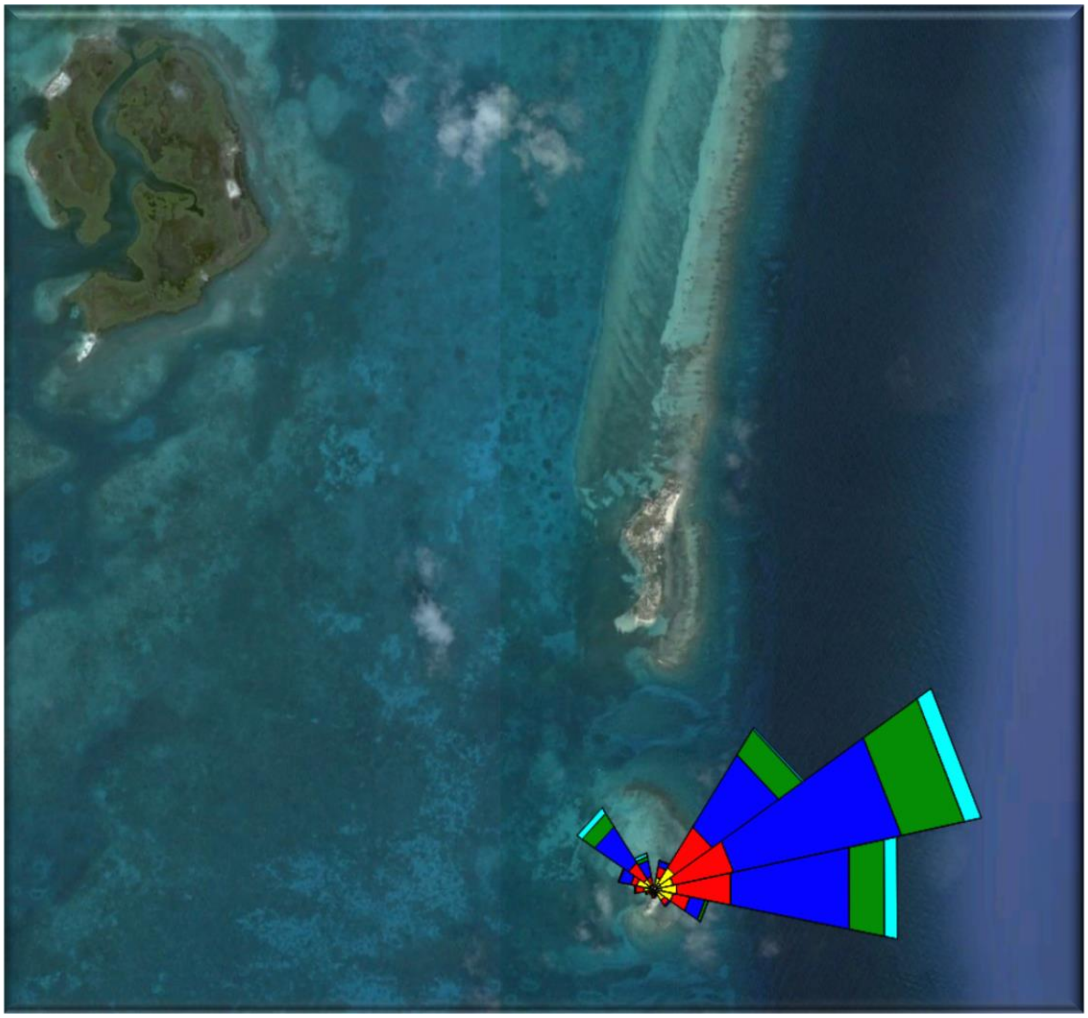

Erosion Study at South Water Caye Marine Reserve Headquarters at Twin Cayes

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Cover Photograph ***Aerial view of the wider Twin Cayes area showing physical features such as the shallow and varied bathymetry of the shelf, South Water Caye and Carrie Bow Caye that are juxtaposed on the Barrier Reef and the channel between them which is one of the connections between the deep open ocean and the southern shelf lagoon. The wind rose plot represents the wind speeds and wind directions recorded at the Carrie Bow weather station. [Background photograph credits Digitalgobe; Wind rose produced with WRPLOT]***

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List of Acronyms

APAMO	Association of Protected Areas Management Organization
BBR	Belize Barrier Reef
BFD	Belize Fisheries Department
CITES	Convention of International Trade on Endangered Species
CORS	Continuously Operating Reference Station
CRRH	Regional Commission of Hydraulic Resources/ Comité Regional de Recursos Hidráulicos
CMI	Crane Materials International
CZMAI	Coastal Zone Management Authority and Institute
ERI	Environmental Research Institute
FD	Forest Department
GNSS	Global Navigation Satellite System
MBRS	Mesoamerican Barrier Reef System
MHW	Mean High Water
MLLW	Mean Lower Low Water
MSL	Mean Sea Level
MPA	Marine Protected Area
NGS	National Geodetic Survey
PACT	Protected Areas Conservation Trust
SLR	Sea Level Rise
SWCMR	South Water Caye Marine Reserve
TC	Twin Cayes
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey

1 EXECUTIVE SUMMARY

In April 2016, the Fisheries Department commissioned this short term consultancy to assess the erosion problem experienced at the Rangers Station located on the south-western most point of Twin Cayes in the South Water Caye Marine Reserve (SWCMR). The principal aim of this undertaking was to generate a report to elucidate the drivers of the erosion process, make recommendations on the implementation of the best erosion control mechanisms to arrest the erosion\ property loss; highlight the projected costing of each of the recommended solution.

In order to fulfill the mandate at hand, the study comprises three distinct but related components. Part one addresses the physical description of the Southern Shelf Lagoon including the coastal oceanographic and meteorological conditions. Some of the most remarkable characteristics of the lagoon include its intricate bathymetry, diverse habitats and rich biodiversity. Amidst numerous shoals are the Victoria and the Inner Channels that facilitate navigation in and out of the barrier reef complex. In view of the erosion and accretion processes, the most critical oceanographic conditions are the tidal setup, wave, climate and current regime. On the other hand, the wind direction and wind speed are recognized as the most vital meteorological conditions.

Part two focuses on the options for erosion remediation and their technical and environmental considerations. The scarce sand supply, the review of the topo-bathymetric surveys coupled with the oceanographic and meteorological data for the locality of the Twin Cayes indicates that the property is currently unstable. With the intention to abate the erosion and protect assets at the ranger's headquarters, the property must be armored. Three options are provided for detailed review and considerations. **Option A:** is the Twin Caye Gabion Seawall backfilled with dredged sand from a nearby shoal. **Option B:** is the Twin Caye Vinyl Sheet Pile Seawall backfilled with dredged sand from a nearby shoal. **Option C:** is the Twin Caye Steel Sheet Pile Seawall backfilled with dredged sand from a nearby shoal.

The third and final part of the report addresses the cost effectiveness of each of the aforementioned options. ***Option C*** is the costliest of the three options because of the materials involved and the longevity it guarantees. ***Option B*** offers a good armor and aesthetics to the island and the cost of this alternative is considered intermediate. ***Option A*** guarantees stability with minimal maintenance and is considered to be the most cost effective option. Independent of the restoration option adopted, it is important to still consider inherent risks. Realistically, the risk to lives in a coastal storm event such as a hurricane at Twin Cayes should be manageable simply by voluntary or forced evacuation given the early warnings from the Belize Meteorological Department. The risks to assets in a hurricane are ranked moderate to high, irrespective of the option selected. Due to the low-lying nature of the island, it will remain vulnerable to storm surge and inundation even after remedial work is completed.

Since the designation of the SWCMR and the establishment of the Ranger's Station at Twin Cayes there have been several attempts to curb the rapid erosion rates. One notable event was the construction of a four feet high retaining zinc wall, backfilled with marls dredged just south of the island. Today the retaining wall and most of the dredged material have been eroded. It is paramount that a well-designed, armored sediment guard is emplaced around the property and backfilled with sediment from the adjacent seascape. This solution to the erosion problem would safeguard the assets, blend with the environment and enhance the aesthetics of the Twin Cayes.

2 INTRODUCTION

In 1996 the South Water Caye Marine Reserve (SWCMR) was designated as one of seven components of the Belize Barrier Reef System - World Heritage Site. Since then a management plan was approved and a corresponding management structure has been in full effect to protect and sustain the biodiversity in that locality. The main operating hub for the reserve is physically located on Twin Cayes in the Stann Creek District. It consists of living quarters for reserve staff, operations office and storage facilities for equipment and supplies.

The seascape in southern Belize of which the SWCMR is an integral part, includes tidal flats, channels, shoals, coral reefs, numerous low-lying coral and mangrove islands. The Twin Cayes is a mangrove dominated island with a maximum elevation of approximately 2 feet above mean sea level. The vulnerability of this landmass to the biogeophysical impacts of climate variability and climate change include inundation and erosion. Continued exposure to events of inundation could lead to the displacement of lowlands/ wetlands. However, of more urgent attention is the erosion on southernmost end of the Twin Cayes that currently pose a threat to property and overall landmass stability. Based on long-term observations, the sediment supply in the immediate vicinity of the island has been very meager and this is corroborated by the longevity of the existing wetland. The erosion process displaces the sediment around southern end of the island into deeper water just a few meters seaward. The accretion of sediment in a *sink* beyond the wave breaking zone explains the sediment lost from the beach system and hence naturally unavailable for stabilization of the Twin Cayes. This is probably one of the main driving factors why the island was restored through a nearshore dredging operation in 2005. Subsequent to the dredging operation, the reclaimed land was enclosed with a zinc wall. Once the wall was breached, the wave climate coupled with the tides, general current circulation and deficient sediment supply exacerbated the erosion of this property to this critical state.

To date, a comprehensive assessment of the Twin Cayes erosion process, sediment source/supply; restoration and mitigation options have not been completed. It is envisaged that this study elucidates the root cause of the erosion problem and offer pragmatic and economically feasible solutions.

3 OBJECTIVES OF THE EROSION STUDY

Specific Objectives:

The specific objectives of this exercise were to:

a) Identify the current wave actions/currents that are causing the erosion problem at Twin Cayes Headquarter;

b) Identify options for the best erosion control mechanisms to install to minimize land lost and subsequent investment in the area;

c) Identify along with the various options the projected cost of each control mechanisms.

4 STUDY AREA

The Twin Cayes is nested in the Southern Shelf Lagoon. It is geographically located 2.5 km North-northwest of South Water Caye, 3.3 km northwest of Carrie Bow Cay and 20 km southeast of Dangriga Town, Stann Creek District (Figure 4.1). This well-studied locality is an integral part of the South Water Caye Marine Reserve. It is 1.4 km long and 1.1 km wide and comprises two islands (Figure 4.2). These two islands, the East Island and the West Island, are separated by a 0.5 to 2.0 m deep meandering creek (Woodroffe, 1995).

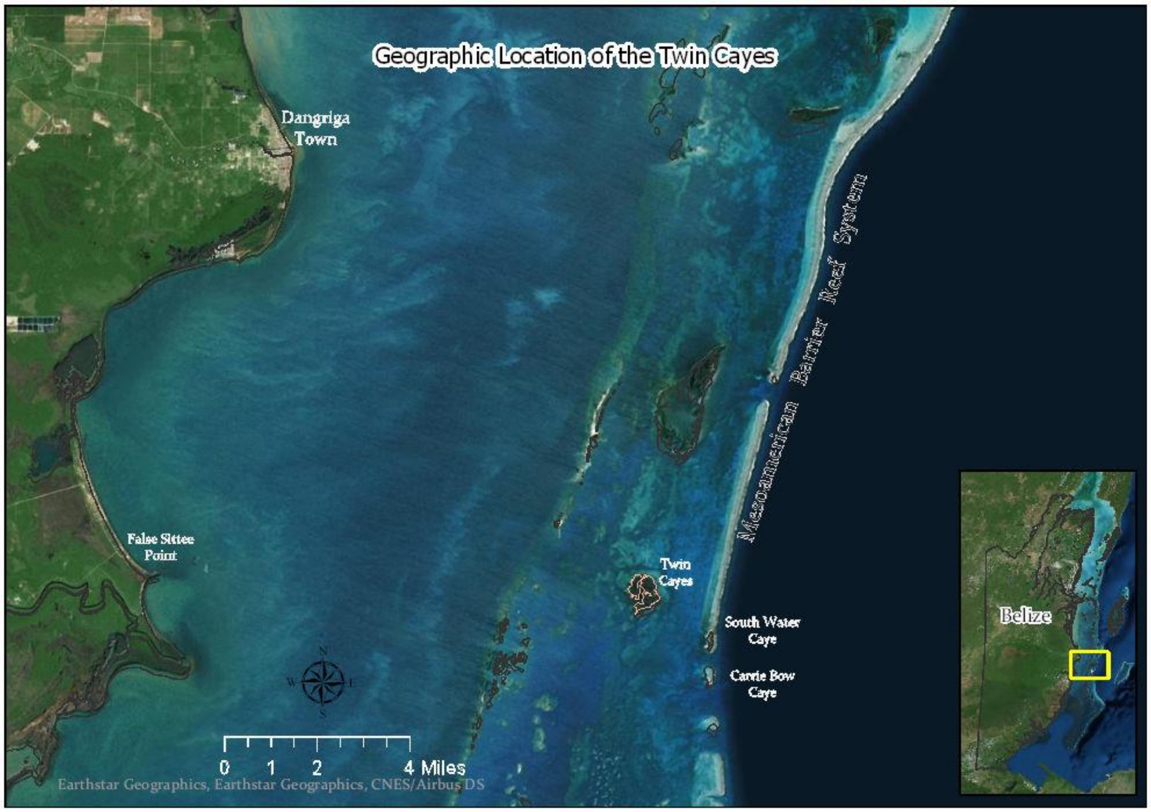
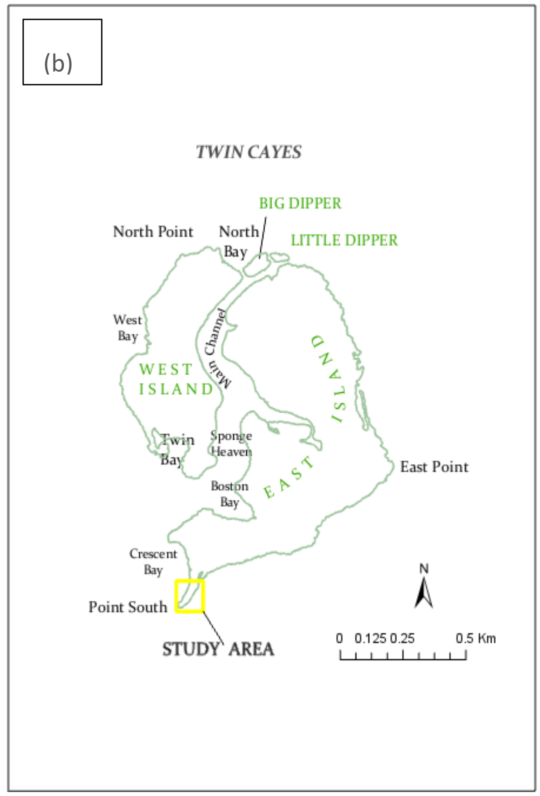


Figure 4.1. Geographic Location of the Twin Cayes

The SWCMR Headquarters is sited on National land and occupies an area of 0.3 acres with reference to MSL on Point South. This is the effective study area that is challenged by shoreline erosion and warrants remedial action (Figure 4.2 (c)).



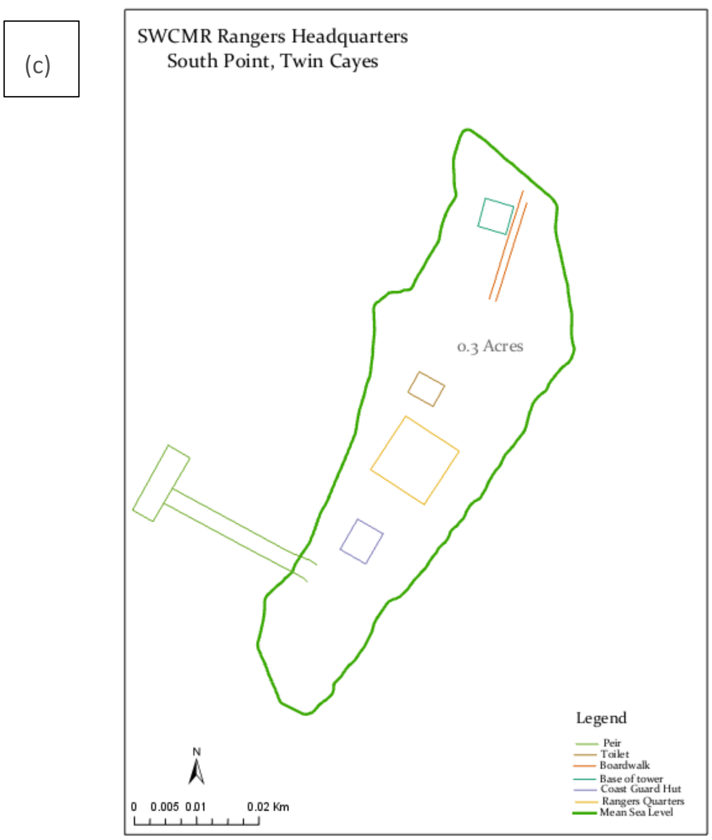


Figure 4.2. The study area (a) Aerial view of the Twin Cayes, (b) Schematic of the Twin Cayes highlighting the study area, (c) SWCMR Rangers Quarters on South Point.

5 METHODOLOGY

This consultancy involved both a field and a desktop component. The Field component included the gathering of qualitative and quantitative data through planned surveys and interviews. The desktop component addressed the literature review, data analysis, cartography and report preparation.

The specific methods used in this project are as follows:

Literature Review: A thorough review of relevant publications, studies, and reports were conducted throughout the assessment. The literature reviewed include among others, documents from the Fisheries Department, Forest Department, the Environmental Research Institute (ERI), Association of Protected Areas Management Organization (APAMO) and the Smithsonian Institute that are pertinent to the Twin Cayes and the wider South Water Caye Marine Reserve area. Furthermore, a review of geospatial datasets including satellite imagery and aerial photographs was conducted to aid in reconstructing the historical extent of the Twin Cayes and make inferences about the rate of change.

Field Visits: Several field visits were programmed strategically to conduct on-site observations within the study area and facilitated the gathering of both qualitative and quantitative data for analyses, interpretation and representation.

5.1 Topo-bathymetric survey

The survey team established appropriate benchmarks at the field station and defined the coastal configuration of the area of interest. This provided a precise calculation of the net landmass at the headquarters. Furthermore, several beach profiles (traverses perpendicular to the coastline) were surveyed. The survey data was obtained using a combination of conventional line of sight equipment (Leica TCR805power) and modern Global Navigation Satellite System (GNSS) equipment (JAVAD Triumph 1 and Leica GPS 900). Conventional equipment was used mainly for the acquisition of onshore and near shore topography. Control Points were established initially as arbitrary locations and were converted to absolute global locations using static GNSS observations referenced to the United States National Geodetic Survey (NGS) and Continuously Operating Reference Station (CORS) network. The closest operational CORS point is located in Chetumal, Mexico, and is referred to as CHET in the NGS database accessible at http://www.ngs.noaa.gov/CORS_Map/. The array of beach profiles was used to compute the nearshore bathymetry. ANNEX 1 presents detailed information on the survey equipment specifications.

5.2 Substrate Identification and Potential Sediment Sources

The substrate identification around the island was done concurrently with the bathymetric surveys. A special ground truthing trip around the entire Twin Cayes was conducted to validate the digital data (reflectance) seen on three Quickbird Satellite Images. Through this exercise, the team was able to identify potential sources of sand for land reclamation.

5.3 Water Currents

The magnitude and direction of the general circulation within the barrier reef system were assessed from the literature. Local currents were measured using the *Lagrangian* method within the vicinity of the Field Station. From three established bench marks the total station was used to track the semi-submerged targets as they were displaced by the local current in the vicinity of South Point.

5.4 Wind, Fetch and Waves Analysis

Considering that most of the local waves are wind generated, attention was focused on the wind data from the weather station at Carrie Bow Caye. A 15-minute wind direction and wind speed data set was sourced courtesy of the Smithsonian Institution. Lakes Environmental Software, WRPLOT View™ was utilized to generate the wind statistics and plot the wind rose diagrams. Inferences on the wind behavior were made based on the interpretation of the wind roses.

The methodology described by the US Army Corps Engineers was employed to calculate the fetch and fundamental wave parameters necessary for this study. These include wave frequency, period and significant height.

5.5 Tides

The measurement of tides is usually done over a long period of time using tide gauges. The setup of tide gauges was beyond the scope of this project. However, time and efforts were dedicated to identify agencies that have tide gauges and data pertinent to the barrier reef lagoon. One data set representing intermittent periods was obtained from the Smithsonian Research Station on Carrie

Bow Cay. The data was parsed into MS Excel document and analyzed to validate tidal ranges reported for the Belize Barrier Reef Lagoon.

5.6 Key informant interviews

Interviews were conducted with key informants including former and current staff members of the SWCMR to gather data related to the evolving destabilization of South Point on Twin Cayes. This consultation exercise validated critical information about altering sea state, abnormal tides, seasonal changes and wave climate with the area of interest.

5.7 Shore Protection Options

By integrating the findings of the Desktop and Field components of this study, key diagnostic indicators highlighted the shore protection options that could be utilized to preserve the landmass on the Twin Cayes. These options were evaluated in accordance with the Terms of Reference considering design, installation methodologies, feasibility and cost-benefits.

6 THE SOUTHERN SHELF LAGOON & TWIN CAYES

6.1 OVERVIEW

As indicated in section 4, the Twin Cayes is nested within the Southern Shelf Lagoon. This shelf is that area of the Belize Barrier Reef Lagoon that extends from the Sibun estuary to the Gulf of Honduras including the southern half of the barrier reef and the inner islands.

This lagoon is the link between the terrestrial environments such as the Maya Mountains, coastal plains, rivers and the marine environment. Therefore, it is strongly influenced from the sea and the land though geologic time. From a coastal oceanographic stand point, this is an intricate area in terms of its physical, chemical, biological and geological characteristics. The geologic controls, including tectonics, faulting, erosion and sedimentation contribute to the geomorphology and bathymetry of the Southern Shelf Lagoon. It is composed of two sets of alternating sub-parallel reefal plateaus and submarine valleys (Figure 6.1.1). The two reefal plateaus are a pinnacle, patch and rhomboidal reef-dominated high running down the center of the lagoon, and the barrier reef tract. The two submarine valleys are (1) the Inner Channel along the western side of the lagoon ranging in depths from 0 to 50 meters and (2) the Victoria Channel on the eastern side with depths of 30 to greater than 50 meters. These submarine valleys are believed to be the main conduits for rivers and siliciclastic sediment during the sea level low stands (Esker et al, 1998).

Both terrigenous and biogenic materials are found distributed in the Southern Shelf Lagoon. The terrigenous materials include the quartz sand and muds of varying composition such as kaolinite, illite and montmorillonite that originated from the Maya Mountains and the southern coastal plain. The biogenic materials are derived primarily from the remains of marine organisms including corals, coralline algae and mollusks. Purdy (1975) mentioned that unlike the Northern Shelf, the occurrence of cocoliths in the southern shelf sediments is very rare.

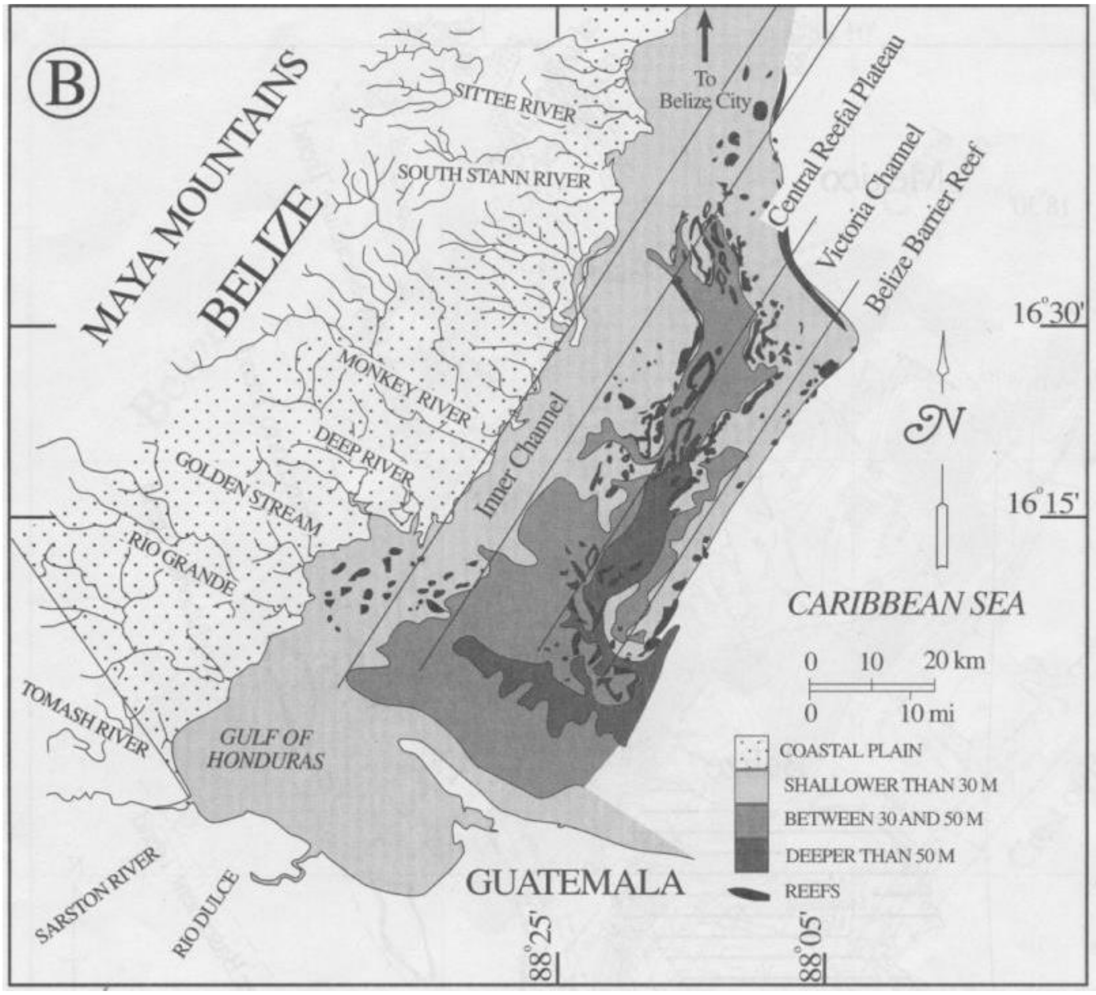


Figure 6.1.1. *Geomorphic and Bathymetric representation of the Southern Shelf Lagoon.* (Source: Esker et al., 1998)

The sediments of the lagoon demonstrate a clear trend in their spatial distribution. The sequence described by James and Ginsburg (1979) shows quartz sand in the nearshore area; mollusk marl and Halimeda marl in the mid reaches of the lagoon and Halimeda sand towards the reef area. They also document the increase in carbonate content of 30% to 90 % from the nearshore areas towards the reef (Figure 6.1.2).

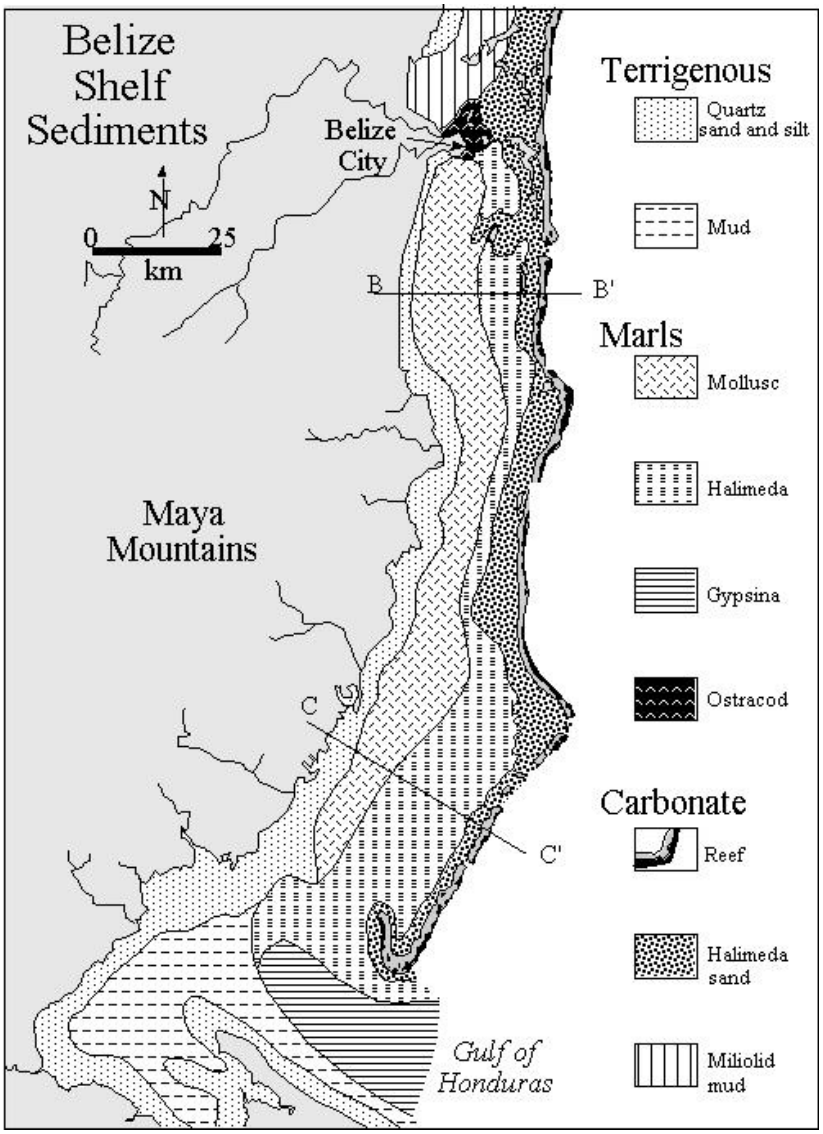


Figure 6.1.2. The areal distribution of surficial sediments on the southern part of Belize shelf (Source: Wantland & Pusey, 1971; Purdy, 1974b).

The physical component includes the effects of the wind, waves, tides; salinity and temperature distribution as drivers of the local and regional water circulation patterns. The chemical aspect involves the chemical composition of the water especially as it relates to nutrient loading to support the biodiversity component of the system. Consequent to this interconnectivity of features, more than 500 mangrove, coral and sand cayes are distributed within the Southern Shelf Lagoon.

6.2 GEOLOGY & PALEOENVIRONMENTS OF THE TWIN CAYES

The spatial and temporal characteristics of the Twin Cayes are quite interesting. An understanding of these characteristics is invaluable to comprehend the present and paleo-ecology; genesis and distribution of sediment and organic matter. During the Late Pleistocene, some limestone topographic highs were formed. This antecedent topography then became the platform upon which the Twin Cayes was developed. Through the Holocene transgression, mangrove derived peat accumulated to thickness of 10 m on the platform (Woodroffe, 1995; Macintyre et al., 2003, 2004). Littler *et al*., (1995) documented that the mean rate of peat accumulation is 4.3 m per thousand years.

From just above mean sea level to depths of 3 m in the channels is a rich deposit of sediments comprised of carbonate silts, mud, sands, peat, detritus, and siliceous skeletal materials derived from diatoms and sponges. Fine grained limestone is produced by the physical erosion of the nearby reefs, diagenesis and reworking of the shelf sediments and transported via currents to the mangroves. Sands are produced within the mangrove assemblage by digestion or decay of calcareous green algae *Halimeda sp.* (Rutzler and Feller, 1988).

Macintyre et al., (2003) compared sediment grain-size patterns with depositional environments around the Twin Cayes and discerned eight depositional environments which are described as follows: (1) *Mangroves* – this environment is dominated by mangroves and large volumes of peat and organic matter, (2) Sparse mangroves- wetland areas with very fine sediment and less dense mangrove vegetation (3) No mangroves – shallow ponds on the caye with thick peat deposits but lacks mangroves, (4) Mud – higher percentages of mud occurs in the low energy, deeper, sheltered channels of the island; (5) *Thalassia* on mud- mud with a rich cover of Thalassia occurs in the deeper (2-7 m) of the windward coast, all through the main channel between the islands, continuing outward along the bayside; (6) Sand- small isolated pockets of well sorted and compacted sands; (7) Sand with *Thalassia* – *Thalassia* on sand directly adjacent to the shorelines, consist of shallow (0-4 m) flats of compact sand with scattered *Thalassia*. Around the north coast, the sand with *Thalassia* depositional environment meets a shoreline of eroding peat and mangroves. (8) *Thalassia* on sand- muddy sands found in protected sites off the coast in the deep (Figure 6.2.1).

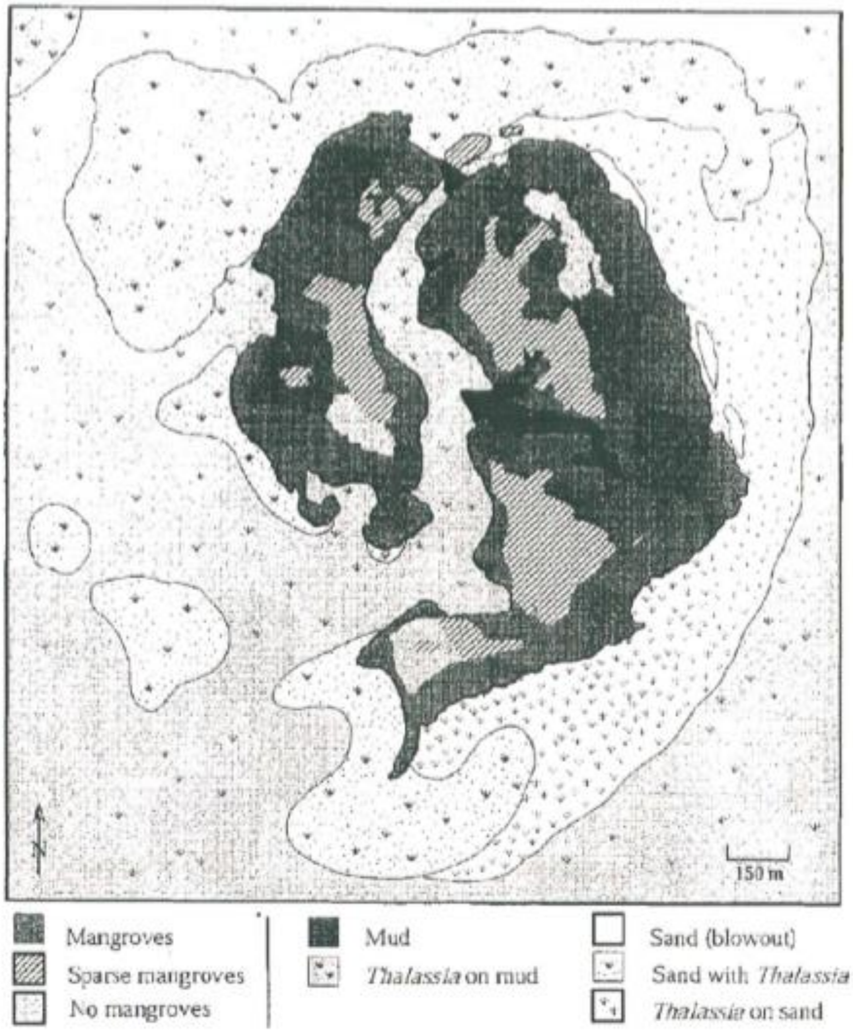


Figure 6.2.1 Depositional environments map of Twin Cayes based on 1982 field observation and aerial photographs. (Macintyre *et al*., 2003)

Three major mangrove species dominate the swamps of the Belize Barrier Reef System. These are (1) *Rhizophera mangle* (red mangrove) which is found in the flooded intertidal zone. This species is easily identified by its prop roots. (2) *Avicennia germinans* (black mangrove) is found in the shallower water a little higher up on the coastline. *A. germinans* is characterized by its horizontal roots with pneumatophores extending few centimeters above the ground. (3) *Laguncularia racemosa* (white mangrove) usually inhabit the highest elevation in succession to *R. mangle* and *A. germinans* (Mckee et al., 1988) (Figure 6.2.2).

Figure 6.2.2 Types of mangroves. (a) *Rhizophera mangle* (red mangrove); (b) *Avicennia germinans* (black mangrove), (c) *Laguncularia racemosa* (white mangrove)

The mangrove distribution at Twin Cayes is dominated by *R. mangle* and *A. germinans* (Rutzler and Feller, 1988; Mckee, 1988). R. mangle forms a fringe around the caye and the banks of the channels. Dwarf *R. mangle* are also seen within the ponds. *A. germinans* occur in isolated patches on some parts of the caye and intermixed in transition zones with *R. mangle*. *L. racemosa* is found and scattered throughout the caye with zones of *R. mangle* and *A. germinans* (Mckee et al., 1988) (Figure 6.2.3).

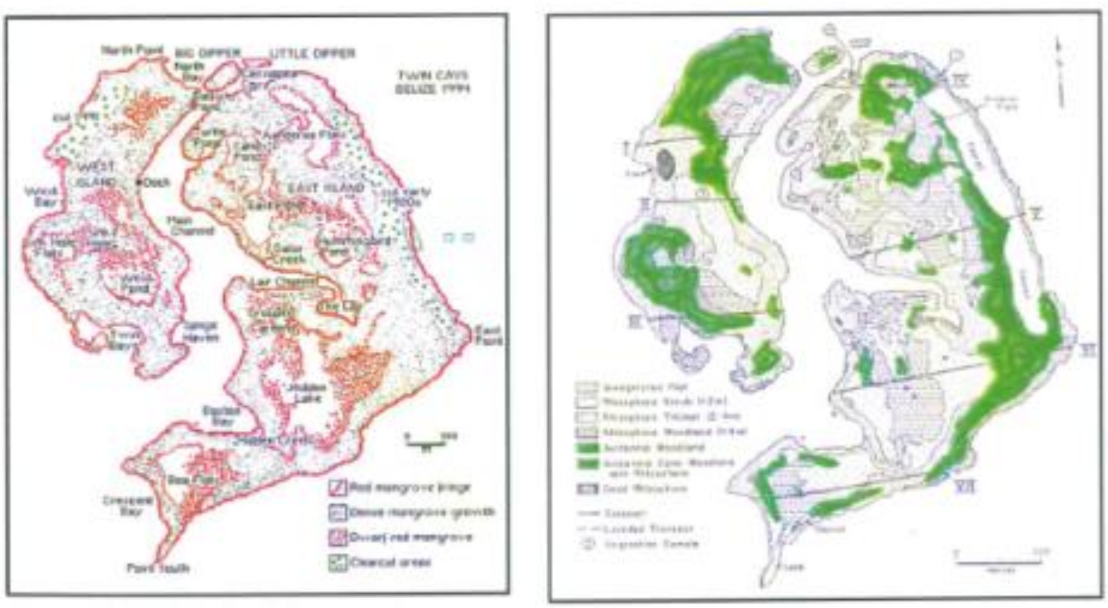


Figure 6.2.3 (a) Distribution of *Rhizophera mangle* (red mangrove); (b) Distribution of *Avicennia germinans* (black mangrove), (c) *Laguncularia racemosa* (white mangrove)

Over the years, the mangrove vegetation in this locality has provided, and undoubtedly will continue to provide stability and shoreline protection to Twin Cayes. Clear cutting mangroves to facilitate other land use in the area would exacerbate coastline erosion.

Thalassia sp. (turtle grass) is the most abundant plant at the bottom of the mangrove environment. It stabilizes the muddy bottom, provides substrates for eggs, and feeding and shelter for a myriad of coastal/ marine organisms.

6.3 SATELLITE IMAGE REVIEW

At the onset of this assessment significant time and effort were allocated to review satellite imagery and geospatial data relevant to the current location of the Rangers Headquarters on Twin Cayes. The primary objective of such an undertaking was to reconstruct in time the geomorphology of the Twin Cayes. It was envisaged that reasonable quality data would undoubtedly shed some light on the pristine and uninhabited state of the island property through its evolution to date. While this type of data was readily available for various parts of the country including Belize City, San Pedro, Caye Caulker and Turneffe Islands; that was not the case for this area of interest. Hard copies of aerial photographs inspected were not clear and were rendered practically useless for this assessment. Most agencies that were consulted had photographs of Landsat images and were restricted in size and resolution. A search for high resolution imagery for this area was conducted in the archives of Digitalglobe. Several tiles were available but either the resolution was lacking, too much cloud cover, or the angle of the imagery way off nadir. Nevertheless, the images with the best resolution and cloud free were acquired and aided to reconstruct the development sequence of the Headquarters dating back to 2004 (Figure 6.3.1).

Maps of the area that are available and were collected including those produced by the Directorate of Overseas Survey presented scales of 1:50,000 and 1: 250,000. Similarly, the corresponding bathymetric maps are adequate for identifying major features for example the Inner Channel, the Victoria channel and obvious shoals. At this juncture, this exercise highlighted a data gap for adequate maps to facilitate coastal/ marine engineering and navigation. With more development activities within the coastal zone the demand for such information will increase.

Figure 6.3.1. *South Point prior to land reclamation [Multispectral Image 24 July, 2004]*

Figure 6.3.1 is a multispectral image that was taken on 24 July, 2004. A multispectral image is one that captures data at specific frequencies across the electromagnetic spectrum. The data stored within the bands of this image were useful for several remote sensing applications in this study. For example, to discern wave direction, land water interface, bathymetry, erosion and accretion.

The following image (Figure 6.3.2) confirms that land was reclaimed at the headquarters in 2005. The change in the extent and area of the property is noteworthy. Furthermore, the images provide a snapshot in time of water currents as is indicated by turbidity patterns and sediment plumes.

Figure 6.3.2 Multispectral image just after land reclamation was complete (What3words)

This snapshot in 2005 clearly demonstrate that with a slightly altered sea state the dredged material is perturbed and winnowed (Figure 6.3.3). Between the period of 2005 and 2015 the zinc guard was breached and the reclaimed land eroded at a remarkable rate. Few coconut trees were planted on the island to abate the erosion.

Figure 6.3.3 South Point after land reclamation [Multispectral image 12 April, 2005]

Figure 6.3.4 is a cloud free high resolution panchromatic image of the study area. Unlike the multispectral three band images, it consists of only one band and is usually displayed as a grey scale image. With just a quick glance at these four images you can readily appreciate the sea state variability in this locality.

Figure 6.3.4 South Point massive erosion *[Panchromatic Image 26 July, 2015]*

7 RESULTS AND DISCUSSIONS

7.1 TOPO-BATHYMETRIC SURVEY

The aforementioned bathymetry of the Southern Shelf Lagoon provides a grand scale perspective and depicts the location of major geomorphic features therein. To address the coastal retreat experienced at South Point however, a very fine-scale bathymetric survey was deemed necessary. This enabled the consultant to establish with the highest degree of confidence (1) the rate of erosion, (2) the volume of sediment displaced or lost from the property since the land reclamation in 2004, (3) the current perimeter and area of the property above the mean sea level, (4) the highest and lowest parts of the island with respect to mean sea level, (5) the contour beyond which sediment is lost (sink) from the beach system, (6) the optimum seaward extent to emplace an armor around the property, and (7) the volume of sediment required to restore and stabilize the property to safeguard the existing / future infrastructure and amenities.

Figure 7.1.1 Topo-bathymetric survey work for the Twin Cayes study

State of the art topographic survey equipment (Figure 7.1.1), spatial analysis and engineering software including ArcGIS ® and AutoCAD® Suites were the tools used to carry out this study. Benchmarks were set on strategic locations of the property and traverses were shot on the island and in water generating a cloud of XYZ points (Figure 7.1.2) The point cloud was used to create a Triangulated Irregular Network (TIN) that provided an accurate representation of the land and nearshore morphology of South Point (Figure 7.1.3). Subsequently, topographic and bathymetric contours of 0.1 m intervals were generated from the TIN. The contours and TIN were used to create the Digital Elevation Model (DEM) of the study area to aid in (a) understanding the overall framework and boundary conditions in which the local coastal processes operate, (b) identification of suitable erosion control mechanisms for the extant biogeophysical impacts of land use and climate change and (c) preliminary design and estimates of proposed shore protection solutions.

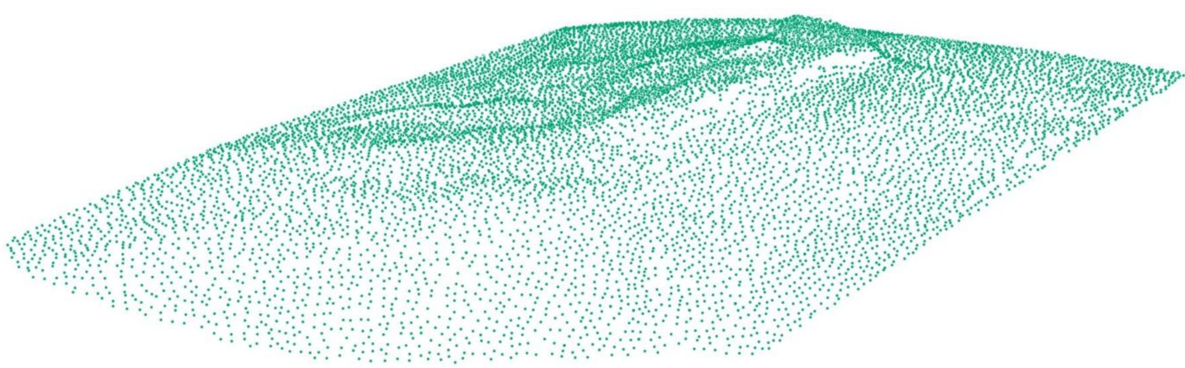


Figure 7.1.2 *Topo-bathymetric point cloud*

Noteworthy, is the extraordinary low-relief of both the landward and seaward extent of the study area. By rotating the perspective and applying various levels of vertical exaggeration to the DEM, it was possible to resolve the inherent characteristics of the area of interest and its response to wave climate, current regime, water levels and the processes of erosion and accretion.

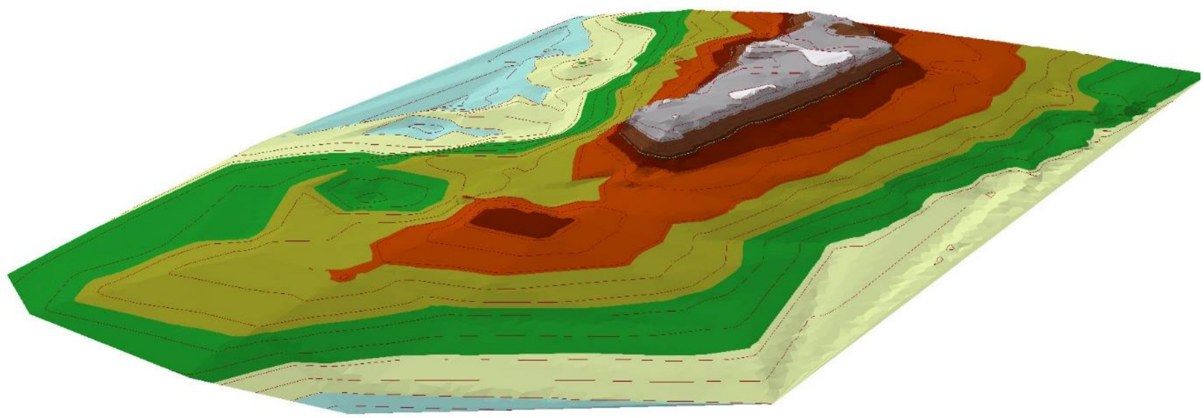


Figure 7.1.3 *Topo-bathymetric Surface with Contours [5x exaggerated]*

In summary, the topo-bathymetric survey is the foundation upon which all the other data and technical knowledge was integrated to develop this comprehensive assessment of South Point. A 0.5 m resolution Quickbird 02 satellite image acquired of the Twin Cayes on the 24 of July 2004, provides a snapshot of the study area prior to any land reclamation. The estimated landmass derived from this image is approximately 0.31 acres. The area of the property post land reclamation calculated from a satellite image acquired on the 10 of April 2005 was approximately 0.45 acres.

The current landmass of the property above MHW is 0.219 acres (888.92 m^2) and has perimeter of 162 meters. Between April 2004 and April 2016 the shoreline at South Point had receded approximately 9.59 meters establishing a rate of erosion of 0.87 meters per annum. Assuming that the land fill level was 0.5 m above sea level, the volume of sediment displaced or lost in that period corresponds to 1,126 m^3 (1,472.75 cubic yards). At present value of BZ$30/cubic yard, this lost corresponds to approximately BZ$44,182.50. The elevation onshore ranges from 0 – 0.6 meters. Depth of closure or the bathymetric contour at which sediment is completely lost from the shore (and normal wave climate cannot bring it back onshore) is -0.4 meters. The irregular seafloor displays nearshore depths that provide accommodation space as sinks for eroding onshore sediment.

7.2 WIND ANALYSIS

Wind is the perceptible natural movement of the air, especially in the form of a current blowing from a particular direction. This meteorological factor is characterized by the magnitude of the movement and its direction. These parameters and their unpredictability contribute to the fetch, propagation of wind driven waves and variability in the intensity and direction of water currents.

Belize is located in the NE Trade Wind zone (Purdy et al., 1975). The wind conditions throughout the year is dominated by weak easterly and northeasterly winds which rarely exceed wind speeds of 5 to 8 m/s (Rutzler and Ferraris,1982). There is a seasonal as well as a daily variation in wind conditions. The strongest winds occur in the period April through August whereas the weakest winds occur in the period from September through December. The transition period is January through March and known to display moderate wind conditions. The basic patterns of the daily winds begin with light breezes during the early morning, gaining strength with onshore breezes during the afternoon and evening, before weakening late at night, sometimes switching to off-shore breezes before sunrise.

Two major processes bring storms to the area. During the period October to April outbreaks of cool, damp northerly winds, the so called ‘northers’ occurs, often in combination with squally conditions and overcast skies. These strong winds are a result of the southward extension of the North American cold fronts with duration of a few days. The second process is that of the tropical storms and hurricanes which may occur in the hurricane season from June to November.

While this summarizes the general annual atmospheric circulation in Belize, there is the need for more local wind statistics to characterize the meteoro-oceanographic conditions of the Twin Cayes. To this end, an archive of 15-minute wind direction and wind speeds was obtained from the Smithsonian Institution weather station at Carrie Bow Cay. This weather station is located within 3 km of the study area and has the most comprehensive data set relevant to this assessment. The data set consists of eight (8) months of data for the period June 2015 to April 2016. Due to problems experienced with the weather station occasionally; complete records were only available for these specific eight months, June, July, August, and December 2015; January, February, March and April 2016. The wind data was carefully examined and subsequently analyzed to produce wind rose diagrams, wind class frequency distribution graphs and normalized frequency tables corresponding to the eight months batch and also for each specific month for the period 2015 and

2016. The wind rose is an effective analytical tool that graphically displays the frequency distribution of occurrences of winds in each of the defined direction sectors and wind speed classes for the specified date, year and time period. The wind class frequency distribution graph displays a wind class frequency distribution expressed as percent recurrence. The table displays the normalized frequency of occurrences of winds in each direction and each wind speed class. The sub-totals for each column and row (total occurrence of wind class and wind direction respectively) are displayed [see Annex 2]. The following section provides a detail review of the wind characteristics at Carrie Bow Caye which is explicitly valid for South Point at the Twin Cayes.

The wind rose diagram illustrated in Figure 7.2.1 represents eight months of wind speed and direction for Carrie Bow Caye. The wind blew out of the east-northeast (ENE) predominantly however, the east and northeast components are significant in terms of frequency and duration. The observed predominant ENE wind direction represent 30.6% of all the hourly wind directions. From this direction, 0.4% of the time the wind blew at speeds of 0.5 and 2.1m/s; 1.3% of the time the wind blew at speeds of 2.1 and 3.6 m/s; 5.6% of the time the wind blew at speeds of 3.6 and 5.7 m/s; 15.6% of the time the wind blew at speeds of 5.7 and 8.8 m/s; 5.9% of the time the wind blew at speeds of 8.8 and 1 1.1 m/s. The ENE winds blew at speeds greater than 11 m/s for 1.5% of the time.

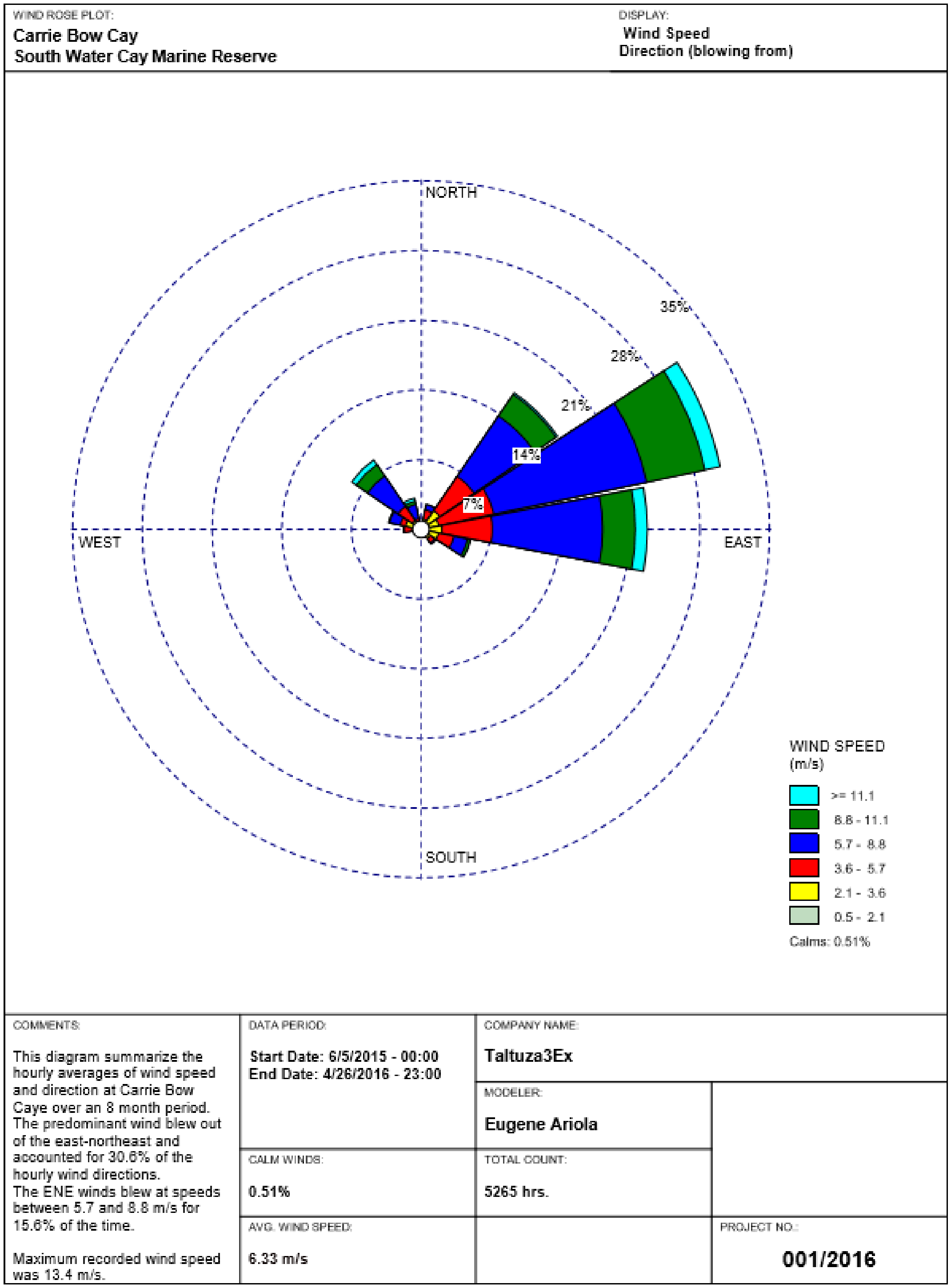


Figure 7.2.1 Wind Rose Diagram for eight months, Carrie Bow Caye - June 2015 to April 2016

The wind class frequency distribution graph (Figure 7.2.2) reveals that the frequency of calm winds during the eight-month period was 0.51%. Conversely, the frequency of wind speeds equal to or greater than 11.1 m/s was 0.38%. The wind class 5.7 to 8.8 m/s represent 42.8% of the total wind speed. The mean wind speed was 6.33 m/s.

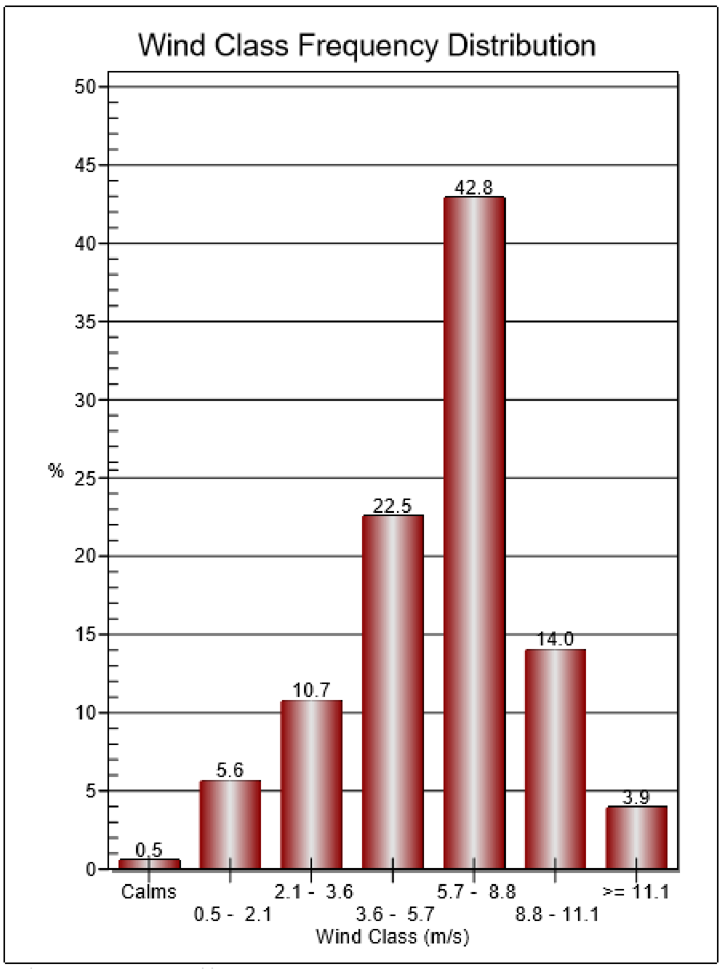


Figure 7.2.2 Wind Class Frequency Distribution June 2015 to April 2016

The wind frequency distribution is summarized in the Table 7.2.1. This provides detailed information on the frequency count for each wind class. At a glance one could recognize the more versus the least dominant wind directions.

Table 7.2.1 (a). Wind Frequency Distribution (count) [Start Date: 6/5/2015 -00:00; End Date 4/26/2016- 23:00]

Wind Direction (Blowing From) / Wind Speed (m/s)

	0.5 - 2.1	2.1 - 3.6	3.6 - 5.7	5.7 - 8.8	8.8 - 11.1	>= 11.1	Total
N	0	1	1	1	0	0	**3**
NNE	10	46	50	28	2	0	**136**
NE	36	84	219	386	137	10	**872**
ENE	23	73	296	824	313	83	**1612**
E	37	74	265	582	172	64	**1194**
ESE	29	66	82	74	16	1	**268**
SE	21	39	27	8	1	0	**96**
SSE	9	9	10	4	0	0	**32**
S	14	12	10	3	0	0	**39**
SSW	18	4	5	3	0	0	**30**
SW	17	5	6	1	0	0	**29**
WSW	11	14	11	8	0	0	**44**
W	20	29	40	5	0	0	**94**
WNW	26	58	29	58	4	1	**176**
NW	17	40	90	195	72	30	**444**
NNW	5	9	45	76	18	16	**169**
Total	293	563	1186	2256	735	205	5265

Frequency of Calm Winds: 27
Average Wind Speed: 6.33 m/s

(b). Normalized Wind Frequency Distribution [Start Date: 6/5/2015 -00:00; End Date 4/26/2015- 23:00]

Wind Direction (Blowing From) / Wind Speed (m/s)

	0.5 - 2.1	2.1 - 3.6	3.6 - 5.7	5.7 - 8.8	8.8 - 11.1	>= 11.1	Total
N	0.000000	0.000190	0.000190	0.000190	0.000000	0.000000	**0.000570**
NNE	0.001899	0.008737	0.009497	0.005318	0.000380	0.000000	**0.025831**
NE	0.006838	0.015954	0.041595	0.073314	0.026021	0.001899	**0.165622**
ENE	0.004368	0.013865	0.056220	0.156505	0.059449	0.015764	**0.306173**
E	0.007028	0.014055	0.050332	0.110541	0.032669	0.012156	**0.226781**
ESE	0.005508	0.012536	0.015575	0.014055	0.003039	0.000190	**0.050902**
SE	0.003989	0.007407	0.005128	0.001519	0.000190	0.000000	**0.018234**
SSE	0.001709	0.001709	0.001899	0.000760	0.000000	0.000000	**0.006078**
S	0.002659	0.002279	0.001899	0.000570	0.000000	0.000000	**0.007407**
SSW	0.003419	0.000760	0.000950	0.000570	0.000000	0.000000	**0.005698**
SW	0.003229	0.000950	0.001140	0.000190	0.000000	0.000000	**0.005508**
WSW	0.002089	0.002659	0.002089	0.001519	0.000000	0.000000	**0.008357**
W	0.003799	0.005508	0.007597	0.000950	0.000000	0.000000	**0.017854**
WNW	0.004938	0.011016	0.005508	0.011016	0.000760	0.000190	**0.033428**
NW	0.003229	0.007597	0.017094	0.037037	0.013675	0.005698	**0.084330**
NNW	0.000950	0.001709	0.008547	0.014435	0.003419	0.003039	**0.032099**
Total	0.055651	0.106933	0.225261	0.428490	0.139601	0.038936	0.994872

Frequency of Calm Winds: 0.51%
Average Wind Speed: 6.33 m/s

Apart from reviewing at the detailed wind statistics an attempt was made to show the geospatial relationship that exists between the wind characteristics and the study area. To this end, the wind rose is displayed at Carrie Bow Caye and indicates the direction from which the wind blows (Figure 7.2.3a).

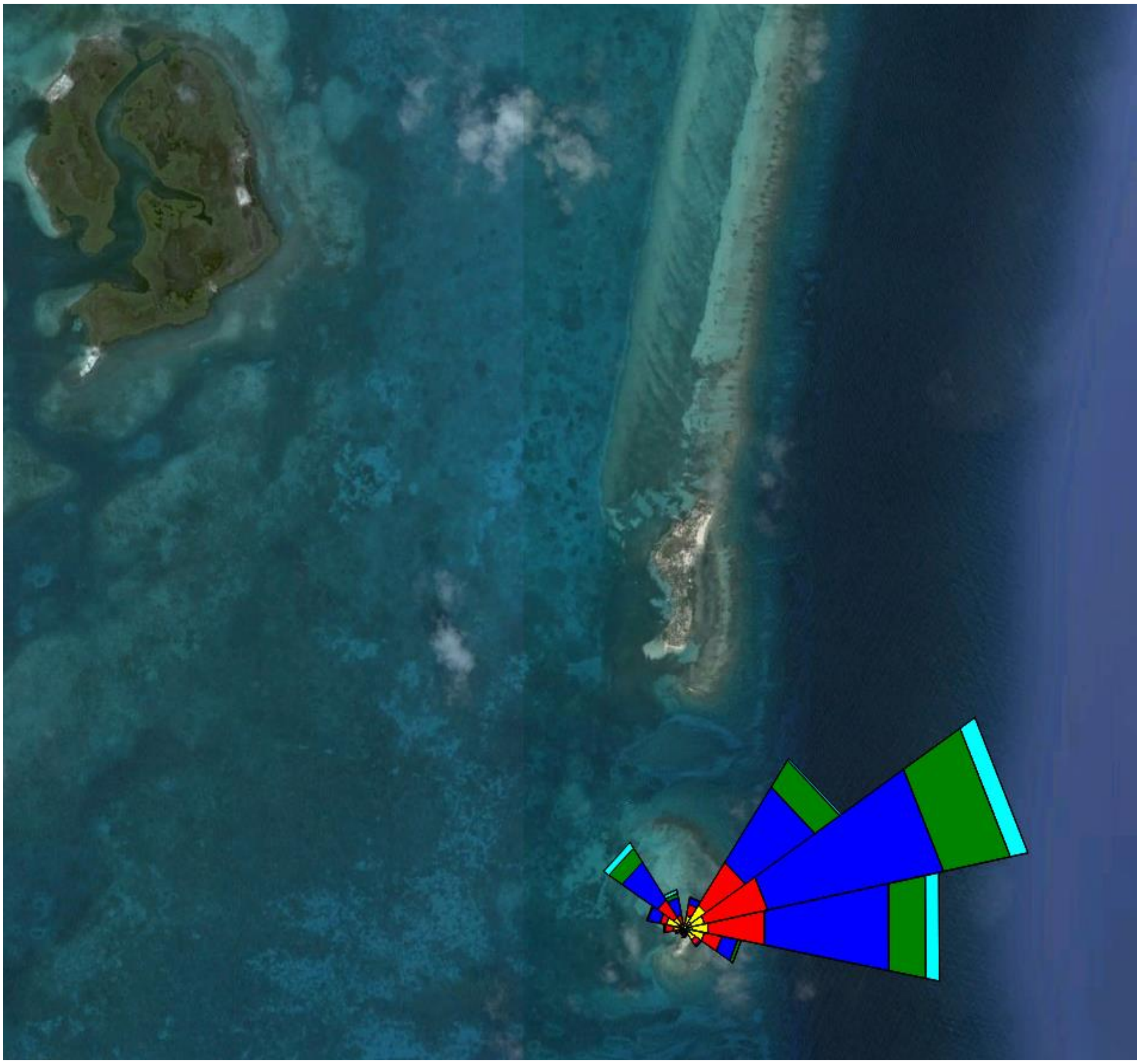


Figure 7.2.3 (a). The wind distribution at Carrie Bow Caye for the period of June 2015 to April 2016. This diagram illustrates the directions from which the wind was blowing. (*Google Earth background Image*)

In Figure 7.2.3 (b) the wind rose diagram is oriented to depict the direction to which the wind is blowing. Generally, this is the direction of propagation of the wind generated waves.

Figure 7.2.3 (b). The wind distribution at Carrie Bow Caye for the period of June 2015 to April 2016. This diagram illustrates the directions to which the wind was blowing to. (*Google Earth background Image*)

The wind analysis conducted on the eight months of data produced a good synopsis of the wind conditions. However, to discern the seasonal variability in the data at a glance, the same wind analysis workflow was used to understand the monthly wind conditions as described below. The respective wind rose diagrams, wind class frequency distribution graphs and wind frequency distribution tables are in Annex 2.

For the month of June 2015, the winds at Carrie Bow Cay blew out of the east-northeast (ENE) most of the time. See the longest spoke in the rose diagram presented in ANNEX-2 Figure 1. The observed predominant wind direction constitutes 42% of the 610 hourly wind directions. From this direction approximately 0.3% of the time the wind blew at speeds of 0.5 and 2.1 meters per second. Furthermore, the winds blew from the ENE at speeds between 2.1 and 3.6 m/s 2% of the time, at speeds between 3.6 and 5.7 m/s 4% of the time, between 5.7 and 8.8 about 17% of the time, between 8.8 and11.1 m/s about 13% of the time. The wind blew at speeds greater than 11.1 m/s about 7% of the time.

The data represented in the wind class frequency distribution graph in ANNEX-2 Figure 1A shows that the frequency of calm winds in June was only 0.16%. However, the frequency of wind speeds greater than or equal to 11.1 m/s was 11.5%. The wind class of 5.7 to 8.8 m/s represents 37.9% of the total wind speed. The mean wind speed is 7.49 m/s. Winds did not blow from the northwest during this period.

The wind patterns through July 2015 were comparatively similar to that observed in June of that same year. The winds at Carrie Bow Cay blew out of the east-northeast predominantly and represented 49% of the hourly wind directions. From this direction approximately 0.3% of the time the wind blew at speeds of 0.5 and 2.1 meters per second. Also, the winds blew from the ENE at speeds between 2.1 and 3.6 m/s 1% of the time, at speeds between 3.6 and 5.7 m/s 3% of the time, between 5.7 and 8.8 about 23% of the time, between 8.8 and11.1 m/s about 18% of the time. The wind blew at speeds greater than 11.1 m/s about 3% of the time. The maximum recorded wind speeds this period was 13.3 m/s. Winds did not blow from the west, west-southwest, southwest, south-southwest and the north-northwest during this period.

The wind class frequency distribution graph (ANNEX- Figure 2A) shows that the frequency of calm winds during in July was 0.0%. On the other hand, the frequency of wind speeds equal to or greater than 11.1 m/s was 4%. The wind class 5.7 to 8.8 m/s represent 53.6% of the total wind speed. The mean wind speed was 7.78 m/s.

For the month of August 2015, the winds at Carrie Bow Cay blew out of the east-northeast most of the time and represents 40% of all the hourly wind directions for this period. From this direction approximately 0.2% of the time the wind blew at speeds of 0.5 and 2.1 meters per second. Additionally, the winds blew from the ENE at speeds between 2.1 and 3.6 m/s 0.7% of the time, at speeds between 3.6 and 5.7 m/s 6% of the time, between 5.7 and 8.8 about 28% of the time, between 8.8 and11.1 m/s about 4% of the time. The wind blew at speeds greater than 11.1 m/s about 1% of the time. The maximum recorded wind speed this period was 13.4 m/s. Of the total 614 hourly winds only 0.33% were calm moments. Winds did not blow from the west or the south-southwest directions during this period.

The wind class frequency distribution graph (ANNEX-2 Figure 3A) reveals that the frequency of calm winds during the month of August was 0.3%. However, the frequency of wind speeds equal to or greater than 11.1 m/s was 1.6%. The wind class 5.7 to 8.8 m/s represent 53.4% of the total wind speed. The mean wind speed was 6.38 m/s.

In December 2015, the winds at Carrie Bow Cay blew directly from the east most of the time and constitute 44% of the 468 hourly wind directions. From this direction approximately 2% of the time the wind blew at speeds of 0.5 and 2.1 meters per second. Furthermore, the winds blew from the east at speeds between 2.1 and 3.6 m/s 1% of the time, at speeds between 3.6 and 5.7 m/s 4% of the time, between 5.7 and 8.8 about 19% of the time, between 8.8 and11.1 m/s about 10% of the time. The wind blew at speeds greater than 11.1 m/s about 7% of the time. Winds did not blow from the west, west-northwest and the southwest during this period.

The data presented in the wind class frequency distribution graph in ANNEX-2 Figure 4A shows that the frequency of calm winds in June was only 0.0%. Conversely, the frequency of wind speeds greater than or equal to 11.1 m/s was 9.6%. The wind class of 5.7 to 8.8 m/s represents 42.4% of the total wind speed. The mean wind speed is 7.23 m/s.

In January 2016, the winds at Carrie Bow Cay blew out of the Northwest most of the time and comprised 28% of hourly wind directions. From this direction approximately 2% of the time the wind blew at speeds of 0.5 and 2.1 meters per second. Furthermore, the winds blew from the ENE at speeds between 2.1 and 3.6 m/s 3% of the time, at speeds between 3.6 and 5.7 m/s 7% of the time, between 5.7 and 8.8 about 13% of the time, between 8.8 and11.1 m/s about 4% of the time.

The wind blew at speeds greater than 11.1 m/s about 0.5% of the time. Winds blew partially from every direction during this period.

The wind frequency distribution plot illustrates that during this period, 1.9 % of calm winds and a frequency of 0.9% of winds equal to or greater than 11.1 m/s occurred. The wind class of 3.6 – 5.7 m/s represents 30% of the all the wind speeds recorded this month. The average wind speed was 4.82 m/s.

There was an interesting change in wind patterns in the month of January. The northwest component of the winds seen in the Wind Rose is the fraction of winds that generate more violent waves that approach and aggressively erode the southwestern side of South Point.

In February 2016, the winds at Carrie Bow Cay blew directly from the northwest most of the time and accounted for 25% of the 668 hourly wind directions. The northwest winds blew at speeds between 2.1 and 3.6 m/s 2% of the time, at speeds between 3.6 and 5.7 m/s 4% of the time, between 5.7 and 8.8 about 11% of the time, between 8.8 and11.1 m/s about 6% of the time. The wind blew at speeds greater than 11.1 m/s about 3% of the time. Winds blew partially from all directions during this period.

The wind class frequency distribution graph indicates a frequency of 0.3% calm winds and a frequency of 3.7% for wind speeds equal to or greater than 11.1 m/s. The wind class of 5.7 to 8.8 m/s represents 40.7% of the total wind speeds recorded during this period. The mean wind speed was 6.13 m/s.

Comparatively, the wind regime observed in January and February 2016 displays some similar characteristics (Figure 7.2.4). The winds blew from every direction and the predominant direction was from the Northwest. The east-northeast and the east winds that a more dominant for most of the year is seen rather weak in January and February. This northwesterly wind enhances wave activity which catalyze erosion rates in the study area.

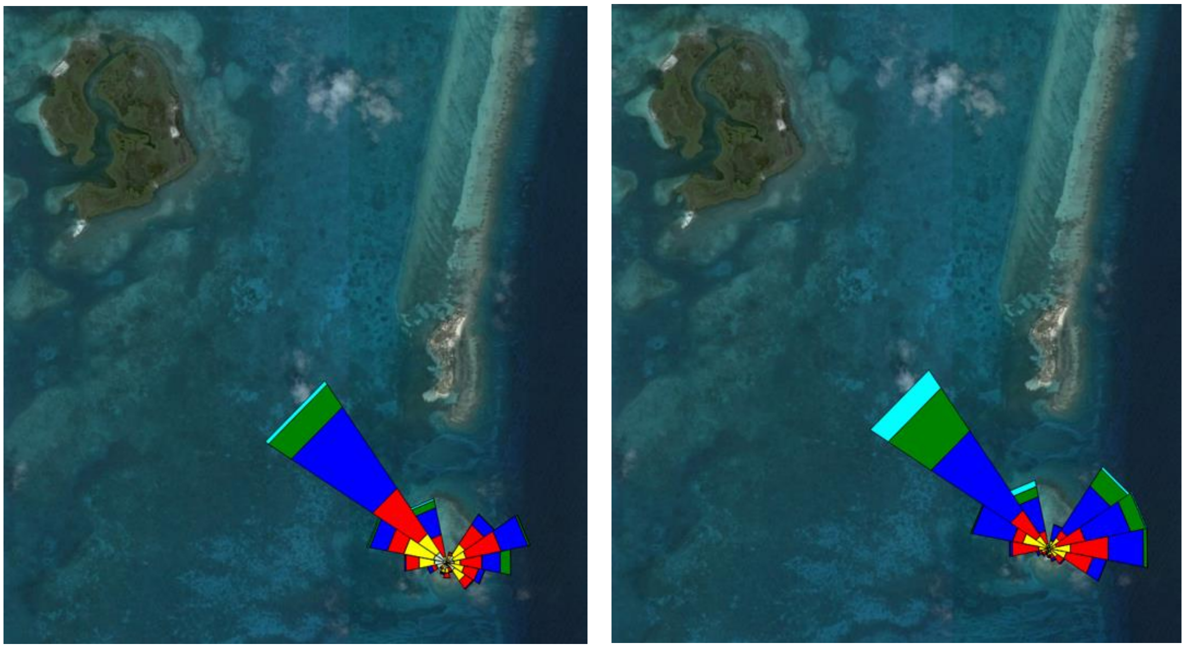


Figure 7.2.4. The wind distribution at Carrie Bow Caye indicating a dominant northwesterly component through (a) January 2016 (b) February 2016. This diagram illustrates the directions from which the wind was blowing. (*Google Earth background Image*)

For the month of March 2016, the winds at Carrie Bow Cay blew out of the east for most of the time and accounted for 34% of the 745 hourly wind directions. From this direction, approximately 1% of the time the wind blew at speeds of 0.5 and 2.1 meters per second. Furthermore, the winds blew from the east at speeds between 2.1 and 3.6 m/s for 2% of the time, at speeds between 3.6 and 5.7 m/s 6% of the time, between 5.7 and 8.8 about 21% of the time, between 8.8 and11.1 m/s about 4% of the time. Winds did not blow from the north during this period.

The wind class frequency distribution graph indicates a frequency of 0.4% calm winds and a frequency of 2.4% for wind speeds equal to or greater than 11.1 m/s. The wind class of 5.7 to 8.8 m/s represents 43.9% of the total wind speeds recorded during this period. The mean wind speed was 5.79 m/s.

For the month of April 2016, the winds at Carrie Bow Cay blew out of the east-northeast (ENE) most of the time and accounted for 36.6% of the 623 hourly directions. From this direction approximately 0.3% of the time the wind blew at speeds of 0.5 and 2.1 meters per second.

Furthermore, the winds blew from the ENE at speeds between 2.1 and 3.6 m/s 2.7% of the time, at speeds between 3.6 and 5.7 m/s 11% of the time, between 5.7 and 8.8 about 21% of the time, between 8.8 and11.1 m/s about 2% of the time. Winds did not blow from the south-southwest during this period.

The corresponding wind class frequency distribution graph indicates a frequency of 0.8% calm winds and a frequency of 0.0% for wind speeds equal to or greater than 11.1 m/s. The wind class of 5.7 to 8.8 m/s represents 42.7% of the total wind speeds recorded during this period. The mean wind speed was 5.45 m/s.

The wind dataset used in this analysis was devoid of data corresponding to the months of September, October and November. However, Macintyre (1987) reported comparative wind statistics for the coastal zone of Belize and also pointed out that the predominant northwest wind direction in October/November include only 0.3% of calm winds and that the highest speed range is 9-14 m/s.

7.3 FETCH ANALYSIS

The fetch is defined as the unobstructed distance over which the wind blows over the water surface. South Point is exposed to two principal fetch. The greater fetch is approximately 18.5 kilometers long. The wind blowing from the Dangriga – Sittee coastline can funnel between Stewart and Ragged Cayes towards South Point. The fetch is important in this coastal environment because of the effect it has on the formation of waves. This fetch would generate waves that propagate towards South Point during the late evenings and during the “northers” or cold fronts. On the other hand, as the Trade wind blow from the east it is obstructed by the barrier Reef, South Water Caye, Carrie Bow Caye and Curlew Caye. Therefore, only a small fetch of approximately 3 kilometers exists to the east of South Point. Only small waves can be formed in this small fetch and propagate towards South Point (Figure 7.3.1).

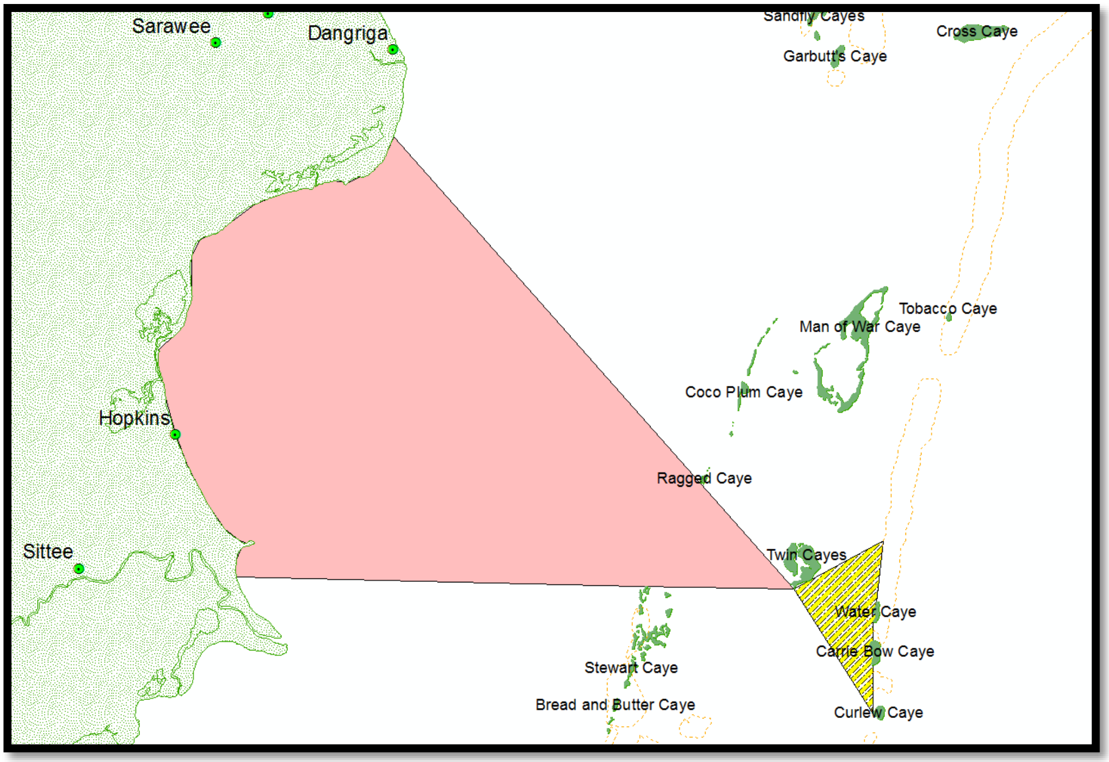


Figure 7.3.1 Schematic view of the fetch affecting South Point. The red cone represents the 18.5 km fetch and the yellow cone corresponds to a 3 km fetch.

7.4 WAVE ANALYSIS

The ocean and atmosphere interaction is the principal driver for wave generation through the transfer of momentum. The wind interacts with the water surface to generate ripples, seas and swells. The characteristics of these surface waves are determined by several factors including *wind speed*, *duration* and the *fetch*. The greater the wind speed the larger the waves. The longer the duration of wind the larger the waves. The greater the fetch the larger the waves.

To enhance our understanding of the erosion, transport and deposition processes at the Twin Cayes it is imperative that we understand the fundamentals of waves and how they function.

The high portion of the wave is referred to as the crest and the low portion is called the trough. The wave height is the difference in height between the crest and the trough. The wavelength (λ) of a wave is the distance between two successive crests or troughs. The wave period (T) is time it takes for two successive wave crests or troughs to pass a specific point. The surface expression of a wave is the apparent up and down motion, however, waves propagate with an orbital motion from the top to the bottom. This orbital motion is greatest at the sea surface and decreases with depth below the surface. At a depth of ½ the wavelength the orbital motion is attenuated to approximately zero. This $\lambda/2$ is called the wave base. In effect what this means is that, as waves travel in deep waters they have no effect below the wave base and hence would not perturb sediments and substrate on the sea floor (Figure 7.4.1).

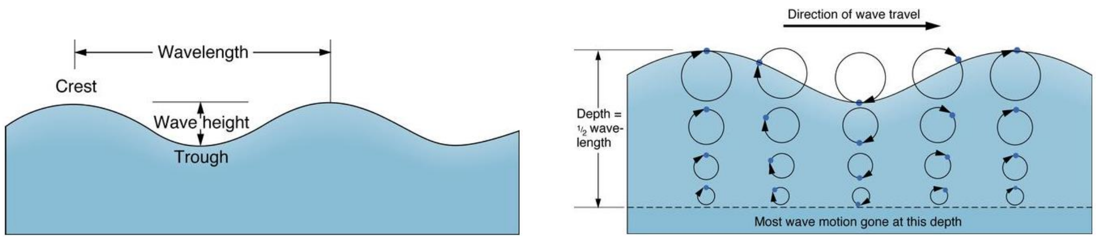


Figure 7.4.1 (a) Wave height is the vertical distance between crest and the trough. Wavelength is the horizontal distance between two crests.] (b) Orbital motion of water in waves dies out with depth. At the surface the diameter if the orbits equal the wave height. [Plummer et.al. 2003]

As waves travel from deep water (open ocean) to shallow coastal environments their behavior is drastically modified. The waves tend to slow down as the water depth becomes less than half the wavelength ($\lambda/2$). The waves get closer together, steeper and taller. Unlike the deep water wave, the orbital motion becomes more elliptical and there is a more of a back and forth motion as opposed to an up and down motion. Because the topography of the seabed is irregular, the waves would drag and slow down where it is shallower and speed up where it is deeper. This results in the bending of the waves and this is known as wave refraction. Eventually, the wave reaches a very shallow threshold, become unstable and collapse as a breaker. Once the wave breaks the energy of the wave is released resulting in the obvious forward swash and backwash on shores. It is at this point that sediment and objects are inevitably displaced (Figure 7.4.2).

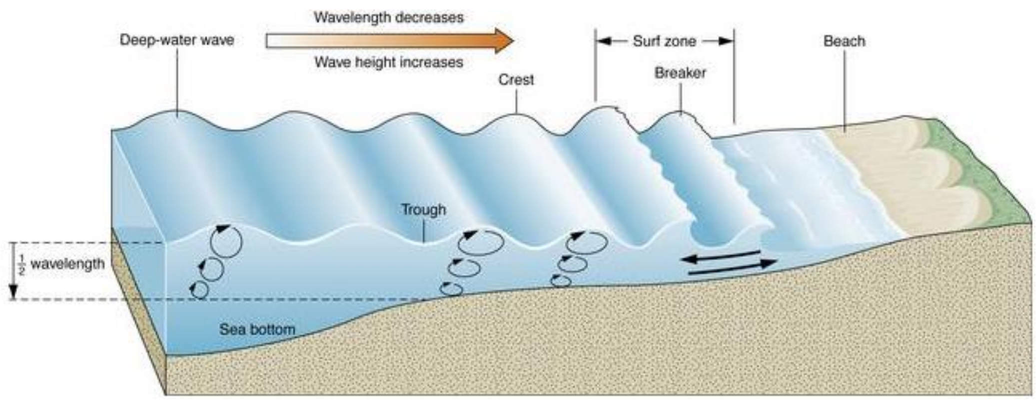


Figure 7.4.2 (a) As a deep water wave approaches shore it begins to feel the sea bottom and slow down. Circular water orbits flatten and the wave peaks and breaks. In the foam surf zone, water moves back and forth rather than in orbits [Plummer et.al. 2003].

The stress and shear of the NE Trade Winds generate most of the waves within the Barrier Reef Complex (Wantland and Pusey, 1975; Rutzler & Macintyre, 1982). Heyman and Kjerfve (2000), state that the seas and swells generated between December and May are usually 1- 3 m height with periods of 3.7 seconds with a mean direction towards the West (250 degrees). These deep water waves are dissipated and refracted as they approach the Barrier Reef. This can be observed at the South Water Caye -Carrie Bow Channel. The waves then travel in the Northwest direction towards the Twin Cayes. The surf and wave energy released contribute to the local currents at South Point and within the wider Southern Shelf Lagoon. Also contributing to this lagoon circulation and erosion are the waves that are generated within the Southern Shelf Lagoon under the stress of 10-mile fetch. These wave approach the Twin Cayes from a Northwesterly direction and refract eastward at South Point. These relatively short bursts of wave energy during 2-3 day cold fronts have the most devastating effect on the leeward side of South Point.

During the field visits at South Point the sea state was calm for most of the time. The sea state would get a little choppy in the late afternoon with ripples and maximum wave heights of 6-8 inches approaching the shoreline. Waves of this magnitude provide enough energy to accelerate the longshore currents and enhance sediment displacement. With the erratic occurrence of ripples and small wave it was difficult to properly analyze the wave properties on location. However, a special remote sensing exercise was conducted on two satellite images to corroborate the interaction of the waves with South Point. Figure 7.4.3 is a schematic derived from a satellite imaged dated 26 July 2015. It shows that on this day the waves approached South Point from the

Southeast direction. The waves refract towards the north at the tip of the headland where it effects the most sediment displacement to the northwestern side of the island.

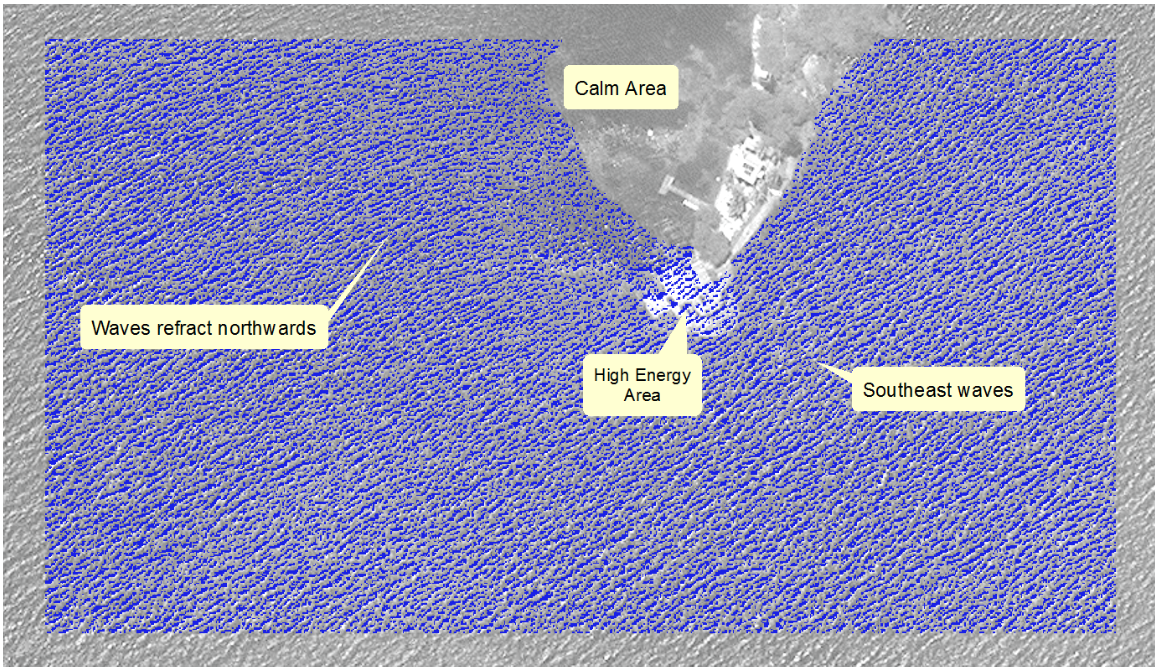


Figure 7.4.3 Satellite image schematic with wave propagation and interaction at South Point

The satellite image that was taken on the 24 July 2004 corroborate that waves propagate from the northwest (Figure 7.4.4). These waves were examined and indicate that they have more of an impact on the leeward side of South Point and as they refract towards the east they release energy and displace sediment into deeper waters less than 20 meters seaward of the headland. The predominant southeaster waves are generally constant but mild during the summer months. Conversely, the northwestern waves tend to be more intense during the winter months. It is this wave interaction which makes South Point very dynamic and unstable.

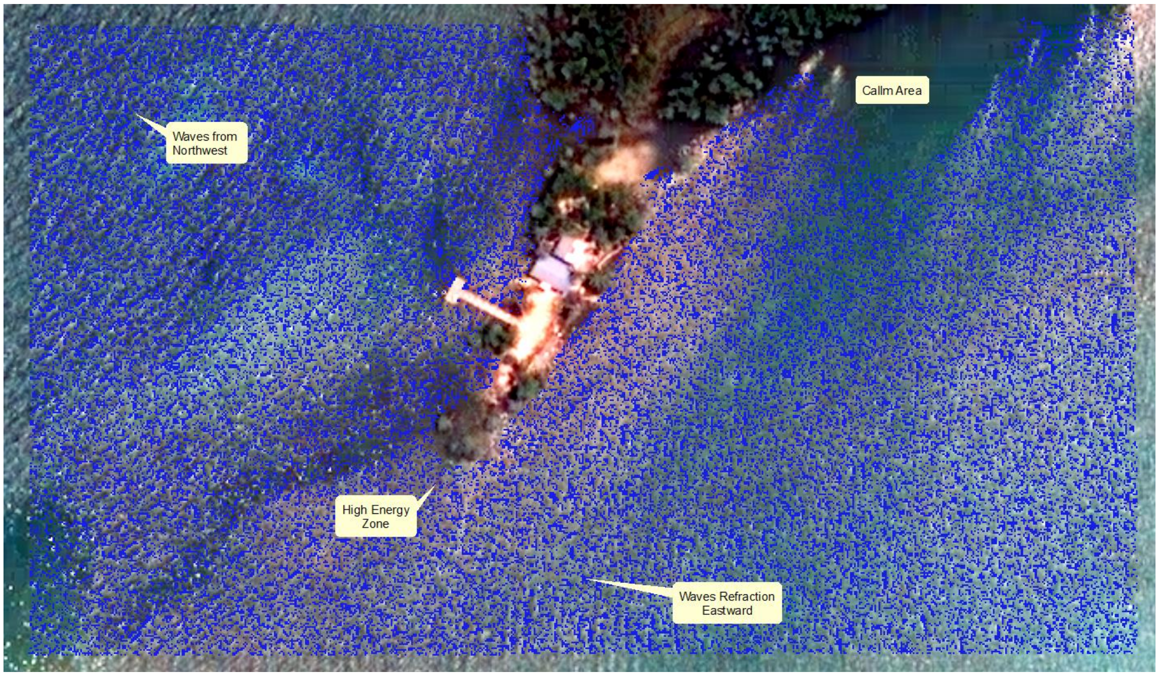


Figure 7.4.4. Schematic view of the wave incidence and refraction on South Point

Wave calculations based on the results of the wind and fetch analysis seen earlier can be done by applying the wave computation method for limited water depths as described by US Army Corps of Engineers (1984). For the purposes of this exercise two time periods were identified (June to December and January to April). The wind speeds and the Northwestern fetch of 20 km and a water depth of 15 m was used for the wave calculations (Table 7.4.1). The corresponding wave characteristics for this scenario is displayed in Table 7.4.2. This procedure was repeated using the same wind parameters against the much smaller eastern fetch of 3 km and average water depths of 2.5 m. The results of this calculation is presented in Table 7.4.3 and the corresponding wind characteristics in Table 7.4.4.

Table 7.4.1 Summary of wind conditions for limited water depths wave calculations (fetch length of 20 km)

Months	**Average Conditions**		**Maximum Conditions**		Typical fetch (km)	Typical water depth (m)
	Speed (m/s)	Duration (hrs.)	Speed (m/s)	Duration (hrs.)		
June to December	7.22	8.0	13.9	2	20	5
January to April	5.55	6.0	12.0	2	20	15

Table 7.4.2 Wave Characteristics for the fetch west of South Point

Months	**Avg. condition** Significant wave height H_s (m)	**Avg. condition** Wave period T (s)	**Max condition** Significant wave height H_s (m)	**Max condition** Wave period T (s)
June to December	0.5	2.95	1.2	3.99
January to April	0.39	2.6	1.0	3.7

Table 7.4.3 Summary of wind conditions for limited water depths wave calculations (fetch length of 3 km)

Months	**Average Conditions**		**Maximum Conditions**		Typical fetch (km)	Typical water depth (m)
	Speed (m/s)	Duration (hrs.)	Speed (m/s)	Duration (hrs.)		
June to December	7.22	8.0	13.9	2	3	2.5
January to April	5.55	6.0	12.0	2	3	2.5

Table 7.4.4 Wave Characteristics for the fetch east of South Point

Months	**Avg. condition** Significant wave height H_s (m)	**Avg. condition** Wave period T (s)	**Max condition** Significant wave height H_s (m)	**Max condition** Wave period T (s)
June to December	0.2	1.6	0.44	2.1
January to April	0.15	1.5	0.37	2.0

Hurricane Generated Waves

Waves formed beyond the Belize Barrier Reef and within the wider Caribbean could quite easily range between 5 to 10 m in height. The Belize margin is unique with the reefs, shallow shelf, and numerous cayes that protect the mainland from the onslaught swells (High, 1967; Wantland and Pusey, 1975; Purdy, 1974, Perkins 1983). Employing the same depth-limited waves methodology can provide the coastal engineers with a good idea of what to expect in various wind scenarios. The table 7.4.5 below, summarizes the significant height and wave period using the 20 km fetch and average water depth of 15 m.

Table 7.4.5 Summary characteristics of potential hurricane induced waves within the Southern Shelf Lagoon.

Hurricane Intensity mph	Significant wave height H_s, at 15 m depth	Significant Wave Period T (s)
110	4.6	6.6
125	5.2	7.0
150	6.1	7.5

To date there is not a comprehensive wave climate dataset for the Belize margin. A detailed compilation of records and statistics is crucial to validate and refine calculated and inferred wave properties.

7.5 WATER CURRENTS

The complexity of the circulation patterns within the Southern Shelf Lagoon are attributed to several local and meso-scale factors. The local-scale factors include the rugged bathymetry of the lagoon, forcing from freshwater influx to the barrier reef lagoon, a small fetch and locally generated wind waves. The meso-scale factors include a meso-scale fetch, seas and swells generated by the Trade winds, the astronomical tides and shifts in atmospheric pressure above the sea surface. Wust (1964) mentioned that the surface waters of Gladden Basin are brought into the western Caribbean through the Caribbean Current, a warm water current that enters the Caribbean from the Atlantic Ocean and flows through the Caribbean into the Yucatan Channel and into the Straits of Florida. Surface circulation in the Yucatan Basin is dominated by a counter-clockwise gyre generated under the influence of the Caribbean Current (Heyman & Kjerve, 2000).

The north-easterly Trade winds generate a predominant southward wind-induced current along the coast of Belize during most of the year (Wust 1964; Rutzler & Macintyre, 1982) (Figure 7.5.1). Water current measurements within the Southern Shelf Lagoon corroborate the existence of the current with speeds of 0.1-0.2 m/s. The predominant southward flow is sometimes reversed to a northward flow in the summer months as was observed in September and October 2000 (WRIScS, 2001). United Tropical Aquatics (1995) documented current speeds between 0.25-0.7 m/s in a SSW direction 8.5 km to the west of Lark Cay off Placencia. Current measurements on the shelf edge at Gladden Spit also indicate a predominant southward current parallel to the Barrier Reef with speeds ranging between 0.1-0.2 m/s. This is consistent with the cyclonic gyres generated south of the Caribbean Current at the outer limit of the Gulf of Honduras. The cyclonic gyres gradually move westwards along the coast of Honduras towards the Belize Barrier Reef (Heyman & Kjerfve, 2000).

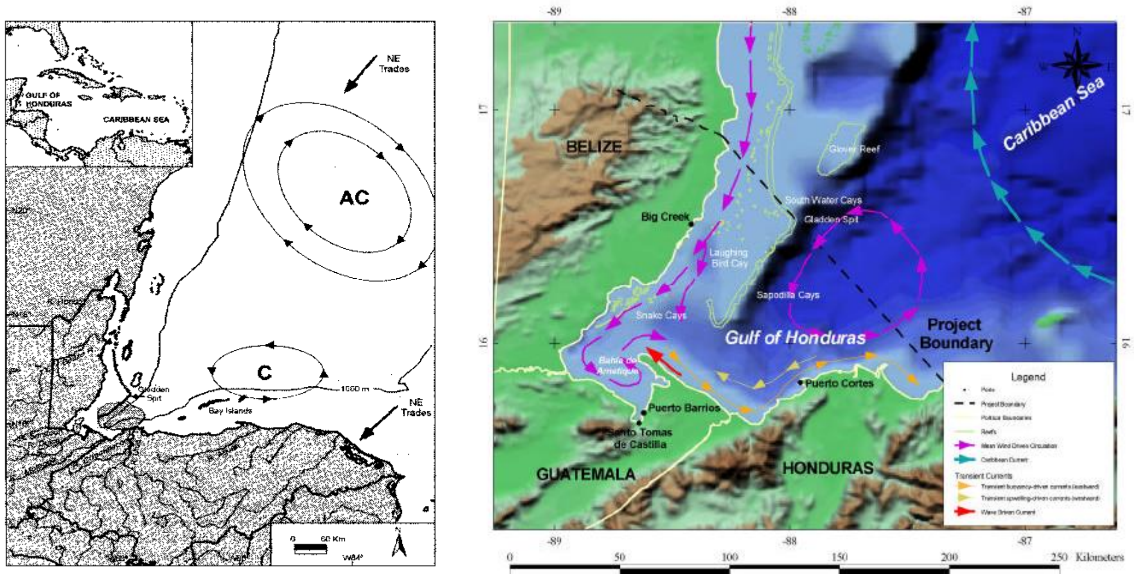


Figure 7.5.1 Schematic representation of water circulation in the Gulf of Honduras depicting the westward progressing cyclonic meso-scale gyres (C) off Honduras and the north-westward progression of a much larger anticyclonic gyre (AC) further north (Heyman & Kjerfve, 2001; Abt Associates, 2003).

The aforementioned meso and local scale currents are discussed intentionally to underscore the fact that the water currents at the level of South Point at the Twin Cayes are also influenced by them. In order to get a better understanding of the currents in the study area a special exercise using the *Lagrangian* method was conducted. A total of five drifters were released at specific locations around the study area. Their trajectories were tracked using the total station to determine the velocity of currents by observing the distance travelled by drifters, time and direction (Figure 7.5.2). The principal direction of the currents interpreted from the displacement of the drifters was towards the Southwest. The velocity of the current was 0.12 m/s and 0.23 m/s on the leeward and windward side of South Point respectively. It is believed that this current was strongly influenced by the rising tide.

Figure 7.5.2 Trajectory of drifters (A, B, C, D and E) released around South Point

The general water circulation patterns play an important role in the transport of larvae, nutrients, and sediment throughout the Caribbean Basin (Rutzler & Macintyre, 1982; Heyman & Kjerfve 2001; Nunny *et al.* 2002).

7.6 TIDES

Tides are caused by the gravitational pull of the moon *and to a lesser extent the sun.* This interaction gives rise to the Spring tide and Neap tide. The Spring tide forms twice in the lunar cycle and increases the tidal range raising the high tide mark decreasing the low tide mark. The Neap tide also occurs twice in a lunar cycle and is characterized by a low tidal range in which the higher tide is lower than normal and the low tide is higher. Without doubt, tides are an important factor in considering coastal processes and have an unequivocal footprint in coastal and marine geomorphology.

Very little processed information about the tides in Belize is available. However, Belize experiences a tidal range very similar to that of the Florida Gulf Coast as confirmed by experts of the National Oceanic and Atmospheric Administration. The only major difference between the tidal ranges of the two localities is the phasing and timing of tide (Ariola, 2002). Tides of the Caribbean and along the Belize Barrier Reef are microtidal and of mixed semidiurnal type with a mean range of 15 cm however, ranges of approximately 0.3 m reported by Stoddart (1962) and more than 0.5 m were documented by Rutzler and Feller (1988). Although the amplitude of the surface tide is small, the currents induced by the tide may be appreciable in constrictions, reaching at times 0.4 m/s in the major reef channels (Kjerfve, 1981; Kjerfve et al., 1981; Greer and Kjerfve, 1982). These tidal generated currents play a significant role in the spatial dispersion of sediment, nutrients and larvae around the back reef (Heyman & Kjerfve 2001).

Tidal constants applicable to Belizean waters as documented in the Admiralty Tidal Tables are presented below (Table 7.6.1).

Table 7.6.1 *Tidal Constants for Belize (Source: Admiralty Tidal Tables)*

LOCATION	TIDAL CONSTANTS				MEAN SEA LEVEL
	SEMI DIURNAL		DIURNAL		
	M2	S2	K1	O1	
HUNTING CAY	0.02	0.01	0.01	0.01	0.28
PLACENCIA	0.01	0.03	0.07	0.01	0.38
BELIZE CITY	0.09	0.03	0.03	0.03	0.03

These tidal constants yield a mean spring tidal range of 0.1 m for Hunting Caye and Placencia and 0.2 m for Belize City. By applying the concept of spatial autocorrelation, the Twin Cayes is expected to display spring tide range similar to Hunting Caye and Placencia being a part of the Southern Shelf Lagoon. The Admiralty Tidal Tables also reflect the seasonal variation in mean sea level.

February through March	0.1 m below MSL
April through August	MSL
September through October	0.1 m above MSL
November through January	MSL

The range of variation in the water level of the sea as a result of tides and seasonal sea level variations will be ±0.2 m relative to MSL.

To establish a local tide datum requires accurate survey benchmarks and a network of high precision tide gauges to collect data for many years. Based on this, a decision was made to utilize the existing bibliographic references to make inferences about the Tides at Twin Cayes.

7.7 HURRICANES AND STORM SURGES

The hurricane season in Belize is from June to November. Hurricane records over the past 127 years indicate that the season peaks in September and October. During this period, 21 hurricanes and 31 tropical storms made land fall in Belize. Of the 52 total hurricanes and tropical storms, 7 occurred in June, 4 in July, 5 in August, 19 in September, 14 in October and 3 were in November.

The National Ocean and Atmospheric Administration (NOAA) states that storm surge is an abnormal rise of water generated by a storm, over and above the predicted astronomical tide. Tropical storm and hurricane force winds exerts a stress on the surface of the water which may cause considerable storm surge. The surge can be positive of negative depending on the direction of the wind, the fetch and the shape of the coastal water body.

Friesner (1993) documented storm surge range of 1.5 and 4.5 in the Belize City during the most powerful storms e.g. 1787, 1864, 1931, 1955 Janet, and 1961 Hattie. He also noted that during the 1920 hurricane, the waters of the Chetumal Bay receded for several kilometers consequent to a negative surge (-2.2 m). Based on this data and reports of surges experienced most recently during Hurricane Earl it is still difficult to predict the extent of a storm surge. Considering a recurrence period of 30 years for a hurricane with surges of 0.8 m; the shore protection structures emplaced should take into account the following parameters:

Storm surge	x
Astronomical tide	0.1 m
Seasonal variation	0.1 m
Wave setup	0.1 (x + 0.1 + 0.1)

In this case, where x = 0.8 m the design level should be around 1.1 m.

At this point there is great uncertainty about the level of storm surge that South Point would be exposed to during a 30-year storm. However, what is known is that seas and swells overtopping the reefs inundate South Point and possibly accelerate the rate of erosion.

7.8 CLIMATE CHANGES PROJECTIONS AND IMPACTS

Central America produces less than 0.5% of the world's greenhouse gases (GHG) emissions, but at the same time it is one of the region most vulnerable to the devastating impacts of climate change. Increases in sea and atmosphere temperatures, reductions and instabilities in rainfall patterns, and the rise in sea level will impact production, infrastructure, and the livelihoods, health and security of the population. It is envisaged that this will also lead to extreme meteorological phenomena such as severe droughts and hurricanes (IPCC, 2007; CRRH, 2007).

According to the studies carried out by the CRRH (2007), the increase in average sea level in the Central American region is slow at the beginning of the 21st century. However, it is expected to increase rapidly towards the middle of the century. A sea level 37 to 44 cm is projected for 2065 in this region (Table 7.8.1).

Table 7.8.1 Time Horizons and projected temperature and sea level scenarios (Source: Echeverría B.J., 2004.)

Time Horizons	2050		2065		2100	
Increase in temperature (°C)	1.5	1.5	--	--	3.6	2.6
Increase in sea level (cm)	18	18	37	44	--	--

7.8.1 Twin Cayes Vulnerability to Climate Change

7.8.1.1 Land Loss due to Erosion

The Bruun rule was modified and applied to estimate erosion of the shoreline at South Point. For this calculation data on crest height, depth of closure, and length of active profile are required. Crest height (crest of South Point) was measured using survey techniques. Depth of closure and length of active profile under the influence of change from erosion to deposition were measured.

Bruun rule: R = G * S * [L/(B+h)]

Where

R = shoreline recession caused by sea level rise S

h = depth of closure

B= crest height

L= active profile width from crest height to depth of closure

G= overfill ratio (assumed to be 1)

Given that:

S = 18 cm (0.59 feet) rise in sea level over the next 34 years.

h = 0.6 m (1.97 feet) B = 0.4 m (1.31 feet) L = 30 m (100 feet)

R = 1 * 0.59 * [100/ (1.31+1.97)] = **18 feet eroded in 34 years**

This rate of erosion is based solely on the projected eustatic sea level for the year 2050. It does not take into account coastal oceanographic and geologic processes such as waves, currents, tides, surges, sedimentation, tectonics, uplift, faulting and subsidence among others.

7.8.1.2 Land Loss Due to Inundation

The coastline at Twin Cayes is predominantly wetlands, mangrove swamps and marshes. Land loss consequent to inundation as an imminent impact of sea level rise is a major concern. Based on the topographic benchmarks established at South Point, the surveyors' project that most of the swamps on Twin Cayes are relatively lower and are exposed to an equal or higher degree of vulnerability to sea level rise. This simply means that if the vegetation does not keep pace with the increasing sea level by trapping sediment or producing enough leaf litter, they will be completely inundated and lost.

7.9 THE SEDIMENT BUDGET

In addition to the coastal processes such as wind, waves, currents, tides, storm surge and sea level rise that were assessed for the locality of the Twin Cayes - another tool referred to as the ***sediment budget*** was utilized to further characterize the study area. The sediment budget describes the varied sources (inputs) and outputs (sinks) of sediments to a particular beach segment.

Segments of the mainland coastline for example Dangriga Town, Hopkins Village and Placencia are known to have multiple natural sources of sediment. These include inputs derived from the weathering of igneous and metasedimentary rocks from the Maya Mountains, and the transport of alluvium from the southern coastal plain by rivers that debouch into the Southern Shelf Lagoon. Another natural source of sediment is from biogenic material including remains of marine animals and plants. Through geologic time, the precipitation of carbonates, fecal pellets and oozes have also contributed to availability of sediment along the coastline. On the other hand, the stability of these coastlines is challenged by several obvious *sinks* to which sediment is lost. These include the southerly longshore drift, cross-shore transport, sand transport to the offshore, sand mining.

Unlike the mainland coastline, the sediment sources for the Twin Cayes is very meager. The primary source of sand is biogenic and is derived from the coralline algae, *Halimeda* sp., break down of corals and other invertebrates including sea urchins and mollusks (Figure 7.9.1). The land reclamation of 2005 is considered an artificial source of material since it was dredged outside of the beach system. The sinks identified include the predominant southward longshore drift and sand transport to slightly deeper waters few meters offshore.

In a complete sediment budget, the difference between the sand added by all sources and the sand removed by all sinks should be zero as expressed by the following equation:

Sum of Sources- Sum of Sinks = 0.

Within the study area the coastal processes continue to operate dynamically. The wave set up coupled with the influence of tides and storms promote the loss of sediment much faster than the entry of sediment. This sediment deficit leads to the constant erosion experienced at South Point.

Figure 7.9.1 Biogenic sand derived from algae and invertebrates.

8 SHORE PROTECTION INTERVENTIONS

There are many approaches, engineering solutions and planning procedures that are available to solve coastal erosion. Quite often the intent is to decrease sediment loss and protect property from the damaging effects of waves and strong currents. These solutions are classified as structural or hard solutions while others are categorized as nonstructural or soft solutions (USACE, 1981, 1984). Within the coastal zone of Belize, several shore protection solutions are employed with varying levels of technological complexity and result in varying levels of success. Although there is a gamut reasons why a shore protection mechanism would fail, the principal reason lies in the fact that there is limited understanding of the coastal dynamics and processes that are drivers of the erosion in that particular locality.

8.1 Hard Shore Protection Solutions

Hard solutions refer to coastal structures constructed of materials including rocks, concrete, timber, polyvinyl or metal. These structures are generally robust and inflexible and have an associated high maintenance cost if not properly seated. Generally, hard solutions are used to armor properties suffering from high erosion rates and little or no sediment influx. Examples of hard shore protection structures are described below.

8.1.1 Seawalls

A seawall is a wall or embankment erected to prevent the sea from encroaching on or eroding an area of land. Examples of these are presented in Figure 8.1.1.

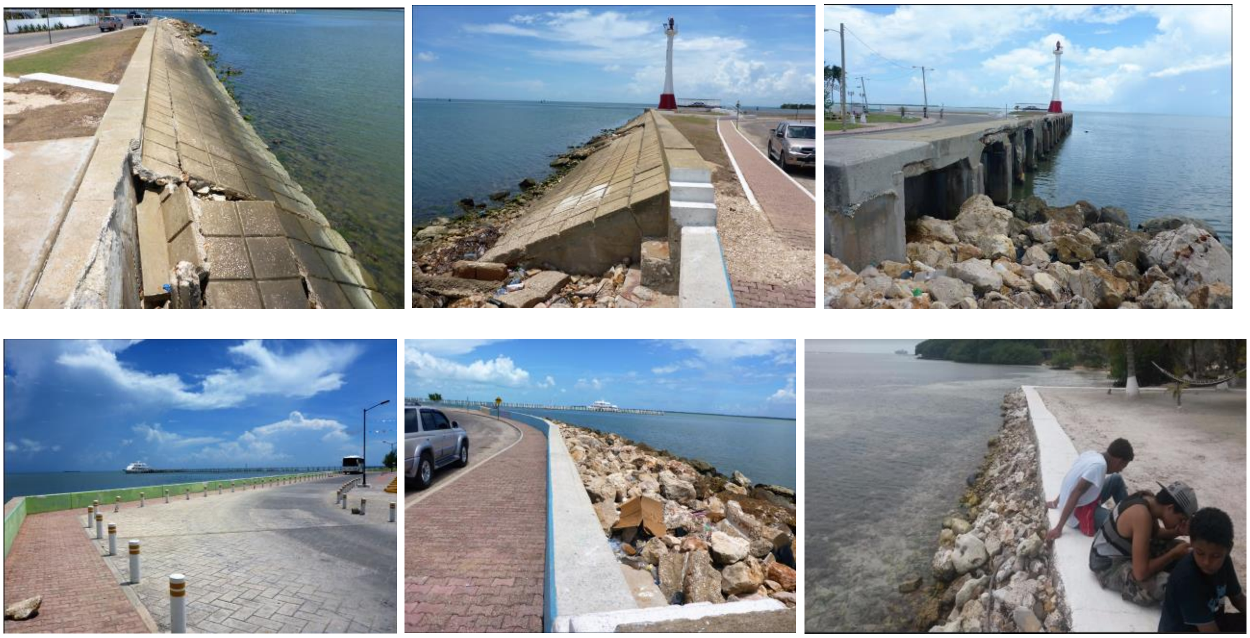


Figure 8.1.1. Examples of seawalls constructed on segments of the Belize coastline

8.1.2 Gabions

Gabions are rectangular shaped metallic cages filled with pebbles of various size (Figure 8.1.2). This is a popular erosion control solution that resists wave action and current thereby offering stability to coastal properties and other civil works around bridges and roads. Gabions do not facilitate the accretion of sediment but provide a light armored protection and are considered as low maintenance structures.

Figure 8.1.2. Examples of gabions

8.1.3 Groins

A groin is a barrier structure that is usually constructed out of concrete, or rocks and are seated perpendicular to the seashore. There function is to trap sand by interrupting the longshore drift i.e. the sand that is transported along the shoreline. There are many examples where groins have proved very successful and this is usually in high energy coasts with abundance of sand moving up and down the coastline. In some instances, the groin is placed in environments that have and marginal supply of sand to the beach system. The groin would trap this supply of sand and reduce the sediment supply to the downdrift beach and induce (or exacerbate) the rate of erosion downdrift of the groin. Another situation in which groins fail is when they were seated in medium to high energy environments that have very poor influx and movement of sand. They affect the wave and current regime in the area. Suffice to say that if the sediment supply to an area is meagre or nonexistent, groins will not function as a shore protection mechanism. Examples of groins can be seen in Figure 8.1.3.

Figure 8.1.3. The negative impact of poorly seated submerged groins

8.1.4 Breakwaters

Breakwaters are structures made of boulders or tetrapods and are constructed parallel to the coasts. These structures can be attached of detached from the coastline depending on the hydrodynamics of the area. Breakwaters are emplaced to reduce the intensity of wave action and storm surges and hence minimize coastal erosion. In coastal systems with high sediment influx, breakwaters are known to encourage accretion of sediment. Sometimes this can lead to excessive build up sand which in turn can act as a barrier to longshore sediment transport. Again it is imperative that the coastal processes be well understood and the structure is emplaced as per design and specifications.

8.1.5 Revetments

Rock revetments are constructed on coastlines, along inlets, canals or channels. These are built of boulders with the prime purpose to abate land loss. Depending on the local environment this type of structure works well in dissipating the wave energy but does not usually enhance sediment accretion.

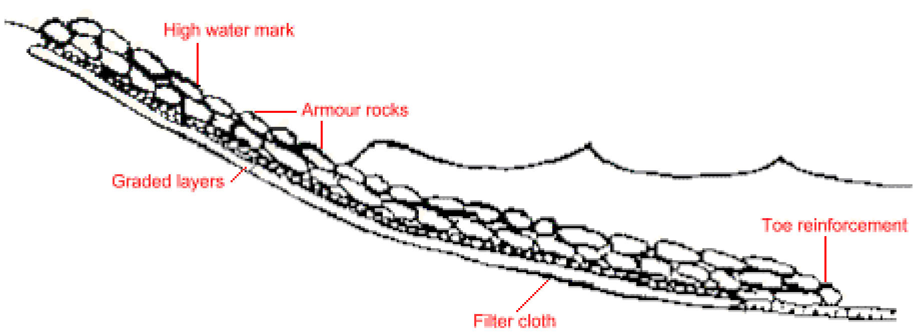


Figure 8.1.5 Schematic Rock Revetments

8.2 Soft Shore Protection Solutions

There are numerous types of soft shore protection solutions and these are coastal defense structures that are flexible and in many cases act as buffers or baffles to dissipate wave energy and promote the deposition of sediment. Examples of soft coastal defense structures include the following:

8.2.1 Vegetating coastal landmass

This solution has been employed in many locations around the world to stabilize coastal property, coastlines and dunes. The effectiveness of this solution is evident in areas where the natural sediment availability is high and the type of vegetation can cope with high sediment influx. A major disadvantage of this method is the seasonal variability in growth and response of the vegetation.

8.2.2 Fences

Some fences are made of sticks that are separated just a few inches apart. Others are made of sticks and wires. Along certain coastline segments in Belize, the palmetto stalks are used to create some of these fences (Figure 8.2.2). Fences are very temporary solutions and the aim is for the fences to catalyze accretion before they are completely deteriorated. Again, this solution only works in environments with high natural flow of sediment.

Figure 8.2.2 Palmetto fence ineffective in catalyzing accretion on this sediment starved coastline

8.2.3 Artificial Reefs

Artificial reefs are becoming increasingly popular because they have the potential to serve multiple purposes. While they offer protection to the coastline by altering the current regime and dissipate wave energy; they also contribute to enhance biodiversity and recreational tourism activities especially snorkeling and fishing.

8.2.4 Beach Nourishment

This is the artificial process of physically sourcing sand from an adjacent or remote location to stabilize and develop an eroding shoreline. Not only is this soft solution complex but it is very costly as it requires monitoring and periodic re-nourishment. The aim of beach nourishment programs is to develop relatively wider beaches, improve the amenity and recreational value of the coast and reduce the impacts of waves and currents.

9 PROPOSED EROSION CONTROL MECHANISMS

Currently the development at South Point extends to the beach thus leaving no accommodation space for natural fluctuations of the coastline (Figure 9.1). With plans to improve the existing infrastructure and construct additional buildings, this can only heighten the vulnerability of the point and the buildings to erosion.

Figure 9.1 (a) View of the buildings at low tide and facing the mainland (west); (b) Buildings low tide facing the barrier reef (east)

The multiparameter evaluation of the erosion process at South Point confirms that the rate of erosion is relatively high in comparison to the other coastline segments on Twin Cayes. The calculated rate of erosion at South Point is 0.87 meters per annum. At this rate the SWCMR Headquarters could be completely vanished within a few years as a result of erosion if no mitigation option is adopted at this time. Also, it must be kept in mind that the low lying South Point is vulnerable to the forecasted higher frequency of more violent storms. This means that in any given hurricane season the headquarters can be totally destroyed. Based on the aforementioned rate of erosion, lack of a suitable natural supply of sediment to the coastal segment, the persistent attack of the coastline by the local wave setup, current patterns, tidal variation and sea level rise; it is recommended that the South Point be armored with a low maintenance shore guard or seawall.

The existing landmass above the mean high water mark is 66.35 meters in length with an average width of 12 meters and covers an area of 889 square meters (0.22 acres). The stabilization of South Point could be accomplished in one of several ways; however, all of them require substantial investments. The nearshore bathymetry was used to determine the optimal extent of the armored shore protection structure and the corresponding extent of land reclamation to rehabilitate South Point. Figure 10.1 is a schematic representation of the proposed extent of the shore protection structure.

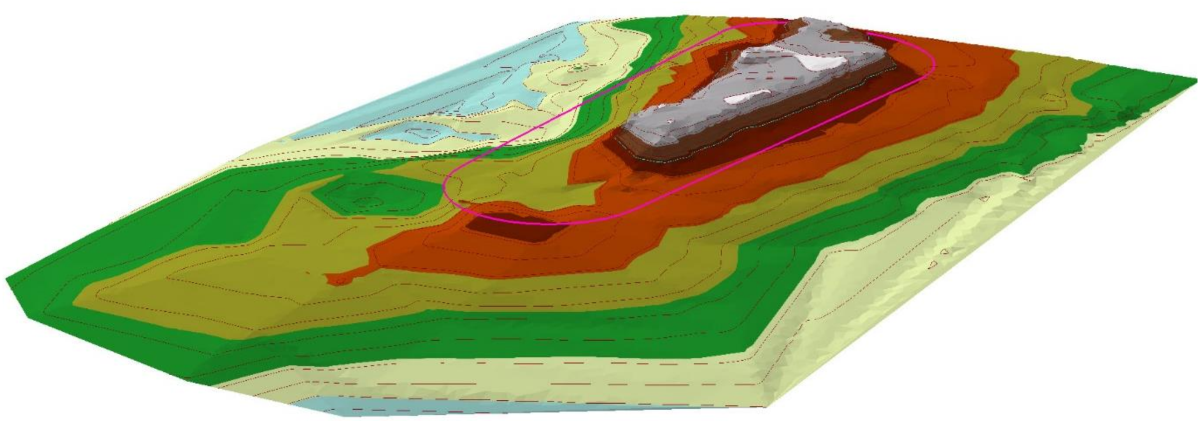


Figure 10.1 *Topo-bathymetric surface with Proposed Reclamation Extent (pink line)*

The proposed extent of the shore protection option has a perimeter of 225 meters, longitudinal extent of 88 meters and an average width of 30 meters. Back filling the armor with 1,500 m^3 of sand to an elevation of 0.6 m would yield a total of 2836 square meters (0.7 acres) of property above the mean high water mark (figure 10.2).

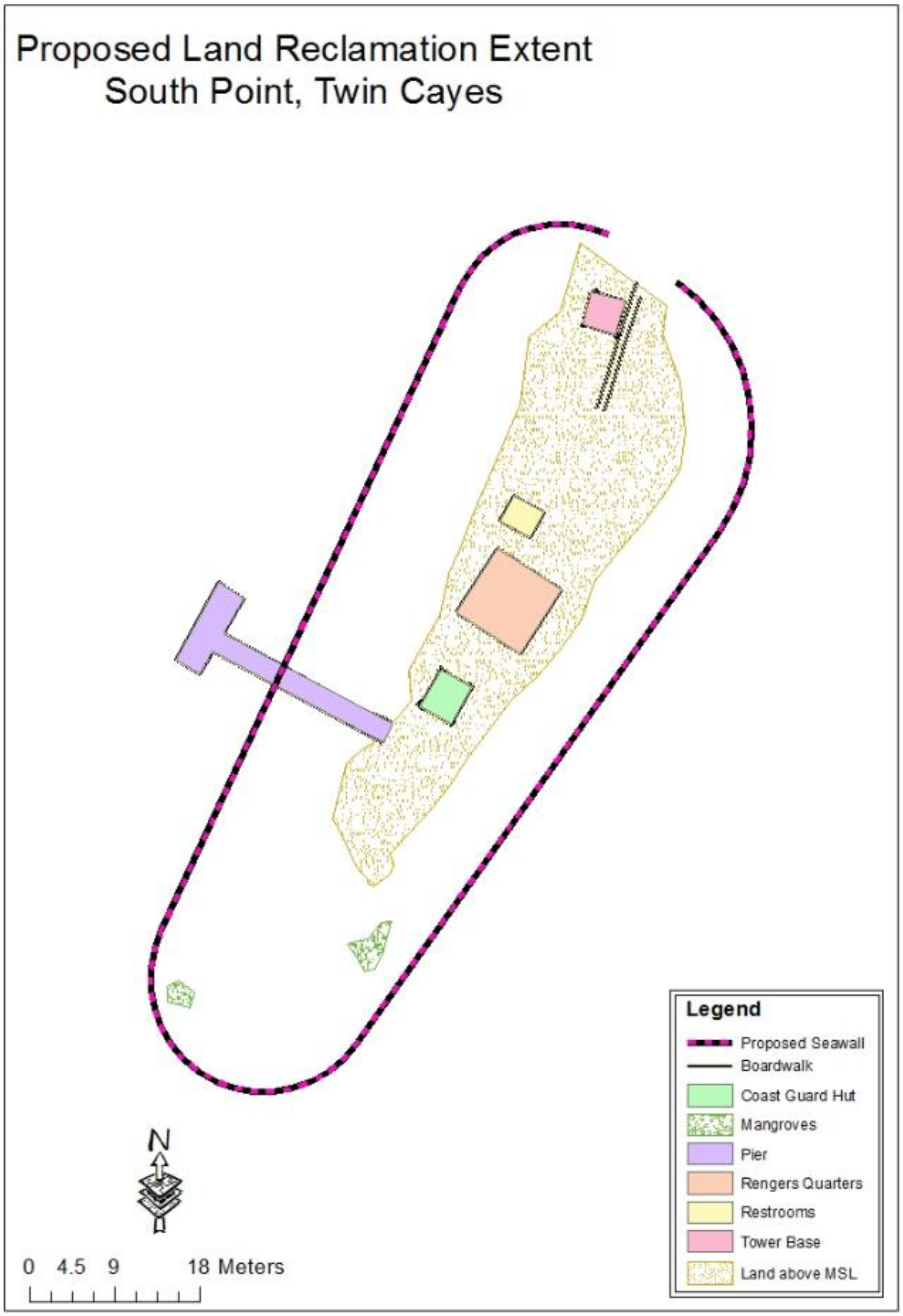


Figure 10.1A *Proposed land reclamation extent for South Point rehabilitation*.

Proposed for consideration are three options for shore protection structures that could function effectively at South Point. Option A is a gabion basket seawall; Option B is the vinyl sheet pile seawall and Option C is the steel sheet pile seawall. Below is a description of each of these options and their corresponding construction costs.

Option A – Gabion Basket Sea Wall Construction

Project consists of constructing a 225 meter (738 feet) long seawall by means of gabion baskets to a finish level of 0.7 meters (2.29 feet) above sea level. This will require the use of two sizes of gabions measuring 54” high by 36” thick and 30” high by 30” thick to adjust for varying existing ground levels (Figure 10.1). Standard length of 7 feet will be used for both sizes. Gabion baskets are to be filled with maximum size of 3” stones down to 1”. Angular shaped stones would be preferable. Break down of quantities are as follows:

Quantity	Description	Unit Cost	Total
28	54" High x 36" Thick Mesh Size: 3/16th Gabion Length: 7ft	$515.05	$14,421.40
78	30" High x 30" Thick Mesh Size: 3/16th Gabion Length: 7ft	$338.06	$26,368.68
215	3” to 1” Angular Rock	$40.00	$8,600.00
	Labour at 40% of material cost		$19,756.00
		Total	**$69,146.08**

Please note that shipping cost and custom duties for the importation of the gabion baskets would need to be added to this cost. Pricing for gabion baskets were obtained from Gabion 1 USA.

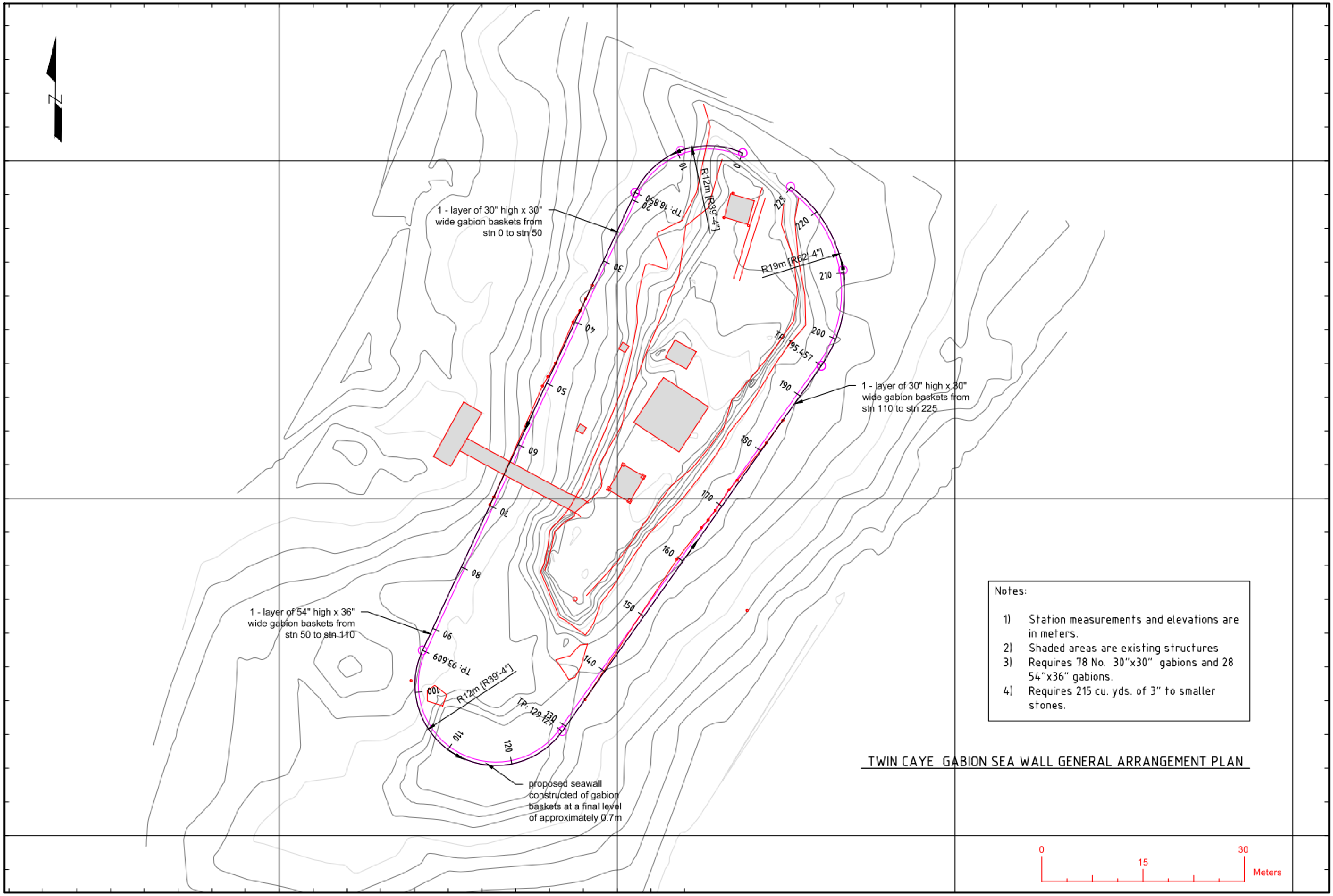


Figure 10.1.1 Twin Caye Gabion Seawall (Option A)

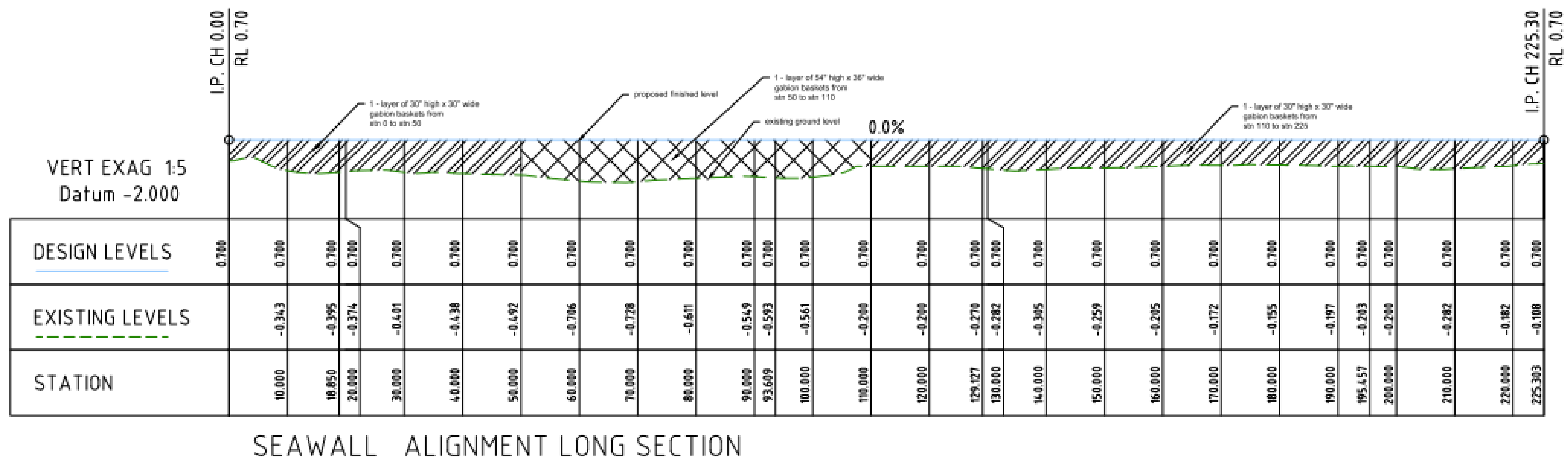


Figure 10.1.2 *Twin Caye Gabion Seawall General Arrangement Plan (Option A)*

Option B – Vinyl Sheet Pile Sea Wall Construction

Project consists of constructing a 225 meter (738 feet) long seawall by means of vinyl sheet piles to a finish level of 0.7 meters (2.29 feet) above sea level. This will require the use of ShoreGuard 325 Vinyl Sheet Piling - 10 feet in length, complete with 1" diameter x 15 long coated steel tie backs, 4x6 wood waler beam and deadman anchors (Figure 10.2). Tiebacks and deadman anchors are to be spaced at 8 feet intervals. Breakdown of quantities are as follows:

Quantity	Description	Unit Cost	Total
1	ShoreGuard 325 Vinyl Sheet Piling (10 feet length) including shipping costs	$60,409.15	$60,409.15
94	1" diameter x 15 feet long coated steel tiebacks	$125.65	$11,811.10
738	4"x6" wood waler beam (ft)	$2.25 per BF	$3,321.00
94	4" diameter x 10 feet wood piling	$2.25 per BF	$2,215.00
	Labour at 40% of material cost		$31,102.50
		Total	**$108,858.75**

Please note that custom duties for the importation of the vinyl sheet piling would need to be added to this cost. Pricing for vinyl sheet piling was obtained from Crane Materials International.

Belize Marine Sands is the only company in Belize that offers the service to construct Vinyl Sheet Pile seawalls. A quote was provided to construct 736 feet of seawall at a cost of BZD$280.00 per foot inclusive of materials. The total cost of the sea wall is BZD$206,080.00. Damien Chamberlain the owner of Belize Marine Sands also confirmed that in addition to constructing seawalls and piers, they also provide the services of marine dredging. This local company is willing to provide a formal quotation for construction of the seawall, the pier and to provide the dredging services all as a turnkey project.

The components of the vinyl sheet piling included in the budget are presented in Figure 10.2.3. The schematics of the elevation view, plan view and a typical cross sectional view of the sheet piling seawall is displayed as a guide for engineers or design professionals that would be contracted to install this type of structure.

Figure 10.2.4 are pictures that highlight the components of the vinyl sheet pile along with the dead man anchors and tie backs which provide structural support.

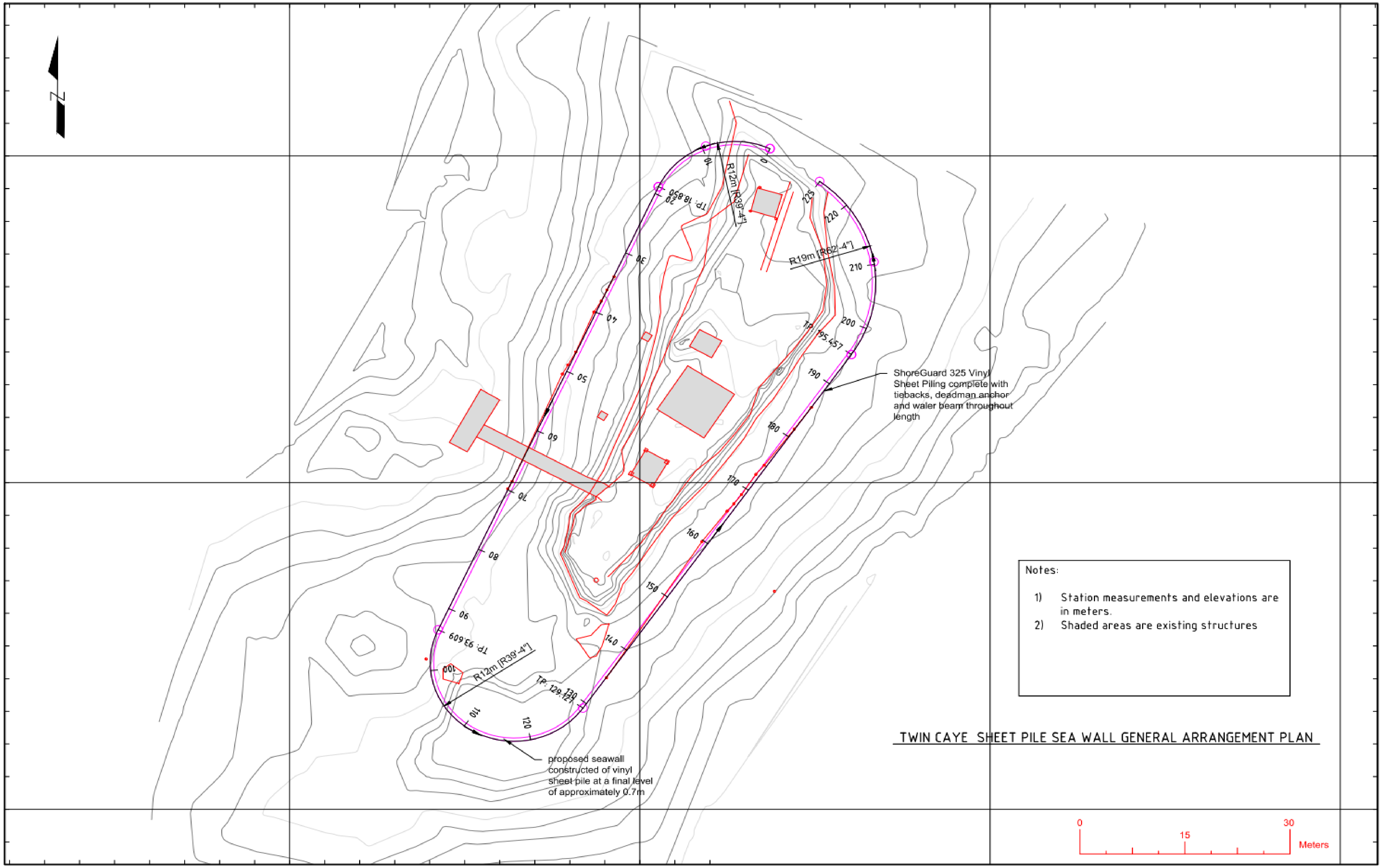


Figure 10.2.1 *Twin Caye Vinyl Sheet Pile Seawall (Option B)*

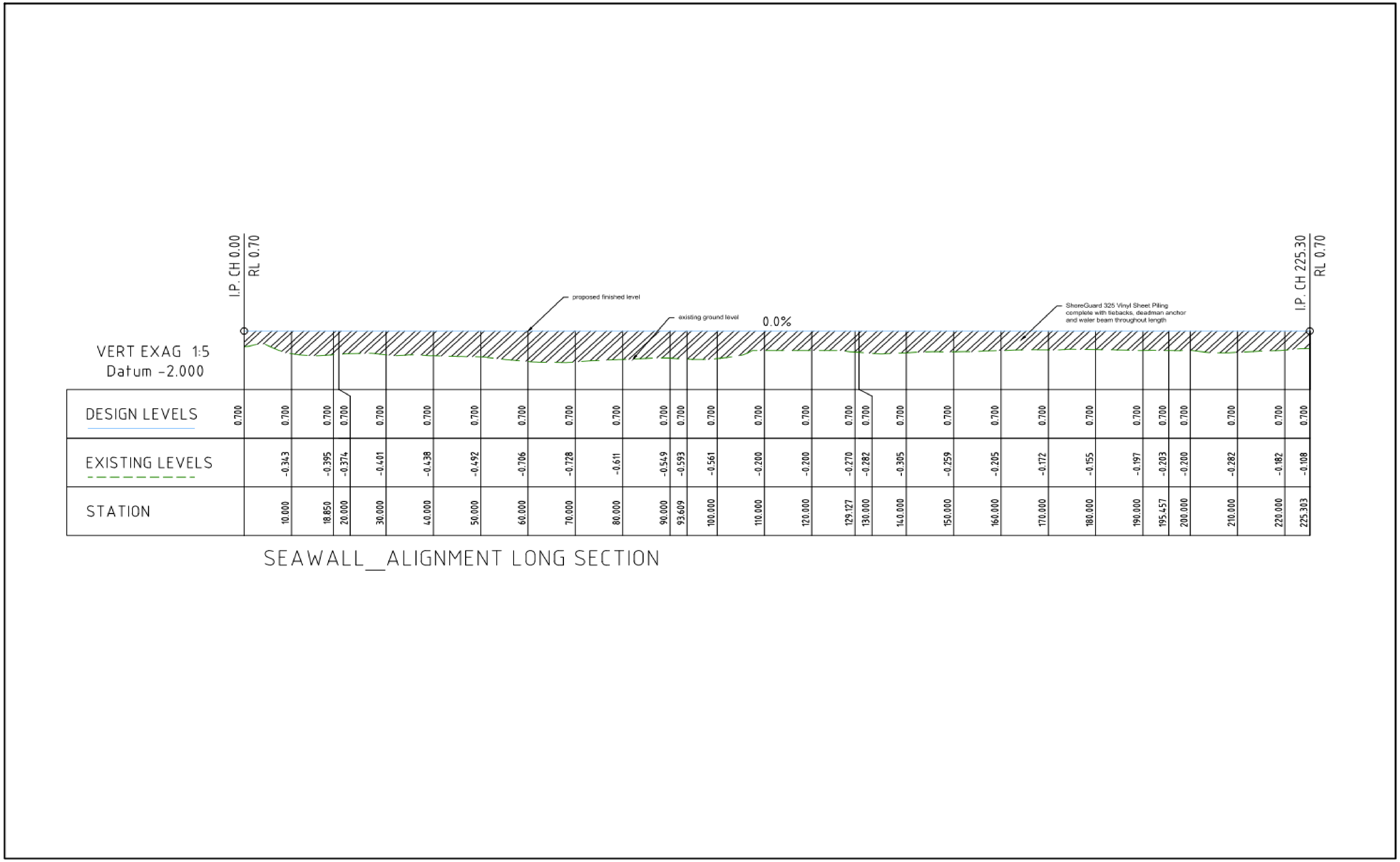


Figure 10.2.2 *Twin Caye Vinyl Sheet Pile Seawall General Arrangement Plan (Option B)*

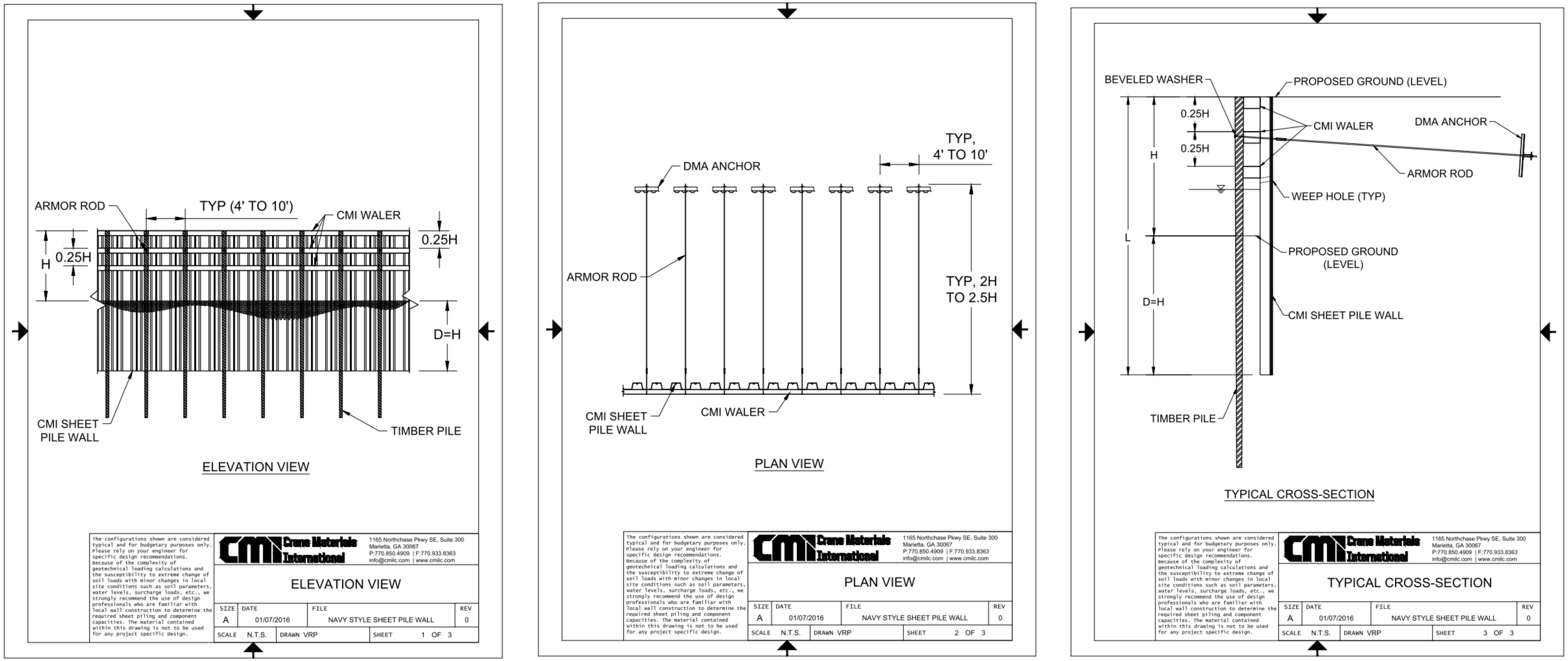


Figure 10.2.3 *(a) Elevation View of the CMI Vinyl Sheet Pile Wall; (b) Plan View of the CMI Vinyl Sheet Pile Wall; (c) Typical Cross-section view of the CMI Vinyl Sheet Pile Wall*

Figure 10.2.4 Examples of vinyl sheet pile walls under construction

Option C – Steel Sheet Pile Sea Wall Construction

Project consists of constructing a 225 meter (738 feet) long seawall by means of steel sheet piles to a finish level of 0.7 meters (2.29 feet) above sea level. This will require the use of PZC13 Steel Sheet Piling coated with 16 mil coal tar epoxy- 10 feet in length, complete with 1" diameter x 15 long coated steel tie backs, 4x6 wood waler beam and deadman anchors. Tiebacks and deadman anchors are to be spaced at 8 feet intervals. Breakdown of quantities are as follows:

Quantity	Description	Unit Cost	Total
159,768	Lbs of PZC13 Steel Sheet Piling (10 feet length) including shipping costs	$2.50	$399,420.00
94	1" diameter x 15 feet long coated steel tiebacks	$125.65	$11,811.10
738	4"x6" wood waler beam (ft)	$2.25 per BF	$3,321.00
94	4" diameter x 10 feet wood piling	$2.25 per BF	$2,215.00
	Labour at 30% of material cost		$125,030.13
		Total	**$ 541,797.23**

Please note that custom duties for the importation of the steel sheet piling would need to be added to this cost. Pricing for steel sheet piling was obtained from L.B. Foster Company.

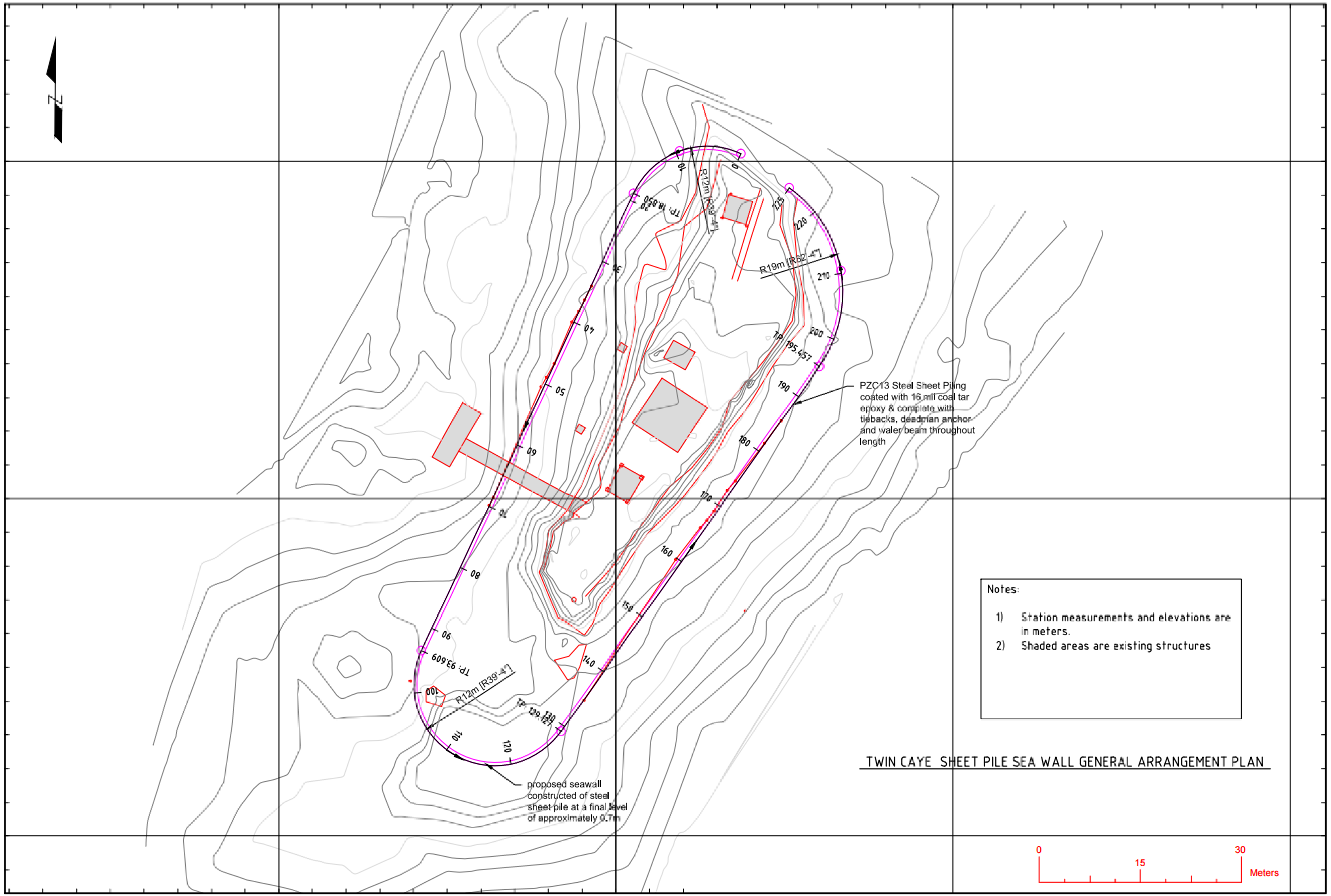


Figure 10.3.1 *Twin Caye Steel Sheet Pile Seawall (Option C)*

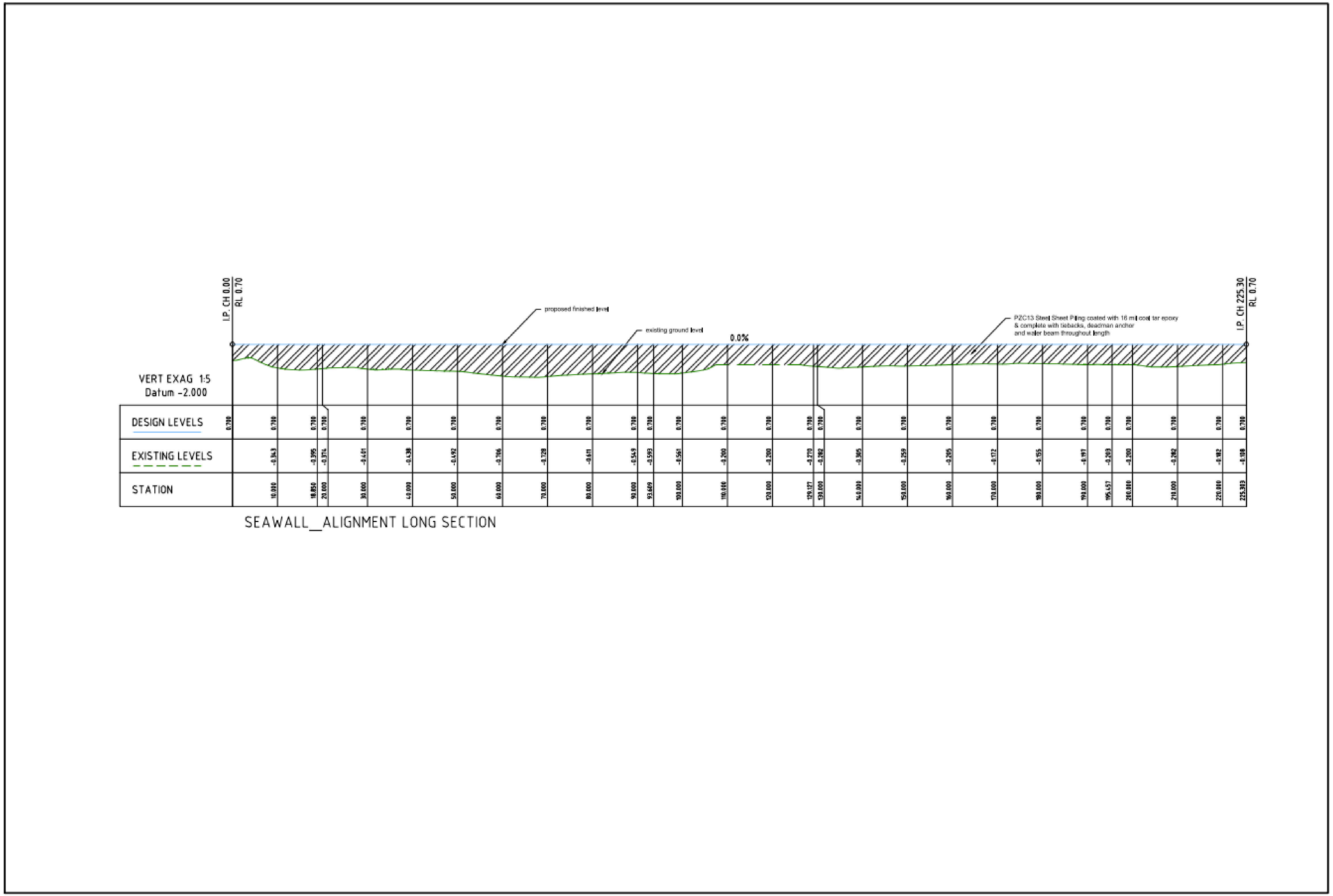
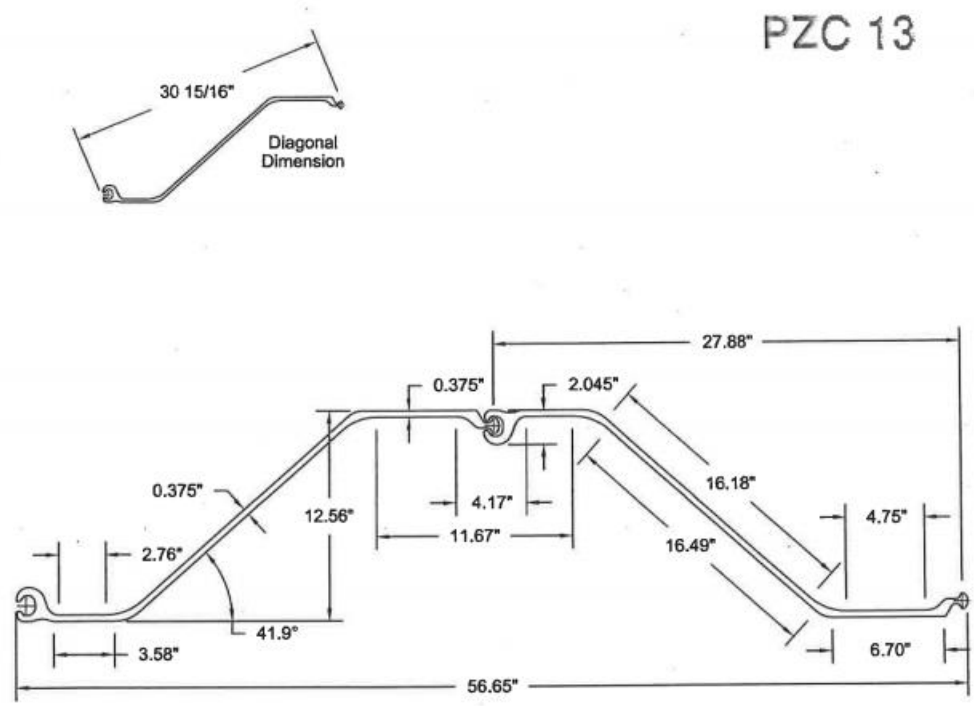


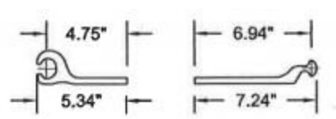
Figure 10.3.2 *Twin Caye Steel Sheet Pile Seawall General Arrangement Plan (Option C)*



Sheet Pile Section Properties											
Nominal Width (in)	Area (in^2)		Weight (lbs)		Moment of Inertia (in^4)		Section Modulus (in^3)		Surface Area (ft^2/ft)	
	Single Section	Per Linear Foot of Wall	Per Foot of Sheet	Per Square Foot	Single Section	Per Linear Foot of Wall	Single Section	Per Linear Foot of Wall	Total Area	Nominal Coating Area *
27.88	14.82	6.38	50.4	21.7	353.0	152.0	56.2	24.2	6.10	5.60

* Excludes socket interior & ball of interlock.

Available Material Grades: ASTM A572 Grade 50 and 60, Also A588 and A690.



Flange Dimensions

LBFoster

PILING DIVISION
L.B. FOSTER COMPANY
SUWANEE, GA 30024

TITLE SHEET PILING DIMENSIONS & PROPERTIES

PROJECT PZC13 STEEL SHEET PILE

CUSTOMER	N/A		
PROJ #	11-052	SO#	N/A
DRAWN	TWT	DATE	07/29/11
CHK'D		SCALE	1-1/2"=1'0"

SP-DC13 0
DWG # SHT 1 of 1 REVISION

REV.	DATE	DESCRIPTION
R0	08/01/11	Issued for Review and Comment.

Figure 10.3.3 *Sheet Piling Dimensions and Properties*

11 MARINE DREDGING ALTERNATIVES

During this assessment, significant time and effort was dedicated to consult with the Mining Unit, Ministry of Natural Resources & Agriculture and authorized companies that provide marine dredging and coastal engineering services locally. A list of these service companies is provided in Annex 3.

The dredger proposed for this operation is a cutter suction dredger as opposed to the more common bucket dredge and excavators. From an engineering stand point, the suction dredger would be more efficient in recovering the necessary volumes of sediment with delivery via pipes especially considering that the location of the sand deposits is within 300 meters of South Point. Environmental impacts associated with marine dredging (including but not limited to large sediment plumes, smothering of fragile habitats, scaring of the seafloor and alteration of the nearshore bathymetry) can be easily constrained and managed effectively to guarantee an environmentally benign operation. (Marine Dredging Guidelines and Policy)

Another dredger option would be that of a trailer suction dredger with hopper capacity. This type of dredge has the advantage of mining sand from a more remote location and sail with volumes of sand to be pumped at the particular restoration site. This alternative is also environmentally friendly but might be more costly especially as it relates to operations time.

Regulatory Framework for Marine Dredging

The Mines and Minerals Act, Chapter 226 Substantive Laws of Belize Revised Edition 2000 and the Mines and Minerals (Safety, Health and Environmental) Subsidiary Laws of Belize Revised Edition 2003 govern the extraction of materials. Mining authorizations are generally required for the dredging of construction materials including sand and gravel. In the past dredging operations involving less than 16,000 cubic yards of and located in areas that are not ecologically sensitive were regulated through quarry permits, which are not subject to the terms and conditions of mining licenses. A recent policy of the Geology & Petroleum Department is to require mining licenses for all marine dredging operations, thus ensuring that environmental conditions are met. A team usually consisting of Geology, Fisheries, Forestry DOE and CZMAI personnel makes a site assessment of each area prior to the granting of permits. Specific requirements for equipment, methods or other means of environmental protection (such as requiring the use of silt curtains or screens) are made on a case by case basis. The Mining Unit is then required to monitor operations for compliance with any stipulations in the permit.

The Environmental Protection Act, Chapter 328 Substantive Law of Belize Revised Edition 2000 and Subsidiary Laws of Belize 2003 also constrain marine dredging through by ensuring best practices and maintenance of good water quality.

12 TECHNICAL CONSIDERATIONS

Ever since the establishment of the SWCMR Headquarters at South Point, coping with inundation during spring tides and land loss consequent to beach erosion especially during the cold front season was an obvious problem. To solve this problem and to gain an incremental amount of landmass, land was reclaimed and guarded with a zinc fence in 2005. In view of the apparently low energy environment of the Twin Cayes, it was envisaged that this project would have solve the inundation and erosion problem perpetually.

Evidently, the project offered some level of protection and stability to the property for a few months before the erosion problem ensued to the extent that inundation is once again a frequent occurrence. The lesson learnt here is that action was taken to abate the erosion problem without fully understanding the dynamics of the coastal processes that operate there. This has resulted in a poorly planned and unprofessionally designed land reclamation with a fence guard which has degraded leaving South Point exposed to an accelerated rate of erosion.

As discussed in section 7 of this report, there are a number of factors that contribute to erosion and inundation. These include (but are not limited to) bathymetry, wind conditions, wave climate, current regime, tidal ranges, sea level rise, subsidence, sediment availability and sediment transport. The shallow nearshore bathymetry with minor channels and depressions less than 300 m from the shore is the principal sink for sediment eroded and transported from South Point and the wider Twin Cayes area. Sand lost to these sinks cannot be re-transported to the coast naturally under normal wave and current regime. However, these sinks can be a valuable source of sediment for a well-planned and properly designed restoration project.

The wind conditions appear to be consistently low speed (5 – 8 m/s) and predominantly from the east and the northeast. By virtue of its geographic location, South Point is generally sheltered from the direct impacts of deep water waves by the barrier reef and neighboring cayes. Therefore, it is the local wind conditions that yield the normal dominant wave climate which impacts and shape the study area. Neglecting or even underestimating the resultant effect of the wind is a fundamental error especially as it relates to the design of a shore protection structure.

The measured elevation on the island range from 0.1 to 0.6 meters. The mean tidal range in Belize is 0.15 m however, ranges of 0.3 and 0.5 m have been documented in the vicinity of the Twin Cayes. Realistically, a significant portion of the island is inundated at every normal high tide twice a day. During a spring tide event most of the island is inundated. The rising tides effect erosion when it coincides local wave conditions. Consider a normal wave climate with wave significant height of 0.25 m acting atop a tidal setup of 0.3 m. This can result in aggressive erosion rates during the 6-hour period of the high tide event. Under more severe weather conditions for example tropical storms and hurricanes; storm surge and overtopping waves can displace large volumes of sediment around the island. This effect can also be exacerbated if coincident with high tides.

The water currents are the net result of deep water waves overtopping the reef or refracting through the reef channels, the local predominant wave stands generated by local wind conditions, and the effect of flood and ebb tides. The current speed measured in the area range from 0.12 – 0.23 m/s. While the hydraulic capacity of these currents is too small to transport medium to coarse sediment fractions as part of the traction load, proven very efficient in transporting the very fine or suspended load over long distances.

In nature, sandy beaches only exist in locations where sand is naturally available in suitable amounts. South Point is one of the few sandy coastline segments on Twin Cayes and the sand is biogenic. Due to the poorly sorted nature of the sand, it is believed that the sand accumulation is consequent to displacement from storms. The production of biogenic material is rather slow in comparison to the rates of erosion, thus the beach system is considered sediment starved. This continuous and prolonged sand deficit is the primary cause of the erosion problem. Only if adequate volumes of sediment are artificially fed into the system on a regular schedule can a beach be maintained at South Point. A beach nourishment program would be desirable but would be very costly considering the varied bathymetry with channels and depressions that are sinks just a few meters offshore.

As a result of global climate change, sea level is expected to rise 0.18 m by the year 2050 and more rapidly to 0.37 – 0.44 m by the year 2065. This projected rate of sea level rise poses an imminent threat to the stability of South Point and the greater Twin Cayes. Adopting the no action option at South Point, the effect of sea level rise alone would permanently inundate more than 90% of the existing landmass in less than 50 years. This is a major concern and must be considered in the long-term shore protection solution.

Subsidence is another factor that contributes to erosion and the instability of structures on the property. Although this was not measured during this study, some indications of sinking were seen on the buildings, lookout tower and the pier. Unlike Tobacco, South Water and Carrie Bow Cayes which overlies ancient reefs; the Twin Cayes sits atop a thick 6 – 10 m of peat. It is believed that the continuous alteration and compaction of this material also bear some current and potential impacts to South Point.

13 CONCLUSIONS

The low-lying South Point is probably the most dynamic and unstable segment of coastline on Twin Cayes based on the bathymetry and the seasonal variability in wave climate. The southwestern orientation of this point exposes it to the direct impact of waves generated in the 20 km fetch from the Dangriga coastline. Without doubt, factors such as the wind setup, tide range, sea level rise and subsidence bear impacts to the coast individually. However, their effect is augmented when one or more of these factors are coincident. For example, the cumulative impact of a 0.18 m rise in sea level coupled with 0.3 m high tides and wave heights of 0.25 m may be critical to a property with a maximum elevation of 0.6 m. Furthermore, the lack of an adequate natural sediment supply is the primary factor driving the erosion process. Intuitively, the solution to the problem would be to artificially add sediment volumes to bring the coastline to equilibrium. As it stands, this might be cost prohibitive especially in these economic times.

The protection of South Point is not a simple problem; neither is it unsurmountable. In view of the drivers of the erosion and inundation problems experience and matching the optimal engineering, and cost effective solution it is recommended that property be armored and reclaimed utilizing any of the three options discussed in section 10. The structure contemplated to protect this property is designed and must be built to specification to withstand the cumulative effects of the coastal oceanographic factors identified in the study area.

Good quality sand; coral rubble, marl and mud deposits are distributed in discrete accumulations in close proximity to South Point. The good quality sand sources may be accessible to the property via pipelines and a cutter suction dredge. The potential environmental impact through sediment dispersal, sediment plumes and the effect on the ecological balance is expected to be minimal for dredging a volume of less than 2,000 cubic yards. The use of sediment curtains or silt screens would further minimize any negative impacts the reefs.

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ANNEX 1

SURVEY EQUIPMENT SPECIFICATIONS

Leica TCR 805 power Total Station:

Technical Data

Telescope

- Transit fully
- Magnification: 30x
- Image: .... upright
- Free Objective aperture: .... 40 mm
- Focusing: .... 1.7 m (5.6 ft) to infinity
- Field of view: ....1°30' (1.7gon)
- Field of view at 100m .... 2.6 m

Angle measurement

- absolute, continuous,
- Updates each 0.3 seconds
- Units selectable
  360° sexagesimal, 400gon,
  360° decimal, 6400 mil, V%, ±V
- Accuracy standard deviation Hz, V
  (acc. to ISO 17123-3)
  TC(R)802 .... 2" (0.6 mgon)
  TC(R)803 .... 3" (1.0 mgon)
  TC(R)805 .... 5" (1.5 mgon)
- Display resolution
  gon 0.0001
  360d 0.0001
  360s .... 1"
  mil 0.01

Level sensitivity

- Circular level: .... 6'/2 mm

Compensator:

- 2-axis-oil compensator
- Setting range .... ±4' (0.07 gon)
- Setting accuracy ....
  TC(R)802 .... 0.5" (0.2 mgon)
  TC(R)803 .... 1" (0.3 mgon)
  TC(R)805 .... 1.5" (0.5 mgon)

Distance measurement (IR: Reflector mode):

Principle:	Phase measurement
Type:	Coaxial, infrared laser Class 1
Carrier wave:	780 nm
Measuring system:	Special frequency system basis 100 MHz ≘ 1.5 m

Principle:	Phase measurement
Type:	Coaxial, visible red laser Class 1
Carrier wave:	660 nm
Measuring system:	System analyser basis 100 MHz - 150 MHz

EDM measuring program	Accuracy* (Standard deviation acc. to ISO 17123-4)	Time per measurement
IR_Fine	2 mm + 2 ppm	<1 sec.
IR_Fast	5 mm + 2 ppm	<0.5 sec.
Tracking	5 mm + 2 ppm	<0.3 sec.

EDM measuring program	Accuracy* (Standard deviation acc. to ISO 17123-4)	Time per measurement
IR Tape	5 mm + 2 ppm	<0.5 sec

* Beam interruptions, severe heat shimmer and moving objects within the beam path can result in deviations of the specified accuracy.

Range: (normal and rapid measurement)

	Standard prism	3 prisms (GPH3)	360° reflector	Tape 60mm x 60mm	Mini prism	360° Mini prism
1	1800 m (6000 ft)	2300 m (7500 ft)	800 m (2600 ft)	150 m (500 ft)	450 m (1500 ft)	450 m (1500 ft)
2	3000 m (10000 ft)	4500 m (14700 ft)	1500 m (5000 ft)	250 m (800 ft)	800 m (2600 ft)	800 m (2600 ft)
3	3500 m (12000 ft)	5400 m (17700 ft)	2000 m (7000 ft)	250 m (800 ft)	1000 m (3500 ft)	1000 m (3500 ft)

1) Strong haze, visibility 5km; or strong sunlight, severe heat shimmer
2) Light haze, visibility about 20km; or moderate sunlight, slight heat shimmer
3) Overcast, no haze, visibility about 40km; no heat shimmer

JAVAD Triumph 1 GNSS Receiver:
Autonomous < 2m; Static, Fast Static
Horizontal: 0.3 cm + 0.5 ppm * base line length
Vertical: 0.5 cm + 0.5 ppm * base line length

Specifications
Receiver Specifications
General Details

Output interval for CMR/ RTCM	1, 5, 10, 20, 50, 100 Hz optional
Elevation	0 to 90 degrees (independent of data logging)
Solution mode	Delay (synchronization) Extrapolation (not synchronized)
Process interval	1, 5, 10, 20, 50, 100 Hz optional
Latency	Delay mode – 20 msec to 20 sec (depends on latency which receives corrections data from base receiver) Extrapolation – 20 to 30 msec
Raw Data logging	The receiver can record raw data at another interval during RTK operation
Status	Fix, Float, DOP, Data Link Status, Receiver Latency, Common satellites, Percentage of fixing
Results	RTK coordinates, HRMS, VRMS, Covariance Matrix
Ambiguity fixing level	Selectable thresholds Low: 95%; Medium: 99.5%; High: 99.9%
Survey Modes	
Base or Rover	Static, Fast Static Kinematic (Stop and Go) RTK (Real-time Kinematic) DGPS (Differential GPS) SBAS DGPS
Survey Accuracy	
Autonomous	< 2m
Static, Fast Static	Horizontal: 0.3 cm + 0.5 ppm * base_line_length[2] Vertical: 0.5 cm + 0.5 ppm * base_line_length
Kinematic, RTK	Horizontal: 1 cm + 1 ppm * base_line_length Vertical: 1.5 cm + 1 ppm * base_line_length
RTK (OTF)	Horizontal: 1 cm + 1 ppm * base_line_length Vertical: 1.5 cm + 1 ppm * base_line_length
DGPS	< 0.25 m Post Processing, < 0.5 m Real Time
Cold Start Warm Start Reacquisition	< 35 sec < 5 sec < 1 sec

1. RTK update rate means the position update rate of the rover working in the “extrapolation” mode. In the extrapolation mode you may use the base with measurements update rate = 1 Hz and run the rover at 100 Hz RTK update rate.
2. The accuracy estimate is applicable to base lines up to several hundreds of km. But normally RTK works predictable on base lines up to 50 km.

Leica GPS 900 RTK System:

10.2.2 Accuracy

☞ Accuracy is dependent upon various factors including the number of satellites tracked, constellation geometry, observation time, ephemeris accuracy, ionospheric disturbance, multipath and resolved ambiguities.

The following accuracies, given as **r**oot **m**ean **s**quare, are based on measurements processed using LGO and on real-time measurements.

Differential code

The baseline precision of a differential code solution for static and kinematic surveys is 25 cm.

Differential phase in post-processing

Static		Kinematic	
Horizontal	**Vertical**	**Horizontal**	**Vertical**
5 mm + 0.5 ppm	10 mm + 0.5 ppm	10 mm + 1 ppm	20 mm + 1 ppm

Differential phase in real-time

Static		Kinematic	
Horizontal	**Vertical**	**Horizontal**	**Vertical**
5 mm + 0.5 ppm	10 mm + 0.5 ppm	10 mm + 1 ppm	20 mm + 1 ppm

Technical Data GPS900 **131**

ANNEX 2

WIND DATA FIGURES & TABLES

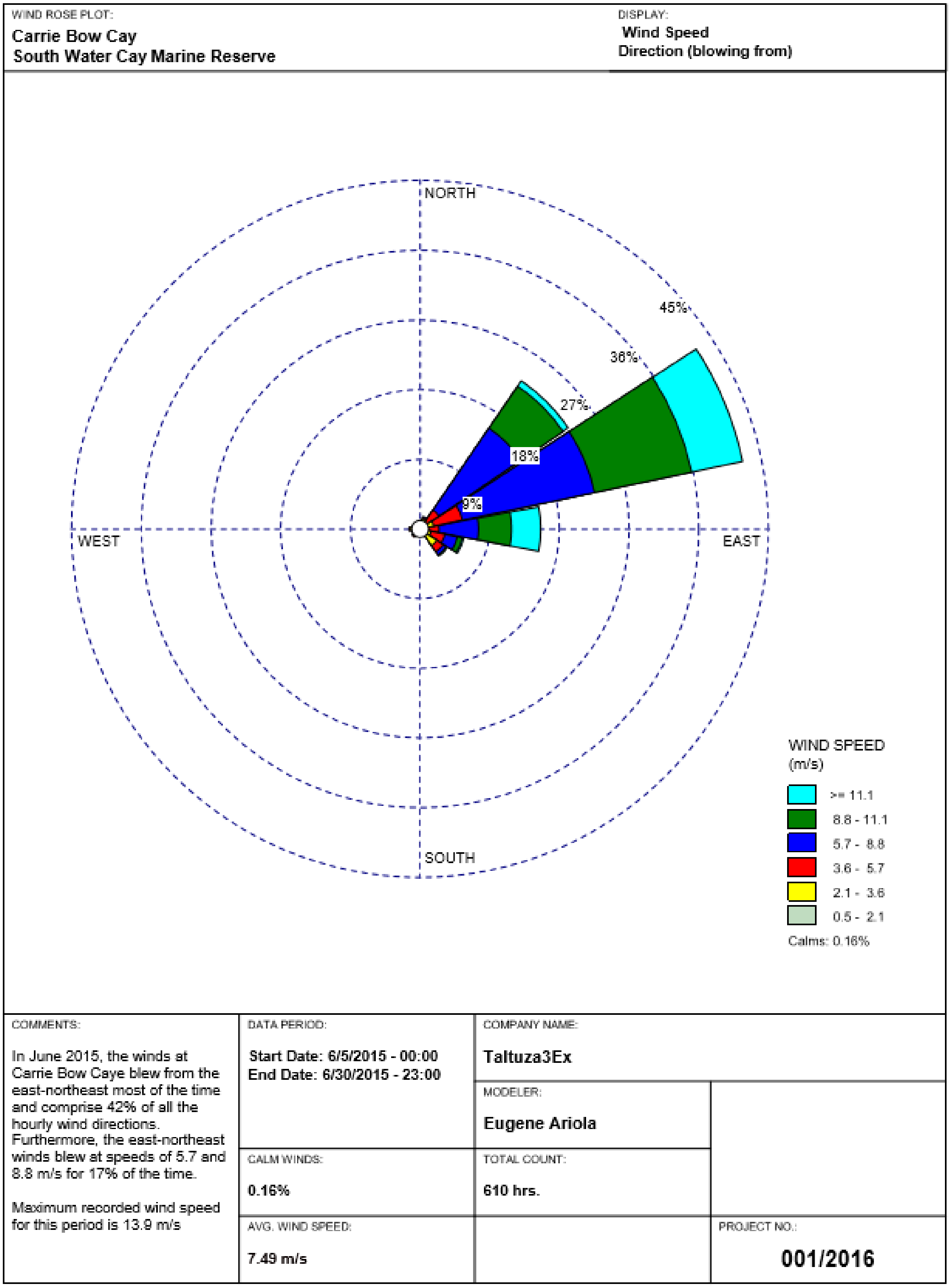

Figure 1. Wind Rose Diagram for the month of June, 2015.

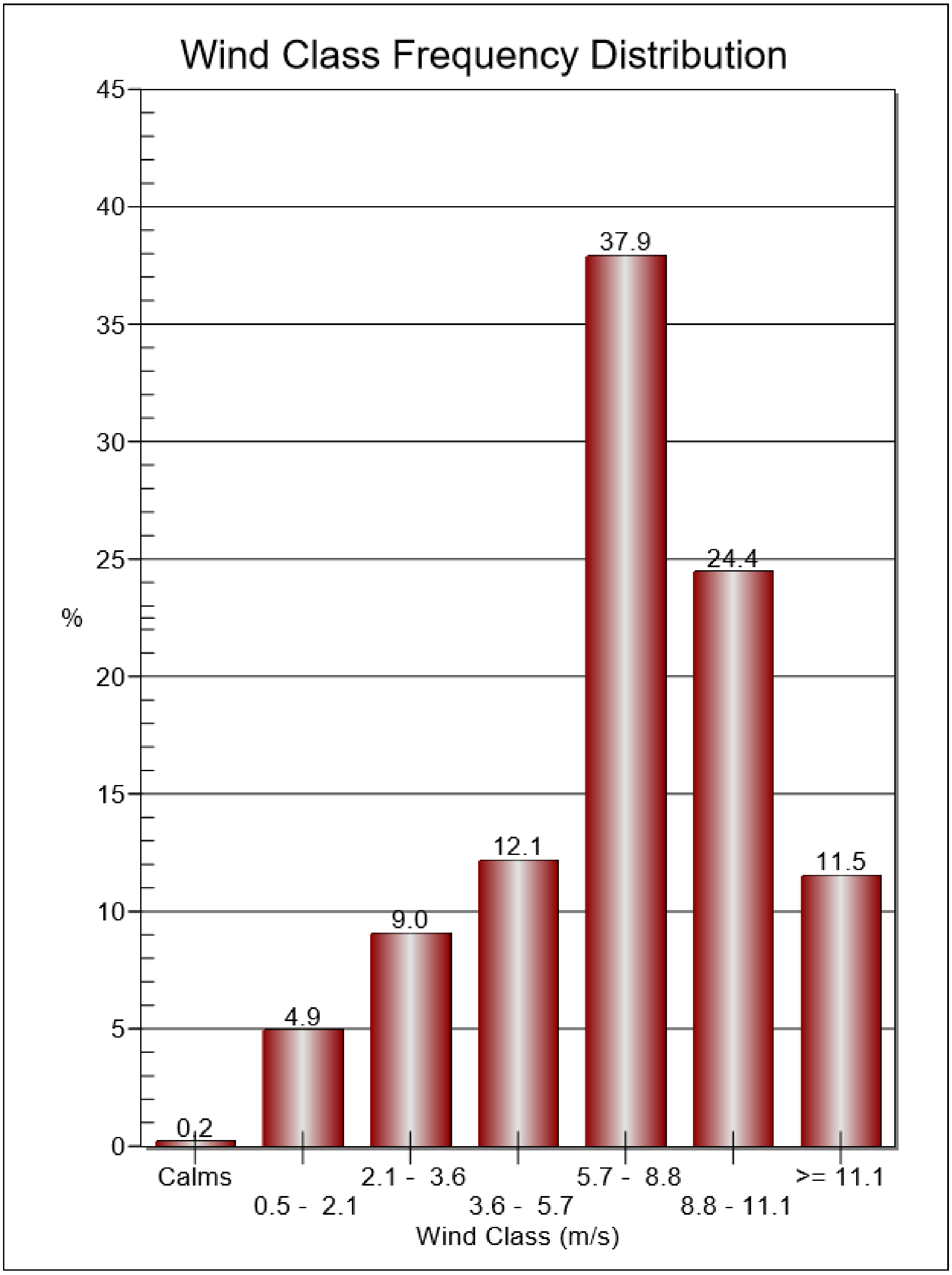

Figure 1A. Wind Class Frequency Distribution June 2015

Table 1A. Wind Frequency Distribution (count) [Start Date: 6/5/2015 -00:00; End Date 6/30/2015- 23:00]

Wind Direction (Blowing From) / Wind Speed (m/s)

	0.5 - 2.1	2.1 - 3.6	3.6 - 5.7	5.7 - 8.8	8.8 - 11.1	>= 11.1	Total
N	0	0	0	0	0	0	**0**
NNE	0	8	1	1	0	0	**10**
NE	1	4	13	78	40	5	**141**
ENE	1	10	23	106	78	41	**259**
E	0	3	12	31	26	23	**95**
ESE	3	6	11	10	4	1	**35**
SE	6	10	6	3	1	0	**26**
SSE	1	0	2	1	0	0	**4**
S	3	0	1	1	0	0	**5**
SSW	3	0	1	0	0	0	**4**
SW	6	1	1	0	0	0	**8**
WSW	0	4	1	0	0	0	**5**
W	3	5	1	0	0	0	**9**
WNW	2	1	0	0	0	0	**3**
NW	0	3	0	0	0	0	**3**
NNW	1	0	1	0	0	0	**2**
Total	30	55	74	231	149	70	610

Frequency of Calm Winds: 1
Average Wind Speed: 7.49 m/s

Table 1B. Normalized Wind Frequency Distribution [Start Date: 6/5/2015 -00:00; End Date 6/30/2015- 23:00]

Wind Direction (Blowing From) / Wind Speed (m/s)

	0.5 - 2.1	2.1 - 3.6	3.6 - 5.7	5.7 - 8.8	8.8 - 11.1	>= 11.1	Total
N	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000000**
NNE	0.000000	0.013115	0.001639	0.001639	0.000000	0.000000	**0.016393**
NE	0.001639	0.006557	0.021311	0.127869	0.065574	0.008197	**0.231148**
ENE	0.001639	0.016393	0.037705	0.173770	0.127869	0.067213	**0.424590**
E	0.000000	0.004918	0.019672	0.050820	0.042623	0.037705	**0.155738**
ESE	0.004918	0.009836	0.018033	0.016393	0.006557	0.001639	**0.057377**
SE	0.009836	0.016393	0.009836	0.004918	0.001639	0.000000	**0.042623**
SSE	0.001639	0.000000	0.003279	0.001639	0.000000	0.000000	**0.006557**
S	0.004918	0.000000	0.001639	0.001639	0.000000	0.000000	**0.008197**
SSW	0.004918	0.000000	0.001639	0.000000	0.000000	0.000000	**0.006557**
SW	0.009836	0.001639	0.001639	0.000000	0.000000	0.000000	**0.013115**
WSW	0.000000	0.006557	0.001639	0.000000	0.000000	0.000000	**0.008197**
W	0.004918	0.008197	0.001639	0.000000	0.000000	0.000000	**0.014754**
WNW	0.003279	0.001639	0.000000	0.000000	0.000000	0.000000	**0.004918**
NW	0.000000	0.004918	0.000000	0.000000	0.000000	0.000000	**0.004918**
NNW	0.001639	0.000000	0.001639	0.000000	0.000000	0.000000	**0.003279**
Total	0.049180	0.090164	0.121311	0.378689	0.244262	0.114754	0.998361

Frequency of Calm Winds: 0.16%
Average Wind Speed: 7.49 m/s

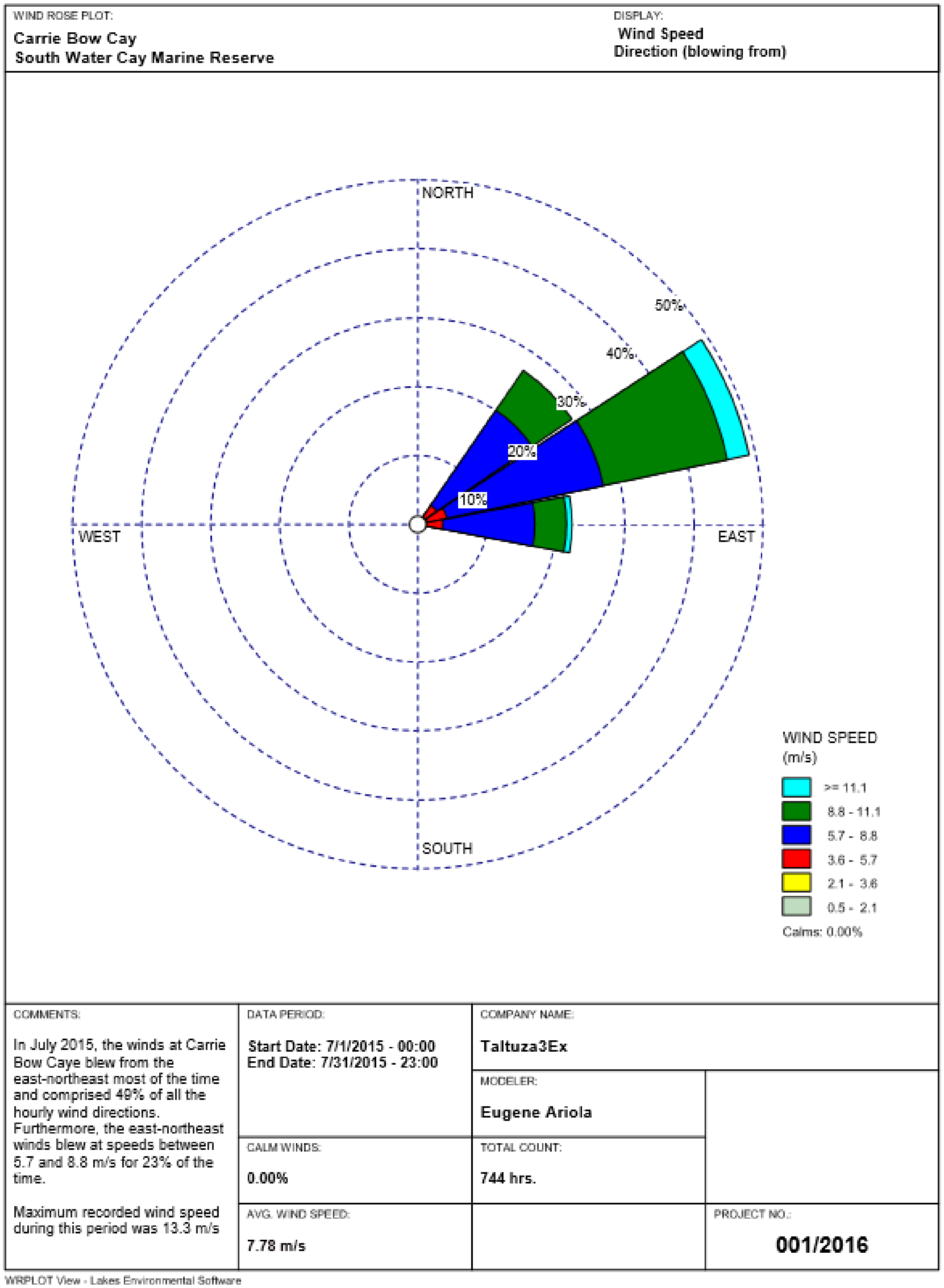

Figure 2. Wind Rose Diagram for the month of July, 2015.

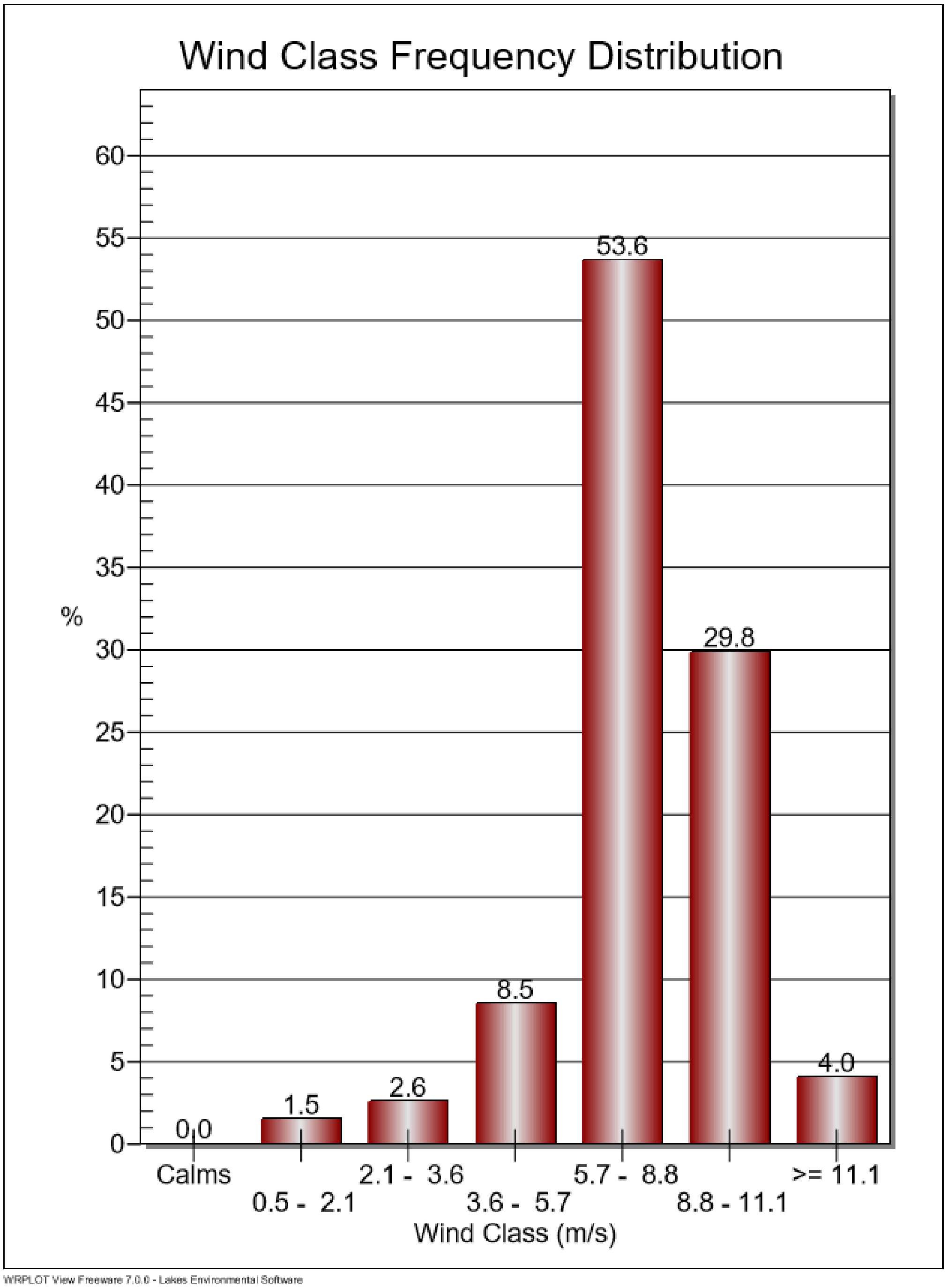

Figure 2A. Wind Class Frequency Distribution July 2015

Table 2A. Wind Frequency Distribution (count) [Start Date: 7/1/2015 -00:00; End Date 7/31/2015- 23:00]

Wind Direction (Blowing From) / Wind Speed (m/s)

	0.5 - 2.1	2.1 - 3.6	3.6 - 5.7	5.7 - 8.8	8.8 - 11.1	>= 11.1	Total
N	0	0	0	0	0	0	**0**
NNE	0	0	2	2	0	0	**4**
NE	4	6	15	124	52	0	**201**
ENE	2	8	22	172	136	24	**364**
E	3	3	21	99	34	6	**166**
ESE	0	2	3	2	0	0	**7**
SE	0	0	0	0	0	0	**0**
SSE	0	0	0	0	0	0	**0**
S	1	0	0	0	0	0	**1**
SSW	0	0	0	0	0	0	**0**
SW	0	0	0	0	0	0	**0**
WSW	0	0	0	0	0	0	**0**
W	0	0	0	0	0	0	**0**
WNW	1	0	0	0	0	0	**1**
NW	0	0	0	0	0	0	**0**
NNW	0	0	0	0	0	0	**0**
Total	11	19	63	399	222	30	744

Frequency of Calm Winds: 0
Average Wind Speed: 7.78 m/s

Table 2B. Normalized Wind Frequency Distribution [Start Date: 7/1/2015 -00:00; End Date 7/31/2015- 23:00]

Wind Direction (Blowing From) / Wind Speed (m/s)

	0.5 - 2.1	2.1 - 3.6	3.6 - 5.7	5.7 - 8.8	8.8 - 11.1	>= 11.1	Total
N	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000000**
NNE	0.000000	0.000000	0.002688	0.002688	0.000000	0.000000	**0.005376**
NE	0.005376	0.008065	0.020161	0.166667	0.069892	0.000000	**0.270161**
ENE	0.002688	0.010753	0.029570	0.231183	0.182796	0.032258	**0.489247**
E	0.004032	0.004032	0.028226	0.133065	0.045699	0.008065	**0.223118**
ESE	0.000000	0.002688	0.004032	0.002688	0.000000	0.000000	**0.009409**
SE	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000000**
SSE	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000000**
S	0.001344	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001344**
SSW	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000000**
SW	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000000**
WSW	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000000**
W	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000000**
WNW	0.001344	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001344**
NW	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000000**
NNW	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000000**
Total	0.014785	0.025538	0.084677	0.536290	0.298387	0.040323	1.000000

Frequency of Calm Winds: 0.00%
Average Wind Speed: 7.78 m/s

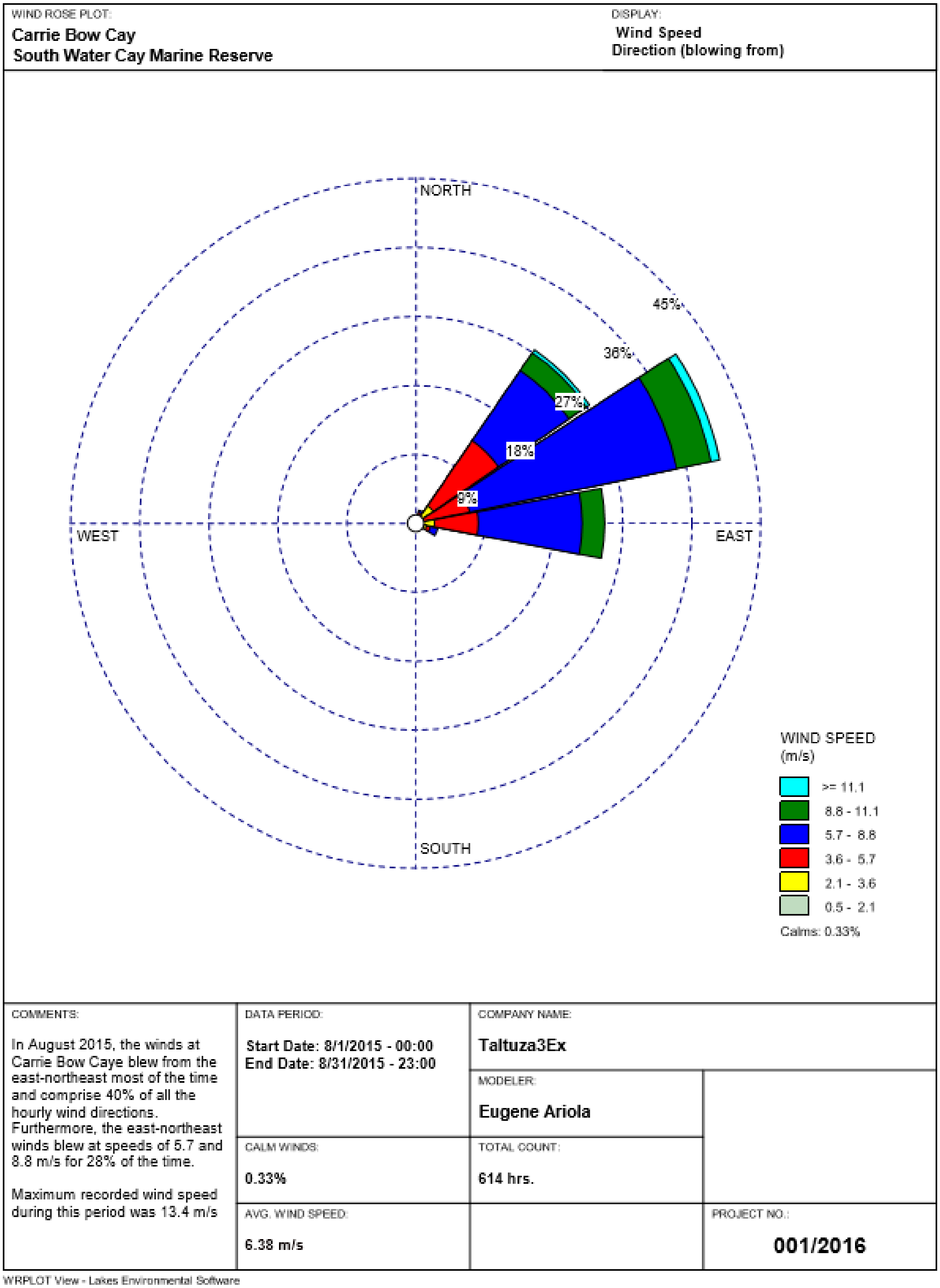

Figure 3. Wind Rose Diagram for the month of August, 2015.

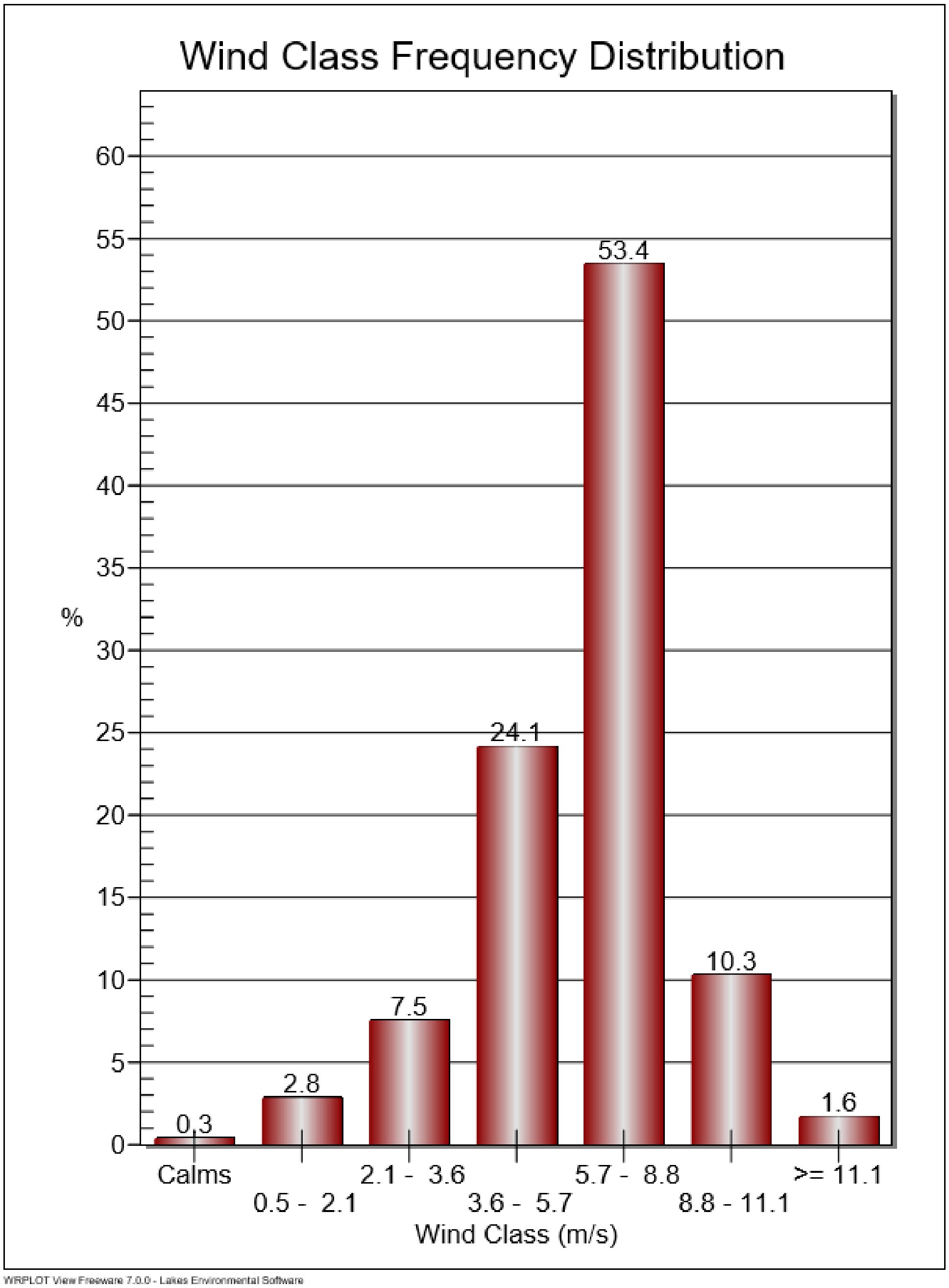

Figure 3A. Wind Class Frequency Distribution August 2015

Table 3A. Wind Frequency Distribution (count) [Start Date: 8/1/2015 -00:00; End Date 8/31/2015- 23:00]

Wind Direction (Blowing From) / Wind Speed (m/s)

	0.5 - 2.1	2.1 - 3.6	3.6 - 5.7	5.7 - 8.8	8.8 - 11.1	>= 11.1	Total
N	0	0	0	0	0	0	**0**
NNE	2	4	3	2	0	0	**11**
NE	5	12	63	68	17	3	**168**
ENE	1	4	39	169	28	7	**248**
E	2	13	35	83	18	0	**151**
ESE	3	6	3	6	0	0	**18**
SE	0	1	1	0	0	0	**2**
SSE	1	2	0	0	0	0	**3**
S	0	2	1	0	0	0	**3**
SSW	0	0	0	0	0	0	**0**
SW	3	0	0	0	0	0	**3**
WSW	0	0	1	0	0	0	**1**
W	0	0	0	0	0	0	**0**
WNW	0	1	0	0	0	0	**1**
NW	0	1	1	0	0	0	**2**
NNW	0	0	1	0	0	0	**1**
Total	17	46	148	328	63	10	614

Frequency of Calm Winds: 2
Average Wind Speed: 6.38 m/s

Table 3B. Normalized Wind Frequency Distribution [Start Date: 8/1/2015 -00:00; End Date 8/31/2015- 23:00]

Wind Direction (Blowing From) / Wind Speed (m/s)

	0.5 - 2.1	2.1 - 3.6	3.6 - 5.7	5.7 - 8.8	8.8 - 11.1	>= 11.1	Total
N	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000000**
NNE	0.003257	0.006515	0.004886	0.003257	0.000000	0.000000	**0.017915**
NE	0.008143	0.019544	0.102606	0.110749	0.027687	0.004886	**0.273616**
ENE	0.001629	0.006515	0.063518	0.275244	0.045603	0.011401	**0.403909**
E	0.003257	0.021173	0.057003	0.135179	0.029316	0.000000	**0.245928**
ESE	0.004886	0.009772	0.004886	0.009772	0.000000	0.000000	**0.029316**
SE	0.000000	0.001629	0.001629	0.000000	0.000000	0.000000	**0.003257**
SSE	0.001629	0.003257	0.000000	0.000000	0.000000	0.000000	**0.004886**
S	0.000000	0.003257	0.001629	0.000000	0.000000	0.000000	**0.004886**
SSW	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000000**
SW	0.004886	0.000000	0.000000	0.000000	0.000000	0.000000	**0.004886**
WSW	0.000000	0.000000	0.001629	0.000000	0.000000	0.000000	**0.001629**
W	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000000**
WNW	0.000000	0.001629	0.000000	0.000000	0.000000	0.000000	**0.001629**
NW	0.000000	0.001629	0.001629	0.000000	0.000000	0.000000	**0.003257**
NNW	0.000000	0.000000	0.001629	0.000000	0.000000	0.000000	**0.001629**
Total	0.027687	0.074919	0.241042	0.534202	0.102606	0.016287	0.996743

Frequency of Calm Winds: 0.33%
Average Wind Speed: 6.38 m/s

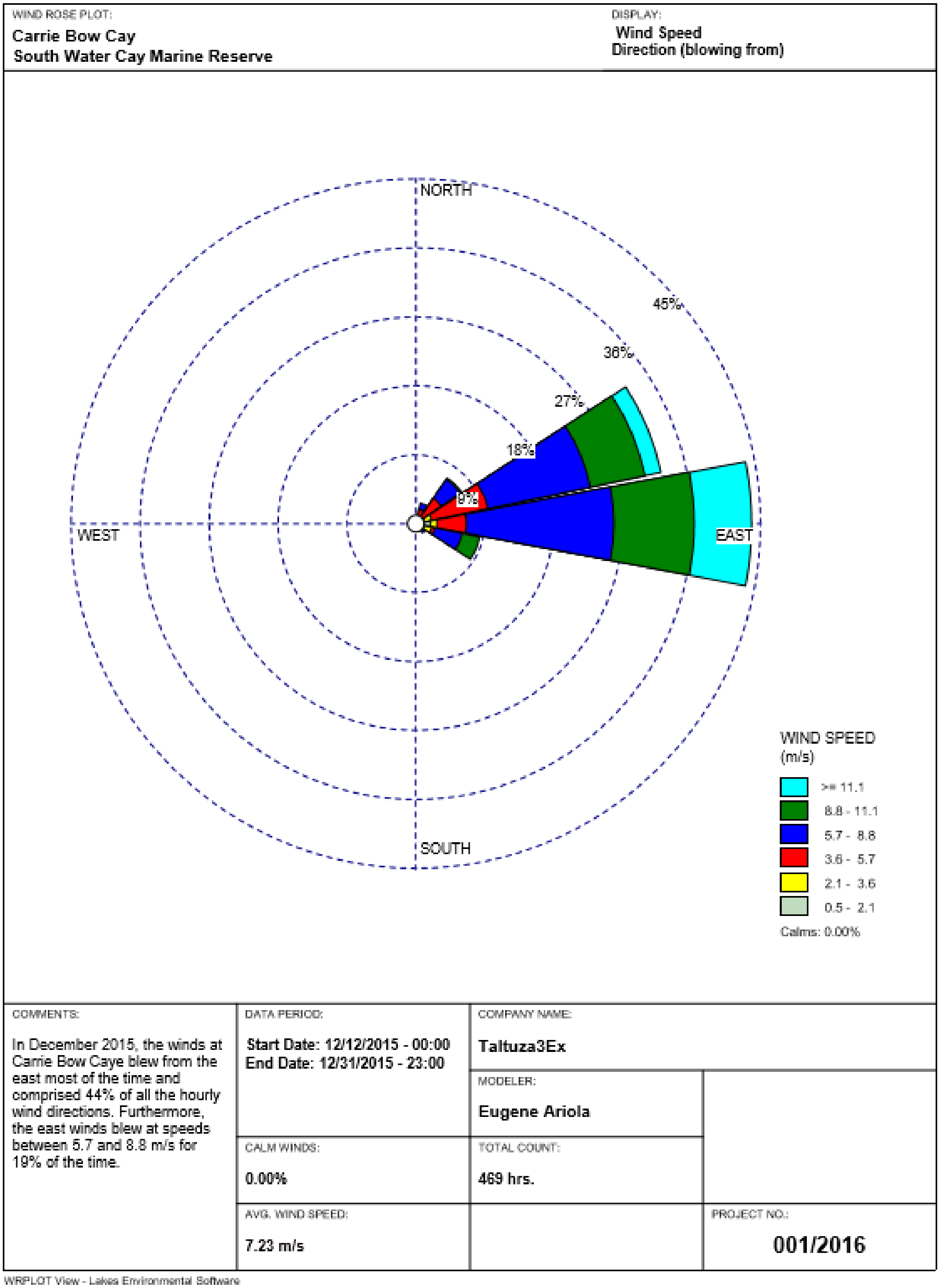

Figure 4. Wind Rose Diagram for the month of December, 2015.

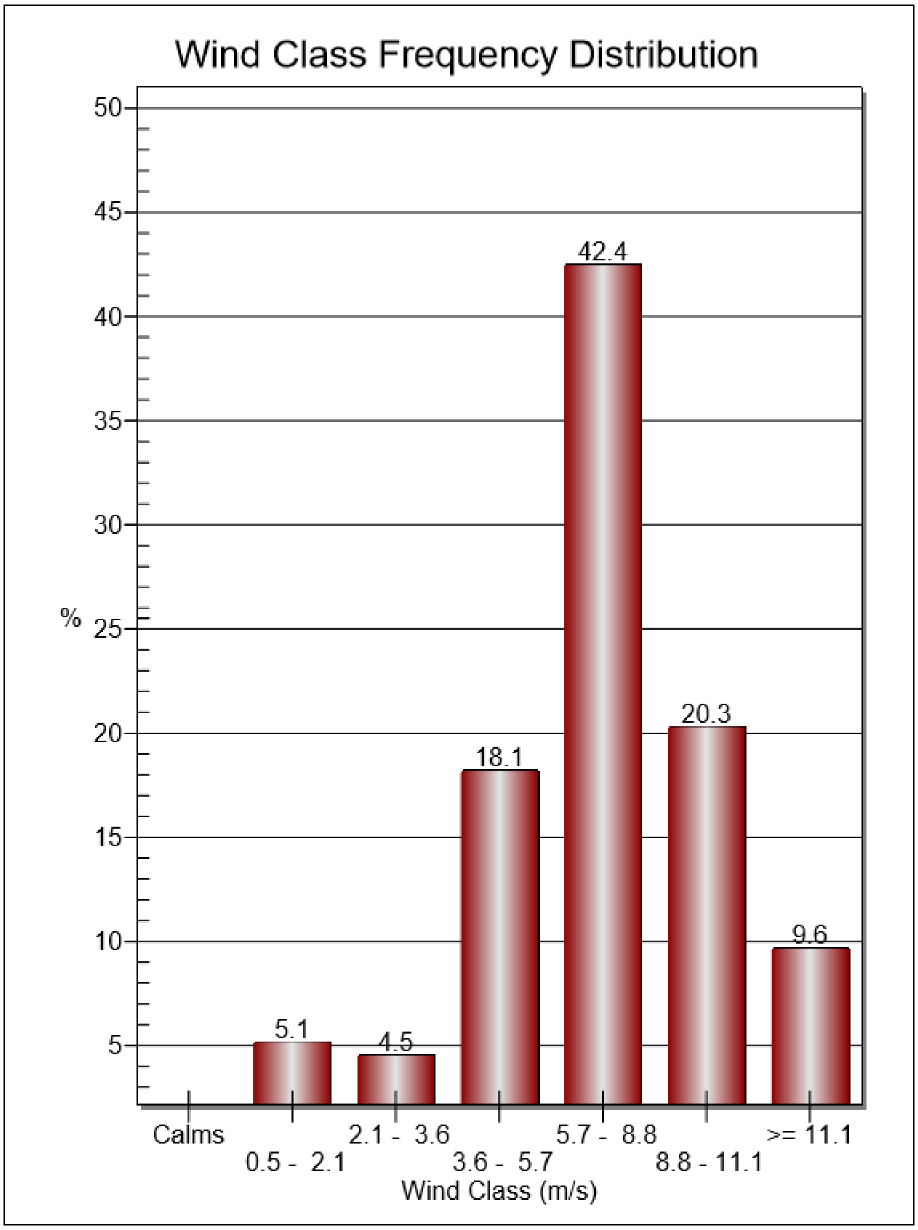

Figure 4A. Wind Class Frequency Distribution December 2015

Table 4A. Wind Frequency Distribution (count) [Start Date: 12/12/2015 -00:00; End Date 12/31/2015- 23:00]

Wind Direction (Blowing From) / Wind Speed (m/s)

	0.5 - 2.1	2.1 - 3.6	3.6 - 5.7	5.7 - 8.8	8.8 - 11.1	>= 11.1	Total
N	0	0	0	0	0	0	**0**
NNE	0	0	9	4	0	0	**13**
NE	1	3	15	14	1	0	**34**
ENE	5	5	35	64	34	10	**153**
E	9	4	18	90	49	35	**205**
ESE	5	5	2	17	11	0	**40**
SE	2	1	1	3	0	0	**7**
SSE	0	1	0	0	0	0	**1**
S	0	0	0	1	0	0	**1**
SSW	2	0	1	1	0	0	**4**
SW	0	0	0	0	0	0	**0**
WSW	0	2	0	2	0	0	**4**
W	0	0	0	0	0	0	**0**
WNW	0	0	0	0	0	0	**0**
NW	0	0	1	2	0	0	**3**
NNW	0	0	3	1	0	0	**4**
Total	24	21	85	199	95	45	469

Frequency of Calm Winds: 0
Average Wind Speed: 7.23 m/s

Table 4B. Normalized Wind Frequency Distribution [Start Date: 12/12/2015 -00:00; End Date 12/31/2015- 23:00]

Wind Direction (Blowing From) / Wind Speed (m/s)

	0.5 - 2.1	2.1 - 3.6	3.6 - 5.7	5.7 - 8.8	8.8 - 11.1	>= 11.1	Total
N	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000000**
NNE	0.000000	0.000000	0.019190	0.008529	0.000000	0.000000	**0.027719**
NE	0.002132	0.006397	0.031983	0.029851	0.002132	0.000000	**0.072495**
ENE	0.010661	0.010661	0.074627	0.136461	0.072495	0.021322	**0.326226**
E	0.019190	0.008529	0.038380	0.191898	0.104478	0.074627	**0.437100**
ESE	0.010661	0.010661	0.004264	0.036247	0.023454	0.000000	**0.085288**
SE	0.004264	0.002132	0.002132	0.006397	0.000000	0.000000	**0.014925**
SSE	0.000000	0.002132	0.000000	0.000000	0.000000	0.000000	**0.002132**
S	0.000000	0.000000	0.000000	0.002132	0.000000	0.000000	**0.002132**
SSW	0.004264	0.000000	0.002132	0.002132	0.000000	0.000000	**0.008529**
SW	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000000**
WSW	0.000000	0.004264	0.000000	0.004264	0.000000	0.000000	**0.008529**
W	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000000**
WNW	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000000**
NW	0.000000	0.000000	0.002132	0.004264	0.000000	0.000000	**0.006397**
NNW	0.000000	0.000000	0.006397	0.002132	0.000000	0.000000	**0.008529**
Total	0.051173	0.044776	0.181237	0.424307	0.202559	0.095949	1.000000

Frequency of Calm Winds: 0.00%
Average Wind Speed: 7.23 m/s

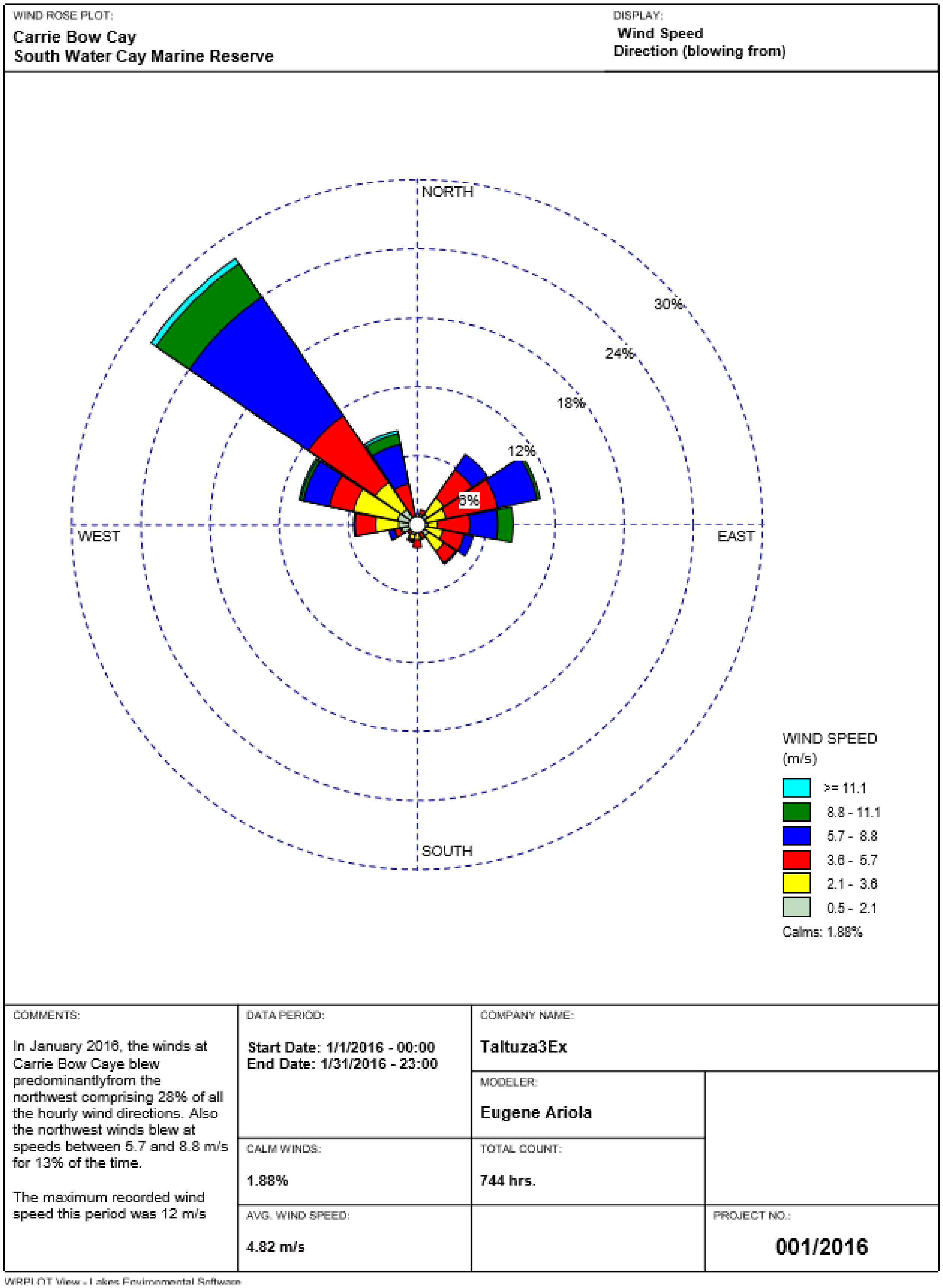

Figure 5. Wind Rose Diagram for the month of January, 2016.

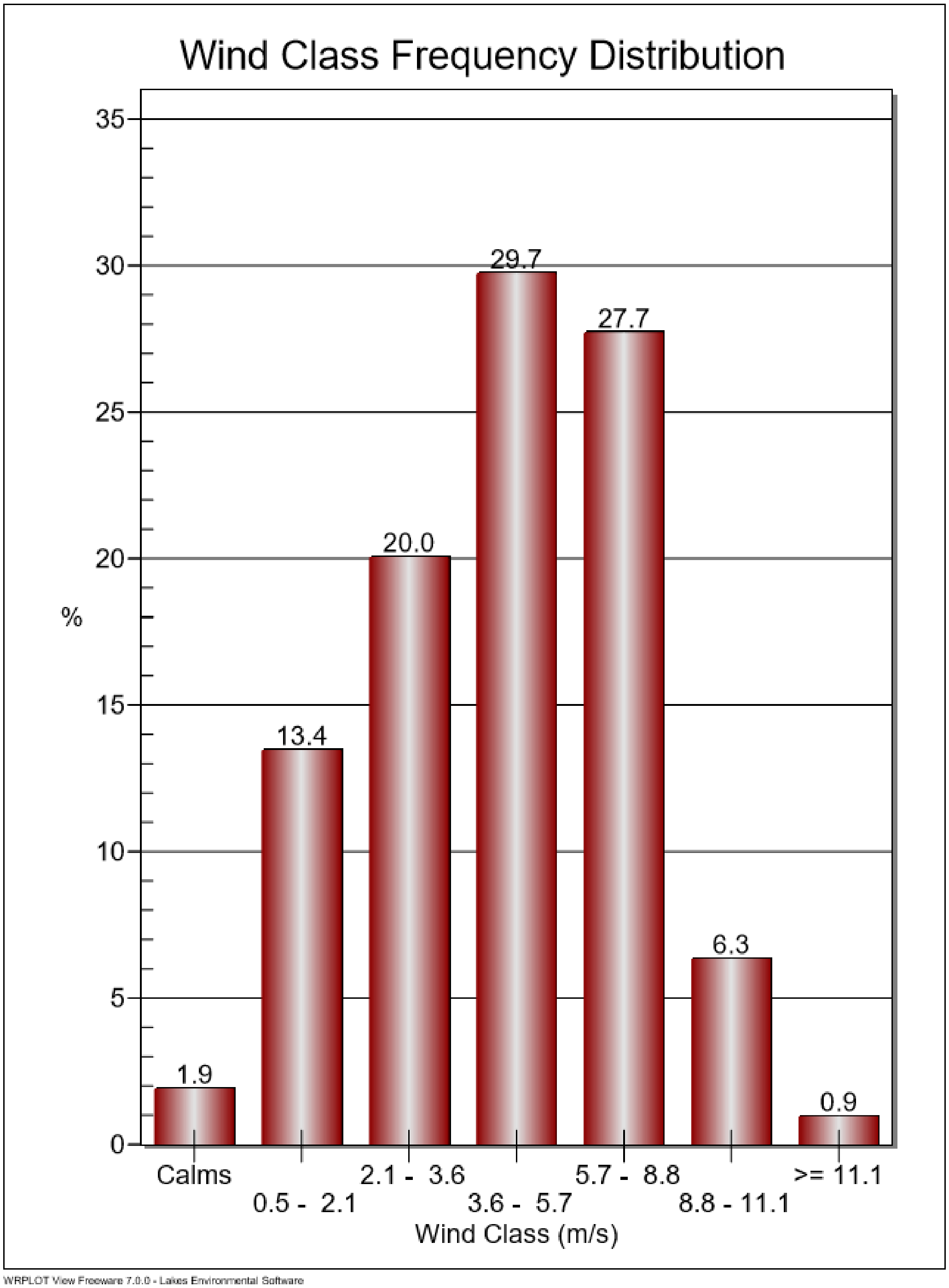

Figure 5A. Wind Class Frequency Distribution January 2016

Table 5A. Wind Frequency Distribution (count) [Start Date: 1/1/2016 -00:00; End Date 1/31/2016- 23:00]

Wind Direction (Blowing From) / Wind Speed (m/s)

	0.5 - 2.1	2.1 - 3.6	3.6 - 5.7	5.7 - 8.8	8.8 - 11.1	>= 11.1	Total
N	0	1	0	0	0	0	**1**
NNE	1	6	3	0	0	0	**10**
NE	8	13	22	12	0	0	**55**
ENE	6	13	34	26	2	0	**81**
E	7	6	21	18	10	0	**62**
ESE	3	14	14	6	0	0	**37**
SE	9	12	9	1	0	0	**31**
SSE	3	2	4	1	0	0	**10**
S	5	5	5	0	0	0	**15**
SSW	7	3	1	1	0	0	**12**
SW	3	3	2	0	0	0	**8**
WSW	10	1	4	4	0	0	**19**
W	12	15	13	1	0	0	**41**
WNW	13	29	16	17	2	1	**78**
NW	12	21	52	93	26	4	**208**
NNW	1	5	21	26	7	2	**62**
Total	100	149	221	206	47	7	744

Frequency of Calm Winds: 14
Average Wind Speed: 4.82 m/s

Table 5B. Normalized Wind Frequency Distribution [Start Date: 1/1/2016 -00:00; End Date 1/31/2016- 23:00]

Wind Direction (Blowing From) / Wind Speed (m/s)

	0.5 - 2.1	2.1 - 3.6	3.6 - 5.7	5.7 - 8.8	8.8 - 11.1	>= 11.1	Total
N	0.000000	0.001344	0.000000	0.000000	0.000000	0.000000	**0.001344**
NNE	0.001344	0.008065	0.004032	0.000000	0.000000	0.000000	**0.013441**
NE	0.010753	0.017473	0.029570	0.016129	0.000000	0.000000	**0.073925**
ENE	0.008065	0.017473	0.045699	0.034946	0.002688	0.000000	**0.108871**
E	0.009409	0.008065	0.028226	0.024194	0.013441	0.000000	**0.083333**
ESE	0.004032	0.018817	0.018817	0.008065	0.000000	0.000000	**0.049731**
SE	0.012097	0.016129	0.012097	0.001344	0.000000	0.000000	**0.041667**
SSE	0.004032	0.002688	0.005376	0.001344	0.000000	0.000000	**0.013441**
S	0.006720	0.006720	0.006720	0.000000	0.000000	0.000000	**0.020161**
SSW	0.009409	0.004032	0.001344	0.001344	0.000000	0.000000	**0.016129**
SW	0.004032	0.004032	0.002688	0.000000	0.000000	0.000000	**0.010753**
WSW	0.013441	0.001344	0.005376	0.005376	0.000000	0.000000	**0.025538**
W	0.016129	0.020161	0.017473	0.001344	0.000000	0.000000	**0.055108**
WNW	0.017473	0.038978	0.021505	0.022849	0.002688	0.001344	**0.104839**
NW	0.016129	0.028226	0.069892	0.125000	0.034946	0.005376	**0.279570**
NNW	0.001344	0.006720	0.028226	0.034946	0.009409	0.002688	**0.083333**
Total	0.134409	0.200269	0.297043	0.276882	0.063172	0.009409	0.981183

Frequency of Calm Winds: 1.88%
Average Wind Speed: 4.82 m/s

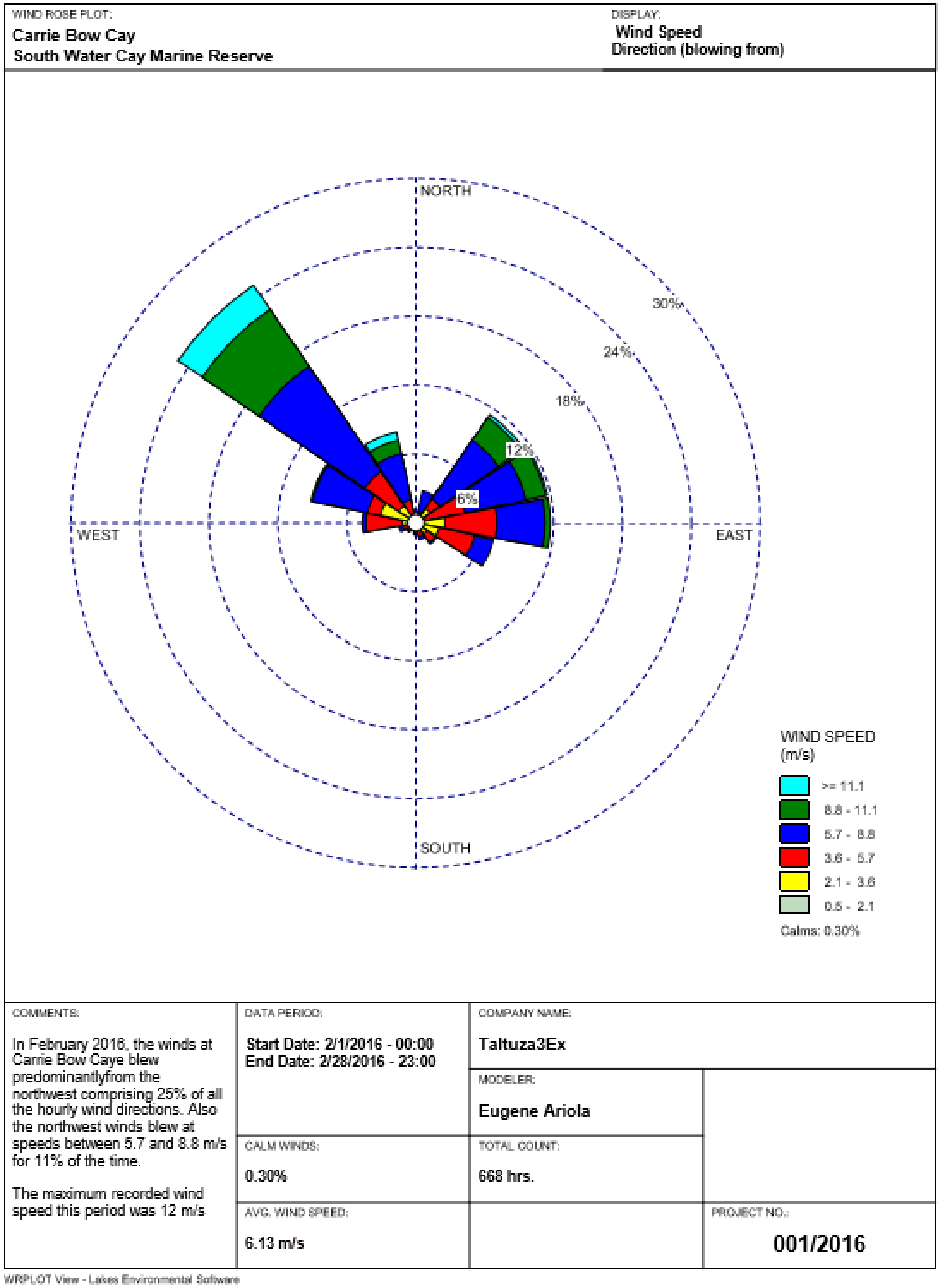

Figure 6. Wind Rose Diagram for the month of February, 2016.

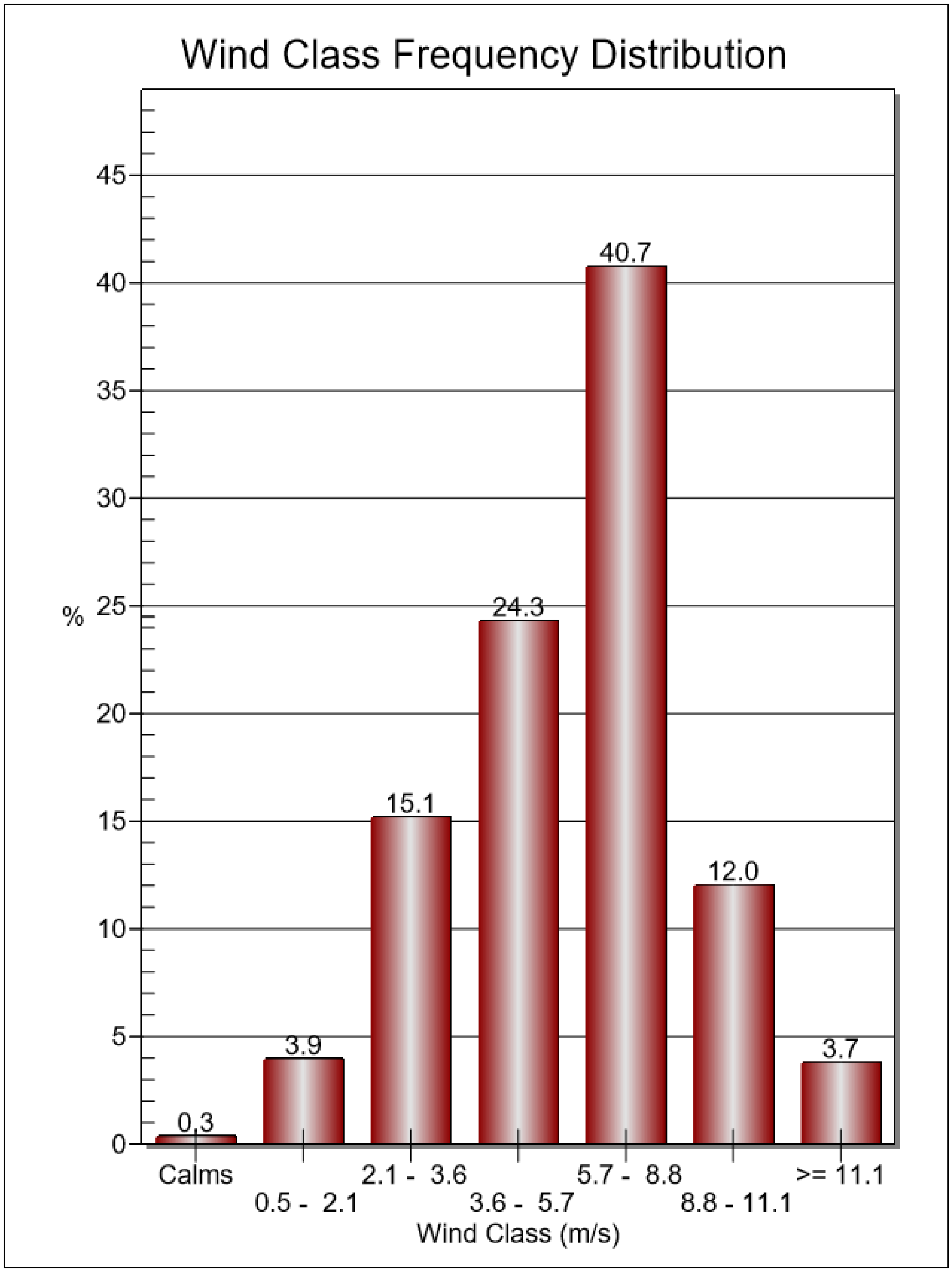

Figure 6A. Wind Class Frequency Distribution February 2016

Table 6A. Wind Frequency Distribution (count) [Start Date: 2/1/2016 -00:00; End Date 1/28/2016- 23:00]

Wind Direction (Blowing From) / Wind Speed (m/s)

	0.5 - 2.1	2.1 - 3.6	3.6 - 5.7	5.7 - 8.8	8.8 - 11.1	>= 11.1	Total
N	0	0	0	1	0	0	**1**
NNE	3	3	1	12	0	0	**19**
NE	2	8	7	41	16	2	**76**
ENE	2	4	23	36	12	1	**78**
E	2	15	30	28	3	0	**78**
ESE	3	11	21	11	0	0	**46**
SE	2	6	6	1	0	0	**15**
SSE	3	2	3	2	0	0	**10**
S	2	3	1	1	0	0	**7**
SSW	2	0	2	1	0	0	**5**
SW	3	0	3	1	0	0	**7**
WSW	0	6	2	2	0	0	**10**
W	1	7	21	2	0	0	**31**
WNW	1	20	8	32	1	0	**62**
NW	0	12	24	74	40	17	**167**
NNW	0	4	10	27	8	5	**54**
Total	26	101	162	272	80	25	668

Frequency of Calm Winds: 2
Average Wind Speed: 6.13 m/s

Table 6B. Normalized Wind Frequency Distribution [Start Date: 2/1/2016 -00:00; End Date 1/28/2016- 23:00]

Wind Direction (Blowing From) / Wind Speed (m/s)

	0.5 - 2.1	2.1 - 3.6	3.6 - 5.7	5.7 - 8.8	8.8 - 11.1	>= 11.1	Total
N	0.000000	0.000000	0.000000	0.001497	0.000000	0.000000	**0.001497**
NNE	0.004491	0.004491	0.001497	0.017964	0.000000	0.000000	**0.028443**
NE	0.002994	0.011976	0.010479	0.061377	0.023952	0.002994	**0.113772**
ENE	0.002994	0.005988	0.034431	0.053892	0.017964	0.001497	**0.116766**
E	0.002994	0.022455	0.044910	0.041916	0.004491	0.000000	**0.116766**
ESE	0.004491	0.016467	0.031437	0.016467	0.000000	0.000000	**0.068862**
SE	0.002994	0.008982	0.008982	0.001497	0.000000	0.000000	**0.022455**
SSE	0.004491	0.002994	0.004491	0.002994	0.000000	0.000000	**0.014970**
S	0.002994	0.004491	0.001497	0.001497	0.000000	0.000000	**0.010479**
SSW	0.002994	0.000000	0.002994	0.001497	0.000000	0.000000	**0.007485**
SW	0.004491	0.000000	0.004491	0.001497	0.000000	0.000000	**0.010479**
WSW	0.000000	0.008982	0.002994	0.002994	0.000000	0.000000	**0.014970**
W	0.001497	0.010479	0.031437	0.002994	0.000000	0.000000	**0.046407**
WNW	0.001497	0.029940	0.011976	0.047904	0.001497	0.000000	**0.092814**
NW	0.000000	0.017964	0.035928	0.110778	0.059880	0.025449	**0.250000**
NNW	0.000000	0.005988	0.014970	0.040419	0.011976	0.007485	**0.080838**
Total	0.038922	0.151198	0.242515	0.407186	0.119760	0.037425	0.997006

Frequency of Calm Winds: 0.30%
Average Wind Speed: 6.13 m/s

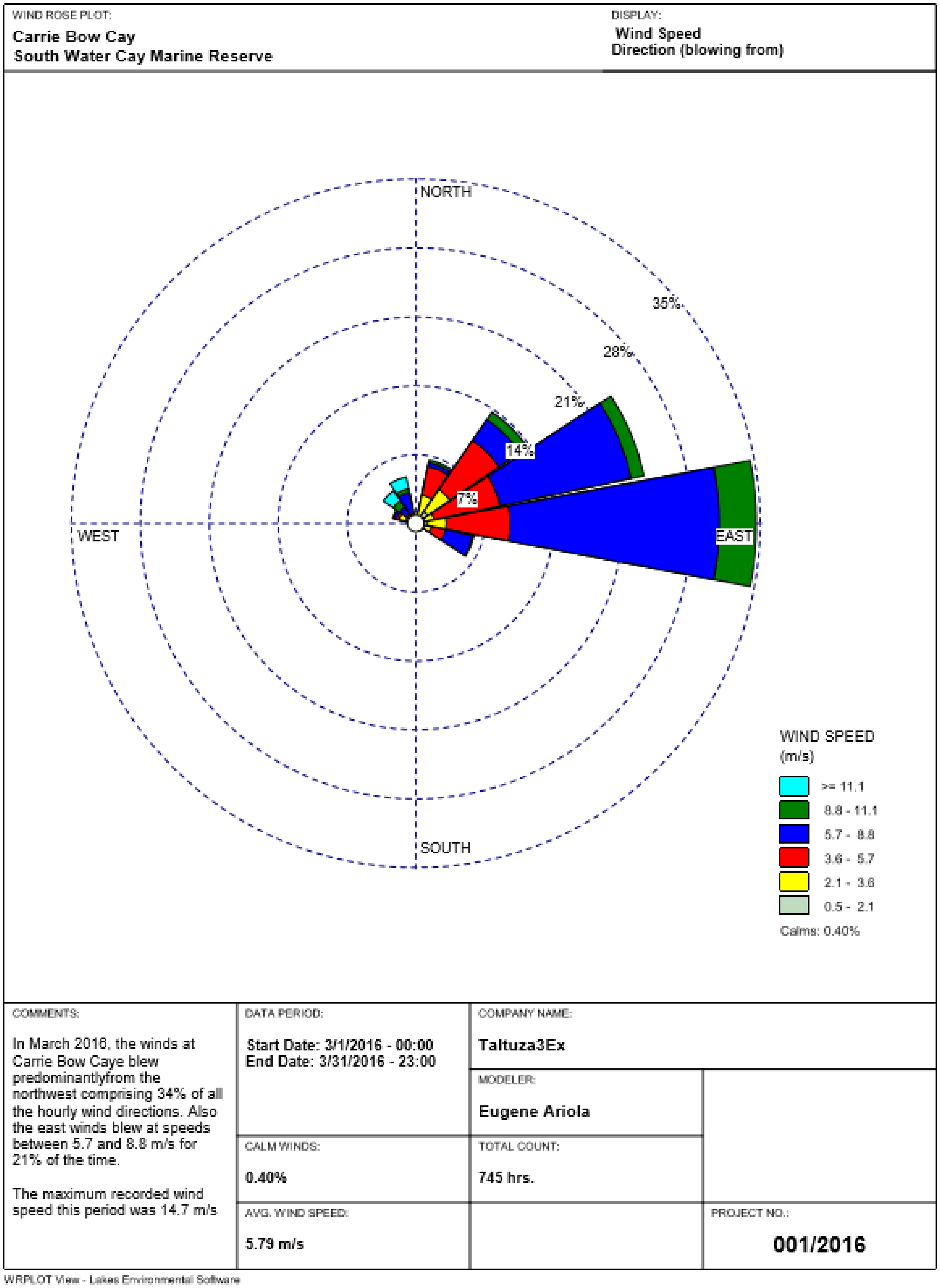

Figure 7. Wind Rose Diagram for the month of March, 2016.

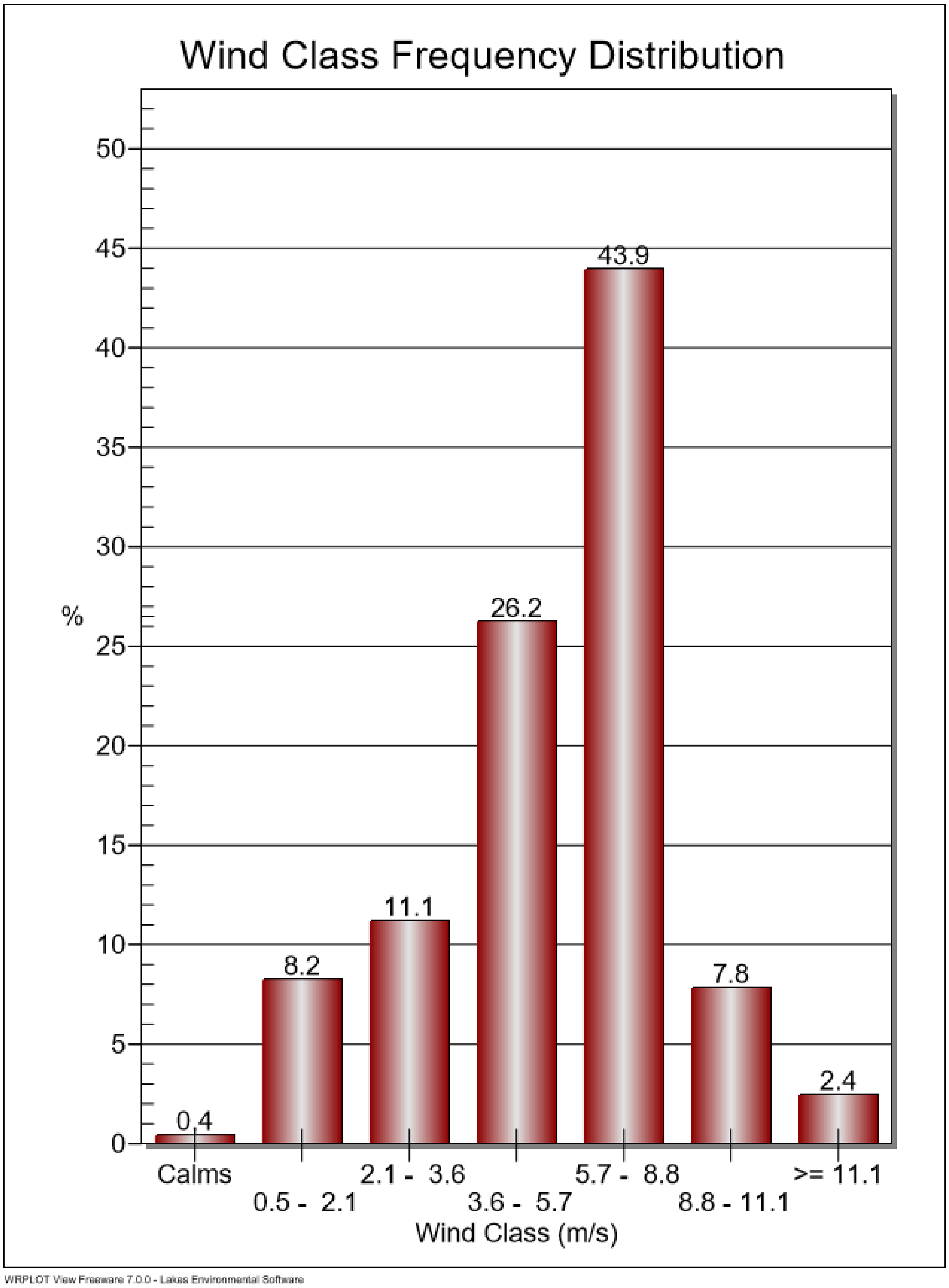

Figure 7A. Wind Class Frequency Distribution March 2016

Table 7A. Wind Frequency Distribution (count) [Start Date: 3/1/2016 -00:00; End Date 3/31/2016- 23:00]

Wind Direction (Blowing From) / Wind Speed (m/s)

	0.5 - 2.1	2.1 - 3.6	3.6 - 5.7	5.7 - 8.8	8.8 - 11.1	>= 11.1	Total
N	0	0	0	0	0	0	**0**
NNE	3	19	22	3	2	0	**49**
NE	11	20	45	19	7	0	**102**
ENE	4	10	51	101	10	0	**176**
E	9	14	48	158	28	0	**257**
ESE	6	6	11	21	1	0	**45**
SE	0	4	3	0	0	0	**7**
SSE	1	0	0	0	0	0	**1**
S	2	2	1	0	0	0	**5**
SSW	4	1	0	0	0	0	**5**
SW	2	0	0	0	0	0	**2**
WSW	1	0	1	0	0	0	**2**
W	2	1	3	1	0	0	**7**
WNW	8	5	2	2	1	0	**18**
NW	5	1	3	6	6	9	**30**
NNW	3	0	5	16	3	9	**36**
Total	61	83	195	327	58	18	745

Frequency of Calm Winds: 3
Average Wind Speed: 5.79 m/s

Table 7B. Normalized Wind Frequency Distribution [Start Date: 3/1/2016 -00:00; End Date 3/31/2016- 23:00]

Wind Direction (Blowing From) / Wind Speed (m/s)

	0.5 - 2.1	2.1 - 3.6	3.6 - 5.7	5.7 - 8.8	8.8 - 11.1	>= 11.1	Total
N	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000000**
NNE	0.004027	0.025503	0.029530	0.004027	0.002685	0.000000	**0.065772**
NE	0.014765	0.026846	0.060403	0.025503	0.009396	0.000000	**0.136913**
ENE	0.005369	0.013423	0.068456	0.135570	0.013423	0.000000	**0.236242**
E	0.012081	0.018792	0.064430	0.212081	0.037584	0.000000	**0.344966**
ESE	0.008054	0.008054	0.014765	0.028188	0.001342	0.000000	**0.060403**
SE	0.000000	0.005369	0.004027	0.000000	0.000000	0.000000	**0.009396**
SSE	0.001342	0.000000	0.000000	0.000000	0.000000	0.000000	**0.001342**
S	0.002685	0.002685	0.001342	0.000000	0.000000	0.000000	**0.006711**
SSW	0.005369	0.001342	0.000000	0.000000	0.000000	0.000000	**0.006711**
SW	0.002685	0.000000	0.000000	0.000000	0.000000	0.000000	**0.002685**
WSW	0.001342	0.000000	0.001342	0.000000	0.000000	0.000000	**0.002685**
W	0.002685	0.001342	0.004027	0.001342	0.000000	0.000000	**0.009396**
WNW	0.010738	0.006711	0.002685	0.002685	0.001342	0.000000	**0.024161**
NW	0.006711	0.001342	0.004027	0.008054	0.008054	0.012081	**0.040268**
NNW	0.004027	0.000000	0.006711	0.021477	0.004027	0.012081	**0.048322**
Total	0.081879	0.111409	0.261745	0.438926	0.077852	0.024161	0.995973

Frequency of Calm Winds: 0.40%
Average Wind Speed: 5.79 m/s

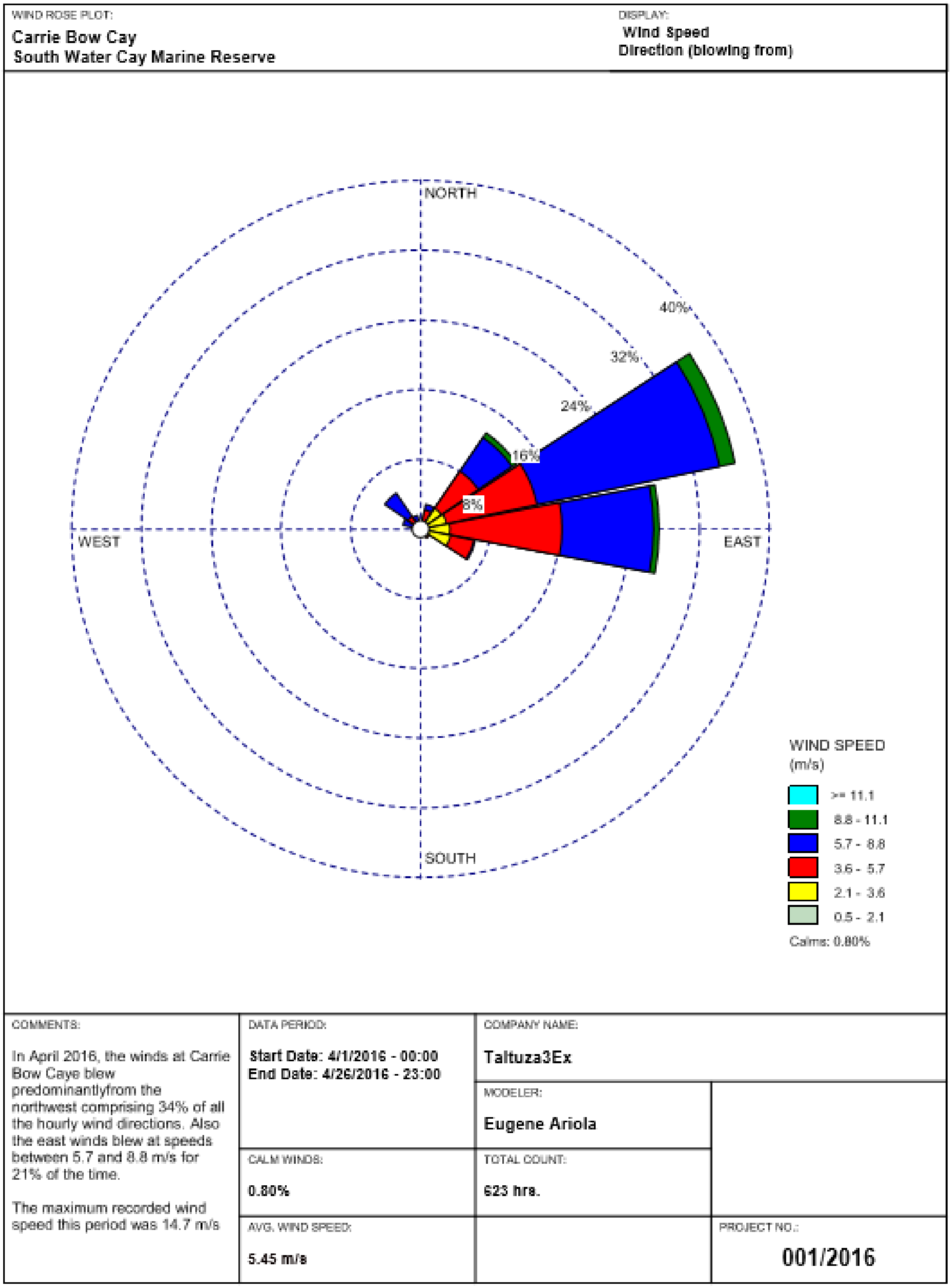

Figure 8. Wind Rose Diagram for the month of April, 2016.

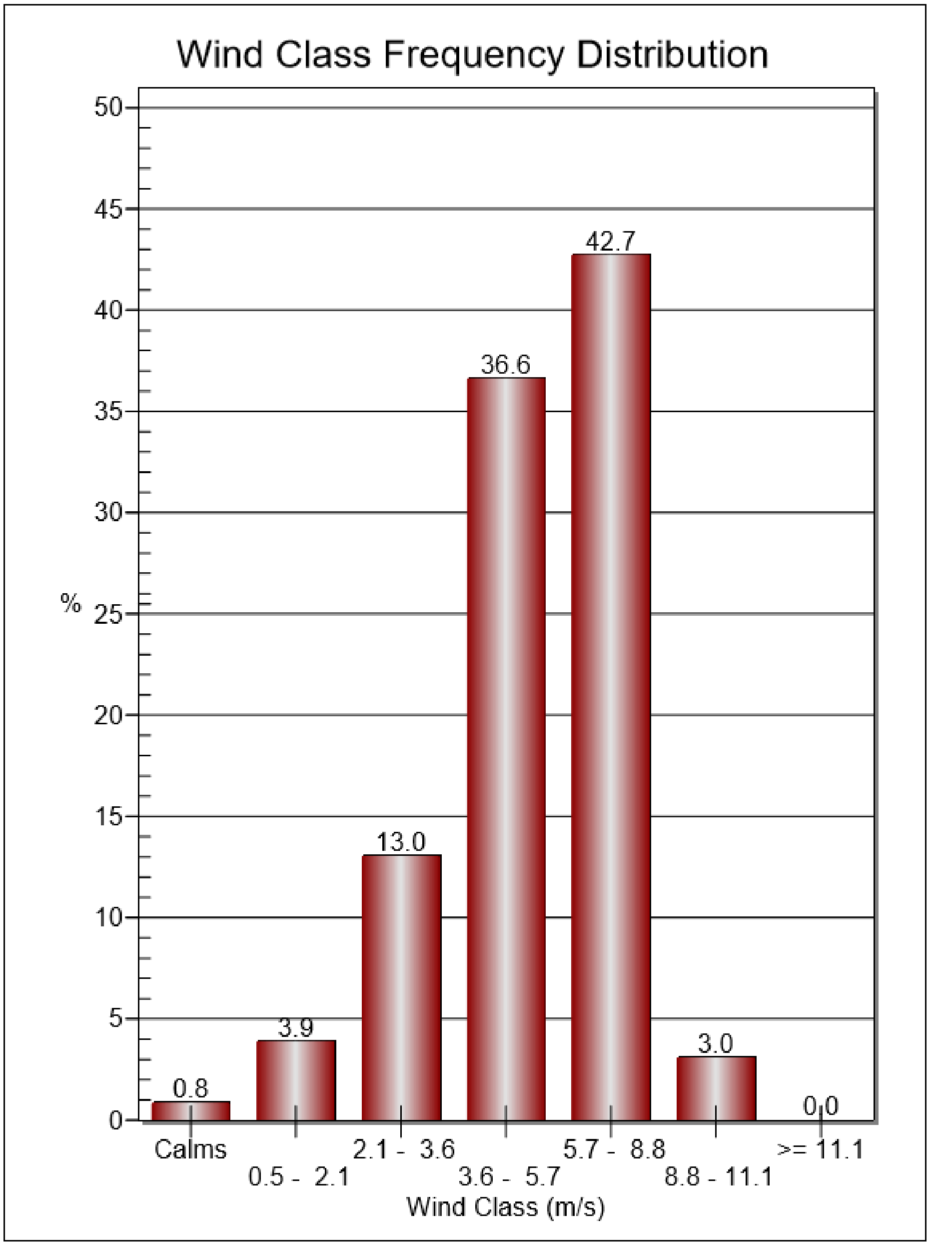

Figure 8A. Wind Class Frequency Distribution April 2016

Table 8A. Wind Frequency Distribution (count) [Start Date: 4/1/2016 -00:00; End Date 4/26/2016- 23:00]

Wind Direction (Blowing From) / Wind Speed (m/s)

	0.5 - 2.1	2.1 - 3.6	3.6 - 5.7	5.7 - 8.8	8.8 - 11.1	>= 11.1	Total
N	0	0	1	0	0	0	**1**
NNE	1	4	9	4	0	0	**18**
NE	4	14	32	29	4	0	**83**
ENE	2	17	66	133	11	0	**229**
E	5	16	80	65	4	0	**170**
ESE	6	16	17	1	0	0	**40**
SE	2	5	1	0	0	0	**8**
SSE	0	2	1	0	0	0	**3**
S	1	0	1	0	0	0	**2**
SSW	0	0	0	0	0	0	**0**
SW	0	1	0	0	0	0	**1**
WSW	0	1	2	0	0	0	**3**
W	2	1	2	1	0	0	**6**
WNW	1	2	3	7	0	0	**13**
NW	0	2	9	20	0	0	**31**
NNW	0	0	4	6	0	0	**10**
Total	24	81	228	266	19	0	623

Frequency of Calm Winds: 5
Average Wind Speed: 5.45 m/s

Table 8B. Normalized Wind Frequency Distribution [Start Date: 4/1/2016 -00:00; End Date 4/26/2016- 23:00]

Wind Direction (Blowing From) / Wind Speed (m/s)

	0.5 - 2.1	2.1 - 3.6	3.6 - 5.7	5.7 - 8.8	8.8 - 11.1	>= 11.1	Total
N	0.000000	0.000000	0.001605	0.000000	0.000000	0.000000	**0.001605**
NNE	0.001605	0.006421	0.014446	0.006421	0.000000	0.000000	**0.028892**
NE	0.006421	0.022472	0.051364	0.046549	0.006421	0.000000	**0.133226**
ENE	0.003210	0.027287	0.105939	0.213483	0.017657	0.000000	**0.367576**
E	0.008026	0.025682	0.128411	0.104334	0.006421	0.000000	**0.272873**
ESE	0.009631	0.025682	0.027287	0.001605	0.000000	0.000000	**0.064205**
SE	0.003210	0.008026	0.001605	0.000000	0.000000	0.000000	**0.012841**
SSE	0.000000	0.003210	0.001605	0.000000	0.000000	0.000000	**0.004815**
S	0.001605	0.000000	0.001605	0.000000	0.000000	0.000000	**0.003210**
SSW	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	**0.000000**
SW	0.000000	0.001605	0.000000	0.000000	0.000000	0.000000	**0.001605**
WSW	0.000000	0.001605	0.003210	0.000000	0.000000	0.000000	**0.004815**
W	0.003210	0.001605	0.003210	0.001605	0.000000	0.000000	**0.009631**
WNW	0.001605	0.003210	0.004815	0.011236	0.000000	0.000000	**0.020867**
NW	0.000000	0.003210	0.014446	0.032103	0.000000	0.000000	**0.049759**
NNW	0.000000	0.000000	0.006421	0.009631	0.000000	0.000000	**0.016051**
Total	0.038523	0.130016	0.365971	0.426966	0.030498	0.000000	0.991974

Frequency of Calm Winds: 0.80%
Average Wind Speed: 5.45 m/s

ANNEX 3

DREDGING CONTRACTORS

Persons Consulted with Reference to Marine Dredging Services

Dredging Services	Company	Contact Numbers	Cost/ Cubic yard of Sand BZ$	Dredge
Damien Chamberlain	Belize Marine Sands	610 0898	30	Cutter Suction
Carlos Ramirez	C. Ramirez Construction/ Seine Bight	633 3342	35	Bucket
Albert Loewen	AL construction, Placencia	610 6373/ 6105847	40	Bucket/ Excavator
Curtis Castillo	DEC & Sons / Dangriga	670 3123		Bucket
Lennox Gibson	Lennox Gibson, Belize City	610 2514	40	Bucket
Armando Graniel	Graniel construction	605 0550	35	Bucket

Edward Swift

Mining Unit Ministry of Natural Resources & Agriculture Government of Belize

Phone: 501- 802- 2328/2711 Ext 177/ 178

Fax: 501- 802 – 2333

Email: Mining@mnra.gov.bz