Study of Bermuda's Shipping Channels to Accommodate Larger Cruise Ships

Prepared for:

Ministry of Transport
Department of Marine and Port Services

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1 INTRODUCTION

The Corporations of Hamilton and St. George's have been ports-of-call for cruise ships since the mid 1930's when the Furness-Bermuda Line provided regularly scheduled cruises to Bermuda from New York. Through the late 1990's, these two ports were the primary destinations for cruise ships arriving in Bermuda. As the cruise industry gravitated toward larger ships in the late 2000's, the Ports of Hamilton and St. George's experienced a decline in cruise ship visitations. This was primarily due to physical limitations of channel width and depth in the shipping channels accessing these ports, forcing larger ships to call on the refurbished and expanded Royal Naval Dockyard facility on the West End.

The change in the pattern of cruise ship visitation to Bermuda has had both positive and negative impacts. On the positive side, the ability of the Royal Naval Dockyard to welcome the industry's larger vessels has allowed the Island to remain a relevant and desirable cruise destination. Activity at the Royal Naval Dockyard has provided positive and growing economic contributions to the Island overall and also helped to support the continued revitalization of the West End. The concentration of cruise ship activity at the West End, however, has resulted in more localized economic losses in St. George's and Hamilton. For Hamilton, these losses have been ameliorated to a degree by the varied nature of its economic base and consistent flows of cruise passengers arriving by high speed ferry from Dockyard. For St. George's, a community that has always had a greater reliance on tourist-based economic activities, the loss of cruise traffic has been more acute. Declines in retail, dinning, tour offering and other sectors clearly evident throughout the Corporation.

The concentration of cruise ships docking at the West End has also taxed the ability of the public transportation system to efficiently move passengers and crew to Hamilton and St. George's. As a result, the Government of Bermuda is faced with balancing the transportation needs of cruise passengers without adding excess capacity to the transportation system that is difficult to maintain and operate in a fiscally responsible manner.

1.1 OBJECTIVES

The inability of Hamilton and St. George's respective channels and harbours to welcome large cruise vessels rests at the heart of addressing the localized imbalance of the economic and social contribution of the cruise industry to Bermuda. Modification of Hamilton and St. George's marine access characteristics would allow for one or both of these vessels to welcome large ships, and thus, more equitably distribute economic impacts associated with the industry. Secondarily, reengagement of Hamilton and St. George's

would allow delivery of transportation services to be more localized and balanced at each of the ports versus the present, increasingly constrained "hub and spoke" method presently employed. As the cruise industry evolves and cruise vessel characteristics change, maintaining Bermuda's status as a cruise destination is also important consideration to the Bermudian economy.

As a means to balance public transportation and declining government and business revenues, the Ministry of Transport, has commissioned this study to evaluate widening and deepening the shipping channels leading to Hamilton and St. George's to improve access by cruise ships. The study evaluated improvements to all shipping channels currently utilized by cruise ships approaching and departing ports in Bermuda as they are integral to the overall strategy of balancing port usage and visitation.

1.2 APPROACH

The intent of this evaluation study is to define minimum access improvements (thresholds) required for each shipping channel to provide safe navigation of cruise vessels into the three ports. This study is not intended as a policy directive for implementation but as a basis for public discourse for the Government, its citizens, and stakeholders to discuss the opportunities and constraints associated with implementation.

Defining the physical changes required to meet this intent is only one aspect in the overall evaluation. The following factors were considered in the defining the threshold:

- Trends and projected growth in the global and regional cruise industry including the Bermuda market.
- Trends in cruise vessel characteristics (length, width, and draft displacement).
- Assessment of the natural environment and potential impacts to terrestrial and marine resources habitats.
- Modification to operational criteria and/or additional equipment/structures to assist in navigation.
- Assessment of the potential impacts to the socio-economic environment (storm vulnerability, transportation, social benefits and economic growth).
- Dredging and dredged material disposal.
- Engineering feasibility and cost to construct improvements.

The initial development and subsequent screening of thresholds was based on balancing safe transit of cruise ships with engineering and economic feasibilities and impacts to the environment.

Several meetings with stakeholders were held during January and February 2011 to provide input into the study and acquire baseline

information related to historic, existing, and future cruise ship visitations, physical and environmental data and studies, and direct and indirect social and economic impact data of cruise ship visitation.

Stakeholders meetings were conducted with:

- Ministry of Transport, Department of Marine and Port Services
- Ministry of Lands, Buildings, and Surveys
- Ministry of Public Works, Department of Conservation Services
- Ministry of Environment, Planning and Infrastructure Strategy, Department of Environmental Protection
- Bermuda National Trust
- Mayor and Representatives of the Corporation of St. George's
- Mayor and Representatives of the Corporation of Hamilton
- Bermuda Pilots Association
- Representatives of Carnival Corporation and PLC
- Representatives of Norwegian Cruise Line Corporation Ltd
- Representatives of Royal Caribbean Cruises Ltd

1.3 PROJECT TEAM

This study was authorized by the Department of Marine and Port Services, Ministry of Transport. Moffatt & Nichol was the prime consultant responsible for conducting and managing the study with contributions from several consultants. The roles of each consultant are identified below:

Moffatt & Nichol

- Participated in stakeholder's meeting and conducted engineering assessment of improvements to the shipping channels.

LandDesign

- Participated in stakeholder's meeting and conducted cruise market and socio-economic assessments.

Bermuda Water Consultants

- Participated in stakeholder's meeting and conducted environmental condition and impact assessments.

Golder Associates

- Conducted geotechnical condition and impact assessments.

Maritime Institute of Technology and Graduate Studies (MITAGS)

- Responsible for full bridge ship simulation studies.

2 Ports and Access Channels – Existing Conditions

There are three primary ports (St. George's, Hamilton, and Royal Naval Dockyard) and six main shipping channels (The Narrows, Town Cut, North Channel, South Channel, Two Rock Passage, and Dundonald Channel) that are utilized by cruise ships in Bermuda as shown in Figure 2-1. Note that term "access channels" is used interchangeable with the term "shipping channels" throughout this report and indicate the same.

These access channels are constructed and marked to facilitate navigation through the coral reef system along the perimeter of the island and inside Grassy and Great Sounds. Cruise ships accessing the three ports begin their transit on the east side of the island at the outer sea buoy, approximately 4.5 kilometers (km) offshore the St. George's Island. From this departure point, the ships transit the Five Fathom Hole region until reaching the Aids to Navigation (ATON) buoy denoting the entrance to the Narrows Channel. From this point, cruise ships can continue to the North and South Channels or approach St. George's Harbour through Town Cut approach.

In this section, the physical and environment characteristics of St. George's Harbour and six access channels are discussed.

2.1 ST. GEORGE'S HARBOUR AND TOWN CUT

St. George's was first settled in the early 1600's due to its location within a natural harbour that provided ships protection from the weather. The natural harbour is approximately 140 hectares and is defined by St. George's Island to the north and west, St. David's Island to the south and southeast and numerous islands to the east including Smith's, Paget's, Higgs and Horseshoe Islands as shown in Figure 2-2. Several other islands lie within the harbour, with the most notable being Hen and Ordnance Islands.

St. George's Harbour has been dredged several times in the last 200 years to accommodate cargo, military, and passenger ships. Water depths within the main harbour average 10 to 15m based on chart datum (CD) (NetSurvey, 2007) with the shoreline and areas around the island average between 2 and 4m. There is an approximately 500m turning basin area within the harbour, at an average water depth of -11m CD, for larger ships to maneuver.

Figure 2-1: Map of Bermuda's Ports and Main Shipping Channels

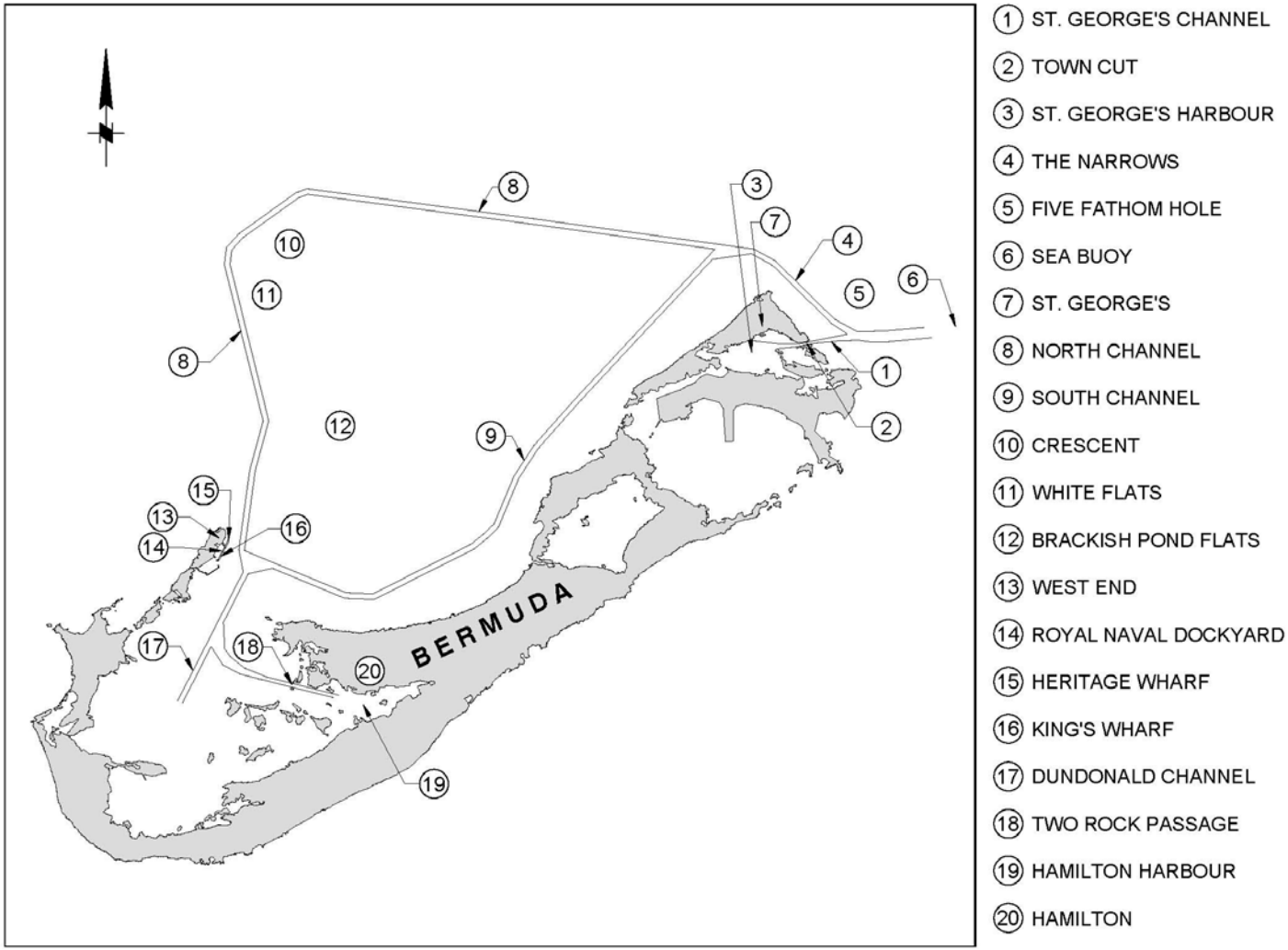
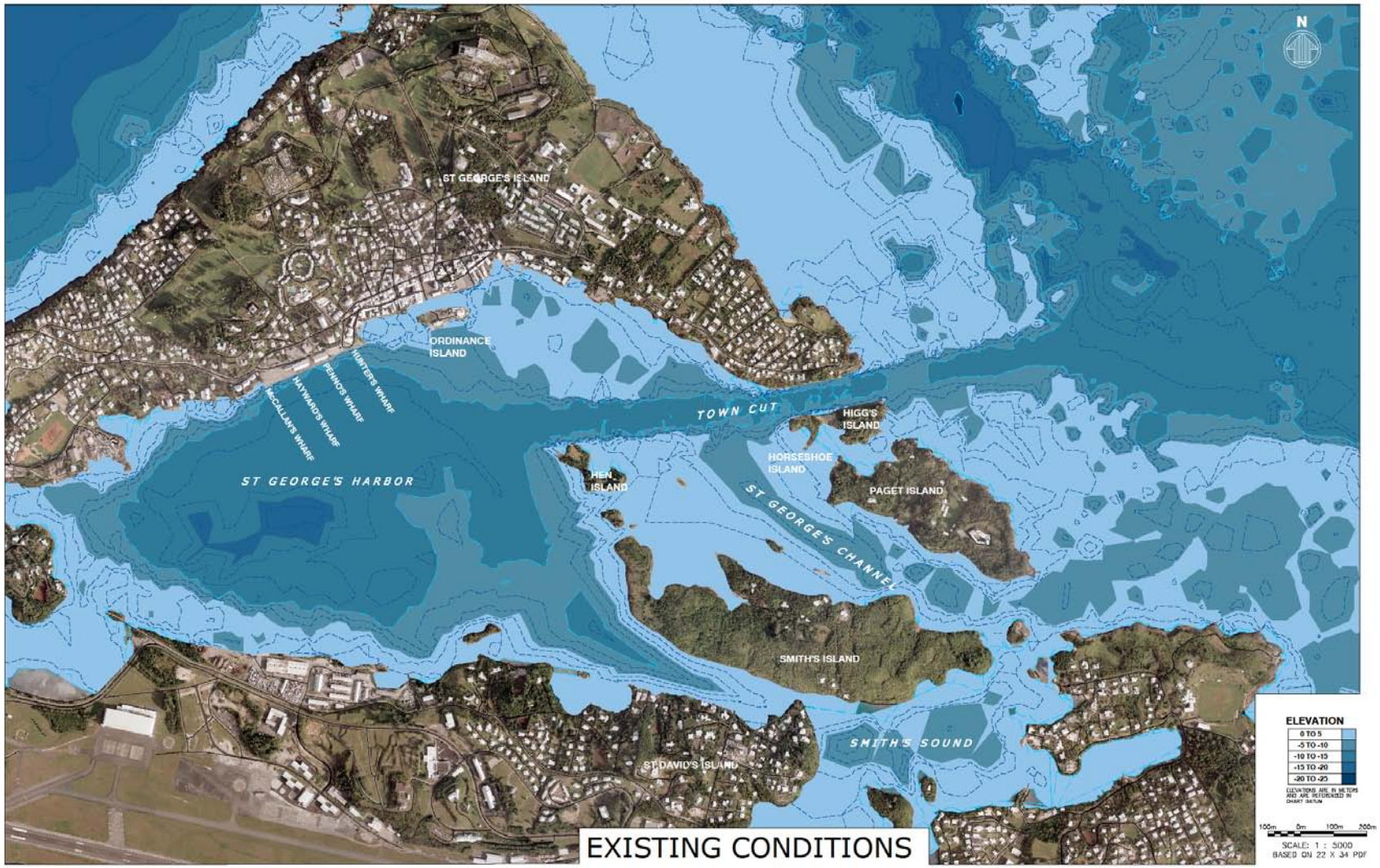


Figure 2-2: St. George's Harbour and Town Cut



Access to the harbour was historically through St. George's Channel on the south and west side of Paget's Island. Town Cut Channel, which is bounded by St. George's Island to the north and Higgs and Horseshoe Islands to the south, replaced St. George's Channel in 1915 to accommodate larger commercial steamships. Town Cut channel is approximately 70m wide at its narrowest point between Gate's Fort and Higgs Island. Gate's Fort is a historical defense structure situated at the entrance to St. George's Island. The average water depth within Town Cut proper is 10m measured using chart datum with a minimum depth of 9.5m. The Bermuda Pilot Association publishes channel information for safe navigation (Bermuda Pilot Associations, 2007) in Town Cut based on mean low water and mean high water (MLW/ MHW) as shown in Table 2-1. The maximum operating width is 70m and maximum allowable ship draft is 7.9m.

Table 2-1: Channel Characteristics of Town Cut

Channel	Length (Km)	Width (m)	Ave. Channel Depth (m)	Maximum Vessel Draft (MLW/MHW – m)
Town Cut	54.5	70	10	7.9/8.5

The approach channel from the ATON's "SG-1 and SG-2" to Town Cut varies in width from 115m at its eastern end to 70m at the entrance to Town Cut, at an average water depth of 10m (CD). The channel from Town Cut into St. George's Harbour varies in width from 70m at the west end to 145m at Hen Island, with an average water depth of 10.5m CD.

Higgs and Horseshoe Islands define the south edge of Town Cut Channel. Higgs Island is approximately 2.0 hectares, at an average elevation of 4.5m CD while Horseshoe Island is approximately 0.9 hectares at an average elevation of 1.5m CD. Hen Island, a 1.1 hectare island which is located approximately 650m to the west of Town Cut, has an average elevation of 1.5m CD. Higgs, Horseshoe Islands are owned by the Government of Bermuda and Hen Island is privately held; all three are operated by the Bermuda National Park System. A loose rockfill between Higgs and Horseshoe islands and rock filled training wall extending 130m to the west of Horseshoe Island were placed to create symmetry of the north and south shores of the Town Cut to balance the hydrodynamic bank suction forces acting upon transiting vessels. This training wall was constructed in the early 1980's and has mitigated some bank suction effects.

2.2 NORTH CHANNEL AND "THE NARROWS"

The Narrows is the connecting channel linking the Sea Buoy and Town Cut approach with the entrance of the North and South Channels, near St. Catherine's Point. The Narrows is approximately 4.5 km long from ATON #1/#2 to the entrances of the North/South Channels. The

marked channel limits range from 175m to 215m in width as shown on the navigation chart (British Admiralty Chart 1315) though the operating conditions listed by the Bermuda Pilot Association indicate identifies a width of 152.5m as shown in Table 2-2. Water depths based on 2007 bathymetric survey range from 12.5m to 16m CD, with an operating depth of 12.5m CD. Expansive coral reefs and sand shoals border this channel. As with Town Cut, the Narrows was last widened and dredged in the 1920's.

The North Channel is the primary channel utilized by cruise ships transiting to Hamilton and the Royal Naval Dockyards. The channel extends from St. Catherine's Point to the entrance of Grass Bay, a distance of approximately 26km as shown in Figure 2-3. The North Channel passes through Murray's Anchorage, a deepwater anchorage for larger ships, and then skirts the northern edge of the Bermuda shelf in slightly deeper waters.

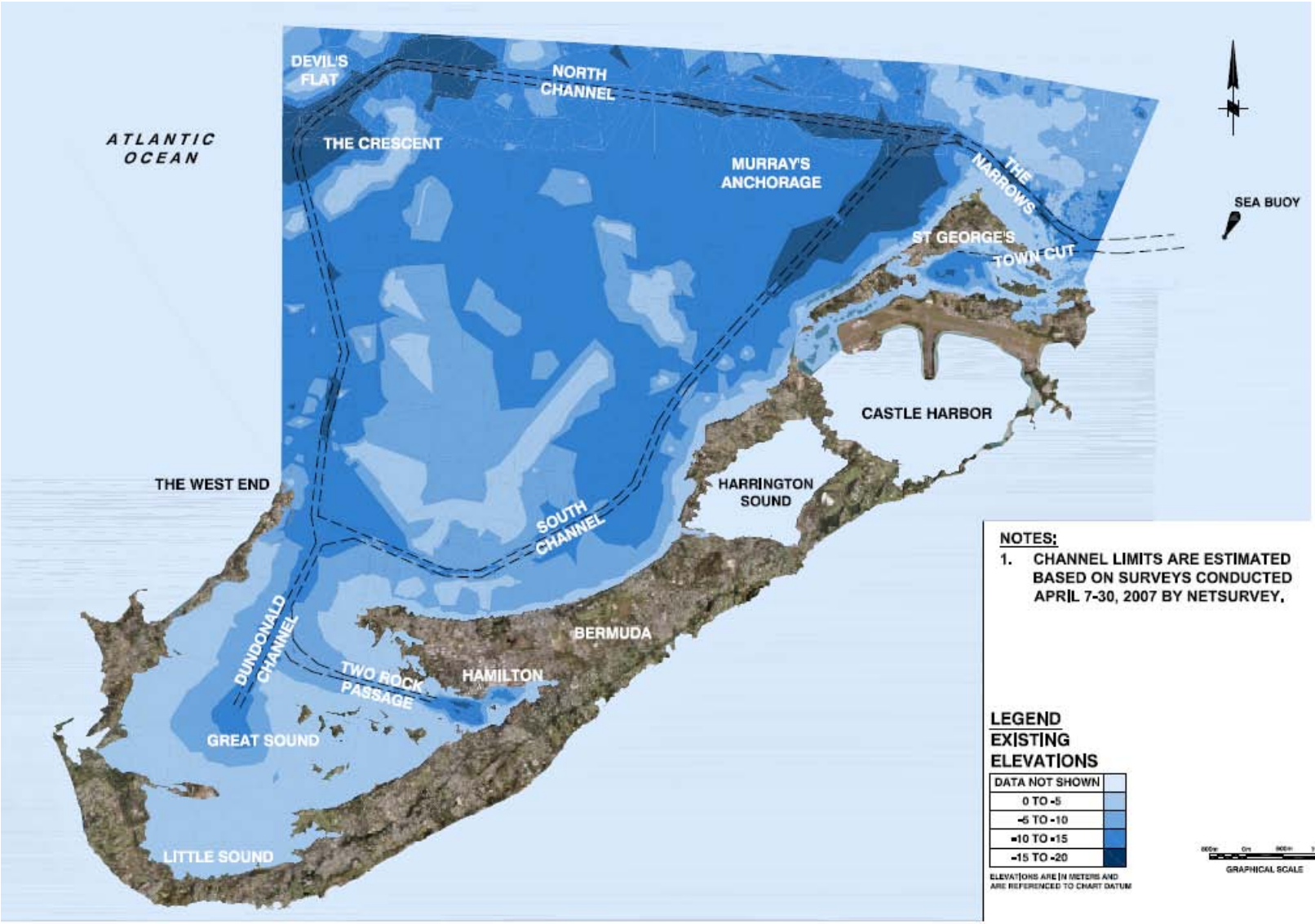
At the northern most point of the transit, the channel makes a number of relatively sharp turns in an area called the "Crescent" in order to negotiate a number of critical reef systems including White Flats. From this area, the channel takes a southerly alignment toward Grassy Bay with an exception of one turn near Brackish Pond Flat. The channel terminates with its intersection with the South Channel, in Grassy Bay. From Grassy Bay, ship traffic may continue into Hamilton by way of Dundonald Channel.

Table 2-2: Channel Characteristics of the North Channel and The Narrows

Channel	Length* (Km)	Width (m)	Ave Channel Depth (m)	Maximum Vessel Draft (MLW/MHW – m)
The Narrows	4.3	152.5	12.5	10.3/10.9
North Channel	26.0	152.5	12.5	10.1/10.9

The width of the North Channel is approximately 152.5m based on information provided by the Bermuda Pilots Association, the channel bank locations defined by the 2007 bathymetric survey, and the location of the existing ATON's. Water depth is a minimum of 12.5m CD within the channel limits, with water depths exceeding 15m CD in several sections.

Figure 2-3: The North and South Channels including "The Narrows"



2.3 SOUTH CHANNEL

The South Channel is a 16 km long, 152m wide channel that lies approximately 800 to 1,500m offshore of the north coast of St. George's and Hamilton Islands. The channel generally follows the alignment of the north coastline as it winds its way through a series of coral patch reefs. The channels is used primarily today by commercial, smaller cruise ships (< 600 feet in length overall) and private vessels transiting to Hamilton and the Royal Naval Dockyard. Water depths on the east half of the channel is greater than 10m CD but less than 9m CD on the west half as shown in Table 2-3.

Table 2-3: Channel Characteristics of the South Channel

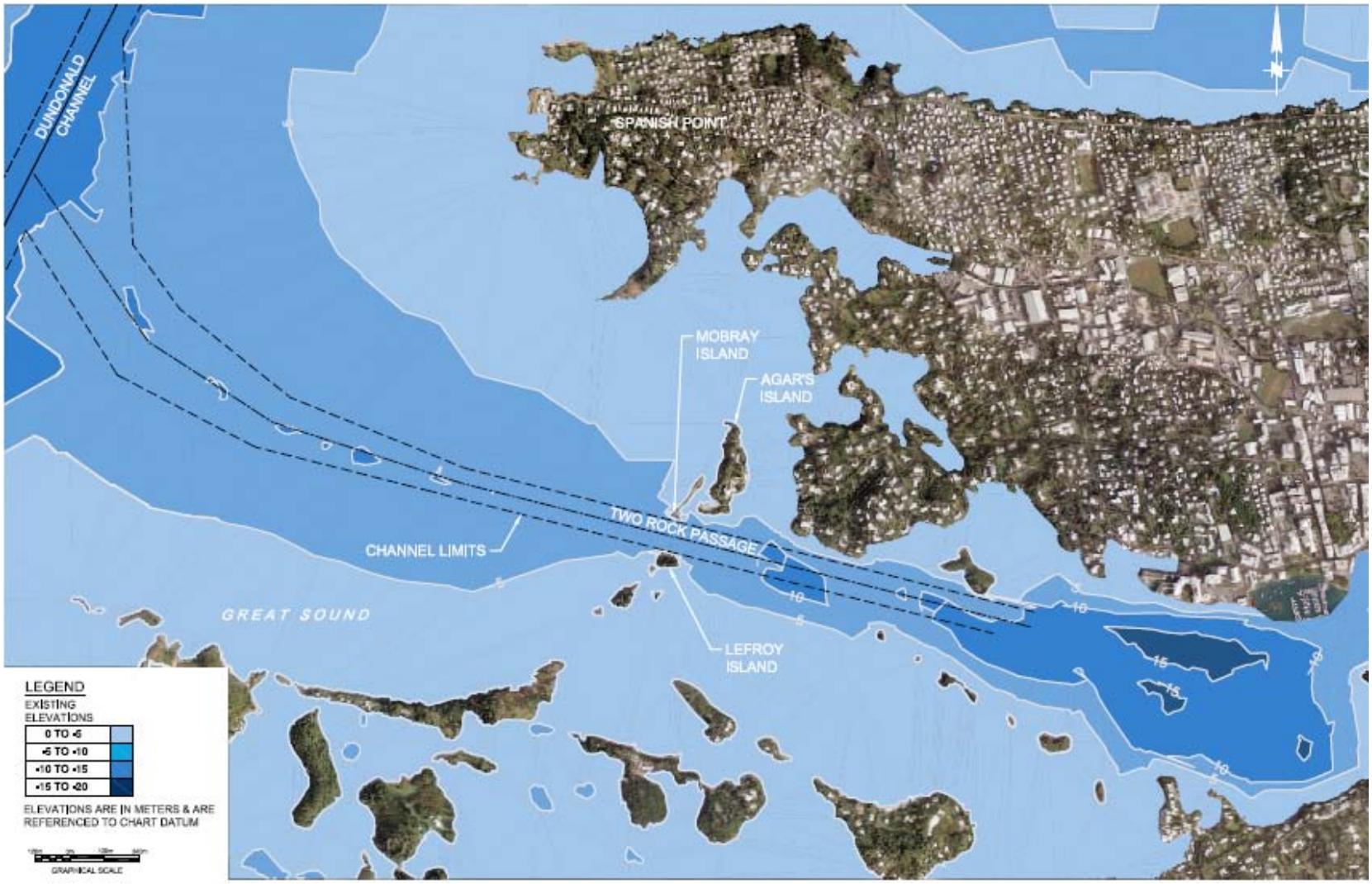
Channel	Length (Km)	Width (m)	Ave Channel Depth (m)	Maximum Vessel Draft (MLW/MHW – m)
South Channel	16.0	152.5	9.0	8.2/8.8

2.4 DUNDONALD CHANNEL, TWO ROCK PASSAGE, AND HAMILTON HARBOUR

Cargo and cruise vessels accessing Hamilton Harbour utilize Dundonald Channel and Two Rock Passage. Dundonald Channel is a 152.5m wide, 3.9km long channel that connects Grassy Bay near Royal Naval Dockyards with Lower Great Sound. Patch reefs border each side of the channel along a 600m section at the north end. The average water depth is -11m CD. Two Rock Passage is 3.5 km long channel with a minimum width of 106.7m as it passes between Mobray Island, a thin strip of rocky out-crop (0.37 hectares) to the north and Lefroy Island, a 1.5 hectare uninhabited island to the south as shown in Figure 2-4. The Two Rock Passage is at its widest point (approximately 550m) where it meets Dundonald Channel then narrows down to the aforementioned width between the islands before terminating into the turning basin within Hamilton Harbour. Agars and Verrill Islands border the channel as it approaches the turning basin while several smaller islands lie to the south of channel where it meets the turning basin (World's End, Butterfield Rock, Spectacle, Reid, and Doctor's Islands). The turning basin within Hamilton Harbour is approximately 425m.

To the east of the turning basin, through 180m wide passage between White's Island and Hamilton Island is the Port of Hamilton. The Port of Hamilton contains berths for cruise and container ships, as well as local ferry operations. Due to limitations in available water area in the main port area, larger cruise ships utilize the turning basin then "back" into and berth at the cruise terminal. The Corporation of Hamilton has recently completed a master plan to update the waterfront, including new berthing accommodations for larger cruise ships.

Figure 2-4: Two Rock Passage



From Dundonald Channel to Two Rock Passage proper, the water depths in the channel average 10m CD. Water depths in the passage average 8.8m CD with some deeper pockets of 10m or greater where the channel meets the turning basin. Table 2-4 summarizes the channel characteristics.

Table 2-4: Channel Characteristics of Dundonald Channel and Two Rock Passage

Channel	Length (Km)	Width (m)	Ave Channel Depth (m)	Maximum Vessel Draft (MLW/MHW – m)
Dundonald Channel	3.9	152.5	11.1	10.1/10.6
Two Rock Passage	3.5	106.7	10.0/8.8 (Approach/Pass)	7.9

2.5 ENVIRONMENTAL BACKGROUND

Waters surrounding and within the bays and harbours of Bermuda support a unique marine ecological environment. The two principal ecological communities are coral reefs and seagrasses. Bermuda is renowned for is spectacular coral reefs but despite their vast expanse throughout the near shore waters of Bermuda, corals and the habitats that they support are considered delicate and potentially threatened due to natural and man-made factors. Similarly, seagrasses support a diverse population of fish and other organisms but are threatened by enhanced nutrients, chemical pollutants, and physical damage by dredging and boat propellers.

The Department of Environmental Protection recognized the significant resources provided by the local marine environment and in 2005 published a "White Paper" (Policy Paper) entitled "The Marine Environment and the Fishing Industry in Bermuda". The document recognized that sedimentation caused by cruise ship propeller wash (along with other natural and mechanically generated sedimentation) can be destructive to marine ecological communities. The discharge of ballast water from vessels can introduce invasive marine species and that severe damage can be caused by ship groundings on coral reefs. In addition, while dredging activities have been used throughout local waterways in maintaining shipping channels and harbours, the White Paper establishes Government's policy going forward to critically evaluate the environmental impacts associated with dredging.

2.5.1 Environmental Concerns with Channel Modifications

Modifications to the shipping channels have been discussed for several years, with ongoing dialogue between various departments in the government and private environmental trusts and foundations. Dialogue have centered on impacts to environment as defined by

government regulations and interpreted by government and private environmental entities.

Development projects such as improvements to the shipping channels must adhere to several government regulations. The Development and Planning Act of 1974 (revised 1989) and the Bermuda Plan 2008 are legislative instruments that are applicable to the terrestrial areas of the Island, while those marine developments designated as those areas below the point of mean high water include foreshore alterations and dredging fall under various legislation and policies governing environmental protection such as the Coral Reef Preserves Act 1966, Fisheries Protected species Act (1978), the White Paper on the Marine Environment and the Fishing Industry (2005) and others.

Key to any development are zoning terms that highlight important environmental issues. For example, *Conservation Base Zones* designate important nature reserves, parklands, coastal areas, open space and woodland areas, and recreational fields for their ecological conservation and environmental, visual and amenity value. Many of these conservation zones are protected as designated areas in accordance with the Development and Planning Act 1974. Within most of the Conservation Base Zones, development or alteration of the landscape is strictly controlled. These controls are designed to protect and conserve areas and features of biological, ecological, geological or scientific significance. This might include terrestrial areas such as mangroves, marshlands, bird sanctuaries, cave and rock formations, islands and other wildlife habitats and marine area which encompass corals and seagrasses.

Department of Conservation Services (DCS) has been one of the primary government agencies participating in this dialogue as a result of their extensive environmental monitoring programs. During the early stages of the study, interviews were held with several DCS investigators. As plans to modify the local shipping channels were only conceptual at this point in the study, discussions were of a general nature; the issue of channel widening and dredging was raised and a variety of potential ecological concerns and issues were discussed.

The general consensus amongst investigators was that ecological impacts on the Bermuda marine environment resulting from channel modifications are a considerable concern. While there are a variety of ecological communities that are likely to be impacted, coral and seagrass communities are probably the most threatened.

2.5.2 Corals

Corals are divided into two major groups. Hard corals for which there are 21 local species, and soft corals, for which there are 17 local species. Corals survive in a highly competitive environment. They are

for the most part warm water animals and thrive in a very narrow temperature band of 20° - 28° C and clear and well sunlight waters. Temperature fluctuations outside this range place a great deal of stress on coral habitats and are believed responsible for a number of coral diseases such as coral bleaching. Bermuda, a subtropical island with winter minimum temperatures dipping as low as 18° C, is only able to support its coral community because of its proximity to the Gulf Stream.

The Government, through DCS, has conducted marine ecological surveys of hard corals, soft corals and seagrass communities together with a comprehensive water quality monitoring program throughout the nearshore waters of Bermuda for many years. Figure 2-5 and Figure 2-6 show the extensive coral coverage in the nearshore waters.

2.5.3 Seagrasses

Four (4) species of seagrass populate the shallow coastal waters of Bermuda; Thalassia testudium (turtle grass), Syringodium jiliforme (manatee grass) the uncommon Halodule bermudensis (shoal grass) and the rare Halophila decipiens. Thalassia is most common and is generally found in coastal and reefal sand channels while Syringodium can be found in shallow protected inshore waters. Seagrass coverage is shown in Figure 2-7.

Seagrasses provide shelter, an important food source, and act as a nursery for juvenile fish. They are also the primary developmental habitat for species such as lobster, conch and green turtles. The sediments provide home to polychaetes, bivalves, crustaceans and gastropods. Seagrass meadows, both near shore and off shore, change over time in their spatial extent. Some of the declines have been linked to both natural and anthropogenic impacts.

2.5.4 St. George's Harbour and Town Cut

Town Cut passes through an extensive line of previously dredged coral fringing reef just outside of the Cut and then on through the narrowest section. St. George's Harbour is marked by shallow sandy and muddy benthos to the north and south of the navigation channel, with sparse coral communities and a fairly extensive expanse of seagrass beds.

Marine ecological surveys conducted by DCS in the area are available, though limited in spatial extent. Area surveys suggest minimal hard and soft coral coverage, and less than 5% coverage of seagrasses. More general and visual observations, however, suggest that areas such as that just outside the Town Cut to the east may display more extensive hard and soft coral coverage while areas of St. George's Harbour may display greater seagrass coverage.

At present no terrestrial survey data is available for Horseshoe and Higgs or Hen islands. However, these islands are currently under the protection of the National Parks Act. This Act recognizes the importance of issues such as open spaces for recreation and various ecological amenities which include their coastal significance and that they may provide habitat for various birds and very possibly the endemic Bermuda skink.

Figure 2-5: Soft Coral Coverage for Waters of Bermuda
Source: Department of Conservation Services

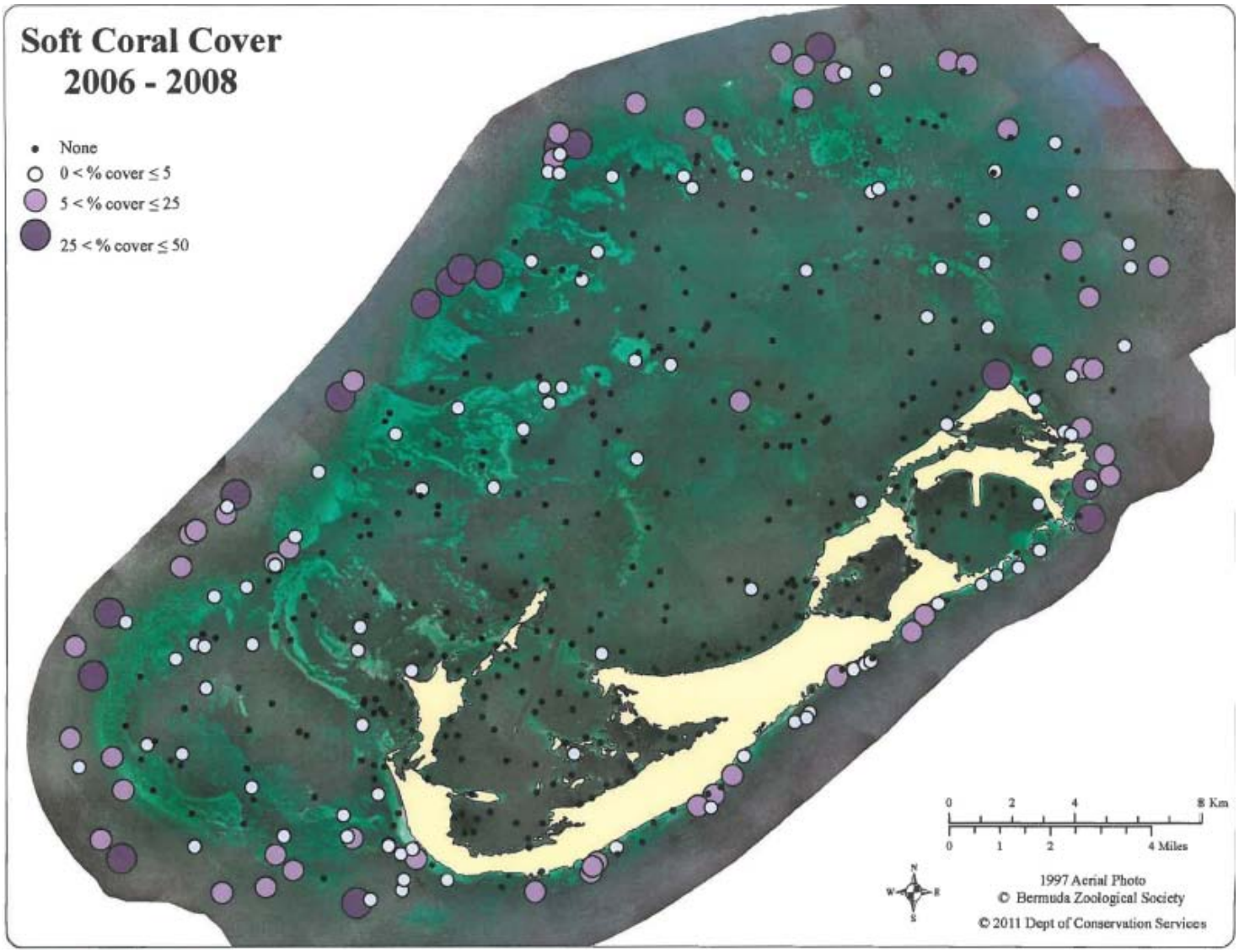


Figure 2-6: Hard Coral Coverage for Waters of Bermuda
Source: Department of Conservation Services

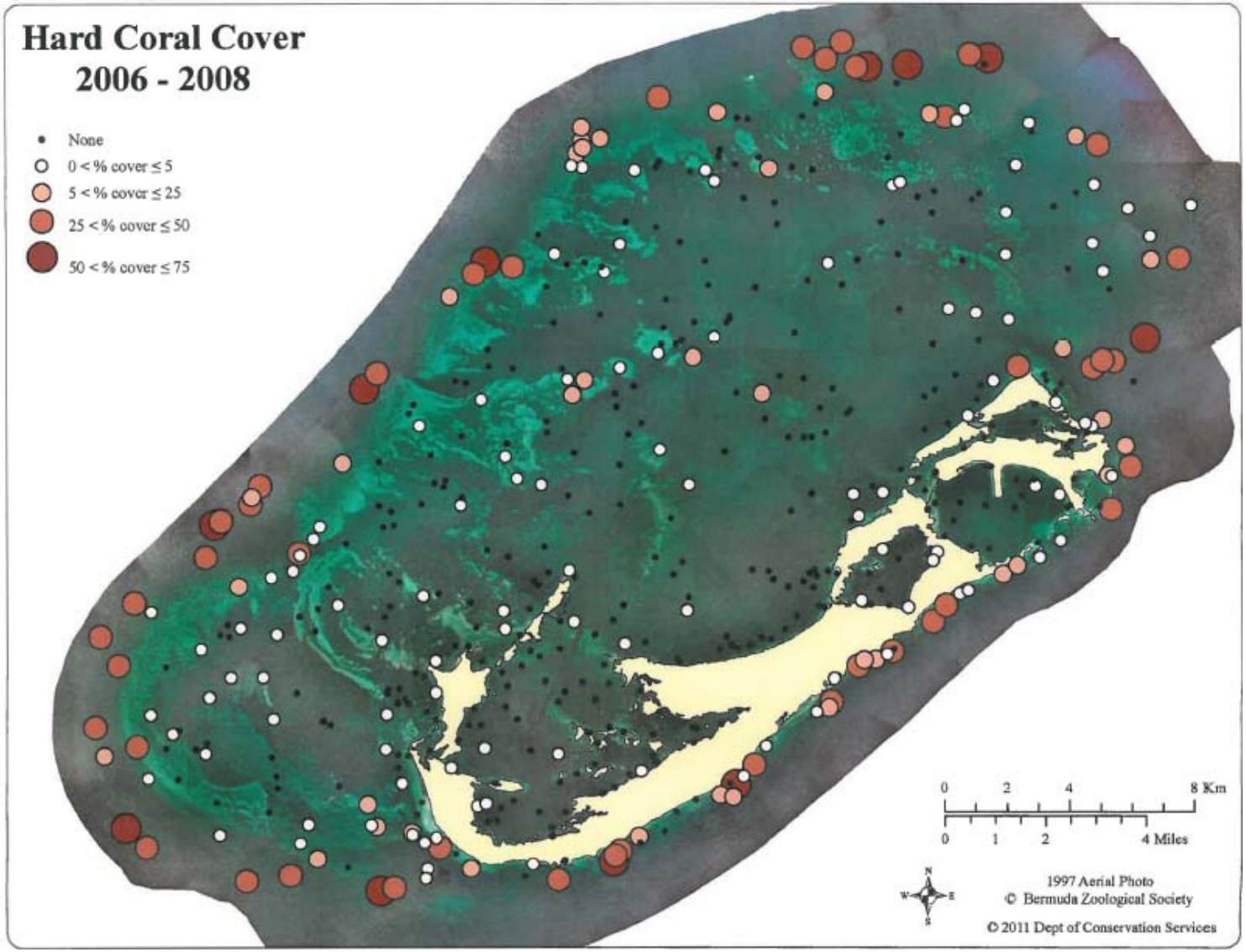
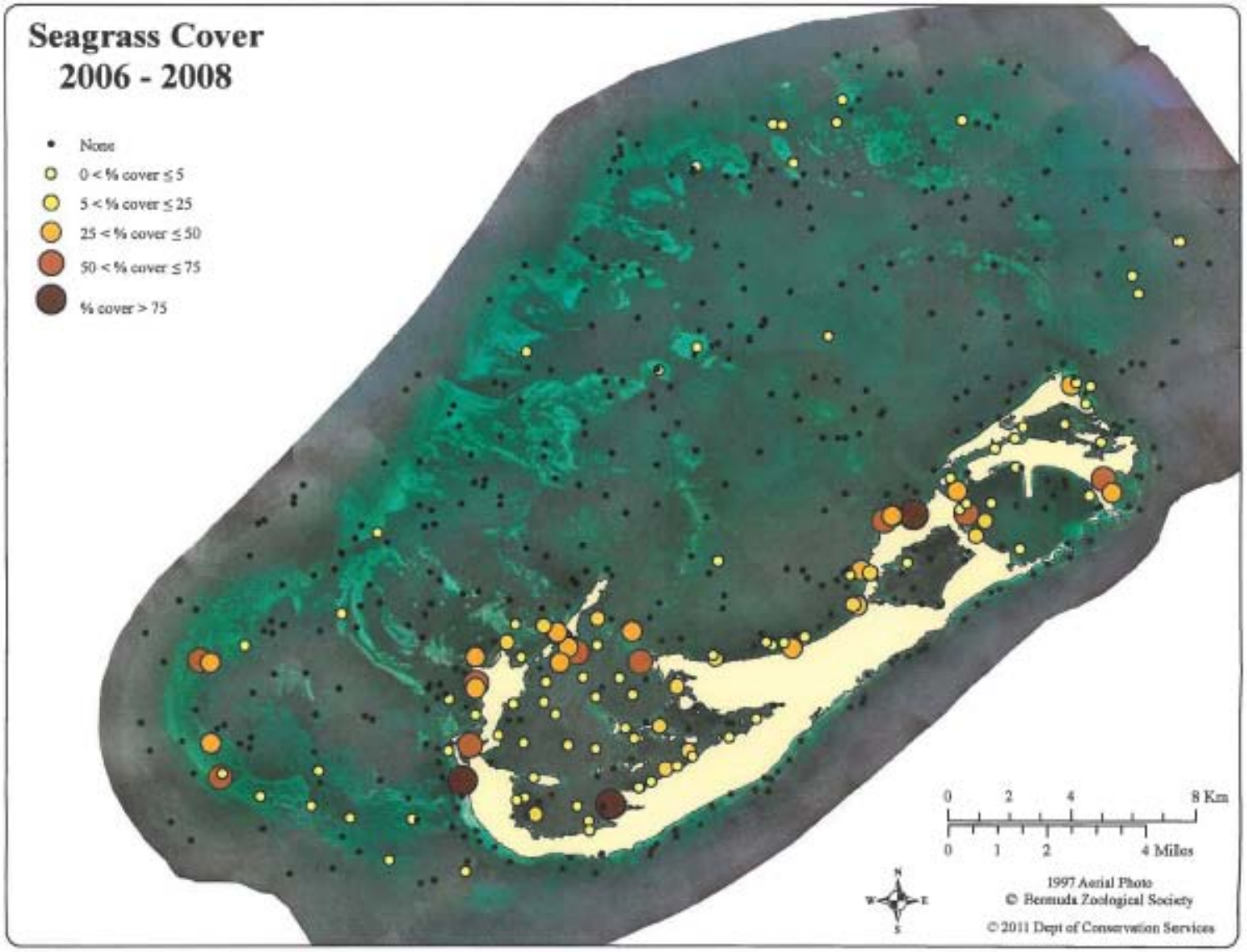


Figure 2-7: Seagrass Coverage for Waters of Bermuda
Source: Department of Conservation Services



2.5.5 North and South Channels including "The Narrows"

The North and South Channels are renowned for its splendid coral reefs and reef communities. The nearshore side of the South Channel has extensive seagrass beds coverage. The area between the North and South Channels and north of the North Channel is known as the North Lagoon. The North Lagoon contains the most pristine and extensive Bermuda coral and seagrass systems. A significant portion of the lagoon has been designated a coral reef preserve. Both the North and South channels have been affected by suspended sediment caused by the passage of large commercial vessels and cruise ships.

2.5.6 Two Rock Passage

DCS marine surveys in Two Rock Passage suggest little if any hard and soft coral and less than 5% seagrass coverage. While specific data is not readily available in Hamilton Harbour in the area defined by the turning basin, the marine ecology is categorized as highly disturbed and in poor condition due to the repeated suspension of bottom sediments as a result of ship movements. Benthic communities on the southern coastline of Hamilton Harbour are considered stressed.

Lefroy Island is two thirds covered with vegetation trees and scrub grasses and is a bird sanctuary. This coastal island, with rocky shoreline also provides habitat for the endemic Bermuda Skink.

2.6 METEOROLOGICAL AND OCEANOGRAPHIC BACKGROUND

2.6.1 St. George's Harbour and Town Cut

Wind

Wind records obtained from the Bermuda International Airport on St. David's Island were analyzed for a time period of 2000 to 2010 to establish prevailing conditions in the immediate area. Winds predominantly blow from the southwest (180 – 260 degrees) with a mean wind speed of approximately 12 knots as shown in Figure 2-8. Cumulative analysis revealed wind speeds below 15 knots occurring on over 75 percent of the record and wind speeds under 20 knots occurring on over 90 percent of the record as shown in Figure 2-9. Winds occurring during the peak cruise season months of April through September share these characteristics.

Figure 2-8: Wind Rose based on Wind Measurements at Bermuda Airport

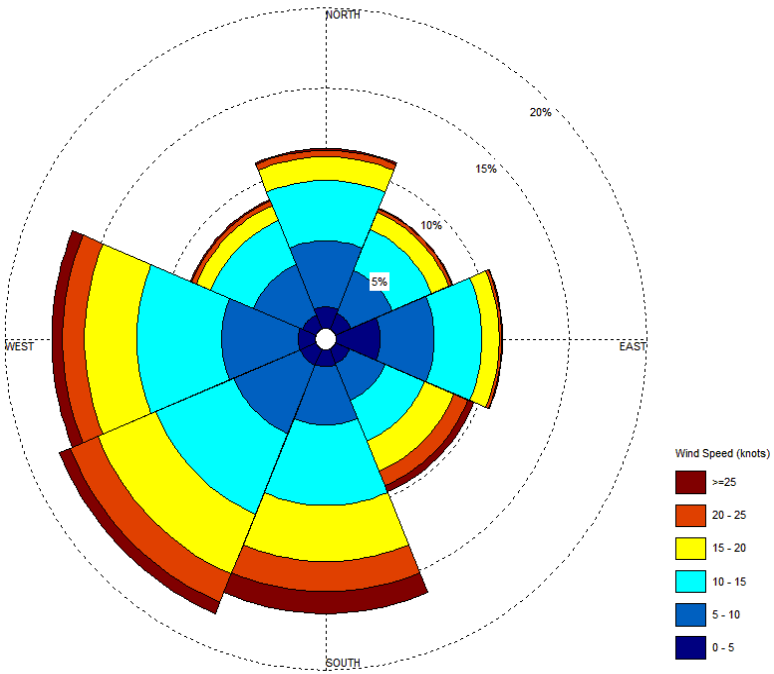
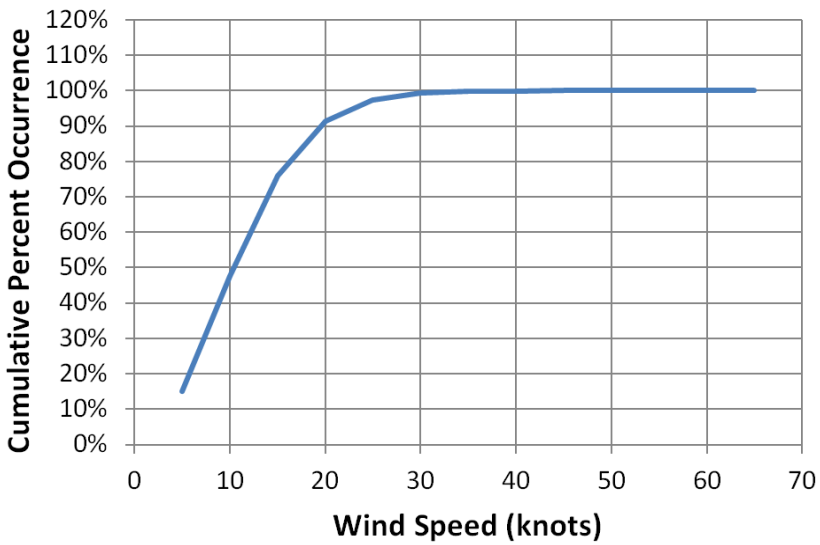


Figure 2-9: Cumulative Wind Speed

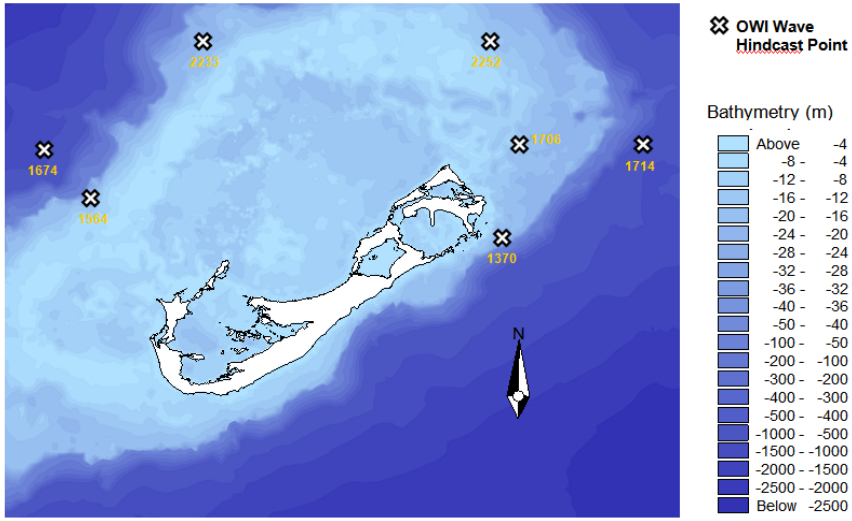


Waves

Measured wave conditions around Bermuda are not readily available for analysis. Nearshore and local wave modeling using offshore oceanographic hindcast data developed by OceanWeather Inc. (OWI) was used to simulate and analyze wave conditions in and around the Bermuda archipelago. OWI's Global Re-analysis of Ocean Waves (GROW) database simulates waves of seas and swells based on model bathymetry, record wind data in the model domain, tidal events, and wave driven hydrodynamics. Results from the Fine Atlantic Basin (GROW-FAB) model provided simulated wave and wind climate characteristics on a high spatial resolution model that has been validated against recorded and satellite data.

A continuous hourly wind and wave climate record was provided for an offshore, deep water hindcast location for a period of 1955 to 2011. Additionally, continuous hourly data for the year of 1995 and 21 unique storm events were included for 6 other offshore locations. The offshore wave hindcast point locations are presented in Figure 2-10.

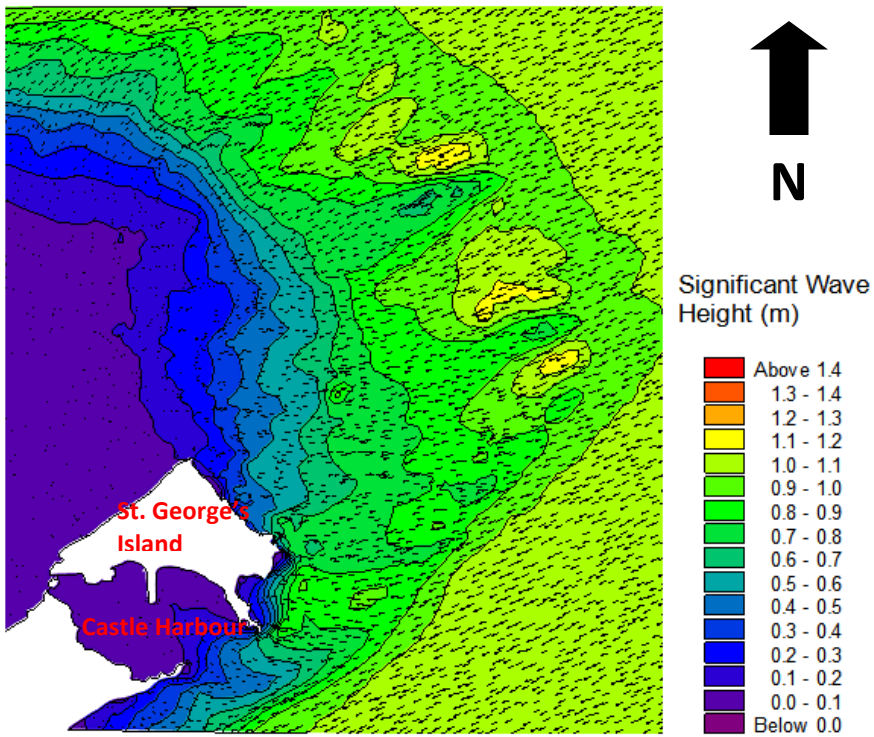
Figure 2-10: Offshore Wave Hindcast Points and Offshore Bathymetry



Two levels of wave models were developed for near shore wave analysis: a regional model was used to propagate wave conditions from the offshore locations to a position closer to St. George's Harbour. Conditions generated from the regional model were then used in a local wave model to study the detailed wave propagation and interaction inside and around the harbour.

Regional wave modeling, utilizing the Danish Hydraulic Institute's (DHI) finite mesh spectral wave model, calculated wave properties of waves propagating from deep offshore conditions to the project area. Wave and wind data from selected GROW-FAB stations were used to define wave conditions along this model's boundaries. Considerations for non-linear wave energy transfer and wave breaking were included in these models. Bathymetry for the spectral model is displayed in Figure 2-10.

Figure 2-11: Example of Wave Results from Regional Wave Model



An example of spectral wave output is presented in Figure 2-11 for the areas around St. George's Island. Local wave propagation and interactions were evaluated using DHI's Boussinesq wave model. This model provides very refined results for small scale analysis of short

and long period waves in ports, harbours and coastal areas. This model incorporates detailed analysis of wave reflection, diffraction, refraction, non-linear wave interactions, and interactions with structures (reflection and transmission) over complex bathymetries. Figure 2-12 shows the existing boundaries and bathymetry used for the local wave modeling. Complete wave reflection was assumed at the land boundaries inside of the Harbour. Model forcing for these simulations were extracted from the regional model at the boundary line between the two models.

Calibration of the regional model was performed to allow proper wave transformation across the complex model domain. The regional mode was forced with a time series of wind and wave conditions at stations 1674, 8077, 2252, and 1714. Results from these simulations analyzed by comparing the time series results extracted from all of the station locations with the data provided by OWI. Figure 2-13 displays an example of this analysis for the hindcast point 1706. Comparisons of the results show good agreement between simulated results and the time series provided by OWI. Differences between the modeled and provided data can be attributed to OWI's lack of coral and shallow water bathymetry and the effects of these conditions on wave propagation in their model.

With the regional model calibrated, the wave conditions were computed, on a unit wave height basis, for 24 directional bins (15 degree increments) and 23 frequency (related to wave period) bins. The combination of direction and frequency resulted in wave spectra for any location within model domain over the 55-year time period. The developed wave spectra included prevailing and storm events.

Figure 2-12: Model Boundary and Bathymetry of Local Wave Model

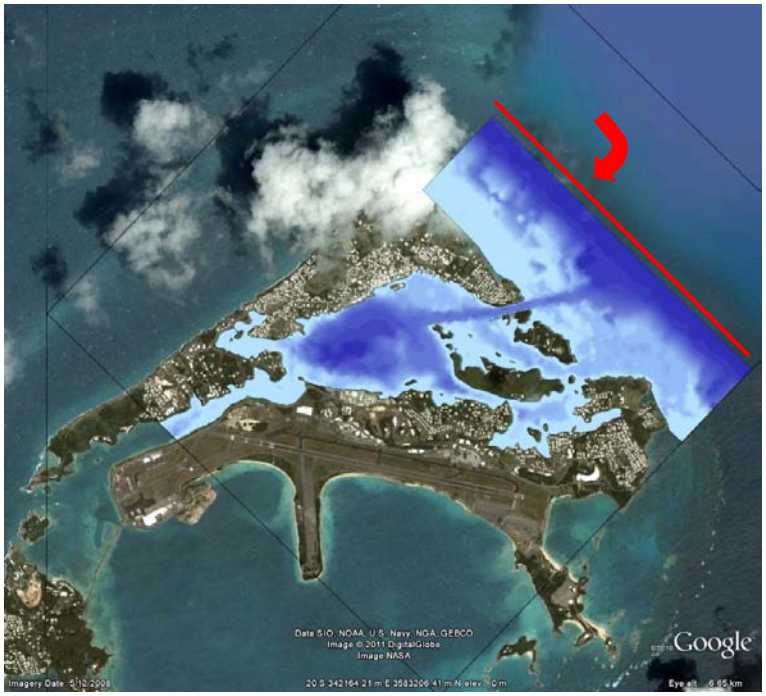
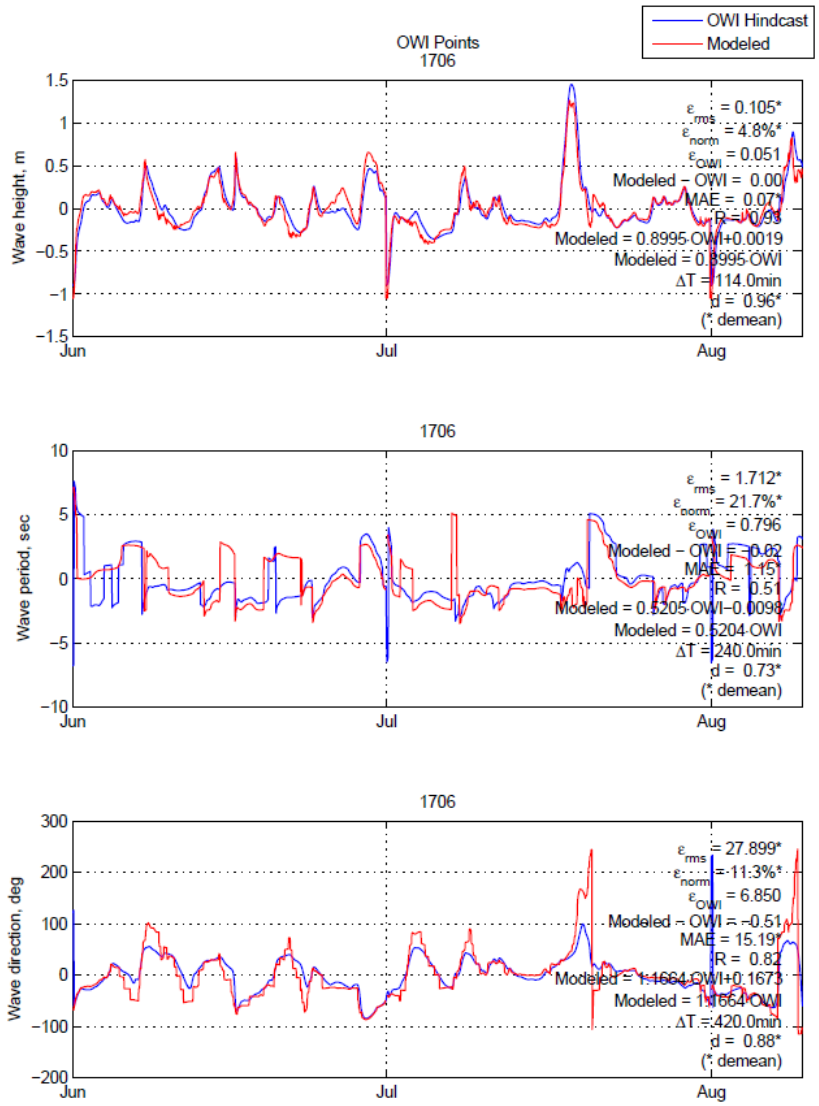


Figure 2-13: Model Calibrations for Regional Wave Model



To determine wave characteristics for specific return periods, significant wave heights from the 55-year continuous hindcast record were subjected to a point over threshold analysis and then mapped to Fisher-Tippett (Type I and II) and Weibull extreme distribution functions of varying shape parameters. Storm events corresponding to particular return periods could then be predicted based on the appropriate function mapping.

Using these return period wave heights and their related characteristics, wave properties for various return periods could be approximated at other locations within the wave modeling domain using the wave spectra generated from the regional nearshore wave modeling. Wave characteristics at the local wave model boundary were extracted from the regional model and used to generate wave spectra for prevailing conditions as well as wave climates associated with 25 and 50-year storm events.

Most spectra around the islands show a predominant wave direction coming from the north, northwest and southern quadrants. Locations farther offshore of the Island typically experienced waves with mean periods of 10 seconds. Areas closer to the Island show much flatter spectra as waves will experience significant transformations when propagating over shallow fringing reefs and tend to display some cross-spectral transfer of energy.

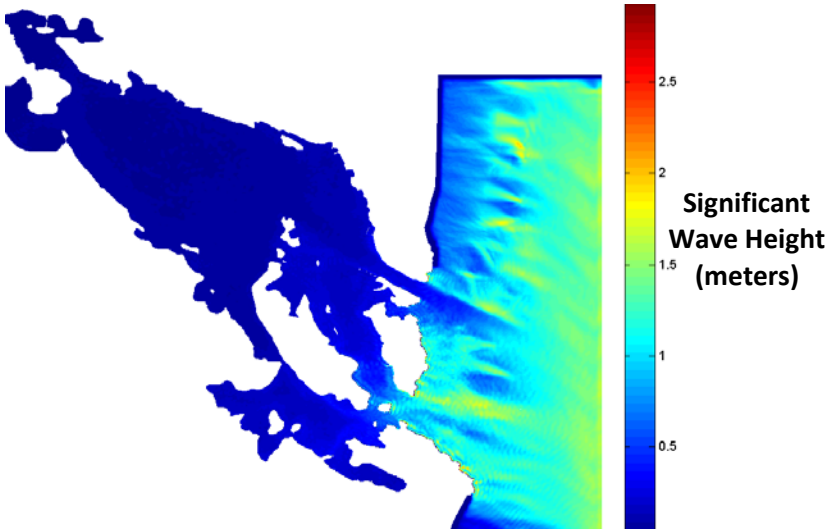
Wave conditions corresponding to the prevailing, 25-year storm and 50-year storm conditions were generated using spectral results and then simulated in the local wave model to measure wave conditions in Town Cut and St George's Harbour. Waves were assumed to travel in the direction of the Town Cut to encourage energy propagation into the harbour.

Local wave simulations revealed significant energy dissipation occurring in the Town Cut attributable to the abrupt depth transition between the channel and the neighboring coral shallows as shown in Figure 2-11. More wave energy appears to advance through St. George's Channel than the Town Cut due to the smaller bathymetric gradient in that area.

Figure 2-14 presents the results of the local wave model forced with prevailing wave conditions corresponding to the predominant wave heights and periods traveling in the direction of Town Cut. Wave heights of 1.5m predicated offshore of Town Cut was less than 0.5m inside the Town Cut and Saint George's Harbour.

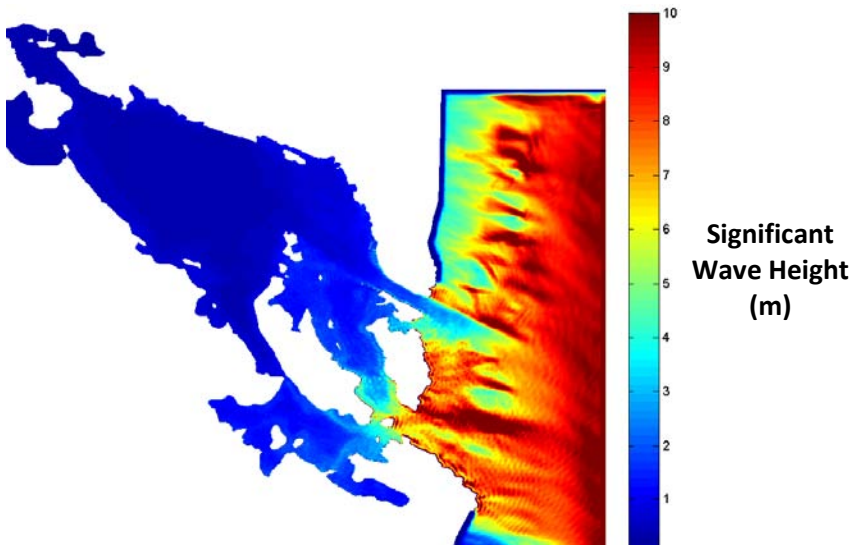
Local wave modeling results for the 50-year storm event is illustrated in Figure 2-15. Waves propagating towards the Harbour from the Five Fathom Hole region may exceed 10m in height but the coral reefs and abrupt changes in bathymetry show waves heights are less than 1m in the Harbour.

Figure 2-14: Significant Wave Heights for Prevailing Conditions



Note that some higher wave heights during the 50-year storm event are evident along east shorelines of Paget, Smith's, and St. David's Islands. These higher wave heights are influenced by the reflective shoreline condition defined in the wave model. In addition, some wave energy is expected to dissipate along the edges of the Town Cut resulting in a reduction of wave heights within the channel and Harbour

Figure 2-15: Significant Wave Heights during 50-year Storm Event



Water Levels

Tides in Bermuda can be considered small relative to other areas around the globe due to the lack of bathymetric effects that usually act to enhance the magnitude of the tide. For example, tidal elevations published by the Government of Bermuda show only a 0.78m difference between mean high water and mean low water stages. Table 2-5 provides the published tidal elevations for Bermuda.

Table 2-5: Tidal Datum Relationship

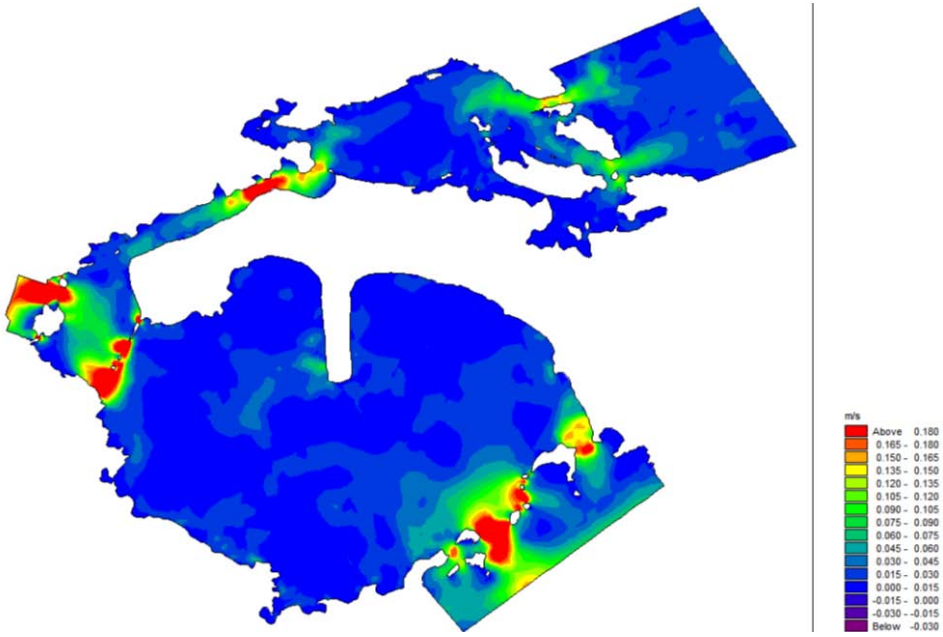
Parameter	Water Level, m CD
Highest Astronomical Tide (HAT)	1.40
Mean Higher High Water (MHHW)	1.17
Mean High Water (MHW)	1.10
Mean Sea Level (MSL)	0.71
Mean Low Water (MLW)	0.32
Mean Lower Low Water (MLLW)	0.29
Lowest Astronomical Tide (LAT)	0.10
Chart Datum (CD)	0.00

Comprehensive analysis of the navigation maneuvers through Town Cut required an understanding of the ambient hydrodynamic behavior in St. George's Harbour and Town Cut. To evaluate these conditions, a two dimensional depth averaged hydrodynamic model of the St. George's and Castle Harbours was developed and run through a complete spring-neap tidal cycle. Boundary locations were determined east of Town Cut, west of Ferry Reach and at the Atlantic Ocean entrance to Castle Harbour. The water levels applied at these boundaries were developed from tidal constituents at the Esso Pier, Whalebone Bay, and Nonsuch Island, respectively. These constituents were identified in a hydrodynamic study of Castle Harbour and Grotto Bay (Applied Coastal Research and Engineering, 2008).

Current speeds extracted from the model show average tidal flows through the Town Cut around 12 centimeters per second (cm/s) and maximums near 20 cm/s.

Local pilots acknowledged that certain environmental processes may accelerate the flow to higher velocities. Therefore current speeds used to evaluate access improvements discussed in Section 4.0 would be modeled at 26 cm/s through Two Cut as shown in Figure 2-16.

Figure 2-16: Tidal Current Velocities from Hydrodynamic Model



Storm Surge

Bermuda's isolation as a seamount surrounded by uninterrupted ocean provides little sheltering from storm and hurricane effects. Though the surrounding ring of coral reef provides some protection from the large seas generated by tropical storms and hurricanes, storm surges related to these events has allowed larger waves to propagate over reefs, resulting in coastal flooding.

In 2003, Hurricane Fabian passed approximately 80km to the west of the islands with a recorded 10-minute average wind speed of 55 meters per second (m/s) and generated wave heights upwards of 10m with a storm surged reported approaching 3m. The storm claimed the lives of 4 individuals on the islands and caused damages estimated at US$300 million.

Apart from limited photographic and anecdotal evidence, no accurate measurements of the storm surge associated with Hurricane Fabian are available for review. However, the storm surge effects related to modifications of the main channels were evaluated. A storm surge model using DHI's finite mesh spectral wave model coupled with the finite mesh hydrodynamic flow model was able to produce wind and wave radiation stress induced storm surges that could be calibrated to available subjective measurements. Due to the circumstantial calibration basis of these models, storm surge effects created by any

modifications to the channels would be evaluated in terms of comparative change relative to the baseline storm surge model.

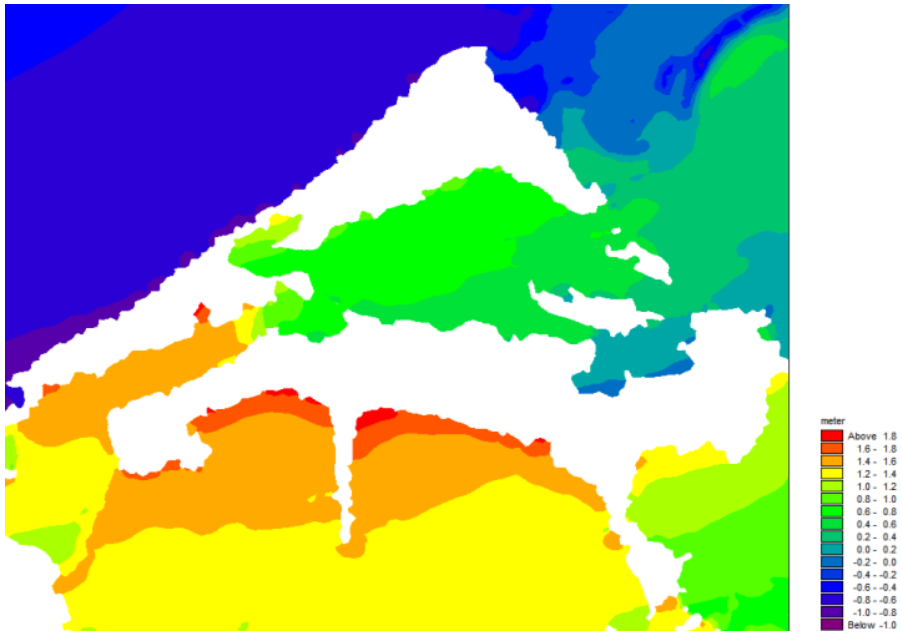
Data related to storm tracks, wind speed, radius of maximum wind speed, central pressure and neutral pressure for Hurricane Fabian was obtained from the US National Weather Service's National Hurricane Center. This information was used to generate wind velocity and pressure fields for Hurricane Fabian.

The storm characteristics for Hurricane Fabian were also used to evaluate the storm surge impacts associated with the hurricane passing to the east of the islands. Hurricanes passing to the east of Bermuda occur less often, but can be shown to produce amplified storm surge effects in St. George's Harbour and surrounding areas.

Mutual interaction between wind generated waves and wind driven set up was simulated using the dynamic coupling in the storm surge model. Topography rendered from GIS surveys provided by the Ministry of Lands, Buildings, and Surveys was incorporated with the model bathymetry in an effort to determine the extent of surge related flooding during a hurricane event similar to Fabian.

Model results show that hurricanes with paths on the west side of the Island tend to push water along the south side of the Island, with higher storm surge elevations evident in Castle Harbour as shown in Figure 2-17. Storm surge elevations reached +1.1m CD at St. George's with wave heights of approximately 1m. If the hurricane track passed to the east of the Island, storm surge was pushed through Town Cut into St. George's Harbour. The maximum surge elevations were higher than the west hurricane track, approaching +1.15m CD at St. George's and +1.25m CD at St. David's Islands. The coinciding wave heights of 1m were predicted at these two locations.

Figure 2-17: Storm Surge Elevations – Hurricane Fabian Approaching from West



Flood maps, which include the effects of storm surge and waves, were developed to illustrate the areas of St. George's and St. George's Harbour that are subject to coastal flooding as shown in Figure 2-18. As seen in Figure 2-18, the areas along the waterfront in the Corporation of St. George's, including Ordnance Island and a portion of Pinno's Wharf, are inundated during a hurricane similar to Hurricane Fabian.

2.6.2 Dundonald Channel, Two Rock Passage, and Hamilton Harbour

Wind

Wind records recorded at the Bermuda International Airport were used in the analysis of these two channels and ports. The wind rose in Figure 2-8 shows a predominant wind direction coming from the south east quadrant. Dundonald Channel and the approaches to Two Rock Passage are exposed to the dominant wind direction. Hamilton Harbour does receive some wind sheltering from the raised topography surrounding the harbour.

Waves

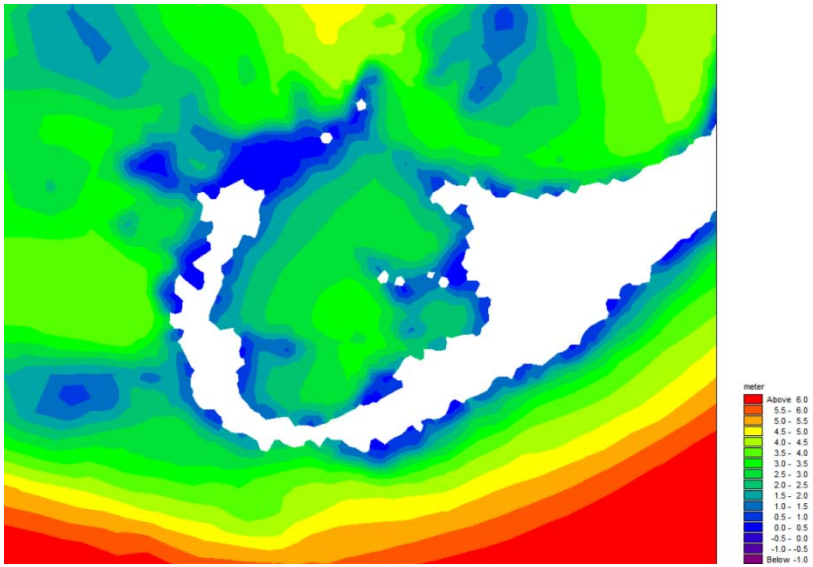
Most of Two Rocks Passage and Hamilton Harbour are sheltered from waves due to their location within Great Sound. The coral reefs around Bermuda attenuate a majority of the incoming wave energy from the Atlantic Ocean. Wave energy that penetrates this natural barrier would only reach Hamilton area after incurring dissipation from wave diffraction and shoaling in and around the Great Sound.

Maximum fetch lengths around the Great Sound shorelines average less than 6km. Wind speeds of 30 m/s (occurring only 1 percent of the time) sustained for an hour blowing over these fetch conditions may generate wind waves up to 1m in height. However, little if any energy would penetrate the chain of islands running south from Spanish Point protecting Hamilton Harbour.

Wind generated wave growth into and across Great Sound during hurricane conditions may be severe. Wave heights measurements in Great Sound are not available but the wave model predicts significant wave heights up to 3m as shown in Figure 2-19 in the north region of the Great Sound. Local wave modeling of the Hamilton Harbour was not conducted for this study. However, Hamilton Harbour was documented as a safe haven for ships during Hurricane Fabian, through there was reported damage to seawalls in and around Hamilton.

Figure 2-18: Areas of Coastal Flooding in St. George's Associated with Hurricane Fabian (West Approach)

Figure 2-19: Significant Wave Heights in Great Sound

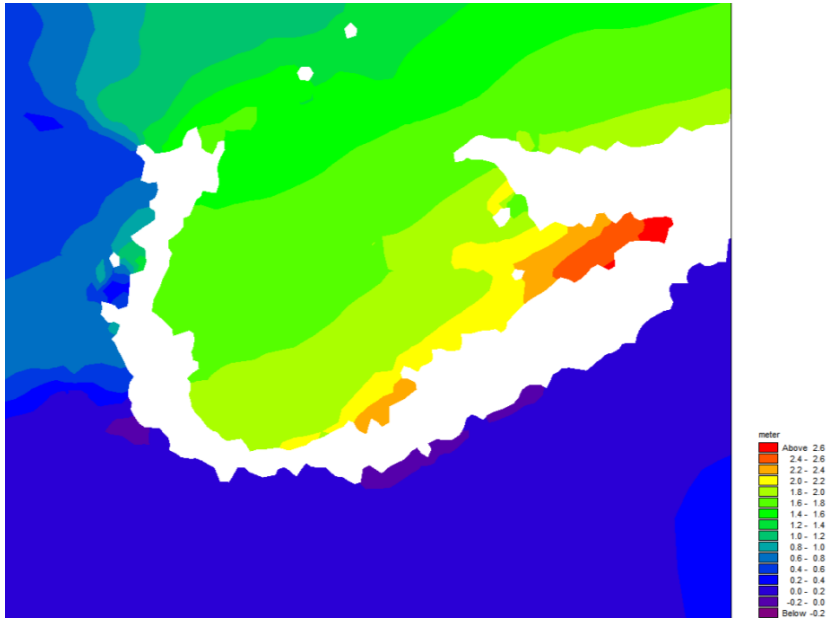


Water Levels and Storm Surge

Similar to St. George's Harbour, water levels and currents associated with the tide in Hamilton Harbour can be considered small. More concern rests with water setup associated with storm events that would affect current waterside structures or future modifications to harbour bathymetry.

In the storm surge model previously discussed, simulation results under conditions identical to Hurricane Fabian produced a set down of water (lowering of water elevations) in the Great Sound and Hamilton Harbour. However, storm surge elevation increased if the hurricane storm track was to the east of Bermuda. Storm surge elevations of approximately +2.5m CD were predicted in the approaches to Hamilton as shown in Figure 2-20.

Figure 2-20: Storm Surge Elevations – Hurricane Fabian Approach from East



2.7 GEOTECHNICAL CONSIDERATIONS

2.7.1 Available Information

Available published geological and geotechnical information on the general geology of Bermuda was collected and reviewed as part of the study, including:

- "An Explanation of the Geology of Bermuda", Bermuda Government, Ministry of Environment, M. P. Rowe, 1998;
- "The Geological Map of Bermuda", Bermuda Government, Ministry of Works and Engineering, H. L. Vacher, M. P. Rowe, P. Garrett, 1989;
- "Geology of the Bermuda Seamount", F. Augmento, B. M. Gunn, 1974;
- Colour aerial photomosaic of the land mass and the adjoining ocean areas – this did not cover the entire project area to the northwest of the Bermuda;
- Geotechnical Guidance Notes prepared for Ministry of Works and Engineering by L.G. Mouchel & Partners Limited, June 1994;
- Report on Preliminary Geotechnical Assessment, New Grotto Bay / Castle Harbour Crossing, Bermuda, prepared for Ministry of Works and Engineering and Housing by Golder Associates Ltd., January 5, 2007; and
- Feasibility Study Draft report to Public Works Department Bermuda on Proposed Training Wall for Town Cut Channel, St. George's, July, 1979.

The information presented in aforementioned studies was used to assess the potential existing geology, stratigraphy and general engineering properties of the geological formations of the study area. No site inspections or investigations were conducted as part of this study.

2.7.2 General Geology

The islands of Bermuda comprise an extensive sequence of sandy aeolian (wind blown) and marine sediments of coralline (calcium carbonate) origin overlying volcanic rock that comprises the Bermuda Seamount. The aeolian and marine sediments were deposited under varying sea levels which are inferred to range from as much as 100 m below to 5 m above present sea level. Evidence of previous lower sea levels is present offshore in the form of organic materials, such as old trees and tree stumps, as well erosional features such as former beach lines and cliffs.

Very little is currently known about the geology and material properties in offshore areas, except in locations where dredging or other construction has previously been conducted. Subsurface data

or construction information relating to the former channels could not be located. Therefore, the following interpretations are based on observations in onshore areas, with postulation of potential conditions offshore based on the inferred geological regime. Eventually, geotechnical inspection and investigations would be required to characterize the conditions likely to be encountered and to provide information for design and cost estimating.

The nearer-surface sandy aeolian, and sometimes marine, deposits have typically been subjected to widely varying degrees of diagenesis, including cementation and cavity formation due to rainwater percolation and solution processes. The coralline deposits have been observed to range from unconsolidated, uncemented to weakly cemented, granular deposits of sand and gravel to highly cemented and sometimes recrystalised calcareous limestone with variable sized cavities. In general, the older limestone deposits found towards the base of the Pleistocene sequence, such as the Walsingham and Town Hill deposits, are more cemented and massive in nature, and include more cavities; voids and/or cavities are sometimes filled, or partially filled, with sediment. Geological interpretations suggest that the Walsingham Formation is unlikely to be encountered at ground surface in the areas of Town Cut and Two Rock Passage, except perhaps towards the eastern end of Two Rock Passage. The more recent Southampton, Rocky Bay and Belmont formations appear to be more dominant in the Town Cut and Two Rock Passage areas.

Carbonate lagoonal sediments and coral are indicated within the North and South channel areas. Relatively weak silt seabed deposits are reported to have been encountered near Horseshoe Island (at Town Cut) and in Grotto Bay. Fine-grained marine and/or pyroclastic sediments, including silt and clay, are known to exist immediately beneath, or interlayered within, the lower portions of the coralline deposits.

Volcanic rock forming the upper portion of the Bermuda Seamount directly underlies the aforementioned coralline and marine deposits. Available information from a limited number of deep boreholes suggests that the depth to the volcanic rock may vary from about 25 m in the Grotto Bay area to 60 m in Hamilton and as much as 100 m in the Southampton area; an average of 75 m is indicated in the North Lagoon area on the geological map. Available information on the properties of the volcanic rock indicates that it is composed of a complex and highly variable sequence of basaltic lava, pyroclastic and intrusive flows. The volcanic rock likely extends to several thousand metres below the ground surface and/or sea floor, and is known to be variably weathered within the upper regions of the formation, possibly becoming more competent and intact with depth. However,

given its geological origin, the volcanic rock may be highly variable and interlayered with more and less competent materials. Given its depth, the volcanic rock is very unlikely to be encountered during dredging work that may be considered.

2.7.3 Anticipated Geological Conditions at Town Cut

Based on the geological mapping and photographs of outcrops along the shoreline which were provided and assessed, the predominant geological units within the Town Cut area are inferred to be the Belmont, Rocky Bay and Southampton Formations. These typically comprise mostly aeolianite exhibiting the classic steeply-dipping dune foreset beds as well as flatter windward beds. The aeolian materials grade seaward to, or are underlain by, beach and localized marine deposits. Surficial sandy and silty seabed sediments may exist, particularly in areas remote from the higher topographic features.

The Belmont Formation (anticipated at Horseshoe Island and Hen Island) is the lower and typically most competent of these three formations, and is overlain in higher areas and generally towards the northeast by deposits of the Rocky Bay Formation (anticipated at Higgs Island), and Southampton Formations further east. The Rocky Bay Formation comprises lightly cemented aeolianite with localised underlying shelly marine deposits, and the Southampton Formation is generally less cemented.

Although unlikely to be exposed at the shoreline in this area, the Belmont Formation is expected to be underlain by the older Townhill Formation, the Lower Member and the Walsingham Formation. It is emphasized that no data is available on the offshore geology. The best interpretation from observations of onshore geology is that these older units may not be encountered within the likely channel depths. Where observed elsewhere on the island, the Town Hill and Walsingham Formations comprise moderately to highly cemented materials which are often more massive, exhibiting less layering and structure.

Sea level is inferred to have been significantly lower than present levels in the geological past. Consequently, diagenetic effects observed in the older onshore formations (such as cementation and voids), as well as erosional features (such as old beach lines and cliffs) may exist on former land surfaces which are now submerged.

2.7.4 Anticipated Geological Conditions at Two Rock Passage

Based on the geological mapping and photographs of outcrops along the shoreline, the predominant geological units within the Two Rock Passage area are inferred to be the Rocky Bay (including the marine

Devonshire Member) overlying the Town Hill, Lower Member and Walsingham Formations. Surficial sandy and silty seabed sediments may exist, particularly in areas remote from the higher topographic features.

Agar's Island, Mobray Island and Lefroy Island are indicated to comprise Rocky Bay and Devonshire Member aeolianite, which are typically less competent and well bedded materials. Further east, the mapping suggests that the more competent Town Hill and Lower Member formations will be encountered, such as at Point Shares, Marshall Island and Hinson Island. It is also likely that the Walsingham Formation will be encountered towards the base of the channel, particularly in more easterly areas.

2.8 SUMMARY

2.8.1 Channel Characteristics

- Town Cut is a 70m wide channel at an average water depth of -10m CD.
- Three Islands (Higgs, Horseshoe, and Henn) define the south extent of Town Cut Channel.
- A training wall on the south side of Town Cut was constructed to mitigate bank suction effects.
- The North Channel is a 152.5m wide channel at an average water depth of -12.5m CD.
- The South Channel is a 152.5m wide channel at an average water depth of -9.0m CD.
- Dundonald Channel is a 152.5m wide channel at an average water depth of -11.1m CD.
- Two Rock Passage has a minimum channel width of 106.7m as it passes between LeFroy and Mobray Islands at an average water depth of -8.8m CD.

2.8.2 Environmental Characteristics

- Hard and soft coral coverage within Town Cut proper is minimal but coral coverage to the east of the channel has greater coverage. St. George's Harbour has fairly extensive seagrass coverage in shallower regions.
- Hard and soft coral coverage is extensive outside of limits of the North and South Channel.
- Hard and soft coral coverage within Two Rock Passage is minimal.

2.8.3 Meteorological and Oceanographic Characteristics

- Predominate wind direction is from the southwest at mean wind speed of 12 knots.

- Winds speeds under 20 knots occurring on over 90 percent of the recorded wind speeds, with these conditions prevalent between April and September.
- Prevailing (non-storm conditions), wave heights within St. George's Harbour are less than 0.5m.
- Wave heights within St. George's Harbour associated with the 50-year storm event are less than 1m.
- Storm surge elevations exceeded 1m in St. George's/St. George's Harbour during Hurricane Fabian; a hurricane that passed to the west of Bermuda.
- Storm surge elevations are higher within St. George's/ St. George's Harbour when hurricanes pass to the east side of Bermuda.
- Ordnance Island, Kings Square, and Town Hall are inundated when storm surge exceeds 1m CD.

2.8.4 Geotechnical Characteristics

- The predominant geological units within the Town Cut area are inferred to be the Belmont, Rocky Bay and Southampton Formations.
- The Belmont Formation (anticipated at Horseshoe Island and Hen Island) is typically most competent material of the three formations.
- The Rocky Bay Formation (Higgs Island) comprises lightly cemented aeolianite with localized underlying shelly marine deposits.
- The Southampton Formation (St. George's Harbour) is generally less cemented aeolianite.
- Two Rock Passage area are inferred to be the Rocky Bay Formation overlying the Town Hill, Lower Member and Walsingham Formations.
- Agar's Island, Mobray Island and Lefroy Island are indicated to comprise Rocky Bay and Devonshire Member aeolianite, which are typically less competent and well bedded materials.

3 CRUISE MARKET ASSESSMENT

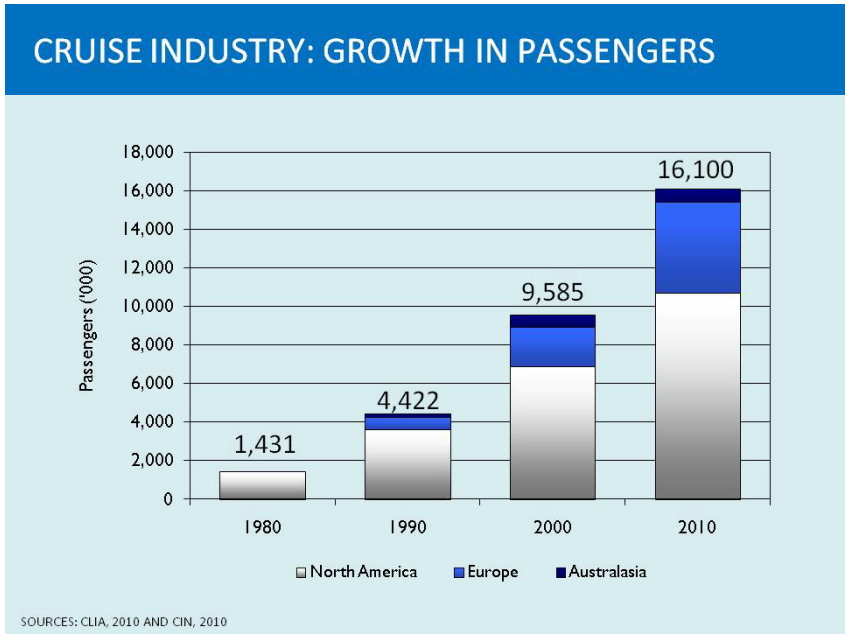
An assessment of the current and future trends in cruise ships size and passenger capacity and how these trends may affect the market in Bermuda is fundamental to the evaluation of access improvements. The outcome of the assessment is to identify potential cruise ship scenarios that will be used as the basis to evaluate port, anchorage, and channel modification alternatives.

3.1 GLOBAL AND REGIONAL CRUISE INDUSTRY CHARACTERISTICS

The modern cruise industry's roots date back to the 1970s, where a combination of factors found traction with travel and leisure enthusiasts. From increased popularity of Transatlantic leisure oriented crossings on Cunard Line's Queen Elizabeth II (versus the transport orientation of previous generations) and North America's enchantment with the original "Love Boat" series to innovative entrepreneurs developing short duration Caribbean holiday cruises for the masses, each element played a role in catapulting the industry into its present day success.

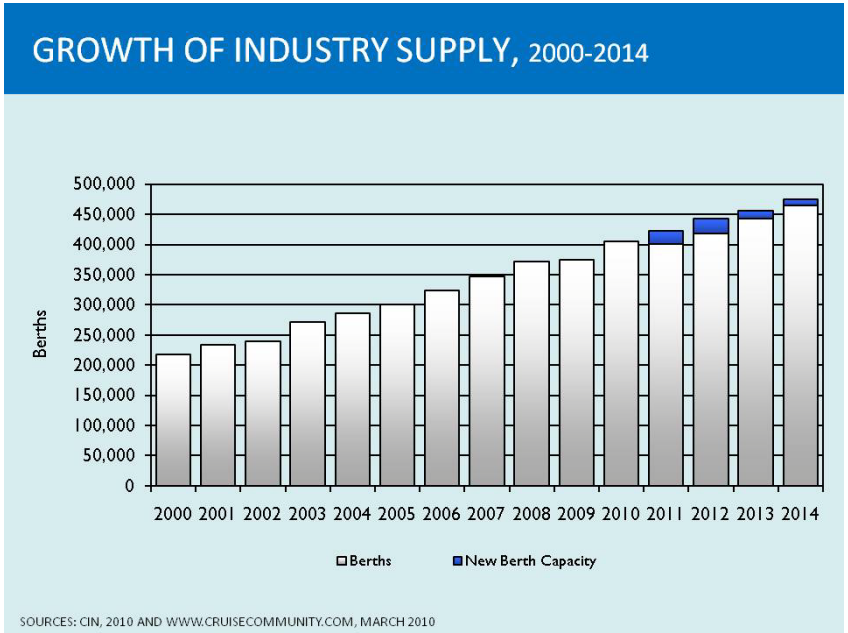
In 1980, over 1.4 million individuals embarked on a conventional cruise; by 2010, this level had increased to over 16.0 million (Figure 3-1). While a majority of these passengers originate from North America, increasing contributions are made by Europe and Australasia.

Figure 3-1: Growth of Cruise Passengers since 1980



Industry supply as measured by vessel berths has also increased significantly, growing from 218,005 berths in 2000 to and estimated 465,000 berths in 2014 as shown in Figure 3-2. A berth is the number of beds on board the vessel.

Figure 3-2: Cruise Ship Capacity



The industry's success over this period is primarily a result of the following:

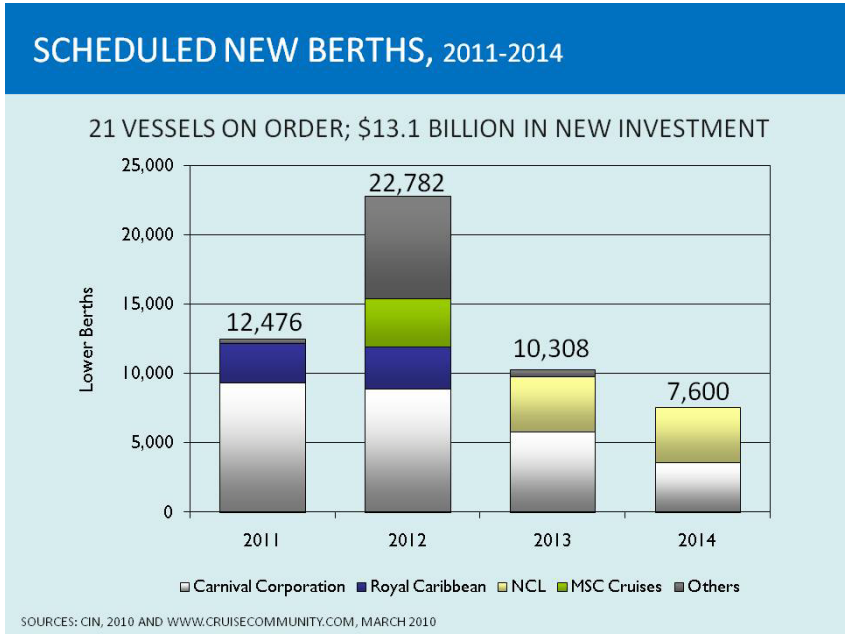
- **Cruise lines were successful in introducing new vessel inventory and developing onboard and landside products that generated sustained interest in cruising.** Discarding smaller ships and older capacity, larger and more lavish vessels furnished with amenities found in the best land-based resorts became the norm in the mid-1990s. Consumers generally met each new vessel launch with enthusiasm, and ultimately, increased passenger bookings. Responding to this demand, cruise lines continue to order new vessels. As of March 2011, 21 new cruise vessels with a total capacity of 53,166 passenger berths are scheduled for delivery through 2014 (Table 3-1). This pattern suggests that the cruise industry is supply-led, with expansion in cruise vessel berth inventories yielding similar positive growth in cruise passenger levels.
- **Cruise lines created products that work to convert land-based resort guests into cruise passengers.** Cruise lines were able to package and mass market an all-inclusive resort package-at-sea that is highly price competitive when compared to similar land-based resort vacations.
- **Cruise industry products consistently deliver a high level of passenger satisfaction.** The Cruise Lines International Association (CLIA), through its annual passenger surveying efforts, has year after year reported the cruise experience consistently exceeds expectations on a wide range of important vacation attributes. On a comparative basis versus other vacation categories, cruising consistently receives top marks. Satisfaction with cruise vacations keeps customers coming back. Cruise lines place considerable emphasis upon passenger retention, as it is easier and less costly

Table 3-1: Cruise Ships on Order Worldwide, March 2011

Source: www.cruisecommunity.com, March 2011

Year	Cruise Line	Ship Name	GRT	Lower Berths	Delivery
2011	AIDA Cruises	AIDAsol			April
	Carnival	Carnival Magic			April
	Costa Cruises	Costa Favolosa			July
	Ponant Cruises	L'Austral			April
	Seabourn	Seabourn Quest			May
	Celebrity Cruises	Celebrity			Autumn
2012	Disney Cruise Line	Disney Fantasy			Spring
	AIDA Cruises	AIDAmar			May
	Costa Cruises	Costa Fascinosa			Winter
	Celebrity Cruises	Celebrity	122,000	3,030	Autumn
	Carnival	Carnival Breeze	130,000	3,690	Spring
	Oceania Cruises	Riviera	65,000	1,260	April
	MSC Cruises	MSC Divina	140,000	3,502	April
	Sea Cloud	Sea Cloud Hussar	Unknown	136	Spring
	GNMTC Libya	Unnamed	139,400	3,478	December
2013	Hapag-Lloyd	Europa 2	39,500	516	Spring
	NCL	Breakaway Class	143,500	4,000	Spring
	AIDA	Unnamed	71,300	2,192	Winter
	Princess Cruises	Unnamed	141,000	3,600	Spring
2014	NCL	Breakaway Class	143,500	4,000	Spring
	Princess Cruises	Unnamed	141,000	3,600	Spring
Total 21 New Cruise Ships and 53,166 Lower Berths representing $13.1 Billion in New Investment					

Figure 3-3: Scheduled New Berths



to keep a current passenger than to market and cultivate new passengers.

- **The cruise industry is adaptable to changing market conditions.** With some degree of ease, cruise lines can shift vessel capacity, itinerary durations, pricing and other components of their offer to adjust to economic, consumer demand, security and other issues. Even the challenging economic conditions of 2009 and 2010—the worst economic crisis since the 1930s—the major cruise lines

have been able to post net profits and take delivery of new vessel inventories.

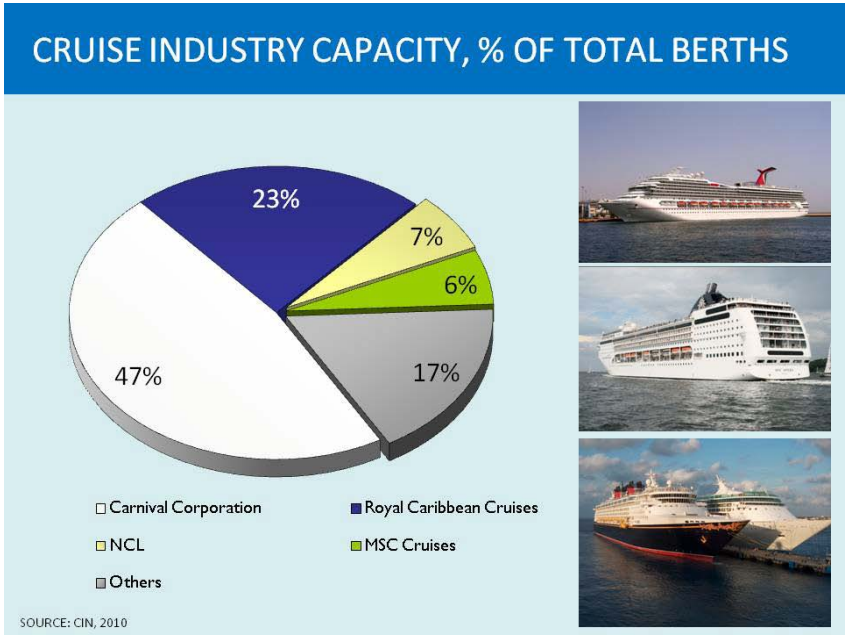
- **Cruise operators have effectively controlled competition, operational costs, and generated revenue streams from several sources beyond net ticket sales.** Innovations in cruise ship design and the move toward larger vessels allowed lines to reap increased economies of scale. Additionally, the majority of cruise industry capacity is held by a handful of cruise conglomerates. This has served to reduce competition by new lines by keeping barriers to entry into the marketplace high; increased leverage on cruise destinations to keep cruise fees low; and, allowed for significant cost-savings resulting from a high degree of vertical integration throughout the cruise onboard and destination delivery cycle.

3.2 THE CASE FOR FUTURE CRUISE INDUSTRY GROWTH

3.2.1 The Industry from 2000 to Present

Since 2000, the cruise industry has had to navigate through a far more challenging business climate than previous decades. The events of September 11 and its aftermath created a period of flux within the industry. Increased financial conservatism by lines, deployment drawback to North American and other home waters and amplified flexibility in deployment were all immediate consequences for many lines; others were forced to close their doors. Lines tightened their belts and industry supply, preferring to seek improved yields on their current fleets.

Figure 3-4: Cruise Industry Capacity



The industry faced further challenges brought on by a combination of war, terrorism concerns, health issues and a relatively weak economic outlook. In particular, the Iraq War (March 2003), terrorism threats and the SARS pandemic in Asia had a dramatic impact on international

travel. Through each of these challenges, the industry adapted and adjusted its flexible business model and found a way to succeed.

Following 2004, the industry welcomed a period of improved prospects. Strong profitability returned for many of the leading lines. Cruise lines also welcomed a number of new vessels, such as Cunard's *Queen Mary 2*, which captured the imagination of cruise enthusiasts and newcomers to the market. Inroads were also made in emerging cruise regions, and more importantly, with consumer groups in Europe, Asia and South America. Lines started shifting capacity to new brands intent on offering tightly focused products tailored to regional tastes and preferences.

Figurative clouds formed on the business horizon in 2007 and early 2008 due to softening in the world economies. Yields in the Caribbean resulted in Carnival and Royal Caribbean moving more vessels into Europe, where North Americans can enjoy their holiday purchased in dollars in the more expensive euro zone. While the weakened dollar has been a positive feature in this instance, it has also made just about everything more expensive for North American cruise lines and their global operations—new vessels from European shipyards, provisioning, global sourcing of passengers and employees, port charges and fuel, to name a few. The high cost of fuel has been a major factor, adding not only increased cost to the cruise but also placing strains on air carriers, thereby making fly/ cruise options more challenging due to limited flights and increasing ticket prices. Terrorism also continues to be a major concern for cruise lines, especially given the high profile of a cruise ship as a potential target.

The clouds turned into a hurricane by late 2008 and through 2009 with the financial meltdown of global markets. The global scale of the recession made for far fewer profitable cruising regions. To fill ships, lines had to greatly reduce ticket prices with the hope of filling vessels and generating revenue from onboard spending and other sources. Still, much like in 2004, the industry shifted away from conservatism and self doubt and did what it does best: Introduce new products that capture the imaginations of guests and tap into underdeveloped markets. The introduction of RCCL's *Oasis of the Seas* and expanded deployments in South America are notable examples.

While the global recession has ebbed in many areas, recovery continues to be slow in North America and some parts of Europe, a circumstance that will undoubtedly impact cruise lines well into 2011. Surging fuel prices and unrest in the Middle East have also emerged as renewed issues that will challenge cruise lines through the spring and summer months.

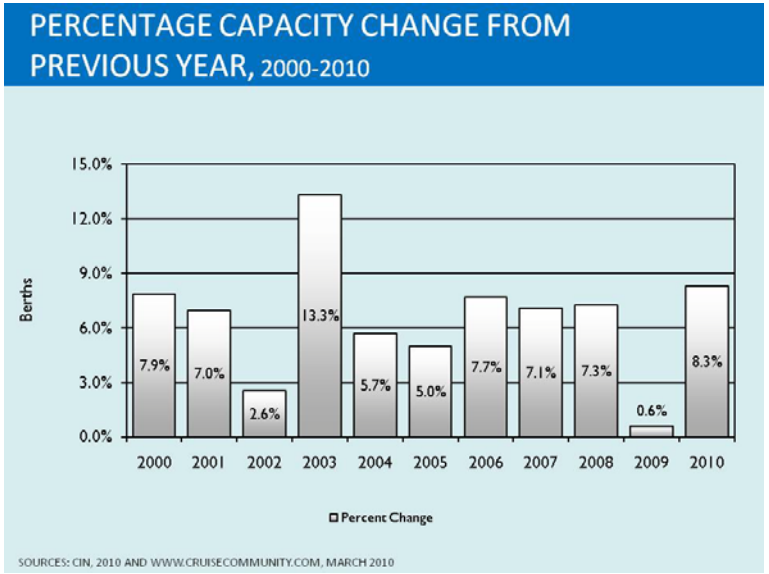
Looking more medium to long term, most lines and experts continue to feel the industry's best days are ahead. The broader industry

fundamentals responsible for its dramatic rise over the past two decades are expected to remain in place and continue to propel the industry forward in terms of passenger and financial expansion. Lines will continue to take delivery of a substantial amount of new capacity over the next four years; nearly 54,000 new cruise ship berths. This capacity increase reflects a trend towards delivery of fewer but larger vessels per annum versus what was observed a decade ago. While year over year growth in industry capacity is not currently forecast to be as robust as the past decade (Figure 3-5), growth is expected to increase by nearly 15% between 2011 and 2014 and then settle to between 2% and 5% in 2015 and beyond.

Measurement of consumer demand and sentiment for the cruise industry remains positive. CLIA's most recent Cruise Market Profile Study indicates 50 million Americans stated intent to cruise within the next three years (Cruise Lines International Association 2010 Cruise Market Overview, 2010). Cruise lines have extend their reach in the global consumer marketplace, bolstering their overall upside potential for growth and reducing somewhat exposure to downturns in the North American market. Cruise lines and their products are as diverse as ever, with many of the largest ships offering cabin categories at 30 to 40 different price points for the same cruise while also allowing for more onboard spending opportunities with bigger stores, spas and other revenue outlets (Cruise Industry News Annual Report 2009: State of the Industry Growth Projections, Cruise Industry News, 2009, New York).

> *"Diversity and range of product will not only fuel growth in existing markets, but will also help build new markets around the world, which in turn may require further product adaptations—whether from Brazilian or Chinese passengers….Therein lies the beauty of the cruise industry. There is literally a cruise for every passenger preference, interest, demographic and psychographic."* (Ibid, p. 424)

Figure 3-5: Change in Berth Capacity



3.2.2 Industry Forecast

From these positive fundamentals and barring some significant unforeseen disaster to the industry, continued expansion is forecasted, both in terms of expected capacity and cruise passenger carryings. From the analysis of the historical record of expansion of global industry capacity and the current cruise vessel order book, three general scenarios of industry growth are forecast through to 2025[1].

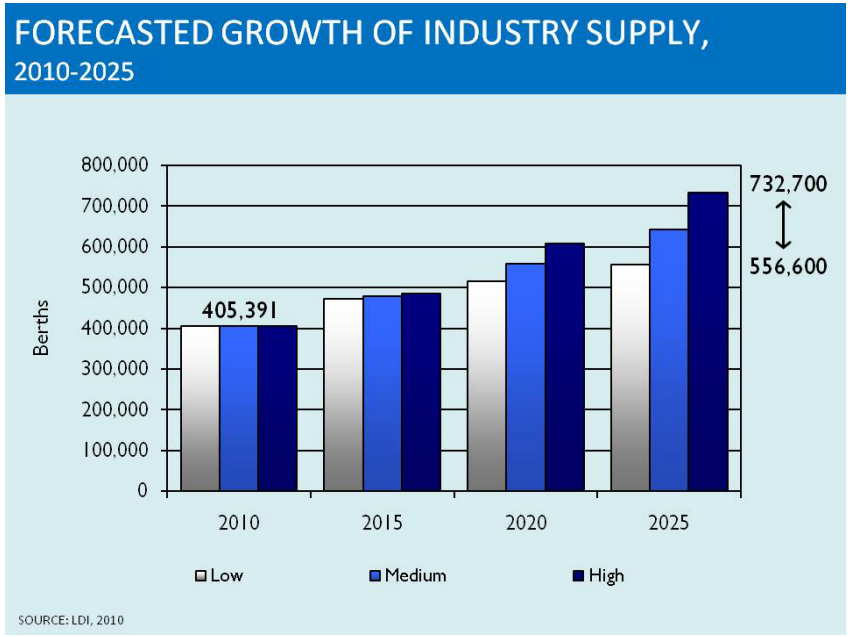
- **Low.** This scenario follows known deliveries to 2014. Starting in 2015, the industry then takes delivery of 3 new vessels (net) per annum representing an expansion of supply of 8,350 new berths.
- **Medium.** This scenario follows known deliveries to 2012. The industry then takes delivery of 6 new vessels (net) per annum representing an expansion of supply of 16,650 new berths.
- **High.** The industry then takes delivery of 9 new vessels (net) per annum representing an expansion of supply of 25,500 new berths.

Under each forecast scenario, the average size of a new vessel from 2014 onwards is assumed to have 2,778 berths.

[1] These scenarios present berths in net terms and envision some withdrawal of older ships, and thus, capacity from service.

The results of each forecast scenario are presented in Figure 3-6. As shown, global industry supply is expected to climb from approximately 405,391 berths in 2010 to between 556,000 (low) and 732,700 (high) by 2025. The ultimate growth line for the global cruise industry is expected to be between the low and high ranges, with vessel deliveries varying between 3 and 9 net new vessels per annum.

Figure 3-6: Forecasted Growth of Industry Supply

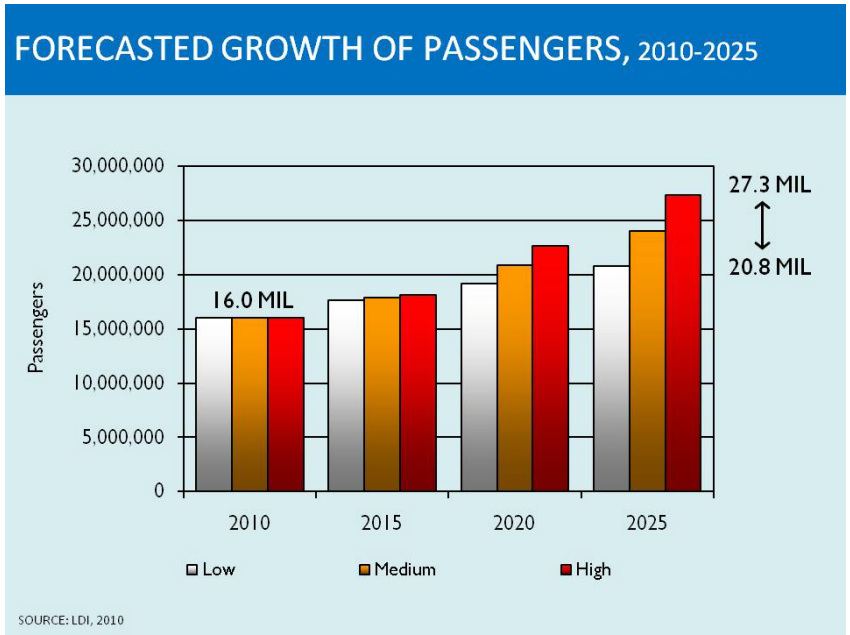


Using the forecast for berth supply expansion presented in Figure 3-6, a range of anticipated global cruise passenger growth was developed

and is presented in Figure 3-7. As shown, passenger levels are expected to climb from 16.0 million in 2010 to between 20.8 million (low) and 27.3 million (high) by 2025. Similar to Figure 3-6, actual passenger levels are anticipated to occur within the range of figures presented in Figure 3-7. The projection model includes a number of assumptions extrapolated out to 2025, including anticipated rates of berth occupancy (91%), average cruise itinerary duration (7 days) and other factors.[2] The model also assumes consumer demand keeps pace with vessel supply over the period reviewed. Due to cruise lines placing vessel orders at a maximum of five years into the future, the model is inherently less reliable beyond 2014.

Projection scenarios herein anticipate ports and destinations will rise to meet this opportunity of continued industry expansion. With the medium and high future growth scenarios above suggesting between 57 and 123 additional (net) new vessels in operation, continued new ship deliveries will place additional demand for port facilities. This trend will create demand for a number of present homeport and port-of-call facilities to expand—especially those found within the industry's most popular and profitable regions—and over the mid- to long-term, encourage expansion into new market regions. Placement of new vessels will be especially challenging during the months of November through April when operations in profitable, cold-water regions are unfeasible.

Figure 3-7: Forecasted Growth of Passengers



3.3 LINES, SHIPS AND OPERATING REGIONS

3.3.1 Cruise Lines

Four major cruise operators dominate the cruise industry worldwide (see Figure 3-4 and Figure 3-8). Each is briefly described below.

[2] Cruise Industry News reports estimated occupancy levels for 2010 at 90.5% for the North American market fleet, 90% for Europe and 90% for Asia.

Carnival Corporation. Publicly held and traded, Carnival Corporation controls over 190,000 berths on 98 vessels and has significant additional capacity on order (see Figure 3-4). Carnival Corporation's portfolio of 11 brands is remarkable and includes: Carnival Cruise Lines, Holland America Line, Princess Cruises, Seabourn Cruise Line, P&O Cruises (UK and Australia), Cunard Line, Ocean Village, AIDA Cruises (Germany), Iberocruceros (Spain), and Costa Crociere. These brands combine to offer a range of vacation products to consumers with varied tastes, income levels, and national origins.

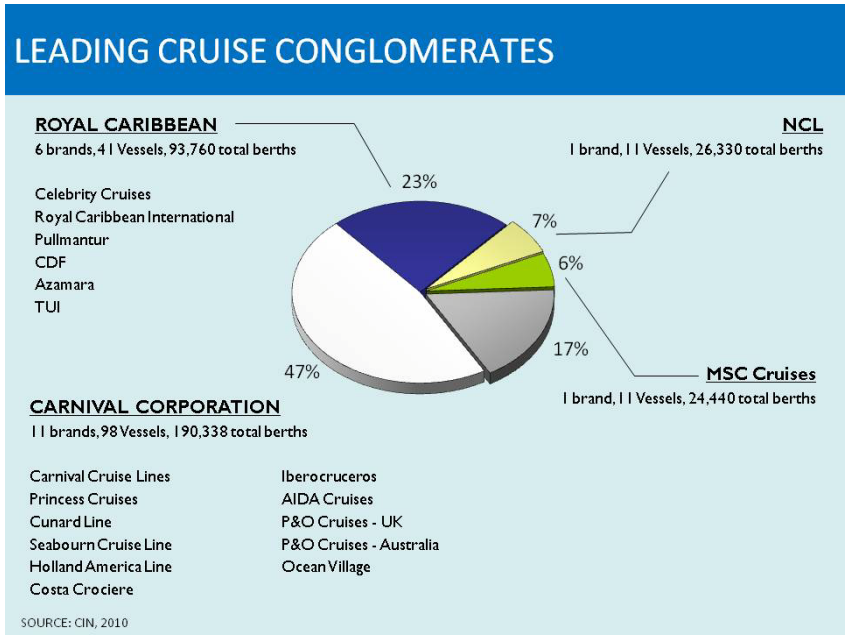
Royal Caribbean Cruises, Ltd. (RCCL). Under its six brands, RCCL operates a fleet of 41 ships with two additional vessels set for delivery. Current fleet capacity is 93,760 lower berths. RCCL is also a publicly held corporation.

NCL. NCL is the third largest operator, with its fleet serving North America. NCL supports a total of 11 vessels.

MSC Cruises. The only leading group privately held, MSC has made significant inroads in the business over the past decade. MSC currently operates 11 ships representing 24,440 berths and markets the majority of this capacity in Europe.

While lines in the "other" category are far smaller in terms of fleet size than the four major conglomerates, the remaining 17% of industry capacity includes a number of important and diverse brands. Representative lines include Disney Cruise Lines, Crystal Cruises, Regent Seven Seas Cruises, Oceania Cruises, Silversea Cruises and others.

Figure 3-8: Leading Cruise Lines



Similar in composition to the hospitality industry, each major cruise group is comprised of several cruise line brands with ships positioned to appeal to different geographic and consumer markets. The majority of cruise brands generally fall into one of the following four segments:

Luxury. The luxury segment offers cruises of greater than seven days on high quality, small and medium-sized ships. Luxury vessels tend to sail worldwide and offer superior food and service.

Premium. The premium segment is geared towards more experienced cruisers, often older and more affluent with time to vacation. Service and food quality are emphasized under the premium segment.

Contemporary. Ships found in the contemporary segment appeal to passengers of all ages and income categories with a focus on middle income levels.

Budget. The budget segment tends to be a less expensive version of the contemporary market, with ships generally older, smaller and offering fewer amenities. There are many of these operations existing in Europe.

Several other secondary market segments exist, including: exploration and soft adventure cruises; niche cruisers; river cruises; and coastal operations. In addition, several tour operators have chartered vessels for their niche market segments.

3.3.2 Cruise Vessels

The evolution of the cruise ship has been one of the principal mechanisms propelling industry growth. It has also required cruise destinations, both the maritime port facilities handling homeport and port-of-call operations as well as the destinations themselves, evolve to meet the challenges presented by these ships if they wish to participate in the large-scale segment of the cruise industry.

Cruise ships have advanced through a number of developmental phases, from the small, 500-passenger vessels of the 1970s to the rise of the Post-Panamax, 3,600-passenger ships of the late 1990's (Table 3-2).

Table 3-2: Sample of Large Cruise Ship Types

Sources: www.cruisecommunity.com, March 2011

Type	Circa 1990s (First Post – Panamax)	Circa Early 2000s (Post-Panamax)	Circa Mid 2000s (Post-Panamax)	Circa Late 2000s (Post-Panamax)
Name	*Grand Princess*	*Queen Mary 2*	*Freedom of the Seas*	*Oasis of the Seas*
Operator	Princess	Cunard	RCI	RCI
Group	Carnival	Carnival	RCCL	RCCL
Built	1998	2004	2006	2009
Pax (LBs)	2,592	2,620	3,634	5,400
Pax (Max)	3,000	2,800	4,375	6,296
GT	108,808	150,000	154,407	220,000
LOA (m)	289.5	345	338	361
Beam (m)	36	45	38.6	47
Draft (m)	8.29	10	8.53	9
Air Draft (m)	60.8	62	63.7	65

With the average length of cruise vessels delivered each year continuing to increase combined with the retirement of older, smaller vessels, it is very likely that within the next decade cruise ships with lengths of 300m will become the operational norm. The prospect of even more orders for larger cruise ships—possibly for vessels even beyond the size and capacity of RCCL's *Oasis of the Seas*—remains as the major operators continue to look to further exploit economies of scale and reduce unit costs as well as to generate excitement around the development of the world's largest vessels.

In the past five years, the newest and most popular generation of ships is smaller in passenger capacity but continues to have greater lengths and drafts to accommodate the height needed for large scale outside cabin development. These vessels range in length from 290 to 335m and have passenger complements of between 2,000 and 3,000. Cruise lines are focusing on improved operational cost savings by ordering standardized hulls for multiple brands.

The average age of a North American cruise vessel is 10 years. Cruise lines continue to extend the life of vessels, using them for longer periods in the North American marketplace and/or shifting these vessels to new ventures and regions around the world. We expect the average age of North American cruise vessels as well as those operating around the world will continue to increase and lines will continue to find new ways to extend the useful life of vessels.

3.4 CRUISE REGIONS

Once focused primarily in the Caribbean and Mediterranean cruising regions, cruise operations are now found around the world. Inclusive of all cruise operators, the Caribbean (1) remains the principal location for cruise capacity placement, followed by the Mediterranean (2) , Northern / Western Europe (3) , Asia / Pacific (4) and the U.S. West Coast (5) (see Figure 3-9 and Figure 3-10).

Operations in seasonal cruising regions usually occur over a six- to eight-month period, with vessels repositioned to another seasonal or year round cruising region during the off-season. By example, operations in Alaska typically occur from late April through late September, with vessels transiting the Panama Canal to return to the Caribbean to offer cruise itineraries through the winter. In total, over eighteen different primary cruise sub-regions are present within the global marketplace, with many of these consisting of even smaller deployment characteristics and typical itineraries.

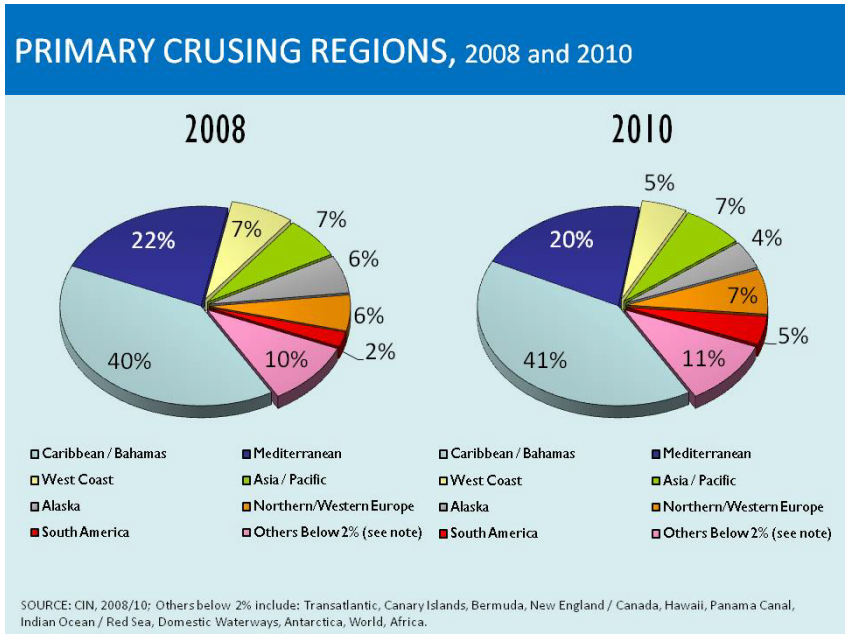
Over the period reviewed, the Mediterranean has been expanding rapidly, from a 15.3% share in 2005 to a 20.0% share in 2010. South America has also been a rising star, with capacity placement more

than doubling over the period. Growth of these regions has for the most part come at the expense of the Caribbean and Alaska, which have steadily declined for the period. Bermuda is one of the smaller cruise regions with less than 1.6% of the market. Future prospects for Bermuda will be discussed in greater detail in the next section.

Figure 3-9: Primary World Cruise Markets

As depicted, the stabilization of cruise capacity in the Caribbean in 2008 to 2010 suggests the region has reached a level of maturity. The region is expected to continue to be the world's largest and also continue to see growth passenger and vessel growth along with its

Figure 3-10: Percent Change in Cruise Regions



peers. Over time, major changes in the region—such as the opening of Cuba to cruise tourism—could lead to a renewal in Caribbean market share expansion. Bermuda's uniqueness both in terms of the destination offer and its proximity to the largest and most lucrative consumer markets along the U.S. East Coast, makes for its long term cruise fortunes to be distinctive from the Caribbean market region and likely not impacted by either growth or retreat of capacity.

3.5 BERMUDA CRUISING

3.5.1 Characteristics

As described in the overview, Bermuda is a cruise region unique in the world. Some of its exceptional characteristics include:

- The Island is strategically positioned in the North Atlantic, accessible within +/- 36 hour cruise vessel transit to the largest and most lucrative consumer markets along the U.S. East Coast (Boston, New York, Philadelphia, Baltimore, Washington D.C., Charleston et.al.).
- Bermuda is both a destination and a cruise region unto itself, offering three different ports-of-call – Hamilton, St. George's and the West End (Royal Naval Dockyard).
- Bermuda is one of the few ports where cruise ships stay for multiple nights.
- The Island garners the highest recorded levels of cruise passenger taxes in the world.
- Bermuda is one of only a handful of destinations that control cruise vessel calls through use of yearly contracts. Contracts allow the Island to make adjustments to the number and type of calling vessels and passengers over time, a public policy feature that allows Bermuda to influence arrivals to fall within the carrying capacity of the Island overall and each of its respective ports-of-call.
- Until the opening of the West End's Heritage Wharf in 2009, Bermuda has been slower than it North American peers to expand port and harbour infrastructure to meet the industry's inclination toward larger vessels.

These last two points have had the most bearing on Bermuda's past, present and future vessel and passenger throughput. Cruise passenger and vessel throughput for the period between 2007 and 2011 (estimated) are shown in Table 3-3 and Table 3-4.

Table 3-3: Cruise Passenger Throughput to Bermuda by Port, 2007 - 2011
Sources: Bermuda's Department of Marine and Ports Services, March 2011

Passengers	2007	2008	2009	2010	2011
St. George's	126,158	40,000	33,962	2,500	1,023
Hamilton	88,054	5,700	4,000	36,965	38,102
Dockyard	169,313	240,703	281,000	289,924	335,000
Other (Tender)*	0	7,000	1,800	35,000	34,000
Total Cruise Arrivals – St. George's, Hamilton and Dockyard	354,024	286,408	318,528	347,931	385,000
Total Cruise Arrivals – All Ports	**383,525**	**293,403**	**320,762**	**364,389**	**408,125**

Table 3-4: Cruise Vessel Throughput to Bermuda by Port, 2007-2011
Sources: Bermuda's Department of Marine and Ports, March 2011

Vessels	2007 [1]	2008 [2]	2009 [3]	2010 [4]	2011 [5]
St. George's	108	23	23	4	2
Hamilton	88	11	8	31	33
Dockyard	84	99	108	92	120
Other (Tender)*	0	6	1	26	25
Total Cruise Arrivals St. George's, Hamilton and Dockyard	**204**	**137**	**138**	**153**	**180**
Total Cruise Arrivals	**280**	**139**	**140**	**177**	**204**

[1] *2007. Norwegian Majesty docking at Ordnance Island and Celebrity Journey, Norwegian Crown and Empress of the Seas docking at Penno's Wharf. Occasional callers + Celebrity Journey, Norwegian Crown and Empress of the Seas.*

[2] *2008. Included Norwegian Majesty docking at Ordnance Island - St. George's's; *6 ships tendering to Hamilton.*

[3] *2009. April 2009 - Heritage Wharf opens. Included Norwegian Majesty docking at Ordnance Island - St. George's's. *1 ship tendering to Hamilton*

[4] *2010. Veendam docking in Hamilton; *Veendam tendering to St. George's's + Others tendering to Hamilton.*

[5] *2011. Projected. Veendam docking in Hamilton; *Veendam tendering to St. George's's + 1 tendering to Hamilton.*

Passenger throughput has shown variability over the period, declining from 383,525 (2007) to 293,403 (2008) and then rebounding with the opening of Heritage Wharf to an estimated 408,135 (2011). The average annual number of cruise passengers visiting Bermuda is estimated at 354.041. In discussions with Bermuda's Department of Marine and Port Services, arrivals are likely to remain consistent with 2011 levels, reflecting the Island's current need to balance arrivals to reduce strain on its waterborne transport system and address other perceived carrying capacity issues.

Vessel arrivals over the period declined from 280 (2007) to an estimated 204 (2011). Nearly all of the vessel traffic planned for this year is scheduled to arrive at the Royal Naval Dockyard.

Bermuda's passenger and vessel volume data, coupled with our analysis in Section 3.3 and discussions with cruise lines, communicate a clear message: The cruise industry has moved to larger cruise vessels, a trend rendering two of Bermuda's traditional ports-of-call nearly inconsequential in terms of direct vessel and passenger arrivals.

Bermuda's cruise traffic can be classified into two groups: (1) Vessels under contact calling on a regular schedule from one of several U.S. East Coast homeports and, (2) occasional calling vessels that call in Bermuda between one and five times per season. Table 3-5 and Table 3-6 lists planned vessel calls for the 2011 season.

Table 3-5: Estimated Vessel and Passenger Throughput to Bermuda, 2011 (Regular/ Contract Ships)

Sources: Bermuda's Department of Marine and Ports Services and LDI, March 2011

Name of Ship	# of Visits	Length overall (m)	Projected Number of Passengers	Number of Crew
Regular/Contract Ships				
Caribbean Princess	7	289.9	3,189	1,163
Explorer of the Seas	25	310.9	3,226	1,181
Enchantment of the Seas	16	301.8	2,293	840
Norwegian Dawn	22	292.0	2,352	1,318
Norwegian Gem	26	294.1	2,399	1,080
Summit	20	294.0	2,058	965
Veendam	24	219.2	1,367	561
Total	**140**			

Detail associated with regular calling (contract) vessels in 2011 is provided below:

- **Celebrity *Summit* (20 visits).** Arrives at King's Wharf, Dockyard Wednesday morning at 8:30 a.m.; departs from Dockyard Friday afternoon at 4:30 p.m. Total length of stay in Dockyard is just over 2.25 days. The *Summit* homeports from Cape Liberty, New Jersey.

Table 3-6: Estimated Vessel and Passenger Throughput to Bermuda, 2011 (Occasional Callers)

Sources: Bermuda's Department of Marine and Ports Services and LDI, March 2011

Name of Ship	# of Visits	Length overall (m)	Projected Number of Passengers	Number of Crew
Occasional Callers				
AIDAluna	3	252.1	2100	607
Amadea	1	192.9	524	262
Carnival Fantasy	5	262.0	2213	920
Carnival Glory	1	290.2	2940	1160
Carnival Miracle	5	293.5	2251	920
Carnival Pride	5	293.5	2251	1029
Crystal Symphony	1	238.4	848	540
Dawn Princess	1	266.0	1890	924
Emerald Princess	1	289.9	3177	1227
Eurodam	1	285.3	2244	929
Europa	1	198.7	378	264
Grand Princess	1	289.9	2604	1100
Pacific Princess	1	181.0	694	373
Poesia	1	293.8	2531	1027
Prince Albert II	1	107.9	133	105
Marina	2	187.8	1052	600
Queen Victoria	2	294.0	1824	900
Regatta	2	180.9	692	386
Seven Seas Mariner	1	216.1	632	445
Seven Seas Navigator	2	172.2	445	345
Silver Whisper	2	186.0	336	295
Total	**40**			

- **NCL's *Norwegian Dawn.* (22 visits).** Arrives at Heritage Wharf, Dockyard Sunday morning at 11:00 a.m.; departs from Dockyard Tuesday afternoon at 5:30 p.m. Total length of stay in Dockyard is just over 2.25 days. The *Norwegian Dawn* homeports from Boston.
- **RCCL's *Enchantment of the Seas* (16 visits).** Arrives at King's Wharf, Dockyard Monday morning at 10:00 a.m.; departs from Dockyard Tuesday afternoon at 3:00 p.m. Total length of stay in Dockyard is 1.25 days. The *Enchantment of the Seas* homeports from Baltimore.
- **RCCL's *Explorer of the Seas* (25 Visits).** The day of arrival and length of stay varies given the vessels rotating schedule from Bermuda to Caribbean itineraries. Generally arrives at King's Wharf, Dockyard, at 9:00 a.m.; departs from Dockyard at 5:00 p.m. The *Explorer of the Seas* homeports from Cape Liberty, New Jersey.
- **NCL's Norwegian Gem (26 Visits)**. Arrives at Heritage Wharf, Dockyard Wednesday morning at 8:00 a.m.; departs from Dockyard Friday afternoon at 5:00 p.m. Total length of stay in Dockyard is just over 2.25 days. The *Norwegian Gem* homeports from New York.
- **Princess's *Caribbean Princess* (7 Visits).** Schedule includes a single day visit on Friday, Saturday, or Sunday. Arrives at King's Wharf/ Heritage Wharf, Dockyard at 9:00 a.m.; departs from Dockyard at 5:00 p.m. The *Caribbean Princess* alternates from the homeports of New York to San Juan.
- **Holland America Line's *Veendam* (24 Visits).** Arrives at Murray's Anchorage (St. George's) Tuesday morning at 8:00 a.m.; shifts to Hamilton, Tuesday afternoon at 6:00p.m.; departs from Hamilton Friday afternoon at 2:00 p.m. Total length of stay in Bermuda is 3.25 days. The *Veendam* homeports from New York.

Cruise activity to Bermuda follows a seasonal pattern, with the majority of contract and occasionally calling vessel traffic occurring between the months of April and October. The season has shown a tendency to stretch deeper into early Spring and late Autumn months, but significant growth of traffic from November to March is not expected given the generally unreliable weather and sea conditions in the North Atlantic at those times.

In terms of vessels throughput by lines, Royal Caribbean followed by NCL provide the majority of cruise traffic to Bermuda in terms of both vessel calls and passenger throughput.

3.5.2 Homeports Supporting Bermuda Cruise Traffic

New York and New Jersey (Cape Liberty) support over 63% of all current Bermuda vessel traffic. Boston and Baltimore support an additional 25% of Bermuda's traffic. In the coming years, New York and New Jersey are expected to continue to provide a majority of cruise passengers to Bermuda. Planned expansion of facilities at Brooklyn's Pier 12 will allow for larger vessels to originate from this facility, including Disney cruise line's newest vessels.

Savannah and Charleston are embarking on plans to improve their homeport capabilities (berthing and terminals) for large vessels. Each of these destinations could likely play a very positive roll in expanding the diversity of passenger origination to Bermuda, tapping into key metro regions in the Southern U.S. (Atlanta, Charlotte, Raleigh, Jacksonville and others). Baltimore and Boston continue to present a strong homeport offer for Bermuda as well. Baltimore continues to improve facilities at South Locust Point—including the recent completion of a new passenger loading bridge—and RCCL reports positive success from this location. While not currently a major supplier of traffic, Norfolk is also a good homeport option in the region.

Overall, the broadening of the number and quality of homeport facilities along the U.S. East Coast is positive for Bermuda. The greater number of quality homeports creates the potential for continued and/or increased demand by cruise lines to offer cruises to Bermuda and tap into these important consumer markets. For Bermuda, more homeport options allows the destination to work with lines to broaden the spending and market profile of cruise passengers on the island as well as look to options to encourage calls more broadly through the week and overall cruising season.

3.5.3 Conversations with Cruise Lines on the Future Outlook for Bermuda

To gauge cruise line outlook on Bermuda and specifically learn of opportunities and challenges associated with vessels coming to Bermuda, stakeholder meetings were held with the three largest cruise conglomerates—Carnival Corporation (including representatives from Carnival Cruise Lines, Holland America Line and Princess Cruises), Royal Caribbean and NCL. Meetings were held in Miami, Florida on February 14 - 15, 2011.

In general, cruise lines expressed an overall positive outlook on the Bermuda cruise market. With relatively few exceptions, the cruise guest experience while on the Island was reported as favorable, with both Bermuda's public and private sector associated with the industry

continually working to improve the experience of passengers and active in correcting any encountered problems. Overall, lines expressed a desire to continue to have as large a presence as the physical capabilities of Bermuda's ports and Government policy allow.

All lines expressed strong interest in having a two- or three-port option in Bermuda, suggesting this works well with the overall perception and value of delivering the Bermuda experience. All lines expressed interest in working with Bermuda to explore and possibly work in partnership to expand the capability of St. George's and Hamilton to welcome larger cruise vessels, especially those at and above the Panamax design threshold.

Specific comments relative to each line are presented below.

- **Carnival Corporation.** Carnival Corporation indicated that all of Bermuda's ports and channels should be designed to accommodate at minimum their Panamax vessels, such as Carnival's *Spirit*-class and Holland America's *Vista*-class. Carnival encouraged exploration of post-Panamax vessels at each of these ports as well, with the long term possibility of welcoming Carnival's *Dream*-class and Princess' *Grand*-class ships. Carnival—in expressing views at a corporate level but also reflecting the general sentiment from representatives of Carnival Cruise Lines, Princess Cruises and Holland America Line—indicated a continued willingness to discuss a potential long term partnership with Bermuda in its efforts to expand their ports and channels. However, Carnival noted that they would not be interested in project alternatives that included purchase and/or use of tractor tugs or similar types of vessel assistance. Carnival expressed a desire to expand its participation in the Bermuda market for all of its key North American brands, including Carnival Cruise Lines, Princess and Holland America.

  Follow up meetings with Holland America in Miami and Seattle confirmed continued commitment by the brand to the overall Bermuda marketplace.

- **Royal Caribbean Cruise Lines (RCCL)**. Similar to Carnival Corporation, RCCL expressed a continued desire to participate in the Bermuda cruise region, inclusive of calling at all of the Island's marquee ports-of-call. RCCL indicated that the North Channel and Royal Naval Dockyard have capability to accommodate a Freedom-class vessel. For St. George's and Hamilton, RCCL would prefer over the long term for these destinations to welcome Celebrity's *Millennium*- and *Solstice*-class vessels and RCCL's *Voyager*-class vessels. For St. George's specifically, RCCL's captains reported that any simulation of Town Cut would need to consider vessel beams at the waterline as well as the overall max

beam of the vessel (accounting for life boats, etc.), which can add 6m or greater to the overall vessel width above the waterline. RCCL reported their current order and production of the new *Sunshine*-class cruise vessel which would have a length of 339m to 350m, 45m beam, 8.7m draft and passenger level of between 4,000 and 4,700. Finally, RCCL reported very positive results with the *Enchantment of the Seas* embarking from the Port of Baltimore.

- **Norwegian Cruise Lines (NCL).** NCL reported continued desire to be present in Bermuda and offer their cruise guests each of the Island's ports-of-call. For the West End, NCL would like to see this location receive their largest post-Panamax vessels, inclusive of their recently ordered *Breakaway One and Two*, which would have a length of 324m, 39.7m beam, 8.3m draft and 4,000 passengers. For St. George's and Hamilton, preference would be for both locations to be able to welcome NCL's *Norwegian Gem, Jade* and/or *Jewel* vessels.

3.5.4 Forecast of Future Cruise Volumes to Bermuda

In preparing cruise forecasts for ports and destinations, it is customary to follow one of several projection methodologies, inclusive of assembly of a series of low, medium and high forecasts based on regression analysis of destination and regional vessel and passenger throughputs, vessel capacity placement scenario modeling and direct discussion with cruise lines as to their overall long term intent for a destination and region. However, in the case of Bermuda, each of these typical methodologies are not relevant given the Island's contractual control of vessel arrivals—an approach not expected to change moving forward—and the current status of its port and harbour infrastructure at St. George's and Hamilton.

Cruise vessel and passenger throughput to Bermuda overall will likely remain consistent with levels observed in 2010 and expected for 2011 and 2012 if there are no channel modifications to St. George's and Hamilton. Royal Naval Dockyard vessel berth utilization is high and the overall carrying capacity of Bermuda's transport system is considered near its peak. It is expected that while cruise passenger arrivals would fluctuate from year to year, average passenger arrivals would stay within the range of 375,000 to 425,000 passengers over the long term and vessel arrivals would stay close to 200 per annum.

Future scenarios including expansion of channel, harbour and port capacity at St. George's and Hamilton create some opportunity for vessel and passenger growth provided the Island's contractual vessel polices move in this direction. By example, if all channels, harbours and ports were designed to accommodate an average vessel size of

2,800 passengers, estimated total Bermuda passenger levels associated with contact ships would approach 537,600 (2,800 x 6 contract vessels x 32 weeks of operation). In Section 5, a series of detailed projection scenarios based on possible expansion of cruise serving marine infrastructure are presented.

3.6 CONSIDERATIONS FOR LARGER CRUISE VESSELS TO BERMUDA

Essential in the development of scenarios for possible future modification and expansion of Bermuda's channels, harbours and ports is establishment of several workable cruise vessel templates for analysis and design simulation. Cruise vessel templates need to consider likely vessel deployments to Bermuda over the long term as well as trending of vessel construction and utilization by the cruise lines.

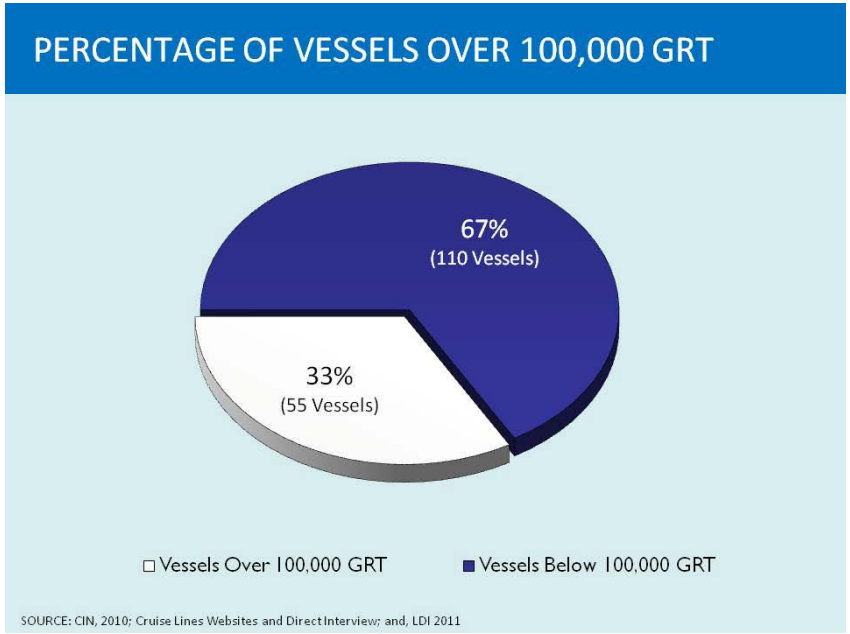
A review of all cruise vessels presently operated or on order by North American lines was conducted. A compendium of these vessels and there basic characteristics—vessel class, tonnage, length, beam and others—is presented in Appendix A. A total of 156 vessels were identified.

As part of this database, ships presently operated by Costa Cruise Lines and MSC Cruises were included. Please note, however, that deployment of vessels for each of these brands is geared toward the European region and marketplace. Thus, these vessels are unlikely to present opportunities for significant levels of throughput to Bermuda other than the occasional call as part of vessel repositioning or other redeployment pattern.

This analysis included vessels operated by Crystal Cruises, Cunard (Carnival), Oceania Cruises, Seven Seas Navigator, Silver Sea Cruises and the Yachts of Seabourn (Carnival). For all of these lines, deployments tend to be focused on a niche and/or worldwide basis and are not envisioned to be a major current or future part of the Bermuda cruise market other than an occasional call. Further, with the exception of Cunard, most of the vessels operated by each of these brands are small, with many already able to call on each of Bermuda's cruise ports.

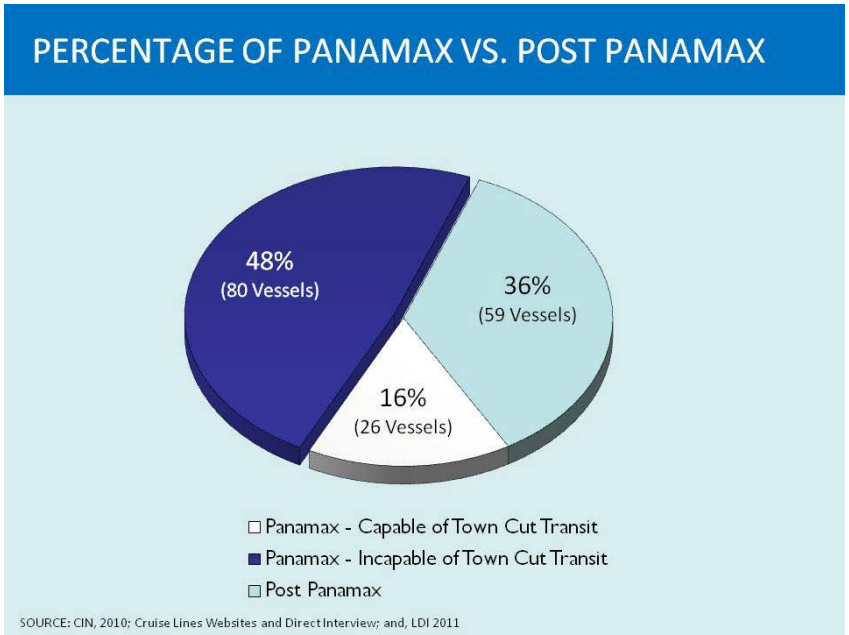
Thirty-three (33%) of all North American vessels in operation or on order are above 100,000 gross registered tons (GRT) as shown in Figure 3-11. The number of vessels over 100,000 GRT continues to grow. Of the 21 cruise vessels presently on order, 13 are larger than 100,000 GRT (Table 3-1). The average age of these larger vessels is approximately 5 years (e.g., constructed in 2006).

Figure 3-11: Percentage of Vessels Over 100,000 GRT



In review of vessels as categorized by Panamax and post-Panamax, the current majority of ships (64%) fall within the current Panama Canal design limitation as shown in Figure 3-12. The dimensions of the Panama Canal have long served as a key threshold in cruise vessel construction, one that allows vessels to have either maximum flexibility in deployment decision making (Panamax) or to be relegated to serving one or two major cruise regions (post-Panamax). With the current expansion of the Panama Canal lock system expected to be complete by 2014, this key threshold no longer limits vessel design as shown in Table 3-7. While the majority of vessels are Panamax, the percentage belonging to this category will diminish.

Figure 3-12: Percentage of Panamax to Post Panamax Vessels



With the large number of vessels designed at the traditional Panamax dimension and the average age of vessels estimated at only 11 years, the prototypical Panamax maximum vessel is considered an important threshold for all of Bermudas Ports. However, given the need to look long term for any major modification to Bermuda's channels and harbours, Panamax size vessels are not considered the ultimate

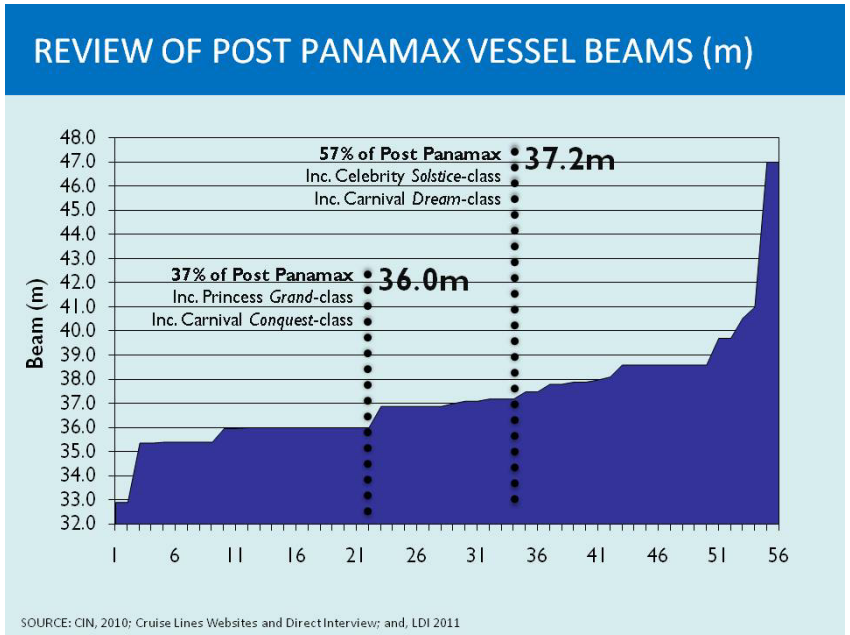
threshold for consideration for Bermuda's more constrained channel and harbour conditions at St. George's and Hamilton.

Table 3-7: Comparison of Panamax and Post-Panamax Sizes
Source: www.wikipedia.com, March 2011

	Locks	Panamax	New locks	New Panamax
Length	1,050 ft (320.04 m)	965 ft (294.13 m)	1,400 ft (427 m)	1,200 ft (366 m)
Width	110 ft (33.53 m)	106 ft (32.31 m)	180.5 ft (55 m)	160.7 ft (49 m)
Depth, draft	41.2 ft (12.56 m)	39.5 ft (12.04 m)	60 ft (18.3 m)	49.9 ft (15.2 m)

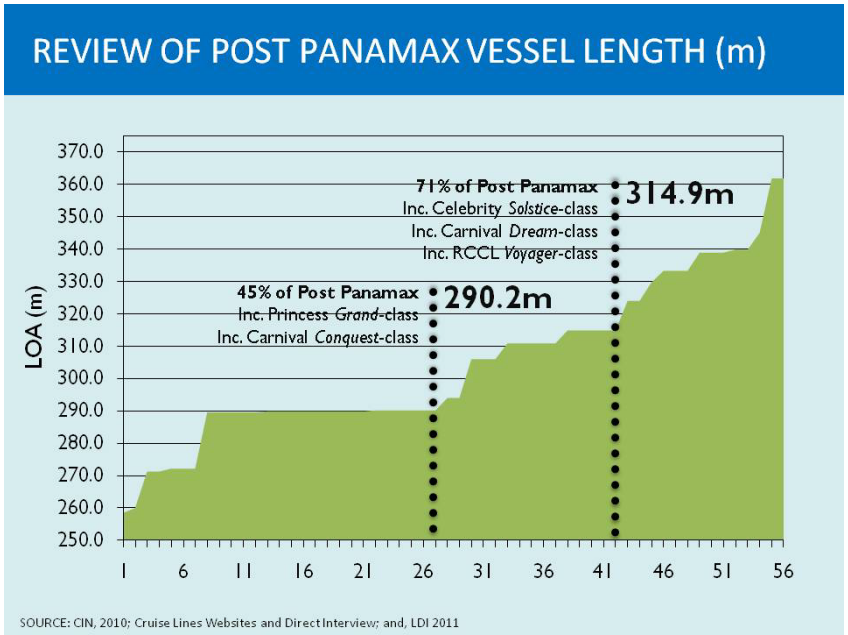
From an in-depth review of all ships in the post-Panamax classification, several dimensional limits became apparent as illustrated in Figure 3-13, Figure 3-14, and Figure 3-15). In review of all vessel dimensions (beam at waterline, draft, and length), the goal is to identify vessel classes that offer Bermuda over time a reasonable additional increment of potential ships that could be accommodated. In review of vessel beams, this threshold seemed to be present at 36m—a level that captures 37% of all post-Panamax vessels and several important cruise line groupings of vessel classes—and then again at 37.2m. For vessel length, critical limits were observed at 290.2m LOA—a level that captures 45% of all post-Panamax vessels—and then again at 314.9m. Important vessel classes at or below 314.9m in length include RCCL's *Voyager*-class, Celebrity's new *Solstice*-class and Carnival's new *Dream*-class.

Figure 3-13: Beams of Post Panamax Vessels



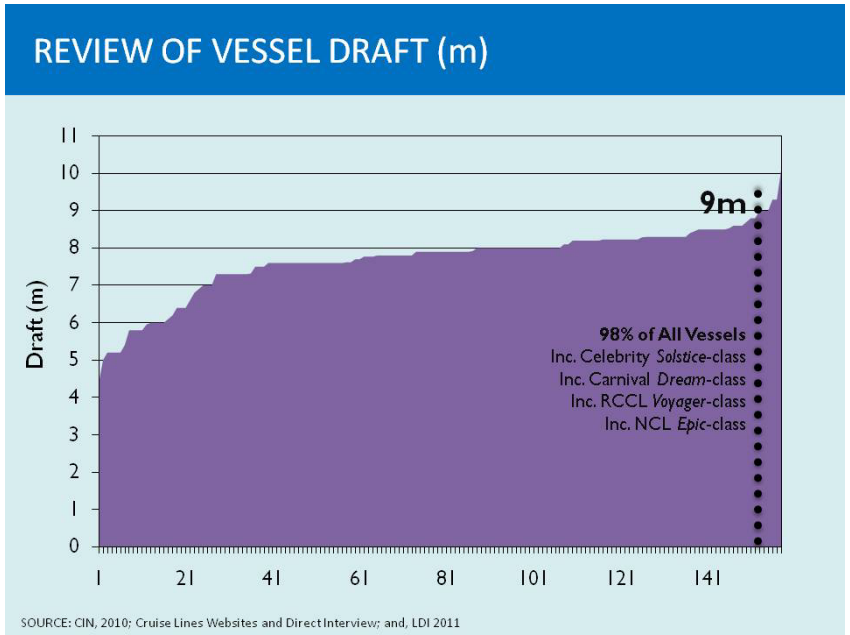
Review of post-Panamax vessel draft showed few critical design thresholds as shown in Figure 3-15. Vessel design has tended to move toward lengthening and widening over the past two decades while keeping the overall draft of vessels between 8m and 9m. From our analysis, 98% of all North American cruise vessels have vessel drafts of 9m or less.

Figure 3-14: Lengths of Post Panamax Vessels



Primary groupings of vessels were defined for study and analysis of channel, harbour and port. Four tiers are presented in Table 3-8. Tier 1 includes Panamax maximum vessels and should be a minimum threshold for study at all of Bermuda's ports-of-call. Tier 2 includes several important classes of vessels and, in total, represents an estimated 82% of all vessels currently in operation or planned. Tiers 3 and 4 add increased numbers of newer vessels operated by Royal Caribbean in North America, including Celebrity's *Solstice*-class and RCCL's *Freedom*-class.

Figure 3-15: Vessel Drafts



Each of these tiers is considered starting points for analysis and further discussion. Additional qualifications for each tier of vessels can be made based on passenger carrying capacity and other qualitative and quantitative factors.

Table 3-8: Four Primary Tiers of Vessel Classes
(LDI, March 2011)

Vessels	Vessel Characteristics	Royal Naval Dockyard	Hamilton	St. George's
Tier 1 – Panamax Representative Vessels Carnival's *Spirit*-class Holland America's *Vista*- and *R*-class	Length: ≤294m Beam: 32.3m Draft: 7.6 to 8.2m Gross Tonnage : 65,000 to 88,500 tons	Yes	Yes	Yes
Tier 2 – Post Panamax 1 Representative Vessels Carnival's *Conquest*-class Princess' *Grand*-Class	Length: ≤294 m Beam: 36m Draft: 8.2m Gross Tonnage : 110,000 to 116,000 tons	Yes	Yes	Yes
Tier 3 – Post Panamax 2 Representative Vessels Celebrity's *Solstice*-class	Length: 315m Beam: 37m Draft: 8.2m Gross Tonnage : 122,000 tons	Yes	Maybe	Maybe
Tier 4 – Post Panamax 3 Representative Vessels RCCL's *Freedom*-class	Length: 339m Beam: 38.6m Draft: 8.8m Gross Tonnage : 155,000 tons	Yes	No	No

4 ACCESS IMPROVEMENTS

Physical constraints such as the width or water depths in the channel and operational/safety considerations (weather conditions, cruise ship scheduling, ship maneuverability within the channel, and improvements to ATONs to permit pilotage of ships at night) have independently or in combination, prohibited most of the current fleet of cruise ships from utilizing St. George's Harbour and Town Cut Approach, Two Rock Passage, or the South Channel. The North Channel currently accommodates most cruise vessels up and including Tier 4. However, ship handling and maneuverability is compromised in several sections of the channel due to physical and operational issues. Access issues to Dundonald Channel were not raised during the stakeholder's meeting. Therefore, access improvements to Dundonald Channel are not provided in this study.

Although operational improvements may increase access to ports or the use of the channels to an extent, they do not resolve all access issues. This study is focused toward the evaluation of physical modifications to channels and/or ports to improve navigation and access. Operational improvements are considered in conjunction with physical modifications when feasible to minimize the overall extent of the physical changes.

4.1 NAVIGATIONAL CONCERNS

4.1.1 St. George's Harbour and Town Cut

Vessels approach the Town Cut from the Sea Buoy located approximately 5.5 km offshore of Town Cut. A line connecting the Sea Buoy with a point on Cherrystone Hill west of St. George's Harbour, defines the sailing line. This sailing line traverses the center point of Town Cut but differs from the centerline of the channel. Ships initiate their transit near the north boundary of the outer approach channel at Five Fathoms Hole then reorient themselves with the centerline of Town Cut as they pass ATONS #1/#2 that defines the start of "The Narrows" channel.

Maintaining this sailing line is complicated by wind blowing from the south and southwest quadrants, tidal currents that flow from north to south in the outer approach channel at Five Fathoms Hole, and waves from the east. Changes to vessel speed and rudder control are primarily utilized by the Bermuda Pilots to counter these environmental conditions. However, the continuing effects of the wind, currents, and waves tend to push the ships to the north, placing them close to the north edge of Town Cut channel. Bank suction effects due to the asymmetrical lengths of the north and south channel banks further affects ship handling. Corrections to the sailing line are difficult to achieve within the narrow confines of Town Cut

channel proper even if vessel speed is increased, the rudder is extensively used, or bow thrusters and/or assistance from rotational stern propulsion systems are employed (specific to a few cruise ships only). The shallower water depth in the channel limit restricts the level of adjustment to vessel speed.

The channel alignment within St. George's Harbour also complicates ship handling and maneuverability. The channel reorients to the north on the west side of Town Cut Channel to avoid Hen Island. The distance from Town Cut to Hen Island is less than 650m, which requires ships that are longer than approximately 625m to make course corrections while a portion of the ship lies within the narrow confines of Town Cut.

Due to these ship maneuverability issues, the use of Town Cut channel is generally limited to the following conditions:

- Vessel Characteristics: 200m in overall length with beams less than 30m, and drafts less than 8.5m at high tide and 7.9m at low tide.
- Vessel speeds less than 8 knots
- Wind speeds less than 15 knots

Because of these conditions, larger cruise ships cannot access St. George's and cruise ships that meet the minimum vessel characteristics may be precluded from entering or leaving depending on weather conditions.

4.1.2 North and South Channels including "The Narrows"

Navigation issues of transiting the North Channel and "The Narrows" are generally limited to channel depth, width, and alignment constraints in "The Crescent" region and the approach to Grassy Bay. Channel widths and water depths in remaining locations of the North Channel and in the "The Narrows" region generally meet ship handling and navigational safety guidelines for current and projected cruise ships that would utilize this channel including Tier 4. However, there are several "high" spots in the channel that do not meet the guidelines. In addition, issues related to resuspension of sediments by passing cruise ships when ships travel at higher speeds to compensate for higher wind speeds, may necessitate adjustment to operational guidelines.

Several turns in the "Crescent" region are required to avoid coral reefs. Upon exiting these turns, the channel passes through White Flats, an area where fringing reefs border both sides of the channel. Shallower water depths on the right side of the channel force ships to take a port-orientated sailing line, which reduces the available maneuvering room. In addition, ship maneuverability is further

compromised by bank suction effects generated by the changing water flow regime in the reefs. The Bermuda Pilots report that the bank suction effects significantly compromises ship handling and is magnified when wind speeds exceed 20 knots.

South of White Flats, the channel follows a southeasterly alignment before making an abrupt shift to the southwest. The transition width at this abrupt shift in channel alignment does not meet recommended guidelines developed by PIANC (PIANC, 1997). These guidelines take into consideration ships swept path through the turn.

The primary navigation restriction that precludes cruise ships using the South Channel is the shallow water depth along the west end. These depths range from 8.5 to 9.5m at chart datum.

4.1.3 Two Rock Passage

The primary limitation of Two Rock Passage is the channel bottleneck (channel width and water depth) between LeFroy and Mobray Islands. The shallow water depths may also compromise navigation in the channel from Dundonald Channel to the bottleneck as the ship lists to starboard (reducing underkeel clearance) as it sweeps through the turn. East of the bottleneck, navigation may be compromised by a set of small islands on the south side of the channel.

4.2 DESIGN PARAMETRES

4.2.1 Vessels

Developing access improvement alternatives that physically modify the navigation channels is based 1) providing safe transit to existing cruise ships that currently call on Bermuda but are precluded from St. George's and Hamilton, 2) existing cruise ships that currently do not call on Bermuda but may in the future as cruise lines retire and/or realign cruise ships, and 3) future cruise ships that may be becoming online in the next five years. Four ship classes or tiers were previously identified Table 3-8)[3] as the basis for evaluating access improvements at some or all of Bermuda's ports-of-calls; St. George's and Town Cut do not currently support any of the tier ships. Given the dominance of Tiers 1 and 2 ship classes in the existing cruise market, access improvements based on these ship classes were evaluated at St. George's and Hamilton.

[3] Four Tiers of Vessel Classes

Tier 1 Panamax	Tier 2 Post Panamax 1	Tier 3 Post Panamax 2	Tier 4 Post Panamax 3
Length: ≤294m Beam: 32.3m Draft: 7.6 - 8.2m	Length: ≤294 m Beam: 36m Draft: 8.2m	Length: 315m Beam: 37m Draft: 8.2m	Length: 339m Beam: 38.6m Draft: 8.8m

The turning basin in Hamilton Harbour is not large enough to accommodate Tiers 3 and 4 ship classes. However, the turning basin in St. George's Harbour can support turning movements associated with the Tier 3 ship class. The access improvements required to accommodate Tier 3 ship class in St. George's was also identified.

Although the channel width is sufficient, the water depth in the South Channel precludes access by Tiers 1 through 4 ship classes. For this study, a threshold water depth in the South Channel to support up to a Tier 2 ship class was established.

The North Channel currently accommodates ships up to Tier 3 and there are ongoing studies to evaluate Tier 4 ship classes. Access improvements in this study identify a range of channel modifications to improve access for Tiers 1 through 4 including the removal of several "high spots" within the channel that do not meet existing operational water depths. In addition, alternatives to improve navigational safety in the main channel at White Flats and farther south are presented.

4.2.2 Channel Geometry

Town Cut, Two Rock Passage, and South Channel require increased width and depth to accommodate any of the aforementioned vessel tiers. Modifications in the width and depth to the North Channel may be required in certain reaches to more safely accommodate Tier 4 vessels. PIANC, a global organization providing guidance for sustainable waterborne transport infrastructure for ports and waterways, publishes guidelines for width and depth of access channels. The PIANC guidelines and methodology was applied to each of the channels in Bermuda to determine the minimum requirement and to assist in the development of channel improvement alternatives for further evaluations. Channel navigation depend on a number of vessel characteristics, including vessel dimension, vessel speed, channel alignment, allowance of passing, channel bottom, and are discussed herein. The guidelines were developed for many types of commercial vessels but individual handling characteristics for a distinct vessels type, such as a cruise ship, may not be full represented in the guidelines.

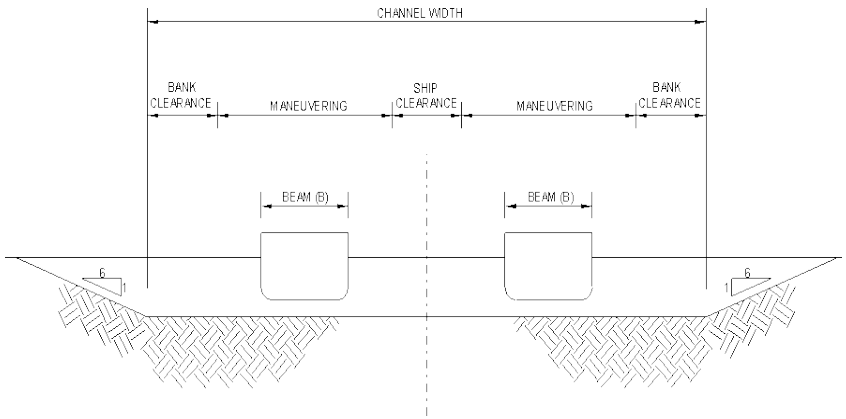
4.2.3 PIANC Criteria

PIANC provides a method for assessing channel dimension (width and depth) given general information on the size and maneuverability of the vessel navigating the channel, the type of channel bank, the effect of other vessels in the channel and the effects of wind and currents (PIANC, 1997).

Width based on Straight Channels

The width required takes into account space for a maneuvering lane, ship clearance and bank clearance as shown in Figure 4-1.

Figure 4-1: Typical Width Requirements for Straight Channels



The Maneuvering Lane

The maneuvering lane must allow for the oscillating track of a maneuvering vessel. The maneuvering lane depends on maneuverability of the vessel which was considered to be moderate to good for Tier 1 through 4 vessels.

Bank Clearance

Bank clearance width depends on vessel speed and steepness/hardness of side slopes. For Town Cut and Two Rock Passage, which has near vertical edges of hard material, an allowance of 50% of vessel beam is added to each side of the channel. For the North and South Channels, where soft material and shallower side slopes may be encountered, bank clearance may be reduced.

The Ship Clearance Lane

It was assumed cruise ships utilizing Town Cut, Two Rock Passage, and the North and South Channels are scheduled to transit these area without passing commercial traffic due to navigation and security reasons. Therefore, an allowance for passing ships was not considered.

Additional Width

The channel width may be increased depending on fluctuations in transit speed, winds, currents, visibility, aids to navigation, underkeel clearance, and the bank slopes.

The following environmental and operational assumptions were applied to cruise ships operations in Bermuda:

- Vessel speed through Town Cut and Two Rock Passage is limited to 6 to 8 knots. Higher vessel speeds may impact shoreline stability and would require deeper channel depths. Higher vessel speeds in the North and South Channels are possible depending on weather conditions and environmental considerations.
- Operational cross winds of up to 25 knots for all channels.

- Waves up to 1 m in height.
- Cross and longitudinal tidal currents up to 0.5 knots.
- Aids to navigation (ATONs) are good to excellent during daytime operations. ATONs are currently not suitable for nighttime operations.

Based on the aforementioned assumption, preliminary required channel widths for each Tier ship class were developed. Table 4-1 presents the range of width assigned to each vessel class.

Table 4-1: Preliminary Channel Width Recommendations

	Low	High
Tier 1	100 m	110 m
Tier 2	112 m	122 m
Tier 3	115 m	126 m
Tier 4	120 m	131 m

Minimum Draft Requirements

The required channel depth relative to a referenced water level is based on the following criteria:

- Loaded vessel draft including trim
- Squat
- Wave induced motions
- Fresh water allowance
- Safety clearance
- Dredging tolerance
- Advanced maintenance dredging
- Controlling channel depth

For the purposes of this assessment all dredging depths and drafts are referred to Chart Datum (CD).

Loaded Draft

Existing cruise ships and those with reasonable prospect for future deployment to Bermuda in the next 5 years generally have drafts of 8.5 to 9.5 m. The arrival and departure drafts are typically identical as the number of passengers and crew does not change. For the purposes of this study, loaded drafted is assumed to include any static trim.

Squat

The position of a vessel's keel relative to the channel bottom will lower as the vessel speed increases. This phenomenon results when increased water velocities flowing past a moving ship hull produce a localized lowering of the water surface. In general, squat is a function of the vessel speed, under-keel clearance, channel width, channel depth and vessel dimensions.

Squat of channel transiting cruise ship is calculated using empirical equations published by PIANC. Utilizing the channel dimensions presented in Table 4-1, the estimated squat for Tier 1 thru Tier 4 vessels for transit speeds of 8 knots in an 11 m channel depth is shown in Table 4-2. These values will be used to evaluate channel depth requirements for Town Cut, Two Rock Passage, and the South Channel. For cruise ships in the North Channel that transit at speeds up to 15 knots, squat values of 2.0m were used for all tier vessels

Table 4-2: Estimated Squat Values

Vessel Class	Squat (m)
Tier 1	0.47 m
Tier 2	0.50 m
Tier 3	0.51 m
Tier 4	0.55 m

Wave-Induced Motions

Cruise ships approaching St. George's Harbour and the North and South Channels are exposed to ocean waves and swell. As vessels approach Town Cut, waves are attenuated. Pilots report little effect of waves on the cruise ships during transit through Town Cut. Therefore, no allowance for wave induced motions is included in this preliminary assessment of Town Cut. For the North and South Channels, wave induced motions of up to 0.5m were considered.

Fresh Water Allowance

The salinity of Bermuda ports is the same as the Atlantic Ocean; therefore no increase in draft due to fresh water density was applied.

Safety Clearance

For vessels transiting over a hard bottom, a minimum safety clearance of 0.9m is recommended by PIANC and the US Army Corps of Engineers. For cruise vessels entering Bermuda Ports, this distance shall be the minimum maintained under normal conditions after the other depth allowances have been included.

Dredging Tolerance

The preliminary geotechnical review indicated that there is a high probability of encountering soft to medium dense material in most channels with pockets of harder material. Tolerances associated with dredging of the medium to harder material depend on methods and equipment used. Therefore, a 0.6m dredge tolerance has been applied.

Advanced Maintenance Dredging

Based on anecdotal information, maintenance dredging of Town Cut, Two Rock Passage and South Channels has not been performed in the last 25 years. Maintenance dredging of the North Channel was performed in 1985 based on anecdotal information. Given the timeframe between maintenance dredging activities, no allowance for maintenance dredging is included in the channel depth calculations.

For ships that fall in Tiers 1 through 3, the minimum water depth to transit at vessel speeds that would be encountered at Town Cut, Two Rock Passage, and South Channel is -11.5m CD. Since vessel squat may be greater due to higher vessel speeds during transit in the North Channel, the minimum channel depth is -12.5m CD for Tiers 1 through 4.

4.3 ST. GEORGE'S HARBOUR – TOWN CUT

4.3.1 Alternatives Development

Based on the channel width and depth guidelines developed for Tier 1 though 3 ship classes, a series of alternatives were developed to improve access at Town Cut. These alternatives are primarily focused on physical changes, but several operational modifications and enhancements discussed during the stakeholder meetings were also incorporated.

Table 4-3: Channel Alternatives for Town Cut

Alternatives	Description
Alternative 1	No Action – Existing 70m wide channel remains
Alternative 2	Widen Channel by 30m (100m total) - No Channel Realignment
Alternative 3	Widen Channel by 30m (100m total) – Channel Realignment to South
Alternative 4	Widen Channel by 30m (100m total) - Channel Realignment to North
Alternative 5	Widen Channel by 30m (100m total) with mule assist – Channel Realignment to South
Alternative 6	Widen channel by 40m (110m total) – No Channel Realignment
Alternative 7	Widen channel by 50m (120m total) – No Channel Realignment
Alternative 8	Widen channel by 60m (130m total) - No Channel Realignment
Alternative 9	Widen channel by 60m (130m total) – Channel Realignment to South
Alternative 10	Widen channel by 60m (130m total) with tug assist – Channel Realignment to South
Alternative 11	Widen channel by 75m (145m total) – No Channel Realignment
Alternative 12	Widen channel by 85m (155m total) – Channel Realignment to South
Alternative 13	Widen channel by 110m (180m total) - Channel Realignment to South
Alternative 14	New 130m channel – St. George's Channel

The preliminary alternatives were then evaluated and ranked using a Level 1 matrix assessment that considered navigation, engineering and operational factors and environmental and socio-economic impacts. The methodology used in this matrix assessment is comprised of assigning numerical weights and values to these factors and impacts for fourteen access improvement alternatives. These values were added within each alternative to obtain a single numeric value. The five alternatives with the lowest numerical score were then selected for further evaluation using full mission bridge simulations at MITAGS as part of Level 2 evaluation. The fourteen alternatives considered in the matrix assessment listed in Table 4-3 and shown on drawings in Appendix B.

Alternative 1: No Action

The No-Action Alternative assumes no navigation improvements will be enacted at Town Cut and is the baseline for the evaluation of navigation, environment, and socio-economic consequences.

Alternative 2: Widen Channel by 30m (100m total) No Channel Realignment

Town Cut Channel is widened by 30m and deepened to -11m CD by excavating the north end of Higgs and Horseshoe Islands and dredging the main channel within its existing limits. This alternative was developed to accommodate the lower bound of Tier 1 ship access.

Alternative 3: Widen Channel by 3 m (100m total) Channel Realignment to South

Town Cut Channel is widened by 30m and deepened to -11m CD by excavating the north end of Higgs and Horseshoe Islands. The navigation channel is also realigned within St. George's Harbour by removing the north end of Hen Island along the south boundary. The existing main channel and realigned section are dredged to -11m CD. This alternative was developed to accommodate the lower bound Tier 1 ship access

Alternative 4: Widen Channel by 30m (100m total) Channel Realignment to North

Town Cut Channel is widened by 30m and deepened to -11m CD by excavating the south shoreline of St. George's Island (north side of channel) and realigning the navigation channel to the north. The boundary of the realigned channel does not affect Gates Fort but may affect several private residences. This alternative would accommodate the lower bound of Tier 1 ship.

Alternative 5: Widen Channel by 30m (100m total) with "mule" assist, Channel Realignment to South

This alternative consists of constructing a fix platform on either side of Town Cut channel to support the use of "mules" (trains) or similar device to guide ships through Town Cut. This approach is similar to

the "mule" operated system at the Panama Canal locks. The Town Cut Channel is widened by 30m and deepened to -11m CD channel to facilitate cruise ship approach and departure. Tiers 1 and 2 ship classes would be accommodated using mule assist.

Alternative 6: Widen Channel by 40m (110m total), Channel Realignment to South

Town Cut Channel is widened by 40m and deepened to -11m CD by excavating the north end of Higgs, Horseshoe, and Hen Islands and dredging the main channel within its existing limits. This alternative was developed to accommodate the upper bound of a Tier 1 ship class and lower bounds of Tier 2 ship class. A channel alignment is assumed in this alternative to provide additional maneuvering room.

Alternative 7: Widen Channel by 50m (120m total), Channel Realignment to South

Town Cut Channel is widened by 50m and deepened to -11m CD by excavating the north end of Higgs, Horseshoe, and Hen Islands and dredging the main channel within its existing limits. As with Alternative 2, realignment of the channel is proposed. The additional channel width provides additional maneuvering room for Tier 2 ship class.

Alternative 8: Widen Channel by 60m (130m total), No Channel Realignment

Town Cut Channel is widened by 60m and deepened to -11m CD by excavating the north end of Higgs and Horseshoe Islands and dredging the main channel within its existing limits. The additional widening is intended to accommodate the upper bound of Tier 3 ship class.

Alternative 9: Widen Channel by 60m (130m total), Channel Realignment to South

In addition to the channel modifications defined in Alternative 8, the north end of Hen Island is removed and the channel realigned within St. George's Harbour. The realignment of the channel is considered to accommodate the overall length of Tier 3 ship classes and its potential restriction on turning movements.

Alternative 10: Widen Channel by 60m (130m total), using Tug Assist, Channel Realignment to South.

Under this alternative, large horsepower tractor tugs would assist in maneuvering cruise ships through Town Cut channel including approach and St. George's Harbour sections. The channel is widened and realigned as discussed in Alternative 9 to provide sufficient room for the tugs to reposition and guide cruise ships into harbour.

Alternative 11: Widen Channel by 75m (145m total), No Channel Realignment

This alternative, along with Alternatives 12 and 13, was developed for cruise ship handling characteristics not wholly considered in the development of the PIANC guidelines. Town Cut Channel is widened by 75m and deepened to -11m CD by excavating a large section of the north end of Higgs and Horseshoe Islands and dredging the main channel. In this alternative, realignment of the channel is not considered though the sweep angle (the track swept out by the extremities of the vessel when maneuvering) of the channel approaches the recommended threshold based on the proposed vessel characteristics and water depth.

Alternatives 12 and 13: Widen Channel by 85 and 110m (155m and 180m total, respectively), Channel Realignment to the South.

The majority of the three islands (Higgs, Horseshoe, and Hen Islands) are excavated and removed to accommodate widening of the channel. The approach channel is also widened in these two scenarios. Both Town Cut and the approach are dredged to -11m CD. The west side of the channel within St. George's Harbour is realigned to the south to maintain a straight sail line.

Alternative 14: New 130m channel – St. George's Channel

Town Cut Channel is abandoned as a cruise ship entry and modifications made to the St. George's Channel to become the primary entry point. The channel would be widened and deepened to 130m and -11m CD to accommodate up to a Tier 2 ship class.

4.3.2 Level 1 Matrix Evaluation for Town Cut

A matrix evaluation was conducted to review and select the top five alternatives out of the initial fourteen alternatives that improve navigation and access to ports while balancing environmental and socio-economic impacts. The selected alternatives were then evaluated in more detail as part of a Level 2 assessment. A comprehensive summary of factors was used in the matrix to evaluate each alternative, with each factor weighed equally. The alternative with the lowest value was considered to balance the navigation requirements with environmental and socio-economic impacts.

Navigation, Engineering, and Operational Factors

- **Clearance (Swept Path)** - The track swept out by the extremities of the vessel when maneuvering. The swept path determines the clear distance between the ship and channel bank. Clearance distance is reduced depending on the environmental conditions at play. For example, wind may

induce a drift into the sail path of the cruise ship whereas the ship may approach the channel on a skewed angle.

- **Rudder Control –** Significant and frequent changes to the rudder are required to maneuver ship through the channel. The amount of rudder control is affected by vessel handling characteristics, safe clearance, environmental factors, and bank suction effects.
- **Underkeel Clearance (UKC) –** The free distance between the lowest point on the ship's keel and the channel bottom. UKC is affected by vessel characteristics, speed, and squat.
- **Risk –** The amount of risk in maneuvering the cruise ship into port based on channel dimension and environmental factors.
- **Dredging/Dredge Material Disposal –** The amount of material to dredge and dispose. A large dredge quantity may be challenging based on demand for the material and potentially significant environmental impact during dredging and disposal.
- **Operations (Downtime) -** Restrictions due to physical and operational issues that result in cruise ships not accessing St. George's.
- **Construction and Operating Cost –** Cost to construct and maintain channel modifications.

Environmental

- **Terrestrial Species/Habitat** – Impacts to quantity (area) and quality of terrestrial habitats.
- **Aquatic Species/Habitat -** Impacts to quantity (area) and quality of aquatic habitats.
- **Coral Reefs –** Degradation or loss of coral reefs due to direct and indirect impacts of channel modifications.
- **Water Quality –** Degradation of water quality that affects aquatic species and habitat.
- **Coastal Processes –** Shoreline is susceptible to erosion due to channel modifications.

Socio-Economic Factors

- **Storm Surge and Coastal Flooding –** Impacts on personal property due to changes to storm levels and coastal flooding as a result of channel modifications.
- **Transportation –** The anticipated improvement and/or reduced strain on the public transportation system as a result of cruise ships accessing St. George's.
- **Waterborne Activity –** The impact on waterborne activity including recreational, fishing, and commercial craft accessing and utilizing St. George's Harbour.

- **Public Access-** The improvements and/or reduction in public access to lands owned and/or operated by the Government of Bermuda, (Higgs, Horseshoe, and Hen Islands).
- **Economic (Tax Revenue) –** The direct and indirect economic impact of improving access for various size cruise ships.

Rating System

Factors were ranked on the appropriate scale from 1 to 7 as follows:

1.	None/Significant Positive Benefit
2.	Low/Positive Benefit
3.	Low+/Minor Positive Benefit
4.	Moderate/Neutral
5.	Moderate+/Minor Negative Benefit
6.	High/Negative Benefit
7.	High+/Significant Negative Benefit

Each alternatives was categorized by the scale for each of the 17 factors, a rating was then calculated for each of the three general categories for each alternative. The average rating for each design alternative was calculated using the following formulas:

$$\text{Weighted Average of the Impact Rating for Navigation, Engineering, and Operational Factors} = \frac{\text{Sum of Ratings}}{\text{7 (Navigation, Engineering, and Operational Factors)}}$$

$$\text{Weighted Average of the Impact Rating for Environmental Factors} = \frac{\text{Sum of Ratings}}{\text{5 (Environmental Factors)}}$$

$$\text{Weighted Average of the Impact Rating for Socio-Economic Factors} = \frac{\text{Sum of Ratings}}{\text{5 (Socio-Economic Factors)}}$$

The three impact ratings were assigned a value based on order of importance to arrive at an overall weighted impact rating. For this evaluation, the following weighted values were assigned:

- 33% - Navigation, Engineering, and Operational Factors
- 33% - Environmental Factors
- 33% - Socio-Economic Factors

Preliminary Ranking

Alternatives with the five lowest scores consisted of the Alternatives 2, 9, 10, 12, and 13 as shown in Table 4-4. The weighed value of Alternative 7 is within 0.01 of Alternative 10 so it was also included. Alternative 1 was the baseline condition and therefore is not considered for further evaluation in this study. Alternative 2, which was developed to accommodate a Tier 1 ship, has the lowest environmental impact but the highest risk associated with navigation while Alternatives 12 and 13, which were developed to accommodate Tiers 1, 2, and 3 ships, has the greatest environmental impact but

Table 4-4: Level 1 Test Matrix

Factors	Alt. 1	Alt. 2	Alt. 3	Alt. 4	Alt. 5	Alt. 6	Alt. 7	Alt. 8	Alt. 9	Alt. 10	Alt. 11	Alt. 12	Alt. 13	Alt. 14
Navigation, Engineering, and Operational Factors (Weighted Average = 33%)														
Clearance (Swept Path)	7	6	6	6	2	6	5	5	4	3	2	2	1	4
Rudder Control	7	6	6	6	4	6	5	5	5	3	5	2	1	5
Underkeel Clearance	7	5	5	5	1	5	4	4	3	3	3	2	1	4
Risk	7	6	6	6	7	6	6	5	4	7	4	2	2	4
Dredging	1	2	3	3	5	4	4	5	5	5	6	6	7	7
Operations	7	7	7	7	7	6	6	5	5	4	3	2	1	4
Construction and Operating Costs	7	3	4	4	7	4	5	5	5	7	6	6	6	7
Environmental Factors (Weighted Average = 33%)														
Terrestrial Habitat	1	3	4	4	4	3	4	5	5	5	6	6	7	4
Aquatic Habitat	1	3	4	4	5	4	4	5	5	5	6	6	7	7
Coral Reefs	1	3	4	4	5	4	5	5	5	5	6	6	7	7
Water Quality	1	3	4	4	5	3	4	4	4	5	5	5	4	5
Coastal Processes	1	2	2	2	2	2	2	3	3	3	4	5	6	6
Socio-Economic Factors (Weighted Average = 33%)														
Storm Surge and Wave Susceptibility	1	2	2	2	2	3	3	4	4	4	5	6	6	3
Transportation	7	5	5	5	4	5	4	4	3	3	2	1	1	3
Waterborne Activity	7	6	6	6	6	5	5	4	3	2	2	1	1	2
Public Access	1	2	3	5	5	4	3	4	5	5	6	7	7	2
Economic	7	4	4	4	3	4	4	3	3	3	2	1	1	3
Weighted Average	3.88	3.83	4.25	4.38	4.26	4.19	4.16	4.31	4.10	4.15	4.27	3.94	4.00	4.42
		(1)					(6)		(4)	(5)		(2)	(3)	

least risk with navigation. Alternatives 9, 10 and 12, developed to accommodate up to a Tier 3 ship, balance the three factors. For Level 1 evaluation, Alternatives 2, 7, 9, and 10 were initially selected for evaluation in the Level 2 assessment. If the results of the full bridge ship simulations indicated that a wider channel is required, Alternatives 12 and 13 would then be added to the Level 2 assessment.

A tractor tug system was selected in lieu of utilizing a mule-assist system (Alternative 5) to guide the cruise ship through a widened channel due to navigational and operational safety concerns. Mule operations typically require calm sea and mild wind conditions to maneuver, tie-up, and pull a ship along the channel. Vessels approaching the fixed platform may be subject to cross winds, tidal currents, and waves, increasing the difficulty and risk in temporarily mooring the ship at the channel entrance. Once tied to the mule, the cruise ship continues to be subject to oceanographic conditions that increase the difficult and risk to pulling the ship through the channel. A tractor-tug alternative is more suitable to assist a cruise ship in maneuvering through the channel during varying oceanographic conditions.

4.4 NORTH CHANNEL AND "THE NARROWS"

Cruise ships associated with Tiers 1 through 3 currently transit the North Channel. The Government of Bermuda is currently discussing accommodating a Tier 4 ship, such as the *Freedom-class,* in the North Channel. However, the Bermuda Pilots Assocation have expressed concern that navigation of Tier 3 and potentially Tier 4 ships may be compromised along several reaches of the channel due to the following issues:

1) "High" points in several locations that reduce full use of the channel width, compromising navigation;
2) Channel bank suction effects in the White Flats region that compromise ship handling; and,
3) Channel alignment near Brackish Pond Flats that affects ship handling.

Each of these concerns was analyzed to determine appropriate solutions to minimize impacts. Each alternative is shown in Appendix B.

Alternative 1: Dredge Channel by approximately 0.5m (-12.5m CD)

The PIANC guidelines indicate that the minimum channel depth for Tiers 1 through 4, taking into consideration vessel squat and vessel drafts associated with a Tier 4 ship is -12.5 m CD to -13.5 m CD. The

2007 bathymetric survey shows that the majority of the North Channel has a minimum depth of -12.5 m CD with the exception of the "high points" near White Flats and the entrance to Grassy Bay. The "high" points reduce this depth by up to 0.5m. For this alternative, the channel would be dredged to -12.5m CD

Alternative 2: Widen and Dredge Channel at White Flats (215m wide at -13.5m CD total)

Modifications to the channel width and depth were evaluated to reduce the effects of bank suction and improve navigation through White Flats. Representatives of the Bermuda Pilots Association indicate that the channel width is too narrow and water depth too shallow to make corrections to the ship sailing line to compensate for bank suction effects and high winds. Cruise ships increase speed in this area to compensate. The Pilots suggest a channel width of 300m and a channel depth of -13.5 m CD to minimize these issues.

The magnitude of the bank suction forces increases with decreasing water depth/draft ratios so increasing channel depth offsets this issue (PIANC, 1997). Similarly, bank suction forces are a function of distance from the channel bank, with the forces decreasing as a cube of the clear distance.

PIANC recommends an additional width of 0.75 times the beam of the largest ship to utilize the channel to compensate for bank suction. Applying Tier 3 characteristics, a channel width of 215m increases the width by 30mon both sides of the channel. Since existing practice by the Pilots is to compensate by increasing vessel speed, which increases squat, a channel water depth of -13.5m CD is required for this reach.

Alternative 3: Realign and Dredge Channel at Brackish Pond Flats (215m wide at -12.5m CD total)

When a bend occurs in channels that are not minor, a supplementary width is added to the channel width to account for maneuvering difficulties and a larger swept path of the ship. The channel width approaching and departing the channel bend at Brackish Pond Flats does not allow for this change in the channel alignment. Applying a water depth to draft ratio of 1.25, the width of the swept path as a function of vessel beam for rudder angles between 10 to 20 degrees is 1.15 to 1.25. Therefore, an additional channel width of 6 to 10m on either side of the channel up to a distance of 10 times the additional width on either side of the bend is suggested by PIANC. Implementing these changes would consist of widening the channel by 20m for a distance of 200m on either side of the bend. This additional width would significantly impact coral reefs on either side of the bend.

In lieu of widening the channel at the bend, the channel is realigned to increase the radius of curvature of the bend to eliminate the need for additional channel width. Once the radius of curvature exceed a ratio of 10:1 and the rudder angle is diminished, the channel bends are considered minor and do not require widening through the bend (Canadian Fisheries and Ocean, 2008). The realigned channel begins approximately 900m north of the channel bend and extends 1600m south of the bend. The water depth in the realigned exceeds -12.5 m CD except near ATONs 33A and 37A, where patch reefs reduce water depth as shown in Appendix B.

4.5 SOUTH CHANNEL

The main restriction to the South Channel is water depth. The primary access improvement to the South Channel is deepening to facilitate transit of Tier 1 and Tier 2 ships. As previously discussed, channel depth guidelines for Tier 1 and 2 ship classes requires the South Channel be dredged to -11.0 m CD. As shown in Appendix B, dredging to this depth extends a distance of approximately 6.5 km along the west section of the South Channel as it approaches Grassy Bay. The average dredge cut is 2m. Dredging will also be required offshore of Crawl Point, impacting patch reefs.

4.6 TWO ROCK PASSAGE

4.6.1 Alternatives Development

The diameter of the turning basin within Hamilton Harbour is approximately 425m, which limits the size of the cruise ship that can berth at the port. A ratio of 1.2 to 2.0 times the length of the largest ship anticipated to use the turning basin is recommended by PIANC. The appropriate ratio depends on the use of tug assist, on-board ship maneuvering equipment, and environmental factors,e.g. wind, currents. Applying a turning basin ratio of 1.5, the largest ship that can utilize the turning basin in Hamilton Harbour is approximately 300m; the upper threshold associated with Tier 2 ships.

The minimum channel width at Two Rock Passage is 106.7m, which straddles the upper and lower bounds of channel width for Tier 1 ship class. Three alternatives were evaluated to accommodate Tier 2 ships as shown in Appendix B.

Alternative 1: Widen Channel by 13.3m (120m total), Channel Realignment to the South.

The channel constriction at Two Rock Passage is widened by 13.3m and deepened to -11m CD by excavating the north end of Lefroy Island. This channel width approaches the upper bounds required for a Tier 2 ship based on PIANC guidelines. The approach from

Dundonald Channel to the constriction needs to be dredged to -11m CD and widened a distance of approximately 850m west of the constriction to Lefroy Island. From the constriction to the turning basin, the channel is widened to the south by the 13.3m. A portion of the shoals surrounding Worlds End Island are removed.

Alternative 2: Widen Channel by 23.3m (130m total), Channel Realignment to the South.

This alternative is similar to Alternative 1 with the extra channel width added to further minimize bank suction effects that have been acknowledged by the Bermuda Pilots when transiting this section of the channel.

Alternative 3: Widen Channel by 23.3m (130m total), Channel Realignment to the North.

This alternative is similar to Alternative 2 but the channel alignment is shifted to the north from approximately 850m east and west of Mobray Island. The south end of Mobray Island is removed. Prior to terminating the channel modification at the turning basin, the channel alignment is shifted toward the south to avoid indirect impacts to the shorelines of the Point Shares area of Hamilton and Saltus Island. However, additional shoreline protection due to passing ship wakes may be required for these shorelines.

Given the limited number of alternatives, a Level 1 matrix evaluation was not conducted. Alternatives 1 and 2 were selected for further evaluation as part of the Level 2 assessment. Alternative 3 was not brought forward for consideration at this time due to concern for indirect impacts to the shorelines of Point Shares area and Saltus Island. If the results of the Level 2 evaluation indicates that Alternative 2 meets the study objectives, the merits of Alternative 3 can be evaluated in future studies.

4.7 LEVEL 2 EVALUATION – SHIP SIMULATIONS

Full Mission Bridge simulations for Town Cut and Two Rock Passage were undertaken to validate and improve the alternatives developed based on the simulated reactions of a cruise vessel with an experienced pilot on the bridge. Ship simulations are considered a standard practice in the maritime industry to evaluate ship movements through channels. A Level 2 evaluation of the North and South Channels was not conducted as part of this study. The full mission bridge ship simulations were performed at MITAGS between May 9 and 12, 2011.

The full MITAGS simulations report is found in Appendix C. The following is a summary of the results and findings of the simulations and development of threshold values for channel access improvement

associated with Tiers 1 through 3. Tier 4 ship class was not evaluated for Town Cut and Two Rock Passage.

4.7.1 Vessel Characteristics

Each vessel modeled in the simulator is validated and put through a series of "sea trials" to verify that the response and handling of the vessels reasonably matches the full scale ship. For the purpose of this study, previously validated models were used from the simulators database of ship models. The models were selected to reasonably match the Tier 1, Tier 2, and Tier 3 vessel sizes identified previously but do not match all parameters exactly. Vessels include the Spirit Class (Carnival Spirit) for Tier 1, the Gem-Class (Diamond Princess) for Tier 2 and Voyager-Class (RCCL Voyager of the Seas) for Tier 3.

Table 4-5 summarizes characteristics of vessel used in the simulations. Each model was equipped with azipod propulsion. However, for the purposes of testing the most limiting condition, all azipods were fixed to simulate conventional propulsion.

4.7.2 Town Cut Simulation Matrix

Initial sets of navigational simulations were compiled for the proposed modifications to the existing 70m wide Town Cut Channel. These sets established the testing sequence of the simulations and identified the bathymetric and environmental conditions utilized in the simulator. Most simulations were dependent on the outcome of prior runs and failure of an earlier run would eliminate those runs dependent on it.

Table 4-5: MITAGS Vessel Models Used in Simulations

Ship Parameter	Tier 1	Tier 2	Tier 3
Prototype Model	Carnival Spirit	Diamond Princess	Voyager of the Seas
Length Overall	293.2m	288.3m	311m
Length Between Perpendiculars	260.2m	254.1m	287.9m
Beam	32.2m	37.5m	38.6m
Draft	8.15m	8.6m	8.6m
Gross Registered Tonnage	90,090 tons	115,875 tons	137, 276 tons
Displacement	46,500 tons	60,636 tons	64,200 tons
Propulsion Type	Twin Fixed Prop	Twin Fixed Prop	Twin Fixed Prop
Propulsion Power	2 x 40,000 kW	2 x 40,000 kW	2 x 42,000 kW

The alternative channel alignments developed in Section 4.3 were narrowed using the Level 1 Evaluation Matrix. Alternatives 3 and 8 were added to the test matrix as these channel modifications could be readily performed without significant additional effort.

The Town Cut alternatives carried forward to the simulations were:

- Alternative 2: 100m wide channel with no channel realignment
- Alternative 3: 100m wide channel with channel realignment
- Alternative 7: 120m wide channel with no channel realignment
- Alternative 8: 130m wide channel with no channel realignment
- Alternative 9: 130m wide channel with channel realignment
- Alternative 10: 130m wide channel with channel realignment and tug assist
- Alternative 12: 155 m wide channel with channel realignment
- Alternative 13: 180 m wide channel with channel realignment

The test matrix established an initial set of simulations to evaluate each alternative's performance for inbound and outbound cruise vessels under a range of environmental conditions presented in Section 3.0:

- Southerly winds of 15 and 25 knots, with occurrences of 70 to 97% of the year.
- Waves of 1m with a wave period of 7 seconds from the east.
- Tidal currents of 0.5 knots transverse to the channel centerline for the Town Cut approach channel and longitudinal through Town Cut.

An initial matrix of 38 potential runs (scenarios) was identified before entering the simulator as shown in Appendix C. It was recognized that some tests may be dropped depending on the results of previous tests or that matrix parameters may be adjusted as the tests progressed.

4.7.3 Town Cut Simulations and Modifications

Simulations were conducted in the MITAGS simulator between May 9 and 12, 2011 with pilots from Bermuda Pilots Association - Capt. Rudolph Cann and Capt. Anthony Robinson - piloting each simulation. Mr. Francis Richardson, Director of Marines and Ports Services, and Mark Pirrello, Moffatt & Nichol's project manager, were present during the simulations. The pilot's experience in navigating Town Cut was an asset in developing realistic scenarios and ultimately in modifying the channel configurations to represent realistic conditions.

The following is a summary of the results of the simulations for the alternative channel alignments. Full details of the simulations are presented in Appendix C.

Simulations were evaluated based on a several criteria which provide indicators of the controllability and safety of the maneuvers:

- Underkeel Clearance – Assesses the remaining water under the hull after accounting for squat, heave, pitch, and roll.

- Drift – Measures the minimum distance from the vessel swept path to the edge of the channel.
- Rudder Angle – The amount of rudder applied during maneuvers. Extensive use of rudder, including instances where the rudder is "hard over" for a significant portion of the maneuver is not considered safe as there is not reserve rudder control to make course corrections.
- Engine Telegraph – Engines used to full capacity in a 'power burst' mode indicates corrective measures outside of normal planned maneuvers

Alternative 2: Widen Channel by 30 m (100 m total) No Channel Realignment (Runs 1 through 3 – MITAGS)

Alternative 2 was evaluated for a Tier 1 vessel without applying environmental factors (wind, waves, or current). Inbound and outbound transits were accomplished successfully. When a 15 knot southerly wind was added, the vessel experienced drift angles of up to 3.5 degrees which increased swept path and reduced the bank clearance to less than 8m on the north side of Town Cut as shown in Figure 4-2. Pilots noted that the sailing line on approach to Town Cut was selected to have the vessel path avoid Hen Island upon entering St. George's Harbour, increasing the difficulty of the approach and reduce maneuverability in the channel.

The outbound maneuver was not attempted due to the unacceptable performance of the inbound maneuver. Minimum underkeel clearance for the Alternative 2 tests was 1.5m. Figure 4-3 shows the under keel clearance (UKC), rudder angle, drift angle, and engine RPMs over the 5,000m length of the simulation.

Figure 4-2: Swept Path of Tier 1 Cruise Vessel with 15 Knot Wind speed

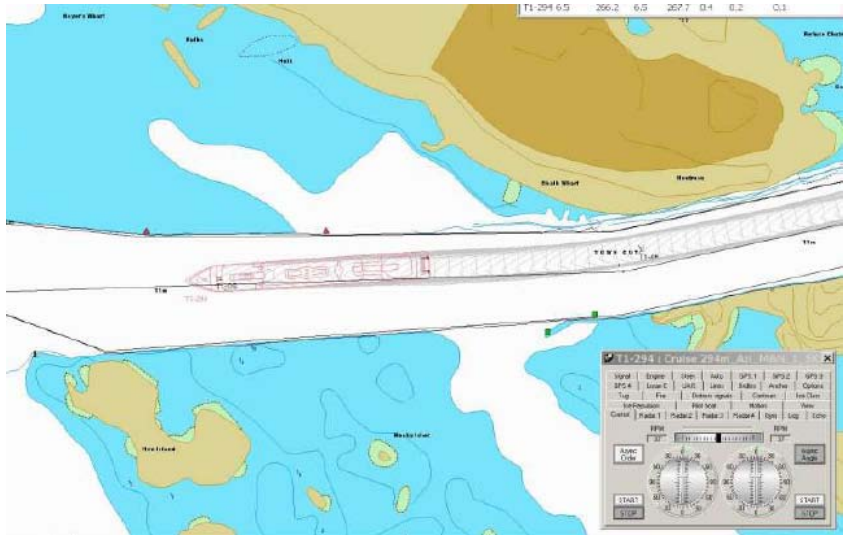
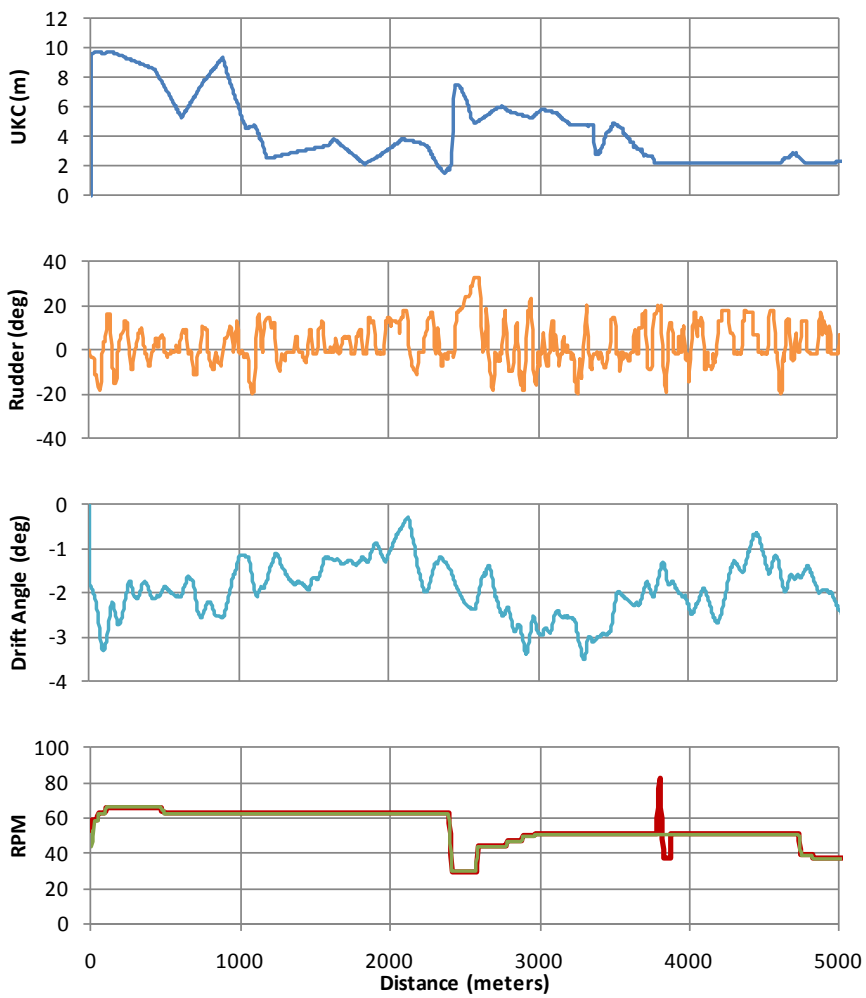


Figure 4-3 shows that maximum rudder was used only briefly and engine rpm were slowly varying over the simulation, indicating reserve capacity in both these control mechanisms during the simulation.

Figure 4-3: Plot of UKC, Rudder, Drift Angle and Engine RPM for Run 2 at 15 knots.



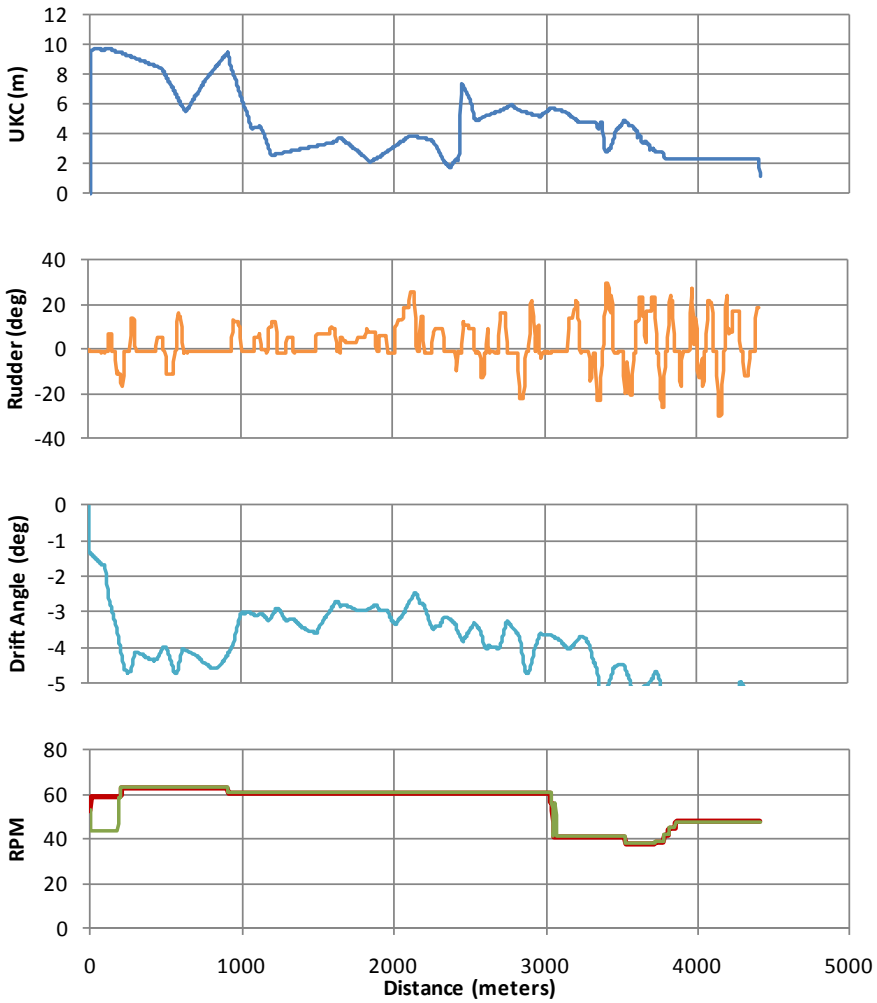
Based on the results of first two simulations (no wind and 15 knot wind), it was decided to simulate the next series of vessel maneuvers through the channel applying a 25 knot wind. A 25 knot wind encompasses 97% of the wind occurrence and is generally considered the maximum operating wind for most channels by the Pilots. This cumulative percentage also minimizes downtime of cruise vessels at St. George's.

Alternative 3: Widen Channel by 30 m (100 m total) Channel Realignment to South (Run 4 – MITAGS)

Alternative 3 was evaluated for a Tier 1 vessel. The vessel was simulated for an inbound maneuver with a 25 knot southerly wind with no waves and no current. The larger drift angle shown in Figure 4-4 prevented the vessel from keeping upwind through Town Cut and the vessel grounded on the north bank of the channel. Significant rudder including several "hard overs" was required as the ship approached the channel. Pilots indicated that the channel is not wide enough to accommodate the swept path of inbound cruise ships at this wind speed.

After review of the simulation results, the 100m wide channel did not provide sufficient clearance for the environmental conditions. Since recommended clear distance between the ship and the channel bank ranges from 0.5 to 1.0 times the vessel beam (PIANC, 1997), it was

Figure 4-4: Plot of UKC, Rudder, Drift Angle and Engine RPM for Run 4.



determined that Alternative 7 (total channel width of 120m) is not acceptable and was eliminated from the test matrix. Bermuda Pilots also indicated that widening the channel to 130m would require realigning the channel to the south since the departure angle leaving Town Cut is difficult to accomplish with the 4 to 5 degree drift angles observed in the previous simulations. Thus, Alternative 8 (130m wide channel with no channel realignment) was removed from the test matrix.

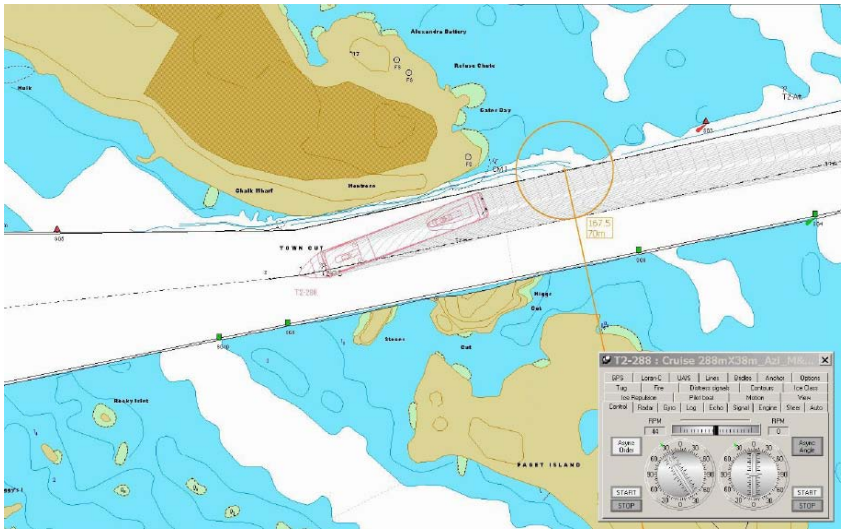
Alternative 9: Widen Channel by 60m (130m total) Channel Realignment to South (Runs 5 through 8- MITAGS)

Alternative 9 was tested with the Tier 2 vessel. This tier ship class was selected in lieu of Tier 1 since the 130m width was identified in the Level 1 matrix evaluation as supporting a Tier 2 ship. Environmental conditions were 25 knot southerly winds coincident with 0.5 knot currents and offshore waves.

Inbound and outbound transits were simulated. During inbound maneuvers with the 25 knot cross wind, drift angles up to 5 ½ degrees were noted, resulting in a swept path of 70m. The stern of the ship passed within 10m of the north bank of the channel as shown in Figure 4-5. On the outbound maneuver, the Pilot was able to maintain the desired course even with the 4 to 5 degree drift angle. However, the Pilot indicated that this maneuver in the real world

situation presents a higher risk to ship safety. The environmental conditions were modified, reducing the wind speed to 15 knots to assess if transit conditions through the 130m wide channel provided an acceptable level of risk. Both inbound and outbound transits were completed successfully. The closest approach to the channel edge during the inbound maneuver was 42m with a minimum underkeel clearance of 0.7m. An underkeel clearance of 1.5 to 2m is preferred by the cruise industry.

Figure 4-5: Swept Path of Tier 2 Cruise Vessel for Run 5



Rudder angles over 30 degrees were required to maintain the 2 degrees or less of drift angle. During outbound transit, the bank clearance was 46m with an UKC of approximately 1.3m. Figure 4-6

Figure 4-6: Plot of UKC, Rudder, Drift Angle and Engine RPM for Run 7.

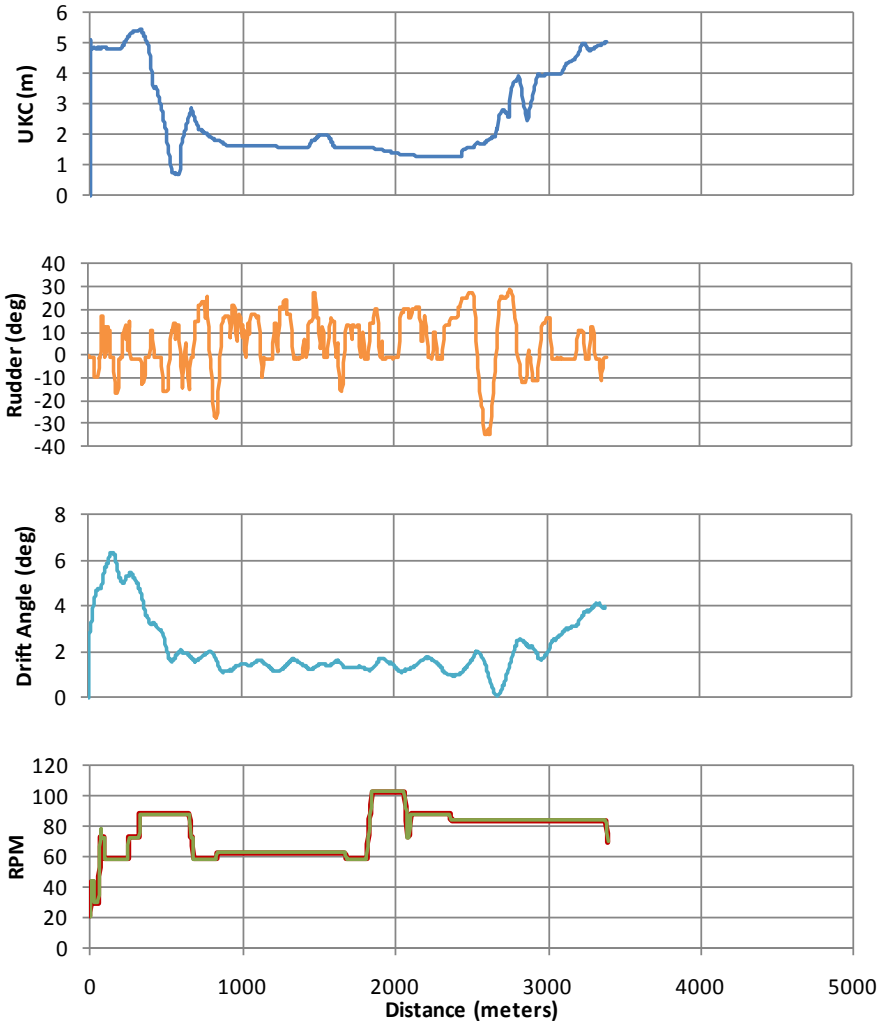
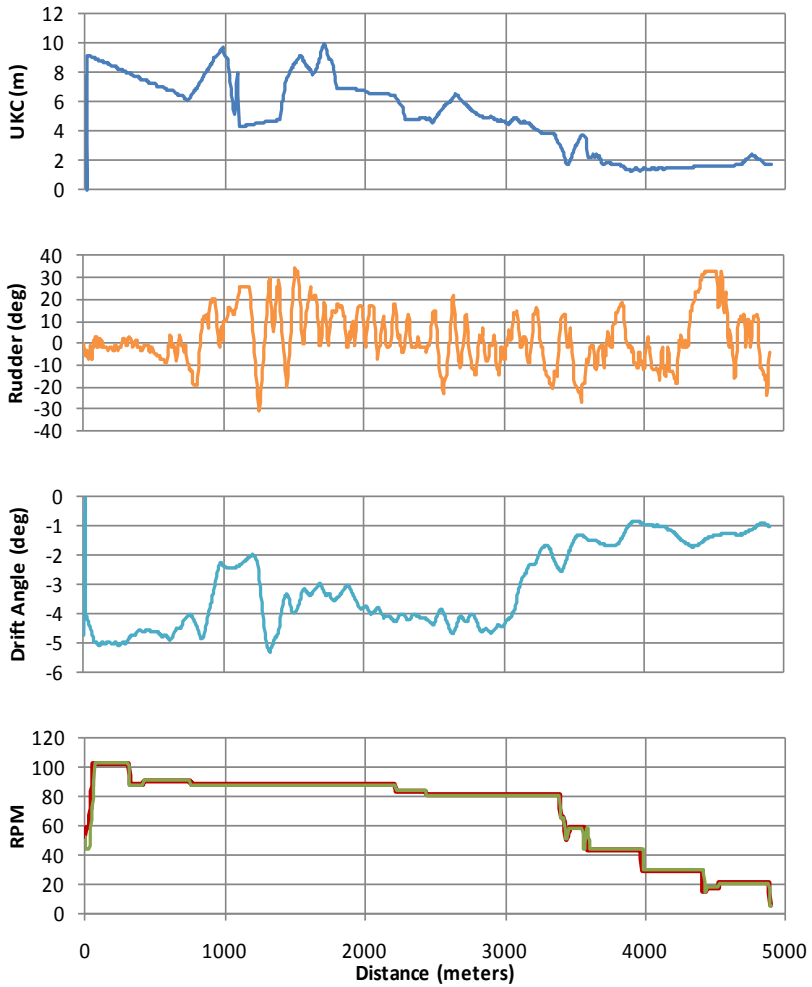


Figure 4-7: Plot of UKC, Rudder, Drift Angle and Engine RPM for Run 8.



and Figure 4-7 show the UKC, rudder angle, drift angle, and engine speed for the inbound and outbound maneuvers, respectively.

Although the Tier 2 ship was able to transit through the 130m wide channel at the 15 knot wind speed with sufficient bank clearance, considerable use of the rudder was required to maintain control during the transit. The lack of reserve capacity in the rudder would pose a significant safety risk to controlling the drift angle and maintain bank clearance if varying wind speeds would occur during transit. The Bermuda Pilots agreed with this conclusion.

Alternative 10: Widen Channel by 60 m (130 m total) Channel Realignment to South with Tug Assist (Runs 9 through 11-MITAGS)

Tugs were added to the simulation to attempt transit of a Tier 2 ship under 25 knot winds. The simulator modeled two, 60-tonne bollard pull tractor tugs. The tugs were controlled from the simulator terminal. Three attempts (two inbound and one outbound) were made using tugs pulling on the bow and stern. In all cases, the drift angle of the vessel was over 4 degrees. On the two inbound transits, the cruise ship ran aground as shown in Figure 4-8. On the outbound maneuver, one of the tug ships ran around as there was insufficient room to position the tug to provide the proper pull to counteract the drift of the cruise ship.

The simulation highlighted the lack of sufficient room for the tugs to operate inside the channel with enough lead to control the vessel

path. Furthermore, the Bermuda Pilot indicated that tug escort would have to be a regular occurrence to be proficient. If tugs are only needed above 20 knots, Pilots would not obtain sufficient experience to use the tugs effectively. Use of tugs also adds another level of complexity as the Pilot has to communicate with the tugs and there would be a delay in the tug response desired by the Pilot.

Figure 4-8: Cruise Vessels Grounds in Run 10.

Initial Findings and Modifications

Based on the initial set of simulations for Alternatives 2, 3, and 9, the minimum width for a Tier 2 vessel through Town Cut would be 130m. However, even at this width, operating wind speed would likely be limited to less than 15 knots, which results in significant downtime and impacts on cruise ship arrival and departure schedules. A straightened and widened channel will be necessary to consistently accommodate a Tier 1 or Tier 2 for wind speeds of 15 knots or more. Tug assist will likely be ineffective in controlling the vessel in a narrow straight channel for 25 knot winds.

The channel alternatives were subsequently modified to include two additional channel widths: a 155 m wide channel (Alternative 12) and a 180 m wide channel (Alternative 13). Additionally, the port side buoys from Green Buoy '2' to the navigation marker on Higgs Island were relocated southward for both alternatives at the request of Pilots to provide more room to steer the vessel into the southerly winds on approach to Town Cut. Alternatives 12 and 13 were tested with the Tier 2 and Tier 3 vessels.

Alternative 12: Widen Channel by 85m (155m total), Channel Realignment to the South (Runs 16 and 17, 21 and 22).

Alternative 12 was tested with both the Tier 2 vessel and the Tier 3 vessel for 25 knot southerly winds coincident with wave and currents. For these tests, the channel depth was reduced to mimic the deeper draft of most Tier 3 ships that is not represented by the Tier 3 vessel used in the simulator.

Both inbound and outbound maneuvers for the Tier 2 vessel were successful even with a drift angle of 4 to 5 degrees through most of the maneuvers as shown in Figure 4-9. Performance was acceptable to the Pilots. Figure 4-10 and Figure 4-11 show the output parameters from the Run 16 and 17 simulations for the Tier 2 vessels. The closest approach to edge of the channel was 34m and the minimum UKC was 1.4m. Heavy use of the rudder was made, but maneuvers were controllable. Realigning the southern buoys allows the Pilots to stay upwind prior to entering Town Cut and allowing the vessel to enter Town Cut along the centerline of the channel.

Figure 4-9: Swept Path of Tier 2 Cruise Vessel for Run 16

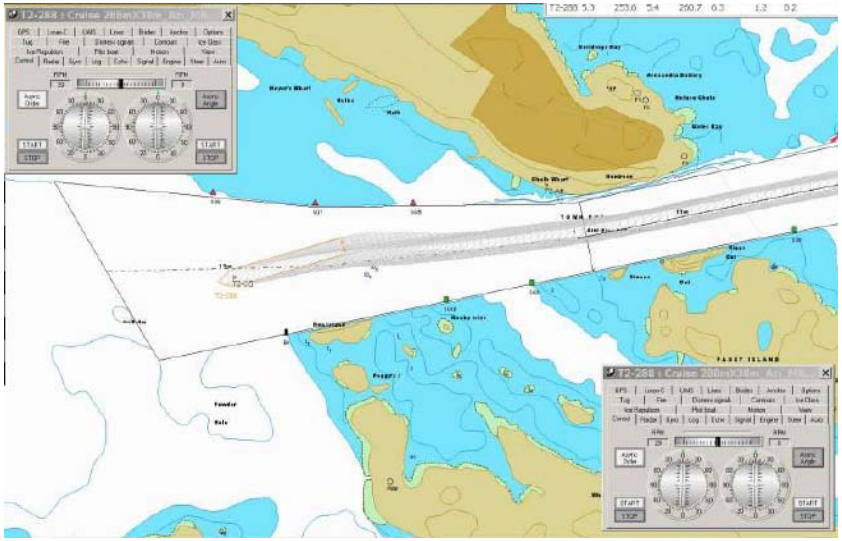


Figure 4-10: Plot of UKC, Rudder, Drift Angle and Engine RPM for Run 16

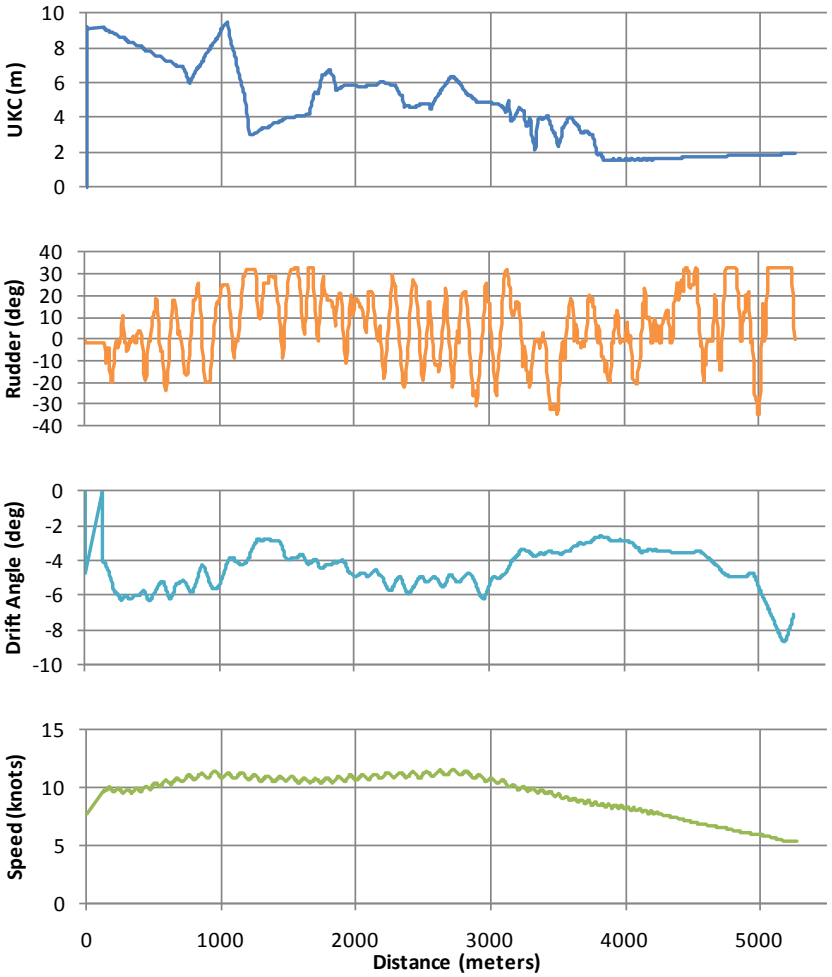
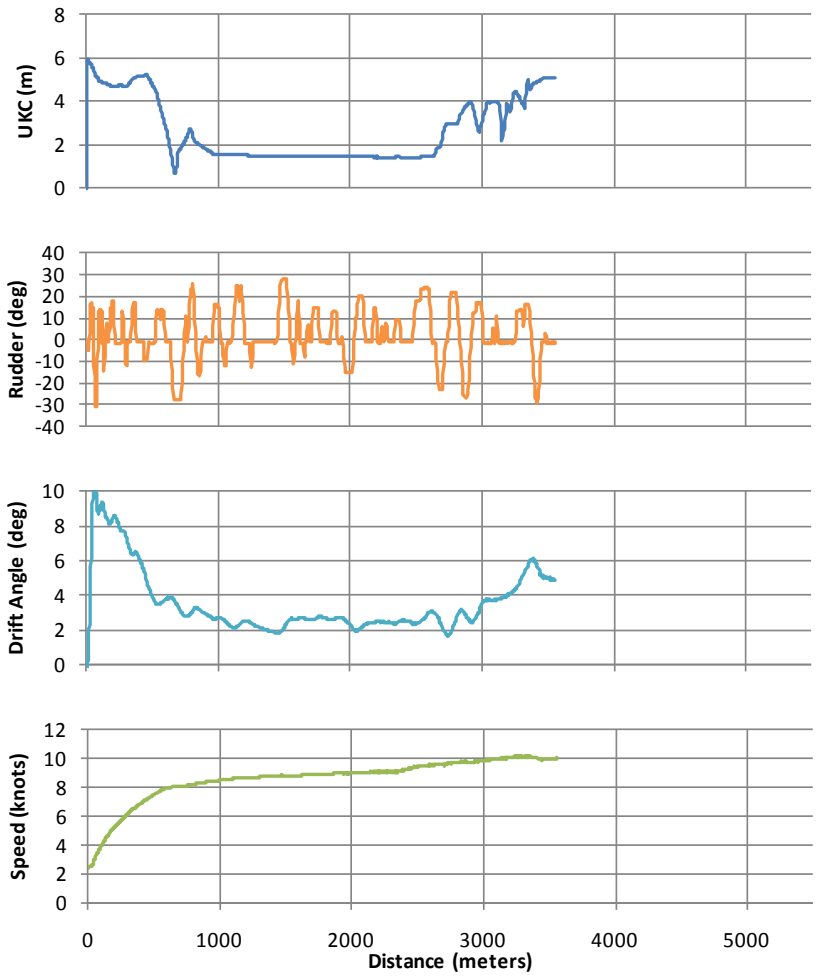
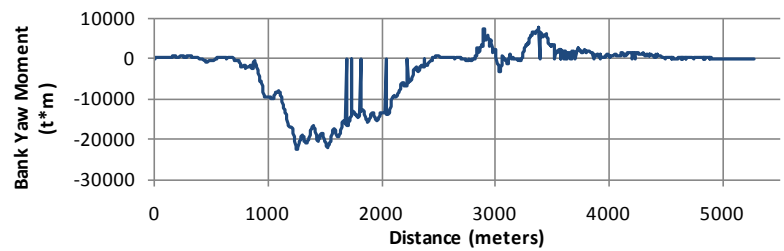


Figure 4-11: Plot of UKC, Rudder, Drift Angle and Engine RPM for Run 17



The widened channel has few bank effects. Figure 4-12 displays the imposed bank suction yaw moment on the vessel. In the last 1,500m of the approach (when the vessel is passing through Town Cut) the vessel experiences little bank suction induced yaw. As a result, the training wall discussed previously on the south side of the channel adjacent to Horseshoe Island may not be required with a widened channel.

Figure 4-12: Bank Yaw Moment



The simulations with the Tier 3 vessels for Alternative 12 were successful, but with little reserve rudder. The closest approach of the hull to the side of the channel was 32m on the inbound maneuver, slightly closer than the Tier 2 vessel. Hard over rudder (angle of greater than 30 degrees) was required for close to one minute at the inner part of Town Cut to maintain course on the inbound maneuver. No reserve rudder was available at this portion of the maneuver. The Pilots reported that the inbound bank clearance was not an acceptable risk (less than one beam width) while the outbound

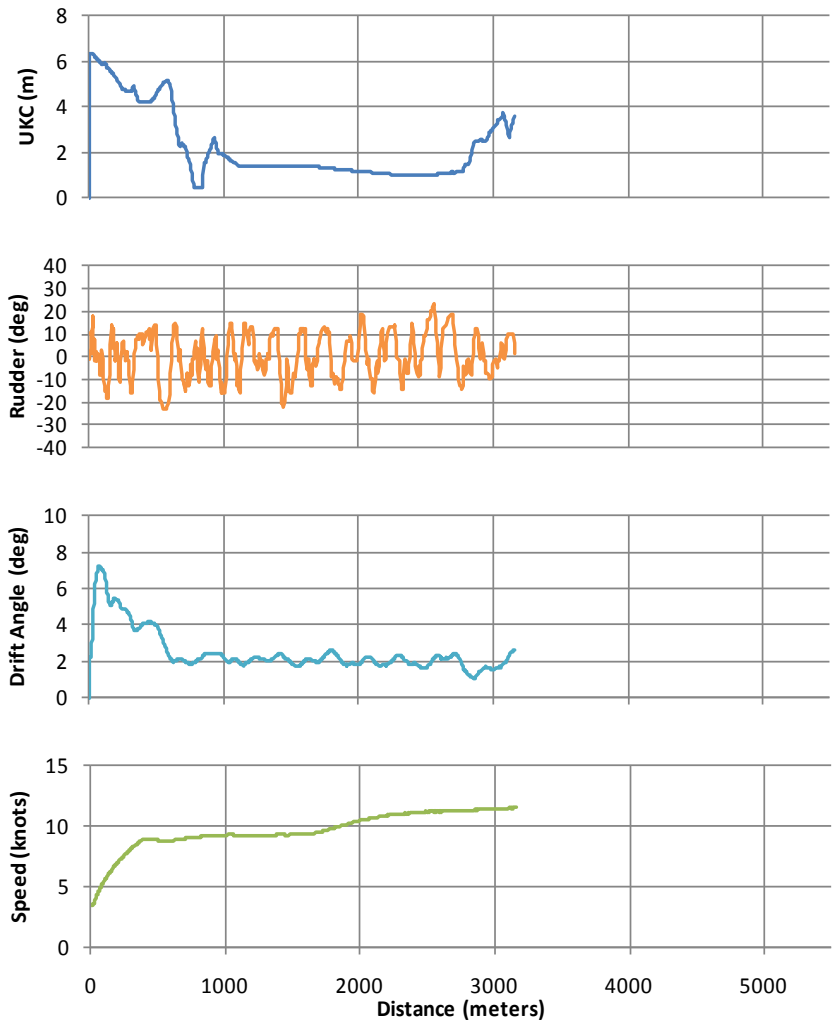
maneuver was acceptable. Results of these tests indicate that UKC would decrease to 0.7m if deeper draft Tier 3 ship utilizes the channel. The low underkeel clearance may have contributed to the heavy rudder use required on the inbound maneuver. The Tier 3 vessel may require deeper and/or wider channel to maintain a well-controlled maneuver.

Alternative 13: Widen Channel by 110m (180m total), Channel Realignment to the South (Runs 18, 19, and 20, 21 and 22).

Alternative 13 modeled a channel with minimum width of 180m to accommodate Tier 3 vessels. The results of the simulation runs for this alternative were comparable to those of Alternative 12. All runs were simulated with the Tier 3 vessel. The Tier 3 simulator vessel model has a draft of 8.6m, while some vessels of this length may have arrival drafts of up to 9m. To model the effects of the reduced underkeel clearance (UKC) these vessels would experience in the 11 m deep channel, the simulated water depth in Town Cut was reduced to 10.5m with a resulting static UKC of 1.9m.

For inbound maneuvers, the vessel maintained drift angles of less than 3 degrees within Town Cut. Minimum bank clearance was 60 meters. The reduced UKC required significant application of rudder to make course corrections as shown in Figure 4-13 with rudder hard over for 1.5 minutes at the end of the track.

Figure 4-13: Plot of UKC, Rudder, Drift Angle and Engine RPM for Run 22



Outbound, the drift angle was 2 to 3 degrees, which was considered manageable by the Pilots. Maneuverability through Town Cut was improved on the outbound transit, but UKC was still less than 1m.

For Tier 3 vessels, the channel depth should be increased by 0.5 to 1.0m (-11.5 to -12.0m CD). The 180-meter width is greater than required for maneuvering the Tier 3 vessel, even with degraded ship handling due to shallow water.

4.7.4 Conclusions and Recommendations – Town Cut

The full mission bridge simulations of Town Cut resulted in the following summary of conclusions and recommendations for channel widths associated with the four tier vessels[4].

- PIANC guidelines used to develop the initial channel widths underestimated the widths for cruise vessels with large sail areas and relatively shallow draft. Channels required in cross winds must account for increased drift angle.
- Channel width of 130m (60m wider than the existing 70m wide channel) was marginal for a Tier 2 ship when wind conditions were less than 15 knots.
- Channel width of 155m provides sufficient width for Tier 2 vessel to navigate Town Cut under 25 knot winds
- The rock training wall structure may not be required for a 155m wide channel – simulations show little to no bank suction effects.
- Channel width of 155m is marginally successful for Tier 3 vessels but required hard over rudder for extended time to successfully execute. No reserve rudder remained for unexpected maneuvering.
- A channel width of 180m provides sufficient clearance for Tiers 1, 2, and 3. The Pilots indicated that a slightly narrower channel width may accommodate a Tier 3 ship.
- Channel dredge depth of -11m CD provides minimum UKC of 1.4m for the Tier 2 vessels but drops to less than 1m for Tier 3 vessels. Channel depth of -12.0m CD is recommended for Tier 3 vessels.
- Transits through Town Cut are not recommended during winds greater than 25 knots, regardless of width.

[4] Four Tiers of Vessel Classes

Tier 1 Panamax	Tier 2 Post Panamax 1	Tier 3 Post Panamax 2	Tier 4 Post Panamax 3
Length: ≤294m Beam: 32.3m Draft: 7.6 - 8.2m	Length: ≤294 m Beam: 36m Draft: 8.2m	Length: 315m Beam: 37m Draft: 8.2m	Length: 339m Beam: 38.6m Draft: 8.8m

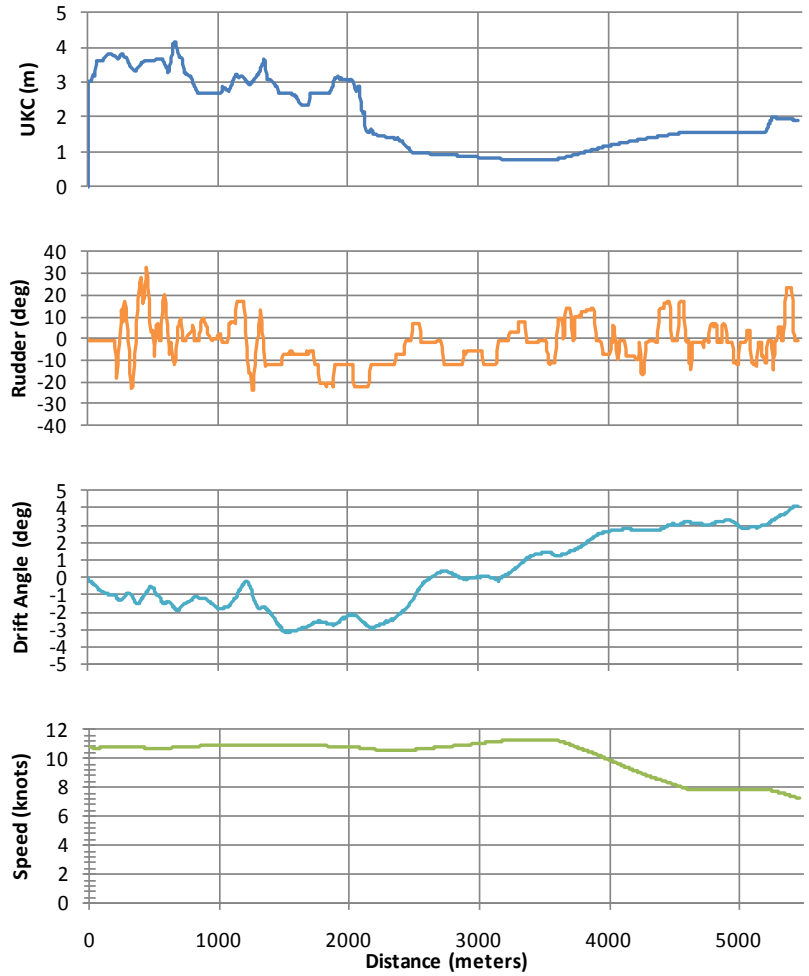
4.7.5 Test Matrix and Simulations – Two Rock Passage

Two of the three alternatives developed for Two Rock Passage were evaluated at the MITAGS full mission bridge simulator: Alternative 1, which widens the channel by 13.3m (total 120m); and Alternative 2, a total channel width of 130m realigned to the south. All simulations were conducted with the Tier 2 vessel since Tier 3 vessels were eliminated from consideration due to the size of the turning basin at Hamilton Harbour. Environmental conditions were limited to a 25-knot southerly wind. Two Rock Passage is well protected from waves or significant tidal currents so these environmental conditions were not incorporated into the simulations.

Alternative 2: Widen Channel by 23.3m (130m total), Channel Realignment to the South. (Runs 12, 13, and 14).

Alternative 2, the wider channel, was simulated first based on the outcome of the Town Cut simulations. Inbound simulations to Hamilton were initiated in Dundonald Channel near Buoys 33 and 34 at an initial speed of 8 knots. To maintain steerage through the turn into Two Rock Passage, the Pilots accelerated to 11-12 knots through the turn and then reduced speed through the constriction at Two Rock. Two inbound simulations were conducted with varying speeds through the turn. One outbound simulation was conducted.

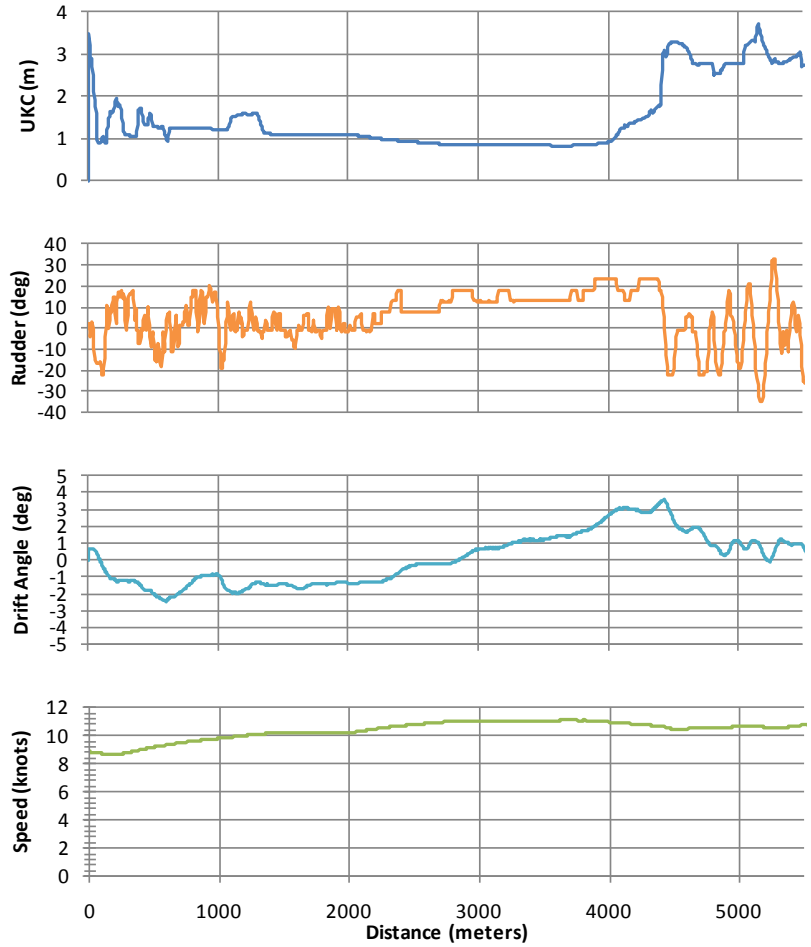
Figure 4-14: Plot of UKC, Rudder, Drift Angle and Engine RPM for Run 12



displays the tracked simulation parameters for the inbound passage: UKC, drift angle, rudder angle, and speed. The maneuver is well controlled throughout the transit. Rudder angles are less than 30 degrees over most of the transit and drift angles are less than 3 degrees. The vessel passes through the middle of the Two Rock narrows with the closet approach to the channel edge at 34m. However, the Pilots maintain a speed of 11-12 knots through the bend to maintain steerage. As a result the vessel squats and heels resulting in an UKC of about 0.8m through the bend, which is less than the recommended safety allowance of 1 to 2m.

Figure 4-15 displays the simulation parameters for the outbound passage. The results are similar to the inbound scenario. The maneuver is well controlled with reserve rudder and drift angles generally less than 3 degrees. The clear distance to the channel edge was 35m. Again, the speed through the turn to Dundonald Channel decreases underkeel clearance to 0.8m. While the channel and bend widths seem sufficient for the maneuver, the turn may need to be deepened by approximately 0.5m (-11.5m CD) to provide sufficient safety clearance through the bend.

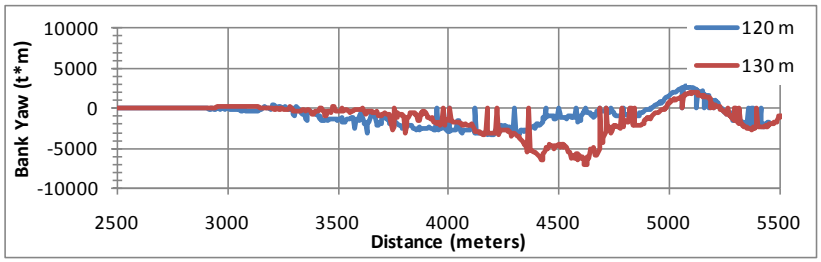
Figure 4-15: Plot of UKC, Rudder, Drift Angle and Engine RPM for Run 14



Alternative 1: Widen Channel by 13.3m (120m total), Channel Realignment to the South.

A single simulation was conducted for the 120m wide channel through Two Rock. Overall the results of the simulation were similar to the 130m alternative. However, the pilots noted increased bank effects for the narrower channel where increased rudder is used at the end of the simulation. Figure 4-16 displays the bank suction yaw moment imposed on the vessel for the 130m channel and the 120m channel. With the narrower channel the imposed moment at the Two Rock narrows is twice as much as the 130m width. Pilots reported the effect was not acceptable when passing through Two Rock. It is therefore recommended that the minimum width for safe passage of a Tier 2 vessel is 130m.

Figure 4-16: Two Rock Bank Suction Yaw Moment



4.7.6 Conclusions and Recommendations – Two Rock Passage

The full mission bridge simulations of Two Rock Passage resulted in the following conclusions and recommendations.

- Minimum recommended channel width at Two Rock is 130m for a Tier 2 cruise ship.
- Recommended dredge depth through the bend from Dundonald Channel to Two Rock Passage should be -11.5m CD for a Tier 2 vessel to accommodate increased speed in the turn (for a maximum draft of 8.6m).
- The selection of the channel alignment (130m wide channel to the north or south) should be further evaluated with respect to environmental and shoreline impacts.

4.8 ACCESS IMPROVEMENT THRESHOLDS

4.8.1 Town Cut

Results of the Level 1 and Level 2 assessments for Town Cut were used to develop thresholds to improve access associated with Tier 1, 2, and 3 ship classes.

A 130m wide channel did not provide sufficient bank clearance (less than 10m) when winds exceeded 15 knots for a Tier 2 ship class during simulations. However, a Tier 2 ship was able to transit with

controllable drift within the 155m wide channel up to a 25 knot wind. Interpolating these results to maintain a minimum bank clearance of one beam width (Tier 1 beam width is 32m) up to a 25-knot operating wind speed, a 145m channel at a design depth of -11m CD is considered the threshold channel geometry for the Tier 1 ship class to transit Town Cut.

The 155m wide channel at a design depth of -11m CD is considered the threshold channel geometry for the Tier 2 ship class up to a 25-knot operating wind speed. Sufficient bank clearance and underkeel clearance were maintained for this ship class.

A Tier 3 ship class was able to navigate through the 180m wide channel with controllable swept path and bank clearance exceeding 1.5 times the beam of the Tier 3 ship up to a 25-knot operating wind speed. Underkeel clerance in the channel was the primary concern related to ship handling. A water depth of -12m CD is the minimum required to maintain rudder control for a Tier 3 ship.

Based on the maneuvering simulations, a 155m wide channel is marginal for transit of a Tier 3 for a 25-knot operating wind speed. Bank clearance of less than one beam width was observed on the inbound transit of the Tier 3 vessel, which poses a safety risk. Widening the channel by 10m to 165m total width provided adequate bank clearance. For this feasibility study, a 165m wide channel at a design channel depth of -12m CD is deemed the minimum channel threshold. If the threshold improvement associated with a Tier 3 vessel is selected, additional simulations may be used to optimize channel width in final design.

In summary, the three thresholds for access improvement at Town Cut shown in Figure 4-17, Figure 4-18, Figure 4-19, and Appendix D are:

- Tier 1 - 145m wide channel at a channel depth of -11m CD
- Tier 2 – 155m wide channel at a channel depth of -11m CD
- Tier 3 – 165m wide channel at a channel depth of -12m CD

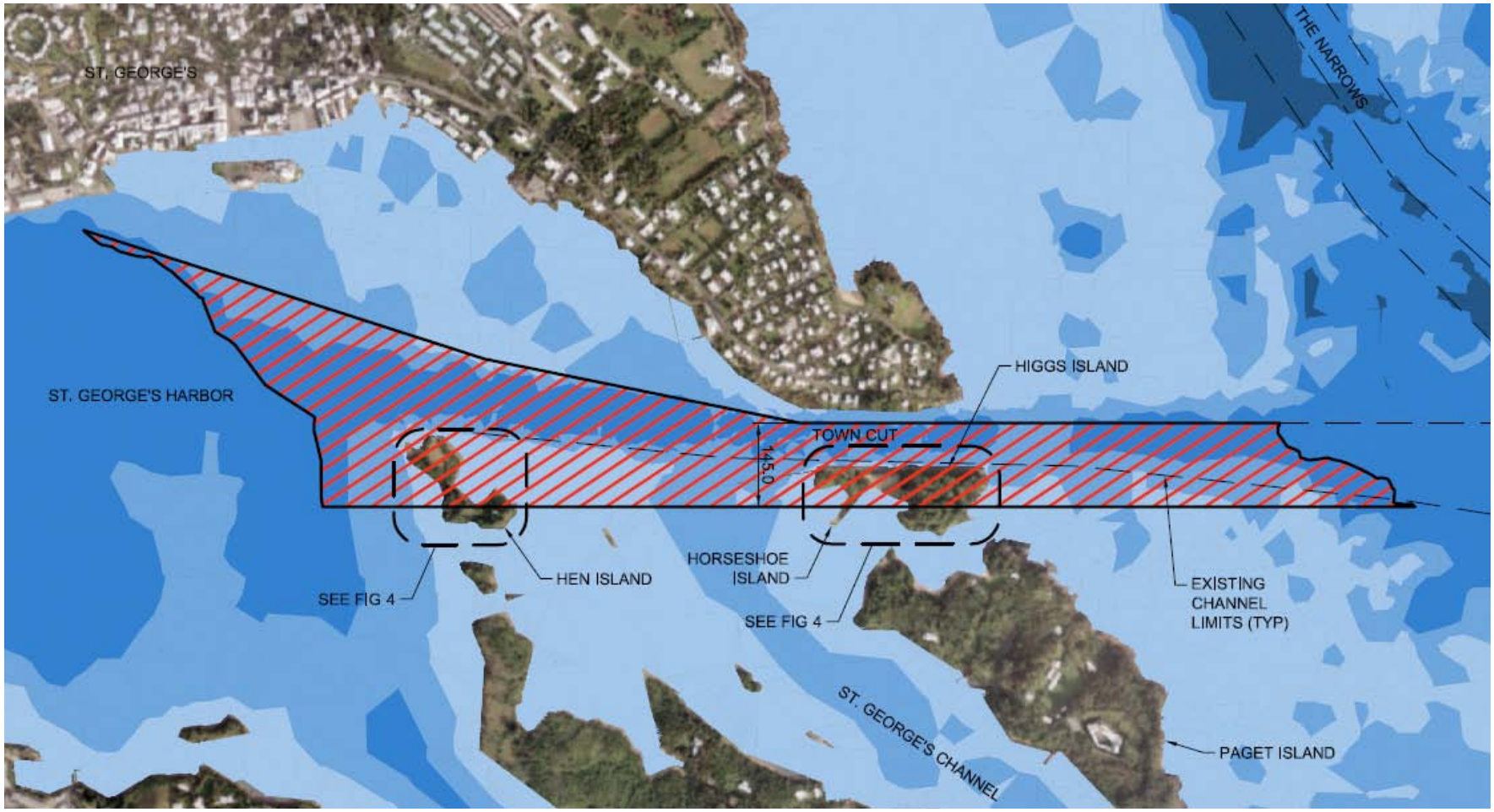
4.8.2 North and South Channels

The access improvements for the North Channel (Alternatives 1 and 3) presented in Section 4.4 and the alternative presented in Section 4.5 was identified as the minimum threshold channel improvements for access and navigational safety to accommodate Tier 4 vessels. Alternative 2 of the North Channel significantly enhances navigational safety through the Whites Flat region by increasing bank clearance and reducing bank suction effects. Figure 4-20, Figure 4-21, and Figure 4-21, and Figure 4-22 show the access improvements for the North Channel. Figure 4-23 shows the South Channel Improvements. Appendix D contains all North and South Channel improvements.

4.8.3 Two Rock Passage

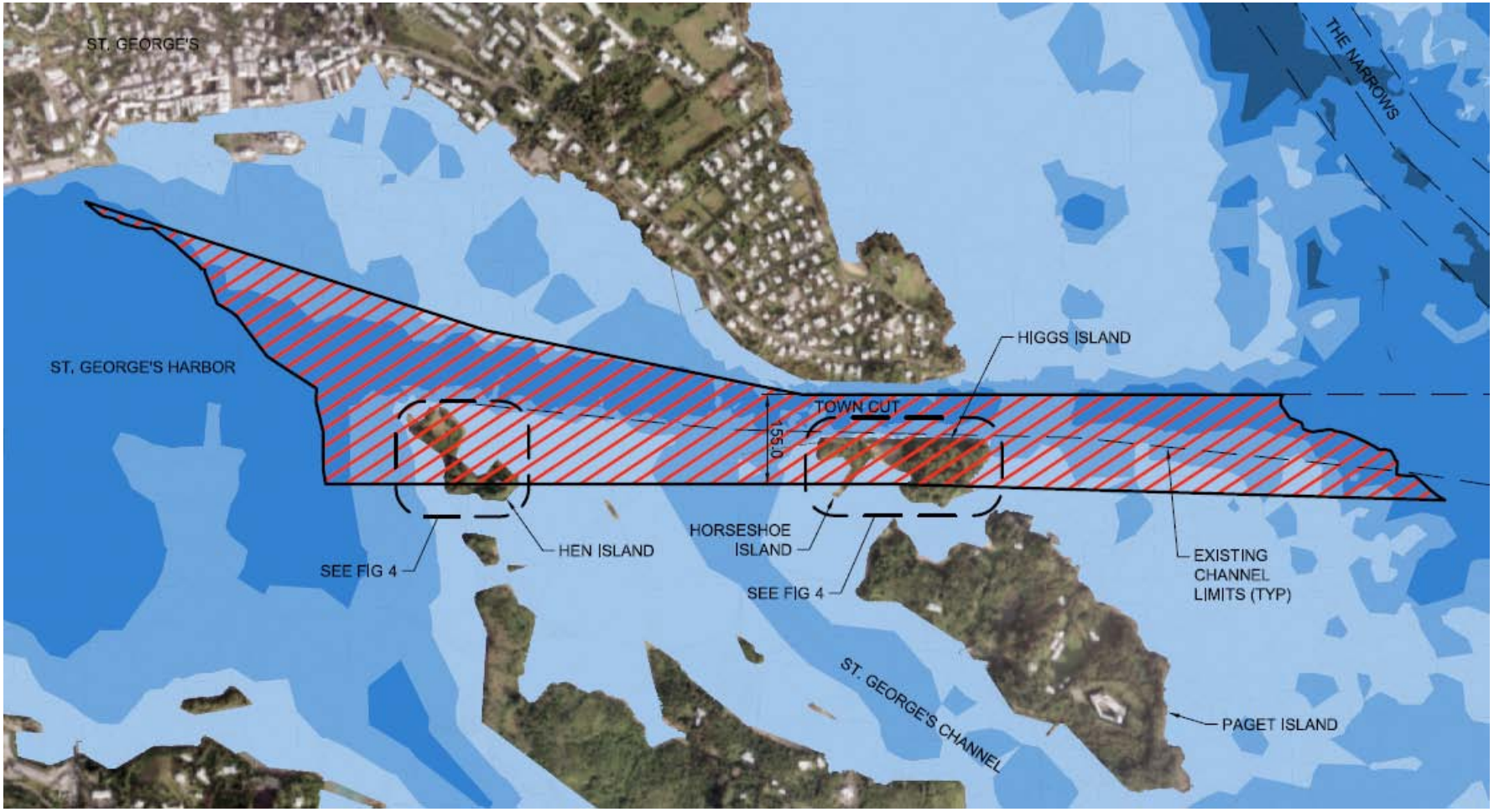
At 130 m wide, Tiers 1 and 2 ship classes were able to transit Two Rock Passage without significant rudder usage and adequate bank clearance. Channel depths of -11.5 m CD from Dundonald Channel to the constriction and -11m CD from the constriction to the turning basin were identified based on limited underkeel clearance during the simulations. Figure 4-24 and the figures in Appendix D show the access improvement.

Figure 4-17: Tier 1 Threshold for Town Cut – 145m Wide Channel at -11m CD and Channel Realignment



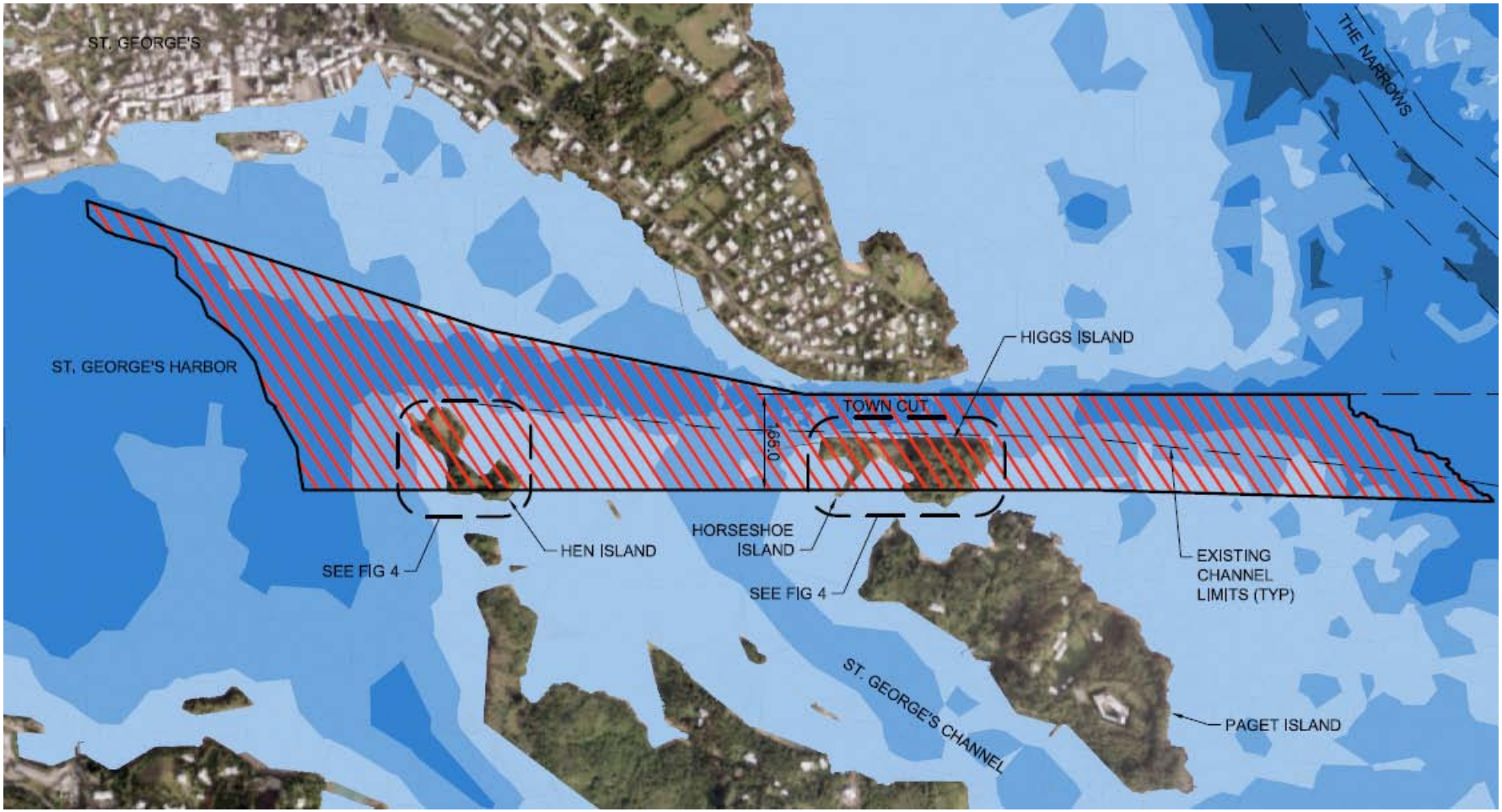
Proposed Improvement

Figure 4-18: Tier 2 Threshold for Town Cut – 155m Wide Channel at -11m CD and Channel Realignment



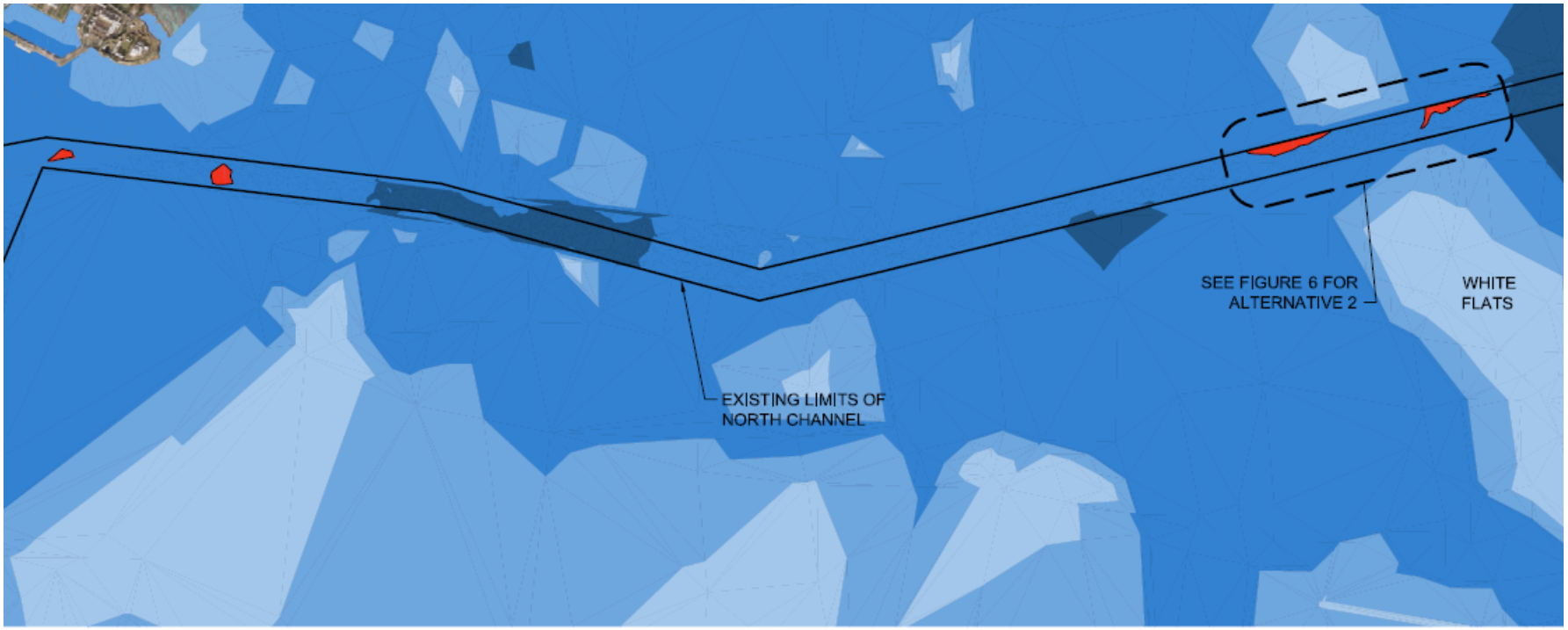
Proposed Improvement

Figure 4-19: Tier 3 Threshold for Town Cut – 165m Wide Channel at -12m CD and Channel Realignment

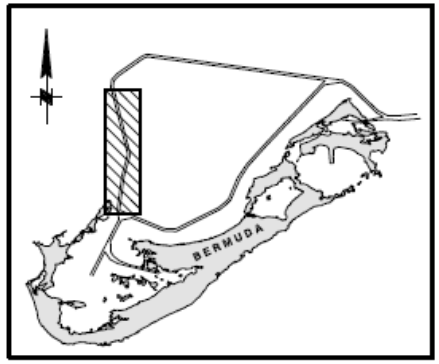


Proposed Improvement

Figure 4-20: A 152.5m Wide Channel at -12.5m CD

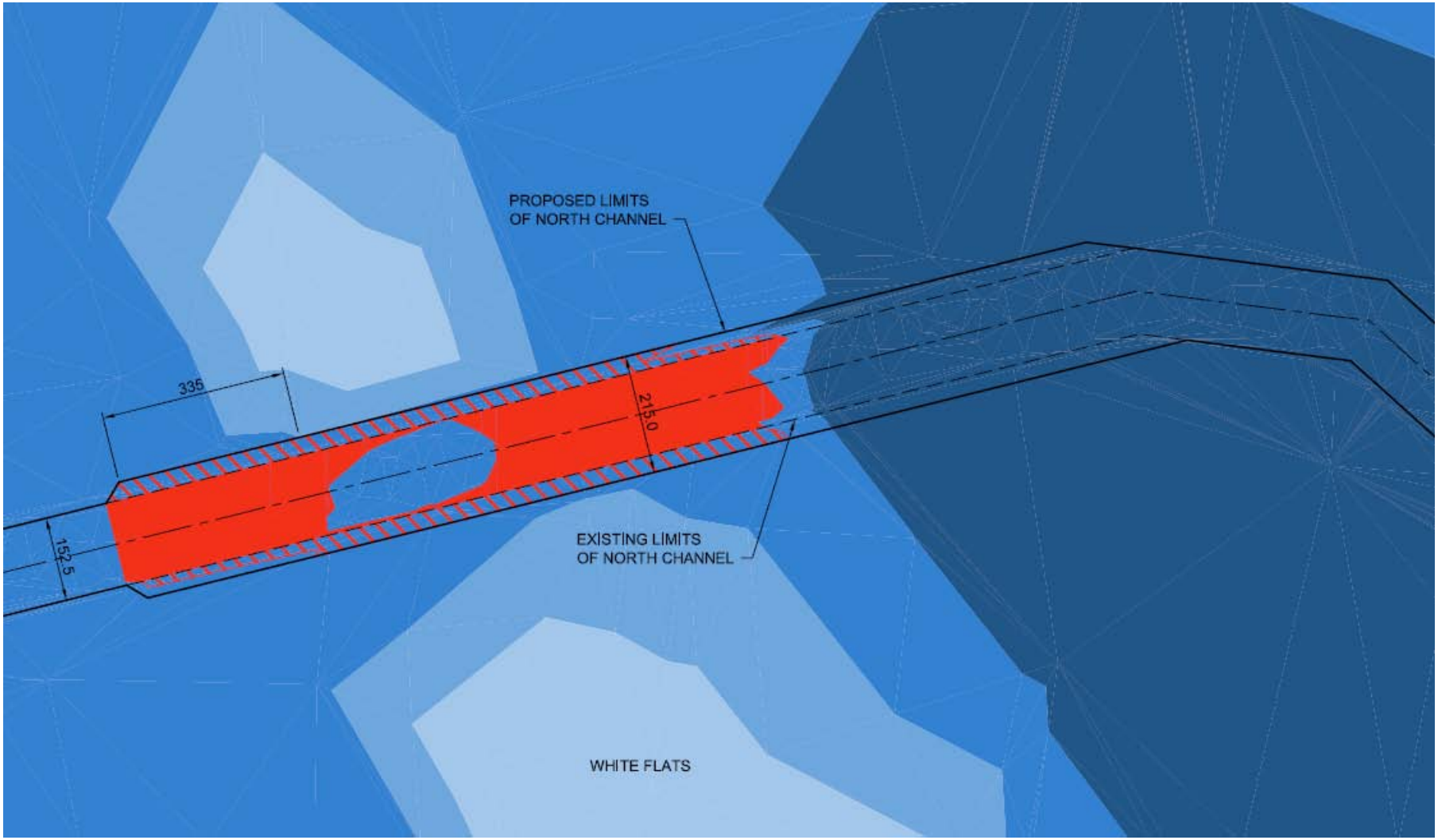


Proposed Dredge Area



KEY PLAN

Figure 4-21: A 215m Wide Channel through White Flats at -13.5m CD



Proposed Dredge Area

Proposed Improvement

Figure 4-22: A 152.5m Wide Realigned Channel through Brackish Pond Flats Region at -11m CD

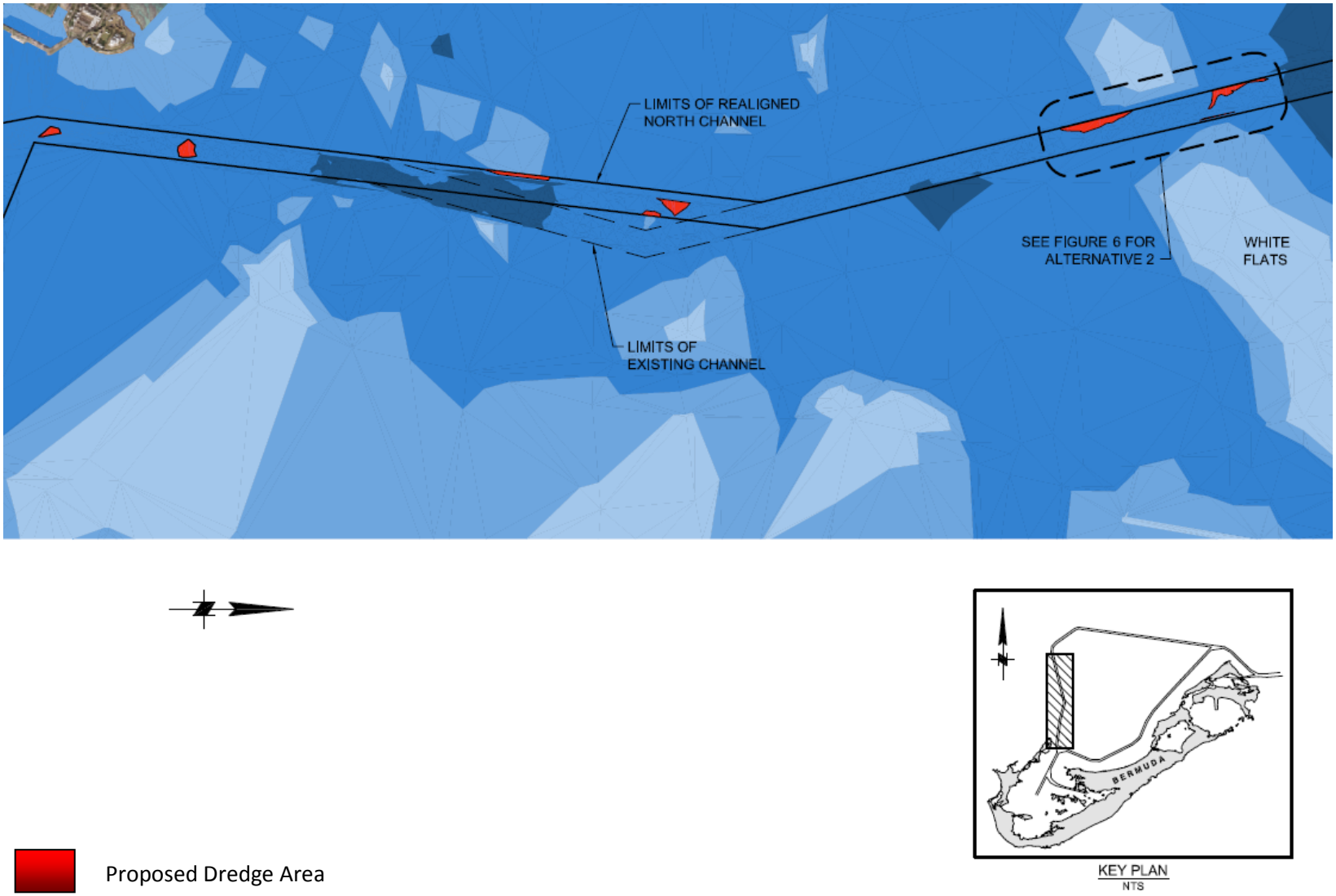
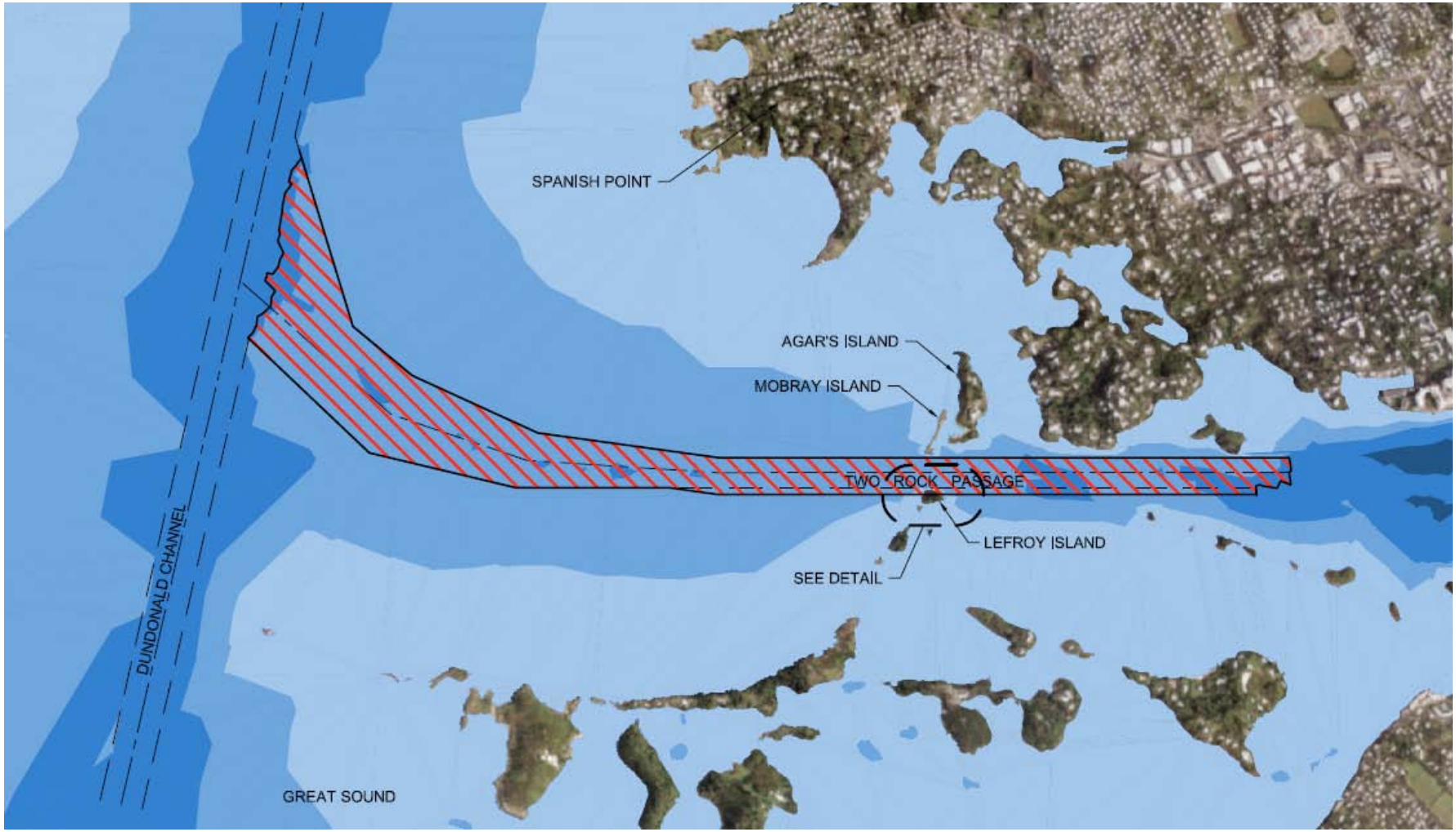


Figure 4-23: A 152m Wide Channel at -11m CD

Figure 4-24: A 30m Wide Channel at -11 and -11.5m CD and Channel Realignment



Proposed Improvement

5 IMPACT ASSESSMENT

In this section, environmental, storm vulnerability, and socio-economic impacts are evaluated for each access improvement threshold associated with Town Cut, Two Rock Passage, and the North and South Channels.

5.1 ENVIRONMENTAL IMPACTS

In the marine areas where channel modification requires dredging, impacts are twofold, the first may involve the permanent loss of corals and seagrasses directly associated with the active dredge site and secondly, dredging activities generate large quantities of suspended sediment which can be carried by currents and deposited downstream. The impact of sediment deposition on corals, seagrasses and other marine ecological species can be directly related to the dredging. At sites where sediments are disturbed, water quality parameters such as heavy metals, organic and inorganic, and antifouling compounds together with changes in dissolved oxygen levels, turbidity, etc. may also need to be considered.

Dredging activities may be considered a short term impact and organisms which survive may potentially re-establish themselves. Longer term impacts must also be considered as increased frequency of larger cruise ships movements and related sedimentation may contribute to the ecological impacts over an extended period.

In the instance where islands and other terrestrial and coastal features are lost due to dredging some reestablishment of benthic and coastal communities may occur over time. However, major topographical features will have been lost permanently. This will be the situation in the case of Higgs, Horseshoe, and Hen Islands in St. George's and Lefroy Island in Hamilton Harbour.

5.1.1 Town Cut

Three (3) proposed thresholds (channel widths of 145m, 155m and 165m and channel depths of -11m CD, -11m CD, and -12m CD respectively, were evaluated. These alternatives involve the loss of more than 90% of the total area of Higgs, Horseshoe, and Hen Islands.

Marine ecological surveys in the area are available, though limited in spatial extent. Area surveys suggest minimal hard and soft coral coverage, and less than 5% coverage of seagrasses. However, more general and visual observations suggest that areas east of Town Cut may display more extensive hard and soft coral coverage while areas of St. George's Harbour may display greater seagrass coverage. At present, no terrestrial survey data is available for Horseshoe, Higgs, and Hen Islands. From discussions with project stakeholders, these

Islands--especially Hen Island--are thought to provide habitat and nesting areas for the protected White-Tailed Tropicbird (aka Bermuda Longtail) and the Bermuda Skink. However, these islands are currently under the protection of the National Parks Act. This Act serves to protect open spaces for recreation as well as areas possessing significant and/or unique natural habitat or other attributes worthwhile of preservation.

5.1.2 North Channel

Three alternatives are proposed as potential solutions to the issues experienced in the North Channel. Depending on the future criteria for ship sizes and maneuvering requirements, various aspects of each proposal or a combination thereof may be chosen. Any decision would also require environmental considerations. The first alternative calls for dredging a total of 5,755m^3 of material in four specific locations between White Flats and Royal Naval Dockyard to achieve channel depths of at least -12.5m CD. The second alternative proposes a more extensive modification program at White Flats. The area would be widened to 215m and dredged to a minimum depth to a depth of -13.5m CD. This would see the removal of some 168,630m^3 of material which includes a portion of reef removal. The third alternative which also encompasses the North Channel between White Flats and Royal Naval Dockyard is similar to the first, but also calls for realignment or straightening of the channel and dredging in three additional locations with a total of 30,880m^3 of material removed

In respect to environmental considerations, the North Lagoon as a whole is known for its coral reef, fish and associated ecology. North Channel proposed modifications will require the excavation of coral, the disturbance of associated benthic communities and the resuspension and redeposition of large quantities of sediment.

5.1.3 South Channel

South Channel modifications require dredging to -11m CD, but little, if any, widening. Two areas are identified, one small area just off Bailey's Bay and the second a more extensive stretch between Shelly Bay and Grassy Bay. The proposed dredging will likely require the excavation of the 934,150m^3 of seabed, with little direct removal of coral reef. These works will see the disturbance of benthic communities and the resuspension and redeposition of large quantities of sediment.

5.1.4 Two Rock Passage

Modifications to Two Rock Passage will require dredging to -11.5m CD from Dundonald Channel through Two Rock and extending into the turning basin of Hamilton Harbour. This will require about 30% of

Lefroy Island to be removed. Lefroy, a small 0.4 hectare rocky limestone island, is two thirds covered with vegetation trees and scrub grasses. It is a bird sanctuary and as a coastal island with rocky shoreline is a habitat type for the endemic Bermuda Skink. DCS marine surveys in the area suggest little if any hard and soft coral and less than 5% seagrass coverage.

5.1.5 Mitigation

A variety of mitigation measures may be considered to reduce the potential ecological impact to the proposed channel modification sites. All of the impacted areas will likely re-establish benthic communities over time once the dredging works are completed and the channels resume their role in service to marine traffic albeit altered based on the redefined marine climatic and topographical conditions. However, best operational practices require that the greatest care and attention should be to avoid and minimize any and all impacts as possible.

In instances where impacts are unavoidable due to dredging, mitigation may be considered in the design phase. If loss or damage to corals is likely to occur, consideration may be given to the transplantation of corals and seagrasses; a practice which has seen some success among local marine ecologists. If sediment resuspension is the principal issue, techniques such as the installation of silt screens to reduce sediment transport may be a consideration.

The impact to islands such as Horseshoe, Higgs, Hen and Lefroy Islands cannot be replaced and impacts cannot be reduced by simple mitigative measures. Other options may need to be considered such as land exchanges and ecological redevelopment of alternate sites to the benefit of reforestation, bird populations and social recreation.

5.2 STORM VULNERABILITY

During stakeholder meetings with representatives from the Corporation of St. George's, concern was expressed that widening of Town Cut or any similar marine modification may increase the vulnerability of St. George's and St. George's Harbour to storm surge and coastal flooding during hurricanes and winter storm events. An assessment using previously developed wave and storm surge models was conducted to evaluate changes in storm vulnerability for St. George's coastal areas and Harbour as well as Town Cut. Wave heights and storm surge elevations computed for each channel alternative for these areas were compared to wave heights and storm surge elevations for Town Cut's current configuration (i.e., existing condition). The relative difference in wave heights and storm surge elevations was then tabulated.

Wave and storm surge models were developed for each alternative presented in Section 4. wide are only discussed in this section. The wave and storm surge impacts for all channel improvements alternatives previously discussed for Town Cut are bracketed by these channel widths.

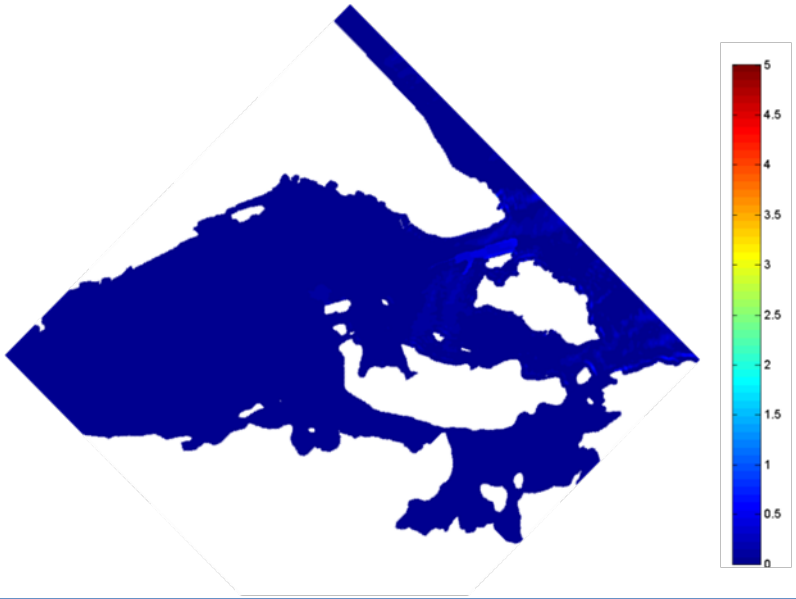
5.2.1 Waves

The local wave model discussed in Section 2.6.1 was modified to reflect the channel alternatives. The topographic and bathymetric contours were altered to widen and dredge the channel and remove the north section of Higgs, Horseshoe, and Hen Islands. The boundary conditions for prevailing and storm events (25- and 50-year return period) from the regional wave model were applied.

Changes in prevailing (daily) wave climate within St. George's Harbour as a result of modifications to the Town Cut are minimal as shown in Figure 5-1. The abrupt change in water depth between the approach channel east of Town Cut and the adjacent fringing coral reefs significantly attenuates the wave energy before it reaches Town Cut irrespective of the channel configuration alternative. Additional attenuation of the wave energy was noted in the model along the centerline of Town Cut as a result of the deepening associated with the channel modifications. This coastal engineering phenomena, where attenuation occurs as waves propagate from shallower to deeper water, is a result of diminished shoaling effects as waves are no longer influenced by bathymetry.

The removal of the north half of Hen Island allows for a further reduction in wave energy in St. George's Harbour. The near vertical shoreline of Hen Island reflects wave energy to the north and east, where it superimposes with the energy of incoming waves propagating through Town Cut. Channel modifications reduce the length of near vertical shoreline on Hen Island and the associated amount of reflected wave energy that can be superimposed with the incoming waves.

Figure 5-1: Wave Height Difference Plot for Prevailing Conditions - 130 m Wide Channel

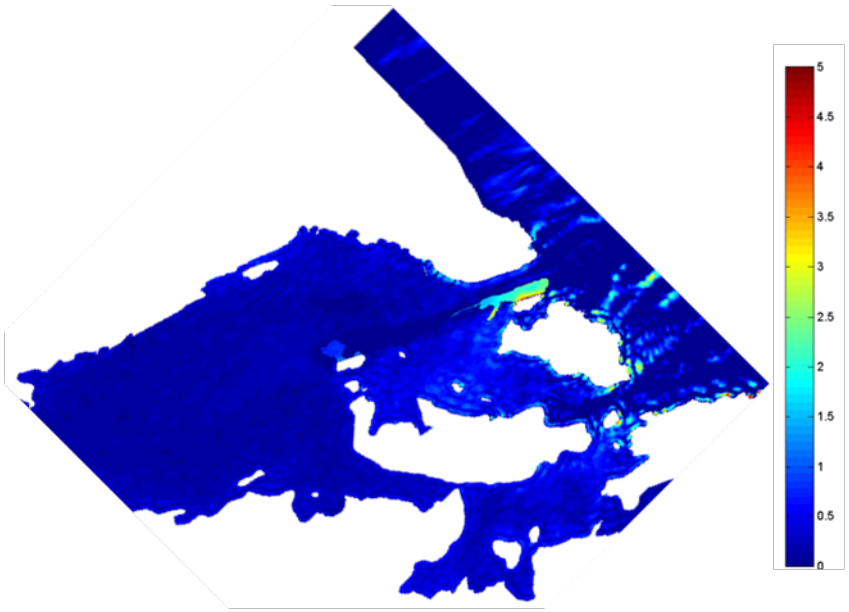


Larger wave heights occur in St. George's Harbour during the 25- and 50-year storm events as discussed in Section 2.6.1. Widening of Town Cut and removal of the north end of the three islands allow more wave energy to propagate through Town Cut.

Wave heights increased up to 0.5m within St. George's Harbour for the 25- and 50-year storm events when the channel was widened to 130m as shown in Figure 5-2. Figure 5-2 illustrates the wave height difference between pre- and post channel modifications for the 50-year storm event. Increased wave heights, on the order of 0.5 to 0.75m, occur within St. George's Channel and the north shore of Smith's Island due to the removal of the north section of Horseshoe Island. Localized increases in wave height at Town Cut approached 1 to 1.5m though some of the increased magnitude shown in Figure 5-2 occurs in newly created open water locations resulting from land area removal. The magnitude of the wave heights inside the Harbour did not vary between the 25- and 50-year storm events for this channel width but the larger wave heights penetrated further into the Harbour.

When the channel was widened to 155m, the wave heights in St. George's Harbour associated with the 25- and 50-year storm event were similar to those observed for the 130m wide channel with the exceptions of the previously noted areas of Smith's and Paget Islands and St. George's Channel as shown in Figure 5-3. The increases in wave height along the north shores of the two islands ranged from 0.75m to 1.3m for the 155m wide channel. At Town Cut, wave height increased up to 2m but as previously stated, some of the increase illustrated in Figure 5-3 is due to the conversion of land to open water. Additional wave energy was also observed along the north shoreline of St. George's Harbour between Chalk and Meyer's Wharf.

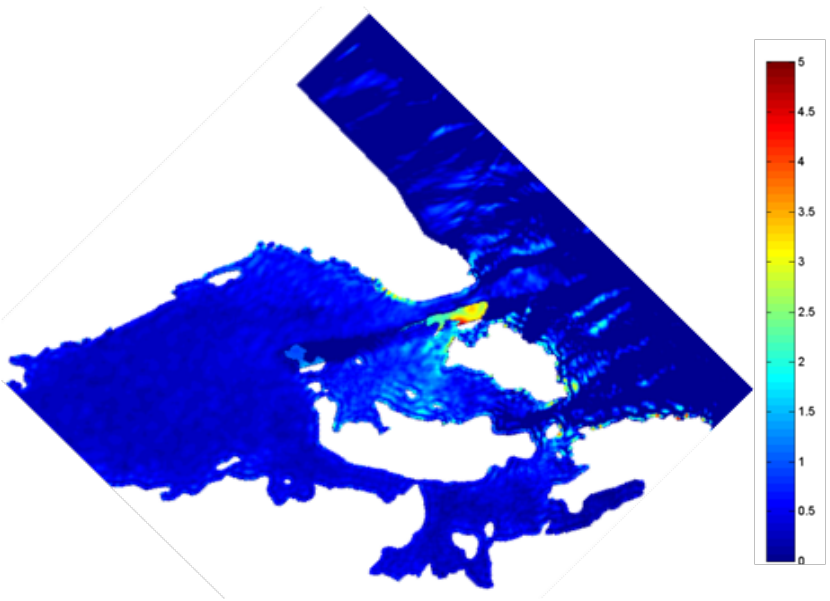
Figure 5-2: Wave Height Difference Plot for 50-year Storm Event - 130m Wide Channel



The construction of a new training wall along the south side of Town Cut may provide additional protection to the north shoreline of

Smith's and Paget Islands while balancing hydrodynamic forces on transiting vessels.

Figure 5-3: Wave Height Difference Plot for 50-year Storm Event - 155 m Wide Channel



5.2.2 Storm Surge

Similar to the changes in wave heights discussed in the previous section, the widening and deepening of Town Cut increases the volume of water that can enter St. George's Harbour, resulting in higher storm surge elevations and greater risk of coastal flooding to low lying areas around the Habour perimeter. An assessment of changes in storm surge elevation was conducted utilizing the hydrodynamic model discussed in Section 2.6.1. Similar to the previous analysis, two hurricane tracks were evaluated: 1) A hurricane track that passes by Bermuda from the west, similar to Hurricane Fabian; and, 2) a hurricane track that passes Bermuda to the east. Hurricane tracks that pass to the west of Bermuda force water from Castle Harbour through Ferry Reach into St. George's Harbour. For easterly hurricane tracks, water is forced into St. George's Harbour through St. George's Channel and Town Cut.

Storm surges associated with Hurricane Fabian were modeled in a manner identical to the analysis of the existing conditions for the 130m and 155m wide channel. When the hurricane track passes to the west of Bermuda as occurred during Hurricane Fabian, storm surge elevations within St. George's Harbour were reduced with each incremental widening of Town Cut. The larger channel cross section of the 130m and 155m wide channels allows more water volume to exit through Town Cut, reducing the total volume of water in St. George's Harbour. Coastal flooding (combined storm surge and wave effects) of low lying areas along the south coast of St. George's Island remains due to hurricane force winds pushing water against the shoreline. However, properties at the periphery of the existing coastal flood areas may experience reduced flooding. The

contribution of larger wave heights to coastal flooding as a result of the channel modifications is offset by the overall lower storm surge elevations within Harbour.

Figure 5-4 and Figure 5-5 show the differences in the extent of coastal flooding for the 155m wide channel alternative. The areas shown in green are no longer affected by coastal flooding in comparison to existing conditions as a result of the channel modifications.

Simulations of hurricanes that have tracks passing to the east of the Bermuda produce the opposite results of westerly tracking storms. The channel modifications allow more water volume into St. George's Harbour. Since water cannot exit as the same rate through Ferry Reach, the storm surge elevations in the Harbour increase. Overall, a uniform increase in storm surge within the Harbour raises the coastal flood elevation by +0.6m CD for the 155m wide channel based on the modeling results.

The higher storm surge due to the channel modifications do not significantly increase the extent of coastal flooding within St. George's Harbour. Apart from the existing low-lying areas, the majority of properties are located along or on top of the rolling topography where incremental changes in coastal flood elevations have minimal impacts. Figure 5-6 and Figure 5-7 show the differences in the extent of coastal flooding for the 155m wide channel alternative for easterly tracking hurricanes. The areas shown in red demarcate those areas that may now be subject to coastal flooding due to the channel modifications.

5.2.3 Summary

- Wave heights increased up to 0.5m within St. George's Harbour for the 25- and 50-year storm events when the channel was widened to 130m. Localized wave height increases of 0.5 to 0.75m occur along the north shoreline of Smith's Island.
- When the channel was widened to 155m, the wave heights in St. George's Harbour associated with the 25- and 50-year storm event were similar to those observed for the 130m wide channel. Localized increases in wave height along the north shores of Smith's and Paget Islands ranged from 0.75m to 1.3m.
- When hurricane track passes to the west of Bermuda as occurred during Hurricane Fabian, storm surge elevations within St. George's Harbour were reduced with each incremental widening of Town Cut.
- Incremental widening of Town Cut increases the storm surge elevation when simulated hurricane tracks pass to the east of the Bermuda. A uniform increase in storm surge within the Harbour raises the coastal flood elevation by +0.6m CD for the 155m wide channel alternative.

Figure 5-4: Reduction in the Extent of Coastal Flooding (highlighted in green) for a Westerly Tracking Hurricane and 155m Wide Channel Alternative

Figure 5-5: Reduction in the Extent of Coastal Flooding for St. George's (highlighted in green) for a Westerly Tracking Hurricane and 155m Wide Channel Alternative

Figure 5-6: Increase in the Extent of Coastal Flooding (highlighted in red) for Easterly Tracking Hurricane and 155m Wide Channel Alternative

Figure 5-7: Reduction in the Extent of Coastal Flooding for St. George's (highlighted in red) for Easterly Tracking Hurricane and 155m Wide Channel Alternative

5.3 SOCIO-ECONOMIC IMPACTS

5.3.1 Conceptualizing Cruise Growth to Bermuda

As presented previously, the Bermuda cruise market behaves in a non-traditional fashion versus others observed in the broader worldwide marketplace. Bermuda's proximity to primary U.S. East Coast homeports and intrinsic characteristics as a cruise destination have and will continue to create levels of cruise line and passenger demand that cannot be met under the current supply of cruise facilities—berths, channels, transport infrastructure, navigation aids and other elements. In short, growth of cruise activities to Bermuda is a function of supply rather than demand. This somewhat unique circumstance has allowed Bermuda to regulate cruise throughput through a combination of policy and pricing mechanisms.

They key to conceptualizing future growth of cruise activities to Bermuda rests in modifying one or several of the key attributes in the current cruise facilities supply chain. The primary supply chain features are summarized in Table 5-1. As shown, the primary key attributes are the channels supporting access to each of Bermuda's ports-of-call. In development of cruise growth scenarios for Bermuda, channel scenarios and the types of vessels they potentially can accommodate serve as the primary points of differentiation. It serves to note that, for each of Bermuda's port-of-call destinations, additional supply chain adjustments are needed to some extent at each destination to welcome expansion of cruise throughput. For St. George's, once the limitations of Town Cut are overcome, only transport system expansion is felt to be a secondary outstanding issue. Hamilton's chain of improvements is more complex, with investments expected in both Hamilton Harbour (secondary) and waterfront (primary) infrastructure. For Dockyard, the current level of cruise throughput already strains waterborne and land based transport systems. Any expansion of throughput is felt to necessitate expansion of ferry and bus infrastructure.

Finally, changes in cruise infrastructure supply chains will not by itself result in expanded cruise throughput to Bermuda's ports; policy and pricing will still play the central role in regulating the types and timing of cruise operations to Bermuda's ports. Policy and pricing strategies are not reviewed as part of this effort.

5.3.2 Cruise Passenger Growth Scenarios

A series of cruise passenger growth scenarios were generated to estimate potential net increases in cruise activity based on improvement to Bermuda's channels and harbours. These scenarios range from "no improvement" (i.e., do nothing) to

Table 5-1: Primary Supply Chain Features for Bermuda's Ports

	Channels	Harbour	Berth(s)	Transport
St. George's	**Primary** (Town Cut + Approach) The narrowness and depth of Town Cut limits the size of vessels to only a handful of vessels operating in North America.	**Not a Factor** St. George's Harbour) St. George's's generally has the size and water depth required to maneuver Panamax and most Tiers 2/3 Post-Panamax vessels.	**Not a Factor** (Penno's Wharf) Pennos's Wharf has capability (with minor modification) to welcome Panamax and most Tier 2/3 Post-Panamax vessels.	**Secondary** St. George's is a walking destination unto itself and supports only a single large vessel at a time. However, some expansion of transit operations, is needed for improved passenger mobility.
Hamilton	**Primary** (Two Rock Passage) Two Rock Passage limits the size of vessels that transit the channel and enter Hamilton Harbour.	**Secondary** (Hamilton Harbour) Some modification to turning radii near White's Island is needed to support any expansion of larger vessels into the Hamilton Harbour.	**Primary** (Berths 1 and 5/6) Hamilton's cruise berths need to be lengthened / modified to welcome most Panamax and Tier 2 and 3 Post-Panamax vessels.	**Not a Factor** Like St. George's, Hamilton is a walking destination unto itself. Unlike St. George's, Hamilton is the central point of all transport activity on the Island.
Royal Naval Dockyard	**Secondary** (North Channel) Dockyard can welcome all but the very largest cruise vessels in operation. Widening and adjustment of several North Channel segments is needed to allow the West End to accommodate Post-Panamax Tier 4 vessels.	**Not a Factor** (Grassy Bay) Waters surrounding King's and Heritage Wharf are capable of accommodating the largest cruise vessels in operation.	**Not a Factor** (King's and Heritage Wharfs) Both facilities have capability to welcome very large vessels. With modification, Heritage Wharf can accommodate Post-Panamax Tier 4 vessels.	**Primary** Current cruise operations at the West End's two facilities are already placing significant strains of Bermuda's waterborne and landside transit system. Any growth of throughput to the West End requires expansion of transport capacity.

improvement over time to channels providing access to all three of Bermuda's ports-of-call.

- **Scenario 1 - No Improvement.** No improvements are made to channels and harbours at St. George's, Hamilton or Dockyard. Under this scenario, passenger levels are assumed to decline through 2021 as smaller ships, such as the Veednam, retire without suitable replacements that can transit existing channels in Bermuda. This scenario does assume modest growth for occasional callers (1% per year). Note that modest growth for occasional callers is consistent for all scenarios presented.
- **Scenario 2 – North Channel Improvements.** Improvements to the North Channel are made allowing Tier 4 Post-Panamax vessels to operate from Dockyard by 2013. The 2013 timeframe accounts for the time to conduct field investigations and environmental studies and mobilize and construct the improvements. This scenario derives growth primarily through arrival by NCL's planned *Breakaway*-class RCCL's *Freedom*-class, or similar vessel to Dockyard as part of a regularly contracted season.
- **Scenarios 3 and 4 –Town Cut Improvements Only.** Town Cut is widened in Scenario 3 to allow for Panamax vessels to operate from St. George's for an average of 6 days over a 24 week core operating season. Under Scenario 4, Town Cut is widened to accommodate Tier 2 Post-Panamax Vessels. Given the anticipated time to conduct field investigationscost, complexity and mobilization required to modify Town Cut, net increases in passenger throughput are not realized in our model until 2017. The 2017 timeframe takes into consideration the time to conduct field investigations and environmental studies and mobilize and construct the improvements.
- **Scenarios 5 and 6 – Two Rock Passage and Related Hamilton Harbour Improvements Only.** For Scenario 5, Two Rock Passage and Hamilton Harbour are improved by 2017 to allow for Panamax vessels to operate from Hamilton for an average of 6 days over a 24 week core operating season. Under Scenario 6, Hamilton Channels are widened to accommodate Tier 2 Post-Panamax Vessels.
- **Scenarios 7 and 8 – North Channel and Town Cut Improvements are Pursued.** Under Scenario 7, North Channel expansion occurs in 2013 as described under Scenario 2 above. Town Cut expansion is also pursued for Panmanx vessels in 2017. Under Scenario 8, North Channel expansion occurs in 2013 and Town Cut expansion is also undertaken to accommodate Tier 2 Post-Panamax Vessels in 2017.

- **Scenarios 9 and 10 – North Channel and Two Rock Passage and Related Hamilton Harbour Improvements.** Scenario 9 and 10 follow the general logic presented for Scenarios 7 and 8 above, with the exchange of Town Cut improvements for Two Rock Passage and Related Hamilton Harbour Improvements in 2017.
- **Scenarios 11 and 12 – All Channels and Harbours are Improved.** For scenario 11, North Channel improvements are undertaken in 2013, Town Cut is expanded to welcome Panamax vessels by 2017 and Hamilton improvements are made to accommodate a Panamax vessel by 2021. For Scenario 12, North Channel improvements are undertaken in 2013, Town Cut is expanded to welcome Tier 2 Post-Panamax Vessels by 2017 and Hamilton improvements are made to accommodate Tier 2 Post-Panamax Vessels by 2021.

Under each scenario, several assumptions were made as follows:

- Modest growth for occasional callers occurs at 1% per annum. This business is effectively allowed to continue at 2011 levels, with vessels filling in the available gaps during Bermuda's primary season and into the late fall and early spring months.
- Contract vessels are assumed to spend an average of 3 days in Bermuda, and based on scenarios above and berth availability, visit 2 of 3 of Bermuda's ports-of-call. No cruise vessel is assumed to visit each port.

A summary of the growth projections are presented in Table 5-2 and Figure 5-8. Appendix E contains passenger and revenue growth projections.

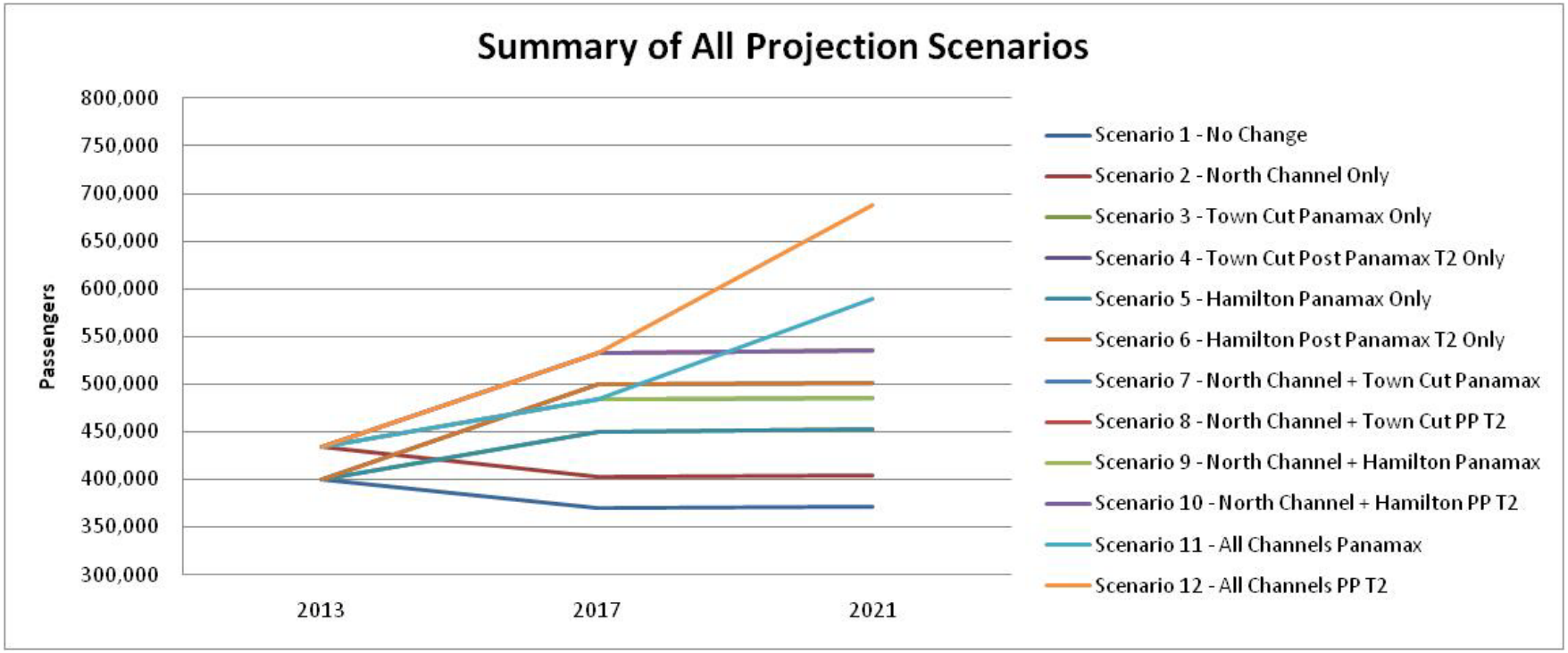
5.3.3 General Assessment of Economic and Social Impacts

Ports-of-call and homeports receive direct, indirect and induced economic impacts associated with cruise operations. Direct economic impacts are associated with spending by cruise passengers and crew, cruise line expenditures for operations and port services, capital expenditures for port terminals and other facilities and other areas. Indirect impacts are the production, employment and income changes occurring in other businesses in the community that support cruise activities. Induced impacts are the effects of spending by the households in the local economy as the result of direct and indirect effects from an economic activity. The induced effects arise when employees who are working in support of cruise activities in the community spend their new income in the community.

Table 5-2: Summary of Growth Projections for All Project Scenarios

Scenario Number	Total Passengers			Net Change from Baseline (Scenario 1)		Notes
	2013	2017	2021	2017	2021	
Scenario 1 - No Change	400,574	369,457	371,595	n/a	n/a	Baseline
Scenario 2 - North Channel Only	433,641	402,524	404,662	**33,067**	**33,067**	
Scenario 3 - Town Cut Panamax Only	400,574	450,344	452,482	**80,887**	**80,887**	Scenarios 3 - 6 yield the same results given deployment assumption. Evaluation of feasibly, costs, policy and other factors becomes next step to see which scenario works best within the context of Bermuda.
Scenario 4 - Town Cut Post Panamax Tier 2 Only	400,574	499,592	501,730	**130,135**	**130,135**	
Scenario 5 - Hamilton Panamax Only	400,574	450,344	452,482	**80,887**	**80,887**	
Scenario 6 - Hamilton Post Panamax Tier 2 Only	400,574	499,592	501,730	**130,135**	**130,135**	
Scenario 7 - North Channel + Town Cut Panamax	433,641	483,411	485,549	**113,954**	**113,954**	Scenarios 7 - 10 yield the same results given deployment assumption. Evaluation of feasibly, costs, policy and other factors becomes next step to see which scenario works best within the context of Bermuda.
Scenario 8 - North Channel + Town Cut Post Panamax Tier 2	433,641	532,659	534,797	**163,202**	**163,202**	
Scenario 9 - North Channel + Hamilton Panamax	433,641	483,411	485,549	**113,954**	**113,954**	
Scenario 10 - North Channel + Hamilton Post Panama Tier 2	433,641	532,659	534,797	**163,202**	**163,202**	
Scenario 11 - All Channels Panamax	433,641	483,411	588,941	**113,954**	**217,346**	
Scenario 12 - All Channels Post Panama Tier 2	433,641	532,659	687,437	**163,202**	**315,842**	Most deployment over time; highest net change

Figure 5-8: Summary of All Project Scenarios



Aside from measurable economic impacts, the cruise industry presents destinations with a number of economic trade-offs, externalities and opportunity costs which are often discussed in literature but not quantified. For some destinations, the development and promotion of cruise tourism may involve trade-offs and opportunity costs. Cruise tourism may, for example, undermine land-based tourism, consume scarce resources, or strain existing infrastructure during a destination's high tourism season. On the positive side, the cruise business may form the basis for a sustainable natural resource or ecological tourism by making it unnecessary to develop shore-based accommodation and other tourist facilities which may damage the environment. It may also promote the area as a tourist destination with passengers returning as shore based tourists.

The standard practice of preparing economic and social impact assessment is to conduct an input/output analysis based on the spending profiles of passengers, crew and cruise liners to determine income and employment multipliers. While a detailed economic and social impact assessment of this type is recommended as part of a future detailed feasibility study channel improvements, an order of magnitude economic and social impact analysis associated with each major channel alternative was conducted. For example, does expansion of St. George's Town Cut to welcome a Panamax cruise vessel lead to significant expansion of economic and social benefit versus its current configuration?

5.3.4 Economic Impacts to Bermuda

Bermuda's Ministry of Transport currently estimates the direct economic impact of cruise operations to the Island through quantifying the primary categories where benefits are derived, namely: (1) Cruise line payment of Government port charges and related fees; (2) Cruise passenger and crew spending on goods and services while on the Island: and, (3) The estimated magnitude of net spending (i.e. not including cruise line receipts) on shore excursions. These three categories comprise the majority of economic contribution, and thus, represent in terms of orders of magnitude the primary current and future benefit to be derived from any expansion of cruise throughput to the island.

- **Spending by cruise lines on Bermuda Government port charges and related fees.** At present, Bermuda levies port charges in two main areas: (1) Head taxes of $20 per day, per passenger (totaling $60 per passenger cruise visit); and, (2) A cabin tax of $14 assessed each two days a vessel is in Bermuda waters during peak season (and with other exemptions / variability). The Government also receives other fees associated with pilotage,

tugs and other services. The total annual spend within this "other" category is estimated by Bermuda's Ministry of Transport at $1 million annually.

- **Cruise passenger and crew spending on goods and services.** While in Bermuda, cruise passengers and crew spend money on retail goods, dining, entertainment, transportation, and on other items. Bermuda's Department of Tourism annually surveys passengers and crew on the total amounts (excluding shore excursions) they spend while in Bermuda. As part of the Department's most recent survey, cruise passenger spending was reported to be $125 per passenger and $40 per crew member.
- **Net spending on shore excursions.** Approximately 40% of all passengers to Bermuda take some form of shore excursion while on the Island. Many of these excursions are purchased onboard the cruise vessel prior to arrival. Taking into account only the portion of cruise passenger expenditure that is received directly by the Bermuda shore excursion provider (i.e., net of all cruise markup), Bermuda's Ministry of Transport estimates each shore excursion contributes $40 per passenger in direct economic benefit.

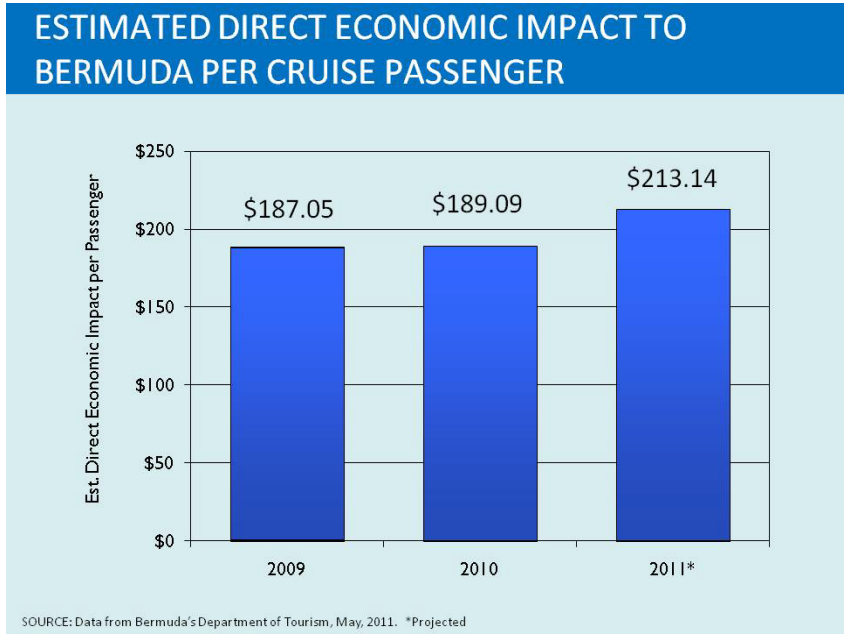
Using the estimated spending figures in each of the categories listed above, Bermuda's Ministry of Transport estimated that $68.9 million in direct economic impacts associated with cruise operations were observed in 2010. For 2011, total direct economic impacts are expected to climb to $84.3 million. While not currently assessed by the Ministry, indirect and induced economic impacts associated with cruise activities may equal or exceed estimated total direct economic impacts.

Figure 5-9 illustrates another way to conceptualize direct economic impact figures. When all direct economic impact measures are aggregated and then divided by reported (or estimated) cruise passenger level, an estimate of economic impact per passenger is derived. So, for example, in 2010, each cruise passenger arriving to Bermuda carried with him or her direct economic impact value of approximately $189. For 2011, this value is expected to increase to just over $213.

Projecting Economic Impacts Forward based on Growth Forecasts

Our aggregate per passenger approach is carried forward and used to prepare a generalized estimate of direct economic impacts associated with each growth scenario presented in the previous section. Each net increase over time in annual cruise passenger throughput is multiplied against an average per passenger direct economic impact estimate. The analysis includes the following assumptions:

Figure 5-9: Direct Economic Impact per Cruise Passenger



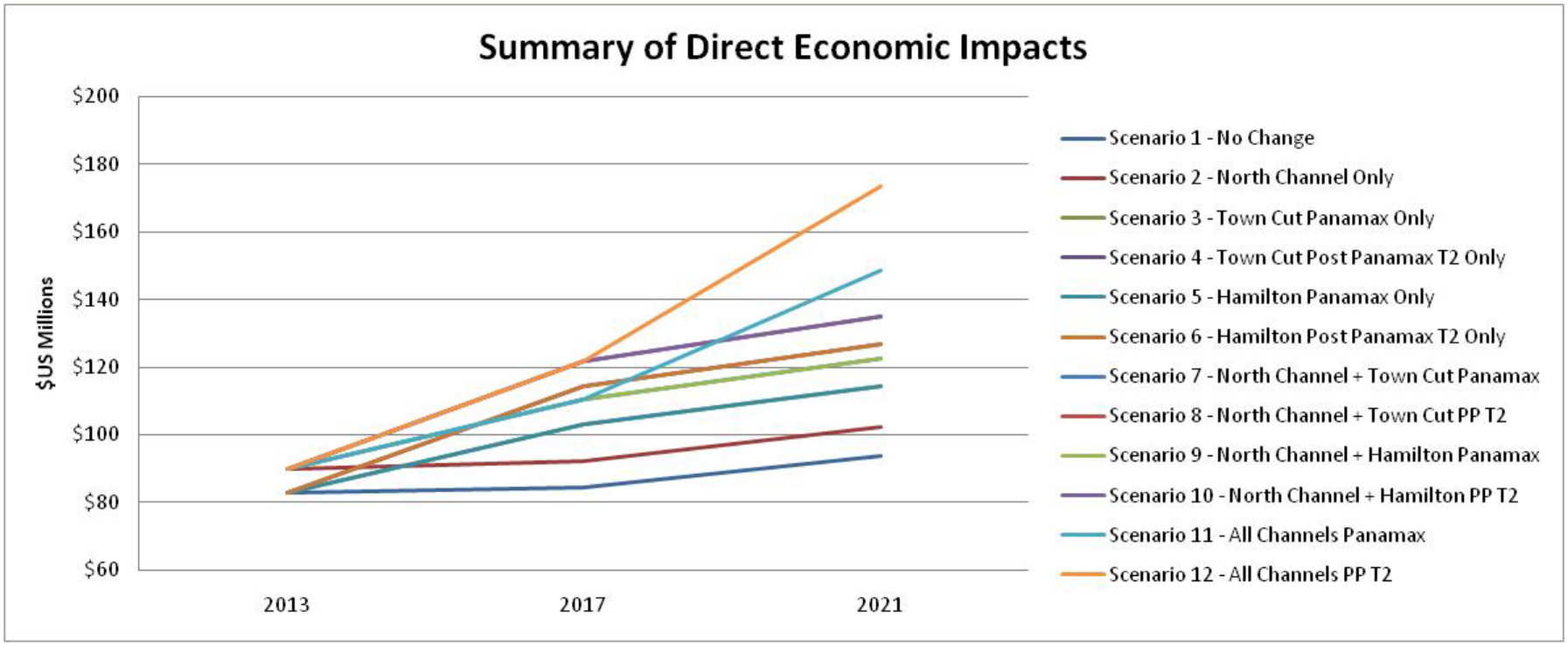
- An average estimated direct economic impact figure for 2009, 2010 and 2011 (estimated) of $197.30 was tabulated and used throughout the analysis.
- To take into account some anticipated increases to government port charges and related fees and modest inflation over time, the average per passenger direct economic figure was increased by 2.5% per annum. Thus, for the reporting years used in this study, average per passenger figures climb to $207.28 in 2013, $228.80 in 2017 and $252.55 in 2021.
- It is assumed that the average per passenger spending represents the majority of direct economic impacts to the Island associated with cruise operations. This figure and approach is conservative, with other direct impacts not assessed in the Ministry of Transport figures as well as indirect and induced anticipated to add greatly to the overall total economic impact picture to the Island.

Table 5-3 and Figure 5-10 illustrate estimated future direct economic impact associated with cruise activities for review years 2013, 2017, and 2021. All figures shown represent annualized direct economic impacts. Estimated direct economic impact ranges from $83.0 million to $89.9 million in 2013. Taking into account the various improvements to channels and harbors under each scenario, total

Table 5-3: Summary of Direct Economic Impacts for All Growth Scenarios

Scenario Number	Estimated Economic Impact ($US Millions)			Net Change from Baseline (Scenario 1)		Notes
	2013	2017	2021	2017	2021	
Scenario 1 - No Change	83.0	84.5	93.8	n/a	n/a	Baseline
Scenario 2 - North Channel Only	89.9	92.1	102.2	**7.6**	**8.4**	
Scenario 3 - Town Cut Panamax Only	83.0	103.0	114.3	**18.5**	**20.5**	Scenarios 3 - 6 yield the same results given deployment assumption. Evaluation of feasibly, costs, policy and other factors becomes next step to see which scenario works best within the context of Bermuda.
Scenario 4 - Town Cut Post Panamax Tier 2 Only	83.0	114.3	126.7	**29.8**	**32.9**	
Scenario 5 - Hamilton Panamax Only	83.0	103.0	114.3	**18.5**	**20.5**	
Scenario 6 - Hamilton Post Panamax Tier 2 Only	83.0	114.3	126.7	**29.8**	**32.9**	
Scenario 7 - North Channel + Town Cut Panamax	89.9	110.6	122.6	**26.1**	**28.8**	Scenarios 7 - 10 yield the same results given deployment assumption. Evaluation of feasibly, costs, policy and other factors becomes next step to see which scenario works best within the context of Bermuda.
Scenario 8 - North Channel + Town Cut Post Panamax Tier 2	89.9	121.9	135.1	**37.4**	**41.3**	
Scenario 9 - North Channel + Hamilton Panamax	89.9	110.6	122.6	**26.1**	**28.8**	
Scenario 10 - North Channel + Hamilton Post Panamax Tier 2	89.9	121.9	135.1	**37.4**	**41.3**	
Scenario 11 - All Channels Panamax	89.9	110.6	148.7	**26.1**	**54.9**	
Scenario 12 - All Channels Post Panamax Tier 2	89.9	121.9	173.6	**37.4**	**79.8**	Most deployment over time; highest net change

Figure 5-10: Summary of Direct Economic Impacts



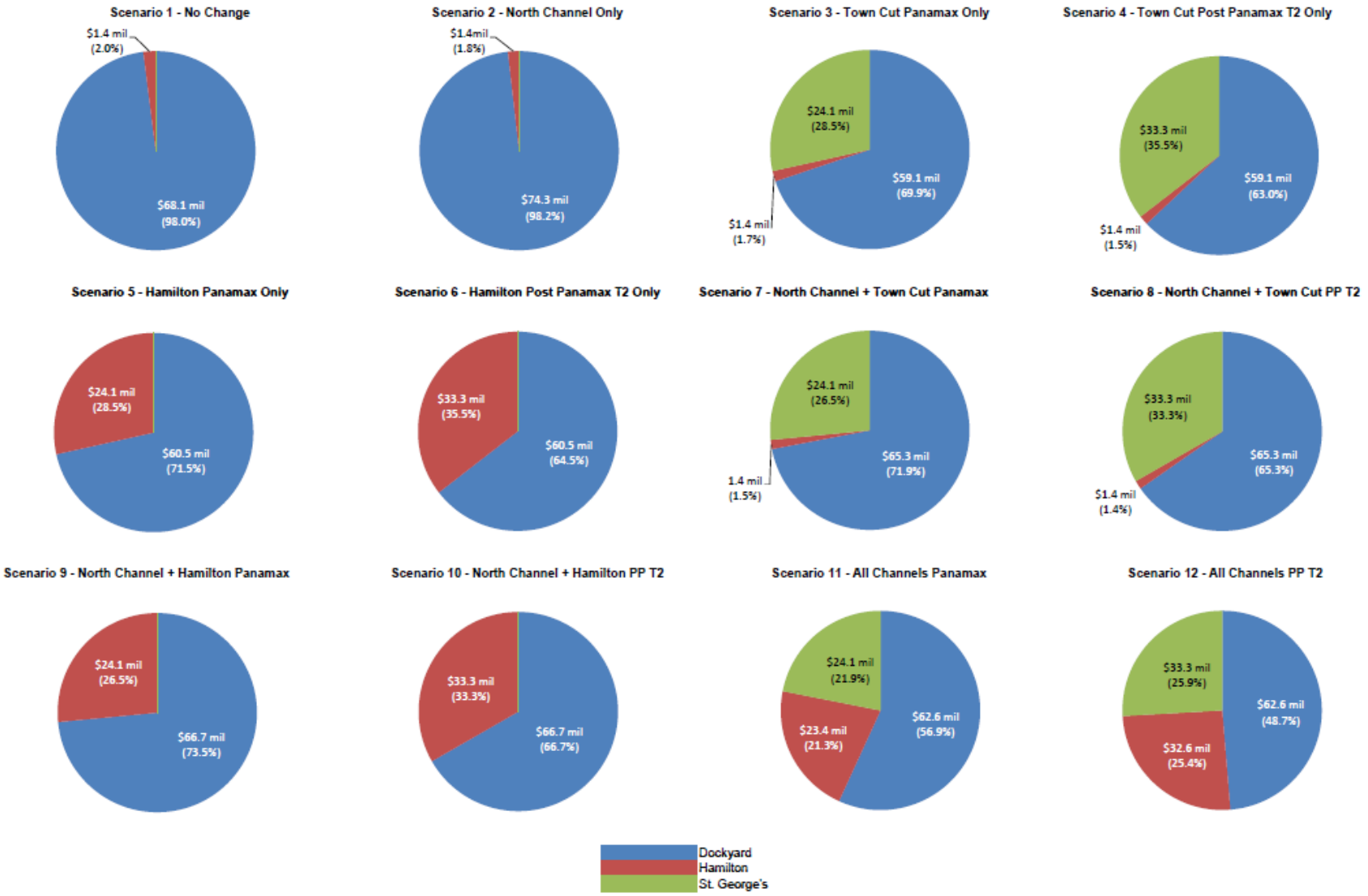
impact grows to a range of $93.8 million for the baseline scenario (Scenario 1) to the highest rate of $173.9 million under Scenario 12 by year 2021.

Table 5-3 also presents our estimated net increase to direct economic impact associated with each improvement scenario. Net increases shown represent annualized direct economic impacts above the baseline scenario. As presented in Table 5-3, all scenarios provide some amount of net increase to total estimated direct economic improvement. As expected, the greatest net change is forecast for those scenarios that have multiple improvements (North Channel, St. George's and Hamilton) and welcome the largest ships (Scenarios 11 and 12). When aggregate results by group, potential net increases to annualized direct economic impacts come into sharper focus:

- Improvements to the North Channel (Scenario 2) are conservatively forecast to add up to $8.4 million per annum in direct economic impact.
- Individual projects contemplated under Scenarios 3 through 6 (e.g. expansion of Town Cut to accommodate Tier 2 vessels) yield an average of $24.2 million per annum in direct economic impact starting in 2017. This average increases to $26.7 million per annum in 2021.
- Individual projects combined with improvements to North Channel—Scenarios 7 through 9—provides an additional increment economic impact. For 2017, the average net increase per annum is $31.8 million; for 2021, the average increases to $35.1 million.
- Scenarios 11 and 12 which contemplate improvements at all three locations provide the greatest total net increase to direct economic impact. For 2017, the average net increase per annum is $31.8 million; for 2021, the average increases to $67.4 million.

The forecasts were further subdivided to provide some insight as to the potential direct economic impact by receiving port. Results of this analysis are presented in Figure 5-11 and Table 5-4. All figures offered are net of estimated port charges and related fees as these accrue directly to the central Government. What these forecasts suggest is the proximity of the potential economic benefit to each of Bermuda's ports-of-call. For example, under Scenario 4 (expansion of Town Cut to accommodate Tier 2 vessels), restored cruise business to St. George's places cruise passengers worth an estimated $33.3 million in spending power (35.5% of the total) on Corporation's doorstep in 2021. This is not to say that all $33.3 would be spent in St. George's—passengers and crew members will naturally travel to other Island locations and tour providers will spend incomes in other parishes.

Figure 5-11: Summary of Estimated Direct Economic Impacts Excluding Government Fees by Receiving Port, 2021



(1) Total economic impact is reduced by an assumed Government fees average of 26% of the total.

Table 5-4: Summary of Estimated Direct Economic Impacts Excluding Government Fees by Receiving Port[1]

Scenario Number	Estimated Economic Impact (Excluding Government Fees) for 2013							
	Dockyard		Hamilton		St. George's		Total	
	$US Millions	%	$US Millions	%	$US Millions	%	$US Millions	%
Scenario 1 - No Change	55.3	90.1%	6.1	9.9%	0.0	0.0%	61.4	100%
Scenario 2 - North Channel Only	60.4	90.8%	6.1	9.2%	0.0	0.0%	66.5	100%
Scenario 3 - Town Cut Panamax Only	55.3	90.1%	6.1	9.9%	0.0	0.0%	61.4	100%
Scenario 4 - Town Cut Post Panamax T2 Only	55.3	90.1%	6.1	9.9%	0.0	0.0%	61.4	100%
Scenario 5 - Hamilton Panamax Only	55.3	90.1%	6.1	9.9%	0.0	0.0%	61.4	100%
Scenario 6 - Hamilton Post Panamax T2 Only	55.3	90.1%	6.1	9.9%	0.0	0.0%	61.4	100%
Scenario 7 - North Channel + Town Cut Panamax	60.4	90.8%	6.1	9.2%	0.0	0.0%	66.5	100%
Scenario 8 - North Channel + Town Cut PP T2	57.8	86.8%	8.8	13.2%	0.0	0.0%	66.6	100%
Scenario 9 - North Channel + Hamilton Panamax	60.4	90.8%	6.1	9.2%	0.0	0.0%	66.5	100%
Scenario 10 - North Channel + Hamilton PP T2	60.4	90.8%	6.1	9.2%	0.0	0.0%	66.5	100%
Scenario 11 - All Channels Panamax	60.4	90.8%	6.1	9.2%	0.0	0.0%	66.5	100%
Scenario 12 - All Channels PP T2	60.4	90.8%	6.1	9.2%	0.0	0.0%	66.5	100%

Scenario Number	Estimated Economic Impact (Excluding Government Fees) for 2017							
	Dockyard		Hamilton		St. George's		Total	
	$US Millions	%	$US Millions	%	$US Millions	%	$US Millions	%
Scenario 1 - No Change	61.4	98.1%	1.2	1.9%	0.0	0.0%	62.6	100%
Scenario 2 - North Channel Only	67.0	98.2%	1.2	1.8%	0.0	0.0%	68.2	100%
Scenario 3 - Town Cut Panamax Only	53.4	70.0%	1.2	1.6%	21.7	28.4%	76.3	100%
Scenario 4 - Town Cut Post Panamax T2 Only	53.4	63.1%	1.2	1.4%	30.0	35.5%	84.6	100%
Scenario 5 - Hamilton Panamax Only	54.6	71.6%	21.7	28.4%	0.0	0.0%	76.3	100%
Scenario 6 - Hamilton Post Panamax T2 Only	54.6	64.5%	30.0	35.5%	0.0	0.0%	84.6	100%
Scenario 7 - North Channel + Town Cut Panamax	59.0	72.0%	1.2	1.5%	21.7	26.5%	81.9	100%
Scenario 8 - North Channel + Town Cut PP T2	59.0	65.4%	1.2	1.3%	30.0	33.3%	90.2	100%
Scenario 9 - North Channel + Hamilton Panamax	60.2	73.5%	21.7	26.5%	0.0	0.0%	81.9	100%
Scenario 10 - North Channel + Hamilton PP T2	60.2	66.7%	30.0	33.3%	0.0	0.0%	90.2	100%
Scenario 11 - All Channels Panamax	59.0	72.0%	1.2	1.5%	21.7	26.5%	81.9	100%
Scenario 12 - All Channels PP T2	59.0	65.4%	1.2	1.3%	30.0	33.3%	90.2	100%

Scenario Number	Estimated Economic Impact (Excluding Government Fees) for 2021							
	Dockyard		Hamilton		St. George's		Total	
	$US Millions	%	$US Millions	%	$US Millions	%	$US Millions	%
Scenario 1 - No Change	68.1	98.0%	1.4	2.0%	0.0	0.0%	69.5	100%
Scenario 2 - North Channel Only	74.3	98.2%	1.4	1.8%	0.0	0.0%	75.7	100%
Scenario 3 - Town Cut Panamax Only	59.1	69.9%	1.4	1.7%	24.1	28.5%	84.6	100%
Scenario 4 - Town Cut Post Panamax T2 Only	59.1	63.0%	1.4	1.5%	33.3	35.5%	93.8	100%
Scenario 5 - Hamilton Panamax Only	60.5	71.5%	24.1	28.5%	0.0	0.0%	84.6	100%
Scenario 6 - Hamilton Post Panamax T2 Only	60.5	64.5%	33.3	35.5%	0.0	0.0%	93.8	100%
Scenario 7 - North Channel + Town Cut Panamax	65.3	71.9%	1.4	1.5%	24.1	26.5%	90.8	100%
Scenario 8 - North Channel + Town Cut PP T2	65.3	65.3%	1.4	1.4%	33.3	33.3%	100.0	100%
Scenario 9 - North Channel + Hamilton Panamax	66.7	73.5%	24.1	26.5%	0.0	0.0%	90.8	100%
Scenario 10 - North Channel + Hamilton PP T2	66.7	66.7%	33.3	33.3%	0.0	0.0%	100.0	100%
Scenario 11 - All Channels Panamax	62.6	56.9%	23.4	21.3%	24.1	21.9%	110.1	100%
Scenario 12 - All Channels PP T2	62.6	48.7%	32.6	25.4%	33.3	25.9%	128.5	100%

(1) Total economic impact is reduced by an assumed Government fees average of 26% of the total.

What it expected, however, is that a large percentage of this $33.3 million would be expanded in St. George's given the economic impact's proximity. For Dockyard and Hamilton, this notion of proximity impact is more complex. Passengers arriving to Dockyard travel in large numbers to Hamilton and, given Hamilton's broad commercial offer and other intrinsic characteristics, likely extend significant amounts of their discretionary spending within the Corporation. Thus, while Scenario 2 (North Channel Expansion only) suggests an annualized benefit of $74.3 million to Dockyard in 2021, it is expected both Dockyard and Hamilton share at near equal levels economically from the presence of this activity.

Finally, review of estimated direct economic impact by receiving port provides insight on the potential economic balance (or imbalance) between scenarios. As shown in Figure 5-11, Scenarios 3 through 12 all expand the possibility of economic expenditure to 2 or 3 of Bermuda's ports-of-call. As depicted, Scenarios 11 and 12 present the most balanced set of economic opportunities for all three ports. Given the likelihood that the sharing of passenger economic impact already exhibits some parity between Dockyard and Hamilton even without improvements to Hamilton's facilities, we would expect that alternatives that present expansion of activity to St. George's (Scenarios 3, 4, 7 and 8) also present an equitable, positive balance similar to that of Scenarios 11 and 12.

The above analysis presents a starting point. Clearly, the next step in movement forward on any scenarios would necessitate a more detailed economic impact assessment that utilizes surveyed direct passenger expenditure data by Bermuda port-of-call. Benefits also need to be taken in context with potential costs associated with each scenario. Estimated costs are discussed as part of Section 6.

5.3.5 Other Societal Benefits Associated with Scenarios

As discussed previously, there are a number of potential societal benefits associated with cruise activities. These can range from community vitality to communication of a destination's brand for follow-on visitation as part of a land based vacation. In the following section, several of these are outlined on an observed or anticipated qualitative level. Where possible, the potential for certain scenarios to expand or reduce expected societal benefits associated with cruise activities are differentiated.

- **Employment.** Clearly linked to economic impact, cruise activities and their direct, indirect and induced impacts create jobs across several job classifications. Employment is most readily observed in sales and related occupations in retail, food and beverage and

similar trades as well as service related industries such as tour providers and guides. Cruise activities also support employment of transportation providers, harbour pilots, security personnel and other public and private sector workers. Net increases under any of the improvement scenarios are anticipated to have a direct and positive impact on Bermuda's employment.

- **Community Development and Vitality.** The presence of cruise activities can provide an economic and societal engine for community development. Dockyard presents a positive example of this in action. Today's Dockyard—from the number and types of businesses to the level of site restoration—is a world apart from the Dockyard of the mid 1990s. The expansion of cruise traffic to Dockyard has played an important role in Dockyard's revitalization. Conversely, St. George's has clearly experienced a moderate level of decline—mostly observed within the Town Center—from its loss of cruise activities over the past five years; stains that are evident in the number of unoccupied storefronts, restaurants and overall street life during the late spring, summer, and early fall months. Bringing back cruise operations through pursuit of scenarios that modify Town Cut (Scenarios 3, 4, 7, 8, 11 and 12) are expected to help reverse this trend to a degree. Other efforts being pursued within and proximate to the Corporation, such as redevelopment of Club Med site for a new hotel property, will also likely have a cumulative positive effect.

There is a threshold (aka, carrying capacity) as to how much cruise activity a community can sustain until the community development and vitality benefits are overshadowed by strains on transportation and other destination delivery systems. Negative impacts are generally most evident: (1.) In locations where vessel peaking—either weekly or seasonally--causes significant fluctuations in demand of destination infrastructure; (2.) locations with underdeveloped transportation assets and/or infrastructure; (3.) destinations with poor pedestrian or other alternative mobility options; (4.) poorly managed venues that result in over-visitation and poor management of visitor traffic; and, (5.) poorly managed cruise arrivals areas (e.g., no operational control of vendors, poorly managed ground transportation areas, and others).

While each destination's threshold varies due to a number of factors, from experience, ports and destinations perform better when they take an active role in management of not just the immediate operational aspects of cruise activity at the dock, but activities throughout the destination. Management includes both public and private sector entities working in collaboration to plan for cruise activities in concert with all other destination activities (land based

tourism, commercial businesses, commuting patterns, entertainment and special events, and others). Dockyard provides a good example of this in action. Collaboration and work in multiple sectors over the last decade has allowed Bermuda to leverage expansion and modernization of a waterbourne transit system that increased the carrying capacity of Dockyard for cruise activity while at the same time providing great benefit to Island residents and visitors arriving by air. Certainly there have been challenges with this approach, but on balance and through discussions with stakeholders throughout this project effort, the ultimate result has been positive over the past decade.

- **Public Access.** Cruise activities can have both beneficial and harmful influences on public access to waterfront areas. For many locations, cruise arrivals and departures occur with already designated port zones and areas that, due to safety and security concerns, do not provide public access. In these locations, growth of cruise businesses is basically neutral in terms of impact to public access. In other locations, such as Bermuda, cruise activities arrive in waterfront zones that are located within town centers and are generally open to the public when vessels are not present. In these zones, public access has to be balanced against the need for security, transportation logistics areas (even if temporary) and other operational needs. When planned properly, operational needs and public access aspirations can be balanced and, in fact, enhanced due to the ability of this activity to be a contributor toward capital costs for waterfront revitalization and renewal. Given that each of the locations—Dockyard, Hamilton and St. George's—all have facilities in place within each town center area, we do not see any specific scenario having a strong societal benefit toward public access. Hamilton's plans to redevelop its waterfront and greatly improve public access related amenities would receive some benefit from having cruise activities in the Harbour.

Also of note, scenarios reviewed for St. George's for expansion of Town Cut all required reduction to lands owned and/or operated by the Government of Bermuda, i.e. Higgs, Horseshoe, and Hen Islands. Thus, these scenarios have a negative impact on public access as they reduce the quantity of land available for recreation and environmental habitat.

- **Environmental Quality.** Society derives benefit from the quality of its environmental resources. While a discussion of environmental impacts is treated elsewhere in this report, all scenarios presented environmental some level of environmental trade off and impact. A precise measurement of the direct and

indirect societal value of terrestrial and aquatic environmental assets will need to be conducted as part of any follow-on project feasibility assessment.

- **Reoccurring Visitation and Community Investment.** The presence of a cruise vessel in your town offers the potential to market a destination to visitors and potentially entice them to return as part of a land based vacation or to look to the destination as a place of interest for business or second home investment. In this way, the cruise business presents a unique opportunity for a destination to market its brand and possibly reap the broad economic and societal benefits associated with return visitation, community investment and/or overall positive brand status in the global marketplace. For scenarios reviewed, those alternatives that broaden the number of ports cruise vessels visit while in Bermuda have the possibility to open the window somewhat for expanded marketing and brand communication. However, given the amount of time vessels and passengers spend in Bermuda overall and the likelihood passengers take in multiple locations while on the Island, the additional benefit derived from these more balanced, multiple port alternatives is likely small.

6 CONSTRUCTION AND FINANCING

The benefits derived from implementation of the access improvements to individual channels/ ports or a combination of multiple channel/ ports discussed in Section 5.3.3 can be reviewed within the context of anticipated capital expenditures for these improvements and other environmental and social costs. A preliminary opinion of probable construction cost for dredging and excavation for each scenario was developed. This opinion is highly dependent on geotechnical considerations, the equipment required to perform the work (material, type, and location of equipment), and disposal location.

Upon understanding the capital expenditures associated with each access improvement alternative, an overview of the financing options that may be used is provided.

In the following section the estimated costs and other considerations associated with geotechnical conditions, quantity of material removed/disposed associated with dredge activities, and overall channel and harbor improvements are presented. A discussion of possible project financing costs for moving project alternatives forward is also discussed.

6.1 GEOTECHNICAL ENGINEERING MATERIAL PROPERTIES

Since there is limited information on the engineering properties of the offshore materials; this discussion is based on general information on the engineering properties of the various geological units primarily from onshore observations and limited additional data from the 1979 Town Cut and the 2007 New Grotto Bay / Castle Harbour Crossing studies and projects, as well as knowledge gained during construction of local projects (Golder, 2011). Furthermore, this discussion does not consider the condition or geometry of the existing dredged channels; which may be a good indication of long-term performance of dredged slopes and channels.

All of the materials likely to be encountered within the marine channels are expected to be of carbonate composition, and consequently would be less abrasive than silicon or quartz based materials. The structure and engineering properties of the materials are largely determined by the depositional environment and subsequent diagenetic effects. In general, the younger formations show less cementation and have well defined stratigraphy (beds), whereas the older formations are more highly cemented and massive but can have fissures/faults and other structure.

- The unconsolidated surficial silty and sandy seabed sediments are expected to be loose/soft and uncemented. These materials will be highly susceptible to erosion under wave, current and propeller wash action. Stable unprotected slopes within these materials will be highly dependent on wave and current conditions, but they should be assumed to be relatively flat – no steeper than 10 horizontal to 1 vertical (10H:1V). Steeper slopes could be developed, if required, by placing granular slope protection;
- The structure of the aeolian materials reflects their mode of deposition. The younger sandy aeolian and finer-grained marine formations (Southampton, Rocky Bay, Belmont formations, in increasing age) exhibit strong bedding (thin steeply sloping foreset beds and more massive flat-lying windward and marine beds), and are lightly to moderately cemented. From review of the available data, unconfined compressive strengths (UCS) of the intact material (unaffected by rock structure) are considered likely to range from less than 1 to 25 MPa. The weakest of these materials (e.g. Southampton Formation) are marginally cemented and would be highly susceptible to erosion; even the more cemented units can have zones of weakly cemented materials. These units are typically easier to excavate using mechanical equipment because of their bedding and light to moderate cementation. The stability of excavated slopes within these units will be highly dependent on the degree of cementation as well as the structure and orientation of the bedding and fissures, as well as the erosion exposure. For conceptual purposes, it is recommended that an average effective long-term slope be no steeper than 1H:1V, although the actual excavation may be steeper than this initially; and
- The older formations (Town Hill, Lower Member and Walsingham formations) are moderately to highly cemented and altered and more massive, with the bedding often obscured; faults, fissures and joints sometimes cross the bedding. Caves are more commonly associated with the older Walsingham Formation. These units are a source of the more competent building materials in Bermuda, being used for armour stone, aggregate, building stone and roofing slate. From the data which is available, UCS strengths of the intact material (unaffected by rock structure) are considered likely to range from 25 to 50 MPa. Being more massive and well cemented, these materials will be much more resistant to erosion, but they will also be more difficult to excavate without resorting to impact hammers/chisels or blasting. The stability of excavated slopes within these units will be highly

dependent on the structure and orientation of the bedding and fissures. For conceptual purposes, it is recommended that an average effective long-term slope no steeper than 1H:4V.

Some of the improvements under consideration involve onshore excavations. It is anticipated that these can be conducted using conventional excavation methods and equipment, at least down to the water level. While the younger, lightly to moderately cemented, thinly bedded and fractured materials can likely be excavated using heavy mechanical excavation equipment, without prior breaking, the older and more massive units will likely require breaking by blasting (if permitted) or by using mechanical rock hammers/chisels for efficient excavation. In areas remote from buildings, and where environmental conditions permit, there may be some advantage to loosening the rock by blasting within onshore areas down to channel invert level to allow subsequent more efficient excavation using conventional equipment.

Where blasting is not permitted in offshore areas, the common marine excavation approaches for rock are using cutter suction dredges (CSDs) for larger projects and excavators or clamshells, with hydraulic hammers/chisels as necessary, where quantities are limited. Trailing suction hopper dredges (TSHDs) fitted with a ripper draghead have also been used, particularly where currents and wave action limit the use of CSDs. Key geotechnical considerations in selection of the most efficient excavation equipment are the compressive and tensile strength, mineralogy, structure and abrasivity of the material to be excavated. The ability of such equipment to efficiently excavate the materials expected at the site would need to be assessed in future phases, following a program of investigation to characterize the subsurface conditions. Based on published information, it is anticipated that CSD and TSHD equipment could excavate rock having some structure with UCS of the rock material typically in the range of 1 to 15 MPa, and a percentage of material up to 30 or 40 MPa. This suggests that it would be feasible for all but perhaps the harder and more massive Town Hill, Lower Member and Walsingham (in particular) formations. The impact of the harder materials is greater wear and slower progress, and therefore increased cost. Therefore, small quantities of harder material do not necessarily preclude use of such equipment; rather they result in increased risk and cost.

6.1.1 Town Cut Alternatives

The alternatives under consideration for deepening and widening the Town Cut channel involve dredging to -11 to -12m CD and widening up to 165m.

Widening to the south will require excavation on Horseshoe, Higgs, and Hen Islands for all schemes. The geological information suggests

that these excavations would likely be within the Rocky Bay and Belmont Formations which are expected to have significant bedding and relatively light to moderate cementation, and therefore amenable to excavation using CSD or TSHD with relatively low risk of prior breaking by blasting or hydraulic hammers being required. Given the distance to residential properties, it might be acceptable to loosen the rock down to invert level by blasting within the onshore areas, thereby permitting more efficient excavation using conventional equipment in these areas where large volumes would have to be excavated.

6.1.2 Two Rock Passage Alternatives

Widening the channel to 130m and realigning it the south in conjuction with dredge depths of-11m and -11.5m CD will require approximately 2m of dredge cut in the channel and deeper excavations through Lefroy Island. The available bathymetry suggests that at least the upper portion of the excavation (at Lefroy Island) will most likely encounter Rocky Bay and Devonshire Member units which are expected to have significant bedding and relatively light to moderate cementation, and would therefore be amenable to excavation using CSD or TSHD with relatively low risk of prior breaking by blasting or hydraulic hammers being required.

Given the distance to residential properties, it might be acceptable to loosen the rock down to mean sea level by blasting at Lefroy Island, thereby permitting more use of conventional equipment in these areas. There is some risk of encountering harder more massive material of the Town Hill, Lower Member and Walsingham formations at the base of the channel, particularly in more easterly areas; this harder material may be problematic for CSDs and THSDs without prior breaking.

This preliminary assessment has been provided using available information. Geotechnical investigations should be undertaken to explore the actual site and surface conditions. In general, the greater the knowledge of the subsurface conditions, the easier it is to plan and manage the construction risk and costs.

Ideally, for detailed evaluation and design, subsurface exploration along the channel alignments would be desirable in order to characterize the underlying materials for risk assessment and costing, although, this may be prohibitively costly. A phased approach could be considered, involving:

- Inspection, sampling and mapping of outcrops along the nearby shorelines.
- Marine geophysical sub-bottom profiling while also collecting accurate bathymetrical data. This equipment should be capable

of identifying significant near-surface unconsolidated deposits, but is not expected to be successful in identifying voids or deeper subsurface features, and is unlikely to be useful in differentiating between lightly to highly cemented rock materials. The geophysical profiling could be augmented by a video diving survey and/or low-level high quality aerial photography under suitable weather conditions.

- Drilling in accessible onshore areas in proximity to proposed improvements. Road access is available on the north side of the Town Cut; access to the various islands which might be impacted may be more challenging, but may nevertheless be less costly to investigate than within the channels themselves.
- Bottom sampling and probing using light portable equipment where soft sediments exist at seabed to determine characteristics and thickness.
- Cored boreholes in channel areas where significant excavation within consolidated rock materials is expected, along with a laboratory testing program to evaluate strength, structure and abrasivity. Wave, swell and current conditions have a significant impact on the type of equipment required for such work, along with the associated costs. There is equipment available locally which can operate in relatively calm water, but more exposed areas would require specialized jack-up drilling platforms which would have to be imported at significant cost.

6.2 MATERIAL QUANTITIES

Figure 6-1 lists the estimated excavation and dredging quantities for the access improvement by alternative. The quantities are based on dredging to the neat line and do not include an overdredge allowance. Depending on material, it is anticipated that a 0.3 to 0.6m overdredge allowance would occur, which may or may not be considered a payable item to the dredge contractor.

6.3 OPINION OF PROBABLE CONSTRUCTION COST

With the very limited geotechnical information, a preliminary percentage of material type (soft marine sediment, medium sediment/with easily ripped rock, and hard material – rock) was estimated. Geotechnical investigations are required at each site to define the correct percentages. Since unit cost increases with the hardness of material, the cost to perform work may change (decrease or increase) accordingly. The disposal site was assumed to occur within 1 to 1.5 km of each site.

Figure 6-1: Area and Volume of Material Removed for Each Threshold Alternative

Access Improvements			Area (m^2)	Volume (m^3)	Average Depth of Cut (m)
St. George's Harbour/ Town Cut	Tier 1 Threshold 145m wide channel	Existing Channel - Dredge to -11.0m CD	244,484	294,208	1.20
		Channel Widening - Dredged to -11.0m CD	136,738	767,786	5.62
		Higgs & Horseshoe Island - Excavation and Dredging to -11.0m CD	17,655	276,970	15.69
		Hen Island - Excavation and Dredging to -11.0m CD	8,829	103,698	11.75
		Total - Dredge and Excavation	407,706	1,442,662	
	Tier 2 Threshold 155m wide channel	Existing Channel - Dredge to -11.0m CD	244,484	294,208	1.20
		Channel Widening - Dredged to -11.0m CD	169,969	941,785	5.54
		Higgs & Horseshoe Island - Excavation and Dredging to -11.0m CD	19,455	302,237	15.54
		Hen Island - Excavation and Dredging to -11.0m CD	10,068	119,456	11.86
		Total - Dredge and Excavation	443,976	1,657,686	
	Tier 3 Threshold 165m wide channel	Existing Channel - Dredge to -12.0m CD	283,194	552,789	1.95
		Channel Widening - Dredged to -12.0m CD	196,180	1,210,942	6.17
		Higgs & Horseshoe Island - Excavation and Dredging to -12.0m CD	20,552	336,721	16.38
		Hen Island - Excavation and Dredging to -12.0m CD	11,384	147,106	12.92
		Total - Dredge and Excavation	511,310	2,247,558	
Two Rock Passage	Tier 1/Tier 2 Threshold	LeFroy Island - Excavate and Dredge to -11.0m CD	1,109	13,308	12.00
		Widen Channel - Dredge to -11m CD and -11.5m CD	803,120	1,539,727	1.92
		Total - Dredge and Excavation	804,229	1,553,035	
South Channel	Tier 1/Tier 2 Threshold	Existing Channel - Dredge to -11.0m CD	952,198	934,144	0.98
		Total - Dredge	952,198	934,144	
North Channel	Alternative 1	Existing Channel - Dredge to -12.5m CD	38,207	5,754	0.15
	Alternative 2	Whites Flat - Dredge to -13.5m CD and widen to 215m	252,825	168,930	0.67
	Alternative 3	Realigned Channel - Dredge to -12.5m CD	17,262	25,124	1.46
		Total for Alternatives 1, 2, and 3- Dredge	308,294	199,808	

The opinion of probable construction costs represents the likely base cost for each alternative; additional costs are likely to be incurred. The following items are not reflected in the costs:

- The cost of building and managing the disposal area.
- The cost to move Aids to Navigation.
- The cost to build to rebuild the training structure.
- The cost of environmental mitigation.
- The premium in cost for offshore disposal of dredged material from the North and South Channels will depend on disposal location.

Each cost includes mobilization/demobilization and setup costs which may range from $4.5 million to $6.5 million depending on equipment and where it is located. In addition, a 20% contingency has been added to account for the variability in material. If several projects are performed at once, the mobilization/demobilization costs be lower overall as these occur only once (some costs not reported here would likely be incurred for moving equipment from job site to job site). Table 6-1 shows the opinion of probable construction cost for each channel alternative.

6.4 PROJECT SCHEDULE

The timing associated with implementation of access improvements depends on the number of factors including:

- The number of access improvements to be completed and the associated phasing.
- The scope and timing of field investigations and environmental studies.
- Equipment availability and timing.
- Duration of physical construction activities.

The completion of field investigations and environmental studies generally takes 1 to 3 years to complete depending on the scope of the project and the range of potential environmental impacts. Due to smaller scale of access improvements in the North Channel, it is anticipated that completion of these investigations and studies would fall on the lower end of the aforementioned range while the remaining access improvements fall on the higher side.

Similarly construction timing depends on the scope of work. Improvements to Two Rocks and Town Cut are anticipated to take a minimum of 18 months to complete. Completion of the South Channel may take up to 1 year while the North Channel can be completed within a year.

Table 6-1: Opinion of Probable Construction Cost

Site	Dredging Cost (US$)	Mob/Demob & Equipment Standby (US$)			TOTAL COST (US$)			Additional Contingency - 20% (US$)		
Town Cut - St. George's (145-meter wide channel)	$43,680,364	$4,500,000	to	$6,500,000	$48,180,364	to	$50,180,364	$9,636,073	to	$10,036,073
Town Cut - St. George's (155-meter wide channel)	$50,160,951	$4,500,000	to	$6,500,000	$54,660,951	to	$56,660,951	$10,932,190	to	$11,332,190
Town Cut - St. George's (165-meter wide channel)	$65,159,607	$4,500,000	to	$6,500,000	$69,659,607	to	$71,659,607	$13,931,921	to	$14,331,921
Two Rock Passage (130-meter wide channel)	$51,740,336	$4,500,000	to	$6,500,000	$56,240,336	to	$58,240,336	$11,248,067	to	$11,648,067
South Channel	$18,192,649	$4,500,000	to	$6,500,000	$22,692,649	to	$24,692,649	$4,538,530	to	$4,938,530
North Channel (All Alternatives)	$3,961,298	$4,500,000	to	$6,500,000	$8,461,298	to	$10,461,298	$1,692,260	to	$2,092,260

Therefore, the earliest completion date for the North Channel is assumed to be 2013 while the completion of the South Channel, Town Cut, and Two Rock Passage is anticipated by 2017. The timing of these latter projects may be accelerated if studies and investigations can be completed within 12 to 18 months, thereby reducing the completion timeframe by 1 to 2 years.

6.5 FINANCING

Financing for the proposed access improvements could be constructed in various ways depending if the Government of Bermuda has expertise or capacity to fund the project on its own. If the Government does not have ability to fund the project, some form of debt issuance via bonds will be involved. The issuance of Government bonds can be challenging and costly if the revenue base is not sufficiently stable and protected. It may be more acceptable to engage in a Public-Private-Partnership in lieu of traditional bond issuance. For either approach, some revenue collection method and means of protecting the revenues generated by the access improvements from use other than paying down the debt would be necessary, possibly requiring changes to government policies.

Evaluation of revenue potential is the initial step in considering potential financing options. The analysis in Section 5.0 indicates that the proposed access improvements allow for Panamax and possibly Post-Panamax ships to access Hamilton and St. George's, increasing the total passenger throughput and thus generating additional revenues. If these estimated revenues were applied to financing the access improvements, it would take between 17 to 30 years to pay down the construction cost, depending on construction phasing and trends in the cruise market[5].

The Government of Bermuda has three options or a combination of the three options to finance the access improvements:

1. Issuance of bonds to be repaid from its general tax revenues.
2. Link the cost more directly to the economic activity supported by the channel improvement via a Private-Public-Partnership.
3. Allow the companies, or cruise lines, that benefit from these access improvements to finance the improvements and pay for the maintenance of the channel depth and width.

The third option is least likely to work because it would require granting excess market power to the cruise lines (the government

[5] These revenue levels are insufficient by themselves to support the channel improvements, and without the channel improvements, there are NO additional revenues. Therefore, some combination of general government revenues likely will need to be combined with the incremental tax revenues to fund these improvements.

loses some control) and the cruise lines may not want to be liable to pay down the debt. The first two options listed are considered preferable. The following discussion provides a framework of Option 2, funding improvements via a Private-Public-Partnership (PPP).

The additional per passenger fees, revenues due to passenger volumes exceeding the baseline forecast, should be applied to finance the upfront access improvement costs. However, it is likely that these additional revenues may not exceed US$5 million per year and therefore require a very long payback period. Some form of revenue enhancement should be considered, e.g. an additional tax.

St George's economic activity has declined over the last decade but would see a resurgence of activity once cruise ships more frequently call on the port. Retail, restaurant and other tourist service establishments would be created or enhanced, resulting in increases in real estate values. The increase in real estate taxes and building permit fees could be used to help finance the channel enhancements. This might require some changes in government policies, but would enhance the credit quality of any bonds issued to finance the improvements and therefore lower the interest expenses.

The Government may also wish to increase, perhaps for a fixed period of time, the tax basis of cruise ship activity in order to improve its ability to finance the access improvements. For example, Bermuda could introduce a Harbor Maintenance tax.

In the US, the Harbor Maintenance Tax (HMT) is a federal tax imposed on shippers based on the value of the goods being shipped through ports. The tax is placed in a trust fund to be used for maintenance dredging of federal navigational channels. The HMT was enacted by Congress in 1986 to recover a portion of the cost of maintaining, not improving, the nation's deep-draft navigation channels. The amount of tax paid by the shipper, who owns the cargo, was based on the value of the goods being shipped rather than a tonnage tax which was chosen to minimize the impact on U.S. exports, particularly price-sensitive bulk commodities. In addition, a cost-share formula was implemented for improving (widening and deepening) harbors and channels, with local port sponsors paying a part of the cost and the Federal government paying a portion from the General Treasury.

The Government of Bermuda could enact a similar HMT in order to fund the channel's dredging, widening and maintenance. Similar to the ad valorem HMT in the US, the Bermuda HMT could vary by ship size or number of passengers, with larger and fuller ships paying a higher tax for the use of that harbor.

The payments from the Bermuda HMT, which would be similar in concept to pass-through tolls on highways, would be used as revenue,

often referred to as ***availability payments*** in US transportation infrastructure finance, to compensate a private concessionaire for its responsibility to dredge, widen and maintain the access channel for a set period of time. Availability payments have been used extensively in Canada, Europe, and Australia, but are just beginning to gain interest in the U.S.

These payments are made by a public project sponsor (in the US, a State DOT, for example) based on particular project milestones or performance standards. The Government of Bermuda could create a special agency to fulfill such a role.

Availability payments are often used for highway toll facilities that are not expected to generate adequate revenues to pay for their own construction and operation. The project sponsor, in this case the Government of Bermuda, retains the underlying revenue risk associated with the HMT rather than its private sector partner. In this manner, there is less overall revenue risk to the private entity than with a full concession. This is important to a private concessionaire, as there is significant environmental and operational risk in this project.

Rather than relying on achieving certain levels of traffic and revenue, the concessionaire receives a predictable, fixed set of payments over the life of the agreement. The concessionaire also can rely on the public agency's credit to secure financing rather than unpredictable HMT revenue. Private financings involving an availability payment concession could include private equity, taxable debt and government-provided credit assistance.

If the Government of Bermuda is unable to do this, it could allow a private equity group to do it. The private equity group would fund the project using a consortium of lenders (usually banks) and would charge the cruise ship companies for using the facilities. The private equity group charges could be fixed by the government so as to limit the profits earned from this. The profits earned by the private equity group would be a cost of not trusting the government. This cost could be avoided if the government were able to issue the bonds or acquire loans at a lower interest rate on its own.

7 SUMMARY OF FINDINGS

The following summarizes the findings from this study

- Global cruise industry is anticipated to grow with vessel deliveries varying between 3 and 9 net new vessels per annum.
- Global cruise industry growth will create demand for a number of present homeport and port-of-call facilities to expand—especially those found within the industry's most popular and profitable regions like Bermuda.
- Bermuda is strategically positioned to grow depending on the implementation of channel/port improvements and changes in government policy.
- Panamax and Post-Panamax cruise ships comprise 64% of existing market. The number of Post-Panamax ships anticipated to grow with Panama Canal expansion. Cruise industry will take delivery of fewer but larger vessels (Post-Panamax class) through 2014.
- Four ship or tier classes consisting of Panamax and Post-Panamax cruise ships were identified to assess improvements to Bermuda's shipping channels and ports.
- Principal ecological communities within the waters of Bermuda are coral reefs and seagrass beds. Channel improvements will most likely impact these marine resources.
- Wave heights in St. George's Harbour are less than 0.5mduring prevailing conditions and less than 1m during the 50-year return period storm event. Channel improvements at Town Cut to affect wave conditions inside the Harbour. Channel improvements do not affect wave conditions at other ports or channels.
- Westerly tracking hurricanes like Hurricane Fabian produce lower storm surges in St. George's Harbour and Great Sound than easterly tracking hurricanes.
- The geological conditions of Bermuda consist of marine sediments of calcium carbonate overlaying volcanic rock. Marine sediment varies in strength and density characteristics with soft, medium, and hard layers.
- Level 1 analysis conducted to identify and assess improvements to shipping channels and ports for four tier ship classes. Fourteen (14) alternatives were developed for St. George's/Town Cut, three (3) alternatives for North Channel, one (1) alternative for South Channel, and three (3) alternatives for Two Rock Passage.
- Physical and operational considerations and environmental and socio-economic impacts were evaluated in Level 1 analysis.
- Full mission bridge simulations were conducted as part of a Level 2 analysis to further refine the channel improvement for alternatives for Town Cut and Two Rock Passage.

- Three channel improvement thresholds (145m, 155m, and 165 m wide channels) corresponding to Tiers 1 through 3 ship classes were identified for Town Cut.
- Three channel improvement thresholds for North Channel were identified; 1) deepening channel to -12.5m CD, 2) widening and deepening channel at White Flats, and 3) realigning and deepening channel at Brackish Pond Flats.
- One channel improvement threshold was identified for the South Channel; deepening channel to -11m CD.
- One channel improvement threshold was identified for Two Rock Passage, a 130m wide channel at -11m/ -11.5m CD water depth.
- All access improvements occur some level of environmental trade off and impact.
- Seagrass and coral reefs will be impacted as a result of channel improvements for all channels and ports. Aquatic resource surveys will be required to accurate determine the amount of impact.
- The north sections of Higgs, Horseshoe, Hen, and LeFroy Islands will be removed for the channel improvements. Terrestrial habitats and recreational opportunities for the public will be lost. Terrestrial survey will required to determine the amount of impact.
- Wave heights increase up to a 1m during the 50-year storm event within St. George's Harbour.
- Coastal flooding decreases in St. George's Harbour for westerly tracking hurricanes when channel improvements are implemented. The Coastal flooding elevation increases by +0.6m CD in St. George's Harbour for easterly tracking hurricanes.
- Projections of passenger growth in Bermuda range from -34,000 to 316,000 depending on the number of channel improvement implemented. The corresponding projected growth in revenues ranges from US($) 8 million to US($) 80 million.
- Net increases in passenger levels and associated revenues under any of the access improvement scenarios are anticipated to have a direct and positive impact on Bermuda's employment.
- The return of cruise operations to St. George's by implementing modifications to Town Cut are expected to help reverse the recent decline in business and overall community vitality.
- The opinion of probable construction cost to implement one or more of the channel improvements range from US($) 8.5 million to US($) 71 million.
- There are two primary financing options for the project: 1) issuance of government secured bonds or 2) public private partnership.

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