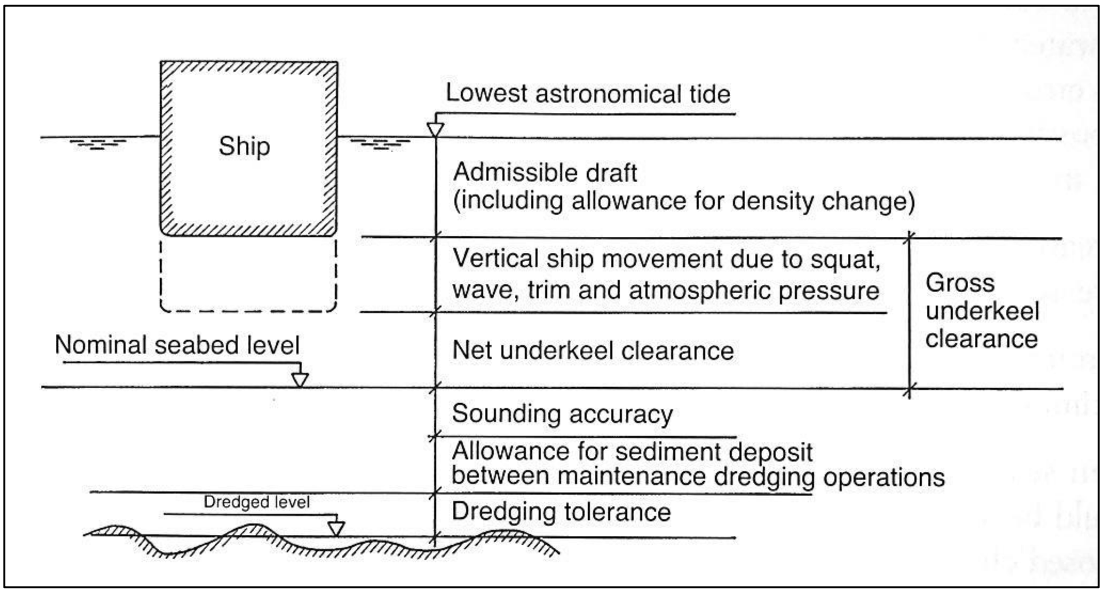


Figure 7-19 Factors affecting channel depth (Thoresen, 2010)

The specific parameters that influence channel depth are described by PIANC (PIANC, 1997), and values relating to Saldanha Bay are listed in Table 7-10.

Table 7-10 Channel depth parameters

	Description	**Depth (m)**	**Notes**
d_{LNGC}	Draught	13	Design vessel draught
Z_1	Cargo distribution	0	Assumes even trim of LNGC.
Z_2	Salinity	0	Assumes neutral salinity (ρ=1.025)
Z_3	Squat	0.25	Using Hoofte eqn. given in PIANC (Hoofte, 1974)
Z_4	Wave induced motions	0.5	Conservative value for large vessels (Thoresen, 2010)
Z_5	Under Keel Clearance	0.5	Sand and shale sea bottom (SANHO, 1999)
Z_6	Sounding inaccuracies	0.2	Conservative accuracy of multibeam survey (estimated)
Z_7	Dredging tolerance	0.5	Conservative estimation (Thoresen, 2010)
Z_8	Atmospheric pressure	0.5	Infrequent poor visibility (fog).
Z_9	Pitch and Roll	1	Conservative estimation
Z_{10}	Silting	0.2	Low littoral transport in Saldanha
D	**TOTAL DEPTH**	**16.65 m**	Ratio Depth/Draught = 1.28

The calculated depth of D = - 16.65 mCD using the PIANC guidelines proves to be more conservative than values attained using simplified formulae in Ligterengen & Velsink (Ligteringen & Velsink, 2012) and Thoresen (Thoresen, 2010), which reveal Depth/Draught ratios of 1.19 and 1.25 respectively.

A Depth/Draught ratio of 1.3 is selected, delivering a conservative channel depth of **D = 16.9 m**.

This ratio mirrors Thoresen's recommendation, which suggests a ratio of 1.3 for ship speeds under 6 knots.

7.8.6 Turning circles depth & radius

The turning area of the port provides a dedicated space for the vessel to come to a halt at the end of the approach channel and align itself to prepare for berthing. This procedure is conducted with the assistance of tug boats. The turning area should ideally be protected from waves and strong winds.

The dimensions of the turning circle are a function of the draught, length and manoeuvrability of the design vessel. The depth can be taken as that of the approach channel, which has been calculated as 16.9 m. The diameter of the circle should be at least twice the length of the design vessel (Ligteringen & Velsink, 2012). Taking the high freeboard of the design vessel into account, and the inherently low Dead Weight Tonnage of LNG carriers, this factor will be increased to $Ø = 2.2 \times L_{OA}$. Therefore, the diameter of the turning circle is Ø = 657 m or **Ø = 660 m** for ease of future calculations.

The LNG carrier will be turned through 180° inside the turning circle, and reversed into its berth with the assistance of the tugs. In this way the vessel will be able to disembark the terminal with relative ease during the onset of inclement weather.

7.8.7 Orientation of jetty

Factors affecting the approach channel orientation have been mentioned already, and many of these can be applied to jetty orientation. Most relevant are prevailing wind direction, prevailing swell direction and prevailing current direction. It has been shown that current velocities in Saldanha are minimal, and will not have a detrimental effect on the navigation or berthing of LNGC's.

The import jetty will ideally be sited such that swell wave height is minimised, either by natural or artificial protection. Wave height limits for various vessel operations (berthing, unloading, safe mooring etc) are stated in *Section 8.3 – Wave Induced Downtime*. As a rule of thumb wave heights at the terminal should be below H_s=1 m to ensure uninterrupted operations. Regardless of the extent of wave attenuation, the terminal should, if possible, be orientated such that the bow of the ship faces the dominant wave direction when moored. Wave direction in Saldanha Bay will be localised due to refractive and diffractive effects at each site. Nonetheless initial swell direction can be estimated looking at offshore wave data and bathymetry of the area.

The direction of prevailing wind will probably have the greatest bearing on the final orientation of the proposed LNG jetty. It is possible to attenuate wave height using artificial protection or intelligent siting, but wind speed cannot be allayed. LNG carriers are particularly susceptible to wind loading, and it is for this reason the LNG terminal should be configured to keep the moored vessel's bow into the prevailing wind direction.

In the case of Saldanha Bay, where there may exist a conflict between wind and wave direction, wind direction may take precedence in terms of jetty alignment. The site-specific wave height must be considered however, and if necessary a compromise of the two directions may be chosen. The prevailing wind direction in Saldanha is southerly, and an ideal jetty configuration may run N-S (180°) to NNE-SSW (202.5°) to accommodate wind and wave approach. Cross-jetty winds or even quartering winds will place substantial load on either the jetty structure or the mooring lines depending on wind direction. It is likely that jetty layouts inside Saldanha Bay will ultimately lean towards a southerly orientation to counter severe wind loading.

7.9 Safety Exclusion Zone

7.9.1 Introduction to LNG Safety Exclusion Zones

The LNG industry has an excellent safety record, and the risk of explosion or catastrophic failure at an LNG terminal is statistically insignificant, despite the negative public perception of the industry. Since the inception of international LNG trade in the mid-1960s, there has not been a single reported incident that has led to a breach of an LNGC's cargo containment system. There has never been a reported loss of life due to unintentional LNG release, either on board a vessel or at a quayside (Sandia, 2008) & (GIIGNL, 2013).

The industry's enviable safety record is attributable to a well-structured risk reduction strategy that appears to be universally implemented. It is suggested that the many elements of the strategy are over-designed, making system failure very unlikely. The major players in LNG trade are typically International Oil Companies or energy conglomerates, who have decades of experience of working in high risk environments and are aware of the need for implementation of strict safety codes.

The aim of this Section is to describe the risks associated with LNG transport, storage and transfer, and to define separation distances between specific terminal elements and the general public.

7.9.2 Safety Elements of an LNG Terminal

The generic safety strategy of an LNG terminal consists of four key elements; primary containment, secondary containment, safeguard systems and separation distances.

1. **Primary containment** describes the insulated vessel that contains bulk volumes of LNG. This applies to both land based LNG storage tanks, and the LNG containment systems on board vessels. Primary containment tanks are constructed from Invar, 9% nickel-steel, or an aluminium alloy, all of which are resistant to the extremely low LNG temperature.
2. **Secondary containment** refers to the outer barrier between the primary tank and the external environment. Aboard LNGC's the secondary barrier is another insulated tank made of Invar, 9% nickel steel or Triplex. Onshore, storage tanks typically use a 9% nickel steel shell and pre-stressed concrete with a carbon liner as the secondary containment method. The secondary containment is only called into use when there is rupture of the inner tank. Additional measures include a bund wall around storage tanks, capable of holding 110% the volume of the largest tank. This measure is not mandatory for "full containment" type tanks (CEN, 2006).
3. **Safeguard systems** aim to minimise the net amount of LNG spilled during cargo transfer. An automated Emergency Shut Down (ESD) system acts to shut down LNG transfer pumps and close all in-line ESD valves in the case of spill detection. On the quay side, an Emergency Release System (ERS) will automatically detach the cargo transfer arms from the LNG vessel manifold when it senses vessel motions exceed pre-defined limits (usually surge). The volume of LNG spilled is therefore proportional to the speed of the safeguard systems. A study by GIIGNL (Acton, et al., 2004) shows that 73% of 102 recorded incidents between

1994 and 2000 that resulted in LNG spill were of volumes less than 100 ℓ. This statistic gives an indication of the efficacy of the safeguard systems at a terminal.

4. **Separation distances** should be implemented around the LNG terminal facilities to minimise the risk of injury to port employees and general public in the unlikely event of a large LNG release. A large spill will only occur if safety elements 1, 2 and 3 are surpassed and there is no means of immediately stopping the release. The odds of LNG ignition or explosion are still low, surprisingly, when a large LNG volume has been exposed to the elements.

Of the four safety elements described above, only one applies to general port planning and terminal sizing: separation distances.

7.9.3 Potential Hazards of Large LNG Release

Pool Fires

When released above water, LNG will float to the top of the water as its density is $\rho = 450$ kg/m^3. The LNG will begin to vapourise as it heats up, and rise above the floating pool of LNG. The LNG vapour is initially colder and denser than the surrounding air, so it accumulates directly above the LNG pool. This vapour pool will be highly concentrated but cover a small surface area. The vapour pool, consisting primarily of methane, needs two additional components to ignite. Firstly the methane to air ratio must be 5% to 15% for the fuel to combust. If this ratio is reached (for a large volume of the spill), an ignition source is necessary to initiate combustion. LNG terminals are designed to operate in such a way that minimises all sources of sparks or electrical shorting. If the vapour does ignite however, the extent of the fire will be confined to the size of the pool surface area (Sandia, 2008). It should be seen that the probability of a pool fire is quite low. It is expected that in most cases the combustion ratio is not achieved before the methane is evaporated into the atmosphere, or that a source of ignition is not presented (Foss, 2006).

Sandia Laboratories (Sandia, 2008) have conducted a study that aims to predict the extents of thermal hazards resulting from an *intentional* breach of an LNGC hull. This study, initiated by the United States Government Accountability Office following the "September 11" attacks in 2001, presumes a terrorist attack resulting in a 5 m^2 hole on a 265,000 m^3 Q-Max vessel (GAO, 2004). Such a hull breach would be inconceivable during in-port navigation.

The Sandia study reveals two zones of thermal hazard. Zone 1 falls within 500 m of the spill area and will lead to heat flux levels of 37.5 kW/m^2, resulting in damage to process equipment after 10 minutes of heat exposure. Zone 2 falls within 1600 m of the combustion site and will lead to heat flux levels of 5 kW/m^2, which may cause second degree burns on bare skin after 30 seconds of exposure.

Considering the intentional nature of the spill, the cargo capacity of the vessel and the size of the rupture, these appear to be very conservative limits indeed. Nonetheless, these limits are imposed at all new-build LNG terminals in the US and enforced by the US Coast Guard (Foss, 2006).

Vapour Clouds

Following an LNG spill above water, the vapour cloud that forms directly above the pool may be blown downwind of the spill area. As the vapour cloud travels downwind it also rises, forming a well dispersed high-level cloud. This cloud may travel up to 1600 m downwind before it is assimilated into the atmosphere. Should the combustion ratio be healthy before or at this distance, and an ignition source activates combustion, a "fireball" may develop. Spectacular as it may seem, according to Sandia "*a fireball is the most benign form of combustion that can result. The hazards are principally short-time thermal damage high in the air and away from structures and people*" (Sandia, 2004).

Rapid Phase Transition

A Rapid Phase Transition is a flameless explosion that occurs when a gas in liquid form vapourises extremely quickly, exploding as it expands outwards. These localised explosions may be powerful enough to cause damage to lightweight structures (Foss, 2006). Though theoretically possible, such a phenomenon is not likely to occur following an LNG spill (GAO, 2004).

It should be clear that of the potential hazards associated with a large LNG spill, *pool fires* are the most threatening to port activities and public health and safety. To date, pool fires have only been created in controlled environments, and have not been reported at a marine terminal.

7.9.4 Dimensions of Safety Exclusion Zones

Interestingly, there are no international codes or standards that stipulate exclusion distances from an LNG terminal. It is recommended that a numerical vapour dispersion model is instigated towards the detailed design stages of the LNG terminal project to refine the safety zones (Sandia, 2004). At the conceptual stage, initial assumptions will be implemented. These distances are as follows:

- **300 m** - Distance to non-essential employees and infrastructure at the LNG berth
- **300 m** – Distance from moored LNGC to passing ship (Cork & Bentiba, 2008)
- **500 m** – Distance to other port infrastructure and port users (Sandia, 2008)
- **1600 m** – Distance to residential areas (Sandia, 2008)

7.10 Conceptual Site Layouts

7.10.1 Introduction to Conceptual Site Layouts

In this Section *Conceptual Site Layouts (CSL's)* are presented, taking into account the physical dimensions of the terminal and the few potential development areas identified in Saldanha Bay. The dimensions of both wet and dry infrastructure, derived in Section 7.7 to Section 7.9, are summarised in Table 7-11 below.

The conceptual layouts, four in total, will provide a platform for the generation of more detailed *terminal layout schemes* in succeeding Chapters. The layouts are quite rudimentary, and their initial boundaries, orientations and technical merits should be considered quite pliable and subject to change.

The conceptual site layouts are concerned with the *wet area planning* of the terminal design. This stage pertains to the approach channel orientation, berth orientation, and dredging operations in particular. These issues must be addressed early on in the design study as they become very difficult to alter as the design advances. The planning of wet area elements is independent of the dry infrastructure and the choice of terminal design (jetty, SBM etc).

The need for and extent of artificial wave attenuation measures (breakwaters, caissons, baffles etc) forms a crucial element of wet area planning. The topic of wave protection is discussed in succeeding Chapters, however, and will not contribute to this Section.

Table 7-11 Key dimensions of conceptual LNG terminal

Description	Dimension	Notes
Wet Infrastructure		
Depth of Approach Channel	16.9 m	
Width of Approach Channel	250 m	Single vessel use. Tug assisted.
Orientation of Approach Channel	225°	Approximate direction. Reduces quartering and cross channel waves.
Diameter of Turning Circle	660 m	Tug assisted manoeuvre.
Orientation of Jetty	202°	Approximate direction. Reduces cross jetty winds.
Safety Exclusion Zone 1	300 m	Distance to passing ships.
Safety Exclusion Zone 2	500 m	Distance to other port operations.
Safety Exclusion Zone 3	1600 m	Distance to residential areas.
Dry Infrastructure		
LNG Regasification and Storage	9 ha to 13 ha	
CCGT	8 ha	

Note that in the cases where the conceptual layout shares the turning circle of the existing port, the diameter increases from 580 m to 660 m.

7.10.2 Conceptual Site Layout 1 – Hoedjiespunt

A traditional L or T type trestle jetty is proposed at Hoedjiespunt. The LNGC carrier will berth directly against the jetty, or may offload onto a moored FSRU, either alongside or cross-jetty. The jetty is positioned in approximately -14 m of water depth, 650 m east of Hoedjiespunt point. This location is expected to be particularly well protected from the swell waves that approach the outer Bay from the SW. Due to depth induced wave refraction coupled with wave diffraction around Marcus Island, waves are predicted to approach the jetty from the southeast. Consequently, an approach channel running SE/NW leads from the existing turning circle to the jetty to keep waves on the bow when approaching or leaving the berth. The vessel will be reversed into the berth.

The entire length of the new entrance channel will have to be dredged. The proposed dredge depth is -16.9 mCD. The average seabed depth over the length of the channel is -14.5 mCD, while the highest spot is -13.1 mCD towards the northern boundary of the berth pocket. The channel width is 250 m.

The jetty is orientated N-S, such that the bow of the vessel will point directly into the prevailing southerly wind. Wet and dry infrastructure is located entirely outside the boundaries of Small Bay. The 500 m safety exclusion zone remains free of any other port activities. There are no residential areas or business areas contained within the secondary 1600 m exclusion zone.

A conceptual visualisation of the layout is shown in Figure 7-20. A Moss type LNGC, carrying the dimensions of the design vessel, is shown to help determine a sense of scale.

Figure 7-20 Conceptual Site Layout 1: Hoedjiespunt

7.10.3 Conceptual Site Layout 2 – North Bay

An "offshore" type terminal is proposed in North Bay. The area enclosed between Marcus Island and North Bay Point is preferred over a more westerly site near Malgas Island, as 1) the pipeline distance to shore is shorter, 2) the berth is visible from the Port Control tower on Hoedjiespunt and 3) the beach area offers a softer landing should the vessel go aground.

The water depth is approximately -22 mCD and the berth located 1000 m south of Die Bomgat rocks on the Hoedjiespunt headland. The berth may be a tower type SPM or a GBS. In the case of a tower mooring, the LNGC will point bow-to-wind, as shown in Figure 7-21 (assuming the prevailing southerly wind is in effect). If a GBS is selected the LNGC will be moored on the leeward side of the caisson, where protection is offered from the prevailing swell waves. The wave direction is expected to be from the southwest.

The water depth and distance offshore is selected so that the LNGC can approach the mooring from any direction with relative ease. If the wind is from the north, the vessel may be able to sail directly to the SPM without much tug assistance. If it blows from the south or southwest, which is most likely, the vessel will require greater tug assistance. There is significant manoeuvring room and water depth downwind of the buoy to negate dredging. The use of a GBS will require at least four tugs.

The 500 m safety exclusion zone remains free of any other port activities. There are no residential areas or business areas contained within the secondary 1600 m exclusion zone.

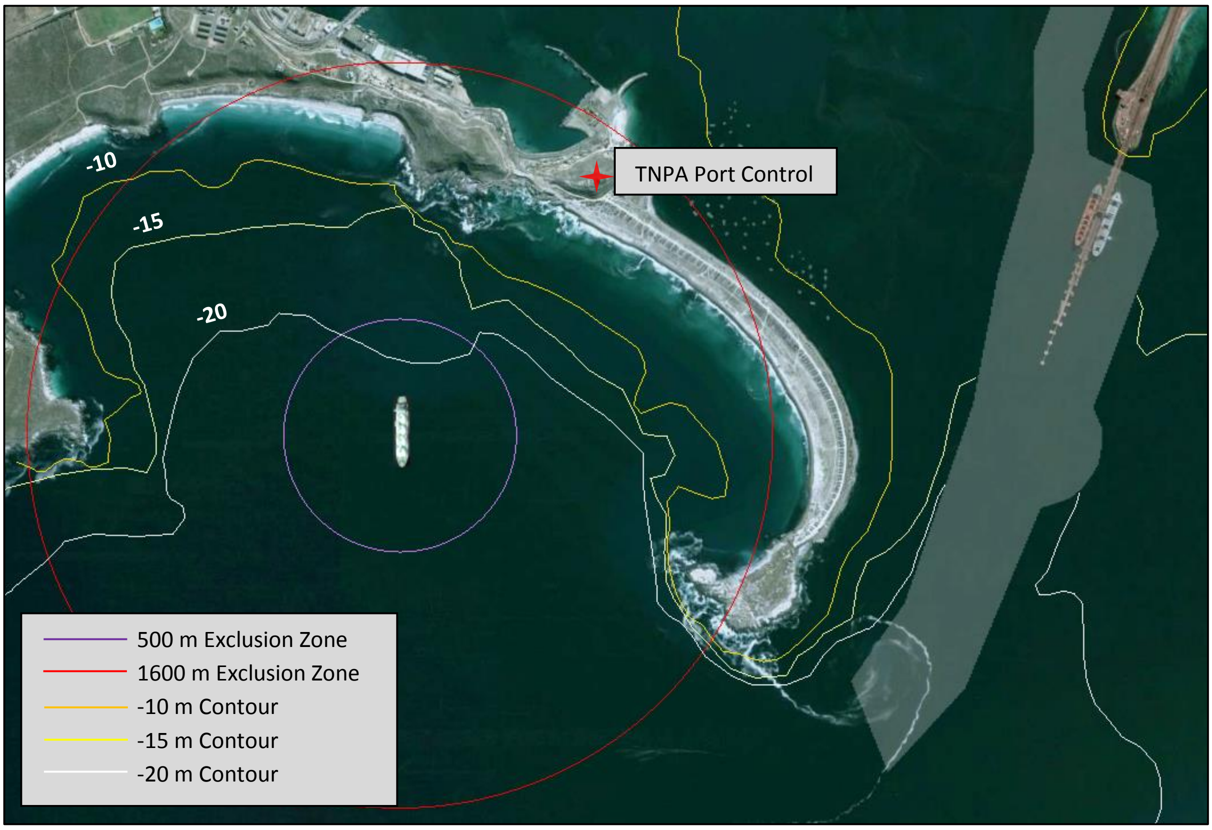


Figure 7-21 Conceptual Site Layout 2: North Bay

7.10.4 Conceptual Site Layout 3 – Big Bay (Causeway)

A jetty type terminal proposed in Big Bay aims to make use of the natural wave protection to the east of the existing port causeway. It is anticipated the swell wave height in this location will be significantly attenuated by the combined presence of Marcus Island, the beach breakwater, the caisson structure at the iron ore terminal, and Elandspunt headland on the Donkergat peninsula.

In relation to the other sites, the water depth is quite shallow by the causeway. The average depth is -10.5 m, and a significant amount of dredging will be required to link the berth to the existing turning circle. The approach channel runs in a south-westerly direction, which corresponds with the expected direction of wave attack due to refraction and diffraction around Marcus Island. The berth is orientated SSW, to ensure both prevailing wind direction (S to SSW) and wave direction (SW) are within a few degrees of being bow-on. The approach channel is 250 m wide and -16.9 m deep.

In theory the berth could be located closer to shore and nearer the causeway to further reduce wave action. This placement would necessitate far more dredging however, which the present siting aims to reduce. In addition, the berth may only afford to move another 150 m-200 m west before the primary 500 m exclusion zone impedes on other port activities at the multi-purpose terminal.

The terminal may be a standard trestle jetty, or may utilise a FSRU for the regasification of LNG. There are no residential areas within the secondary safety exclusion zone. The site layout concept is illustrated in Figure 7-22.

Figure 7-22 Conceptual Site Layout 3: Big Bay - Causeway

7.10.5 Conceptual Site Layout 4 – Big Bay (Open Water)

An open water import terminal is suggested as a conceptual terminal in Big Bay. The terminal may be a tower type SPM or a GBS. Water depth at the site averages -17 m. It is intended that the LNGC would sail directly to the mooring and hook up with the assistance of tugboats. The Port Instructions insist however that all large tankers must be tug assisted when entering the Port. In the case of a northerly wind the tugs can escort the LNG carrier directly to the berth and assist connection. With a prevailing southerly wind it would be sensible to swing the vessel 180° in the turning circle so that it faces due south before manoeuvring it to the SPM or GBS.

A short approach channel leads from the existing turning circle to the proposed site. The channel, highlighted in Figure 7-23, merely indicates the most direct route from turning circle to terminal. Dredging will not be required as water depth is sufficient at the site. Occasional maintenance dredging may be required north and east of the mooring, as depths here border on the minimum ideal depths for the design vessel.

Waves are expected to approach from the SW (as indicated by the wave crests in Figure 7-23) and the prevailing wind is from the south to south-southwest. The site is far removed from any residential zones.

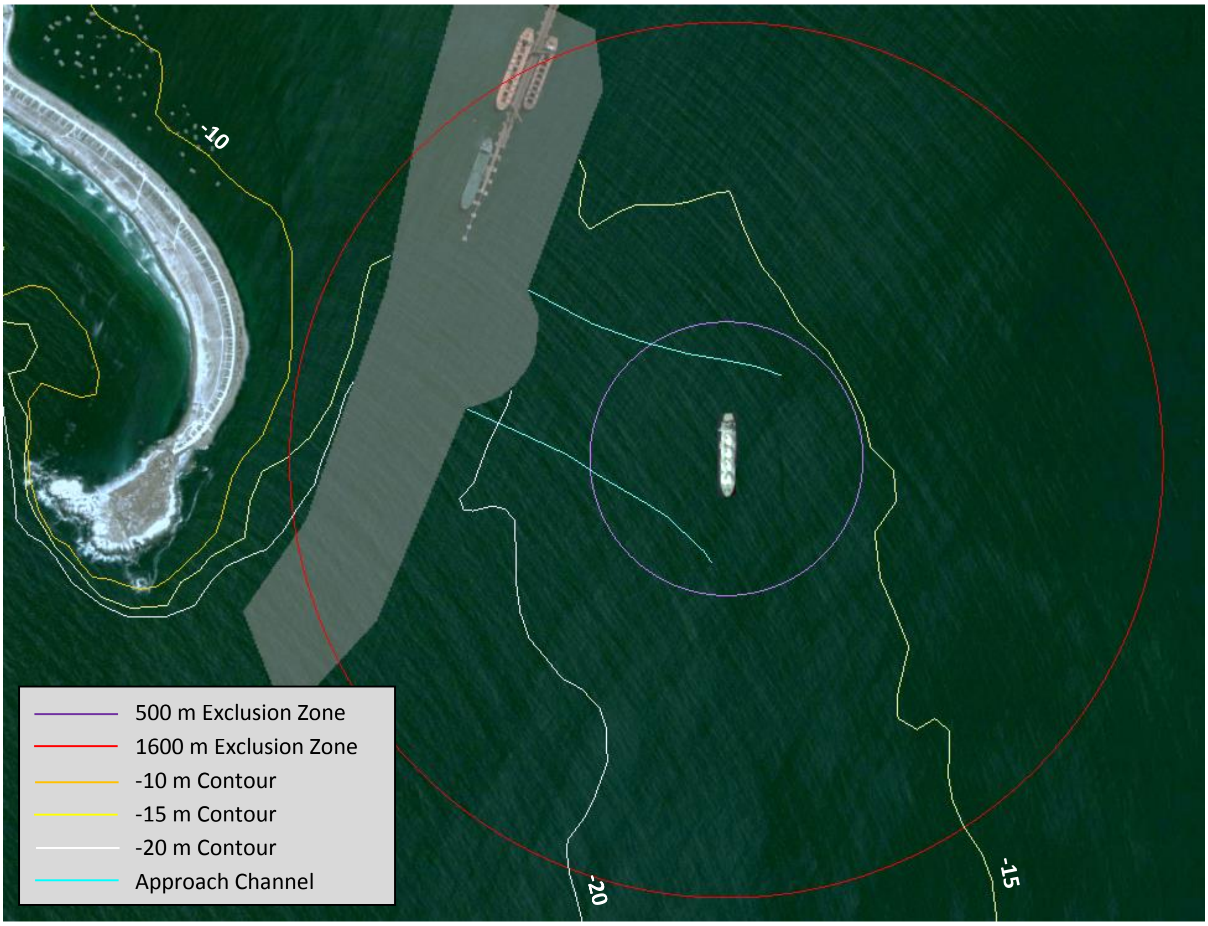


Figure 7-23 Conceptual Site Layout 4: Big Bay - Open Water

8 DOWNTIME ANALYSIS

Four basic LNG terminal layouts have been developed and described in Section 7 – Conceptual Site Layouts. These layouts will be scrutinised and expanded upon as the study progresses. Each layout will eventually be ranked according to several key design parameters, one of which is downtime. The percentage of wave and wind induced downtime expected at each of the conceptual sites will be estimated in this Chapter.

8.1 Introduction to Downtime

Wave Downtime

Wave-induced downtime is perhaps the most critical parameter to consider when evaluating terminal efficacy or deciding overall feasibility. The four conceptual layouts have been applied in the existing Saldanha Bay area without great consideration of the wave climate, save for estimated wave directions.

A study is conducted is to gain an understanding of the specific wave climate at each of the proposed sites. A numerical wave model is used to calculate H_s, T_p, Direction and Spreading at each of the four sites for an array of recorded offshore wave conditions. A virtual historical wave timeseries is generated at each site, and the data are analysed to determine site-specific wave height exceedance values.

Exceedance values derived from the numerical model are compared with pre-determined wave height limits for terminal operations and survivability. The percentage annual downtime at each berth layout is thereafter projected.

Long Waves

Long waves have been known to cause mooring difficulties at Saldanha Bay (Soler, 2006). Determination of long wave effects in a confined bay is a lengthy and resource intensive process, often requiring specialist numerical model studies. In addition, mooring and operational downtime resulting from long waves is acutely site-specific. For this reason long wave mooring issues are often addressed toward the detailed design stage of terminal development. Long wave induced downtime will therefore not be considered in this conceptual study.

Wind Downtime

The wind climate at each site is expected to be near-identical, as none of the four sites are positioned in the lee of a large or high land mass. In south to south-southeast winds a "funnelling" effect is known to occur along the length of Langebaan Lagoon. This localised phenomenon is not expected to have an influence on the wave climate at any of the study sites, as they are too distant from the mouth of the lagoon.

The same percentage of annual wind-induced downtime will be ascribed to each of the sites. Downtime for the Saldanha Bay area is calculated using the wind climate statistics referenced in *Section 7.3.4 – Wind*.

8.2 Numerical Wave Modelling

8.2.1 Introduction to Wave Modelling

The "SWAN" wave model was used to generate wave characteristics at five areas of interest within Saldanha Bay. SWAN (Simulating Waves Nearshore) is a spectral 3rd generation wave model developed at Delft University of Technology (Delft University of Technology, 2013). The model is based on the discrete spectral action balance equation and is fully spectral in all directions and frequencies, implying short-crested random wave fields propagating simultaneously from widely different directions can be accommodated. The model accounts for refractive propagation and represents the processes of wave generation by wind, dissipation due to white-capping, bottom friction, depth-induced wave breaking and non-linear wave-wave interactions. It is important to note that the model *does not* account for diffractive effects (Deltares, 2011).

The SWAN model is fully contained and executed within the Delft 3D modelling suite. The Delft 3D suite, developed by Deltares, provides a convenient and practical Graphical User Interface (GUI) through which SWAN is run. In addition the GUI allows one to visualise model input, reference data and simulation results as time series and animations of 1D, 2D or 3D data sets. The Delft 3D "WAVE" standalone extension was used to conduct the refractive wave modelling (Deltares, 2011b).

8.2.2 Setup of Saldanha Bay Model

Bathymetry

Bathymetric data was compiled from a number of sources and combined as a single depth file for use with the WAVE model. The majority of data points were extracted from digitised SANHO (South African Navy Hydrological Office) nautical charts. SAN 1010 "*Approaches to Saldanha Bay*", SAN 1011 "*Entrance to Saldanha Bay*", SAN 1012 "*Saldanha Bay Harbour*" and SAN SC2 "*Saldanha Bay and Langebaan Lagoon"* were sufficient to cover the areas of interest. Samples of these SAN charts are provided in APPENDIX A - SAN Charts.

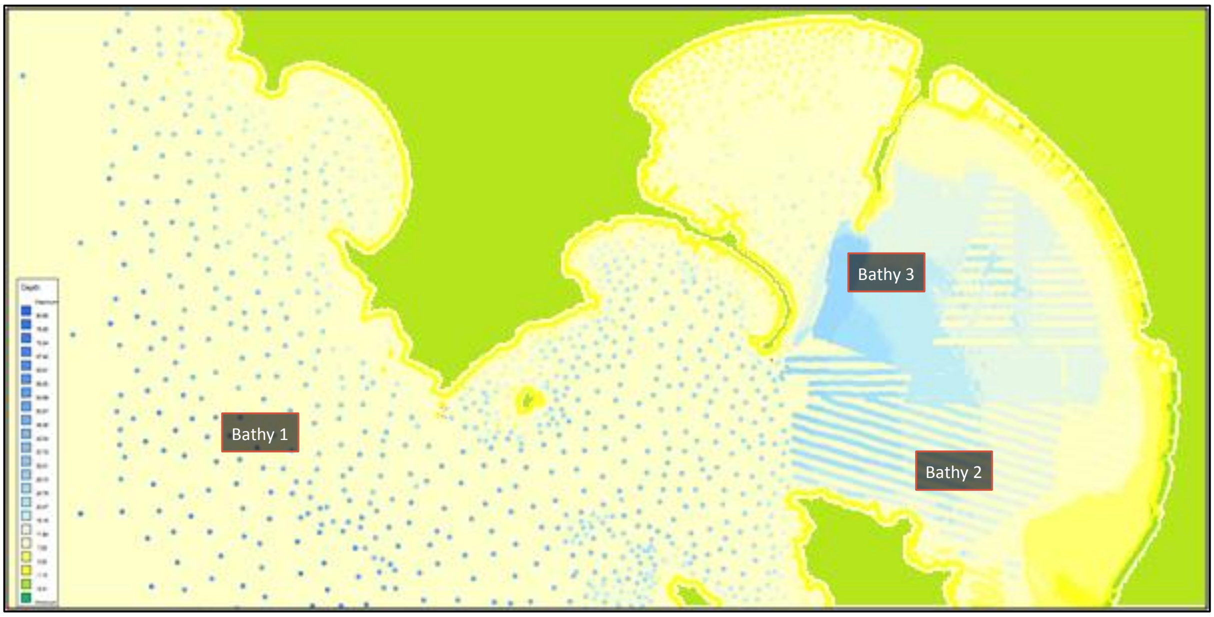


Figure 8-1 Bathymetric depths samples in Delft 3D

Detailed bathymetric data of the existing Port area and patches of Big Bay and Small Bay was provided by CSIR, who have previously conducted echo-sounder scans inside the Bay for the National Port Authority. The areas of sparse depth samples (from digitised SANHO charts) are described as “Bathy 1” in Figure 8-1. Single beam echo-sounder depth samples in Big Bay and off Donkergat Peninsula are shown as “Bathy 2” and higher resolution swathes are highlighted as “Bathy 3”.

Grids

Three rectilinear computational grids were nested in the Delft 3D model. The dimensions of the Coarse, Medium and Fine grids are noted in Table 8-1. The deepwater boundary of the Coarse grid runs along the -100 m depth contour, orientated approximately NNW to SSE.

Table 8-1 Model grid dimensions

Grid	Resolution	Dimensions	Depth at boundary
Coarse	200 m x 200 m	20 km x 30 km	100 m
Medium	100 m x 100 m	12.4 km x 13.4 km	40 m
Fine	**25 m x 25 m**	**8.1 km x 9.2 km**	**35 m**

The boundary depth of the Coarse grid was selected to at least equal the depth at the Cape Point Waverider buoy (Figure 8-2). Historical wave data from the Waverider buoy was used to calibrate the SWAN model. The depth of water the Cape Point buoy (CP01) is approximately 70 m.

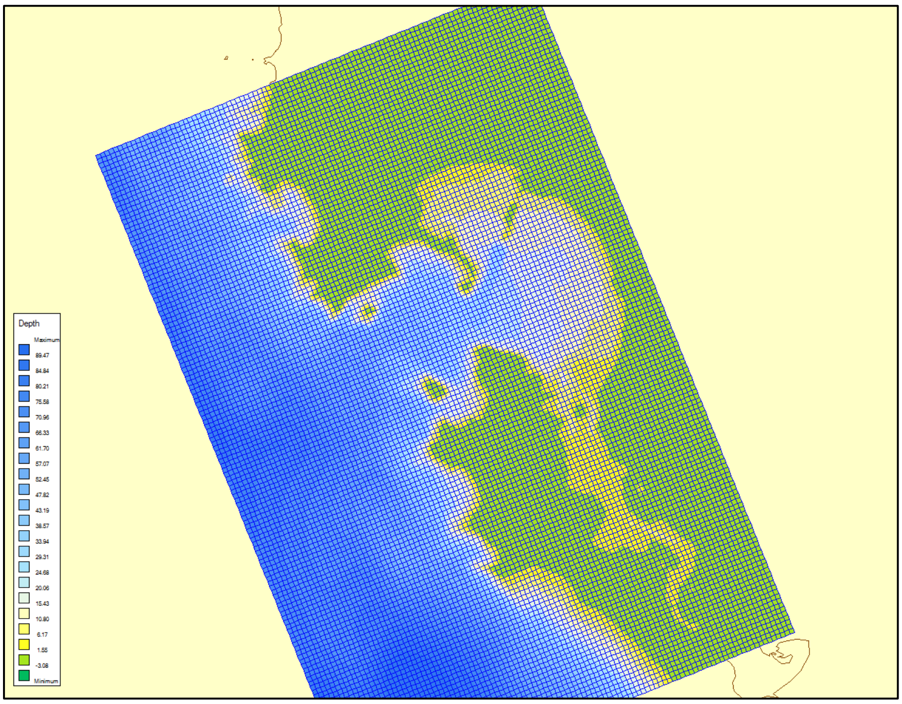


Figure 8-2 Coarse model grid

The boundary of the Medium grid incorporates the entire shoreline of the Donkergat Peninsula, North Head, Malgas Island and Jutten Island (Figure 8-3). The “wave shadows” behind these features are adequately represented.

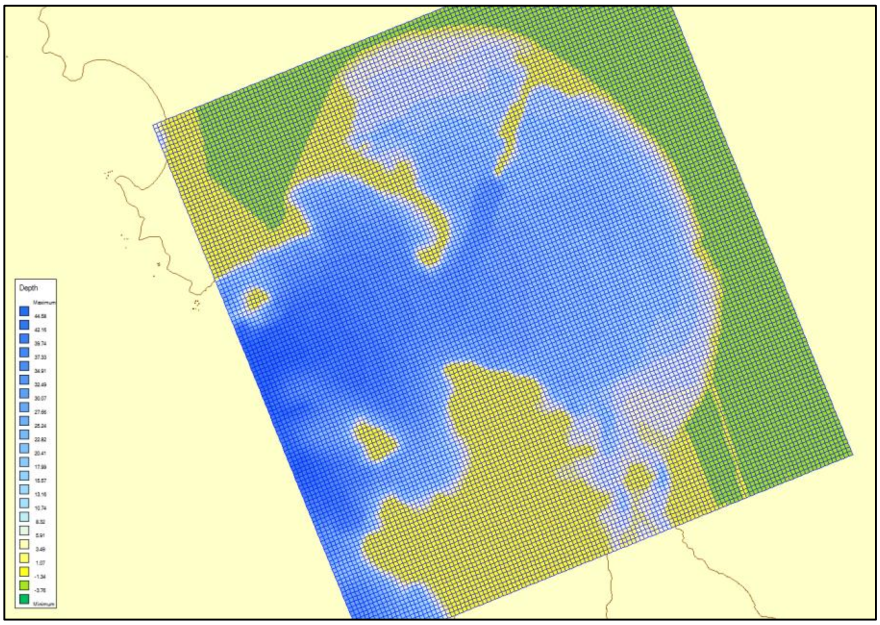


Figure 8-3 Medium model grid

The boundary of the Fine grid covers the main areas of interest for the site selection study, namely North Bay, Hoedjiespunt, Small Bay and the northern section of Big Bay. Elandspunt and North Bay Point are included within the Fine grid boundaries (Figure 8-4).

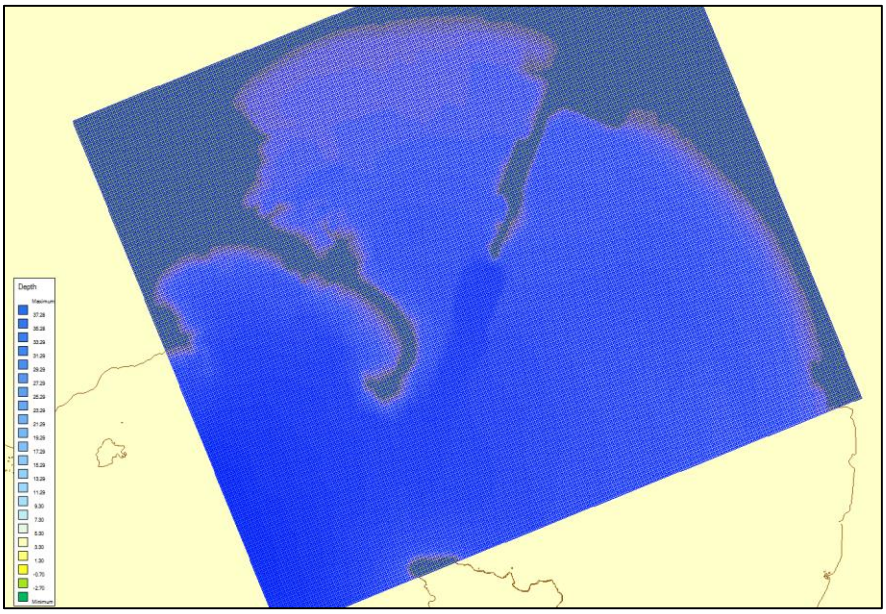


Figure 8-4 Fine model grid

8.2.3 Calibration of Saldanha Bay Model

Two sets of historical wave data were used to calibrate the numerical model. The Coarse boundary conditions were input directly from timeseries recorded at the “Cape Point Waverider buoy (CP01)”, at position 34°12'14.40"S, 18°17'12.01"E. This buoy is moored approximately 5.4 km offshore of Kommetjie on the Cape Peninsula at a water depth of 70 m. Wave data from a Waverider buoy inside Saldanha Bay was used to calibrate the SWAN model. The Saldanha Bay buoy (SB01), moored in 23 m of water, is located at the entrance to the approach channel at position 33° 03’00"S, 17°58'24"E . The exact location is highlighted on SAN SC2 in APPENDIX A - SAN Charts.

Selection of Representative Storms

Five storm events were initially selected as input boundary conditions for the model calibration exercise. These storms, selected from historical timeseries, were chosen to represent a broad range of wave directions, wave periods and wave heights that could be expected in Saldanha Bay. Wave directions varied between 227° and 265°. This is the range that allows the greatest amount of wave energy into the Bay. Waves coming from outside this range are impeded by the North Head and South Head promontories (Figure 8-5).

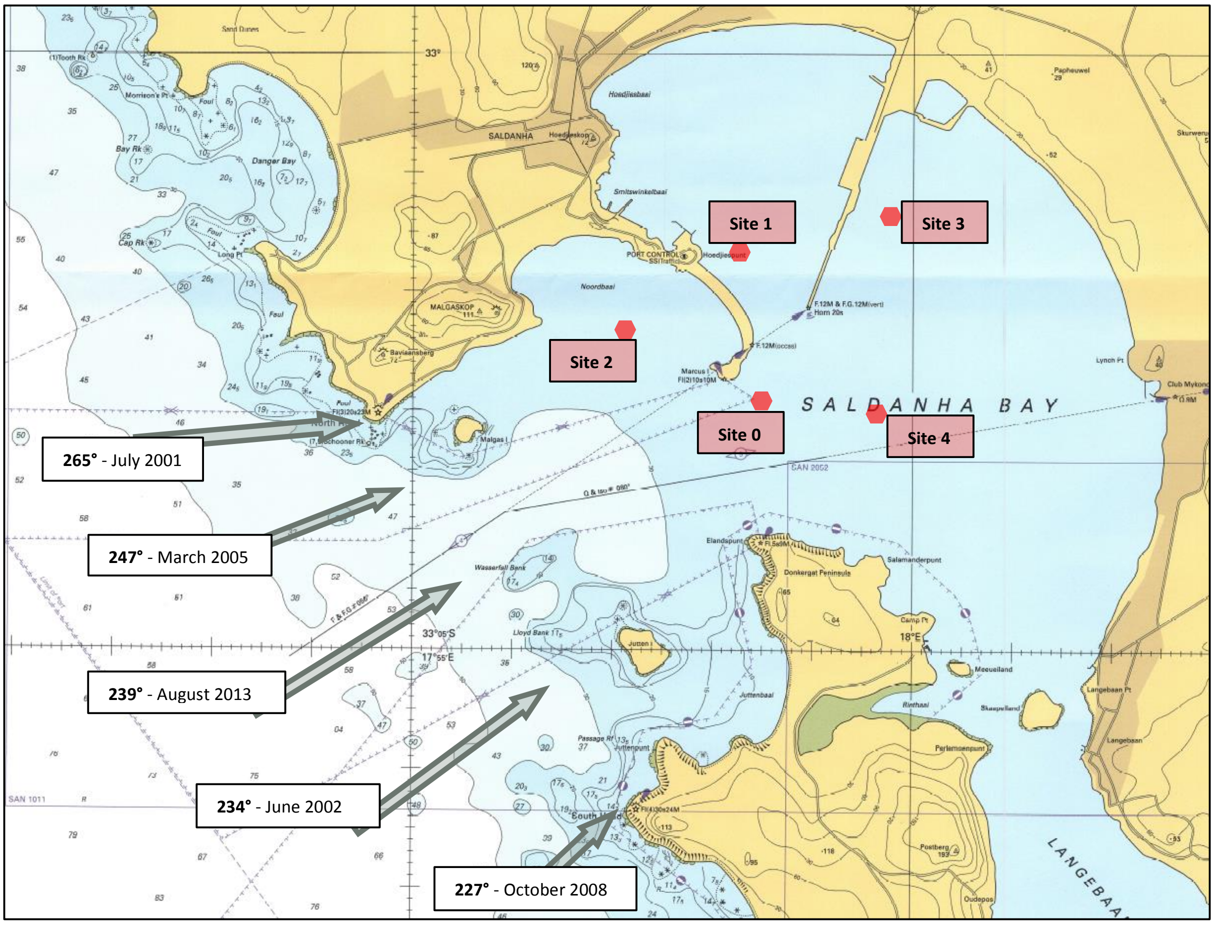


Figure 8-5 Peak direction of calibration storm events (SANHO, 2007)

The Cape Point storm peaks were observed, and the corresponding H_s, T_p and wave direction recorded in Saldanha Bay during the same storm were similarly identified. An example of storm peak identification for the CP01 H_s time series and the corresponding SB01 H_s time series is shown in Figure 8-6. Although the storm events are identified by their peaks, storm wave parameters are recorded and averaged over a 3-hour sampling period. A summary of the calibration wave data is given in Table 8-3.

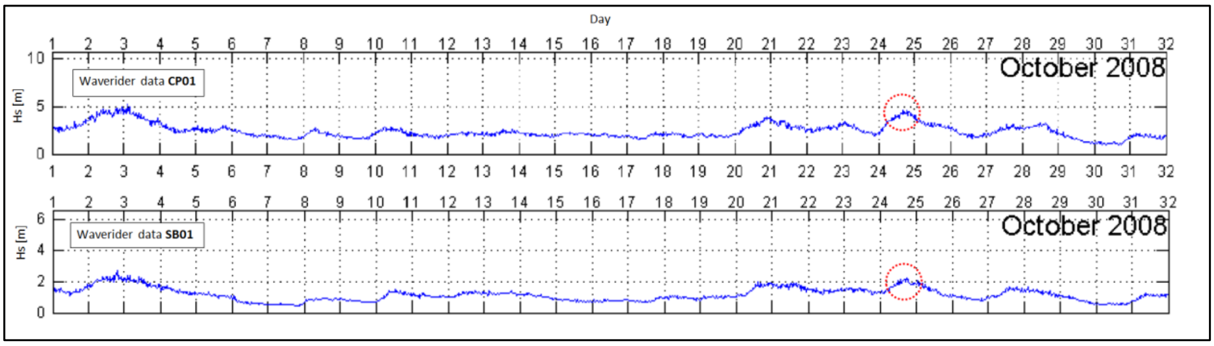


Figure 8-6 Identification of corresponding Cape Point (CP01) and Saldanha Bay (SB01) storm peaks (CSIR, 2013a) & (CSIR, 2013b)

Calibration Runs

It was assumed that the deepwater conditions at the Cape Point Waverider buoy (CP01) would be reasonably accurate as input wave conditions, considering the model boundary was also in deep water. Nonetheless, a series of SWAN calibration runs were initiated to determine the sensitivity of the offshore boundary conditions on the computational model. A SWAN model template was created based on the parameters in Table 8-2. These modelling parameters were kept fixed so that only the individual storm wave parameters would change (H_s, T_p, Direction & Spreading).

Table 8-2 SWAN model parameters

Model Parameter	**Value**
Spectral shape	JONSWAP
Peak enhancement factor	3.3
Spectral directional resolution	36 directions
Spectral frequency resolution	24 bins
Spectral frequency range	0.25 Hz – 0.03 Hz
Bottom friction coefficient	Madsen [0.05 m] *(Madsen, et al., 1988)*
Depth induced breaking	Battjes & Janssen [α=1 γ=0.73] *(Battjes & Janssen, 1978)*
Whitecapping	Komen et al. *(Komen, et al., 1984)*

*Note: **Wind** was not an input condition to the model. Wind related downtime is addressed in a separate Section in this study.*

Using these fixed model parameters, the selected calibration storms were input as boundary conditions at the coarse grid. The SWAN model was run through Delft 3D, and the output wave conditions were extracted at the model's calibration point, i.e. the location of the Saldanha Bay Waverider buoy (SB01).

In the case of the five selected calibration storms, the output significant wave height and peak period was within a ±4% range when compared to the SB01 Waverider data during the same storm (Table 8-3). The Saldanha Bay buoy does not record wave direction or directional spreading, so these parameters could not be compared.

Table 8-3 Calibrated storm characteristics

Waverider	Year	Month	H_s [m]	T_p [s]	Direction [°]	Spreading [°]	% Error H_s	% Error T_p
CP01	*2001*	*July*	*6.73*	*13.3*	*265*	*17*	-	-
SB01	2001	July	3.42	13.47	-	-	-	-
SB model	2001	July	3.4	13.78	246	8	- 0.6%	2.2%
CP01	*2002*	*June*	*7.06*	*18.1*	*234*	*16*	-	-
SB01	2002	June	4.43	18.29	-	-	-	-
SB model	2002	June	4.33	17.96	241	7	- 2.3%	- 1.8%
CP01	*2005*	*March*	*1.52*	*15.4*	*247*	-	-	-
SB01	2005	March	1.17	13.47	-	-	-	-
SB model	2005	March	0.94	15.05	243	7	- 4.3%	- 3.1%
CP01	*2008*	*Oct*	*4.39*	*13.3*	*227*	*15*	-	-
SB01	2008	Oct	2.01	12.5	-	-	-	-
SB model	2008	Oct	2.16	13.8	239	8	1.4%	3.6%
CP01	*2013*	*August*	*5.56*	*15.3*	*239*	*20*	-	-
SB01	2013	August	3.26	15.3	-	-	-	-
SB model	2013	August	3.37	15	242	8	3.3%	- 2.0%

Note: The "% Error" values describe the difference between the modelled *wave conditions and the* recorded *wave conditions at the SB01 position.*

The spectral shape of each storm was also considered during the calibration process. The measured spectra at the SB01 Waverider and spectra acquired from the model runs at the calibration point were directly compared. The recorded and modelled spectral comparisons are illustrated in Figure 8-7 to Figure 8-11.

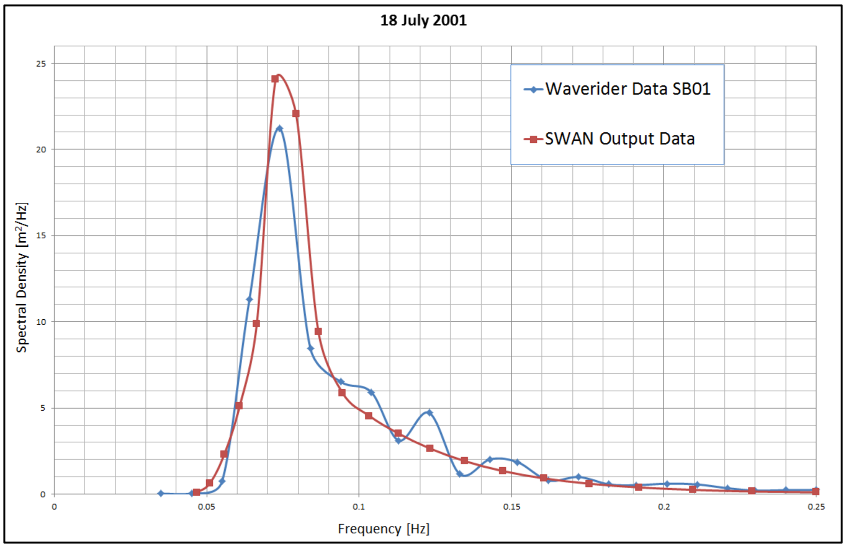


Figure 8-7 Storm spectral comparison - July 2001

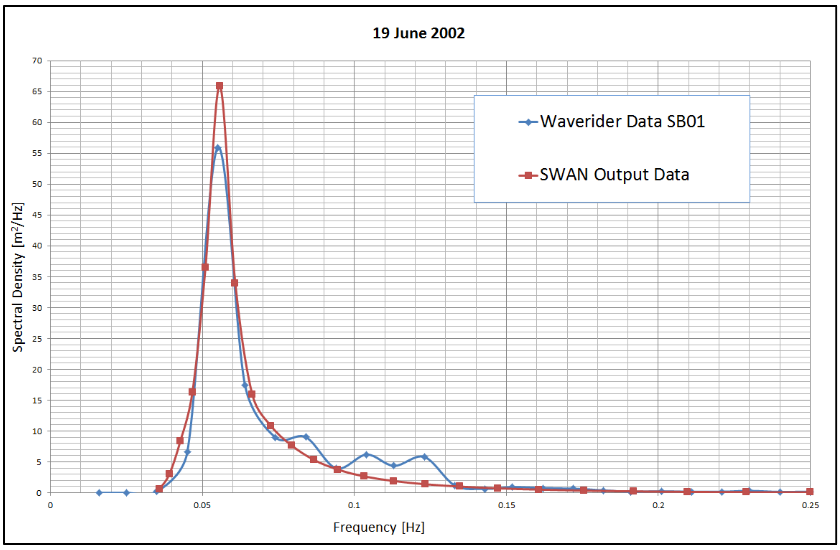


Figure 8-8 Storm spectral comparison - June 2002

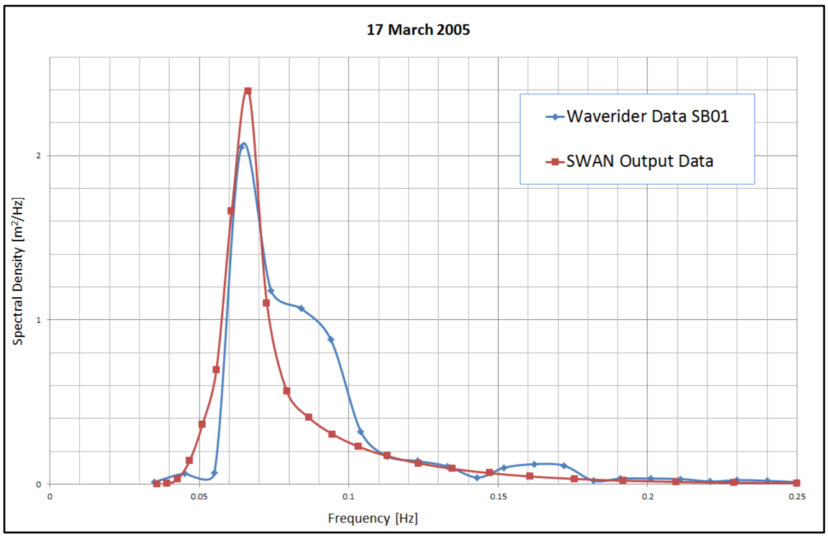


Figure 8-9 Storm spectral comparison - March 2005

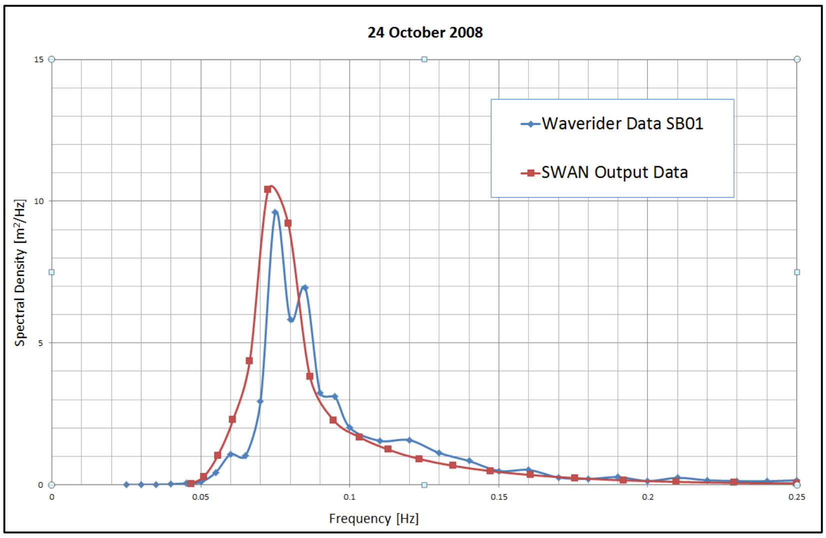


Figure 8-10 Storm spectral comparison - October 2008

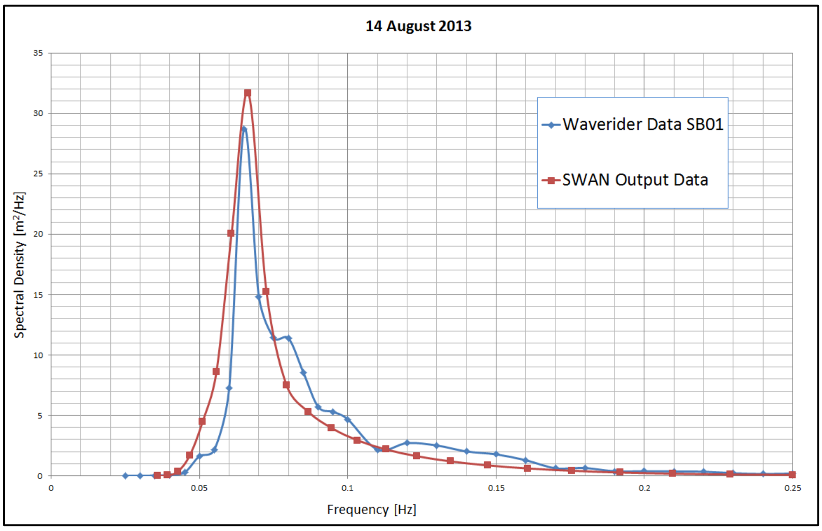


Figure 8-11 Storm spectral comparison - August 2013

In each of the spectral comparisons, the modelled spectral shape matches the recorded shape well. The spectral density peaks are well represented. The storm of March 2005 records an unusual amount of high frequency energy however that is not accurately modelled. This is a low wave and low period condition (H_s=1.17 m & 13.5s) and it is clear that short period wind waves have distorted the spectrum. It is unlikely a wave of this height will have any influence on port downtime however.

The calibration exercise suggests the SWAN model is adequately calibrated, and that wave parameters recorded in deep water offshore of Kommetjie can be used as input boundary conditions to the SWAN model.

8.2.4 Derivation of Historical Time Series from the SWAN Model

Offshore Wave Data Matrix

The relationships between the input Cape Point Waverider boundary conditions and the output SWAN wave conditions were used to derive virtual timeseries, based on the raw historical wave timeseries at the Waverider.

The offshore wave climate was binned into representative values of wave height, period and direction, and a 3 x 3 x 4 matrix of these parameters was created. The idealised representative parameters are shown in Table 8-4. In order to minimise computational time, a single value was used for spreading. It was found that the mean spreading values of the four directions were between 22° and 24°. A fixed value of 23° was used considering the mean variation was so narrow.

Table 8-4 Bin sizes for characterising offshore wave data at Cape Point Waverider (CP01)

H_s [m]	T_p [s]	Direction [°]
3	12	215
6	16	235
9	18	255
-	-	280

Production Runs

The offshore wave matrix comprised 36 different wave conditions, consisting of H_s, T_p and Direction. The 36 conditions were used as input boundary conditions to the calibrated SWAN model. Each condition demanded an individual model run. Output wave conditions were extracted at five different model locations of interest. The locations are; Site 0 (location of Waverider Buoy SB01), Site 1 (Hoedjiespunt), Site 2 (North Bay), Site 3 (Big Bay: Causeway) and Site 4 (Big Bay: Open Water). Sites 1-4 were identified as plausible jetty sites following a review of potential development zones in Saldanha Bay in *Section 7 – Conceptual Site Layouts*. The approximate locations of the model extraction points, corresponding to Site 0 to Site 4, are shown in Table 8-5. The locations of the output points are described by Table 8-5 and Figure 8-5.

Table 8-5 Location of SWAN wave data extraction points

			Chart Co-ordinate		Model Co-ordinate		
Loc #	**Output point**	**Description**	**S**	**E**	**X**	**Y**	**Depth [m]**
0	SB01	Waverider Buoy	33° 03'00"	17°58'42"	404640	341546	23
1	Hoedjiespunt	600m E off Hoedjiespunt	33° 01'39"	17°58'18"	403966	344006	14.55
2	North Bay	1250m W of Marcus Island, 600m N	33° 02'18"	17°57'10"	402248	342800	24.35
3	Big Bay Jetty	500m E of causeway corner, 200m S	33° 01'16"	17°59'48"	406300	344760	12.26
4	Big Bay SBM	850m E & 900m S off end of oil jetty	33° 02'34"	17°59'33"	405925	342423	19.77

An example of the wave data extracted at the five output sites for a single input boundary condition (H_s = 3 m, T_p = 12s, Dirn = 210°) is shown in Table 8-6. The variation in wave direction due to wave refraction is patently obvious, whereas the spreading narrows due to shoaling and formation of long crested waves. There is little variation in wave period. The effects of refraction and wave shadow from islands and headlands can be seen on the output wave heights (H_s).

Table 8-6 Example of output model wave parameters following SWAN run

	INPUT				OUTPUT					
Run ID	**Dirn**	**Hs**	**Tp**	**av spr**	**Loc**	**Loc #**	**Dirn**	**Hs**	**Tp**	**av spr**
210_01	210	3	12	23	SB01	0	237	1.53	11.5	9
					Hoedjiespunt	1	143	0.21	11.5	7
					North Bay	2	210	1.61	11.5	10
					Big Bay Jetty	3	209	0.31	11.5	8
					Big Bay SBM	4	239	1.22	11.5	6

Following the execution of the 36 production runs, each input condition was correlated with a resultant output for every site. A representative wave matrix for each Site was thereafter generated. The model output matrix for Site 1 – Hoedjiespunt – is shown in Table 8-7. Model outputs at Site 1 to Site 4 are presented in Appendix C.

Table 8-7 Derived wave data at Site 1 – Hoedjiespunt

	INPUT				OUTPUT					
Run ID	Dirn	Hs	Tp	av spr	Loc	Loc #	Dirn	Hs	Tp	av spr
210_01	210	3	12	23	Hoedjiespunt	1	143	0.21	11.5	7
210_04	210	6	12	23	Hoedjiespunt	1	143	0.41	11.5	6
210_07	210	9	12	23	Hoedjiespunt	1	143	0.58	11.5	6
210_02	210	3	16	23	Hoedjiespunt	1	142	0.23	16.4	7
210_05	210	6	16	23	Hoedjiespunt	1	142	0.43	16.4	7
210_08	210	9	16	23	Hoedjiespunt	1	142	0.62	16.4	7
210_03	210	3	20	23	Hoedjiespunt	1	142	0.24	19.6	7
210_06	210	6	20	23	Hoedjiespunt	1	142	0.45	19.6	7
210_09	210	9	20	23	Hoedjiespunt	1	142	0.64	19.6	7
235_01	235	3	12	23	Hoedjiespunt	1	143	0.21	11.5	6
235_04	235	6	12	23	Hoedjiespunt	1	143	0.40	11.5	6
235_07	235	9	12	23	Hoedjiespunt	1	143	0.56	11.5	6
235_02	235	3	16	23	Hoedjiespunt	1	142	0.22	16.4	6
235_05	235	6	16	23	Hoedjiespunt	1	142	0.41	16.4	6
235_08	235	9	16	23	Hoedjiespunt	1	142	0.59	16.4	6
235_03	235	3	20	23	Hoedjiespunt	1	142	0.22	19.6	6
235_06	235	6	20	23	Hoedjiespunt	1	142	0.42	19.6	6
235_09	235	9	20	23	Hoedjiespunt	1	142	0.60	19.6	6
255_01	255	3	12	23	Hoedjiespunt	1	143	0.17	11.5	6
255_04	255	6	12	23	Hoedjiespunt	1	143	0.33	11.5	6
255_07	255	9	12	23	Hoedjiespunt	1	143	0.47	11.5	6
255_02	255	3	16	23	Hoedjiespunt	1	142	0.19	16.4	6
255_05	255	6	16	23	Hoedjiespunt	1	142	0.36	16.4	6
255_08	255	9	16	23	Hoedjiespunt	1	142	0.52	16.4	6
255_03	255	3	20	23	Hoedjiespunt	1	142	0.20	19.6	6
255_06	255	6	20	23	Hoedjiespunt	1	142	0.38	19.6	6
255_09	255	9	20	23	Hoedjiespunt	1	142	0.54	19.6	6
280_01	280	3	12	23	Hoedjiespunt	1	143	0.12	11.5	6
280_04	280	6	12	23	Hoedjiespunt	1	143	0.22	11.5	6
280_07	280	9	12	23	Hoedjiespunt	1	143	0.32	11.5	6
280_02	280	3	16	23	Hoedjiespunt	1	142	0.14	16.4	6
280_05	280	6	16	23	Hoedjiespunt	1	142	0.27	16.4	6
280_08	280	9	16	23	Hoedjiespunt	1	142	0.39	16.4	6
280_03	280	3	20	23	Hoedjiespunt	1	142	0.16	19.6	6
280_06	280	6	20	23	Hoedjiespunt	1	142	0.30	19.6	6
280_09	280	9	20	23	Hoedjiespunt	1	142	0.44	19.6	6

Generation of Virtual Timeseries

A timeseries of offshore wave data, sampled between January 1998 and August 2013, was used to derive virtual timeseries at each of the SWAN output locations. The data series was loaded as input into a MATLAB script that interpolated each input line variable (H_s, T_p, Direction) to determine its location within the input matrix cloud. Utilising the relationship between the input and site specific output matrices, the corresponding site-specific H_s was determined for each of the input samples (approximately 46,000 3-hour averaged samples). A new virtual timeseries was generated at each site, using the same sampling increments as the offshore timeseries on which it is derived (CP01).

Validation of Model

The virtual timeseries generated at the calibration point (Site 0 – "location of Waverider Buoy SB01") is compared to the historical dataset recorded by the in situ Waverider buoy. The virtual timeseries, derived from offshore wave data and a calibrated SWAN model, compares relatively well with the recorded data, as illustrated in Figure 8-12.

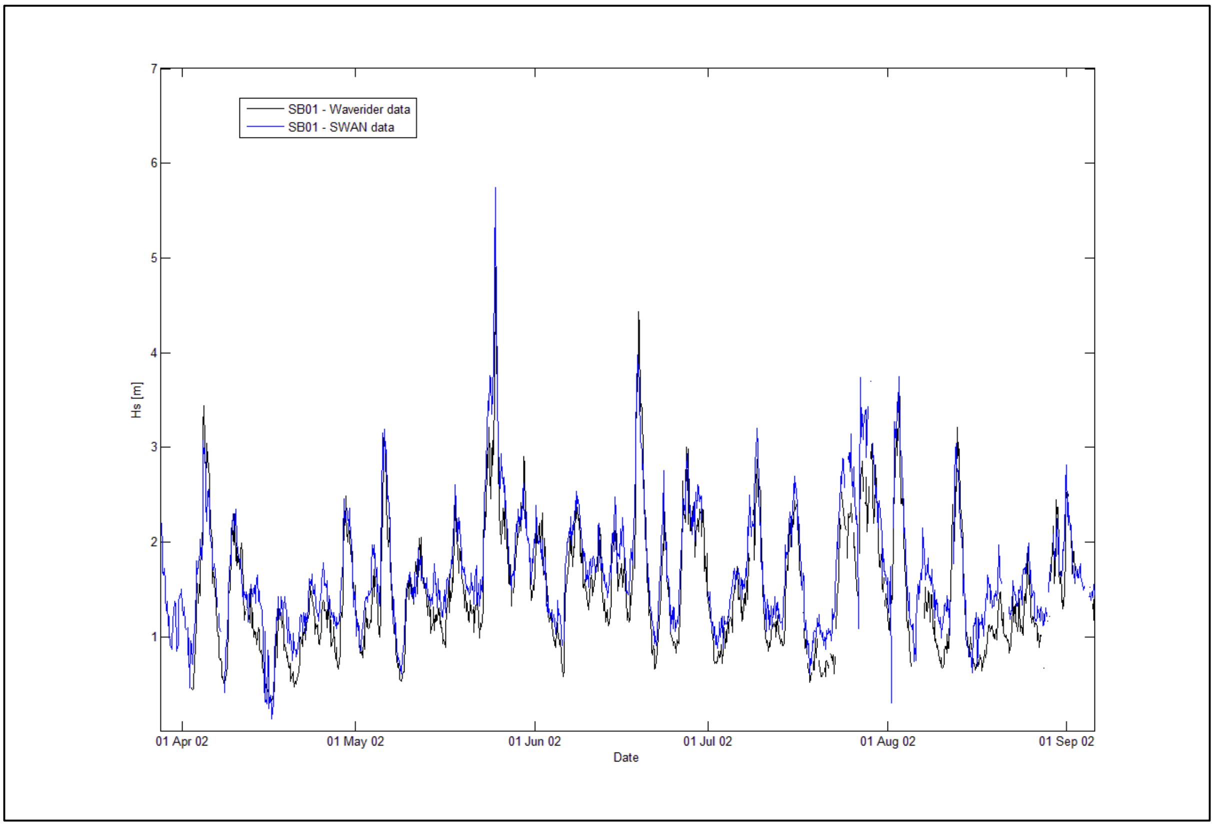


Figure 8-12 Comparison of recorded and model timeseries at Site 0 (SB01)

In some instances however, particularly where H_s<1.5 m, the SWAN model tends to over-estimate the wave height by a factor of 1.1 to 1.2 (refer to Figure 8-13). Storm wave heights above H_s=2 m are accurately modelled however. The slight over-estimation of low amplitude waves should not have an effect on the critical wave height exceedance analysis, nor on the subsequent derivation of downtime.

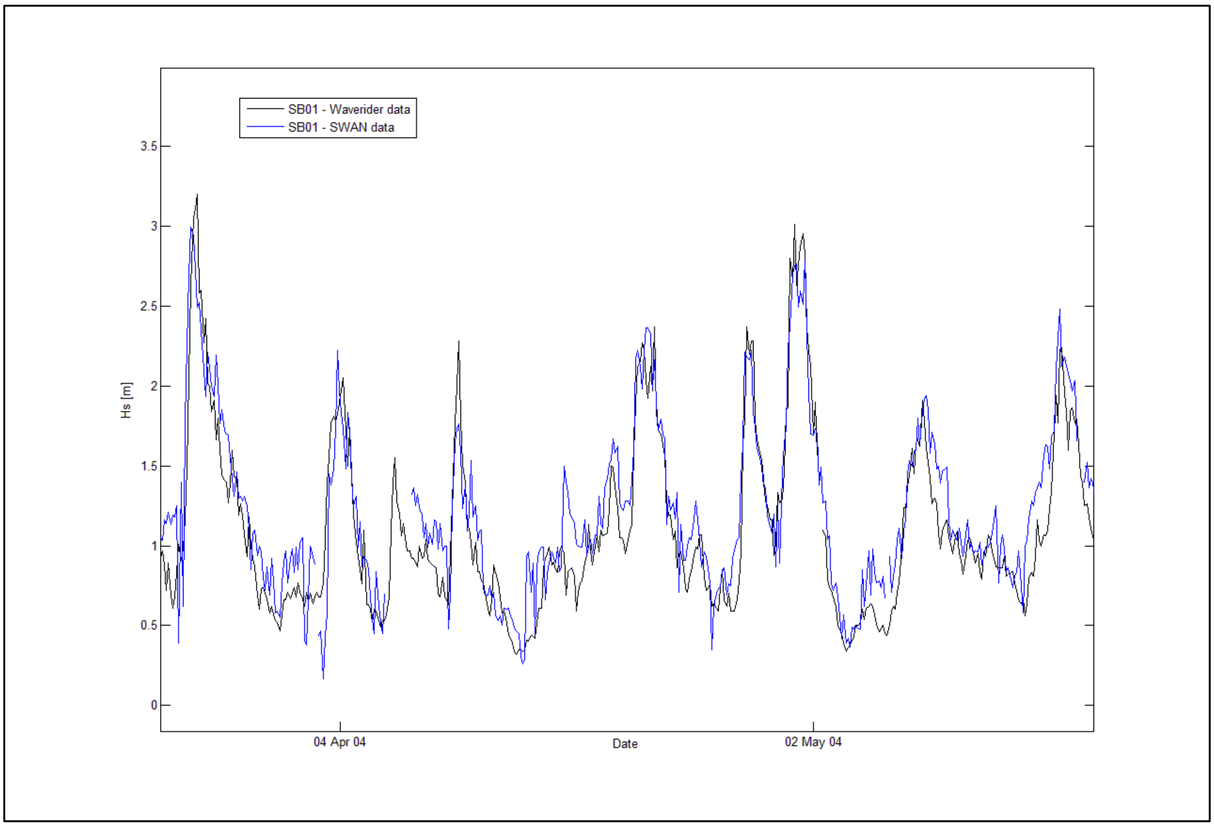


Figure 8-13 Detail of storm peak representation

A virtual timeseries was derived and plotted at each site location for the period between January 1998 and August 2013. An example of a derived virtual time series, in this case at “Site 2 – North Bay”, for the period of January to December 2002, is given in Figure 8-14. The gaps in the trace are caused by gaps in the Cape Point wave data set, from which the virtual timeseries is derived.

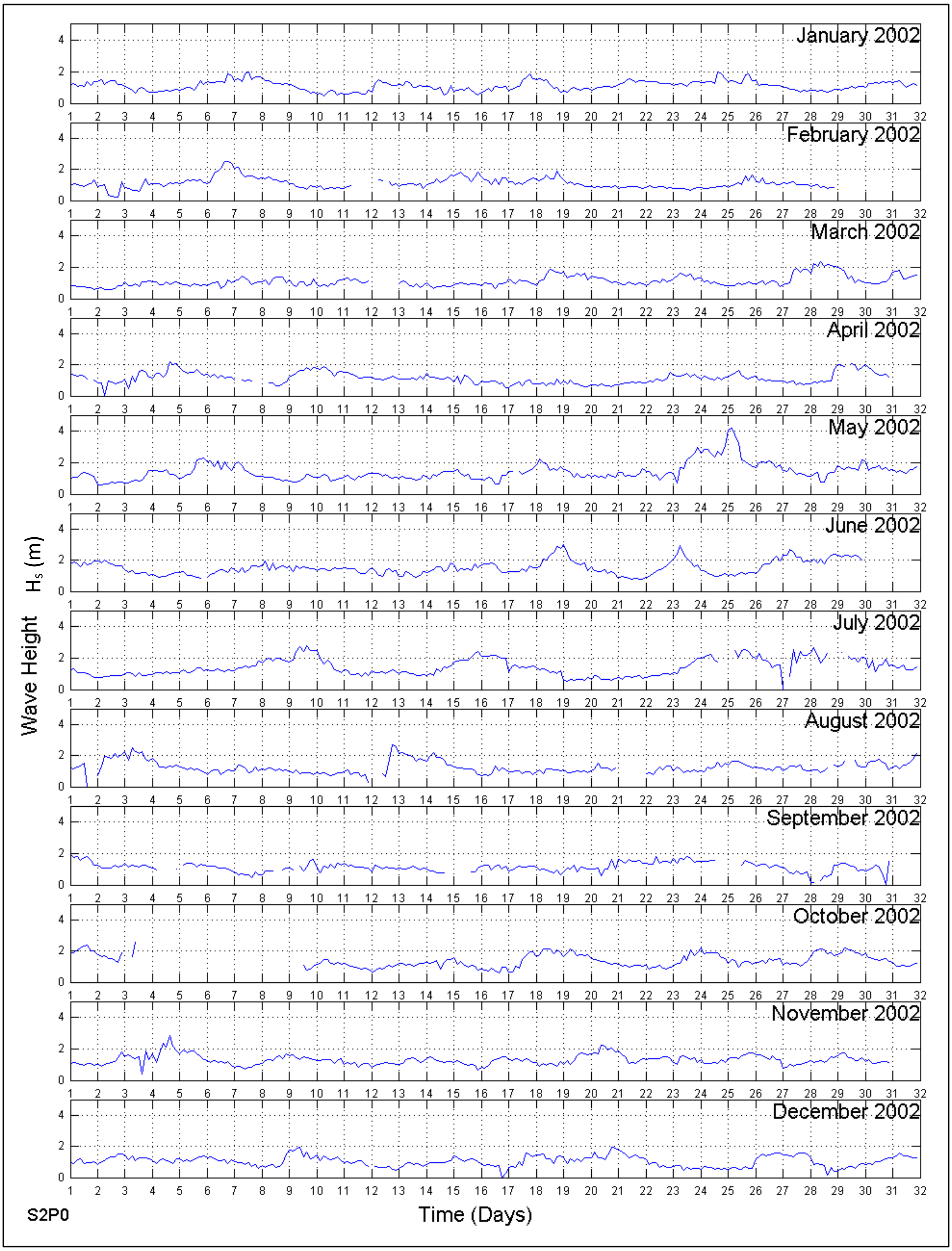


Figure 8-14 - Virtual wave height time series for Jan-Dec 2002 at Site 2 - North Bay

8.2.5 Wave Height Occurrence and Exceedance

The ultimate product of the SWAN modelling exercise is a wave height data set at each of the five output locations. From these individual data sets, wave height exceedance curves are derived. The five curves are compared in Figure 8-15. It is shown that significant wave heights are greatest at the Waverider Site (Site 0), as this location is more exposed and experiences fewer refractive, diffractive and shoaling effects than any other site due to its depth and location near the centre of the harbour mouth.

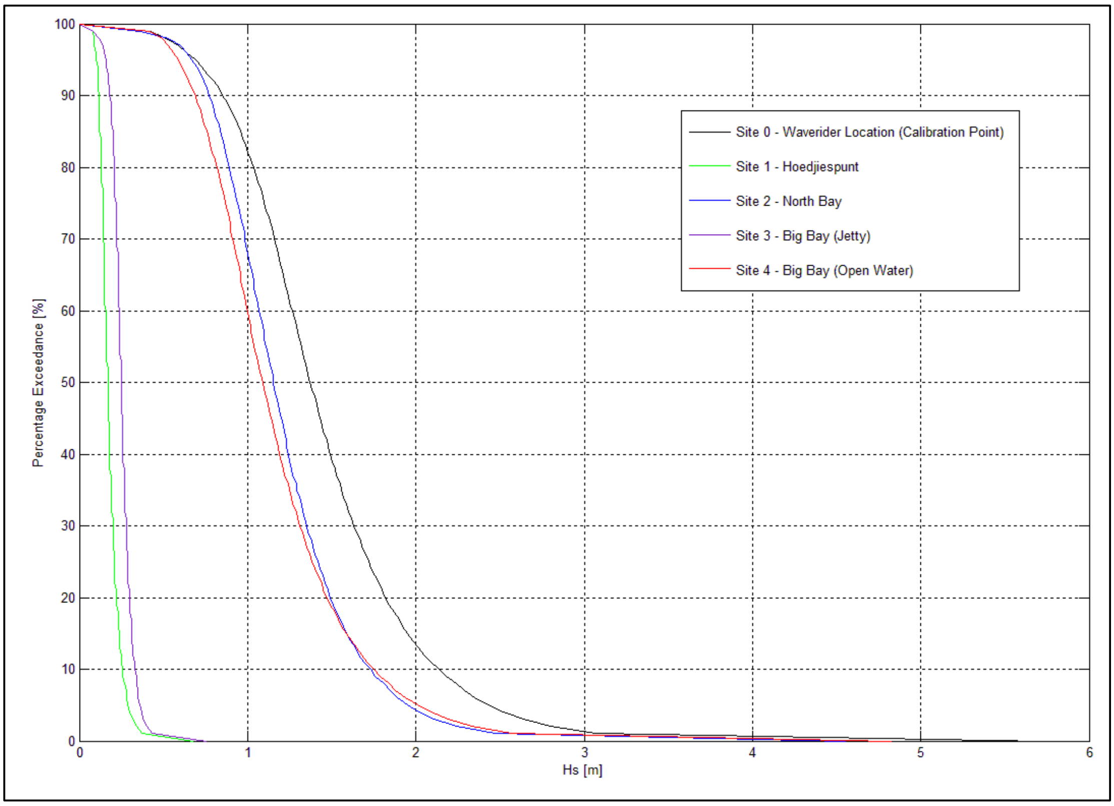
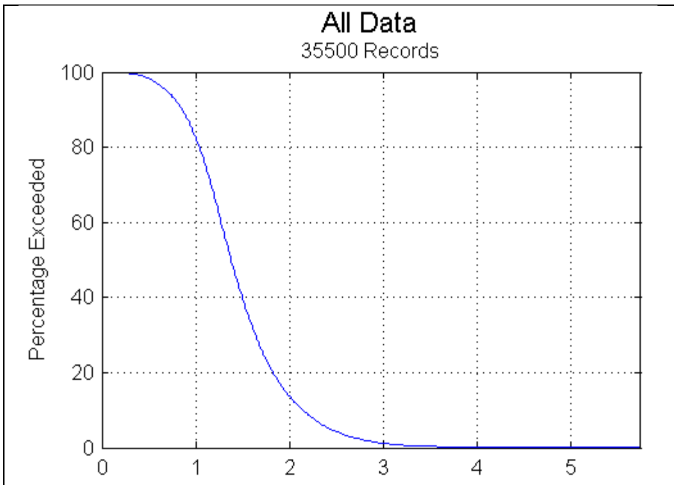


Figure 8-15 Comparison of percentage exceedance curves at model output locations

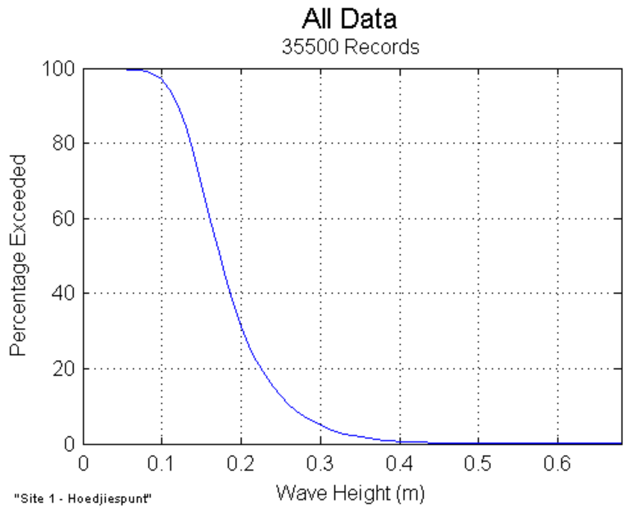
Individual percentage wave height exceedance values at Site 0 to Site 4 are tabulated alongside their respective curves in Figure 8-16 to Figure 8-20.



Site 0 - Saldanha Bay Waverider buoy

Wave Height H_s Exceeded (m)					
	1.0%	5%	10%	25%	50%
All Data	3.1	2.4	2.1	1.7	1.4
Summer	2.4	2.0	1.8	1.5	1.3
Autumn	3.0	2.4	2.1	1.7	1.4
Winter	3.4	2.8	2.4	2.0	1.6
Spring	2.9	2.3	2.1	1.7	1.4

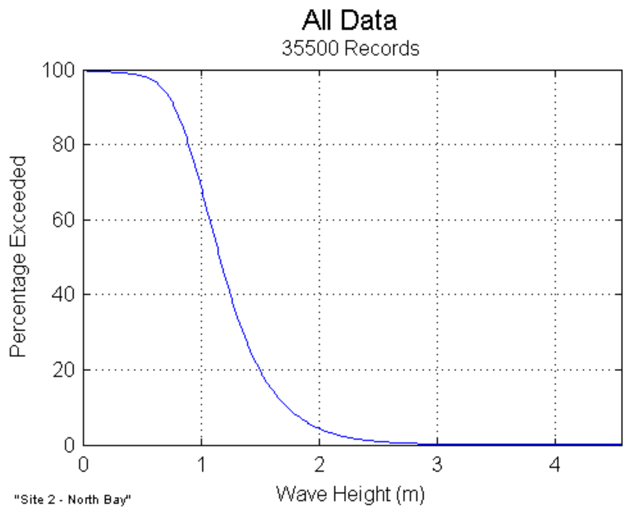
Figure 8-16 Percentage wave height exceedance values at Site 0 - Saldanha Bay Waverider buoy



Site 1 – Hoedjiespunt

Wave Height H_s Exceeded (m)					
	1.0%	5%	10%	25%	50%
All Data	0.4	0.3	0.3	0.2	0.2
Summer	0.3	0.2	0.2	0.2	0.2
Autumn	0.4	0.3	0.3	0.2	0.2
Winter	0.4	0.3	0.3	0.2	0.2
Spring	0.4	0.3	0.3	0.2	0.2

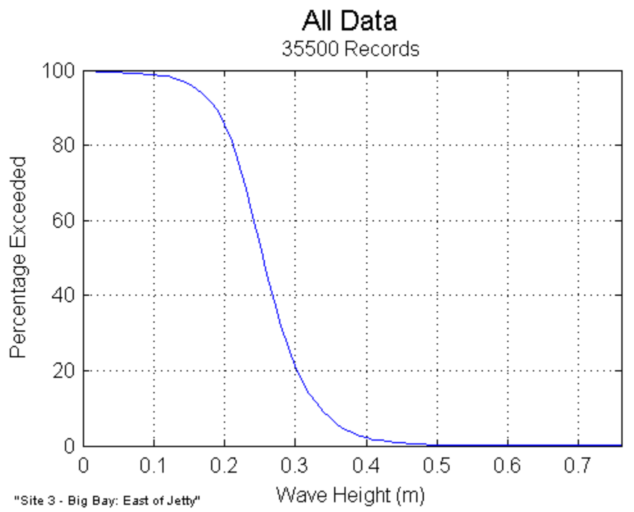
Figure 8-17 Percentage wave height exceedance values at Site 1 – Hoedjiespunt



Site 2 - North Bay

Wave Height H_s Exceeded (m)					
	1.0%	5%	10%	25%	50%
All Data	2.5	2.0	1.7	1.4	1.2
Summer	2.0	1.7	1.5	1.3	1.1
Autumn	2.4	1.9	1.7	1.4	1.1
Winter	2.7	2.2	1.9	1.6	1.2
Spring	2.4	1.9	1.7	1.4	1.2

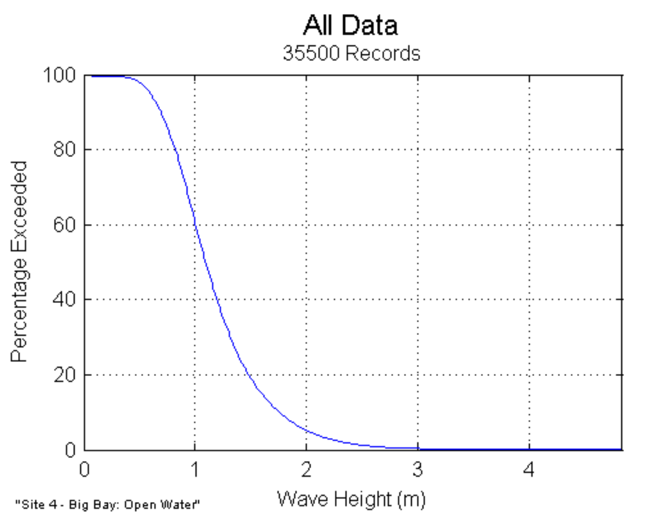
Figure 8-18 Percentage wave height exceedance values at Site 2 - North Bay



Site 3 - Big Bay: Causeway

Wave Height H_s Exceeded (m)					
	1.0%	5%	10%	25%	50%
All Data	0.4	0.4	0.3	0.3	0.3
Summer	0.4	0.3	0.3	0.3	0.2
Autumn	0.4	0.4	0.3	0.3	0.3
Winter	0.5	0.4	0.4	0.30	0.3
Spring	0.4	0.4	0.3	0.3	0.3

Figure 8-19 Percentage wave height exceedance values at Site 3 - Big Bay: Causeway



Site 4 - Big Bay: Open water

	Wave Height Exceeded (m)				
	1.0%	5%	10%	25%	50%
All Data	2.6	2.0	1.8	1.4	1.1
Summer	2.0	1.6	1.4	1.2	1.0
Autumn	2.6	1.9	1.7	1.3	1.1
Winter	3.0	2.3	2.0	1.6	1.3
Spring	2.4	1.9	1.7	1.4	1.1

Figure 8-20 Percentage wave height exceedance values at Site 4 - Big Bay: Open water

8.3 Wave Induced Downtime

8.3.1 Berthing Procedure

The safe mooring of an incoming vessel is the result of a succession of sequential navigational phases that begin many miles offshore. Inability to timeously execute any one of these procedures will lead to berth downtime.

The expected procedure of berthing and mooring a laden LNGC at Saldanha Bay is described as follows;

1. Rendezvous with pilot boat in a position with North Head light bearing 58° x 5 Nm offshore (TNPA, 2010). Pilot may board while vessel is underway.
2. Vessel meets tugboats approximately 1Nm seaward (SW) of the approach channel. LNGC speed is reduced and tugs will connect with vessel.
3. Vessel will be escorted under own steam into the approach channel. Tugs will begin to assist manoeuvrability under the lee of the breakwater, or earlier of possible.
4. Tugs will slow LNGC as required as it approaches the turning circle. LNGC depends on tugs for steerage and propulsion at speeds lower than 4kn.
5. Tugs will turn LNGC 180° inside the turning circle, and manoeuvre the vessel alongside the berth. In the case of an SPM, only one or maximum two tugboats should be necessary to assist the vessel (van Wijngaarden & Oomen, 2004).
6. At standard jetties and GBS structures, berthing dolphins are utilised to assist the berthing operation. At FSRU terminals there are no such leverage points to use, potentially making the operation more difficult and time consuming. FSRU terminals therefore call for low wave action.
7. Tugs maintain position of vessel against fenders. Mooring lines are connected to the quayside bollards and tensioned.

Although downtime may occur at any of the stages noted, it is usually the pilot's ability to board, and the tugs' ability to assist effectively that are of the greatest concern.

8.3.2 Operational Wave Limits

A literature study has been conducted to determine values of limiting wave heights (H_s) for a range of LNGC navigational and berthing operations. Limiting wave height values are stated in Table 8-8.

Table 8-8 Limiting wave conditions for LNGC navigation & operations

Scenario	Location	H_s range	Notes	Source
Pilot boarding	5 Nm SW of North Head (offshore)	3 m – 3.5 m	-	(TNPA, 2013)
Tug connection	1 Nm WSW of entrance channel	3 m	-	(TNPA, 2013)
Tug effectiveness	Approaching/inside channel	1 m – 1.5 m	Standard tug	(Cork & Bentiba, 2008)
Tug effectiveness	Approaching/inside channel	1.5 m – 2 m	Tractor tug	(Cork & Bentiba, 2008)
Berthing operation	Trestle jetty/Alongside FSRU/GBS	1.5 m – 2 m	-	(Thoresen, 2010) (Ligteringen & Velsink, 2012)
LNG offloading	Trestle jetty/Alongside FSRU/GBS	1.5 m – 2.5	-	(Levitan & Associates Inc., 2007) (van Wijngaarden & Oomen, 2004)
Stay at berth	Trestle jetty/Alongside FSRU/GBS	3 m	Alongside FSRU	(Levitan & Associates Inc., 2007)
Berthing: SPM	SBM/Tower/ Bow-to-Stern FSRU	3 m	Tower or Bow-to-Stern FSRU	(van Wijngaarden, et al., 2002)
LNG offloading: SPM	SBM/Tower/ Bow-to-Stern FSRU	5 m	Tower or Bow-to-Stern FSRU	(van Wijngaarden, et al., 2002)
Stay at berth: SPM	SBM/Tower/ Bow-to-Stern FSRU	5.5 m	Tower or Bow-to-Stern FSRU	(van Wijngaarden, et al., 2002)

8.3.3 Percentage Annual Downtime

Berthing operations can be split into two categories: unprotected operations and sheltered operations.

Unprotected Berthing Operations

The unprotected operations are independent of terminal site or indeed of vessel type. Operations consist of pilot boarding, tug connection and tug assistance, and apply to all cargo vessels entering the Bay. Limiting wave conditions and corresponding percentage exceedance are tabulated in Table 8-9. It is critical to note that these operations are currently in practice in Saldanha Bay, used to berth iron ore bulk carriers, oil tankers and multi-purpose vessels.

Table 8-9 Percentage exceedance of limiting wave height (H_s) during specific tugboat operations

Scenario	H_s range	Data set	% Exceedance
Pilot boarding	3 m – 3.5 m	Cape Point Waverider	23% - 13%
Tug connection	3 m	Saldanha Bay Waverider	1%
Tug effectiveness (standard)	1 m – 1.5 m	Saldanha Bay Waverider	82% - 39%
Tug effectiveness (tractor)	1.5 m – 2 m	Saldanha Bay Waverider	39% - 13%

Three important points should be noted, with reference to Table 8-9.

- The ability of the pilot to board governs all other berthing practices. All port operations are affected if the pilot cannot gain access to an incoming vessel. This will occur at least 13% of the time, according to the analysis of the offshore time series. This is evidently not the case however, as the Port of Saldanha as a whole does not suffer such extreme downtime. Limiting values stated may be underestimated. It is more likely however that upon making contact offshore, the pilot boat will accompany the vessel into more sheltered waters as the pilot boards, effectively reducing the wave height.
- Tug connection, made 1Nm WSW of the channel entrance, is not possible 1% of the time.
- Predicted downtime caused by ineffective tug assistance is very high in Table 8-9. However, these values are calculated at the Waverider buoy, in the exposed entrance to the channel. In general, the tugs will only begin to assist when the vessel has manoeuvred to the shelter of the beach breakwater, where wave heights are rarely above 1 m. Exceedance values corresponding to the four sites are elaborated in Table 8-10, and will give a more accurate reflection of sheltered operational tug downtime.

Since downtime resulting from unprotected operations affects the four conceptual sites an equal amount, this downtime will not be a judging factor when rating the sites.

Sheltered Berthing Operations

Analysis of the virtual timeseries generated during the numerical modelling exercise reveals the percentage wave height exceedance at each site. These values are presented in Table 8-10 for a range of wave heights between H_s= 0.5 m and H_s= 5.5 m.

The limiting wave heights for sheltered berthing operations are presented in Table 8-11. Exceedance values are presented on a site by site basis.

It can be deduced that berthing operations can be executed at **Site 1** and **Site 3** at all times, provided the pilot can board and tugs can connect and assist.

Berthing may be possible at open water **Site 2** and **Site 4** over 99.7% of the time if a SPM/Tower terminal is employed. If a GBS terminal is employed, berthing may only be possible 80.8% to 95.8% of the time at Site 2 or 81.4% to 95% of the time at Site 4.

Table 8-10 Percentage exceedance of limiting wave height (H_s) at potential terminal sites

	Waverider Buoy - SB 01	Site 1 - Hoedjiespunt	Site 2 - North Bay	Site 3 - Big Bay: Causeway	Site 4 - Big Bay: Open Water
H_s (m)	**% Exceedance**				
0.5	98.34	0.10	98.23	0.19	97.72
1	82.02	-	67.68	-	59.20
1.5	39.03	-	19.43	-	18.56
2	13.44	-	4.17	-	5.01
2.5	4.20	-	0.87	-	1.19
3	1.18	-	0.19	-	0.34
3.5	0.38	-	0.06	-	0.12
4	0.15	-	0.02	-	0.03
4.5	0.07	-	<0.01	-	<0.01
5	0.02	-	-	-	-
5.5	<0.01	-	-	-	-

With regard to a GBS terminal, the effect of a minor increase in the wave height **threshold** during berthing cannot be ignored. Increasing the acceptable H_s threshold from H_s=1.5 m to H_s=2 m will lower annual downtime from approximately 19% to under 5%. This variation will have a major influence on the overall feasibility of the port. For this study, the limiting height will be taken as 2 m for GBS berthing operations. The sensitivity of the berth and the tug operations between H_s=1.5 m and H_s=2 m would be addressed in the pre-feasibility stage of port design. Nonetheless, one should be wary of the use of a GBS terminal at Site 2 and Site 4.

Table 8-11 Percentage exceedance of limiting wave height (H_s) during specific berthing operations

Scenario	**H_s range**	**% Exceedance**			
		Site 1	**Site 2**	**Site 3**	**Site 4**
Trestle Jetty or GBS					
Berthing operation	1.5 m – 2 m	-	19.4% - 4.2%	-	18.6% - 5%
LNG offloading	1.5 m – 2.5	-	19.4% - 0.9%	-	18.6% - 1.2%
Stay at berth	3 m	-	0.2%	-	0.3%
SPM					
Berthing	3 m	-	0.2%	-	0.3%
LNG offloading	5 m	-	-	-	-
Stay at berth	5.5 m	-	-	-	-

Conclusions On Wave Downtime

Wave downtime can be considered negligible at Site 1 (Hoedjiespunt) and Site 3 (Big Bay: Causeway), regardless of terminal choice (refer to Table 8-11). Downtime is acceptable at Site 2 (North Bay) and Site 4 (Big Bay: Open Water) if an SPM type terminal is used. In the case where a GBS type terminal is employed, wave downtime may be considered acceptable when the upper limit of H_s = 2.0 m defines berthing feasibility. However when this limit is lowered, a GBS terminal at Site 2 or Site 4 is no longer practical. Artificial protection measures (such as a breakwater) would not be practical at these sites, and would negate the use of a GBS.

It is evident that a more focused study is required to calculate the feasibility of a GBS terminal option at Site 2 and Site 4. For the purpose of this study, GBS options at Site 2 and Site 4 will be considered as they add a degree of variety and innovative technology to the conceptual terminal solutions, and there is not enough evidence to disqualify these options at this level of scoping.

Wave induced downtime is considered acceptable at each site. Additional wave protection measures (i.e. breakwaters) will not be necessary for any of the four conceptual site layouts.

8.4 Wind Induced Downtime

8.4.1 Operational Wind Limits

Local wind climate plays a significant role in the operational efficiency of an LNG terminal. LNG carriers, due to their significant freeboard, relatively shallow draft and light cargo, are particularly susceptible to the effects of wind loading.

Windspeed limits affecting the navigation, berthing and operation of LNG carriers at ports have been compiled in Table 8-12. There is much agreement among the sources regarding the operational limits. Ligteringen & Velsink (2012) however state an uncharacteristically high limiting windspeed bracket of 12.5 – 15 m/s for berthing operations. This range refers to both LNGC's and heavier, deep-draught bulk oil carriers which are not as sensitive to wind loading, thus raising the limits. A more conservative limit for berthing operations will therefore be adopted; 10 m/s – 12.5 m/s.

Wind is usually not a critical factor when the pilot is boarding or tugs are connecting, as the LNGC can provide a sheltered lee side to conduct these operations. The berthing procedure is governed by the windspeed at the jetty however, and tugs will not make fast if windspeed exceeds the berthing wind limits. Similar wind speeds are expected inside and outside the Bay area. The effective windspeed limit for tug connection should therefore be equal to the berthing limits. If this limit is exceeded the vessel will lie at anchor until the wind drops and stabilises.

Table 8-12 Limiting windspeeds for LNGC navigation & operations

Scenario	Location	Windspeed range	Source
Pilot boarding	5 Nm SW of North Head (offshore)	15 – 17 m/s	(TNPA, 2013)
Tug connection	1 Nm WSW of entrance channel	15 – 17 m/s	(TNPA, 2013)
Berthing operation	Trestle jetty/Alongside FSRU/GBS	10 – 12 m/s$ or 12.5 – 15 m/s*	$ (Cork & Bentiba, 2008) & *(Ligteringen & Velsink, 2012)
LNG offloading	Trestle jetty/Alongside FSRU/GBS	15 – 17 m/s	(Thoresen, 2010) (Cork & Bentiba, 2008)
Disconnect arms	Trestle jetty/Alongside FSRU/GBS	20 m/s	(Cork & Bentiba, 2008) (Thoresen, 2010)
Stay at berth	Trestle jetty/Alongside FSRU/GBS	24 – 25 m/s	(Cork & Bentiba, 2008) (Thoresen, 2010)

Wind limits for berthing, offloading, arm disconnection and survivability are expected to be much higher for a weathervaning SPM/Tower type terminals. Guidelines are not available for such limits however. Consequently, the values used for standard terminals in Table 8-12 will be applied to SPM terminals.

8.4.2 Percentage Annual Downtime

The wind climate in Saldanha Bay is described in Figure 7-8 where a wind exceedance curve is presented. Derived exceedance values are presented in Table 8-13, based on wind speeds recorded at the Port Control tower on Hoedjiespunt.

Table 8-13 Percentage exceedance of limiting windspeed during specific berthing operations

Scenario	Windspeed	% Exceedence
Berthing operation	10 – 12.5 m/s	13.79% – 4.72%
LNG offloading	15 – 17 m/s	0.99% - 0.17%
Disconnect arms	20 m/s	0.01%
Stay at berth	24 – 25 m/s	-

It can be seen that using a liberal windspeed threshold of 12.5 m/s results in a berthing downtime of 4.7%, whereas a more conservative limit of 10 m/s will increase the downtime to a potentially unacceptable 14%. A more detailed investigation of local wind effects should be conducted to deduce the wind climate particular to each site. This process will necessitate a wind sensor at or nearby the conceptual sites and may additionally require a numerical wind model. A specific survey of limiting windspeed levels and practices at existing terminals will also assist the investigation.

Conclusions On Wind Downtime

For the purpose of this study the upper wind limit of 12.5 m/s will be assumed, qualifying the four conceptual LNG sites as "feasible" for terminal design. Indeed, this limit may be perceived to sit at the upper, and therefore less conservative, end of the windspeed bracket. Further study should be initiated to refine the rather broad limiting windspeed range. Moreover, a survey should be conducted at existing LNG terminals to identify the wind limits used in practiced.

At this high level of scoping, there is not enough convincing evidence to eliminate the prospect of a conceptual LNG terminal at each of the four sites (or anywhere else in Saldanha Bay).

Wind induced downtime is considered acceptable at each site.

8.5 Combined Operational Downtime

Percentage annual wave induced downtime and wind induced downtime have been separately discussed in this Chapter. The effect of combined downtime events must not be neglected. Wind and wave exceedance curves are presented in *Section 7.3.4 - Wind* and *Section 7.3.6 – Nearshore Wave Conditions* respectively. These curves show that windspeeds are greatest during the summer and lowest during the winter months, whereas wave heights are greatest during winter and lowest during summer. It is therefore unlikely that extreme wind and wave downtime events will occur simultaneously. An overall (combined) downtime feasibility study should be conducted during future design phases. Such an investigation will not form part of this conceptual planning study.

9 KEY DESIGN PARAMETERS

A number of design factors have been identified as having a critical technical bearing on the ultimate design, layout and performance of the terminal. These Key Design Parameters (KDP's) *are examined in detail in the specific context of Saldanha Bay, and the sensitivity and influence of each parameter at the four conceptual sites is investigated.*

9.1 List of Key Design Parameters

In this Chapter, eleven Key Design Parameters are analysed in total. The KDP's are listed as follows:

1. Swell Wave Penetration
2. Wind Wave Penetration
3. Terminal Type
4. Wind Loading & Tug Selection
5. Navigation
6. Geotechnical
7. Dredging
8. Location of Onshore LNG Facilities
9. Safety
10. Environmental Concerns
11. Constructability

The investigation of these critical design factors should highlight the strengths and weaknesses of each conceptual site location with regard to the KDP's. Once the relative merits at each site are identified, more detailed and effective terminal layout schemes can be developed. This will be the focus of the next Chapter.

9.2 Swell Wave Penetration

9.2.1 Introduction to Swell Wave Penetration in Saldanha Bay

The penetration of swell waves at each site is largely dependent on the direction of the incoming offshore swell. Naturally, the amplitude of nearshore waves is directly proportional to the H_s and T_p values recorded offshore. The derived wave data set at Site 1 – Hoedjiespunt- illustrates this (refer to Table 8-7). This applies to all sites, as shown in *APPENDIX C – SWAN Model - Output Wave Conditions at Conceptual Sites.*

Influence of Wave Period

The variation of significant nearshore wave height in the Bay for various wave periods is illustrated in Appendix C. With fixed input wave parameters H_s=6 m and Direction=210°, the extent of wave penetration is seen to increase slightly as offshore T_p is raised from 12s to 20s.

Influence of Wave Direction

The four sites are offered varying degrees of wave shelter by the geographical layout of the harbour, its headlands and islands. As a consequence each site will be sensitive to wave penetration from specific wave directions. For example, the North Bay site and the Hoedjiespunt site are more vulnerable to wave approach from the south whereas the open water Big Bay site is relatively sheltered for these waves.

The effect of offshore wave direction on the significant wave height within Saldanha Bay is clearly illustrated in Figure 9-1. The boundary conditions in this example are H_s = 6 m, T_p = 16s and Directional Spreading = 23°. This wave height has an exceedance value of 0.57%. It is interesting to note that in spite of the 70° variation in offshore wave direction, the nearshore wave direction at each site inside the Bay remains more or less constant. Only Site 2 – North Bay – experiences moderate directional shift, as the waves at this location are less influenced by depth induced refraction.

Wave shelter

Jutten Island, Malgas Island, Marcus Island and beach breakwater, South Head and Elandspunt provide a tremendous amount of shelter from offshore swell waves. The protective effect of these land masses is illustrated by the coarse grid Delft 3D plot in Figure 9-2.

9.2.2 Site 1: Hoedjiespunt

Significant wave height is greatly diminished by the time wave crests reach Hoedjiespunt. Site 1 (S1) does not appear to be susceptible to extreme wave attack under any offshore wave direction. The effect of wave refraction is pronounced at the entrance to the approach channel, and the range of wave direction at the Waverider buoy is just 9°, from 237° to 246°. At Site 1 the wave approaches from 142° to 143° regardless of offshore direction. The majority of the wave energy is attenuated by Marcus Island and the beach breakwater. Significant wave heights do not exceed 0.5 m.

9.2.3 Site 2: North Bay

The North Bay site is extremely sensitive to offshore wave direction. In the example given, where H_s = 6 m and T_p = 16s, a 280° offshore wave will produce a wave height of 1.0 m at Site 2 (S2), whereas a 210° wave will result in a wave height of 3.0 m (≈300% variation). Wave approach may vary by up to 13° due to an offshore variation of 70°. The site is relatively vulnerable to the prevailing SW wave direction. Greater protection results as the swell direction moves clockwise to WSW and WWSW.

9.2.4 Site 3: Big Bay – Causeway

The causeway site (S3) is similarly offered protection by the breakwater and Marcus Island. Refracted swell waves do not exceed 0.5 m. Wave approach is from SSW, varying between 204° and 209°.

9.2.5 Site 4: Big Bay – Open Water

Due to its location directly landwards of the mouth of Saldanha Bay, Site 4 remains exposed under all offshore wave directions. By the time offshore waves reach the mouth between Marcus Island and Elandspunt, wave rays have assumed an average direction of approximately 241°. Very little additional dissipation of energy occurs before striking Site 4 (S4). In the detailed design stage, downtime may be reduced by shifting the site slightly N or NW. However the swing radius or berthing room of the LNGC may interfere with the existing entrance channel and turning channel if this solution is implemented. Furthermore, site 4 appears to sit on a very clear boundary dividing areas of low wave height and moderate/high wave height. The cause of this H_s "jump" is likely to be due to the refractive influence of the sides of the dredged approach channel, located SW of Marcus Island, and the very steep, shallow bathymetry between the leeward side of Marcus Island and the dredged channel.

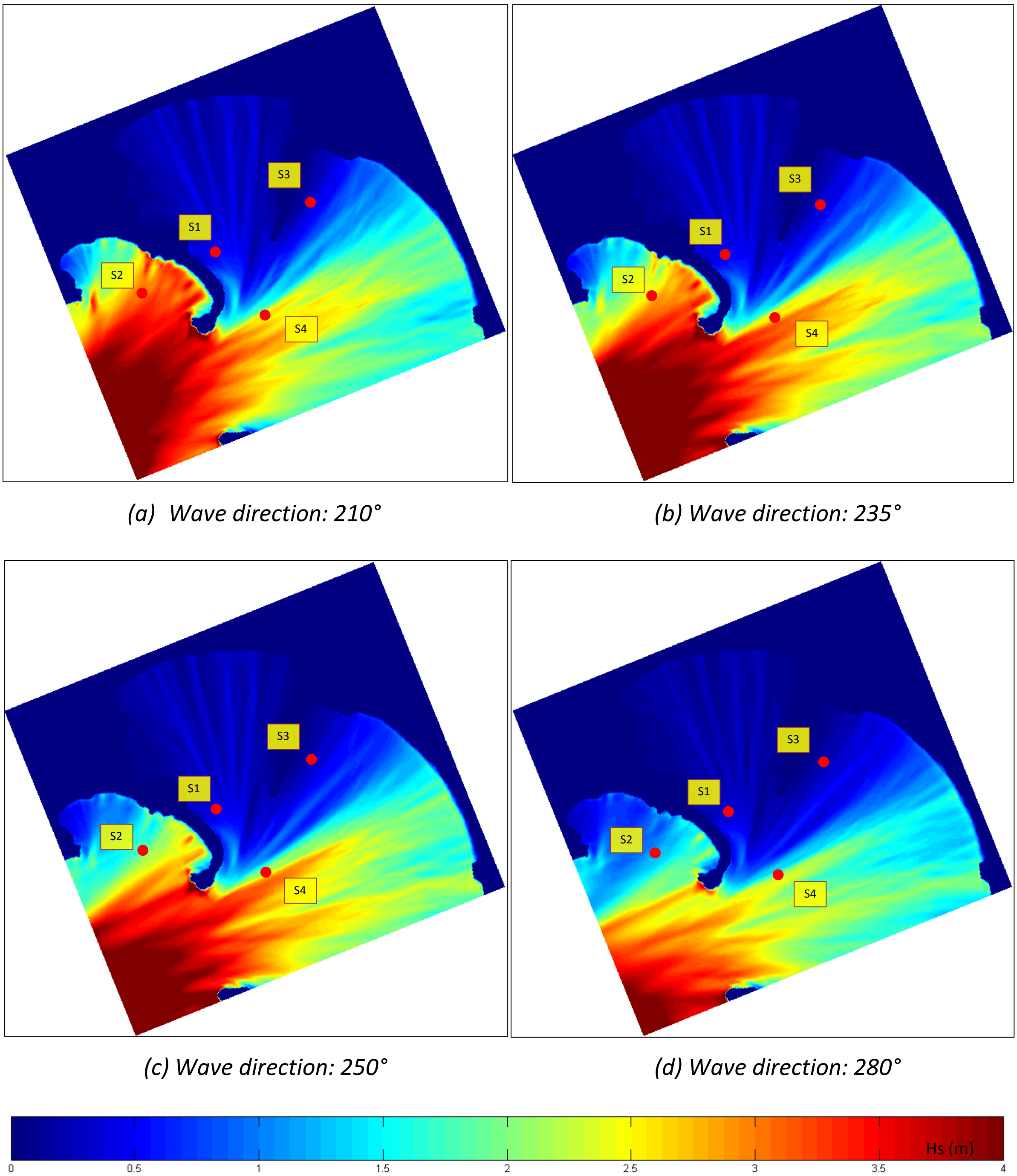


Figure 9-1 Plots of H_s variation due to change in offshore wave direction

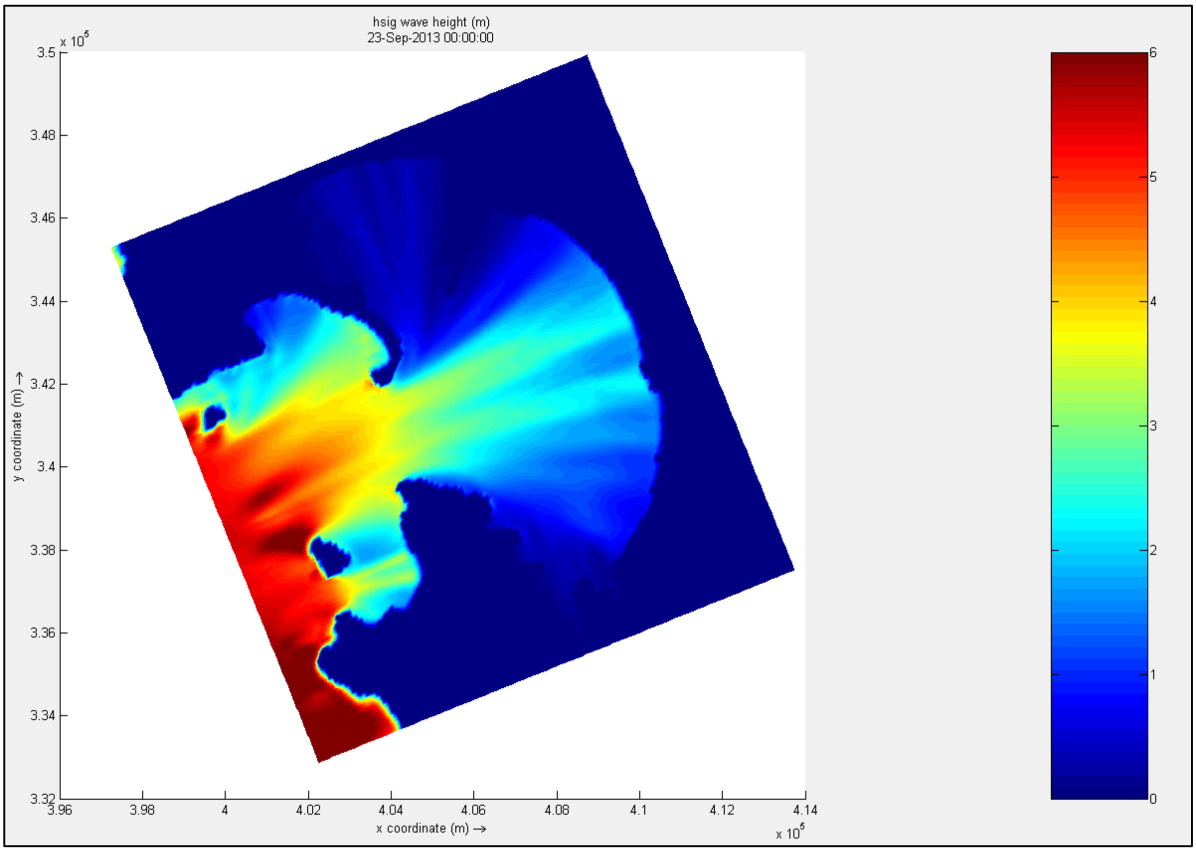


Figure 9-2 Effect of wave shelter provided by land masses

9.3 Wind Wave Penetration

9.3.1 Introduction to Wind Waves in Saldanha Bay

Fetch Limited Wind Wave Height

Locally generated wind waves must be considered as an influential design parameter in addition to the transformed offshore waves previously discussed. Saldanha Bay is subject to a strong wind climate, and the large fetch between Langebaan and the port area may contribute to sizable wind waves.

The prevailing southerly wind is expected to be the most influential in wind wave generation as *a)* higher windspeeds prevail from this direction and *b)* winds blow for longer periods from this direction, enabling full development of fetch-limited seas. Under fetch limited conditions, winds have blown constantly long enough for wave heights at the end of the fetch to reach equilibrium. In Saldanha this time is calculated to be between 1hr – 1.5hr (maximum)[xxix]. Since the 1hr averaged windspeeds have been used to describe local windspeeds, fetch limited wave heights will be considered as opposed to duration limited waves.

[xxix] Refer to example in Appendix D.

The fetch limited (significant) wind wave height is given by Equation (9.1), reproduced from the Shore Protection Manual; Table 3.2, pg 3-48 (CERC, 1984).

$$H_s = 5.112 \times 10^{-4}. U_A. \sqrt{F} \tag{9.1}$$

where H_s is the fetch limited significant wind wave height [m], F is the fetch length [m] and U_A is the wind stress factor [m/s].

The wind stress factor, U_A, accounts for the nonlinear relationship between wind stress and windspeed, and is stated as Equation (9.2) below, reproduced from the Shore Protection Manual; Eqn 3-28a, pg 3-30 (CERC, 1984).

$$U_A = 0.71U^{1.23} \tag{9.2}$$

Where U_A is the wind stress [m/s] and U is the Saldanha Bay U_{10} windspeed [m/s] derived in Section *7.3.4.*

Derivation of Wind Wave Height at Study Sites

The local wind data tabulated in *Section 7.3.4 Wind* is used as a baseline for the derivation of wind wave height values at the individual study sites. The baseline windspeed is assumed to be constant across the Bay. The fetch, *F*, is site specific and influences H_s. Derived values of H_s at each site are tabulated as seasonal and total wave height exceedance percentages in Table 9-1 to Table 9-4.

Fetch values are calculated as the distance from each study site to the nearest land mass due south of that site. In the case of Hoedjiespunt, where the distance to the breakwater is negligible, a SSE fetch is considered, resulting in larger relative wave heights. Fetch distances are illustrated in Figure 9-3.

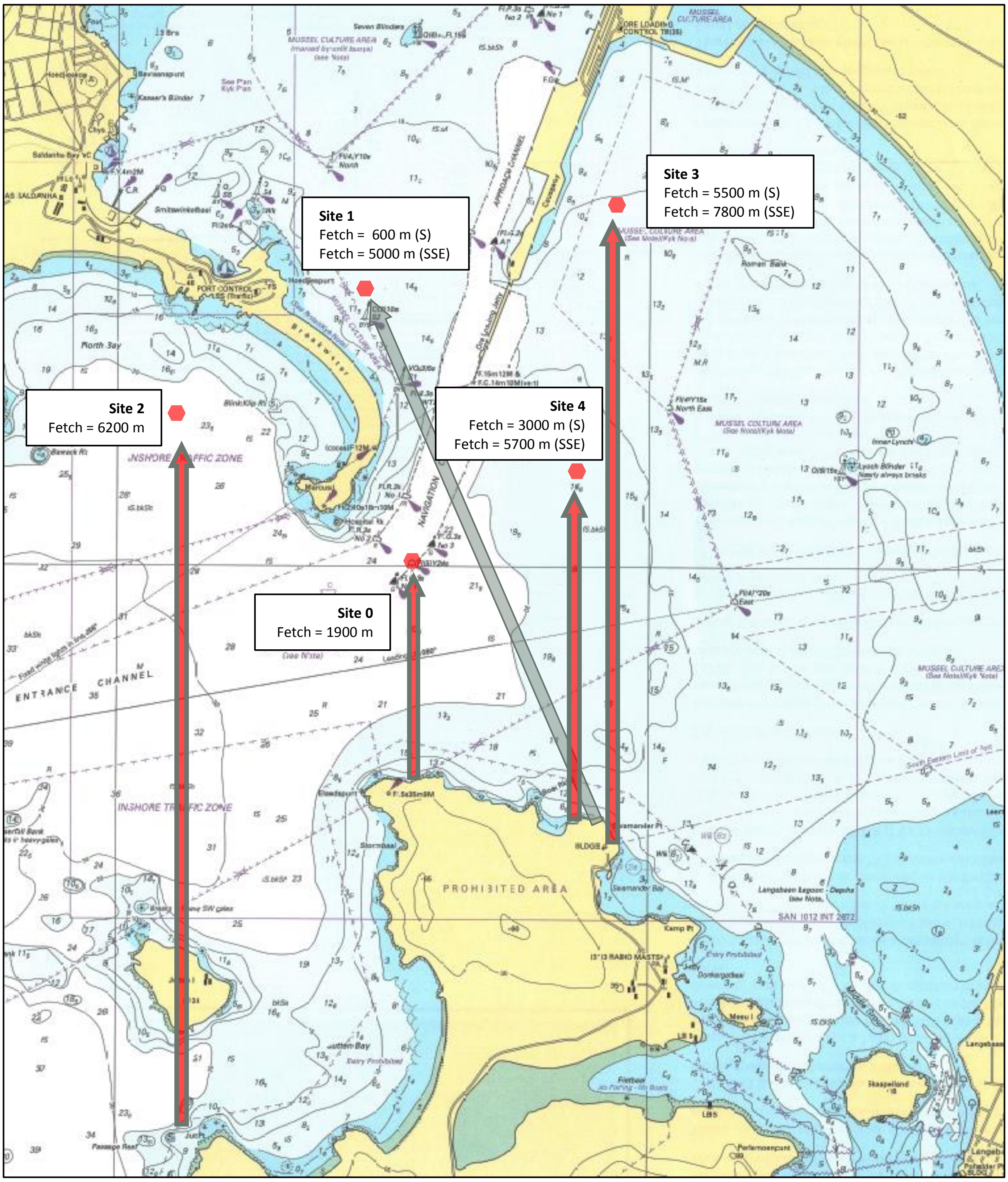


Figure 9-3 Fetch distances to each conceptual site location (for strongest winds) (SANHO, 2000)

Derived wind wave heights can be confirmed using the nomograph provided in Appendix D (CERC, 1984). The nomograph of wind generated wave height prediction curves can additionally be used to estimate wave period and minimum wind duration to fully develop the wave height.

It is unlikely that wind waves of such short period (2s to 3.5s) will have any influence on the manoeuvrability of an LNGC or its motions while moored. The wind waves may have a considerable effect on tug operations however, particularly when combined with swell conditions from the southwest or south-southwest. Delayed tug operations may contribute to total berth downtime.

9.3.2 Site 1: Hoedjiespunt

The Hoedjiespunt site is protected from wind waves caused by prevailing southerly winds by the beach breakwater. The 600 m southerly fetch to the breakwater will only develop a wave height of 0.25 m, exceeded 1% of the time. Consequently, the SSW fetch of 5000 m to Salamanderpunt is used as a conservative value. Wind waves with a more easterly component will be impeded by the caisson berth at the iron-ore terminal. Therefore only wind waves approaching from SE to SSE are considered to be problematic. Wind originates from these directions just 14% of the time. The wave height exceedance values stated in Table 9-1 should only be applied when the wind approaches from this narrow directional window.

Table 9-1 Wind wave height exceedance values at Site 1 - Hoedjiespunt

Wind wave H_s [m] for Site 1: Fetch=5000 m & d= 20 m					
Exceedance	**1 %**	**5 %**	**10 %**	**25 %**	**50 %**
All Data	0.7	0.6	0.5	0.4	0.2
Summer	0.8	0.6	0.6	0.4	0.3
Autumn	0.7	0.5	0.5	0.3	0.2
Winter	0.7	0.5	0.4	0.3	0.2
Spring	0.7	0.6	0.5	0.4	0.3

9.3.3 Site 2: North Bay

The North Bay site is exposed to a 6.2 km fetch from the south, resulting in the large wind wave heights given in Table 9-2. The site is relatively well protected from other wind wave directions. North Head prevents wave attack from waves coming from north of WSW and Marcus Island prevents wind waves originating north of 120°. SW waves will be categorised as swell and have been discussed. Therefore values stated below apply to southerly wind wave only, and those approaching from other directions will be lower in magnitude and less frequent.

Table 9-2 Wind wave height exceedance values at Site 2 - North Bay

Wind wave H_s [m] for Site 2: Fetch=6200 m & d= 32 m					
Exceedance	**1 %**	**5 %**	**10 %**	**25 %**	**50 %**
All Data	0.8	0.7	0.6	0.4	0.2
Summer	0.9	0.7	0.6	0.5	0.3
Autumn	0.8	0.6	0.5	0.3	0.2
Winter	0.8	0.6	0.5	0.3	0.2
Spring	0.8	0.7	0.6	0.4	0.3

9.3.4 Site 3: Big Bay – Causeway

Site 3 is exposed to minor swell from the SW, and wind waves from the foreshore due east of the causeway through to Elandspunt to the SSW. The prevailing wind initiates a fetch from Salamanderpunt, 5500 m south. H_s exceedance values for this fetch distance are stated in Table 9-3. A substantial 8 km fetch separates the conceptual site from Skaapeiland at the mouth of Langebaan

Lagoon. Should the wind blow from this direction the H_s stipulated in Table 9-3 will be increased by a factor of 1.19.

Table 9-3 Wind wave height exceedance values at Site 3 - Big Bay: Causeway

Wind wave H_s [m] for Site 3: Fetch=5500 m & d= 13 m					
Exceedance	**1 %**	**5 %**	**10 %**	**25 %**	**50 %**
All Data	0.8	0.6	0.5	0.4	0.2
Summer	0.8	0.7	0.6	0.4	0.3
Autumn	0.7	0.6	0.5	0.3	0.2
Winter	0.7	0.5	0.5	0.3	0.2
Spring	0.8	0.6	0.5	0.4	0.3

9.3.5 Site 4: Big Bay – Open Water

Site 4 is more exposed to the south-westerly swell element than any other site. The influence of swell will predominate. The site is open to wind waves from the shallow water beach in the NE through to Elandspunt in the SSW. The shallows will effectively reduce the influence of wind wave height if the wind originates from the NE or E foreshore. A radial fetch arcing from NE to SSW can be approximated as 3000 m. Wave heights corresponding to this fetch are tabulated in Table 9-4. In the event of a SSE wind blowing from Skaapeiland (10% frequency of occurrence), a 5700 m fetch will develop, and the increased H_s values given in Table 9-3 can be used instead.

Table 9-4 Wind wave height exceedance values at Site 4 - Big Bay: Open Water

Wind wave H_s [m] for Site 4: Fetch=3000 m & d= 14 m					
Exceedance	**1 %**	**5 %**	**10 %**	**25 %**	**50 %**
All Data	0.6	0.5	0.4	0.3	0.2
Summer	0.6	0.5	0.4	0.3	0.2
Autumn	0.6	0.4	0.4	0.2	0.2
Winter	0.5	0.4	0.3	0.2	0.1
Spring	0.6	0.5	0.4	0.3	0.2

9.3.6 Conclusion

The influence of wind waves alone[xxx] should not raise concerns for port downtime. The greatest annual wind wave height (all data), exceeded 1 % of the time, is just H_s = 0.8 m at the most exposed site (Site 2: North Bay). It has been stated in *Section 8.3.2 - Operational Wave Limits* that port operations may be affected at wave heights greater than H_s = 1.0 m.

[xxx] The effect of wind wave related downtime *combined* with swell wave downtime and wind induced downtime should be specifically studied at a later stage during pre-feasibility analysis of conceptual layouts. As noted in *Chapter 8*, combined probability analysis of downtime will not form part of this thesis study.

9.4 Terminal Type

9.4.1 Introduction to Terminal Types in Saldanha Bay

The choice of terminal type will have a significant influence on many subsequent key design parameters. It will be shown that each site can host at least two terminal styles, resulting in an array of terminal layout possibilities. In most civil projects the ultimate deciding factor will be cost, and an ill-conceived terminal choice at this stage may lead to over-expenditure in marine works, dredging, land acquisition, environmental mitigation etc. The most plausible terminal styles are described below at each site. The synergy between terminal type and co-dependent key design parameters is considered in the following Chapter – *Proposed Terminal Layout Schemes.*

9.4.2 Site 1: Hoedjiespunt

9.4.2.1 Trestle Jetty

A trestle jetty is the obvious terminal choice at Hoedjiespunt. The distance from the site to the shore is minimal, and jetty construction costs are therefore reduced. Furthermore the limited sheltered area south of Small Bay prohibits the use of an SPM, which demands a large swing radius and approach circle. A GBS cannot compete with the construction costs of a trestle jetty.

Undeveloped land at this side of the Bay is extremely limited. Reclamation of land may have to be considered if a standard LNG jetty terminal is selected. The use of an FSRU alongside the jetty may address the issue of land availability.

9.4.2.2 Trestle Jetty with FSRU alongside

The use of a quasi-permanently moored FSRU at the trestle jetty will greatly minimise the terminal's demand for land. The practice of floating regasification enables the natural gas product to be piped ashore to the consumer. At this location however the import terminal is likely to be several kilometres away from the potential CCGT plant. This factor will be addressed in a subsequent Section. Figure 9-4 illustrates a potential FSRU layout at Hoedjiespunt. A 177,000 m^3 design vessel is berthed alongside the FSRU.

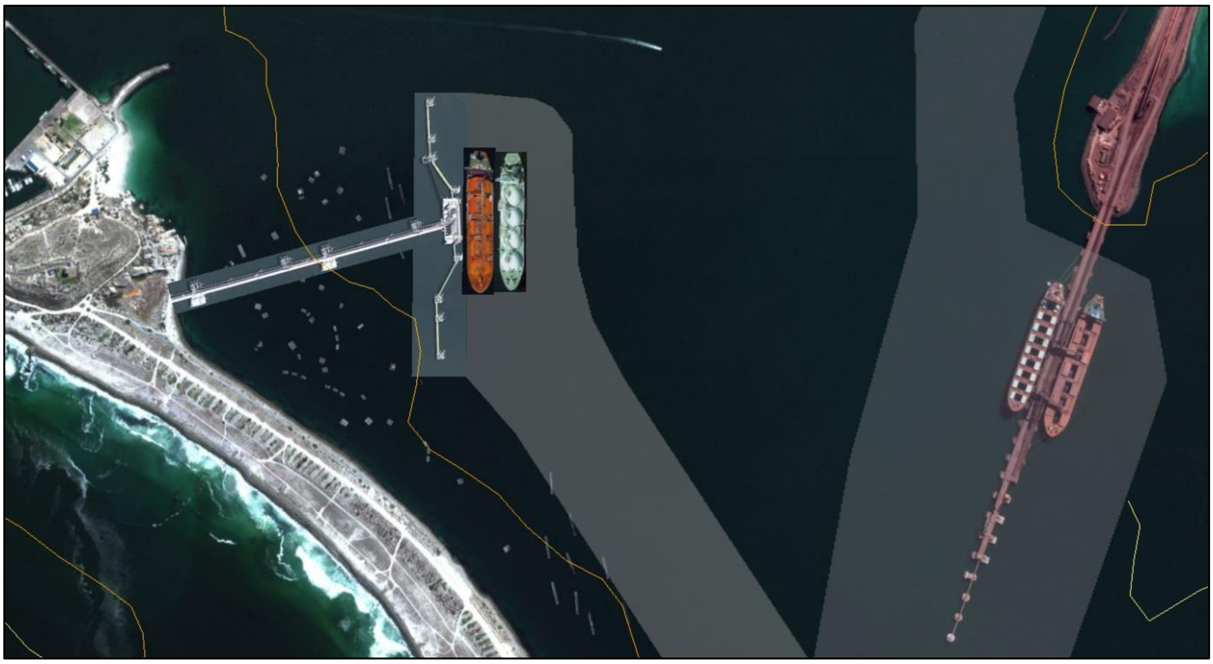


Figure 9-4 Conceptual FRSU terminal alongside a trestle jetty at Hoedjiespunt

9.4.3 Site 2: North Bay

9.4.3.1 SPM – Tower type

The natural depth at North Bay makes it ideal for single point (tower) use. In northerly winds the LNGC may be able to sail directly to the single point terminal and connect with the assistance of one tugboat. In southerly winds however one or two (maximum) additional tugs may be required to assist with navigation, as the vessel will not be able to approach from downwind (i.e. from north). Similar to the Hoedjiespunt layout, there may be transmission difficulties regarding the natural gas pipeline network on the shore. An SPM type terminal in North Bay represented by Figure 9-5.

9.4.3.2 GBS

Water depth and shore steepness in North Bay may prevent the use of a GBS structure. More significantly, a GBS terminal will require a full complement of tugboats for berthing operations, which is not the case for the SPM terminal. The wave climate in North Bay is quite severe, and wave heights occasionally exceed the limiting wave condition for tug effectiveness (4% to 19% of the time depending on tug type; refer to Table 8-10). Additionally, the GBS may not be overly successful at blocking wave attack from the prevailing direction due to the variation in direction noticed at the site. The steep shoreline may induce a local reflected wave which would approach the vessel from the “sheltered” Northerly side.

Figure 9-5 Conceptual Tower/SPM type terminal in North Bay

9.4.4 Site 3: Big Bay – Causeway

9.4.4.1 Trestle Jetty

A standard trestle jetty, either with or without a floating regasification option, is most suitable adjacent the Port of Saldanha causeway. The limited depth makes the site ideal for trestle jetty construction, but also implies substantial dredging. Development land is available onshore, just east of the iron ore stockpile. LNG will ideally be pumped ashore to be processed at the land based storage and regasification facility. A typical LNG terminal super-imposed at the site is portrayed in Figure 9-6.

9.4.4.2 Trestle Jetty with FSRU alongside

The choice between standard trestle jetty and a FSRU terminal at a trestle jetty may ultimately be a financial decision. Regarding the wet infrastructure there are very few technical differences between the two terminal types. Dredge zones, approach direction and jetty piling are similar. The wave climate is quite mild and there should be no survivability concerns for a perennially moored FSRU. The key design contrasts lie ashore, at the storage and regasification facility.

Figure 9-6 Conceptual trestle jetty at the Big Bay: Causeway site

9.4.5 Site 4: Big Bay – Open Water

9.4.5.1 SPM – Tower type

Both SPM and GBS options appear credible at the Big Bay site. If the wind blows from the north or northeast the vessel may be able to approach an SPM tower without much assistance. To attach to the tower during a prevailing southerly, the LNGC will require significant tug assistance, as there is very little remaining under-keel clearance just north of the SPM. Indeed, regular maintenance dredging may be required at Site 4 to assure the berth depth of -16.9 m. This issue can be mitigated of course by relocating the terminal further seaward into deeper water. The local significant wave height will consequently increase accordingly.

9.4.5.2 GBS

Water depth at Site 4 is adequate for GBS operation, and the seabed is relatively flat to provide a stable foundation. A conceptual layout is sketched in Figure 9-7. The LNGC will enter the port via the approach channel as any other bulk carrier would, and will be re-oriented in the turning circle by the tugs. Tugs will deliver the vessel to the GBS berth using the segregated GBS channel. This channel will be maintenance dredged, if necessary, to -16.9 m. The GBS is aligned parallel to approaching wave crests, as can be seen in the image. This orientation encourages a quartering wind on the vessel's port side, which is not ideal as it will push the LNGC off the fenders and place the stern mooring lines under immense strain. A similar yet more pronounced effect would occur at a GBS in North Bay.

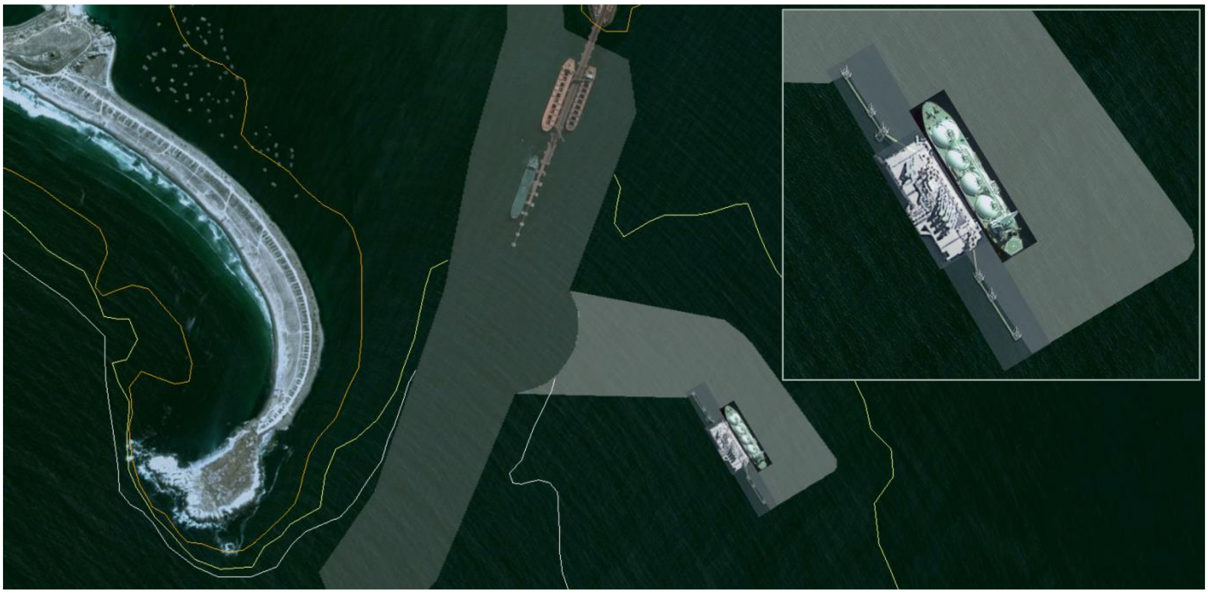


Figure 9-7 Conceptual GBS terminal at the Big Bay: Open Water site

9.5 Wind Loading & Tug Selection

9.5.1 Introduction to Wind Effects in Saldanha Bay

The operational wind limits recommended for use in Saldanha have been examined and specified in *Section 8.4 - Wind Induced Downtime.* These limits are useful in determining statistical occurrences of wind events, or for defining port regulations, based on the observations and experience of other LNG terminal operators. It is important however to understand the specific wind loading on LNGC vessels in Saldanha, taking the local climate and design vessel into account. This focused investigation will determine the local effects of wind on vessel manoeuvrability, and will assist in the selection of a suitable tug fleet.

9.5.2 Wind Drag Force

The wind drag force on LNGC vessels can be described by Equation (9.3), which is reproduced from the Mooring Equipment Guidelines (OCIMF, 2008) as

$$F_w = {}^{1}/_{2}\, C_w \rho_a V^2 A \tag{9.3}$$

where F_w is the total wind drag force on the vessel [kN], C_w is the wind drag force coefficient, ρ_a is the density of air [kg/m^3], V is the wind velocity [m/s] and A is the area exposed to the wind [m^2].

The wind drag force can be split into two components, namely the longitudinal wind force F_{xw} and the lateral wind force F_{yw}. The lateral wind forces, acting on the beam of the ship, tend to be greater in magnitude than longitudinal forces due to the increased affected cross-section. The sign convention used in this Section is shown in Figure 9-8, where a longitudinal wind blowing from stern to bow is at 0° and a lateral beam wind blowing from starboard to port is at 90°. Thus a positive longitudinal force (F_{xw}) acts from stern to bow, and a positive lateral force (F_{yw}) acts from starboard to port.

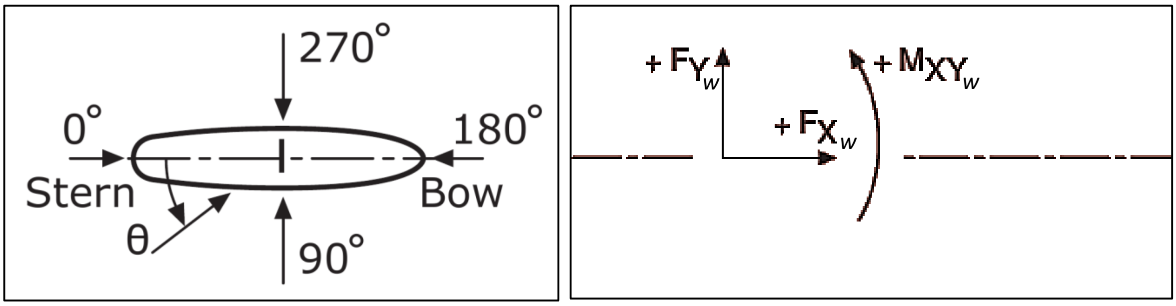


Figure 9-8 Standard co-ordinate system used in tanker wind force equations (OCIMF, 2008)

The longitudinal and lateral force components are $F_{xw} = {}^1/_2\, C_{xw} \rho_a V^2 A_T$ and $F_{yw} = {}^1/_2\, C_{yw} \rho_a V^2 A_L$ respectively.

9.5.3 Projected Wind Area, *A*

The Mooring Equipment Guidelines stipulate vessel characteristics for LNGC's between 75,000 m^3 and 125,000 m^3, as this was the range of model vessels used to determine empirical values for C_w. Thoresen (2010) provides data that has been updated to accommodate the largest Q-Max vessels. Values used to determine the wind forces on the design vessel in Saldanha Bay are stated in Table 9-5.

Table 9-5 Projected wind areas of design vessels in Saldanha Bay (Thoresen, 2010)

Vessel Size	LNG Capacity [m^3]	Fully Loaded Projected Area: Lateral [m^2]	Fully Loaded Projected Area: Longitudinal [m^2]	Ballast Loaded Projected Area: Lateral [m^2]	Ballast Loaded Projected Area: Longitudinal [m^2]
Minimum	75,500	5100	1150	5800	1300
Standard	145,000	7600	1950	8400	2100
Design	177,000	8900	2300	10200	2500

9.5.4 Wind Drag Force Coefficient, C_w

The longitudinal and lateral wind drag force coefficients are presented graphically in Figure 9-9 and Figure 9-10 for both Moss (spherical) and membrane/prismatic type carriers. The graphs account for the relative angle of wind action on the vessel. C_{Xw} and C_{Yw} derived from these graphs are presented in Table 9-6. In each scenario the more conservative value (typically attributed to spherical tanks) was used.

Table 9-6 Wind drag force coefficients for LNGC vessels

Wind Direction	0°	15°	30°	45°	60°	75°	90°	105°	120°	135°	150°	165°	180°
C_{xw}	1	1.1	0.96	0.8	0.55	0.18	0.03	-0.08	-0.28	-0.55	-0.8	-0.095	-1.02
C_{yw}	0	-0.22	-0.5	-0.75	-0.95	-1.08	-1.17	-1.15	-1.08	-0.83	-0.46	-0.2	0

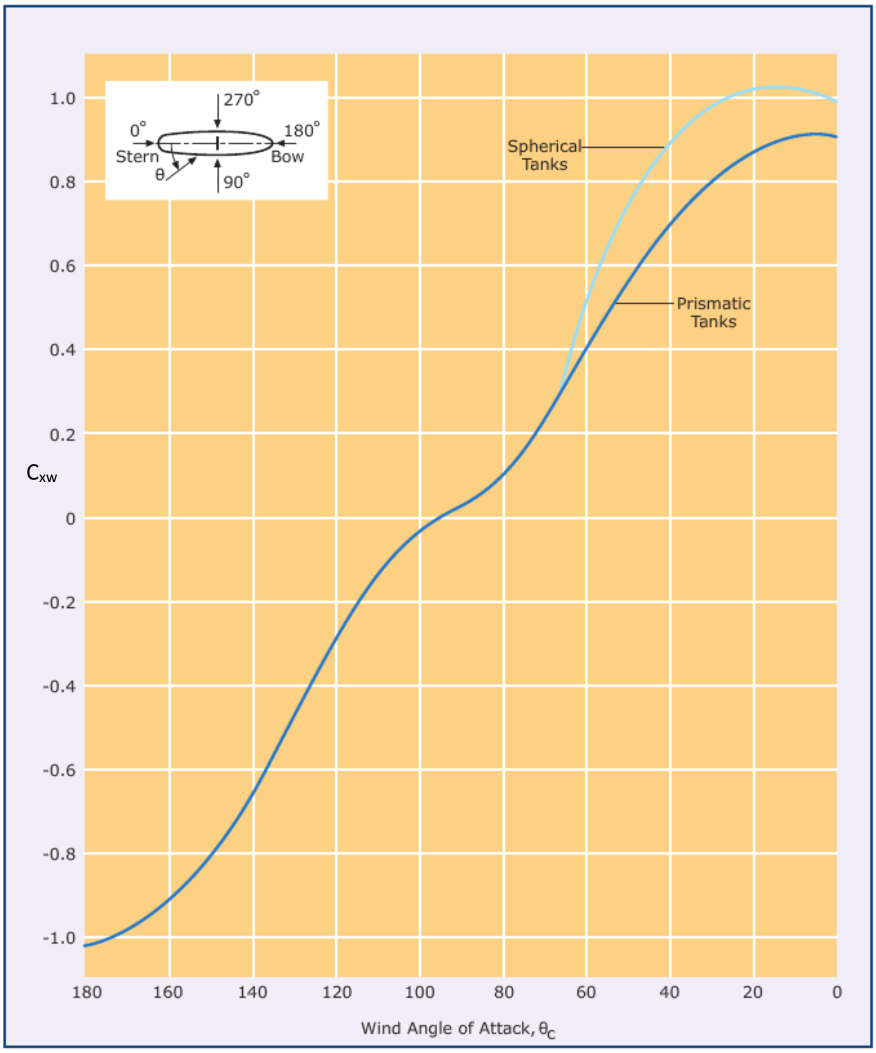


Figure 9-9 Longitudinal wind drag force coefficient C_{Xw} (OCIMF, 2008)

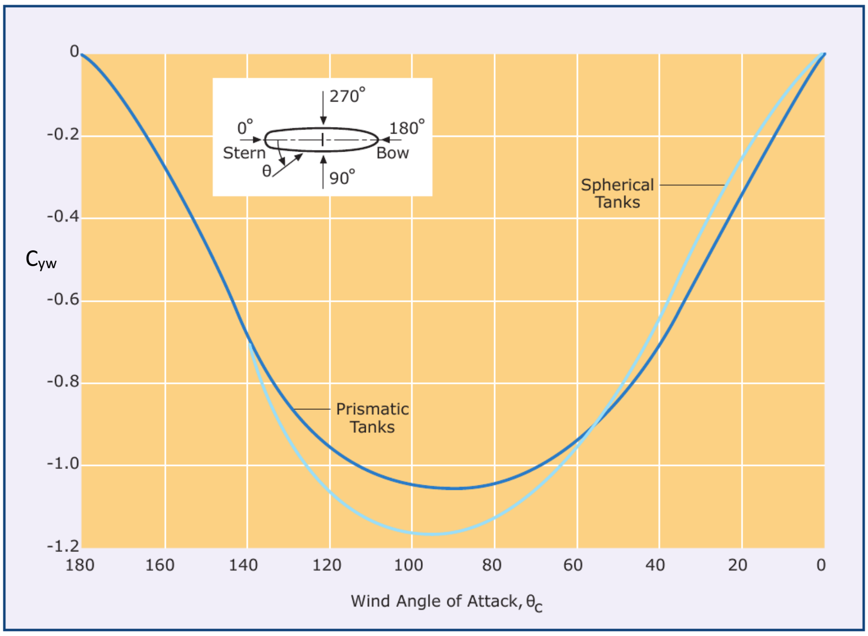


Figure 9-10 Lateral wind drag force coefficient C_{Yw} (OCIMF, 2008)

9.5.5 Calculation of Wind Forces

The longitudinal and lateral wind forces on the design vessel (177,000 m^3) as calculated are presented in Table 9-7. All wind forces are stated in kN. The wind velocity V used in Equation (9.3) is the 10-metre windspeed, converted to a 30s average windspeed, U_{30}, to account for gusts (Thoresen, 2010). It is critical that the correct windspeed factor is applied (refer to Equation (7.1)), as the wind forces will be vastly underestimated if a longer time-averaged windspeed is used[xxxi]. The air density is assumed to be 1.28 kg/m^3. In all cases the more sensitive "ballast" loading condition was used.

Absolute values of F_{Yw} are shown, while negative F_{Xw} values denote winds from the bow.

Table 9-7 Wind forces [kN] on design vessel under varying wind speed and direction

Wind	Windspeed	Direction of Wind												
Load	U_{30} [m/s]	0°	15°	30°	45°	60°	75°	90°	105°	120°	135°	150°	165°	180°
Fxw	8	102	113	98	82	56	18	3	-8	-29	-56	-82	-10	-104
Fyw	8	0	92	209	313	397	451	489	480	451	347	192	84	0
Fxw	10	160	176	154	128	88	29	5	-13	-45	-88	-128	-15	-163
Fyw	10	0	144	326	490	620	705	764	751	705	542	300	131	0
Fxw	12	230	253	221	184	127	41	7	-18	-65	-127	-184	-22	-235
Fyw	12	0	207	470	705	893	1015	1100	1081	1015	780	432	188	0
Fxw	14	314	345	301	251	172	56	9	-25	-88	-172	-251	-30	-320
Fyw	14	0	281	640	960	1216	1382	1497	1471	1382	1062	589	256	0
Fxw	16	410	451	393	328	225	74	12	-33	-115	-225	-328	-39	-418
Fyw	16	0	368	836	1253	1588	1805	1955	1922	1805	1387	769	334	0
Fxw	18	518	570	498	415	285	93	16	-41	-145	-285	-415	-49	-529
Fyw	18	0	465	1058	1586	2009	2284	2475	2432	2284	1756	973	423	0
Fxw	20	640	704	614	512	352	115	19	-51	-179	-352	-512	-61	-653
Fyw	20	0	574	1306	1958	2481	2820	3055	3003	2820	2167	1201	522	0
Fxw	22	774	852	743	620	426	139	23	-62	-217	-426	-620	-74	-790
Fyw	22	0	695	1580	2370	3002	3412	3697	3633	3412	2622	1453	632	0
Fxw	24	922	1014	885	737	507	166	28	-74	-258	-507	-737	-88	-940
Fyw	24	0	827	1880	2820	3572	4061	4399	4324	4061	3121	1730	752	0

9.5.6 Wind Loading During Berthing Operations

The operational wind limits were set at 10 m/s to 12.5 m/s in Section 8. If a maximum operational limit of 12.5 m/s is assumed, the corresponding maximum wind force on the design vessel is 1193 kN, which occurs when the wind strikes the vessel at 90°. This is the theoretical force required by the tugs to hold the LNGC against a beam wind of 12.5 m/s.

9.5.7 Tug Requirements

In the evaluation of total tug requirements, it should be assumed that 1) the design LNGC vessel's main engine and bow thrusters are out of action and 2) the force required to *move* the vessel against wind and current is approximately 30% greater than the force required to *hold* the vessel against wind and current (Thoresen, 2010).

The total bollard pull required for berthing operations is simplified to:

$$B_p = S_f \times F_w \times F_g \qquad (9.4)$$

where Bp is the bollard pull [kN], Sf is the safety factor to account for uneven bollard pull when using several tugs, F_w is the wind force and F_g is the gust factor.

[xxxi] If raw data is available as 1-hourly averaged samples, the wind velocity must be multiplied by a factor of 1.35 to achieve the correct 30 s windspeed.

Thoresen recommends $S_f \geq 1.2$ to 1.5 & $F_g = 1.2$. The recommended bollard pull in Saldanha for a 12.5 m/s wind is:

$B_p = (1.3) \times (1193) \times (1.2) = 1861$ kN.

Thoresen (2010) recommends an additional operational safety factor to be applied to determine the Tugboat Capacity, where $T_c = B_p \times 1.2$ to 1.5. This factor accounts for the fact that some of the available bollard pull will be used for manoeuvring, and to prevent the tugs from operating at 100% capacity. Tug capacity T_c = 2419kN where an operational safety factor of 1.3 is used.

The tug fleet should therefore be able to deliver a tug force of 2419 kN during berthing operations, when the limit is a windspeed of 12.5 m/s. This combined pulling capacity equates to approximately 250T. Tug capacity could be provided by 4 x 65T tugboats. The present TNPA fleet in Saldanha consists of 3 x 42T tugs, assisted by 1 x 42T tug from Cape Town when necessary. This fleet may be adequate for deep-draught and low-freeboard iron ore bulkers and oil tankers, but it is unsuitable for use with modern LNG carriers in high winds.

The acquisition of 4 x 65T tugboats is therefore recommended for the LNG terminal.

The use of an SPM type terminal should reduce the demand to 1 - 2 tugs in favourable wind conditions.

9.5.8 Site Specific Tug Demands

The conceptual site layouts, first detailed in Section 7.10, were planned such that during approach to the terminal, the wave and wind forces would be focused on the stern of the laden LNGC where possible. During berthing and while moored, the LNGC would face into the prevailing wind direction. Sites 1 and 3 have rigidly followed these design recommendations. Approach to the offshore terminals (Sites 2 and 4) will be governed by the wind direction at the time of berthing, and LNGC's are may regularly encounter beam winds when manoeuvring.

Berthing procedures at each terminal will be discussed in the Navigation section, and the role of the tug fleet is discussed in greater detail.

9.6 Navigation

9.6.1 Introduction to Vessel Navigation in Saldanha Bay

The ease with which an incoming LNG vessel can navigate towards the new import terminal will be of concern to the Port Authority and LNG vessel operators alike. Time spent during tug connection, escort and assistance contributes significantly to the turnaround time of each LNGC. The extent of tug interaction with the vessel should be minimised where possible, and this is achieved by sensible design of the wet areas of the harbour. The terminal will ideally be located in an area of sufficient water depth in order to minimise or negate dredging. If dredging is deemed necessary, as it is in most sheltered ports, the dredged channels should be of a simple, linear design, with no sharp bends or other intricacies.

Dredged zones should be wide and deep enough to accommodate the loaded design vessel under heavy wind and wave conditions. Channel dimensions have been calculated in *Section 7.8 - Marine*

Design Aspects. The ideal channel width is 250 m, depth is 16.9 m and turning circle diameter is 660 m.

The effects of a new port terminal, approach channel and associated nautical activity are of particular interest to the Port Authority, TNPA. TNPA must ensure that existing port operations remain unaffected by the introduction of an LNG terminal. These considerations must be made in the planning stages of the terminal. Navigation will therefore be designated a key design parameter in this conceptual study.

9.6.2 Site 1: Hoedjiespunt

The LNGC vessel will connect with the tugs 1Nm SW of Marcus Island and will be escorted into the lee of the island before the tugs assist. The vessel will be rotated approximately 115° clockwise in the turning circle so that it faces southeast. Tugs will reverse the vessel parallel to the breakwater until alongside the Hoedjiespunt trestle jetty, against which it is moored. The procedure is relatively straightforward, and a similar approach is used during existing operations at the port. The vessel faces bow-on to the waves as it is reversed along the approach channel, and faces bow into wind once berthed, assuming a prevailing southerly wind.

LNG operations will not interfere significantly with existing port activities. When the vessel is manoeuvring within the port, all other manoeuvring activities such as anchoring, berthing and disembarking, must be suspended. Port operations may continue as normal once the LNGC is safely berthed. Furthermore the main approach channel has been designed for one-way traffic, so any attempts to co-inhabit the channel would be very risky. The 500 m “dynamic exclusion zone” will be in effect from the moment the pilot boards the vessel.

It is the duty of the Port Authority to enforce an exclusion zone around the natural gas pipeline, should the final terminal design call for a subsea pipeline. The exclusion distance shown in Figure 9-11 is 250 m either side of the pipeline, though this distance may be refined following a detailed design study. Additional protective measures may include burial in a trench, rock placement, grout mattresses or steel reinforcing, which may be implemented following a focused risk analysis of anchor damage (HSE, 2009).

In the case of an emergency departure from the terminal, the vessel will need assistance to be pulled off the fenders. From this position the vessel will be able to navigate along the LNG approach channel into the turning circle, and from here it will be able to negotiate its passage into open water without tug assistance. Water depth south and southwest of the turning circle is deeper than -20 m.

Figure 9-11 Navigational zones nearby Site 1 – Hoedjiespunt

9.6.3 Site 2: North Bay

The location of the North Bay terminal is such that a) it will require no dredging for the design vessel and b) an LNGC can approach from 2 boatlengths downwind of the SPM or GBS without risk of grounding, irrespective of wind direction. The blue circle around the vessel in Figure 9-12 indicates the safe approach radius while the shaded yellow area represents the ideal approach area that leads from the Saldanha Bay entrance channel.

When the wind blows from the northern quadrant, the vessel should be able to approach an SPM terminal unassisted, and use its dynamic positioning system to hold in position while a tug attaches the mooring hawser. In heavy conditions perhaps one or two tugs (maximum) will be needed to assist with positioning. If a GBS terminal is selected, the full tug fleet will be required to assist with berthing.

Figure 9-12 Navigational zones nearby Site 2 - North Bay

As the offshore terminal at North Bay is entirely exclusive of Saldanha Bay, LNGC manoeuvres will not interfere with other port operations. An exclusion zone will be enforced around any subsea pipelines however, restricting anchoring areas inside Small Bay. No other vessels are expected to anchor in North Bay, considering its rough climate, and the protection of any subsea pipelines there need not be as extreme as within Small Bay.

9.6.4 Site 3: Big Bay – Causeway

The approach and berthing procedure at the Causeway site is very similar to that practiced at the Hoedjiespunt site, and is identical to the current procedure at the iron ore terminal. Once the tugs have connected and assisted the LNGC to the turning circle, the vessel is rotated approximately 170° anti-clockwise and reversed into the LNG berth. The bow of the vessel will face into the wave crests during manoeuvre, which can be seen in Figure 9-13. Once berthed the vessel faces SSW, which is a compromise between prevailing wind and wave directions at the site. Emergency departure from the jetty is straightforward, as the vessel can manoeuvre directly along the LNG approach channel and into deepwater in a relatively straight line, while keeping the bow into waves.

An alternative layout is to dredge a dedicated turning circle at the end of the LNG approach channel, adjacent to the trestle jetty. This will allow the vessel to move in a forwards direction for the entire length of the assisted approach. This practice may be more efficient than reversing the vessel along the 2.2 km LNG approach channel.

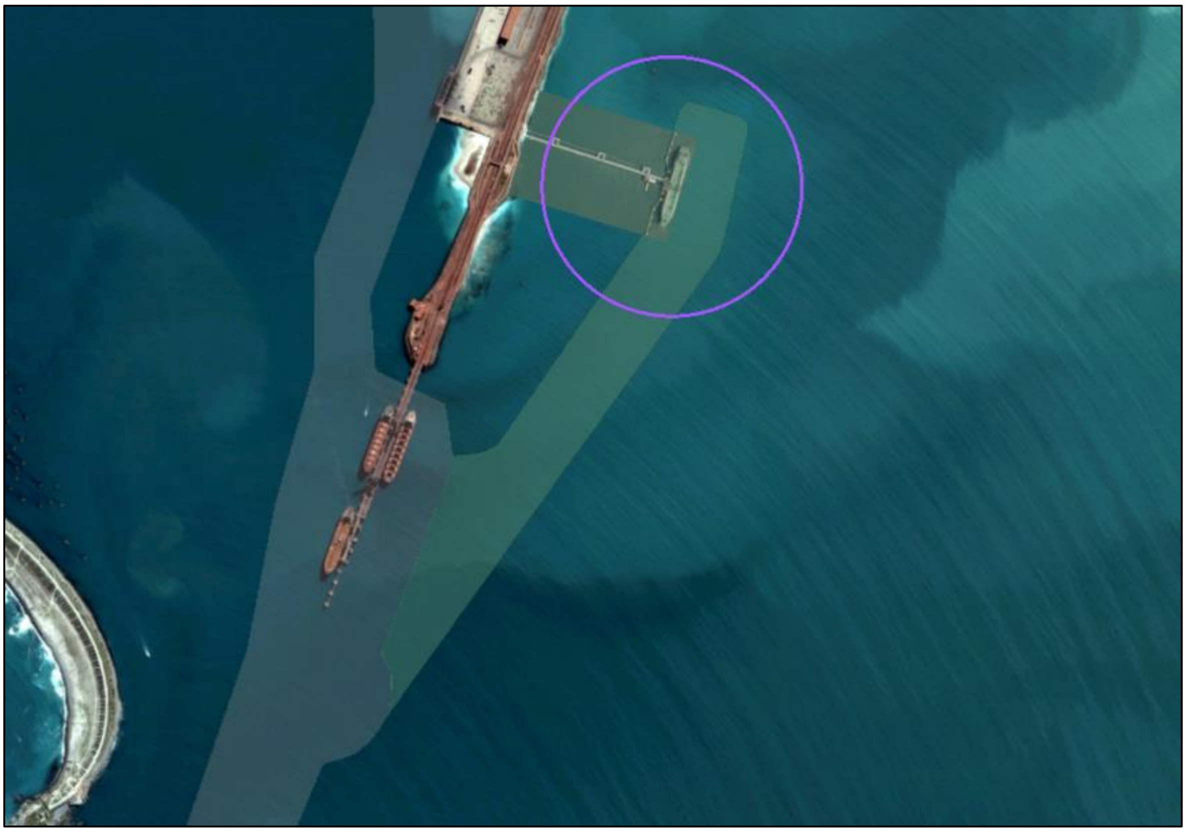


Figure 9-13 Navigational zones nearby Site 3 - Big Bay: Causeway

The superimposed circle around the vessel in Figure 9-13 indicates the 500 m primary exclusion zone, inside which no other port users may operate. This zone dictates the separation distance between the jetty and the causeway, and future port developments must take this into consideration. The protruding nature of the design may also inhibit future berths leeward of the jetty, although the shallow waters in this area do not favour large scale terminal developments.

9.6.5 Site 4: Big Bay – Open Water

GBS

If a GBS is selected for use at the Big Bay offshore site, the LNG approach channel will run due east of the turning circle to the GBS berth. This is not an ideal approach, as waves and wind will be abeam and will tend to push the assisted vessel into shallower water. Once in the lee of the GBS some of the wave action will be attenuated, though diffractive effects around the caisson must be considered. Emergency departure from the berth will require significant tug assistance, as the bow will be pushed further landward, not seaward, by the combined force of the prevailing (and strengthening) wind and waves.

The manoeuvring of the LNGC should not affect independent port operations. The presence of a 4.7 km submerged gas pipeline in Big Bay will reduce anchorage areas in the Bay however. The proposed pipelines are shown as orange lines in Figure 9-14, leading directly from terminal to shore, flanked by red lines that represent an anchor exclusion zone.

Figure 9-14 Navigational zones nearby Site 4 - Big Bay: GBS (l) and SPM (r)

SPM

If the wind direction is suitable, the LNGC may be able to approach the SPM directly and will request tug assistance for hawser connection. Although they may not be required to assist, tugs will escort the vessel to the site as per the Port Instructions. This stipulation by the Port Authority nullifies one of the key advantages of SPM technology: reduced tug demand. Figure 9-14 highlights the LNG vessel approach area, which comprises a safe approach radius of 2 L_{OA} and a channel connecting the area to the port's turning circle. The manoeuvring area may seem substantial, but it will only require maintenance dredging as the entire swing radius and the majority of the safe approach radius is in a water depth greater than -17 m.

9.7 Geotechnical

9.7.1 Introduction to the Geotechnical Characteristics of Saldanha Bay

It is important to determine the geotechnical characteristics of the seabed and substrate at each conceptual terminal location early in the study. The geotechnical composition will have a major influence on the dredging of approach channels, turning circles and berth pockets. The substrate will also affect the construction methodology of piled terminals, and may directly influence the time, cost and material demand at specific sites.

A detailed survey was undertaken in 2006 to determine the geological composition of the Big Bay substrate immediately southeast of the iron ore causeway. Select drawings resulting from this survey are presented in *APPENDIX F – Geotechnical Survey – Eastern Margin of Iron Ore Terminal* (MGS, 2006).

The basic stratigraphy in the Big Bay area consists of the following strata, in order of increasing depth below seabed (PRDW, 2007):

- Recent Bay Deposits: loose to dense, silty, very fine to medium grained sands with a variable shell fraction content. Layer thickness ranges from 0 m to 9 m.

- Langebaan Formation: lithified aeolianites and calcretes (very soft to medium hard rock), interspersed with medium dense to very dense very fine to medium grained sands, and very loose to medium dense sandy silts. Layer thickness ranges from 0 m to 4.5 m.
- Velddrif Formation: alternating layers of sand, very soft to soft rock, and sandy shell gravels. Layer thickness ranges from 0.5 m to 6.0 m.
- Varswater Formation: medium dense to very dense fine to medium sand, with alternating layers of shelly gravels, soft rock calcarenite, coquinites and calcretised sands. Layer thickness ranges from 0 m to 4.5 m.
- Cape Granite Suite: medium strong to strong rock, with medium weathering. Shall be considered as bedrock.

For dredging purposes the stratigraphy can be simplified to four components: 1) *soft recent bay deposits* (sand, mud, shell), 2) *soft calcrete* (Langebaan & Velddrift formation), 3) *hard calcrete* (Varswater formation) and 4) *hard granite* (Cape Granite Suite).

It is assumed that recent bay deposits and both soft and hard calcrete layers can be dredged using a standard CSD (Cutter Suction Dredger) without the need for blasting (Luger, et al., 1998). The hard calcrete will be more difficult to remove and may require a drill barge, or jack-up platform, together with a large backhoe dredger and hopper barges. As removal of the granite bed is a far more labour and time intensive operation than dredging sand and calcrete, granite outcrops should be avoided where possible.

Geotechnical information, which includes the subterranean depths of the strata, is available for the proposed Site 3 and Site 4 conceptual terminal areas. Original geological data could not be sourced for Site 1 (Hoedjiespunt) and Site 4 (North Bay). Calcrete and granite layer depths are interpolated at these sites using the Big Bay survey data.

9.7.2 Site 1: Hoedjiespunt

It is assumed that the Hoedjiespunt site and the Big Bay Causeway site share the same geological traits, as they are located at similar water depths in the same natural bay[xxxii].

The jetty at Site 1 is situated in -14 mCD water depth (before dredging). At this contour line in Big Bay the soft calcrete layer begins at -15 mCD, and meets with the hard calcrete layer at -20 mCD. These stratigraphic depths will therefore be applied directly at Hoedjiespunt. The depth of the granite layer cannot be interpolated however, as the surface elevation varies wildly. It will be assumed that the elevation of the highest granite pinnacle in the Bay is -18 mCD, as that is the shallowest surveyed distance to the granite surface in the Big Bay area (MGS, 2006). Recent bay deposits at Site 1 consist of mud (M) and fine sand and mud admixture (fS.M) (SANHO, 1999).

9.7.3 Site 2: North Bay

The North Bay conceptual LNG site is situated outside of the Saldanha Bay area, and consequently the stratigraphic layer depths recorded in Big Bay cannot be directly applied at Site 2. Some generalisations can be made following from the MGS survey however, and these may be utilised to predict the corresponding layer depths in North Bay.

[xxxii] The reader is reminded that Saldanha Bay was divided into Big Bay and Small Bay in the 1970s, and was a singular natural embayment prior to the construction of the causeway and the beach breakwater.

In general, the sand and shell thickness in the surveyed section of Big Bay stretches approximately 1 m below the surveyed bathymetry, where it meets the soft calcrete surface. The interface between soft calcrete and hard calcrete is typically -6 m below the bathymetric depth. The granite elevation varies considerably, though on average the surface elevation is between -60 mCD and -70 mCD. Granite pinnacles and gulleys have been known to reach between -18 mCD and -98 mCD in the surveyed area.

These relationships are applied to the North Bay site, where the depth varies between - 17 mCD and -5 mCD at the area of interest. The soft calcrete elevation is estimated to vary between - 18 mCD and -25 mCD whereas the hard calcrete elevation ranges between -23 mCD and -31 mCD. Recent bay deposits at Site 1 consist of fine sand and broken shell admixture (fS.bkSh) (SANHO, 1999).

9.7.4 Site 3: Big Bay – Causeway

Recent bay deposits at Site 3 consist of fine sand (fS) and fine sand and mud admixture (fS.M) (SANHO, 1999). The depth of deposits average 1 m – 2 m above the soft calcrete layer. The interface between soft and hard calcrete layers ranges between -16 mCD and -18 mCD in the jetty area and between -18 mCD to -20 mCD in the approach channel. The granite surface is very irregular, and the surface elevation varies between -26 mCD and -50 mCD in the jetty area, and approximately -26 mCD and -96 mCD in the approach channel. The elevations of the granite surface are superimposed on the conceptual terminal layout in Figure 9-15.

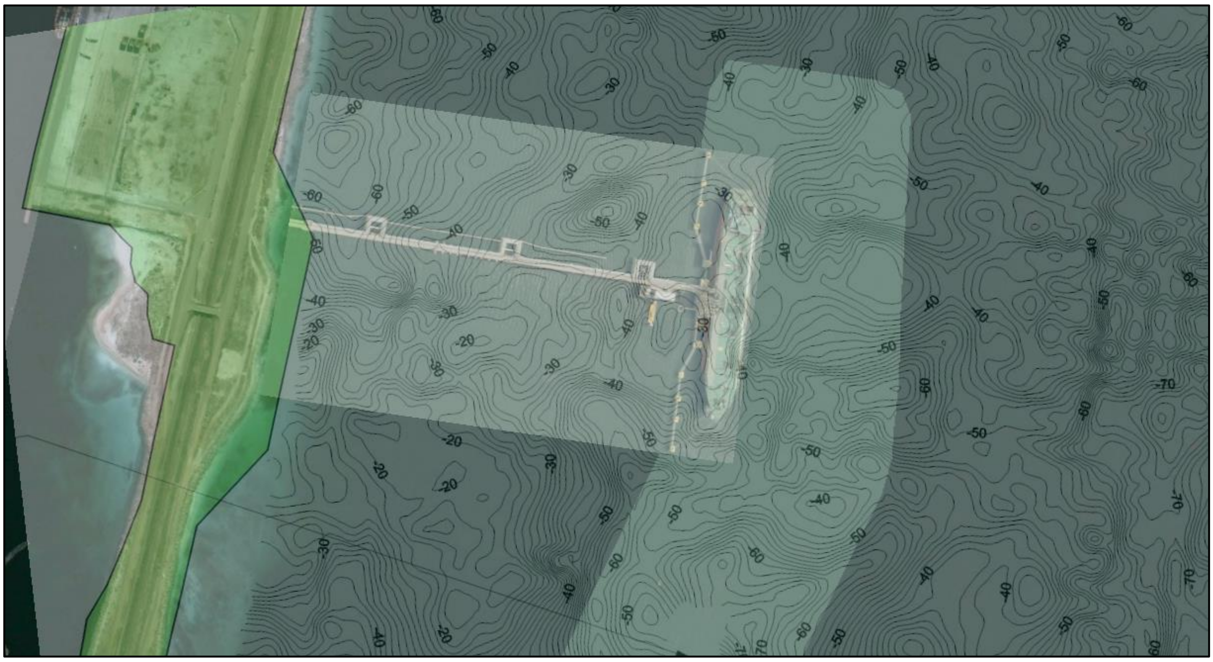


Figure 9-15 Elevation of granite surface at Site 3 (MGS, 2006)

9.7.5 Site 4: Big Bay – Open Water

Recent bay deposits at Site 4 consist of fine sand and broken shell admixture (fS.bkSh) (SANHO, 1999). The depth of deposits average 1 m above the soft calcrete layer. Calcrete reefs are prominent in the area, and it is possible that the seabed surface comprises an uncovered calcrete layer. The interface between soft and hard calcrete layers lies at approximately -23 mCD in the jetty area and approximately -22 mCD to -24 mCD in the approach channel. The granite surface is very irregular, and the surface elevation varies between approximately -36 mCD and -72 mCD in the jetty area, and between -20 mCD and -78 mCD in the approach channel. The elevations of the granite surface are superimposed on the conceptual GBS terminal in Figure 9-16.

Figure 9-16 Elevation of granite surface at Site 4 (MGS, 2006)

9.8 Dredging

9.8.1 Introduction to Dredging in Saldanha Bay

Dredging tends to be one of the largest capital costs of a new port development, and where possible the dredge volumes should be minimised. Additionally, the dredging process can have a significant negative impact on the local water quality due to the suspension of sediment and heavy metals that may be in the soft top layer.

A number of factors influence the total cost of the dredging operation. Key among these are 1) the *volume* of dredge spoil removed, and 2) the *time* required to dredge said volume. The volume is dictated by the natural bathymetry at each site, and the ultimate channel depth after dredging. The time required to dredge depends on the spoil volume, the strength of rock to be removed, the distance to the spoil dumping site and the wave action during dredging.

The necessary minimum dredge volume at each site has been calculated using the “QuickIn” standalone tool that forms part of the Delft 3D package.

9.8.2 Site 1: Hoedjiespunt

The layout of the approach channel at Hoedjiespunt has been described in earlier Chapters. The approximate distance of the channel, including the berthing pocket, is 1500 m. The channel is 250 m wide and connects to the existing turning circle, which is -23.3 mCD deep. The channel will be dredged to -16.9 mCD.

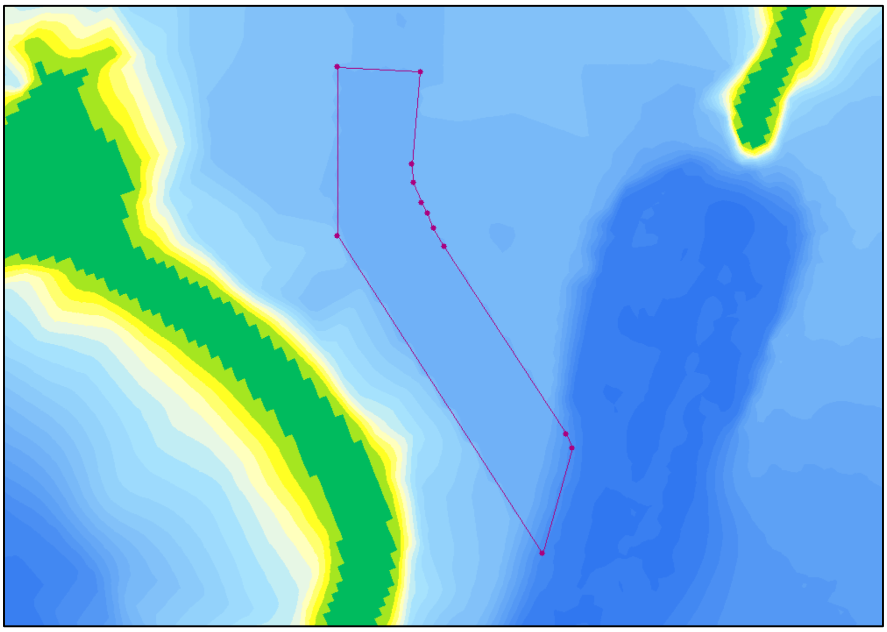


Figure 9-17 Approach channel and dredge boundaries at Site 1

The total length of the channel will be dredged, as the water depth decreases towards the lee of the breakwater. The dredge zone is shown as a purple polygon in Figure 9-17. The dredge volume[xxxiii] has been calculated to be 596,000 m^3. Water depth in the channel area varies between -12 mCD and -14.5 mCD. It is therefore assumed that the dredge spoil will comprise of mud and fine sand (25%) and soft calcrete (75%).

The dredge material may be suitable for land reclamation on the south eastern side of Hoedjiespunt. This would support the argument for shore based LNG facilities and storage tanks.

9.8.3 Site 2: North Bay

Dredging will not be necessary at Site 2. The safe approach area described in *Section 9.6 - Navigation* lies in water depth greater than -16.9 mCD. The Delft3D model of the site is shown in Figure 9-18.

[xxxiii] This calculation does not include the volume of material removed at the side slopes of the channel.

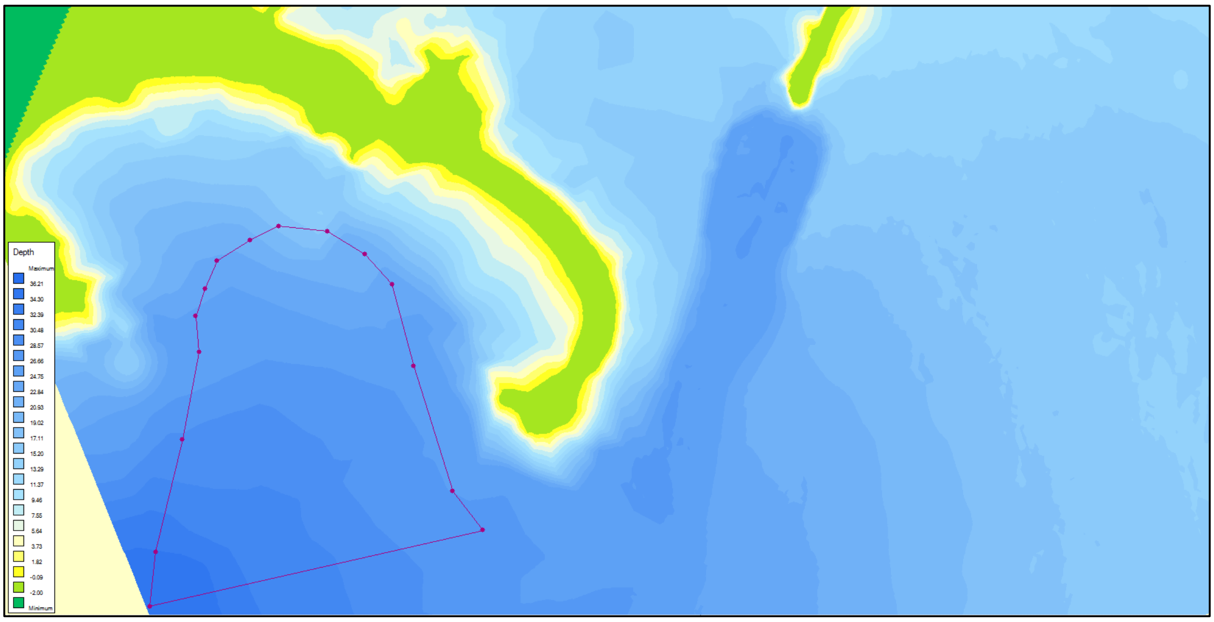


Figure 9-18 Approach channel at Site 2

9.8.4 Site 3: Big Bay – Causeway

The layout of the approach channel to Site 3, running adjacent the Causeway, has been described in *Section 9.6*. The approximate distance of the channel, including the berthing pocket, is 2500 m. The channel is 250 m wide and connects to the existing turning circle at the end of the oil terminal.

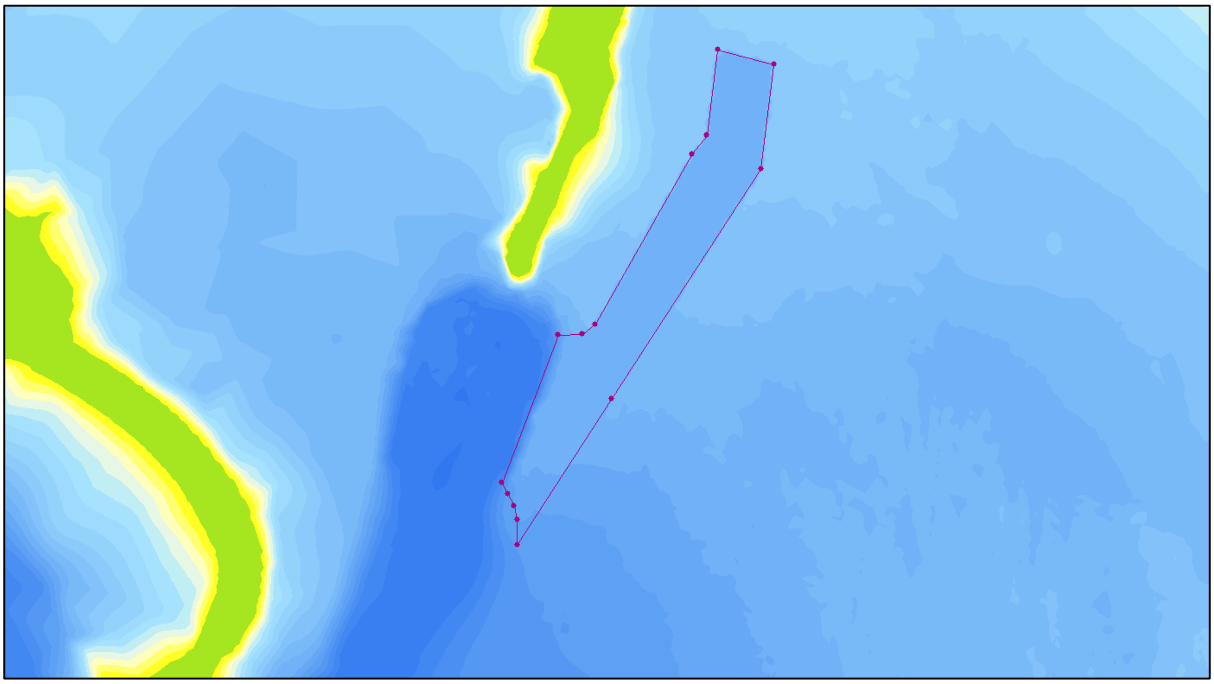


Figure 9-19 Approach channel and dredge boundaries at Site 3

Around 90% of the channel length will have to be dredged: only the southernmost point of the channel is at a natural depth of -16.9 mCD or greater. The dredge zone is shown in purple in Figure 9-19. The dredge volume has been calculated to be 1,229,100 m^3. Water depth in the channel area varies between -10 mCD and -17 mCD, with an average depth of approximately 12 m. The bulk of the dredged material will consist of sand, mud and soft calcrete. Shallow patches (up to 1 m deep) of hard calcrete may have to be removed towards the northern section of the berthing area, where the water depth is 10 m or shallower. Removal of the granite layer is unnecessary. At least 80% of the dredge volume will comprise soft calcrete.

The volume of dredge material is quite significant, and the method of its disposal will be a key cost parameter at this terminal site. It would be wise to use the dredge spoil for land reclamation instead of dumping at sea. This aspect must be studied in the next stage of terminal design, and will not be considered in this study.

9.8.5 Site 4: Big Bay – Open Water

Site 4 in Big Bay was conceived to be an offshore terminal that can be approached and berthed without much tug assistance, and requires minimal maintenance dredging during operation. Figure 9-20 outlines the safe approach area as a circle, connected to the existing port turning circle. The white patches highlight the spots that require dredging to assure the calculated operational depth of -16.9 mCD. These patches are on the periphery of the approach circle are not within the swing radius of the vessel.

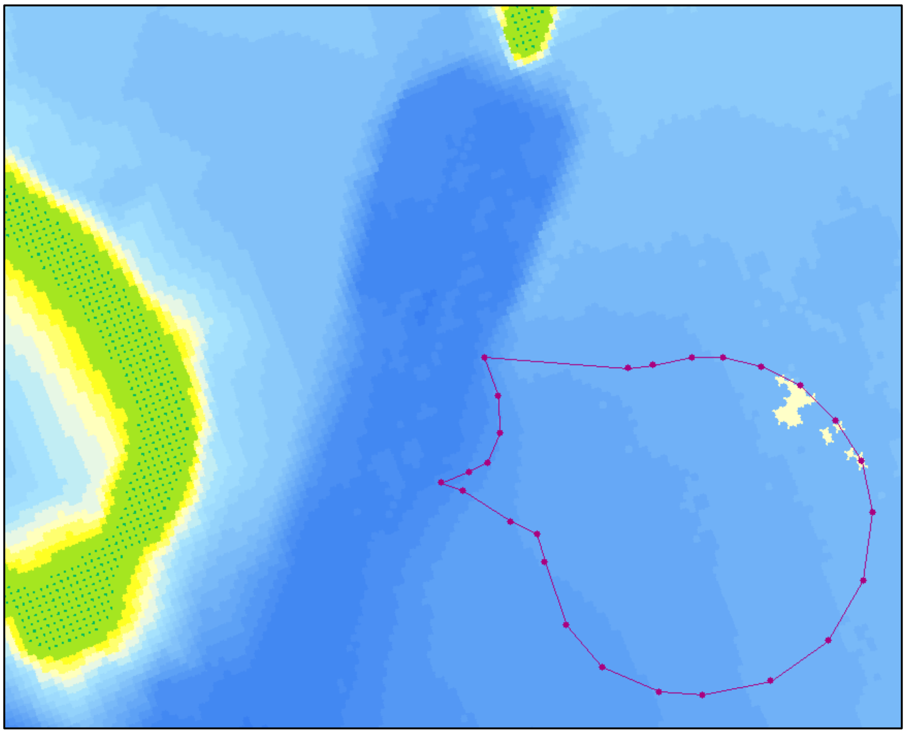


Figure 9-20 Approach channel dredging patches at Site 4

The necessary dredge volume has been calculated to be just 236 m^3. The dredge material will consist primarily of fine sand and broken shell, and may include soft calcrete as an outcrop of calcrete reef is present in this area (MGS, 2006).

9.9 Location of Onshore LNG facilities

9.9.1 Introduction to Key Onshore LNG Facilities in Saldanha Bay

Estimation of Land Area Requirements

The Land Area Requirement (LAR) of the onshore facilities at an LNG import terminal has been determined in *Section 7.7 Land Area Requirements*. Total LAR for the landside LNG storage, regasification, piping and ancillary facilities in Saldanha Bay is estimated to be a minimum of 9 ha to 13 ha. The LAR for the CCGT facility in Saldanha Bay is estimated to be 8 ha.

In scenarios where the LNG is regasified offshore, the landside facilities will be minimal. A natural gas pipeline will deliver the end product to the CCGT, occupying a footprint of no more than 2 m in width when complete. During construction however an 8 m to 10 m wide tract may be necessary to accommodate pipe-laying machinery. The total NG pipeline footprint will depend on the distance from vapouriser to CCGT.

Location of CCGT

For the purpose of this study the CCGT is deemed to be located in the Saldanha Bay area, and preferably in the proposed IDZ plot or the future port expansion zone. Certainly, the power plant is not bound to the terminal area, as it only requires a constant feed of natural gas for operation. However, close proximity to the terminal will reduce the cost of natural gas pipeline installation. Furthermore it is preferable to locate the CCGT adjacent the LNG vapourisers in the case of onshore regasification, for reasons stated in *Section 3.4.4 Complementary CCGT & Vapouriser Siting.*

9.9.2 Site 1: Hoedjiespunt

Standard Trestle Jetty

Land space at the Hoedjiespunt headland is extremely restricted. There appears to be approximately 1 ha of useful land at the Hoedjiespunt/breakwater interface, none of which is flat. Land reclamation on the leeward side of the beach breakwater may be a solution where standard onshore regasification is considered. Figure 9-21 shows a conceptual reclamation area running southeast of the port control tower on Hoedjiespunt. Of the 13 ha of reclaimed land shown, 10.5 ha is used for storage and regasification. Should additional space be necessary, it may be possible to develop further into the Bay area (i.e. in a NE direction).

FSRU Alongside Trestle Jetty

Should an FSRU type terminal be selected, the lack of land availability at Hoedjiespunt will not pose a problem. Reclamation will not be required, unless the trestle jetty construction process calls for it, in which case it is expected to be minimal.

Figure 9-21 Potential reclamation area and regasification facilities at Hoedjiespunt

Natural Gas Pipeline

Irrespective of terminal selection at Site 1: Hoedjiespunt, a natural gas pipeline will be necessary to deliver the natural gas product to the proposed CCGT site. The isolation of the Hoedjiespunt site poses some logistical problems. The most direct route from the terminal to the port expansion site is across Small Bay, landing at the shoreside western boundary of the port plot. This subsea pipeline option is shown as an orange line in Figure 9-22. The solution of laying a pipeline on the Small Bay seabed runs the risk of interference from anchoring vessels. Large bulk carriers under ballast often anchor in the Bay while they wait for berth availability. The anchors from such enormous vessels could impart significant damage on the NG pipeline. To counter this, the pipe will be diverted into the shallower western areas of Small Bay, where large vessels will not cast anchor. A "no-anchor" zone will have to be imposed around the pipeline and enforced by the harbourmaster. The total NG pipeline length is 8.25 km, 4 km of which is subsea.

An alternative solution is to develop a terrestrial pipeline route that skirts the perimeter of the town before the approaching the CCGT site. Land based installation will be far more cost-effective than a subsea one. The land based NG pipeline is shown as a pink line in Figure 9-22. The pipeline is forced to run its course through the SANDF SAS Saldanha property (shown as red shaded area), as there is no room to construct through the town of Saldanha. It is expected that there will be difficulty in acquiring this land for pipeline installation, despite its insignificant footprint. The remainder of the pipeline runs west of Diazville, near the Danger Bay shoreline, and thereafter runs eastward into the port expansion area. The pipeline remains deliberately north of the town area to avoid potential conflicts with residential development in the near future. The total NG pipeline length is 20 km, 5.2 km of which runs through restricted SANDF property.

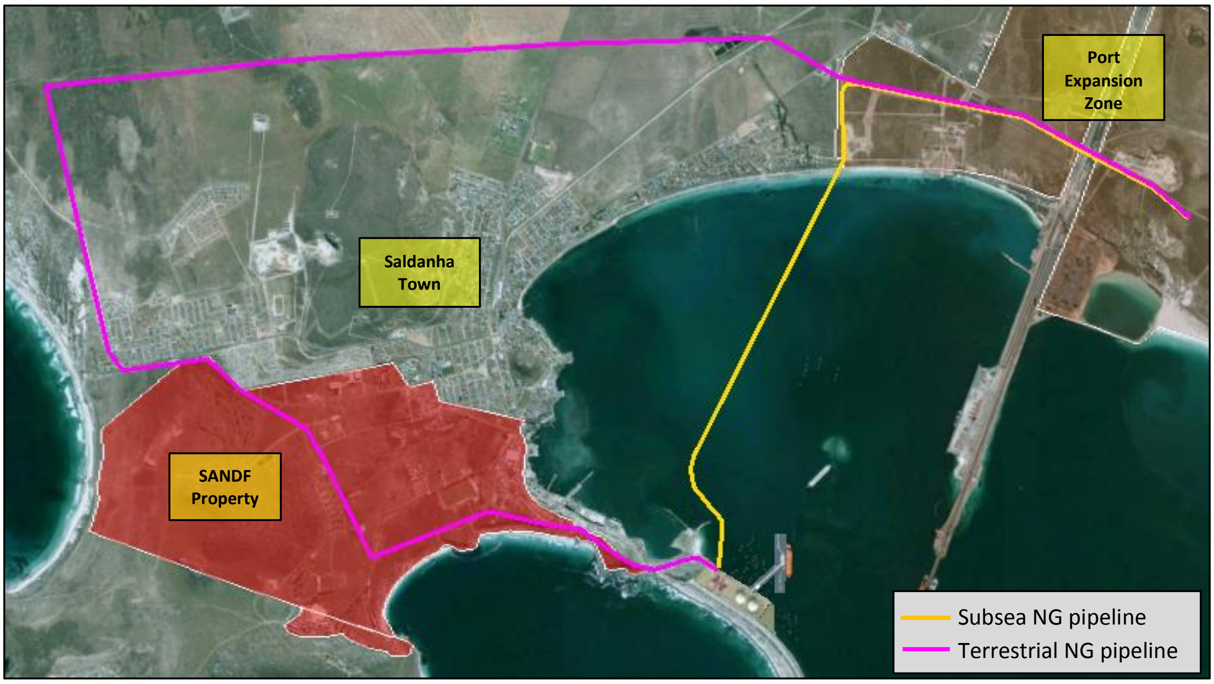


Figure 9-22 Natural gas pipeline options from Hoedjiespunt site

9.9.3 Site 2: North Bay

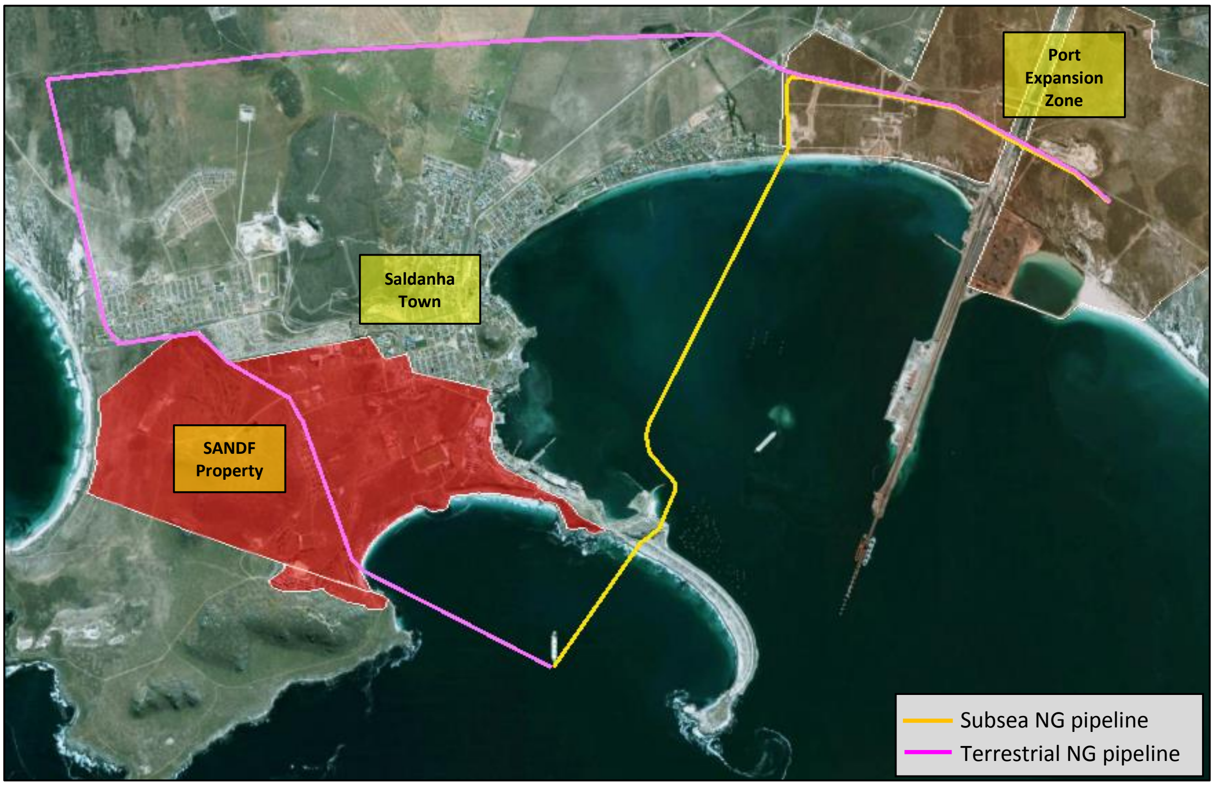


Figure 9-23 Natural gas pipeline options from North Bay site

The pipeline network that delivers natural gas to the CCGT from the North Bay offshore terminal will be very similar to the Hoedjiespunt solution. In both direct and indirect options a subsea pipeline will transfer NG to the mainland at North Bay before piping the product to the CCGT. The solutions are shown in Figure 9-23. Taking the direct route, the total NG pipeline length is 10 km, 5 km of which is subsea. Using the indirect route, total NG pipeline length is 20 km, 3.2 km of which runs through restricted SANDF property and 2 km of which is subsea.

9.9.4 Site 3: Big Bay – Causeway

The future port area will expand either side of the existing iron ore causeway and stockpile, and may ultimately cover an area of 975 ha (Urban Dynamics Western Cape, 2011). Room for onshore LNG storage and regasification is abundant. The shaded orange plot in Figure 9-24 represents a potential LNG facility, occupying a generous 55ha. The superimposed line shown (in green) represents an insulated cryogenic LNG pipeline, carrying LNG from the vessel's containment tanks directly into the onshore storage tanks. The total length of cryogenic pipeline is 3.8 km.

Should an FSRU be considered at the terminal, the natural gas pipeline will also span a distance of 3.8 km. The pipe will feed NG directly into the CCGT however, as storage and regasification facilities on land will be unnecessary.

Figure 9-24 Cryogenic LNG pipeline from Big Bay: Causeway site

9.9.5 Site 4: Big Bay – Open Water

The offshore terminal in Big Bay will pipe NG directly to the CCGT onshore. The total distance of the subsea pipeline is 4.7 km. A direct pipeline to the terminal is expected to be more cost effective than a combination of a short subsea pipeline to the causeway and a raised pipeline thereafter to the CCGT. Large vessels are known to anchor in this section of Big Bay while waiting to berth, so a no-anchor zone will have to be implemented around the submerged pipeline. This may seem an unnecessary hindrance to other port users. Such measures have been successfully implemented at other offshore terminals however, such as at Guanabara Bay in Brazil, where a 10 km subsea pipeline is located in a very active shipping zone. The submerged pipeline is shown in Figure 9-25.

Figure 9-25 Natural gas pipeline from Big Bay: Open Water site

9.10 Safety

9.10.1 Introduction to Safety Exclusion Zones in Saldanha Bay

Safety exclusion zones have been superimposed around the conceptual sites in Figure 9-26 and Figure 9-27. The inner circle (purple line) indicates a 500 m radius centred at the LNG unloading manifold aboard the vessel. This circle represents the extents of a pool fire on the water surface in the case of a spill over water, as described in *Section 7.9 Safety Exclusion Zone*. It should be re-iterated that this represents a very extreme scenario, and that the possibility of such a widely dispersed pool fire is very low (Sandia, 2008).

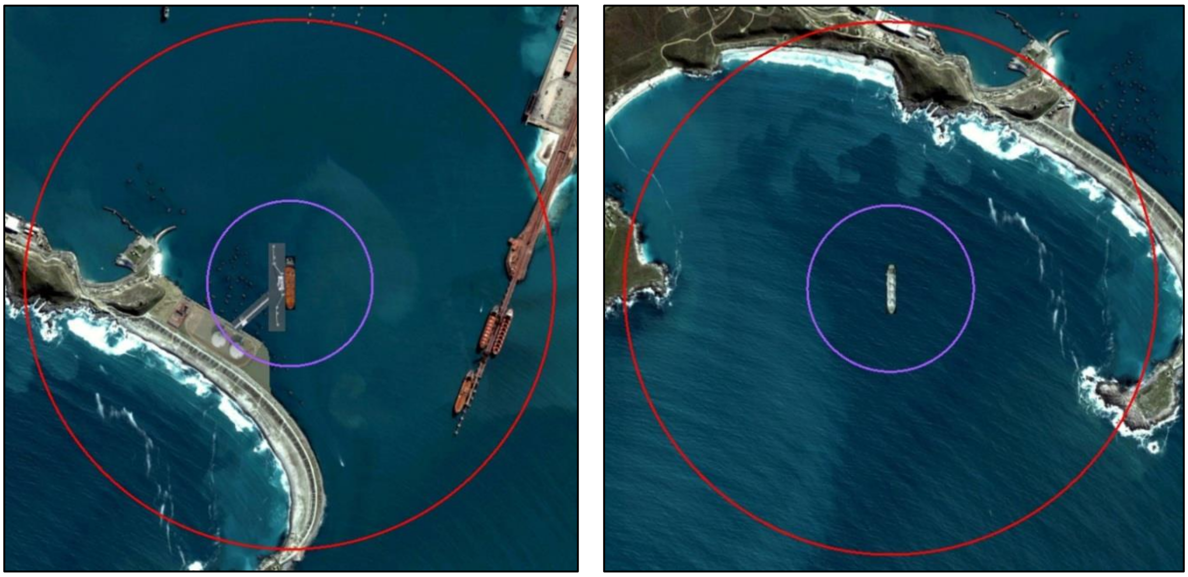


Figure 9-26 Primary and secondary safety exclusion zones at Site 1 (l) and Site 2 (r)

The exclusion zone defined by the outer circle (red line) represents the area that may be affected by the thermal heat effects of an ignited vapour cloud. This distance (1600 m) is a conservative estimate, as it is likely that the LNG vapours will have assimilated into the atmosphere by this distance, or that the specific combustion ratio will have been surpassed. Should the vapour ignite at this boundary, it is likely to be a high altitude incident as the vapours will have risen significantly before being blown that far downwind (Foss, 2006).

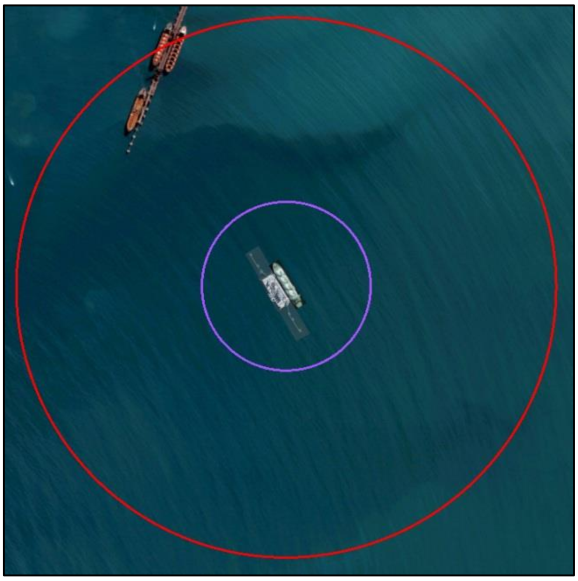



Figure 9-27 Primary and secondary safety exclusion zones at Site 3 (l) and Site 4 (r)

9.10.2 Site 1: Hoedjiespunt

Although the trestle jetty and part of the onshore facilities fall within the 500 m exclusion zone, no other port activities are at risk from a pool fire. The iron ore terminal, oil terminal, TNPA port control tower, TNPA tugboat harbour and the Yachtport SA private boatyard & marina fall within the secondary safety zone. These elements may be at risk when the wind blows from due east (2.2% occurrence). The nearest residential area lies 2.7 km to the northwest of the terminal, and is not at risk of heat exposure from vapour cloud combustion.

9.10.3 Site 2: North Bay

The LNG carrier and the offshore terminal are the only structures at risk from a pool fire event in North Bay. The secondary exclusion zone incorporates the TNPA port control tower, the TNPA small craft harbour, the Yachtport SA marina and some elements of the Navy dockyard. These shore based structures may fall under the combustion area of a vapour cloud when the wind blows from the south, which is the case 22.7% of the time. The nearest residential area, Saldanha town, lies a safe 2.6 km NNW.

9.10.4 Site 3: Big Bay – Causeway

The trestle jetty is the only element of port infrastructure that lies within the primary exclusion zone at the Big Bay: Causeway site. The multipurpose terminal and both iron ore berths wall within the secondary safety exclusion zone. The multipurpose quays may only be at risk when the wind approaches from ESE (which occurs 1.8% of the time). Saldanha lies 4 km to the WNW whereas the Club Mykonos resort lies 5 km ESE.

9.10.5 Site 4: Big Bay – Open Water

Due to its offshore orientation, the Big Bay terminal poses least potential threat to the Saldanha Bay port users and residents. Only the offshore LNG terminal is at risk of pool fire, and the port's oil terminal and iron ore berths may be at risk of vapour cloud combustion, should the wind blow from the southwest (8.5% occurrence).

Navigational Exclusion Zone

Cork and Bentiba (2008) have additionally suggested implementing a 300 m safety zone around the moored LNG which other vessels may not enter while underway. This zone will help minimise disturbances caused by passing ships, particularly those possessing a large displacement volume.

Other sources have recommended the concept of a "moving exclusion zone", which would be implemented around the LNG vessel when manoeuvring in Saldanha Bay (Foss, 2006). A distance of 500 m is proposed, which no vessels other than pilots, tugs or support vessels directly involved with berthing may enter.

9.11 Environmental Concerns

9.11.1 Introduction to Environmental Concerns in Saldanha Bay

The choice of terminal type will be the most influential factor on the environmental welfare of Saldanha Bay. Both short term effects due to terminal construction and long term effects over the assumed 30 year operational period of the plant must be considered.

A thorough Environmental Impact Assessment (EIA) concerning the presence of an LNG terminal must be undertaken at a later stage in the design process. In the pre-feasibility and feasibility planning stages a Strategic Environmental Assessment (SEA) will suffice. In this Section a high level scoping of potential environmental concerns is given.

9.11.2 Environmental Effects of Terminal Construction

Noise

Noise pollution during terminal development usually results from end-tipping of large rock in breakwater construction, from driving piles into substrate and from machinery traffic. None of the designs call for breakwater construction fortunately. Trestle jetties will demand significant pile driving, which may take over one year to complete. An SPM tower will require light piling work for the legs of the structure, and a GBS will require few piles to act as free-standing mooring dolphins.

Machinery traffic will be most active during onshore plant installation, and during site preparation if necessary. The maximum predicted time for CCGT construction is 30 months (IEA-ETSAP, 2010). This timeframe will also be applied to the vapouriser elements.

Turbidity

Pile driving alone will not result in much local turbidity. The increased nautical activity in the zone of construction however, particularly in shallow water, may lead to suspended particles. GBS installation will not result in much sediment suspension, primarily due to its required water depth of 14 m to 20 m. The caisson structure will be floated into position and gradually sunk onto a prepared level seabed. Bed levelling, if necessary, will demand minor dredging, resulting in localised short term turbidity.

Onshore Site Preparation

An LNG terminal that incorporates landside storage and regasification facilities will require an operational footprint of at least 9 ha to 13ha. The construction footprint will be larger still, and is assumed to be 16 ha. This area will be cleared and levelled before construction begins. The CCGT plant will require 8 ha +20% = 9.6 ha. The EIA process will reveal any Critical Biodiversity Areas (CBA) that should be avoided.

9.11.3 Environmental Effects of Dredging

Turbidity

Turbidity caused by dredging can be mitigated somewhat by the choice of dredging equipment and procedure. The extent of these effects is proportional to the volume and surface area of the particular dredge zone. Dispersion of suspended sediment is not expected to be widespread, as the current velocities in the Bay are low, particularly in Small Bay and in Big Bay adjacent to the Causeway, where the main dredge areas are proposed. Suspended particles are therefore expected to return to the seabed in the proximity of the dredge site. Luger et al (1998) have reported that the dredging operation of a 2.5 million m^3 volume at the head of the oil terminal would result in acceptable turbidity levels of 25 mg/l at sensitive sites, which is well below the ecological threshold of 150 mg/l. This local turbidity level is on par with the widespread level induced by typical storm events. The predicted dredge volumes and current velocities at the conceptual LNG sites are far lower than those considered in the 1998 study.

Dredging Induced Wave Refraction

The process of dredging increases the local water depth at a site, usually over a long, narrow strip that runs more or less in line with the incoming wave direction. This sudden jump in bathymetrical depth can induce localised refractive effects, where the incoming wave will tend to divert towards the shallower zones on either side of the dredged channel. This process gives the appearance of reflection off the submerged channel sides, and serves to reduce wave energy penetrating the approach channel. The environmental downside of this is that the local wave field may change significantly, altering what may have been an equilibrium state of wave attack and shoreline erosion.

Refractive effects on port operations, the local current regime and shoreline stability should be investigated in detail during later stages of terminal feasibility study.

9.11.4 Environmental Effects During Operation

Construction of the terminal is expected to impart the greatest relative impact on the local environment. Natural gas combustion, heralded as the “cleanest” of fossil fuel power plant technologies, is not expected to produce much significant long term waste over the predicted 30 year lifespan of the plant. The environmental merits of specific CCGT turbines should be investigated during the EIA process.

Choice of Vapouriser Technology

Individual vapouriser technologies were described in Section 3.4.1. To recap, there are two basic vapouriser types: Open Rack Vapourisers (ORV), which use an open loop saltwater system to regasify LNG, and Submerged Combustion Vapourisers (SCV) which use freshwater in a closed loop system.

ORV vapourisers discharge saltwater brine to the Bay area, at a lower temperature the intake water. The temperature differential is around -5°C, and can be reduced to approximately -2°C if the open loop system is used in the CCGT plant, located adjacent the vapouriser. The siting of the CCGT thus influences the operational environmental effect of the terminal.

SCV vapourisers do not discharge any brine to the local environment. Instead, they use heated water to warm the LNG product during regasification. This process will use diesel or natural gas to heat the SCV water bath, steadily producing carbon emissions in doing so. If, during a detailed environmental study, it is found that the discharge brine will have little effect on the local environment, the ORV technology will be favoured.

Mariculture

Several large portions of Saldanha Bay have been designated as "Mussel Culture Areas" wherein mussel culture operations take preference. The net reduction of Mariculture area due to terminal construction and operation must be considered. The effects of discharge of LNGC ballast water should also be studied.

9.11.5 Aesthetics

The visual design of a large port development can have a major bearing on its acceptance from the local population. The terminal should be discreet where possible, and bulky or tall structures should be avoided. LNG storage tanks, primarily due to their sheer size, are generally not favoured near residential areas. An EIA will study the visual impact of these structures from the viewpoint of residential areas and from identified tourism hotspots.

9.11.6 LNG spill

LNG, when spilled over water, has no medium or short term environmental effects. Due to its low density the cryogenic liquid floats on top of seawater. As it heats it will begin to vapourise, and will be suspended above the spill pool until such a time the vapour reaches ambient temperature, after which it will rise and be absorbed into the atmosphere. Ultimately the total LNG spill will be regasified and released into the environment as methane, a greenhouse gas. Spill protection measures, employed at the oil berth, are therefore unnecessary at the LNG terminal.

9.11.7 Site Specific Environmental Effects

9.11.7.1 Site 1: Hoedjiespunt

The terminal at Hoedjiespunt will be a trestle jetty, and will require substantial piling work. The jetty length between the extreme mooring dolphins is expected to be approximately 400 m, and the trestle causeway will be at least 650 m. Substantial piling is expected, which may take over 12 months to complete. The nearest residential zone is 3.3 km away, and residents may be affected by noise pollution, depending on wind strength and direction. Turbidity is not expected to be a major issue during piling.

Land reclamation will be in the order of 13 ha to 20 ha to account for the storage tanks, vapourisers, and construction yard. There is no flora or fauna of note in the reclamation area, as it will be adjacent the manmade breakwater structure. Dredge spoil from the LNG approach channel will be used as fill material. Turbidity resulting from dredging operations is not expected to interfere with the Small Bay environment. The terminal was located outside of Small Bay specifically for this reason. Current velocities in Small Bay are negligible, and most sediment suspended during dredging should settle in situ.

Wave reflection off the channel will be insignificant. Wave heights at Site 1 rarely reach above H_s=0.3 m, and waves of this magnitude will not be affected by the new channel depth.

The CCGT plant will not be sited at Hoedjiespunt. For this reason there is an argument for the use of a SCV type vapouriser, which does not discharge brine into the local seawater. This applies for both standard and FSRU terminals. The effects of the NG pipeline will be addressed in an EIA. The choice between an 8 km subsea pipe and a 20 km terrestrial pipe is a difficult one, as both have unique environmental challenges. The dry pipeline may encounter many planning issues, and may cross yet unidentified CBA's, while the wet pipeline will require dredging and possibly grouting. Neither are ideal solutions.

The Site 1 terminal will force the removal of one mussel culture zone that presently cultivates on the lee side of the breakwater. The zone is shown as a solid purple area in Figure 9-28, and the primary LNGC safety exclusion zone is marked by a purple circle.

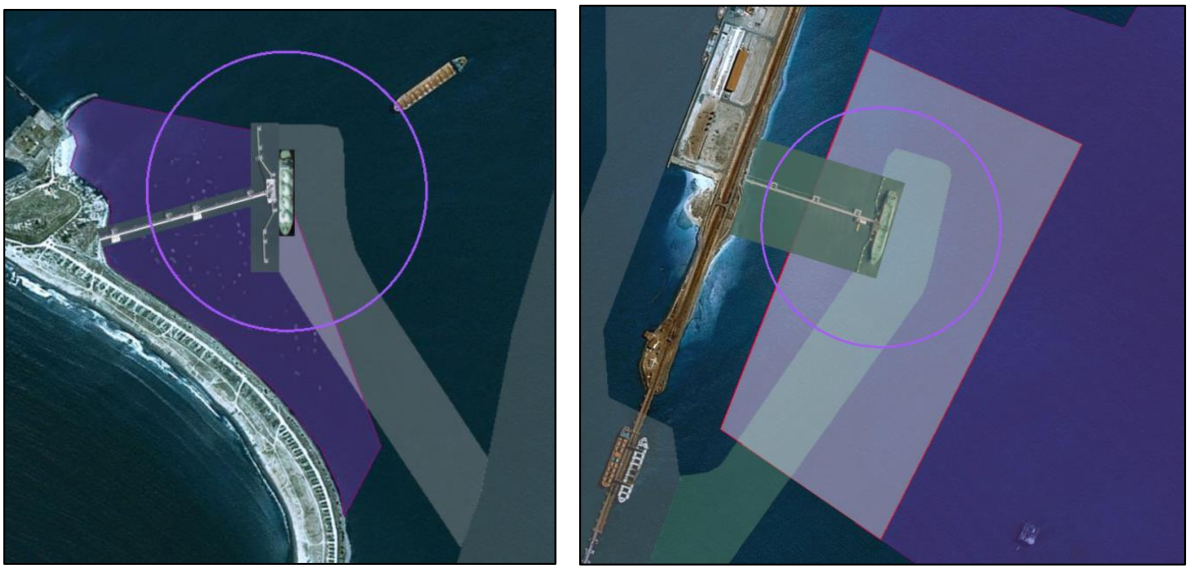


Figure 9-28 Mussel culture areas affected by Site 1 (l) and Site 3 (r)

The trestle jetty is, in itself, quite unassuming. Since it is a permeable, piled structure, it does not seem as looming as the wide MPT terminal or the caisson-built iron-ore terminal. Furthermore it is protected from the view of some Saldanha residents by Hoedjiespunt headland, cannot be seen by the Mykonos residents due to the presence of the iron ore jetty, nor by Langebaan residents by virtue of distance. Zone of Visual Influence (ZVI) analysis is likely to be conducted during the EIA process.

9.11.7.2 Site 2: North Bay

The North Bay site is entirely exclusive of Saldanha Bay, and its isolation brings with it both advantages and disadvantages. As far as the public is concerned, it is out of sight and therefore out of mind. The construction of a tower type SPM should be relatively straightforward, and only a handful of piles will have to be sunk at the site to support the tower structure. The natural gas pipeline options, running across the Small Bay seabed or skirting the town's perimeter, encounter the same environmental issues as at Site 1.

Should a GBS option be selected however, the local environmental concerns at the GBS casting site could be significant. Creation of a dedicated graving dock to construct the GBS inside is a colossal civil works project. The estimated land space required is 550 m x 400 m (at MSL), inside which a 30 m (deep) x 100 m x 200 m hole must be dug to accommodate the caisson (van Wijngaarden & Oomen, 2004). The case for constructing the GBS in Saldanha will not be examined. Installation of the GBS in North Bay is not expected to effect the local environment. Dredging will not be necessary, and turbidity will not pose a problem.

The rectangular cross section of the GBS, facing head on to the wave crests, may lead to a diffractive effect around the caisson. This will leave a wave dead spot behind the GBS, which is exploited by the LNG vessel. A diffractive study must be undertaken to decide if this effect has a negative impact on the North Bay beach, or more importantly on the spending beach breakwater.

North Bay boasts a fairly active swell climate, and water agitation and mixing here is expected to be quite high. For this reason, and due to the fact that the North Bay waters are not marine protected areas, an ORV type vapouriser may be used. An EIA should study this scenario in detail.

9.11.7.3 Site 3: Big Bay – Causeway

A trestle jetty is proposed at Site 3, approximately 600 m off the eastern wall of the Causeway. Jetty dimensions are similar to those at Site 1. Again, much of the noise pollution will be caused by pile driving. The extent of piling will depend on the piling depth, which is dictated by the bedrock level at the site. The granite elevation at Site 3 appears to lie at -30 mCD to -40 mCD. The site is approximately 3.8 km from the nearest residential area.

Sufficient development space for the onshore facilities and CCGT is provided to the east of the iron ore stockpiles. As this area has been earmarked for industrial development, it is assumed that the site does not contain any Critical Biodiversity Areas. Saldanha Municipality's Spatial Development Framework (Urban Dynamics Western Cape, 2011) describes this area as "sensitive vegetation" however. An EIA study should reveal whether or not the sensitive vegetation includes CBA plots. The Spatial Development Framework drawings are included as *Appendix B*.

A total dredge volume of 1,229,100 m^3 is expected to be removed to accommodate the draught of the design vessel as it approaches the terminal. Following from the study conducted by Luger et al (1998), this operation is not expected to result in ecological turbidity issues in the Saldanha Bay area or beyond. All pipelines, whether carrying LNG or NG, will be above-water and will only run 3.8 km. These factors greatly simplifying the pipelaying process.

The dredging of the LNG approach channel will result in refractive behaviour around the channel sides. Wave crests, which run more-or-less in line with the channel orientation, are expected to veer slightly to the east as they encounter the deeper bathymetry. This will result in increased wave energy on the Big Bay shoreline, just to the east of the reclamation dam. The concern is that increased and focused wave energy will erode the Big Bay shoreline and may lead to instability in the beach nourishment balance. CSIR have previously conducted a study to address this question, based on a dredge area very similar to that shown in Figure 9-19. The study shows that 1) the effects of dredging on physical processes in Saldanha Bay are restricted to the embayment from Lynch Point to the reclamation dam, and 2) the effects are virtually insignificant compared to trends of ongoing erosion and accretion without the proposed port developments (CSIR, 2008).

It has been stated earlier that the CCGT power plant will be located at the available “port expansion” land, east of the present iron ore stockpile and reclamation dam. It is sensible to use a tandem heating/cooling system between the regasification plant and the CCGT, as elaborated in *Section 3.4.4 - Complementary CCGT & Vapouriser Siting.* An ORV type vaporiser is recommended at Site 3 to minimise the variation between intake and outfall water temperatures.

The terminal and approach channel impinge on a small corner of the mussel culture area that occupies the majority of Big Bay (see *Figure 7-13 Nautical restricted areas in Saldanha Bay*). It is recommended that the area of this culture area be reduced by 1 km x 1.6 km to allow for LNG operations and safety exclusion zones. The white shaded polygon in Figure 9-28 indicates the mussel culture area to be relinquished to LNG terminal operations.

The terminal, hidden behind the causeway and iron ore operations, will not be visible to Saldanha residents. Club Mykonos residents will have full view of the jetty and onshore storage tanks, 4.5 km in the distance. Langebaan residents may be able to observe terminal operations from a distance of 8 km, though this is unlikely. It is probable that the presence of two Ø100 m x 50 m tanks on the Big Bay foreshore will be of more concern to locals than a piled jetty or weekly LNGC visits.

9.11.7.4 Site 4: Big Bay – Open Water

Similar to the North Bay terminal, the offshore terminal in Big Bay will not require any dredging, save for minimal maintenance volumes when required. A tower structure will necessitate a minor piling operation, whereas a GBS solution will need a suitably level seabed on which to sit. None of these construction operations are expected to result in significant turbidity problems.

The NG pipeline route is straightforward, and runs from the terminal directly to the CCGT onshore. Trenching may be necessary as a protective measure for the pipeline, in which case minor sediment suspension can be expected. A diffractive effect is expected around the GBS caisson, as its longitudinal side faces into the prevailing wave direction. Diffracted waves will create a distorted wave field to the leeward side of the GBS, but the effect is not expected to be substantial enough to contribute to shoreline erosion on at Big Bay, 4 km away.

The site may be far enough from sensitive Langebaan lagoon to use Open Rack Vapourisers at the terminal. A numerical flow model should be initiated to determine the thermal mixing regime of the discharged brine. Similar to the North Bay site, the Big Bay terminal does not interfere with designated mussel culture zones.

It is difficult to predict how the public will respond to the presence of a steel mooring tower or a hulking concrete GBS in Saldanha Bay. The terminal is perhaps close enough to the existing iron ore terminal not to draw criticism on the grounds of visual pollution. The GBS structure is very unorthodox however, and may be considered by many as an eyesore, unoccupied 6 days out of 7. It should be noted that the only operational GBS, the *Adriatic LNG* terminal in Rovigo, Italy, lies 14 km off the coastline.

9.12 Constructability

9.12.1 Introduction to LNG Terminal Constructability in Saldanha Bay

The ease of terminal construction will directly affect the construction time and the construction cost – perhaps the two most critical concepts in large scale infrastructure projects. The process of terminal construction should therefore be as simple as possible, and needlessly risky or unproven solutions should be avoided.

9.12.2 Site 1: Hoedjiespunt

Terminal Installation

The trestle jetty will be installed from the water side using a jack-up barge. The barge is suitable in such shallow water depths, and can easily manoeuvre to position to drive the steel piles. The barge should not experience wave downtime considering the benign wave climate at Site 1 (see Figure 8-17).

Material Delivery

Light construction material may be delivered to the small craft quay in Hoedjiespunt. Water depth is limited to 5.3 mCD here, and space is limited on the small quayside. Equipment may be transported directly from the quay to the construction yard, which will be reclaimed alongside the headland. Potential reclaimed construction yards are highlighted yellow in Figure 9-29. Larger materials may be delivered to the Mossgas quay at the north-eastern corner of Small Bay. This quay draws 7.9 m and is designed for heavy plant. There is an abundance of space for heavy material landward of the jetty. Heavy equipment may be brought to the terminal by road from here.


Figure 9-29 Small craft quay in Hoedjiespunt (l) and the Mossgas quay (r)

Landside Development

The land area required will be reclaimed used the dredge spoil from the channel dredging operation. Heavy plant used for earthworks and for LNG plant construction will come by road, through the town of Saldanha. This is not ideal, and will require the co-operation of the local authorities. Reclamation will not be necessary if a FSRU is used alongside the jetty.

Decommissioning

The lifespan of the onshore LNG tanks and plant is expected to be 30 years, as is that of the CCGT. The cost of decommissioning the onshore facilities is built into their respective capital costs. Once removed, the reclaimed site will be returned to a greenfield state. The jetty may still be in operational condition, (typically designed to last 50 years), and may be converted for some other terminal use.

9.12.3 Site 2: North Bay

Terminal Installation

A tower type SPM terminal will be installed using a jack up rig and floating cranes. The tower frame will require four corner piles for stability. The weathervaning structure will be lowered using a floating crane with dynamic positioning.

The GBS structure will be cast in a dedicated graving yard and floated into position at Saldanha[xxxiv]. The caisson will be gradually weighted down until it rests on the prepared level seabed. This is a very slow and delicate operation, and may take up to five weeks to lower into position (van Wijngaarden & Oomen, 2004), assuming a decent low wave window.

Both installations will be carried out from the sea. It is evident that the tower SPM is a far more simplistic design, with a much shorter lead time. The FSRU, should it be used, will be constructed by an Eastern boatbuilder as a separate contract.

Natural Gas Pipelines

Subsea natural gas (NG) pipelines will be installed between the terminal and Hoedjiespunt, and again from Hoedjiespunt to the CCGT site. A bottom tow installation method is suggested, using a concrete weighted carbon steel pipeline. A trench can be dredged to house the pipeline in the Small Bay area, protecting it from accidental anchor damage. Installation of the NG pipes on land is a far more simple affair, lowering each pipe section onto place by crane before stabilising and welding.

Decommissioning

The decommissioning of a steel SPM tower is straightforward, and very few elements need to be cut away and discarded. The same applies to NG pipelines. The GBS by contrast demands enormous time, cost and logistical effort. The caisson will be re-floated and shipped to a drydock capable of accommodating the unit, where the tank membrane will be disassembled and potentially reused. The reinforced concrete caisson will need to be discarded at sea, as it is unlikely it will be requested for use at another GBS or coastal protection project. Decommissioning costs are expected to be 10% to 20% of the initial total project realisation cost (van Wijngaarden & Oomen, 2004).

[xxxiv] In the case of the Adriatic LNG terminal, the GBS caisson was constructed in Algeciras and floated 3100km over 16 days to its installation position. The tanks were built in South Korea and shipped to Spain for installation.

9.12.4 Site 3: Big Bay – Causeway

Terminal Installation

The trestle jetty will be installed from the water side using a jack-up barge. As for Site 1, the barge should not experience wave downtime considering the low wave conditions beside the Causeway. Pile depths should be between 20 m to 40 m before striking the granite layer.

Material Delivery

Construction materials will be delivered to the Mossgas quay. This quay is incidentally on the "Future Port Expansion" site and access between quay and LNG regasification site should be unhindered. A decent, and quiet, road network joins the quay and the LNG processing site. The iron-ore railway and stockpile separates the two (Figure 9-30).

Figure 9-30 Road infrastructure from Mossgas quay to Hoedjiespunt (blue, on left) and to CCGT site (red, on right)

Landside Development

An excellent road network connects the LNG site to the national road infrastructure, and heavy plant can access the site with ease. Land preparation will be minimal, as the terrain is already very flat. Pipeline installation will not pose any difficulties as it is all above water level. The existing causeway structure will be used to suspend the pipeline on its route from terminal to storage tanks, or directly to CCGT if a FSRU terminal is selected.

9.12.5 Site 4: Big Bay – Open Water

The method of installation of both Tower SPM and GBS is practically the same as at Site 1. The wave climate at Site 4 is marginally lower however (see Figure 8-15), potentially resulting in less downtime during construction. The NG pipeline takes a direct route straight to the CCGT, thus reducing the installation time and costs compared to the North Bay scenario.

10 PROPOSED TERMINAL LAYOUT SCHEMES

LNG terminal design alternatives that result from a Downtime study and KDP analysis are used to generate potential Terminal Layout Schemes in this Chapter.

Four *conceptual site layouts* were developed in Chapter 7 following a study of the metocean characteristics of Saldanha Bay, and analysis of the wet and dry infrastructure necessary at the LNG terminal. These rudimentary layouts proposed initial options for terminal type, jetty orientation and channel orientation at four sites identified as suitable for development.

A downtime study was initiated to determine if any of the sites would be deemed unfeasible due to excessive wind or wave induced downtime.

In the previous Chapter a number of *key design parameters*, identified as having a significant influence on the technical design and operation of the LNG terminal, were analysed. This investigation revealed a number of design alternatives that are particular to each of the individual conceptual sites. Greater emphasis has been placed on the technical design of the terminal layout.

Design alternatives resulting from KDP analysis are used to generate a matrix of potential **Terminal Layout Schemes**. Twelve individual schemes have been developed, listed in Table 10-1. These schemes shall be considered as the basis for ultimate terminal design in the harbour. The schemes will be ranked according to technical merit in Chapter 11.

Table 10-1 List of potential Terminal Layout Schemes

Layout	Site	Terminal Type	LNG Storage and Vapourisation	NG pipelines to CCGT	Dredging	Reclamation
1a	Site 1 - Hoedjiespunt	Trestle Jetty	Onshore	Seabed	Yes	Yes
1b	Site 1 - Hoedjiespunt	Trestle Jetty	Onshore	On Land	Yes	Yes
1c	Site 1 - Hoedjiespunt	Trestle Jetty	FSRU	Seabed	Yes	No
1d	Site 1 - Hoedjiespunt	Trestle Jetty	FSRU	On Land	Yes	No
2a	Site 2 - North Bay	Tower SPM	FSRU	Seabed	No	No
2b	Site 2 - North Bay	Tower SPM	FSRU	On Land	No	No
2c	Site 2 - North Bay	GBS	Offshore	Seabed	No	No
2d	Site 2 - North Bay	GBS	Offshore	On Land	No	No
3a	Site 3 - Big Bay: Causeway	Trestle Jetty	Onshore	On Land	Yes	No
3b	Site 3 - Big Bay: Causeway	Trestle Jetty	FSRU	On Land	Yes	No
4a	Site 4 - Big Bay: Open Water	Tower SPM	FSRU	Seabed	No [a]	No
4b	Site 4 - Big Bay: Open Water	GBS	Offshore	Seabed	No [a]	No

[a] *Layout 4a & 4b may require light maintenance dredging*

11 MULTI CRITERIA ANALYSIS OF PROPOSED SCHEMES

The aim of this Chapter is to rank the twelve Terminal Layout Schemes in order of technical and operational merit. The Multi Criteria Analysis (MCA) method is used to rate the schemes, using a list of pre-determined parameters to score the attributes of each of the schemes.

11.1 Introduction MCA Method

Scoring Parameters, derived from the KDP study, will be assigned individual weights that reflect their relative importance in terminal design feasibility. The MCA method produces a matrix of parameter-scores for each of the 12 layout schemes. The scores are tallied and the layout with the highest cumulative score is deemed the most ideal design. Similarly the layout that acquires the lowest score will be the least desirable solution. The layout schemes are ranked from 1 to 12 in order of descending cumulative points.

The top three terminal layout schemes will be selected for further design development. Since there is some subjectivity in the allocation of Scoring Parameter weights, a brief sensitivity check will be conducted to understand the variability of the results.

11.2 MCA Scoring Parameters

The Scoring Parameters used to rate the layout schemes are developed from observations made in Chapter 9, where the Key Design Parameters were scrutinised. Sixteen Scoring Parameters have been identified, listed as follows:

Construction Aspects

- Installation: complexity of terminal berth and time required to construct
- Dredging: volumes, cost and implications of dumping spoil
- Access to construction site (both land and sea) during construction
- Land area: preparation for construction – earthworks and reclamation
- LNG tank and vapouriser construction: time, cost and ease of construction (includes FSRUs)
- Natural gas pipelines: length, cost, land access, environmental effects
- Wave induced downtime during terminal construction

Operational Aspects

- Wave penetration and downtime during operation
- Wind wave penetration
- Ease of navigation and berthing
- Wind loading on vessel during approach, cargo transfer and departure
- Access to LNG land based facilities and room for future expansion
- Safety exclusion zones: distance to other port users
- Risk to environment during construction and operation

Other

- Terminal type: confidence in technology and industry experience in operation
- Decommissioning of structure or potential for re-use of infrastructure

11.3 Baseline MCA

11.3.1 Scoring Parameter Weightings

The sixteen Scoring Parameters are each assigned a relative weight, out of 10, that reflects their overall contribution to a feasible and efficient LNG terminal. These weightings, listed in Table 11-1, form inputs into the baseline MCA, which is intended to represent a balanced technical solution to the design problem.

Table 11-1 Scoring Parameter weightings for baseline MCA

Construction

Installation complexity & time	**6**
Dredging	**5**
Access to site during construction	**2**
Land preparation	**2**
Regas and Storage construction	**3**
Natural Gas pipelines	**3**
Construction Downtime	**4**
Confidence in terminal technology	**7**

Operation

Wave penetration & downtime	**8**
Wind wave penetration	**4**
Navigation	**7**
Wind loading on LNGC	**6**
Land access and future expansion	**4**
Safety	**5**
Environmental	**6**
Decommissioning & reuse	**3**

It may be noticed that the focus falls on the operational aspects of the terminal layouts as opposed to construction aspects. This slight bias highlights the importance of the terminal as a long term asset of national importance, and places less emphasis on the overnight capital costs. The terminal should take no more than two years to construct, and "time to gas" should be no more than three years. By contrast, the terminal must be fully functional for the following 30 years, providing a reliable gas feedstock to the CCGT plant.

A heavy emphasis is placed on industry confidence in terminal technologies. Floating and offshore technologies are in their infancy whereas the standard land-attached jetty boasts over 40 years of operational success. The terminal cannot afford any downtime resulting from unproven design solutions. Should the terminal construction be postponed by say 10 or 20 years, this weight of this Scoring Parameter will reduce drastically as the industry gains confidence in the use of newer technologies.

11.3.2 MCA Matrix

The 12 terminal layout schemes are awarded points out of ten according to their specific fulfilment of each Scoring Parameter. Points awarded per parameter are multiplied by the parameter weights assigned in the previous Section. This is repeated for each parameter, and the total accumulated weighted score for each layout is determined. The procedure is repeated for each terminal scheme. The MCA table produced using the Scoring Parameter weights given in the previous Section is shown overleaf as Table 11-2.

This process is best illustrated with an example:

Example: Consider the **Dredging** parameter in the baseline MCA (Table 11-2). Schemes 2a to 2d are allocated a maximum of 10/10 points, as dredging will not be necessary in North Bay during the construction or operational phases of the terminal. Schemes 4a and 4b are allocated 9 points, as low volumes of initial and maintenance dredging are expected. Schemes based in Hoedjiespunt (1a to 1d) are allocated 6 points, since approximately 600,000 m^3 of dredge material must be removed. This is not an insubstantial figure, but by no means compares with the 25,000,000 m^3 dredged during port construction, or even the 2,000,000 m^3 removed in 1997 for the expansion of the multi-purpose terminal (Anchor Environmental, 2011). Finally the nearshore schemes proposed in Big Bay are awarded a low 3 points, as roughly 1,200,000 m^3 of material – double that of Hoedjiespunt – must be dredged to create a suitable approach channel.

This method of layout scheme rating is applied for each of the Scoring Parameters listed on the left of Table 11-1. The ratings are multiplied by the fixed parameter weight, and then summed in each layout scheme column. Comparison of the column totals provides an indication of the preferred terminal layout schemes.

Subjectivity

The subjectivity of the Scoring Parameter weights will be later addressed by a sensitivity check. It can also be argued that the rating awarded to each terminal scheme per Scoring Parameter is somewhat subjective. These relative scores have been assigned following the information given in Chapter 9, where the Key Design Parameters are discussed. The ratings (out of 10) may be subjective, but the relative rank per terminal should still be observed.

Table 11-2 MCA analysis of Terminal Layout Schemes using balanced Scoring Parameters

			Terminal Layout Scheme											
	Scoring Parameter	**Weight**	***1a***	***1b***	***1c***	***1d***	***2a***	***2b***	***2c***	***2d***	***3a***	***3b***	***4a***	***4b***
Construction	Installation complexity & time	**6**	7	7	7	7	8	8	4	4	7	7	8	4
	Dredging	**5**	6	6	6	6	10	10	10	10	3	3	9	9
	Access to site during construction	**2**	4	4	5	5	6	6	6	6	8	8	6	6
	Land preparation	**2**	3	3	3	3	9	9	9	9	9	9	9	9
	Regas and Storage construction	**3**	5	5	8	8	8	8	2	2	5	8	8	5
	Natural Gas pipelines	**3**	3	4	3	4	3	4	3	4	9	8	5	5
	Construction Downtime	**4**	8	8	8	8	3	3	3	3	8	8	4	4
Operation	Wave penetration & downtime	**8**	8	8	8	8	4	4	3	3	8	8	4	3
	Wind wave penetration	**4**	8	8	8	8	4	4	4	4	4	4	8	8
	Navigation	**7**	8	8	7	7	8	8	4	4	7	6	7	4
	Wind loading on LNGC	**6**	7	7	7	7	5	5	3	3	7	7	5	3
	Land access and future expansion	**4**	5	5	5	5	9	9	9	9	9	9	9	9
	Safety	**5**	5	5	5	5	5	5	5	5	7	7	9	9
	Environmental	**6**	5	5	5	5	7	7	7	7	6	6	6	6
	Confidence in terminal technology	**7**	9	9	8	8	4	4	5	5	9	8	4	5
	Decommissioning & reuse	**3**	7	7	7	7	8	8	1	1	7	7	8	1
	TOTAL	-	**495**	**498**	**492**	**495**	**462**	**465**	**358**	**361**	**527**	**519**	**490**	**402**

11.3.3 Interpretation of results

The terminal layout schemes are ranked from 1 to 12 in descending order of total points. The ranking order using baseline weighting is presented in Table 11-3. A number of observations can be drawn from the table. Most importantly, the **Top 3** schemes are ***3a*** (Big Bay Causeway site, trestle jetty, onshore regasification), ***3b*** (Big Bay Causeway site, trestle jetty, FSRU regasification) and ***1b*** (Hoedjiespunt Site, trestle jetty, onshore regasification, overland gas pipes).

There exists a healthy points gap between the Top 3 schemes: Layout 3a scores 527 points, layout 3b scores 519 points and layout 1b scores 498 points. However just 8 points separate the 5 layouts ranked between third and seventh place. Such a narrow margin raises concern over the confidence level of the 3rd placed layout. The sensitivity checks that follow this Section should shed light on the deserving 3rd place contender. There is a significant jump again to the layout ranked in 8th position.

Table 11-3 Ranking of Terminal Layout Schemes using baseline weighting

Rank	Layout	Site	Score
1	3a	Site 3 - Big Bay: Causeway	527
2	3b	Site 3 - Big Bay: Causeway	519
3	1b	Site 1 - Hoedjiespunt	498
4	1a	Site 1 - Hoedjiespunt	495
4	1d	Site 1 - Hoedjiespunt	495
6	1c	Site 1 - Hoedjiespunt	492
7	4a	Site 4 - Big Bay: Open Water	490
8	2b	Site 2 - North Bay	465
9	2a	Site 2 - North Bay	462
10	4b	Site 4 - Big Bay: Open Water	402
11	2d	Site 2 - North Bay	361
12	2c	Site 2 - North Bay	358

The order of rank in Table 11-3 clearly illustrated the preferred Sites, namely Site 3 - Big Bay: Causeway, Site 1 - Hoedjiespunt and Site 4 - Big Bay: Open Water. It also appears that trestle jetties, whether standard or with FRSU, take preference over the offshore technologies. Of the offshore terminals the SPM/Tower system overshadows the GBS type terminal.

11.4 Sensitivity Analysis

11.4.1 Introduction to Sensitivity Analysis of Scoring Parameter Weightings

A sensitivity analysis is employed to understand the impact on rankings that a variation in Scoring Parameter weightings might have. The original baseline weightings were contrived to achieve a balanced terminal layout that focused on cost efficiency, technical merit, short construction time and reliable operation. Four additional MCA analyses are initiated, with bias towards environmental repercussions, minimising terminal downtime, increasing safety for additional port users, and cost effectiveness.

11.4.2 Environmentally Biased Weighting

Greater emphasis is placed on the Scoring Parameters that directly affect the local environment during construction and operation. The “Environmental” parameter weight is increased to a maximum 10 multiplier points. “Dredging”, “Natural Gas pipelines” and “Decommissioning and re-use”, having secondary influences, are raised to 6 multiplier points. The resulting layout scheme ranking is shown in Table 11-4.

Table 11-4 Ranking of Terminal Layout Schemes using environmentally biased weighting

Rank	Layout	Site	Score
1	3a	Site 3 - Big Bay: Causeway	602
2	3b	Site 3 - Big Bay: Causeway	591
3	4a	Site 4 - Big Bay: Open Water	562
4	1b	Site 1 - Hoedjiespunt	557
5	1d	Site 1 - Hoedjiespunt	554
6	1a	Site 1 - Hoedjiespunt	551
7	1c	Site 1 - Hoedjiespunt	548
8	2b	Site 2 - North Bay	539
9	2a	Site 2 - North Bay	533
10	4b	Site 4 - Big Bay: Open Water	453
11	2d	Site 2 - North Bay	414
12	2c	Site 2 - North Bay	408

Layouts 3a and 3b remain in first and second position, while layout ***4a*** (Big Bay Open Water site, SPM/Tower terminal, FSRU regasification) has climbed four places and now lies in 3rd place. This performance can be attributed to the minimal dredging requirements of the terminal, and the short, direct natural gas pipeline to the CCGT. There lies a five point jump to layout 1b, lying in 4th place.

11.4.3 Downtime Biased Weighting

The Downtime sensitivity check focuses on the parameters that are likely to influence operational downtime, and to a lesser extent construction downtime. The “Wave penetration & downtime” parameter is increased to a maximum 10 multiplier points. “Construction downtime”, “Navigation”, “Wind loading on LNGC” and “Confidence in terminal technology” are increased to 8 multiplier points, whereas the less influential “Wind wave penetration” parameter is increased to 6 points. The resulting layout scheme ranking is shown in Table 11-5.

Table 11-5 Ranking of Terminal Layout Schemes using downtime biased weighting

Rank	Layout	Site	Score
1	3a	Site 3 - Big Bay: Causeway	613
2	3b	Site 3 - Big Bay: Causeway	603
3	1b	Site 1 - Hoedjiespunt	593
4	1a	Site 1 - Hoedjiespunt	590
5	1d	Site 1 - Hoedjiespunt	588
6	1c	Site 1 - Hoedjiespunt	585
7	4a	Site 4 - Big Bay: Open Water	551
8	2b	Site 2 - North Bay	515
9	2a	Site 2 - North Bay	512
10	4b	Site 4 - Big Bay: Open Water	455
11	2d	Site 2 - North Bay	402
12	2c	Site 2 - North Bay	399

The downtime biased MCA results in the same Top 3 schemes as the baseline scenario. A similar points margin separates the leading schemes. The top sites remain Big Bay Causeway, Hoedjiespunt and Big Bay Open Water, in that order. It should be noted that the Big Bay Causeway options lie in first and second, while the four Hoedjiespunt alternatives lie in 3rd to 6th position. This ranking order can be attributed to the natural shelter provided at both Sites.

11.4.4 Safety Biased Weighting

The Safety sensitivity check emphasises the parameters that are likely to affect the personal safety of LNG terminal operators and of other port users. Attention is paid to distances from exclusion zones, and the likelihood of occurrence of an incident that may lead to LNG spill (rupture of loading arms at manifold, grounding, collision etc.). The "Safety" parameter is increased to 10 multiplier points, while "Navigation", "Wind loading on LNG" and "Confidence in terminal technology" weights are increased to 8 points. The resulting layout scheme ranking is shown in Table 11-6.

Table 11-6 Ranking of Terminal Layout Schemes using safety biased weighting

Rank	Layout	Site	Score
1	3a	Site 3 - Big Bay: Causeway	601
2	3b	Site 3 - Big Bay: Causeway	590
3	1b	Site 1 - Hoedjiespunt	563
4	1a	Site 1 - Hoedjiespunt	560
4	4a	Site 4 - Big Bay: Open Water	560
6	1d	Site 1 - Hoedjiespunt	557
7	1c	Site 1 - Hoedjiespunt	554
8	2b	Site 2 - North Bay	516
9	2a	Site 2 - North Bay	513
10	4b	Site 4 - Big Bay: Open Water	467
11	2d	Site 2 - North Bay	406
12	2c	Site 2 - North Bay	403

Similar to the baseline MCA and the downtime biased MCA, the safety biased investigation reveals **layouts 3a**, **3b** and **1b** to be the optimal terminal layout schemes. Layouts 4a and 1a are tied in 4th position. A narrow nine point margin separates 3rd and 7th position.

11.4.5 Cost Biased Weighting

The majority of terminal capital costs are incurred during the construction phase of the project. Capital cost is not anticipated during the operational stage, unless the LNG terminal is expanded to increase capacity. Decommissioning of the terminal and plant will account for between 5% and 20% of expenditure (van Wijngaarden & Oomen, 2004). The parameter "Installation complexity & time" is raised to a maximum score of 10 points, while "Dredging" is awarded 9 multiplier points. "Land preparation" and "Construction downtime" are increased to 8 multiplier points, and "Regasification plant and storage tank construction" and "Natural Gas pipelines" are assigned 6 points. The resulting layout scheme ranking is shown in Table 11-7.

Table 11-7 Ranking of Terminal Layout Schemes using cost biased weighting

Rank	Layout	Site	Score
1	3a	Site 3 - Big Bay: Causeway	709
2	3b	Site 3 - Big Bay: Causeway	707
3	4a	Site 4 - Big Bay: Open Water	683
4	2b	Site 2 - North Bay	655
5	2a	Site 2 - North Bay	649
6	1d	Site 1 - Hoedjiespunt	647
7	1b	Site 1 - Hoedjiespunt	641
7	1c	Site 1 - Hoedjiespunt	641
9	1a	Site 1 - Hoedjiespunt	635
10	4b	Site 4 - Big Bay: Open Water	556
11	2d	Site 2 - North Bay	503
12	2c	Site 2 - North Bay	497

Again, terminal layout schemes 3a and 3b top the scoreboard, with layout 4a in third position. It is interesting to note that North Bay layouts 2b and 2a have leapfrogged into 4th and 5th position. Together with layout 4a in 3rd position, these represent the three SPM/Tower type terminal configurations considered in this study.

Though the construction costs of a tower terminal may be lower than standard terminals, the poor performance of layouts 2b and 2a in the other MCA analyses will exclude them from further design consideration. It should be duly noted that the three GBS alternatives, 2c, 2d and 4b finished with the least amount of points in each of the 5 MCA exercises. This may be attributed to the complexity of their design and installation, high downtime and cost of the unit. The design seeks to perform as an offshore terminal solution, yet it needs the assistance of a full tug fleet, which requires a sheltered operational environment to assist berthing.

11.5 Summary of MCA Analysis

The baseline MCA aimed to favour well-balanced and operationally superior terminal layout schemes. According this ranking method the Top 3 schemes are 3a, 3b and 1b. Four additional MCA studies were conducted, placing emphasis on environmental effects, downtime, safety and cost. Following this sensitivity exercise, layout schemes 3a and 3b unanimously rank 1st and 2nd, respectively. The third-placed scheme flits between layout 1b and layout 4a.

It is decided to rank layout 1b as the third placed scheme. Of the MCA exercises conducted, layout 1b is preferred to 4a three out of five times. Furthermore, the strong placing of the Hoedjiespunt site alternatives (schemes 1a, 1b, 1c & 1d) in all the MCA studies illustrates confidence in this site and the trestle jetty technology.

The characteristics of the Top 3 layouts are summarised in Table 11-8.

Table 11-8 Summary of Top 3 Terminal Layout Schemes following MCA analysis

Rank	Layout	Site	Terminal Type	LNG Storage and Vapourisation	NG pipelines to CCGT	Dredging	Reclamation
1	3a	Site 3 - Big Bay: Causeway	Trestle Jetty	Onshore	On Land	Yes	No
2	3b	Site 3 - Big Bay: Causeway	Trestle Jetty	FSRU	On Land	Yes	No
3	1b	Site 1 - Hoedjiespunt	Trestle Jetty	Onshore	On Land	Yes	Yes

12 FINAL LAYOUT OPTIONS FOR SALDANHA LNG TERMINAL

Three LNG import terminal layout schemes for Saldanha Bay have been selected following a Multi Criteria Analysis exercise. These rudimentary layouts have been shaped by the prevailing metocean conditions in Saldanha Bay, the wet and dry infrastructure demands of LNG terminals and the influence of existing port layout and operations. The Top 3 terminal layout schemes are described in this Chapter.

12.1 Introduction to Final Layout Options

In order to select an ultimate scheme, a technical pre-feasibility study must be undertaken, focusing on the three layouts presented in Chapter 11. This detailed study typically requires input from a number of specialists in the fields of coastal engineering, environmental management, logistics, structural design, financial planning, port operations, geological survey and port design. The study will revisit the key design parameters listed in Chapter 9 with greater zeal and specialist focus. The goal of the study is to narrow the potential terminal schemes to a single scheme with a definitive layout.

The technical pre-feasibility study does not fall within the scope of this thesis. Three conceptual terminal layouts have been justified for consideration in Saldanha Bay. The three design concepts are elaborated in this Chapter, and their individual idiosyncrasies are described. Individual elements of the terminal schemes are described in depth in *Chapter 9 – Key Design Parameters.*

12.2 Scheme 1 – Layout 3A – Standard Import Jetty by Big Bay Causeway

Scheme 1 – Layout 3A – is a standard trestle jetty terminal with land based storage and regasification facilities. The **jetty** is situated approximately 600 m east of the existing iron ore causeway, in line with the multi-purpose terminal. The berth is orientated south by south-southwest to allow prevailing waves to strike starboard bow and prevailing wind to strike port bow. The berth is likely to be configured with six mooring dolphins and four berthing dolphins[xxxv].

The jetty is accessed via a dredged **approach channel**, which leads from the existing port turning circle. The 2500 m long channel is dredged to -16.9 mCD and is 250 m wide. The channel runs south-southwest, ensuring wave attack is directly on the bow as the LNG carrier is reversed into the berth. An estimated 1,200,000 m^3 of seabed material will be removed during the dredging process. The dredge spoil will be deposited in the reclamation dam adjacent the iron ore stockpile.

LNG will be pumped from the vessel's manifold using unloading arms housed on the jetty's deck. The cargo will be offloaded at a rate of approximately 10,000 m^3/hr. Insulated **cryogenic pipelines** will transfer the LNG cargo from the manifold to LNG storage tanks onshore over a distance of 3.8 km. The cargo is stored onshore in two **insulated tanks**, each capable of holding 150,000 m^3 of LNG, where it awaits regasification.

The regasification facilities are required to convert 321 T of LNG into natural gas per hour. The **vapourisers**, probably Open Rack Vapourisers, will deliver 417,000 m^3/hr of natural gas to the Combined Cycle Gas Turbine.

[xxxv] Estimated. The exact mooring configuration must be verified in a detailed design study.

Figure 12-1 Scheme 1 – Layout 3A – Standard Import Jetty by Big Bay Causeway

The land-based regasification facilities and the CCGT will be located east of the iron ore stockpile. The site is contained within the zone designated for future port expansion by the Saldanha Bay municipality. Storage tanks and vapourisers are expected to occupy up to 13 ha whereas the CCGT footprint will be 8 ha. There is ample room for expansion onshore.

The **wave climate** at the terminal is benign. The 1% exceedance wave height is H_s=0.43 m. Berthing operations are not expected to be thwarted by wave attack at any time. The **wind climate** across the Bay is more problematic. The maximum berthing windspeed of 12 m/s is exceeded 6% of the time. This limitation affects all terminal sites.

Terminal Layout Scheme 1 – Layout 3A – is illustrated in Figure 12-1.

12.3 Scheme 2 – Layout 3B – FSRU at Trestle Jetty by Big Bay Causeway

The layout and orientation of Scheme 2 are very similar to Scheme 1. The storage and regasification facilities differ considerably in that the LNG is processed at the berth aboard a Floating, Storage and Regasification Unit. The FSRU is permanently moored alongside a **trestle jetty**, situated approximately 600 m east of the existing iron ore causeway and in line with the multi-purpose terminal. The berth is orientated south by south-southwest to allow prevailing waves to strike starboard bow and prevailing wind to strike port bow.

A 2500 m long **approach channel** leads from the existing port turning circle. The channel is dredged to -16.9 mCD and is 250 m wide. The channel runs south-southwest, ensuring wave attack is directly on the bow as the LNG carrier is reversed into the berth. Four **tugs**, each with a bollard pull of 65 T, are required to safely manoeuvre the LNGC. The tugs will rotate the vessel in the existing turning circle before directing it towards the LNG berth. The LNGC moors alongside the permanently moored FSRU before offloading.

LNG is pumped from the LNGC into the containment tanks aboard the FSRU. The LNG is regasified aboard using deck-mounted vapourisers, probably Submerged Combustion Vapourisers. **Natural gas** output from the on-board vapourisers is piped ashore to the CCGT via a 3.8 km raised carbon steel pipeline. The CCGT will be located east of the iron ore stockpile, and is expected to occupy 8 ha.

The **wave climate** at the terminal is benign. The 1% exceedance wave height is H_s=0.43 m.

Figure 12-2 illustrates the FSRU terminal concept of Scheme 2 – Layout 3B. A membrane type LNGC can be seen berthed alongside a larger FSRU.

12.4 Scheme 3 – Layout 1B – Standard Import Jetty at Hoedjiespunt

Scheme 3 – Layout 1B – is a standard trestle jetty terminal with land based storage and regasification facilities. The **jetty** is situated approximately 650 m east of the Hoedjiespunt point and 700 m north of the leeward side of the breakwater. The berth is orientated due south to keep the prevailing wind on the bow. The berth is likely to be configured with six mooring dolphins and four berthing dolphins.

The jetty is accessed via a dredged **approach channel**, which leads from the existing port turning circle. The 1500 m long channel is dredged to -16.9 mCD and is 250 m wide. The channel runs southeast, ensuring wave attack is directly on the bow as the LNG carrier is reversed into the berth.

An estimated 600,000 m^3 of seabed material will be removed during the dredging process. The dredge spoil will be used as reclamation material to create additional land space to the lee of the existing breakwater. The reclaimed land will attach to Hoedjiespunt headland to the northwest and will run adjacent to the breakwater in a south-easterly direction.

LNG will be pumped from the vessel's manifold using unloading arms housed on the jetty's offloading deck. Insulated **cryogenic pipelines** will transfer the LNG cargo from the manifold to LNG storage tanks onshore over a distance of just 400 m. The cargo is stored onshore in two **insulated tanks**, each capable of holding 150,000 m^3 of LNG, where it awaits regasification. The **vapourisers**, probably Submerged Combustion Vapourisers, will deliver 417,000 m^3/hr of natural gas to the Combined Cycle Gas Turbine.

The land-based regasification facilities and storage tanks will be located on the reclaimed land, whereas the CCGT will be situated east of the iron ore stockpile. Storage tanks and vapourisers are expected to occupy 13 ha whereas the CCGT footprint will be 8 ha. Should additional land be required for supplementary LNG storage tanks in the future, further reclamation may be feasible in a north-westerly direction towards the TNPA small craft harbour.

Natural gas will be carried from the vapourisers in Hoedjiespunt to the CCGT via a 20 km overland pipeline that runs north of Saldanha town. Should land access for pipeline installation be refused, Scheme 1A may alternatively be implemented, which delivers natural gas to the CCGT via an 8 km pipeline, 4 km of which lies on the Small Bay seabed.

The **wave climate** at the terminal is benign. The 1% exceedance wave height is H_s=0.37 m. Berthing operations are not expected to be affected by wave attack at any time.

Terminal Layout Scheme 3 – Layout 1B – is illustrated in Figure 12-3.

Figure 12-2 Scheme 2 – Layout 3B – FSRU at Trestle Jetty by Big Bay Causeway

Figure 12-3 Scheme 3 – Layout 1B – Standard Import Jetty at Hoedjiespunt

13 FUTURE RESEARCH AND RECOMMENDATIONS

The scope of this study was to present conceptual terminal layout options for the import of LNG into Saldanha Bay. Three layout schemes have been described in the previous Chapter. In order to confidently select one layout option for construction in the Bay, an intensive technical pre-feasibility study of the three qualifying schemes must be executed. The investigative steps involved in this future phase are listed below.

Finally, the author selects his preferred terminal layout, and puts forth arguments in favour of the scheme. These arguments are subjective and may be somewhat biased, though they are founded on the theory presented in this research thesis. Description of the preferential site should be considered as commentary only, and does not form part of the research scope.

13.1 Future Research

The three selected terminal layout schemes should be subjected to a second round of technical scrutiny. The layouts should be critically re-examined according to the Key Design Parameters (KDP's) discussed in Chapter 9 and their performances compared. This pre-feasibility study may require the technical assistance of specialists in the fields defined by these parameters. An additional level of complexity may be introduced to the technical review, with focus on elements such as capital costs, maintenance cost, downtime and structural design. The specific dimensions of the terminal should be investigated, as should the mooring configuration.

A detailed MCA study will be conducted to rank the three terminals, and one single layout will eventually be selected. At this stage cost, constructability and operational proficiency will begin to define the layout.

A feasibility study should begin with reference to a single conceptual layout scheme. The exact location of the terminal berth will be decided following dedicated numerical studies of wave action in the Bay. Terminal and approach channel orientations will be decided, and dimensions of both the wet and dry infrastructure will be defined. The mooring configuration can be calculated following a study of vessel motions at the berth. Both numerical and physical models may be employed to quantify the degree of vessel movement.

The impact of long waves in the harbour cannot be neglected as this will define the mooring configuration, and in extreme scenarios may impact on the choice of berth orientation and siting.

Geotechnical investigations will advise on the structural requirements of the terminal. Detailed structural design will begin to unfold. Material supplies must be considered, particularly if rock is necessary. Planning becomes critical at this stage. Many elements of the LNG value chain will require significant lead time to mobilise, such as the CCGT, vapourisers or an FSRU. LNG product is not as critical, as "spot cargoes" may be purchased while mid or long term contracts are agreed. Environmental planning begins to take hold and an EIA must be initiated. Planning regulations must be scrutinised and potential show-stoppers must be weeded out. Regular interaction with the public and IAPs must take place throughout the course of this process.

Should the subsequent design prove feasible the detailed design phase can begin. Exact dimensions of the terminal elements will be confirmed and detailed structural design of both wet and dry infrastructure will commence. The logistics of site and hinterland access, and the practicalities of construction will be considered. The mooring configuration will be refined and the operational process of the harbour will be streamlined.

The design process, from conceptual site planning, to conclusive detailed design, may take between 2-3 years without any delays. The construction of the site elements, including the CCGT, may take an additional 30-36 months. It is therefore recommended that the holistic design process be carried out as soon as possible, whether or not terminal construction immediately follows. The benefit of having a pre-prepared design and construction plan is that the “time to gas” is reduced to just 36 months as opposed to 5 or 6 years, should the decision to construct go ahead.

13.2 Author’s Recommendation

Unable to refer to a detailed technical pre-feasibility study, the author has based his recommendation for terminal layout on the technical performance of the schemes discussed in Chapters 9, 10 and 11.

Scheme 2 – Layout 3B – is recommended. The scheme consists of a standard trestle “L” jetty located in Big Bay, 600 m east of the multipurpose terminal quay. LNG storage and regasification facilities are provided aboard an FSRU vessel, moored alongside the jetty.

The sole difference between Scheme 1 and Scheme 2 is the use of a Floating Storage and Regasification Unit alongside the jetty. Scheme preference is therefore defined by the floating vs. traditional technology argument.

Some features of Scheme 2, additional to those already noted in previous Chapters, are listed below.

Short Start Up Time
The process of converting an LNG carrier into an FSRU will take under 2 years. The construction of land-based storage and regasification facilities is expected to take at least 1 year longer than this.

Less Land Infrastructure Required
The onshore site will consist of NG pipelines and the CCGT plant. Reduction time and demands are therefore reduced.

Aesthetics
The NIMBY attitude of the public is addressed somewhat by the FSRU alternative. The greatest cause for complaint at standard terminals, understandably, is the sight of the colossal LNG storage tanks, which measure 50 m in height and 100 m in width. It is far more visually appealing to see a vessel moored by the jetty, accompanied by a second vessel once a week, than to see the permanent landside infrastructure. Furthermore, the FSRU does not instil the perception of permanence, as storage tanks do.

Natural Gas Pipelines

Pipelines carrying natural gas from the FSRU vapourisers to the CCGT are standard carbon steel pipelines, suspended above the jetty and the causeway. These lines are far cheaper than cryogenic pipelines used to transport LNG (Layout 3A) and span 3.8 km as opposed to 20 km (Layout 1B).

Location of CCGT

The vapourisers aboard the FSRU may be open loop or closed loop, depending on the environmental demands or mitigation decisions following the feasibility study. Either way, the CCGT will be unable to recycle heating water discharged from the FSRU (in the case of ORV vapourisers). The CCGT location is therefore more flexible, as it is not bound to the vapouriser site.

Lower Decommission Costs

Should the CCGT reach the end of its useable lifetime (≈30yrs), the trestle jetty, designed to last 50 years, can easily be retrofitted to accommodate other cargo vessels. Storage tanks or vapourisers will not have to be dismantled, as they are self-contained on the FSRU.

Flexibility of FSRU Unit & Contract

The primary benefits of the FSRU solution is that the storage and regasification elements of the terminal are 1) mobile 2) temporary and 3) leased under contract.

The FSRU supplier is fully responsible for the construction, delivery and operation of the vessel, removing a significant amount of responsibility from the port developer.

Additionally, the lease period of the unit can be short, mid or long term, depending on LNG demand. This concept is critical considering South Africa's mid-term prospects for natural gas production. If, for example, the Karoo shale or the Ibhubesi offshore fields begin producing in the short or midterm future, the FSRU lease can be annulled, and local natural gas can fire the CCGT plant. This option would not be feasible if permanent land based LNG facilities were installed.

Lower Capital Costs

FSRU terminals are reported to cost approximately 50% of the capital cost of standard shore-based terminals (Blackwell & Skaar, 2009). Port developers have recently begun to ditch established land based terminal designs in favour of floating terminals to help reduce costs (Bloomberg, 2013).

Disadvantages

There are, naturally, some disadvantages associated with this scheme, aside from those diagnosed in the MCA. One possible hurdle is the limiting **size of the storage tanks** aboard the FSRU. The terminal throughput analysis (Chapter 4) has identified the optimum storage tank size to be 300,000 m^3. At present, the largest FSRU on the order books has a capacity of 263,000 m3, due to be delivered in 2016 (MOL, 2013). With a standard bundle of 145,000 m^3 and a storage volume of 263,000 m^3, the buffer period before LNG depletion drops from 9.1 days to 6.9 days. This effect may be countered by reducing the delivery volume and increasing the delivery frequency. A sensitivity analysis should be initiated to estimate the operational limits of the FSRU tank capacity.

An additional concern is that the terminal location inhibits any future development landwards of the terminal (i.e. between the jetty and the reclamation dam). The jetty protrudes 600 m from the causeway to maintain a 500 m safety buffer, and **restricts access to the shallow water area** in the northwest corner of the Bay in doing so. A solution may be to move the terminal much nearer the shore, enabling a longer tract of causeway to be used for future development. This approach will necessitate substantial dredging however, and should only be considered if significant growth and berth demand is predicted in Saldanha Bay. This port Masterplanning issue should be addressed before conducting any pre-feasibility studies in order to identify any future port expansion schemes.

It should be remembered that this recommendation is the personal view of the author, and does not form part of the project scope.

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APPENDICES

APPENDIX A – SANHO Charts
APPENDIX B – Spatial Development Framework Plans
APPENDIX C – SWAN Model – Output Wave Conditions at Conceptual Sites
APPENDIX D – Nomograph of Wind Generated Wave Height Curves
APPENDIX E – Existing LNGC Fleet
APPENDIX F – Geotechnical Survey – Eastern Margin of Iron Ore Terminal

APPENDIX A - SANHO Charts

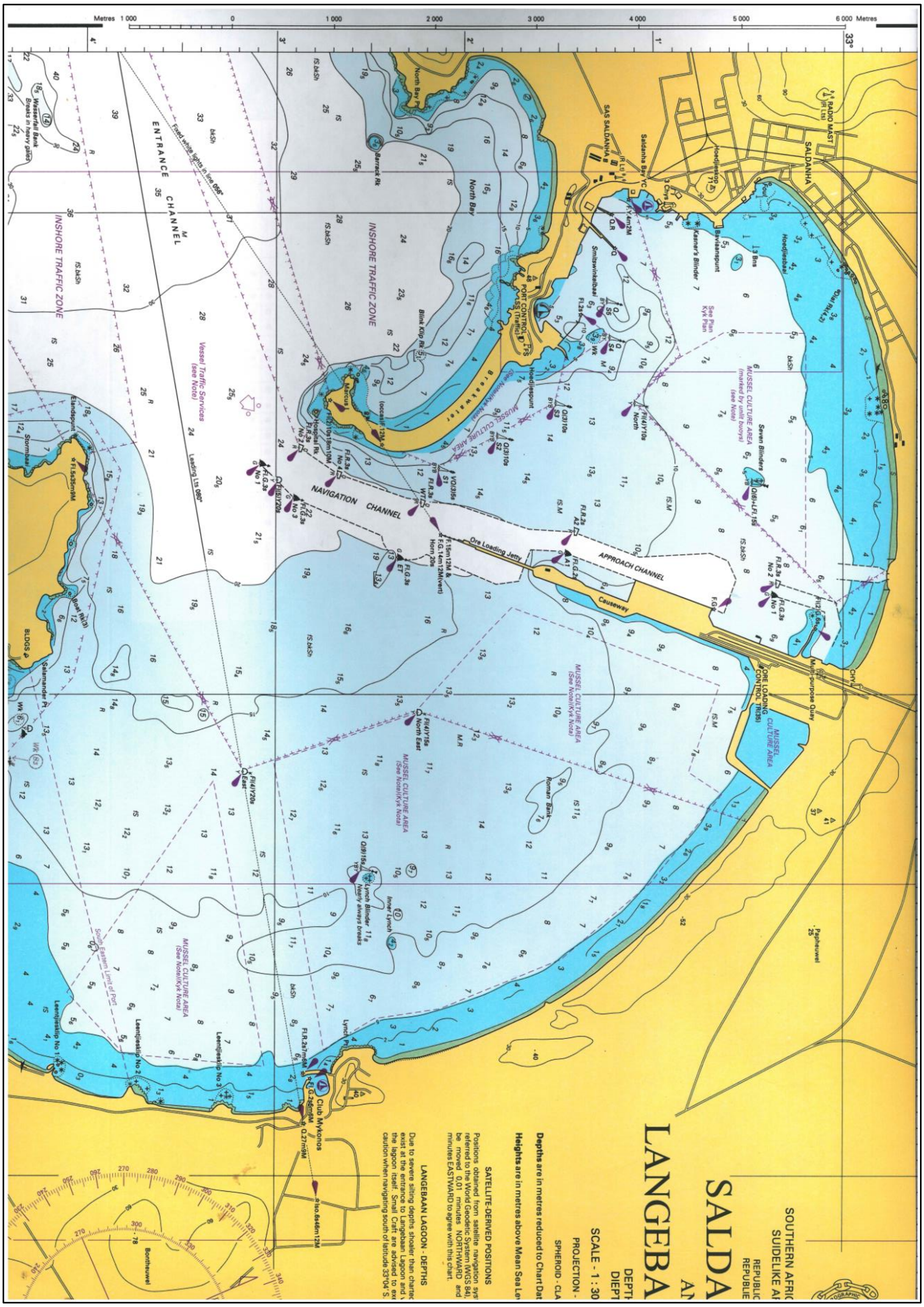

Figure A-1 Excerpt from SAN SC2

Source: South African Navy Hydrographic Office (SANHO, 2000)

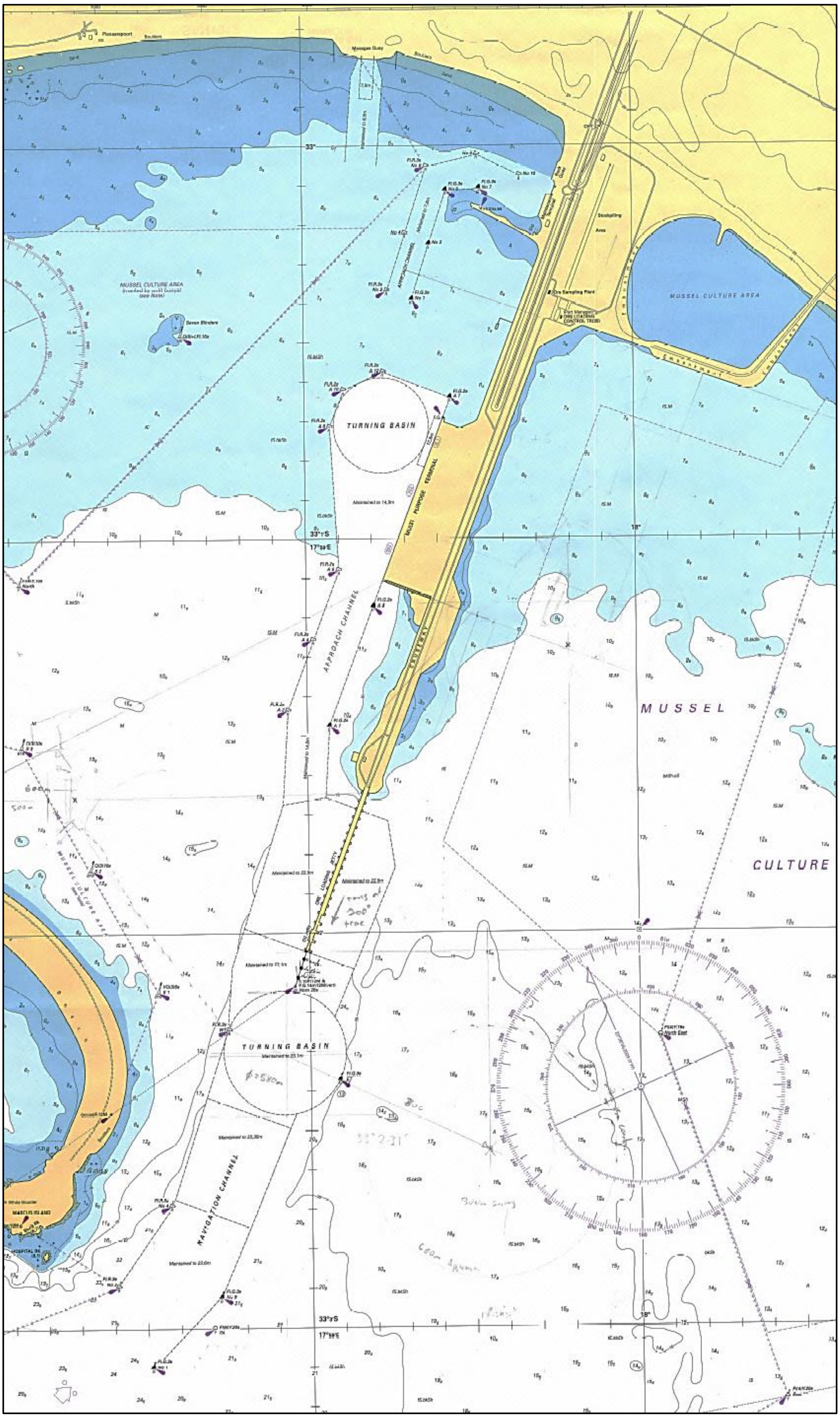

Figure A-2 Excerpt from SAN 1012

Source: South African Navy Hydrographic Office (SANHO, 1999)

Figure A-3 Excerpt from SAN 1010

Source: South African Navy Hydrographic Office (SANHO, 2007)

APPENDIX B – Spatial Development Framework Plans

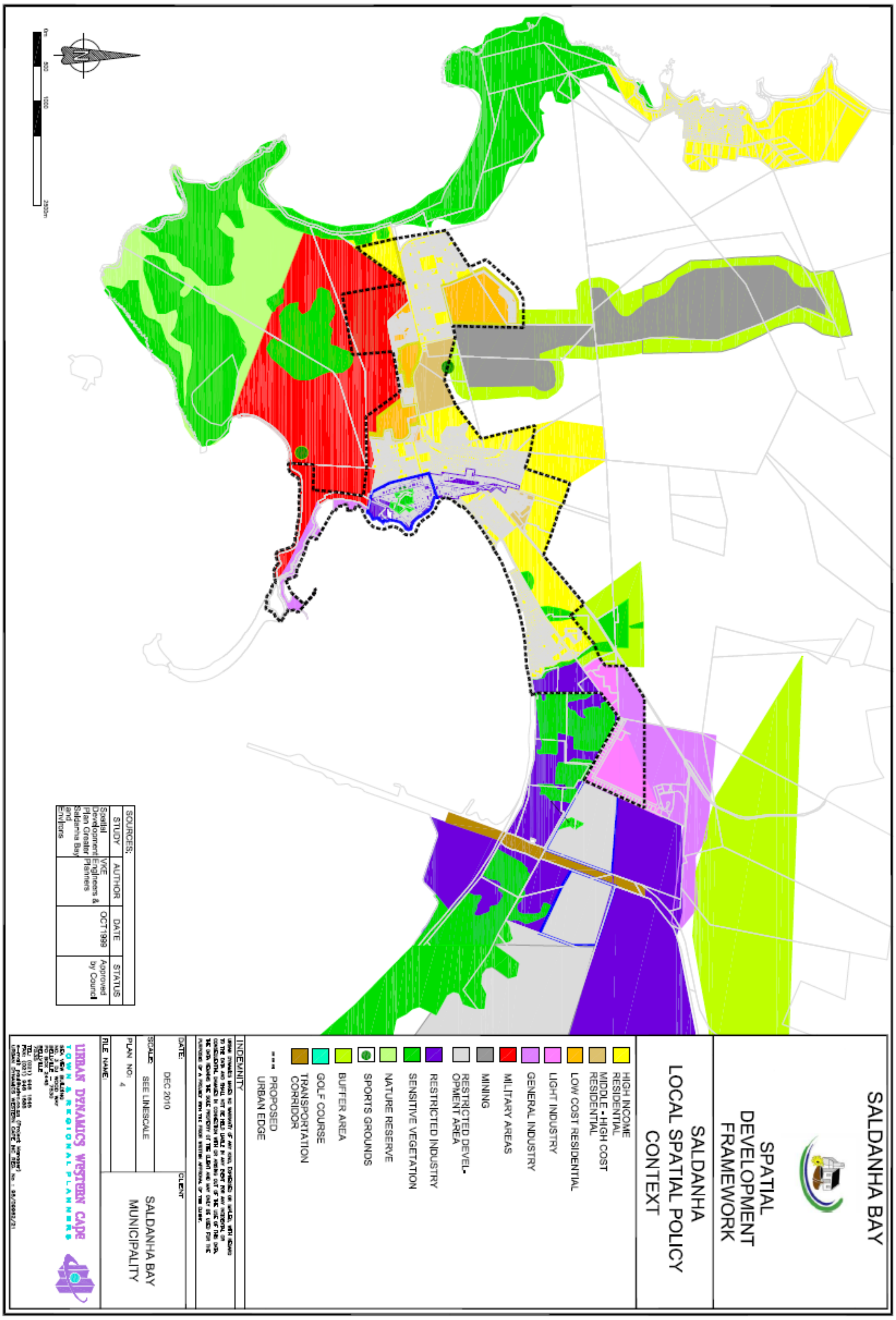

Figure B-1 SDF Zoning - Saldanha Local Spatial Policy Context

Source: Urban Dynamics Western Cape (2011)

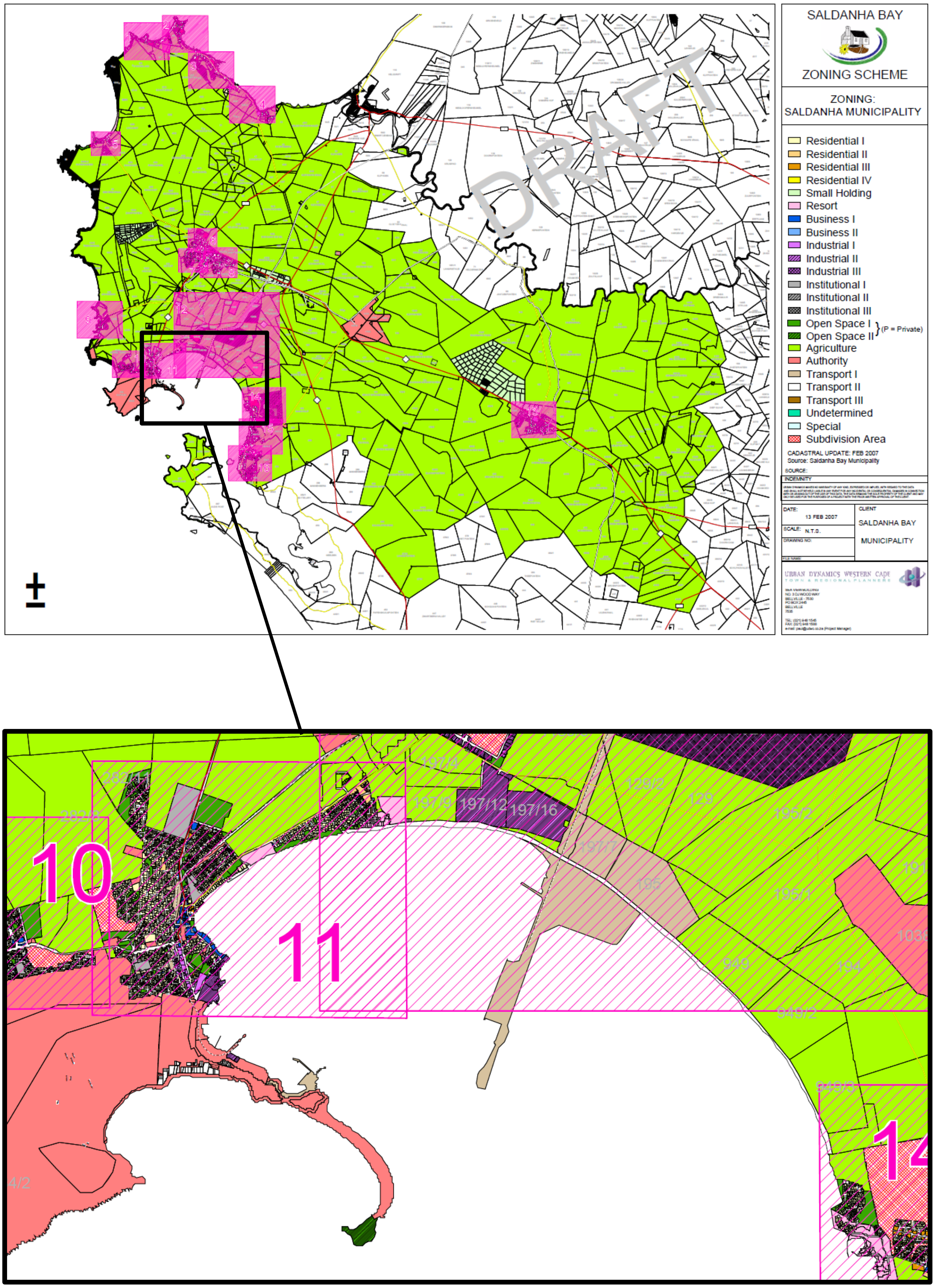

Figure B-2 SDF Zoning – Saldanha Municipality

Source: Urban Dynamics Western Cape (2011)

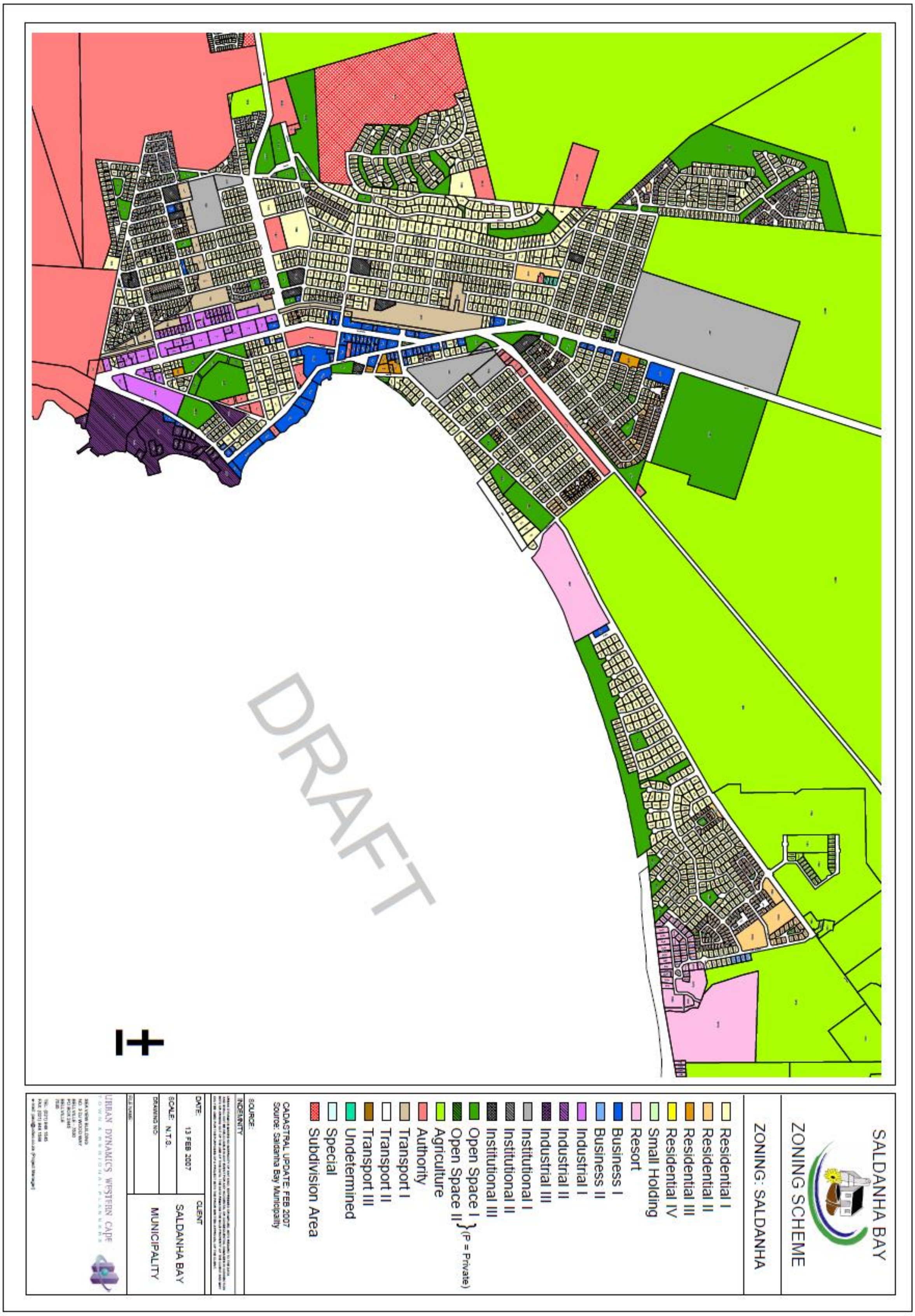

Figure B-3 SDF Zoning Scheme: Saldanha

Source: Urban Dynamics Western Cape (2011)

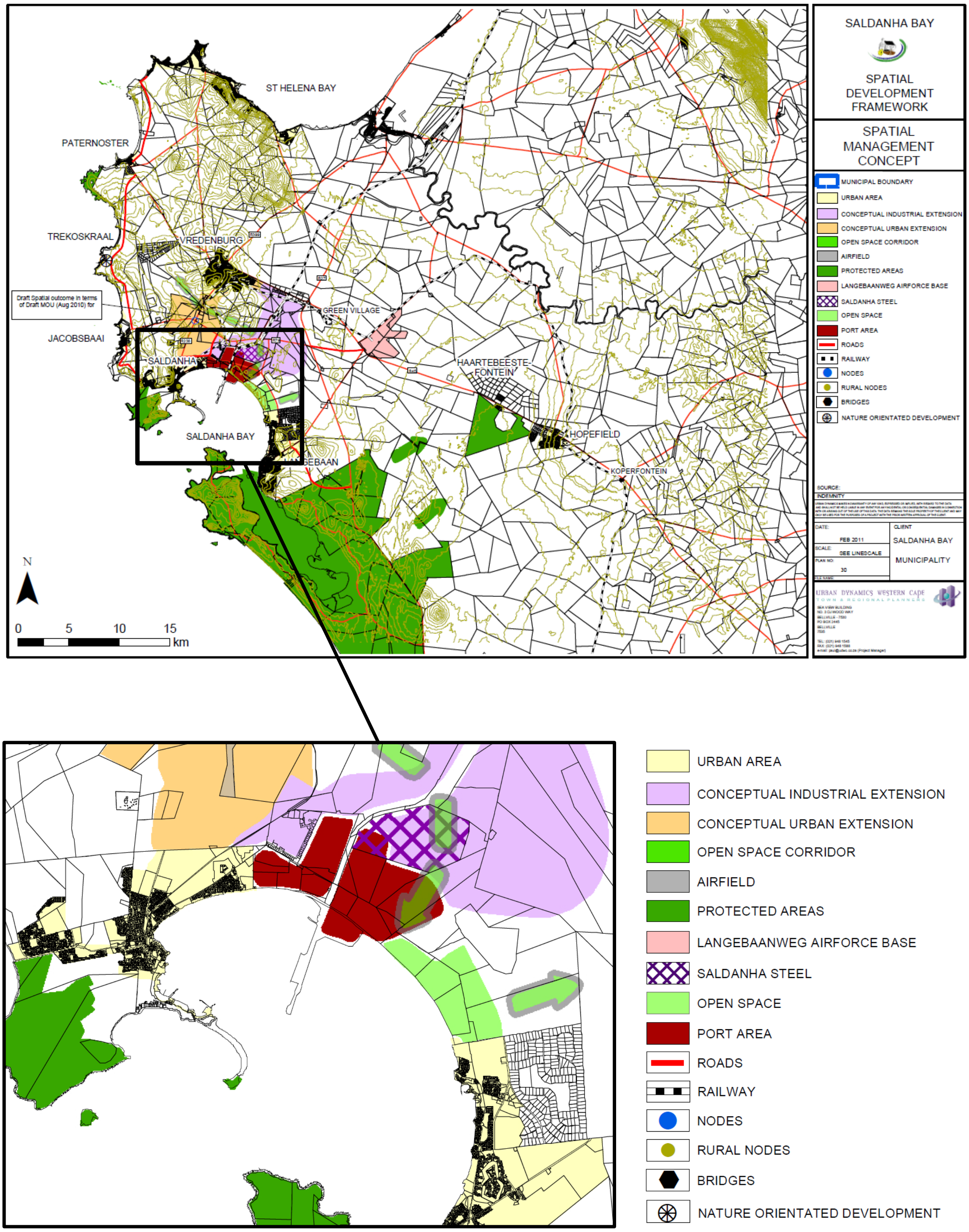

Figure B-4 SDF Zoning – Spatial Management Concept

Source: Urban Dynamics Western Cape (2011)

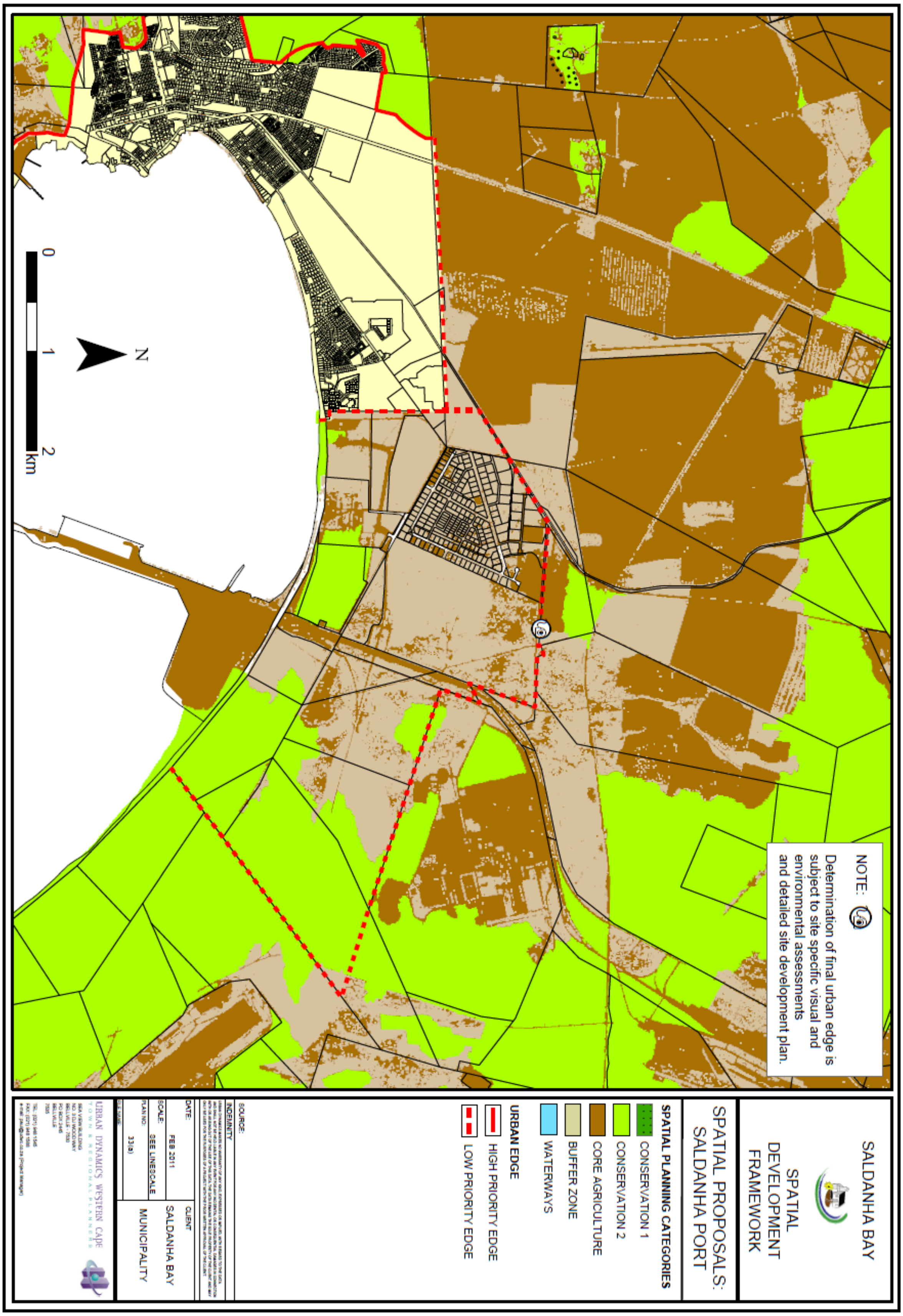

Figure B-5 SDF Zoning – Proposed Port Spatial Zoning

Source: Urban Dynamics Western Cape (2011)

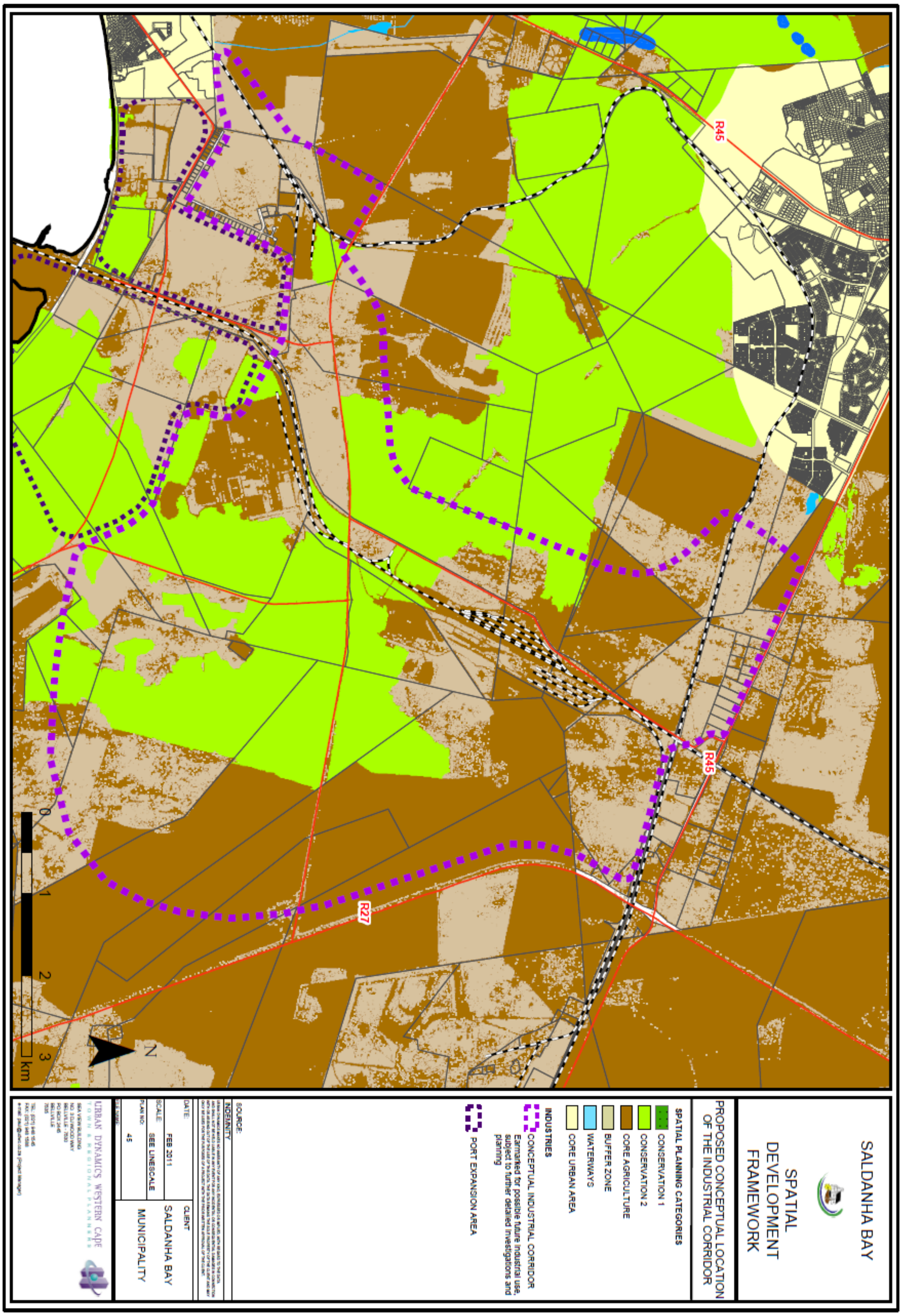

Figure B-6 SDF – Proposed Conceptual Location of Industrial Corridor and Port Expansion Area

Source: Urban Dynamics Western Cape (2011)

APPENDIX C – SWAN Model - Output Wave Conditions at Conceptual Sites

Tables of derived wave characteristics using SWAN model

Table C-1 Derived wave conditions at Site 0: Waverider Buoy using SWAN model

	INPUT				OUTPUT					
Run ID	**Dirn**	**Hs**	**Tp**	**av spr**	**Loc**	**Loc #**	**Dirn**	**Hs**	**Tp**	**av spr**
210_01	210	3	12	23	Waverider SB01	0	237	1.53	11.5	9
210_04	210	6	12	23	Waverider SB01	0	237	2.96	11.5	9
210_07	210	9	12	23	Waverider SB01	0	238	4.17	11.5	9
210_02	210	3	16	23	Waverider SB01	0	239	1.61	16.4	8
210_05	210	6	16	23	Waverider SB01	0	239	3.12	16.4	8
210_08	210	9	16	23	Waverider SB01	0	239	4.49	16.4	8
210_03	210	3	20	23	Waverider SB01	0	239	1.69	19.6	8
210_06	210	6	20	23	Waverider SB01	0	239	3.27	19.6	8
210_09	210	9	20	23	Waverider SB01	0	240	4.71	19.6	8
235_01	235	3	12	23	Waverider SB01	0	241	1.79	11.5	9
235_04	235	6	12	23	Waverider SB01	0	241	3.46	11.5	9
235_07	235	9	12	23	Waverider SB01	0	241	4.84	11.5	9
235_02	235	3	16	23	Waverider SB01	0	241	1.80	16.4	8
235_05	235	6	16	23	Waverider SB01	0	241	3.50	16.4	8
235_08	235	9	16	23	Waverider SB01	0	242	5.06	16.4	8
235_03	235	3	20	23	Waverider SB01	0	242	1.86	19.6	7
235_06	235	6	20	23	Waverider SB01	0	242	3.60	19.6	7
235_09	235	9	20	23	Waverider SB01	0	242	5.22	19.6	7
255_01	255	3	12	23	Waverider SB01	0	244	1.70	11.5	9
255_04	255	6	12	23	Waverider SB01	0	244	3.29	11.5	9
255_07	255	9	12	23	Waverider SB01	0	244	4.65	11.5	8
255_02	255	3	16	23	Waverider SB01	0	243	1.70	16.4	8
255_05	255	6	16	23	Waverider SB01	0	243	3.31	16.4	8
255_08	255	9	16	23	Waverider SB01	0	243	4.82	16.4	8
255_03	255	3	20	23	Waverider SB01	0	243	1.75	19.6	7
255_06	255	6	20	23	Waverider SB01	0	243	3.39	19.6	7
255_09	255	9	20	23	Waverider SB01	0	243	4.94	19.6	7
280_01	280	3	12	23	Waverider SB01	0	248	1.26	11.5	8
280_04	280	6	12	23	Waverider SB01	0	247	2.45	11.5	8
280_07	280	9	12	23	Waverider SB01	0	248	3.52	11.5	8
280_02	280	3	16	23	Waverider SB01	0	246	1.30	16.4	8
280_05	280	6	16	23	Waverider SB01	0	246	2.54	16.4	8
280_08	280	9	16	23	Waverider SB01	0	246	3.71	16.4	8
280_03	280	3	20	23	Waverider SB01	0	246	1.36	19.6	8
280_06	280	6	20	23	Waverider SB01	0	246	2.63	19.6	8
280_09	280	9	20	23	Waverider SB01	0	246	3.85	19.6	8

Table C-2 Derived wave conditions at Site 1: Hoedjiespunt using SWAN model

	INPUT				OUTPUT					
Run ID	**Dirn**	**Hs**	**Tp**	**av spr**	**Loc**	**Loc #**	**Dirn**	**Hs**	**Tp**	**av spr**
210_01	210	3	12	23	Hoedjiespunt	1	143	0.21	11.5	7
210_04	210	6	12	23	Hoedjiespunt	1	143	0.41	11.5	6
210_07	210	9	12	23	Hoedjiespunt	1	143	0.58	11.5	6
210_02	210	3	16	23	Hoedjiespunt	1	142	0.23	16.4	7
210_05	210	6	16	23	Hoedjiespunt	1	142	0.43	16.4	7
210_08	210	9	16	23	Hoedjiespunt	1	142	0.62	16.4	7
210_03	210	3	20	23	Hoedjiespunt	1	142	0.24	19.6	7
210_06	210	6	20	23	Hoedjiespunt	1	142	0.45	19.6	7
210_09	210	9	20	23	Hoedjiespunt	1	142	0.64	19.6	7
235_01	235	3	12	23	Hoedjiespunt	1	143	0.21	11.5	6
235_04	235	6	12	23	Hoedjiespunt	1	143	0.40	11.5	6
235_07	235	9	12	23	Hoedjiespunt	1	143	0.56	11.5	6
235_02	235	3	16	23	Hoedjiespunt	1	142	0.22	16.4	6
235_05	235	6	16	23	Hoedjiespunt	1	142	0.41	16.4	6
235_08	235	9	16	23	Hoedjiespunt	1	142	0.59	16.4	6
235_03	235	3	20	23	Hoedjiespunt	1	142	0.22	19.6	6
235_06	235	6	20	23	Hoedjiespunt	1	142	0.42	19.6	6
235_09	235	9	20	23	Hoedjiespunt	1	142	0.60	19.6	6
255_01	255	3	12	23	Hoedjiespunt	1	143	0.17	11.5	6
255_04	255	6	12	23	Hoedjiespunt	1	143	0.33	11.5	6
255_07	255	9	12	23	Hoedjiespunt	1	143	0.47	11.5	6
255_02	255	3	16	23	Hoedjiespunt	1	142	0.19	16.4	6
255_05	255	6	16	23	Hoedjiespunt	1	142	0.36	16.4	6
255_08	255	9	16	23	Hoedjiespunt	1	142	0.52	16.4	6
255_03	255	3	20	23	Hoedjiespunt	1	142	0.20	19.6	6
255_06	255	6	20	23	Hoedjiespunt	1	142	0.38	19.6	6
255_09	255	9	20	23	Hoedjiespunt	1	142	0.54	19.6	6
280_01	280	3	12	23	Hoedjiespunt	1	143	0.12	11.5	6
280_04	280	6	12	23	Hoedjiespunt	1	143	0.22	11.5	6
280_07	280	9	12	23	Hoedjiespunt	1	143	0.32	11.5	6
280_02	280	3	16	23	Hoedjiespunt	1	142	0.14	16.4	6
280_05	280	6	16	23	Hoedjiespunt	1	142	0.27	16.4	6
280_08	280	9	16	23	Hoedjiespunt	1	142	0.39	16.4	6
280_03	280	3	20	23	Hoedjiespunt	1	142	0.16	19.6	6
280_06	280	6	20	23	Hoedjiespunt	1	142	0.30	19.6	6
280_09	280	9	20	23	Hoedjiespunt	1	142	0.44	19.6	6

Table C-3 Derived wave conditions at Site 2: North Bay using SWAN model

	INPUT				OUTPUT					
Run ID	**Dirn**	**Hs**	**Tp**	**av spr**	**Loc**	**Loc #**	**Dirn**	**Hs**	**Tp**	**av spr**
210_03	210	3	12	23	North Bay	2	210	1.61	11.5	10
210_06	210	6	12	23	North Bay	2	210	3.09	11.5	10
210_09	210	9	12	23	North Bay	2	210	4.30	11.5	9
210_04	210	3	16	23	North Bay	2	211	1.57	16.4	9
210_07	210	6	16	23	North Bay	2	211	3.03	16.4	8
210_10	210	9	16	23	North Bay	2	210	4.40	16.4	8
210_05	210	3	20	23	North Bay	2	211	1.59	19.6	9
210_08	210	6	20	23	North Bay	2	211	3.06	19.6	8
210_11	210	9	20	23	North Bay	2	211	4.45	19.6	7
235_01	235	3	12	23	North Bay	2	214	1.32	11.5	10
235_04	235	6	12	23	North Bay	2	213	2.54	11.5	10
235_07	235	9	12	23	North Bay	2	213	3.53	11.5	9
235_02	235	3	16	23	North Bay	2	213	1.27	16.4	9
235_05	235	6	16	23	North Bay	2	213	2.45	16.4	9
235_08	235	9	16	23	North Bay	2	213	3.56	16.4	8
235_03	235	3	20	23	North Bay	2	213	1.28	19.6	9
235_06	235	6	20	23	North Bay	2	213	2.46	19.6	8
235_09	235	9	20	23	North Bay	2	212	3.58	19.6	8
255_01	255	3	12	23	North Bay	2	218	0.92	11.5	11
255_04	255	6	12	23	North Bay	2	217	1.77	11.5	10
255_07	255	9	12	23	North Bay	2	217	2.48	11.5	10
255_02	255	3	16	23	North Bay	2	216	0.90	16.4	10
255_05	255	6	16	23	North Bay	2	216	1.74	16.4	10
255_08	255	9	16	23	North Bay	2	215	2.52	16.4	9
255_03	255	3	20	23	North Bay	2	216	0.93	19.6	10
255_06	255	6	20	23	North Bay	2	215	1.79	19.6	10
255_09	255	9	20	23	North Bay	2	215	2.59	19.6	9
280_01	280	3	12	23	North Bay	2	223	0.49	11.5	11
280_04	280	6	12	23	North Bay	2	222	0.93	11.5	11
280_07	280	9	12	23	North Bay	2	222	1.32	11.5	11
280_02	280	3	16	23	North Bay	2	221	0.53	16.4	12
280_05	280	6	16	23	North Bay	2	221	1.00	16.4	12
280_08	280	9	16	23	North Bay	2	220	1.45	16.4	12
280_03	280	3	20	23	North Bay	2	220	0.58	19.6	12
280_06	280	6	20	23	North Bay	2	220	1.10	19.6	12
280_09	280	9	20	23	North Bay	2	219	1.57	19.6	12

Table C-4 Derived wave conditions at Site 3: Big Bay Causeway using SWAN model

	INPUT				OUTPUT					
Run ID	**Dirn**	**Hs**	**Tp**	**av spr**	**Loc**	**Loc #**	**Dirn**	**Hs**	**Tp**	**av spr**
210_04	210	3	12	23	Big Bay Causeway	3	209	0.31	11.5	8
210_07	210	6	12	23	Big Bay Causeway	3	209	0.56	11.5	8
210_10	210	9	12	23	Big Bay Causeway	3	207	0.68	11.5	9
210_05	210	3	16	23	Big Bay Causeway	3	206	0.26	16.4	9
210_08	210	6	16	23	Big Bay Causeway	3	206	0.48	16.4	9
210_11	210	9	16	23	Big Bay Causeway	3	205	0.65	16.4	9
210_06	210	3	20	23	Big Bay Causeway	3	204	0.24	19.6	9
210_09	210	6	20	23	Big Bay Causeway	3	204	0.46	19.6	9
210_12	210	9	20	23	Big Bay Causeway	3	204	0.64	19.6	9
235_01	235	3	12	23	Big Bay Causeway	3	209	0.27	11.5	8
235_04	235	6	12	23	Big Bay Causeway	3	209	0.48	11.5	8
235_07	235	9	12	23	Big Bay Causeway	3	207	0.60	11.5	9
235_02	235	3	16	23	Big Bay Causeway	3	206	0.22	16.4	9
235_05	235	6	16	23	Big Bay Causeway	3	206	0.41	16.4	9
235_08	235	9	16	23	Big Bay Causeway	3	206	0.56	16.4	9
235_03	235	3	20	23	Big Bay Causeway	3	205	0.21	19.6	9
235_06	235	6	20	23	Big Bay Causeway	3	205	0.39	19.6	9
235_09	235	9	20	23	Big Bay Causeway	3	204	0.55	19.6	9
255_01	255	3	12	23	Big Bay Causeway	3	209	0.19	11.5	8
255_04	255	6	12	23	Big Bay Causeway	3	208	0.35	11.5	8
255_07	255	9	12	23	Big Bay Causeway	3	207	0.46	11.5	9
255_02	255	3	16	23	Big Bay Causeway	3	206	0.17	16.4	9
255_05	255	6	16	23	Big Bay Causeway	3	206	0.32	16.4	9
255_08	255	9	16	23	Big Bay Causeway	3	206	0.46	16.4	9
255_03	255	3	20	23	Big Bay Causeway	3	205	0.17	19.6	9
255_06	255	6	20	23	Big Bay Causeway	3	205	0.32	19.6	9
255_09	255	9	20	23	Big Bay Causeway	3	205	0.46	19.6	9
280_01	280	3	12	23	Big Bay Causeway	3	207	0.10	11.5	9
280_04	280	6	12	23	Big Bay Causeway	3	207	0.20	11.5	9
280_07	280	9	12	23	Big Bay Causeway	3	206	0.27	11.5	9
280_02	280	3	16	23	Big Bay Causeway	3	205	0.11	16.4	9
280_05	280	6	16	23	Big Bay Causeway	3	205	0.22	16.4	9
280_08	280	9	16	23	Big Bay Causeway	3	205	0.32	16.4	9
280_03	280	3	20	23	Big Bay Causeway	3	204	0.13	19.6	9
280_06	280	6	20	23	Big Bay Causeway	3	204	0.24	19.6	9
280_09	280	9	20	23	Big Bay Causeway	3	204	0.35	19.6	9

Table C-5 Derived wave conditions at Site 2: Big Bay Open Water using SWAN model

	INPUT				OUTPUT					
Run ID	**Dirn**	**Hs**	**Tp**	**av spr**	**Loc**	**Loc #**	**Dirn**	**Hs**	**Tp**	**av spr**
210_05	210	3	12	23	Big Bay: Open Water	4	239	1.22	11.5	6
210_08	210	6	12	23	Big Bay: Open Water	4	239	2.34	11.5	6
210_11	210	9	12	23	Big Bay: Open Water	4	239	3.28	11.5	6
210_06	210	3	16	23	Big Bay: Open Water	4	239	1.30	16.4	6
210_09	210	6	16	23	Big Bay: Open Water	4	239	2.49	16.4	6
210_12	210	9	16	23	Big Bay: Open Water	4	240	3.59	16.4	6
210_07	210	3	20	23	Big Bay: Open Water	4	240	1.37	19.6	6
210_10	210	6	20	23	Big Bay: Open Water	4	240	2.63	19.6	6
210_13	210	9	20	23	Big Bay: Open Water	4	240	3.78	19.6	6
235_01	235	3	12	23	Big Bay: Open Water	4	240	1.47	11.5	6
235_04	235	6	12	23	Big Bay: Open Water	4	240	2.81	11.5	6
235_07	235	9	12	23	Big Bay: Open Water	4	241	3.94	11.5	6
235_02	235	3	16	23	Big Bay: Open Water	4	241	1.54	16.4	6
235_05	235	6	16	23	Big Bay: Open Water	4	241	2.96	16.4	6
235_08	235	9	16	23	Big Bay: Open Water	4	241	4.27	16.4	6
235_03	235	3	20	23	Big Bay: Open Water	4	241	1.62	19.6	6
235_06	235	6	20	23	Big Bay: Open Water	4	241	3.10	19.6	6
235_09	235	9	20	23	Big Bay: Open Water	4	241	4.47	19.6	6
255_01	255	3	12	23	Big Bay: Open Water	4	241	1.39	11.5	6
255_04	255	6	12	23	Big Bay: Open Water	4	241	2.68	11.5	6
255_07	255	9	12	23	Big Bay: Open Water	4	242	3.78	11.5	6
255_02	255	3	16	23	Big Bay: Open Water	4	242	1.51	16.4	6
255_05	255	6	16	23	Big Bay: Open Water	4	242	2.90	16.4	6
255_08	255	9	16	23	Big Bay: Open Water	4	242	4.19	16.4	5
255_03	255	3	20	23	Big Bay: Open Water	4	242	1.61	19.6	5
255_06	255	6	20	23	Big Bay: Open Water	4	242	3.08	19.6	5
255_09	255	9	20	23	Big Bay: Open Water	4	242	4.45	19.6	5
280_01	280	3	12	23	Big Bay: Open Water	4	243	0.98	11.5	5
280_04	280	6	12	23	Big Bay: Open Water	4	243	1.90	11.5	5
280_07	280	9	12	23	Big Bay: Open Water	4	243	2.72	11.5	5
280_02	280	3	16	23	Big Bay: Open Water	4	243	1.15	16.4	5
280_05	280	6	16	23	Big Bay: Open Water	4	243	2.23	16.4	5
280_08	280	9	16	23	Big Bay: Open Water	4	243	3.24	16.4	5
280_03	280	3	20	23	Big Bay: Open Water	4	243	1.29	19.6	5
280_06	280	6	20	23	Big Bay: Open Water	4	243	2.48	19.6	5
280_09	280	9	20	23	Big Bay: Open Water	4	243	3.60	19.6	5

Plots of derived significant wave height using SWAN model

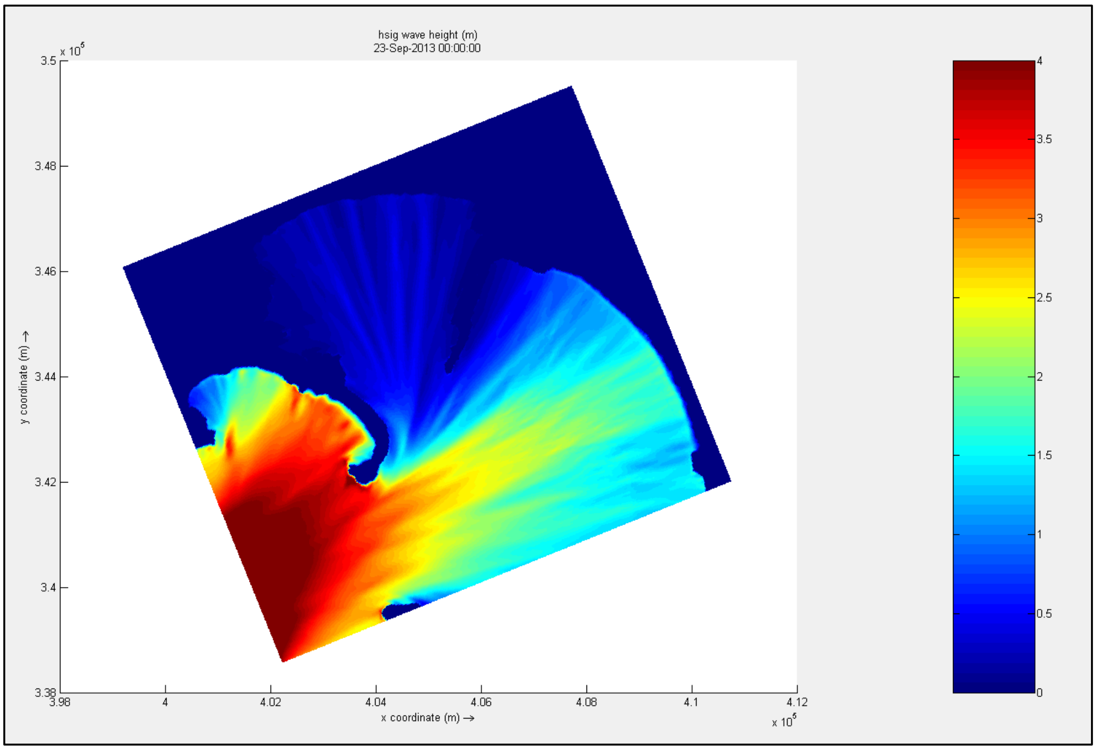

Figure C-1 Significant wave (H_s) penetration plot for offshore H_s=6 m T_p=12s

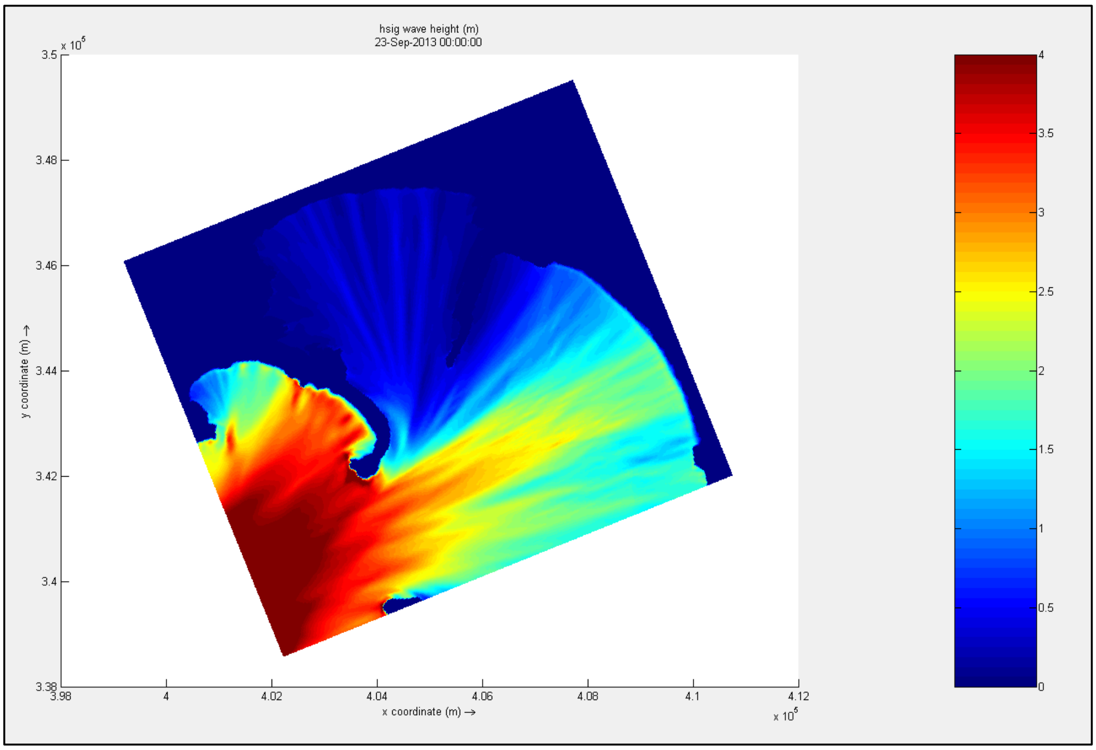

Figure C-2 Significant wave (H_s) penetration plot for offshore H_s=6 m T_p=16s

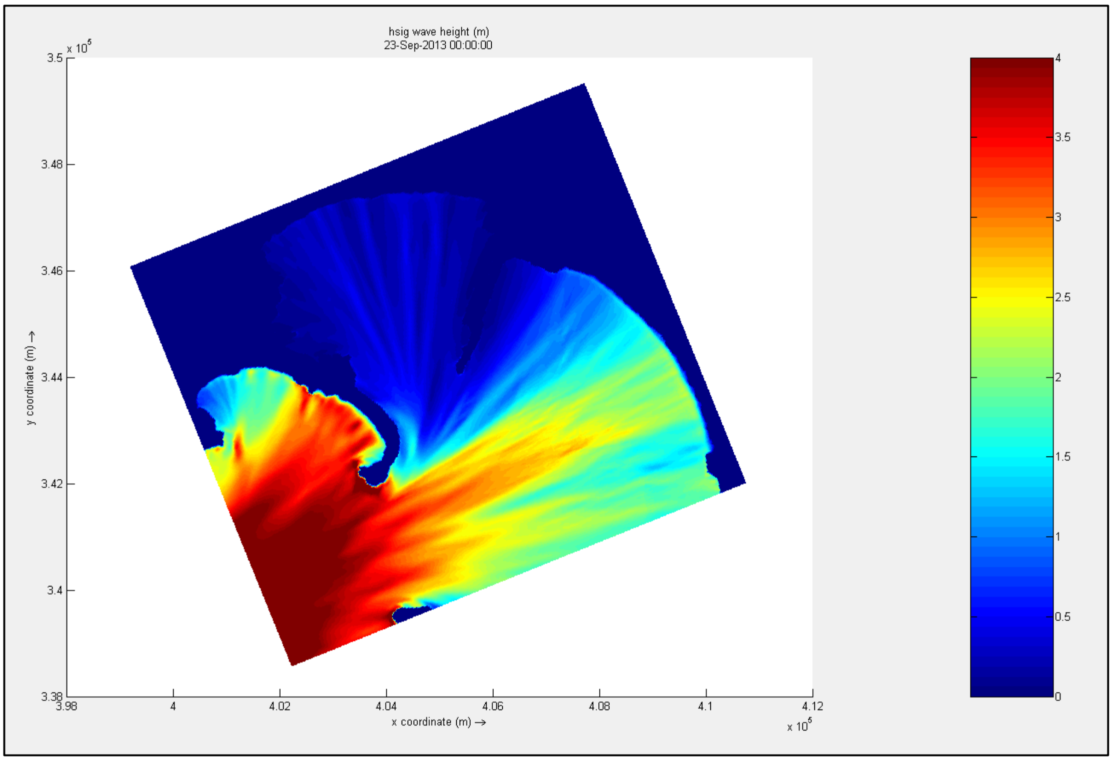

Figure C-3 Significant wave (H_s) penetration plot for offshore H_s=6 m T_p=20s

APPENDIX D - Nomograph of Wind Generated Wave Height Prediction Curves

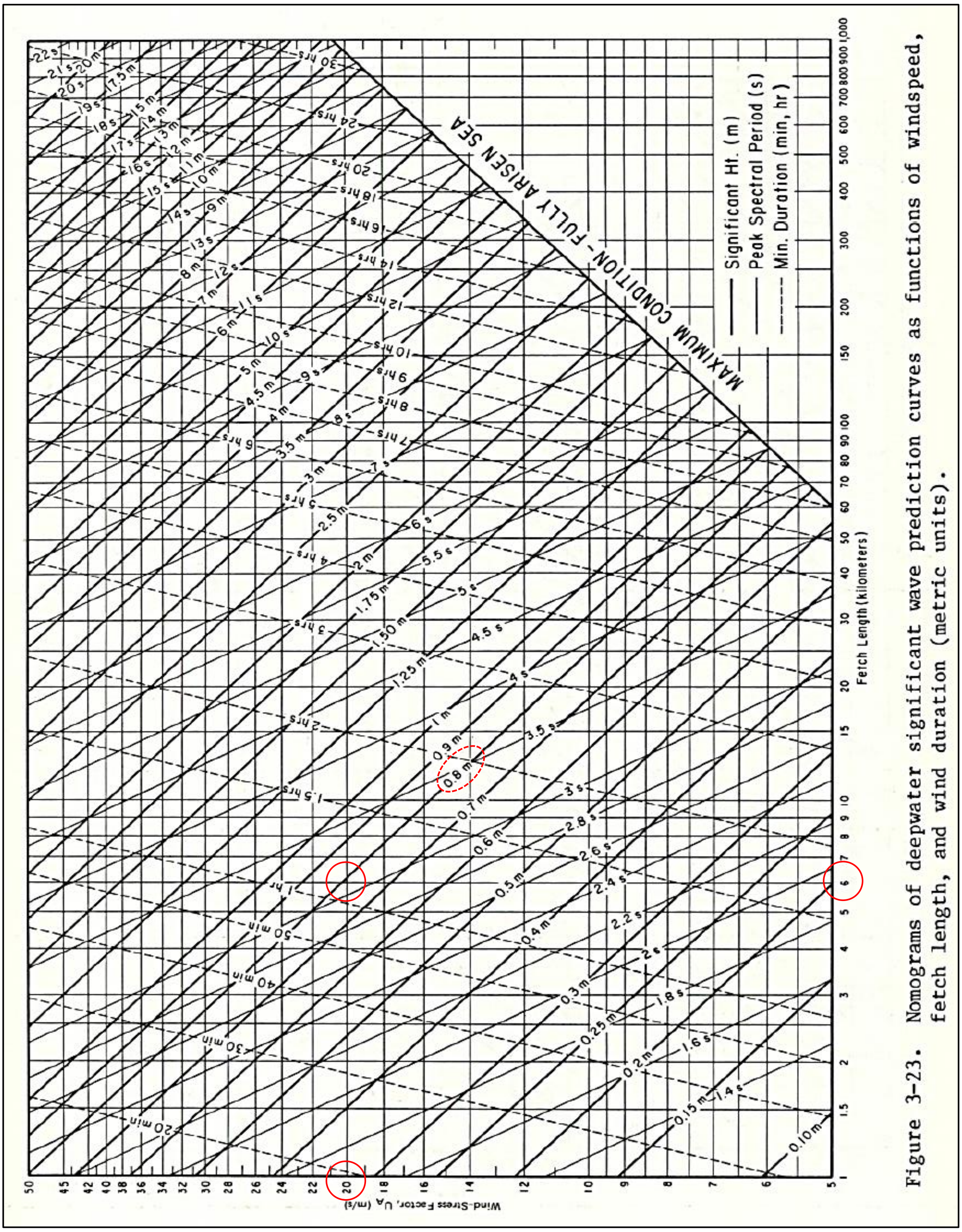

Figure D-1 Nomograph of wind generated wave height prediction curves

Source: CERC (1984)

Nomograph of wind generated wave height prediction curves

Example condition: At Site 2 (North Bay) with fetch distance F=6000 m, wind stress factor U_A=20.33 m/s and water depth d=32 m (deep water), the nomograph yields the following (approximate) values: deepwater significant wave height, H_s=0.8 m, peak spectral wave period, T_p= 3.1s and minimum storm duration to achieve equilibrium wave height, t= 67 minutes.

Nomograph is adapted from the Shore Protection Manual, Figure 3-23, Pg 3-49 (CERC, 1984).

APPENDIX E – Existing LNGC Fleet

Table E-1 Standard Fleet: 14,000 m^3 – 177,000 m^3

Hull #	*Ship Name*	*Delivery*	*Speed (knots)*	*Cargo System*	*# of Tanks*	*Capacity (cu.m.)*	*Price ($mm)*
	Coral Energy	Jan-13	15.8			14,600	
153	Aman Hakata	Nov-98	15.5	TZ Mk. III	3	18,800	
136	Aman Bintulu	Oct-93	15	TZ Mk. III	3	18,928	80
150	Aman Sendai	May-97	15	TZ Mk. III	3	18,928	
1593	Sun Arrows	Sep-07	18.1	Moss		19,100	
1440	Surya Aki	Feb-96	18.5	Moss	3	19,474	101
192	Surya Satsuma	Oct-00	16.5	TZ Mk. III	3	23,096	
1401	Isabella	Apr-75	18	GT NO 82	5	35,500	
1402	Annabella	May-75	18	GT NO 82	5	35,500	
5910	LNG Portovenere	Jun-96	16.5	GT NO 96	4	65,000	200
5911	LNG Lerici	Mar-98	16.5	GT NO 96	4	65,000	200
B 1604-1	Coral Methane	Apr-09	15.5	TGE		7,500	
516	SCF Polar	1969	18.3	GT NO 82	5	71,500	21
517	SCF Arctic	1969	16.5	GT NO 82	5	71,500	21
32M	GDF Suez Global Energy	Dec-06	16	CS1	4	74,100	
290	Belanak	Jul-75	18.3	TZ Mk. I	5	75,000	
25G	Bebatik	Oct-72	18.3	TZ Mk. I	6	75,100	
55	Cheikh El Mokrani	Jun-07		TZ Mk. III	4	75,500	160
88	Cheikh Bouamama	Jul-08		TZ Mk. III	4	75,500	160
1400	Bubuk	Oct-75	18.3	GT NO 82	5	77,670	
1399	Bilis	Mar-75	18.3	GT NO 82	5	77,731	
196	Norman Lady	1973	18	Moss	5	87,600	30
3015	Polar Spirit	Jun-93	18.5	IHI SPB	4	89,880	184
3016	Arctic Spirit	Dec-93	18.5	IHI SPB	4	89,880	184
26A	LNG Lagos	Dec-76	18.5	GT NO 85	6	122,000	52
26B	LNG Port Harcourt	Sep-77	20	GT NO 85	6	122,000	52
1230	Senshu Maru	Feb-84	19.3	Moss	5	125,000	125
1250	Wakaba Maru	Apr-85	19.3	Moss	5	125,000	120
853	Hyundai Greenpia	Nov-96	20.3	Moss	4	125,000	290
760	Hyundai Utopia	Jun-94	18.5	Moss	4	125,182	250
1340	Koto	Jan-84	19.3	Moss	5	125,199	120
302	Mostefa Ben Boulaid	Aug-76	18.5	TZ Mk. I	6	125,260	
1870	WilEnergy	Oct-83	19.3	Moss	5	125,500	132
1889	Echigo Maru	Aug-83	19.3	Moss	5	125,568	125
1890	Wilgas	Jul-84	19.3	Moss	5	125,600	120
1334	WilPower	Aug-83	19.3	Moss	5	125,700	125
84	Gandria	Oct-77	20	Moss	5	125,820	55
26G	Mourad Didouche	Jul-80	20	GT NO 85	5	126,130	112
26L	Ramdane Abane	Jul-81	20	GT NO 85	5	126,130	112
198	Hilli	Dec-75	19.5	Moss	6	126,227	
199	Gimi	Dec-76	19.5	Moss	6	126,277	
41	LNG Aquarius	Jun-77	20.4	Moss	5	126,300	82
42	LNG Aries	Dec-77	20.4	Moss	5	126,300	111
44	LNG Gemini	Sep-78	20.4	Moss	5	126,300	109
46	LNG Capricorn	Jun-78	20.4	Moss	5	126,300	109
48	LNG Taurus	Aug-79	20.4	Moss	5	126,300	107
47	LNG Leo	Dec-78	20.4	Moss	5	126,400	108
49	LNG Virgo	Dec-79	20.4	Moss	5	126,400	111
50	LNG Libra	Apr-79	20.4	Moss	5	126,400	108
53	LNG Edo	May-80	20.4	Moss	5	126,500	131
54	LNG Abuja	Sep-80	20.4	Moss	5	126,500	133
610	Matthew	Jun-79	18.5	TZ Mk. I	6	126,540	88
761	YK Sovereign	Dec-94	18.5	Moss	4	127,125	290
2062	Dwiputra	Mar-94	19.3	Moss	4	127,386	
1410	Northwest Shearwater	Sep-91	18.5	Moss	4	127,500	180
1996	Northwest Sanderling	Jun-89	18.5	Moss	4	127,500	180
2000	LNG Swift	Sep-89	18.5	Moss	4	127,500	180
2041	Northwest Seaeagle	Nov-92	18.5	Moss	4	127,500	216
2074	Northwest Stormpetrel	Dec-94	18.5	Moss	4	127,500	240
1351	Northwest Swallow	Nov-89	18.5	Moss	4	127,500	180
1352	Northwest Snipe	Sep-90	18.5	Moss	4	127,500	216
1370	Northwest Sandpiper	Feb-93	18.5	Moss	4	127,500	216
2061	LNG Vesta	Jun-94	19.3	Moss	4	127,547	
1427	LNG Flora	Mar-93	19.3	Moss	4	127,705	
290	Sunrise	Dec-77	19	GT NO 85	5	129,299	50
1414	Larbi Ben M'Hidi	Jun-77	19.5	GT NO 85	5	129,767	112
1415	Bachir Chihani	Feb-79	19.5	GT NO 85	5	129,767	112
302	Tenaga Dua	Aug-81	20	GT NO 88	5	130,000	120
303	Tenaga Tiga	Dec-81	20	GT NO 88	5	130,000	120

Hull #	*Ship Name*	*Delivery*	*Speed (knots)*	*Cargo System*	*# of Tanks*	*Capacity (cu.m.)*	*Price ($mm)*
1429	Tenaga Lima	Sep-81	20	GT NO 88	5	130,000	120
30E	Puteri Intan	Aug-94	21	GT NO 96	4	130,405	260
30F	Puteri Delima	Jan-95	21	GT NO 96	4	130,405	260
30G	Puteri Nilam	Jun-95	21	GT NO 96	4	130,405	260
30H	Puteri Zamrud	May-96	21	GT NO 96	4	130,405	260
30I	Puteri Firus	May-97	21	GT NO 96	4	130,405	260
16	Hanjin Pyeong Taek	Sep-95	19	GT NO 96	4	130,600	235
1487	Methania	Oct-78	19	GT NO 85	5	131,235	
559	LNG Bonny	Dec-81	20	GT NO 88	5	133,000	118
564	LNG Finima	Jan-84	20	GT NO 88	5	133,000	118
2172	Galea	Oct-02	19.9	Moss	5	134,425	165
2173	Gallina	Mar-03	19.9	Moss	5	134,425	165
2163	Abadi	Jun-02	19	Moss	5	135,000	180
1561	Dukhan	Oct-04	19.5	Moss	4	135,000	170
1073	Hyundai Technopia	Jul-99	20.3	Moss	4	135,000	219
1074	Hyundai Cosmopia	Jan-00	20.3	Moss	4	135,000	219
1156	Hyundai Aquapia	Mar-00	20.3	Moss	4	135,000	219
1157	Hyundai Oceanpia	Jul-00	20.3	Moss	4	135,000	219
2148	Golar Mazo	Jan-00	19.8	Moss	5	135,225	245
2204	K. Freesia	Jun-00	20.5	GT NO 96	4	135,256	219
1470	Al Biddah	Nov-99	19.5	Moss	5	135,279	250
2157	LNG Jamal	Oct-00	19.5	Moss	5	135,333	200
1445	Al Rayyan	Mar-97	19.5	Moss	5	135,358	250
1446	Al Wakrah	Dec-98	19.5	Moss	5	135,358	250
1432	Zekreet	Dec-98	19.5	Moss	5	135,420	
1412	Broog	May-98	19.5	Moss	5	135,466	250
1438	Shahamah	Oct-94	19.5	Moss	5	135,496	271
1390	Al Khaznah	Jun-94	19.5	Moss	5	135,496	271
2210	Disha	Jan-04	19.5	GT NO 96	4	136,026	158
2211	Raahi	Dec-04	19.5	GT NO 96	4	136,026	155
2011	Ekaputra	Jan-90	17.5	Moss	5	136,400	178
1330	Mubaraz	Jan-96	19.5	Moss	4	137,000	250
1331	Mraweh	Jun-96	19.5	Moss	4	137,000	250
1332	Al Hamra	Jan-97	19.5	Moss	4	137,000	250
1333	Umm Al Ashtan	May-97	19.5	Moss	4	137,000	250
2187	Pacific Eurus	Mar-06	19	Moss	4	137,000	180
2176	Pacific Notus	Sep-03	19	Moss	5	137,006	180
2117	Al Jasra	Jul-00	19.5	Moss	5	137,100	250
2165	Puteri Intan Satu	Dec-01	19.5	GT NO 96	4	137,100	180
2169	Puteri Nilam Satu	Sep-03	19.5	GT NO 96	4	137,100	180
2177	Puteri Firus Satu	Sep-04	19.5	GT NO 96	4	137,100	179
1506	Puteri Delima Satu	Apr-02	19.5	GT NO 96	4	137,100	180
1507	Puteri Zamrud Satu	Jan-04	19.5	GT NO 96	4	137,100	179
1562	Puteri Mutiara Satu	Apr-05	19.5	GT NO 96	4	137,100	179
1295	LNG Rivers	Jun-02	19.8	Moss	4	137,200	160
1296	LNG Sokoto	Aug-02	19.8	Moss	4	137,200	160
2162	Sohar LNG	Oct-01	19.5	Moss	5	137,248	200
2089	Al Khor	Dec-96	19.5	Moss	5	137,354	250
2090	Al Wajbah	Jun-97	19.5	Moss	5	137,354	250
2091	Doha	Jun-99	19.5	Moss	5	137,354	250
1429	LNG Bayelsa	Feb-03	19.8	Moss	4	137,500	160
1392	Ghasha	Jun-95	19.5	Moss	5	137,514	271
2067	Ish	Nov-95	19.5	Moss	5	137,540	271
1411	Al Zubarah	Dec-96	19.5	Moss	5	137,573	250
2202	SK Summit	Aug-99	20.5	GT NO 96	4	138,000	219
2208	Excelsior	Jan-05	19	GT NO 96	4	138,000	210
2214	Northwest Swan	Mar-04	19.5	GT NO 96	4	138,000	
2215	Methane Princess	Aug-03	19.5	GT NO 96	4	138,000	165
2218	Excellence	May-05	19	GT NO 96	4	138,000	210
2219	LNG Pioneer	Jul-05	19.5	GT NO 96	4	138,000	165
2236	Iberica Knutsen	Oct-06	19.5	GT NO 96	4	138,000	
2237	Excelerate	Oct-06	19.5	GT NO 96	4	138,000	200
1380	British Trader	Dec-02	20.1	TZ Mk. III	4	138,000	160
1381	British Merchant	Apr-03	20.1	TZ Mk. III	4	138,000	160
1406	Fuwairit	Jan-04	20.2	TZ Mk. III	4	138,000	163
1416	British Innovator	Jul-03	20.1	TZ Mk. III	4	138,000	160
1440	Lusail	May-05	20.1	TZ Mk. III	4	138,000	160
1502	Seri Alam	Oct-05	19	TZ Mk. III	4	138,000	
87	Castillo de Villalba	Nov-03	19.5	GT NO 96	4	138,000	223

Hull #	*Ship Name*	*Delivery*	*Speed (knots)*	*Cargo System*	*# of Tanks*	*Capacity (cu.m.)*	*Price ($mm)*
105	Madrid Spirit	Jan-05	19.5	GT NO 96	4	138,000	171
319	Catalunya Spirit	Mar-03	19.5	GT NO 96	4	138,000	223
321	Bilbao Knutsen	Jan-04	19.5	GT NO 96	4	138,000	209
331	Sestao Knutsen	Nov-07	19.5	GT NO 96	4	138,000	
2203	K. Acacia	Jan-00	20.5	GT NO 96	4	138,017	219
2212	BW Suez Everett	Jun-03	19.5	GT NO 96	4	138,028	155
2207	BW Suez Boston	Jan-03	19.5	GT NO 96	4	138,059	150
2217	Berge Arzew	Jul-04	19.5	GT NO 96	4	138,088	160
2183	Gemmata	Mar-04	19.9	Moss	5	138,104	165
2213	Excel	Sep-03	19	GT NO 96	4	138,106	145
2206	Excalibur	Oct-02	19	GT NO 96	4	138,200	145
54	Hanjin Muscat	Jul-99	20.3	GT NO 96	4	138,200	219
1207	SK Supreme	Jan-00	20.3	TZ Mk. III	4	138,200	219
1428	Methane Kari Elin	Jun-04	20.1	TZ Mk. III	4	138,200	164
62	Hanjin Ras Laffan	Jul-00	20.3	GT NO 96	4	138,214	219
1405	SK Sunrise	Sep-03	20.3	TZ Mk. III	4	138,306	160
61	Hanjin Sur	Jan-00	20.3	GT NO 96	4	138,333	219
1258	SK Splendor	Mar-00	20.3	TZ Mk. III	4	138,375	219
1259	SK Stellar	Dec-00	20.3	TZ Mk. III	4	138,375	219
1425	Milaha Ras Laffan	Mar-04	20.6	TZ Mk. III	4	138,500	165
103	Cadiz Knutsen	Jun-04	19.5	GT NO 96	4	138,826	171
1460	Golar Viking	Jan-05	19.8	TZ Mk. III	4	138,830	162
1532	Arctic Voyager	Apr-06	18.5	Moss	4	140,000	165
1564	Arctic Discoverer	Jan-06	19	Moss	4	140,000	165
2205	Hispania Spirit	Sep-02	19.5	GT NO 96	4	140,500	150
2223	LNG Oyo	Dec-05	19.5	GT NO 96	4	140,500	160
2209	Galicia Spirit	Jul-04	19.5	GT NO 96	4	140,624	152
2216	Golar Arctic	Dec-03	19.5	GT NO 96	4	140,648	160
1469	LNG Akwa Ibom	Nov-04	19.8	Moss	4	141,000	170
1470	LNG Adamawa	Jun-05	19.8	Moss	4	141,000	170
1471	LNG Cross River	Sep-05	19.8	Moss	4	141,000	170
1472	LNG River Niger	May-06	19.8	Moss	4	141,000	170
1521	Energy Advance	Mar-05	19.5	Moss	4	145,000	
1534	Lalla Fatma N'Soumer	Dec-04	18.5	Moss	4	145,000	
1540	Energy Progress	Nov-06	18.5	Moss	4	145,000	150
1545	LNG Dream	Sep-06	18.5	Moss	4	145,000	
1562	Nizwa LNG	Dec-05	18.5	Moss	4	145,000	150
1587	Neva River	Dec-07	18.5	Moss	4	145,000	
1588	LNG Ebisu	Dec-08	18.5	Moss	4	145,000	
1600	Energy Navigator	Mar-08	18.5	Moss	4	145,000	
1625	Taitar No. 2	Dec-09	18.5	Moss	4	145,000	
1626	Taitar No. 4	Oct-10	18.5	Moss	4	145,000	
2236	Pacific Enlighten	Mar-09	19.5	Moss	4	145,000	
2241	Taitar No. 1	Oct-09	18.5	Moss	4	145,000	
2242	Taitar No. 3	Jan-10	18.5	Moss	4	145,000	
2222	LNG Enugu	Oct-05	19.5	GT NO 96	4	145,000	160
2227	Rasgas Asclepius	Jul-05	19.5	GT NO 96	4	145,000	151
2228	Umm Bab	Nov-05	19.5	GT NO 96	4	145,000	151
1903	Hyundai Ecopia	Nov-08	19.5	TZ Mk. III	4	145,000	
1441	Al Thakhira	Sep-05	20.6	TZ Mk. III	4	145,000	160
1442	Al Deebel	Dec-05	20.6	TZ Mk. III	4	145,000	160
1503	Seri Amanah	Mar-06	19	TZ Mk. III	4	145,000	
1553	Methane Rita Andrea	Mar-06	20.2	TZ Mk. III	4	145,000	160
1554	Methane Jane Elizabeth	Jun-06	20.2	TZ Mk. III	4	145,000	160
1555	Methane Lydon Volney	Sep-06	20.2	TZ Mk. III	4	145,000	160
1585	Methane Shirley Elizabeth	Apr-07	20.2	TZ Mk. III	4	145,000	155
1586	Methane Heather Sally	Jul-07	20.2	TZ Mk. III	4	145,000	155
1587	Methane Alison Victoria	Aug-07	20.2	TZ Mk. III	4	145,000	155
1588	Methane Nile Eagle	Dec-07	20.2	TZ Mk. III	4	145,000	155
1589	Seri Anggun	Nov-06	19	TZ Mk. III	4	145,000	171
1590	Seri Angkasa	Feb-07	19	TZ Mk. III	4	145,000	171
1591	Seri Ayu	Oct-07	19	TZ Mk. III	4	145,000	171
1594	Ejnan	Feb-07	20	TZ Mk. III	4	145,000	153
1688	GDF Suez Neptune	Dec-09	19.5	TZ Mk. III	4	145,000	290
1689	GDF Suez Cape Ann	Jan-10	19.5	TZ Mk. III	4	145,000	290
2235	Cygnus Passage	Jan-09	19.5	Moss	4	145,400	
1562	Milaha Qatar	Apr-06	20.6	TZ Mk. III	4	145,500	165
2224	LNG Benue	Mar-06	19.5	GT NO 96	4	145,700	160
2226	Golar Grand	Jan-06	19.5	GT NO 96	4	145,700	151

Hull #	*Ship Name*	*Delivery*	*Speed (knots)*	*Cargo System*	*# of Tanks*	*Capacity (cu.m.)*	*Price ($mm)*
2233	Stena Blue Sky	Jan-07	19.5	GT NO 96	4	145,700	157
2234	Golar Maria	Jun-06	19.5	GT NO 96	4	145,700	151
2235	Simaisma	Jul-06	19.5	GT NO 96	4	145,700	151
2241	Tangguh Towuti	Oct-08	19.5	GT NO 96	4	145,700	161
2242	Tangguh Batur	Dec-08	19.5	GT NO 96	4	145,700	163
2243	Al Jassasiya	May-07	19.5	GT NO 96	4	145,700	151
2244	Maran Gas Coronis	Jun-07	19.5	GT NO 96	4	145,700	
2260	K. Jasmine	Mar-08	19.5	GT NO 96	4	145,700	197
192	STX Kolt	Nov-08	19.5	TZ Mk. III	4	145,700	
2221	LNG River Orashi	Nov-04	19.5	GT NO 96	4	145,914	160
1308	Dapeng Sun	Apr-08		GT NO 96	4	147,000	200
1309	Dapeng Moon	Jul-08		GT NO 96	4	147,000	200
1320	Min Rong	Feb-09		GT NO 96	4	147,000	
1536	Salalah LNG	Dec-05	19.5	TZ Mk. III	4	147,000	150
1573	Ibra LNG	Jul-06	19.5	TZ Mk. III	4	147,000	
1378	Min Lu	Aug-09		GT NO 96	4	147,100	160
1379	Dapeng Star	Dec-09		GT NO 96	4	147,100	160
1621	Shen Hai	Sep-12		GT NO 96	4	147,100	
2184	Arctic Princess	Jan-06	19	Moss	4	147,200	165
2185	Arctic Lady	May-06	19	Moss	4	147,200	165
2215	Ibri LNG	Jul-06	19	Moss	4	147,200	150
2219	Alto Acrux	Mar-08	19.5	Moss	4	147,200	
2229	Grand Elena	Oct-07	19.5	Moss	4	147,200	
2230	Grand Aniva	Jan-08	19.5	Moss	4	147,200	
1681	Grand Mereya	May-08	19.5	Moss	4	147,200	
1520	Energy Frontier	Sep-03	19.5	Moss	4	147,599	
2273	Arkat	Feb-11	19.5	GT NO 96	4	148,000	238
2277	Amali	Jul-11	19.5	GT NO 96	4	148,000	238
2229	LNG Lokoja	Dec-06	19.5	GT NO 96	4	148,300	151
2230	LNG Kano	Jan-07	19.5	GT NO 96	4	148,300	151
2231	LNG Ondo	Sep-07	19.5	GT NO 96	4	148,300	151
2232	LNG Imo	Jun-08	19.5	GT NO 96	4	148,300	151
1527	Fuji LNG	Mar-04	19.5	Moss	4	149,172	150
1563	LNG Borno	Aug-07	19.8	TZ Mk. III	4	149,600	181
1564	LNG Ogun	Aug-07	19.8	TZ Mk. III	4	149,600	181
1719	Ob River	Jul-07	19.5	TZ Mk. III	4	150,000	
1728	Grace Acacia	Jan-07	19.8	TZ Mk. III	4	150,000	170
1729	Grace Barleria	Oct-07	19.8	TZ Mk. III	4	150,000	170
1730	Grace Cosmos	Mar-08	19.8	TZ Mk. III	4	150,000	170
1734	Clean Force	Jan-08	19.5	TZ Mk. III	4	150,000	
1748	Clean Energy	Mar-07	19.5	TZ Mk. III	4	150,000	
1754	Neo Energy	Feb-07	19.8	Moss	4	150,000	
2254	Explorer	Mar-08	19.5	GT NO 96	4	150,900	250
2263	Express	May-09	19.5	GT NO 96	4	150,900	
2270	Exquisite	Oct-09	19.5	GT NO 96	4	150,900	
2271	Expedient	Apr-10	19.5	GT NO 96	4	150,900	
2272	Exemplar	Sep-10	19.5	GT NO 96	4	150,900	
2238	Al Marrouna	Nov-06	19.5	GT NO 96	4	151,700	
2239	Al Areesh	Jan-07	19.5	GT NO 96	4	151,700	
2240	Al Daayen	Apr-07	19.5	GT NO 96	4	151,700	
2261	K. Mugungwha	Nov-08	19.5	GT NO 96	4	151,800	197
2223	Seri Balhaf	Sep-08	19.5	GT NO 96	4	152,000	180
2224	Seri Balqis	Dec-08	19.5	GT NO 96	4	152,000	180
2220	Seri Bakti	Apr-07	19.5	GT NO 96	4	152,300	180
2221	Seri Begawan	Dec-07	19.5	GT NO 96	4	152,300	180
2222	Seri Bijaksana	Feb-08	19.5	GT NO 96	4	152,300	180
1591	LNG Barka	Dec-08	18.5	Moss	4	153,000	
1592	LNG Jupiter	Nov-08	18.5	Moss	4	153,000	
1611	Energy Confidence	Mar-09	19.5	Moss	4	153,000	
193	STX Frontier	May-10	19.5	TZ Mk. III	4	153,000	
32N	Provalys	Nov-06		CS1	4	153,500	227
32P	Gaselys	Mar-07		CS1	4	153,500	227
2260	Trinity Glory	Dec-08	19.5	TZ Mk. III	4	154,000	
2258	Trinity Arrow	Mar-08	19.5	TZ Mk. III	4	154,200	
2263	GDF Suez Point Fortin	Feb-10	19.5	TZ Mk. III	4	154,200	
1777	British Emerald	Jun-07	19.5	TZ Mk. III	4	155,000	185
1778	British Ruby	Jul-08	19.5	TZ Mk. III	4	155,000	185
1779	British Sapphire	Sep-08	19.5	TZ Mk. III	4	155,000	185
1780	Tangguh Hiri	Nov-08	19.5	TZ Mk. III	4	155,000	185

Table E-2 Q-Flex & Q-Max Fleet: 210,000 m^3 – 266,000 m^3

Hull #	*Ship Name*	*Delivery*	*Speed (knots)*	*Cargo System*	*# of Tanks*	*Capacity (cu.m.)*	*Price ($mm)*
Q-Flex							
2245	Al Ruwais	Nov-07	19.5	GT NO 96	4	210,100	215
2246	Al Safliya	Nov-07	19.5	GT NO 96	4	210,100	215
2247	Duhail	Jan-08	19.5	GT NO 96	4	210,100	215
2248	Al Ghariya	Jan-08	19.5	GT NO 96	4	210,100	215
2249	Al Aamriya	Mar-08	19.5	GT NO 96	4	210,100	235
2250	Al Oraiq	Apr-08	19.5	GT NO 96	4	210,100	235
2251	Murwab	May-08	19.5	GT NO 96	4	210,100	235
2252	Fraiha	Sep-08	19.5	GT NO 96	4	210,100	235
2253	Umm Al Amad	Sep-08	19.5	GT NO 96	4	210,100	235
2264	Al Sheehaniya	Feb-09	19.5	GT NO 96	4	210,100	
2265	Al Sadd	Mar-09	19.5	GT NO 96	4	210,100	
2266	Onaiza	Apr-09	19.5	GT NO 96	4	210,100	
2283	Al Khattiya	Oct-09	19.5	GT NO 96	4	210,100	
2284	Al Karaana	Oct-09	19.5	GT NO 96	4	210,100	
2285	Al Dafna	Oct-09	19.5	GT NO 96	4	210,100	
2286	Al Nuaman	Dec-09	19.5	GT NO 96	4	210,100	
1875	Al Utouriya	Sep-08	19.5	TZ Mk. III	4	215,000	234
1696	Al Ghashamiya	Mar-09	19.5	TZ Mk. III	4	216,000	
1726	Al Bahiya	Jan-10	19.5	TZ Mk. III	5	216,000	
1791	Al Gattara	Nov-07	19.5	TZ Mk. III	4	216,200	216
1792	Al Gharaffa	Sep-08	19.5	TZ Mk. III	4	216,200	216
1862	Al Thumama	Jan-08	19.5	TZ Mk. III	4	216,200	234
1863	Al Sahla	Apr-08	19.5	TZ Mk. III	4	216,200	234
1908	Mesaimeer	Mar-09	19.5	TZ Mk. III	4	216,200	
1909	Al Kharaitiyat	May-09	19.5	TZ Mk. III	4	216,200	
1910	Al Rekayyat	Jun-09	19.5	TZ Mk. III	4	216,200	
1605	Tembek	Nov-07	19.5	TZ Mk. III	4	216,200	229
1606	Al Hamla	Feb-08	19.5	TZ Mk. III	4	216,200	229
1643	Al Huwaila	May-08	19.5	TZ Mk. III	4	217,000	240
1644	Al Kharsaah	May-08	19.5	TZ Mk. III	4	217,000	240
1645	Al Shamal	Jun-08	19.5	TZ Mk. III	4	217,000	240
1646	Al Khuwair	Jul-08	19.5	TZ Mk. III	4	217,000	240
2255	Al Ghuwairiya	Aug-08	19.5	GT NO 96	5	261,700	290
2256	Lijmiliya	Jan-09	19.5	GT NO 96	5	261,700	290
2257	Al Samriya	Dec-08	19.5	GT NO 96	5	261,700	290
Q-Max							
1675	Mozah	Oct-08	19.5	TZ Mk. III	5	266,000	
1676	Umm Slal	Nov-08	19.5	TZ Mk. III	5	266,000	
1677	Bu Samra	Dec-08	19.5	TZ Mk. III	5	266,000	
1694	Al Mayeda	Feb-09	19.5	TZ Mk. III	5	266,000	290
1695	Mekaines	Feb-09	19.5	TZ Mk. III	5	266,000	290
1697	Al Mafyar	Apr-09	19.5	TZ Mk. III	5	266,000	290
1751	Shagra	Nov-09	19.5	TZ Mk. III	5	266,000	
1752	Zarga	Mar-10	19.5	TZ Mk. III	5	266,000	
1753	Aamira	May-10	19.5	TZ Mk. III	5	266,000	
1754	Rasheeda	Aug-10	19.5	TZ Mk. III	5	266,000	

Source: Ship Building History (2013)

Revised 01 September 2013

APPENDIX F – Geotechnical Survey – Eastern Margin of Iron Ore Terminal

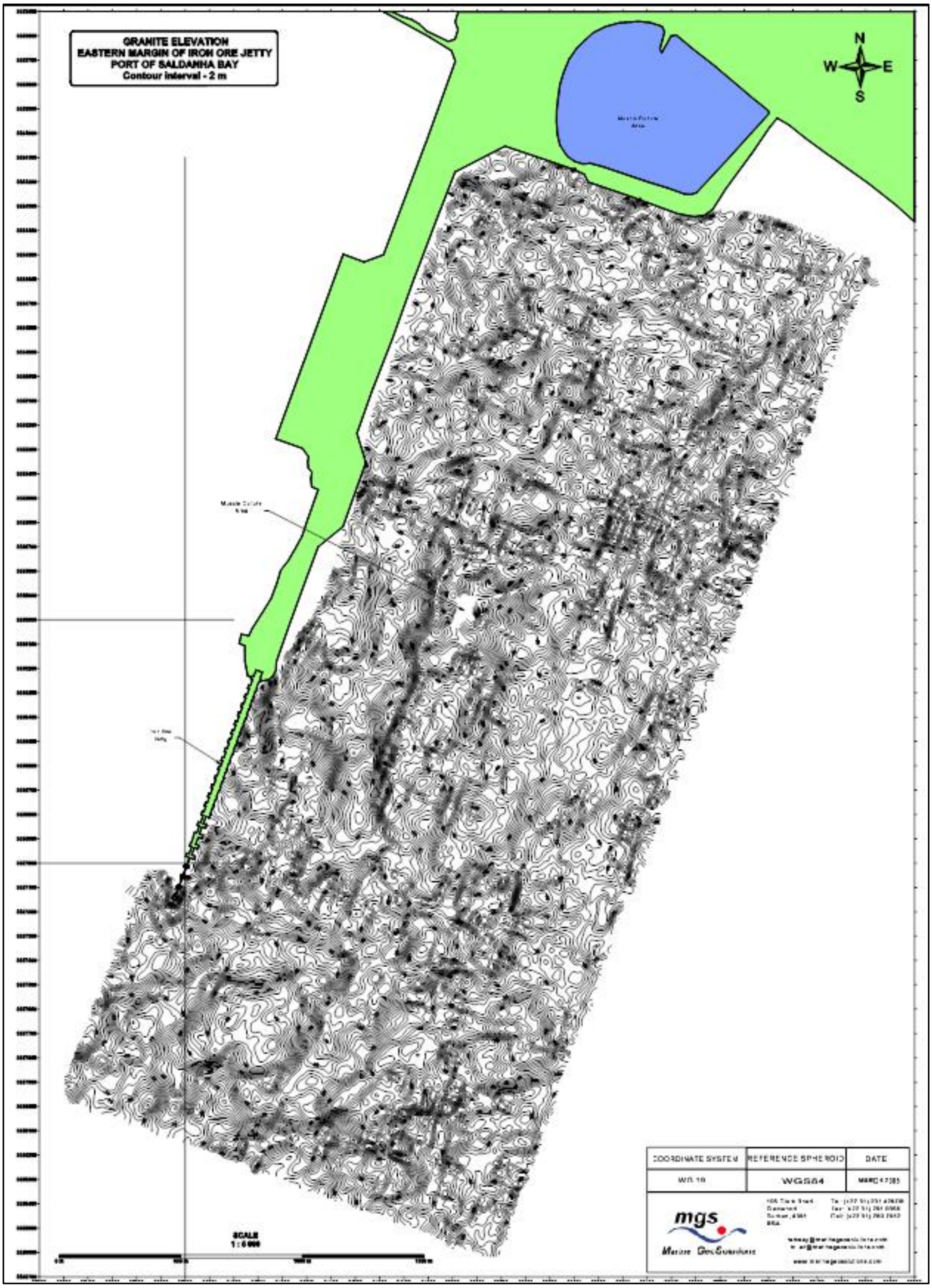

Figure F-1 Granite Elevation – Eastern Margin of Iron Ore Terminal

Source: Marine GeoSolutions (MGS, 2006)

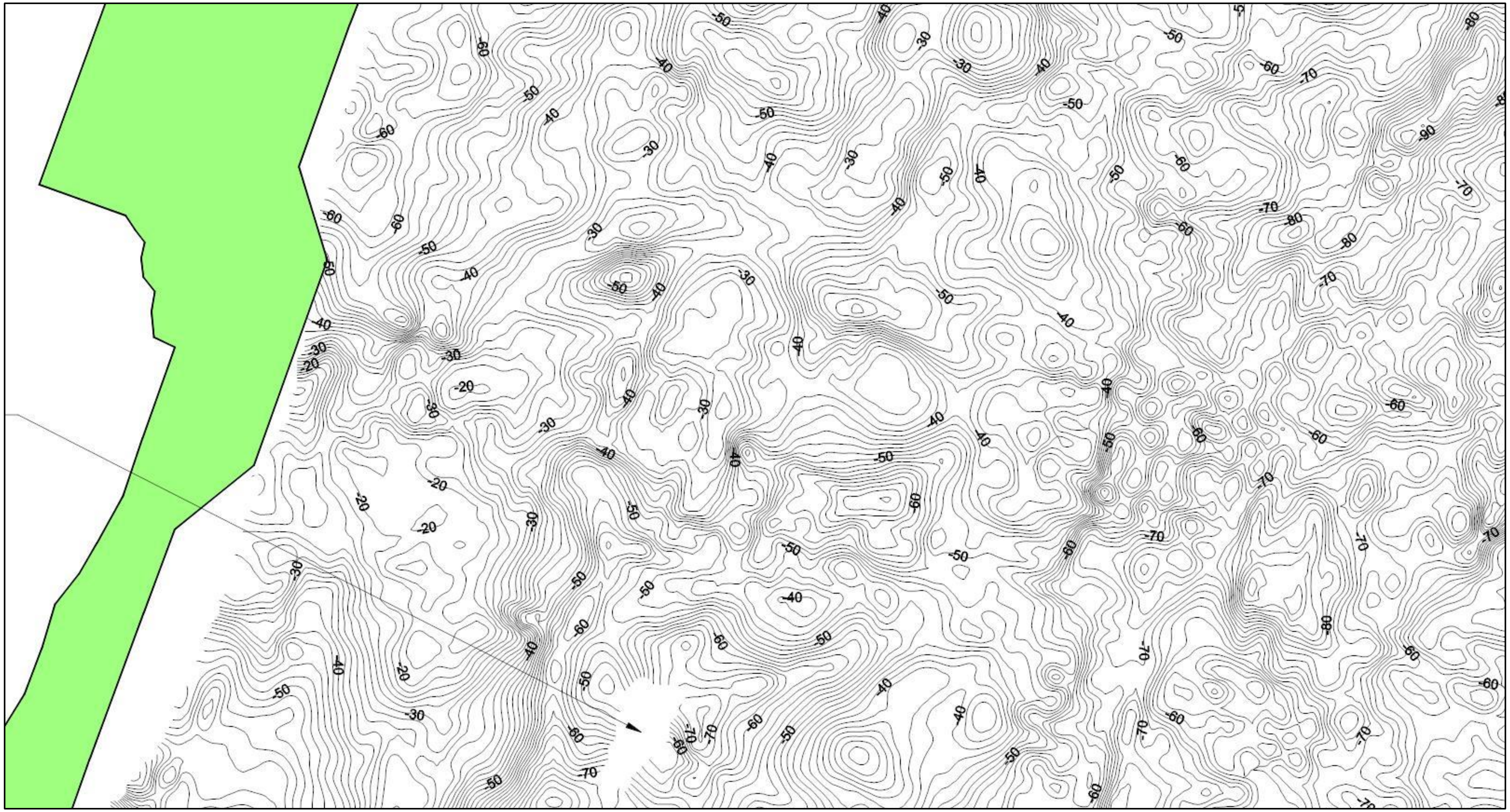

Figure F-2 Elevation levels of granite layer in proximity of Site 3

Source: Marine GeoSolutions (MGS, 2006)

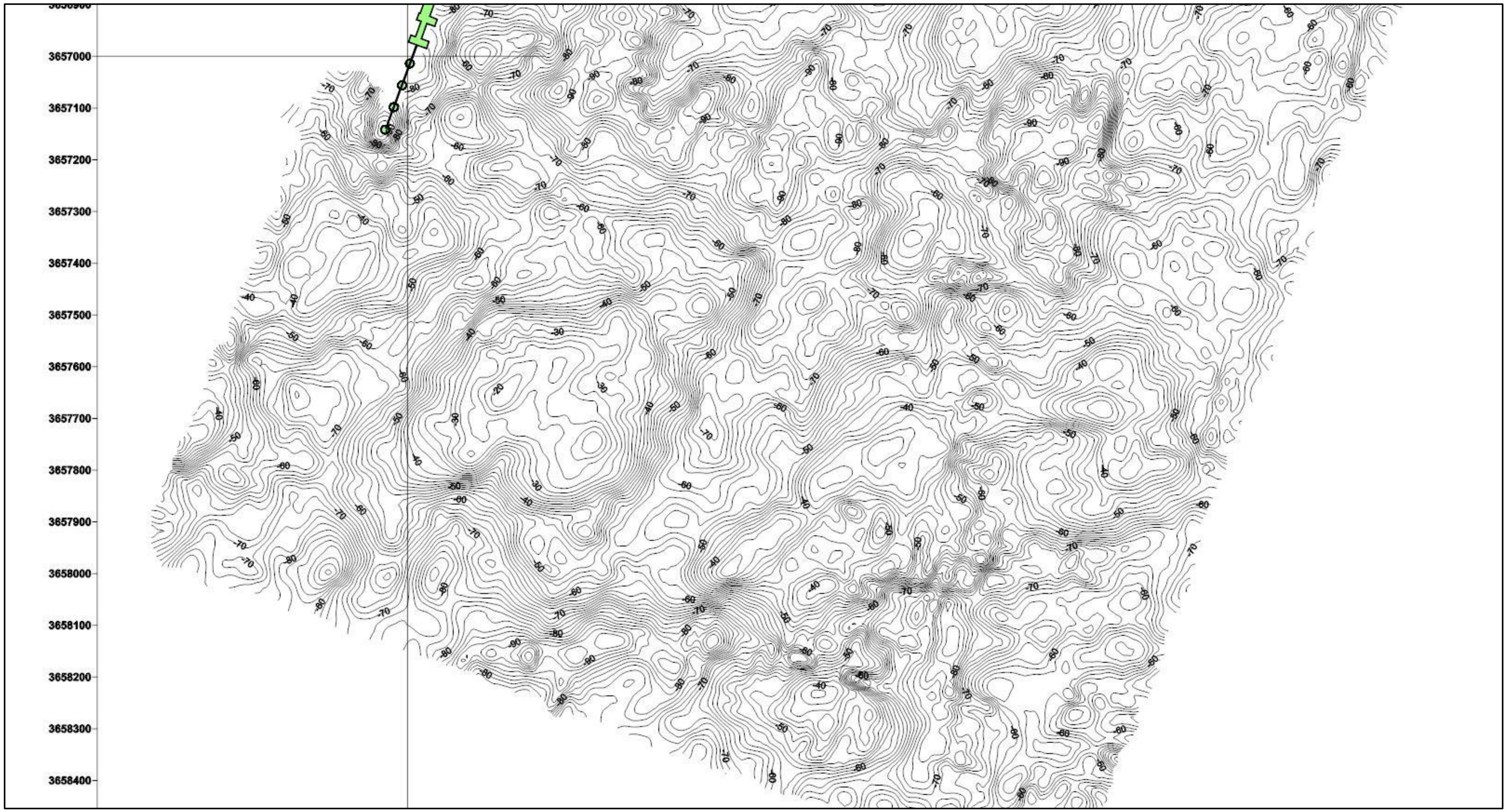

Figure F-3 Elevation levels of granite layer in proximity of Site 4

Source: Marine GeoSolutions (MGS, 2006)

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