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Economic comparison of alternatives to building a port on Goat Islands:
Does Jamaica need to sacrifice a world class conservation site in order to build a world class port?

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A major portion of the analytical work was carried out by Niras Fraenkel Ltd. (NFL), a leading name in port and marine engineering consultancy worldwide. NFL's analyses included site selection (Section 4.1), designing port layouts (4.3), estimating differential costs of construction (4.4), and all underlying analyses such as those related to the wave environment, dredging, breakwaters, excavation and reclamation (4.2). Text from NFL's technical report (Niras Fraenkel 2014) is included throughout the relevant sections of this report both verbatim and paraphrased. The fundamental contribution of NFL to the findings presented here is acknowledged.

Disclaimer

All opinions and errors are solely those of the authors. All estimates were made are in broad terms due to time and budgetary limitations. No attempt was made to generate detailed design of port facilities and no intrusive ground investigation was carried out; additionally, several categories of cost could not be included, notably the cost of land acquisition and cost of maintenance dredging. If one of the alternative sites described in this report is selected for potential development as a port, it would need to be the subject of more detailed investigations before a specific design or detailed costing could be carried out.

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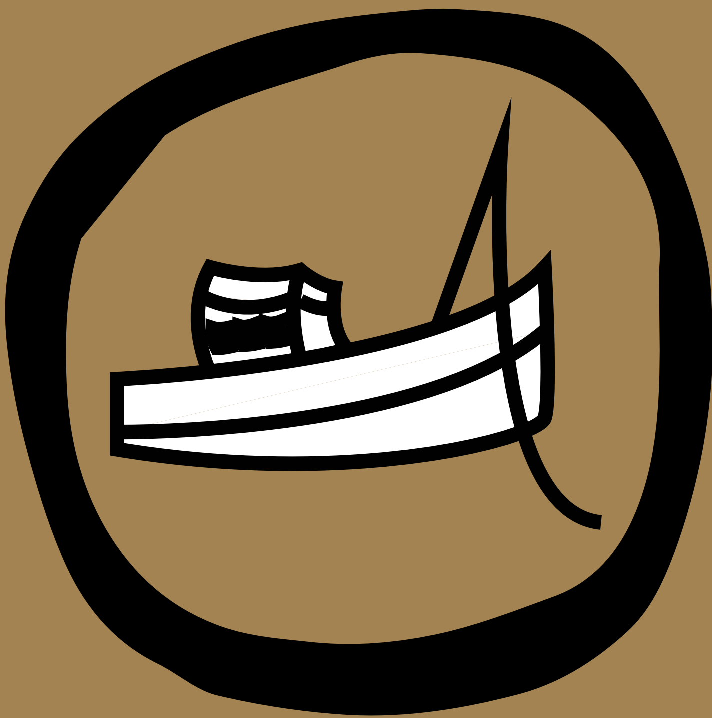

Executive Summary

In 2013, Jamaica's Ministry of Transport, Works and Housing announced that the China Harbour Engineering Company (CHEC) had selected the area on and around the Goat Islands to build a major transhipment port and accompanying industrial complex. Due to the location of the proposed site in the core of the Portland Bight Protected Area, reactions have been heated.

Building a port on Goat Islands requires that Jamaica accept a trade-off – sacrifice an area of outstanding environmental importance in exchange for development. This report assesses whether there are suitable alternative sites that could promote both objectives without imposing undue financial costs on the developer. Our findings show that there appears to be at least one such option: an equivalent facility at Macarry Bay, to the west of Goat Islands, would cost an estimated $200 million less to build. Considering a planned total investment of $1.5 billion, this represents a potential cost savings of more than 10%. Building at Macarry Bay would also impose a far smaller environmental cost.

While advocating that the new port be built at Macarry Bay specifically is beyond the scope of our study, findings strongly recommend that the selection of Goat Islands be reconsidered in light of appropriately detailed analysis of alternative sites.

Methodology

The report uses a Cost-Effectiveness Analysis (CEA) framework to address the question of whether alternative locations offer the potential to build an equivalent facility at lower cost. The CEA is driven by high-level port layouts for potential alternative sites, designed considering wave environment, geology, topography, and bathymetry. We use this information to design necessary breakwaters, as well as identify the composition and calculate the volume of material to be dredged, excavated, and used for reclamation. Cost estimates for these construction activities, based on multiplying volumes by different unit costs depending on the material involved, are used to calculate the total costs of the major construction requirements that differentiate the sites. We do not consider the cost of planned facilities such as the gantry crane assembly plant, whose costs will be roughly the same across all locations. Results are therefore given as differential, rather than total costs.

For developments at the scale considered here, it is not possible to design facilities that are exact equivalents in everything but financial cost. We therefore extend the analysis to include quantifiable environmental damage, for instance related to lost fisheries production or opportunities for tourism development. We also describe and compare several major additional differences between the sites, including factors potentially relevant to both operations and to indirect benefits and costs to Jamaica.

Alternative sites considered include Macarry Bay, which offers potential to build a facility that meets the same size and other requirements specified for Goat Islands. We also consider an option that divides the required facility between two locations, with a transhipment port at Kingston Harbour and an industrial port and shore-side industrial complex on the eastern side of Bowden Harbour. The latter option was included based on the finding that neither site was suitable for the entire facility, but both offer advantages for the functions considered.

Results - Macarry Bay

We consider a layout that is optimal for efficiency of transhipment operations and in terms of minimising environmental impact. The entire port facility is built on reclamation formed by sand dredged in the course of the construction of the port and its approach channel. It is connected across a narrow strip of swamp behind the beach by means of one or more short causeways to proposed industrial estates in the scrub area behind.

The design requires a large volume of dredging (70 million m3), both inside the port and to create the long approach channel. However the material to be dredged is confirmed sand, which is relatively inexpensive to dredge. The total dredging cost is estimated at $500 million. Significant reclamation is also necessary but costs per m3 are minimal due to possibility of using sand dredged from nearby as part of marine works. Two large breakwaters are also required, each over 20 m in height and having a volume greater than 2 million m3. These cost $250 million together. The total differential cost of this option is $931 million.

Results – Kingston/Bowden

The total volume of dredging at Kingston and Bowden combined is approximately half that at Macarry Bay. However, the small amount of dredging required in Bowden Harbour (8 million m3) is likely to require removing soft rock at a far greater unit cost than dredging sand. The total estimated dredging cost in Bowden is $400 million. Most importantly, there is a key unknown cost in this layout related to the material underlying the proposed site in Kingston Harbour. Two scenarios are considered:

Scenario 1: The site is primarily founded on mud, in which case the dredged fill from the adjacent berths and channel deepening is unsuitable for use as hydraulic fill. The combination of imported fill and ground improvement is estimated to cost $850 million. Total differential cost of this scenario is $1.7 billion.

Scenario 2: The site is primarily founded on sand, in which case the dredged fill from the adjacent berths and channel deepening is suitable for use as hydraulic fill, with no additional soil treatment necessary. In this case, reclamation costs drop by nearly $700 million, putting total differential cost at $1 billion.

Results – Goat Islands

The proposed development on and around Goat Islands is the benchmark against which the two alternative designs are compared. The significant majority of cost comes from the need to excavate over 80 million m3 to level the Goat Islands to an estimated 7 m height, and to reclaim an area requiring a similar volume of material between and around the Islands to accommodate the proposed transhipment and portside industrial areas. The key unknowns in this case are the costs at which CHEC can expect to do the necessary quarrying, and the suitability of material dredged in the vicinity of the port for use as fill. Three scenarios are considered:

Scenario 1: Fill and armourstone is obtained from the islands at similar rates to those for purchasing equivalent materials from a local quarry. In this case, excavation and reclamation alone would cost ~$1.8 billion. Total differential cost is $2.1 billion.

Scenario 2: Fill is primarily dredged material pumped into position, but there is a cost for excavating necessary material from the islands even if not used as fill. There appears to be no scope for savings under this scenario given the need to level the Goat Islands regardless.

Scenario 3: Fill and armourstone is obtained from the islands at reduced rates. At 50% of the estimated commercial rates, reclamation and excavation cost an estimated $900 million, with total differential costs of $1.15 billion. Costs at this level would appear closer to those expected by CHEC given public statements that total investment will be $1.5. We cannot know the extent of possible cost reductions, but we note that calculating costs at this level may be optimistic.

Conclusion

Building at Macarry Bay appears to compare favourably to Goat Islands from a construction cost standpoint. An optimum layout at Macarry Bay costs $200 million less to construct than a low-cost scenario at Goat Islands. These differences are driven in large part by the need to excavate and fill areas requiring more than 80 million m3 of material including rock in the Goat Islands case, versus a Macarry Bay design that relies on less expensive dredging of sand and using it to reclaim land nearby.

Furthermore, due to storm surge, locally generated waves, and an orientation that permits Trade Wind waves to enter Portland Bight, Goat Islands faces a more challenging wave environment than might be assumed based on location, while Macarry Bay is less challenging than would initially be assumed due to the prevailing direction of Trade Wind waves and a long, shallow foreshore that significantly reduces deep sea wave heights before they reach the port.

Furthermore, quantified environmental damage from building on Goat Islands is more than three times higher than that from building in Macarry Bay, $6.8 million compared to $1.5 million in present value terms. These estimates are only a partial accounting of ecosystem values; other values are excluded due to data and related limitations. Considering other relevant characteristics, Maccary Bay is superior to Goat Islands except with respect to its access to the road network and Kingston, and likely in terms of the need for maintenance dredging of the approach channel, especially after hurricanes. Macarry Bay appears better in terms of all other characteristics considered, including efficiency of transhipment port layout, ability to expand activities on land and deepen the access channel, environmental impact and local economic impact.

Building at Kingston/Bowden presents the obvious challenge of developing a split facility. However, the combination of sites may offer an opportunity to maximize benefit for Jamaicans from the port development, helping to further Kingston Harbour's competitive advantage in transhipment and at the same time significantly improving connectivity between Kingston and centres of population to the east and Port Antonio to the north. If these gains are deemed potentially worth some complication in design, it would be a relatively simple matter to further investigate whether dividing the proposed facility between Kingston and Bowden is cost-competitive.

While this rapid assessment cannot arrive at absolute conclusions on the best choice for Jamaica's expanded port infrastructure, our findings provide evidence to justify serious consideration of other sites, including Macarry Bay, as alternatives to Goat Islands. If more detailed investigations confirm these findings, Jamaica will be presented with the opportunity to build a new world-class port without losing a world-class conservation site.

School children express their support for the Portland Bight Protected Area following a field trip. © *Ann Sutton*

Introduction & Context

In 2013, the Ministry of Transport, Works and Housing announced that the China Harbour Engineering Company (CHEC) had selected the area on and around the Goat Islands to build a major transhipment port and accompanying industrial economic zone. The news touched off a vigorous debate that continues today, even as initial surveying has begun.

On one hand, success would bring much-needed jobs and economic activity. The third set of Panama Canal locks is set to be completed in 2015, with operations beginning in 2016 (Tronche 2014). Increased capacity will permit transit by much larger Post-Panamax vessels, and in turn significantly increase cargo traffic through the Caribbean. With Kingston Harbour already second only to the Bahamas' Freeport in volume handled by Caribbean ports (Caribbean Journal 2013), Jamaica is well-placed to attract a significant share of this new traffic and associated demand for services.

The new port is seen as important to Jamaica establishing itself as a key player in this context. Minister of Industry, Investment and Commerce Anthony Hylton has articulated the ambitious goal of making Jamaica the fourth key node in the global logistics chain, along with Rotterdam, Singapore and Dubai (MarineLink 2013). The International Monetary Fund (IMF) also notes the relevance of a planned transhipment port and associated industrial area to Jamaica's goal of increasing its role in global logistics (IMF 2014). In terms of benefits to Jamaicans, Minister of Transport, Works and Housing Omar Davies estimates that the project would create 2,000 jobs during construction, and 10,000 once the port and accompanying facilities are fully operational (Davies 2014).

On the other hand, the proposed location for the port is in the core of Jamaica's largest protected area - the Portland Bight Protected Area (PBPA; Figure 1) which has been legally designated for conservation purposes under four separate Jamaican Laws (summary in Annex 1). PBPA is home to numerous globally threatened species and at least seven animal species found nowhere else on earth, including the Jamaican Iguana, one of the 100 most threatened animals in the world (C-CAM and JET 2013; Bailie and Butcher 2012). PBPA also contains what is probably the country's largest nursery for fishable species of all types (Linton 2003, Haynes-Sutton 2010), the largest swath of intact dry limestone forest in Central America and the Caribbean (SSC 2014), and the largest remaining contiguous mangrove system in Jamaica (Linton 2003). Four thousand fishermen and women make use of these resources as the source of their livlihoods (MOAF 2013).

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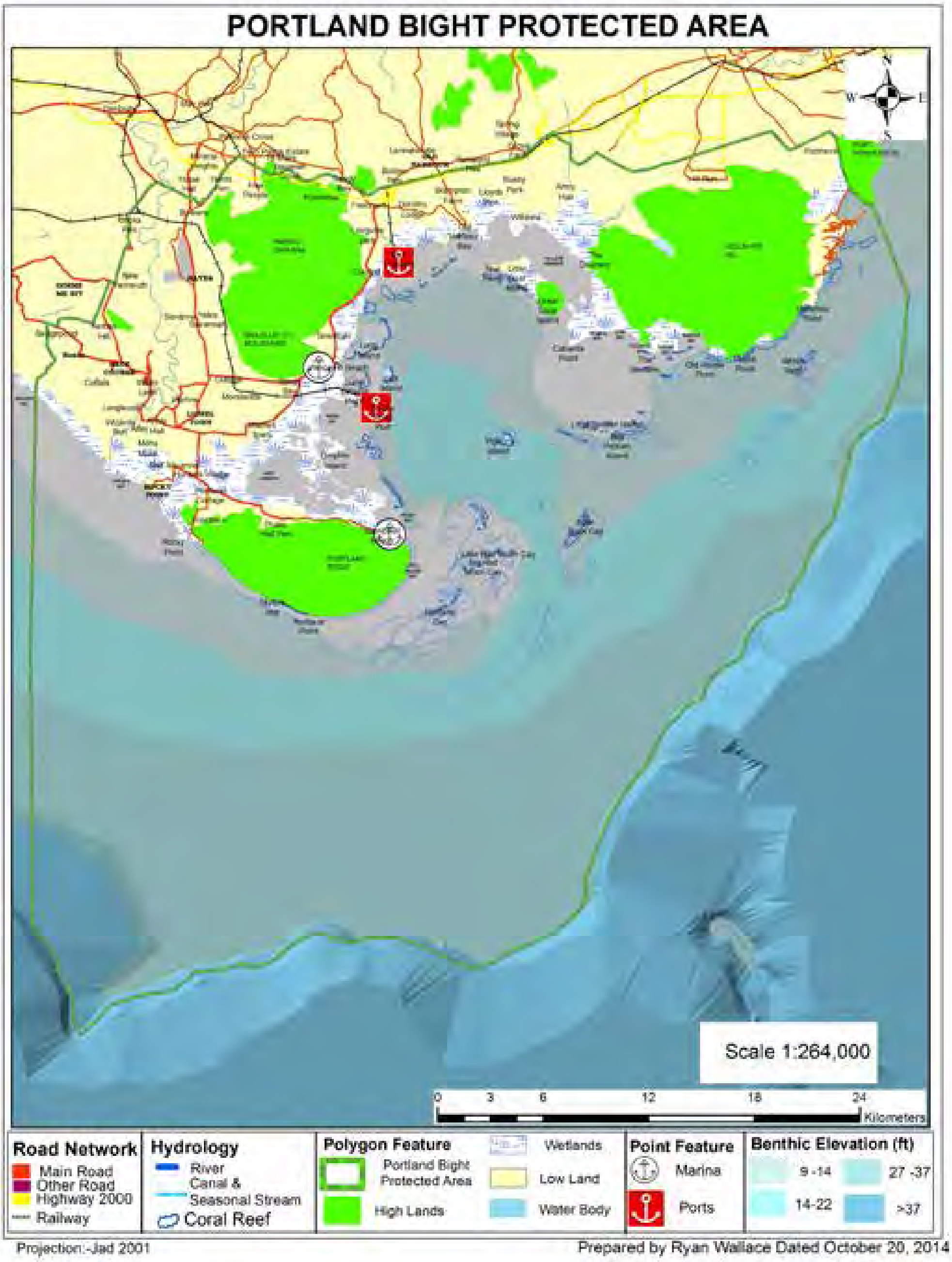
Figure 1: The Portland Bight Protected Area



In recognition of these values, the Ramsar Convention has designated the Portland Bight Wetlands and Cays Ramsar Site as a Wetland of International Importance, and the United Nations has granted conditional approval for designation of a Biosphere Reserve, a classification reserved for just over 600 places of global importance to jointly promoting sustainable development and conservation of biological diversity. The complex of wetlands, reefs, seagrass beds and dry forests on and surrounding the Goat Islands themselves is particularly important. This area includes the Galleon Harbour, which has been designated as a Special Fishery Conservation Area under the Fishing Industries Act, making it one of just 12 areas in Jamaica that are managed as a nursery to support productive fisheries.

Despite the controversial nature of the trade-offs involved, the process of deciding to build on the Goat Islands has not been transparent. At the time of writing, basic official documents describing the port proposal have not been made public, on the grounds that the information is exempt for commercial and confidentiality reasons (JET 2013).[1] As a result, the ability of the nation to engage in informed debate has been limited. Fortunately, recent claims under Jamaica's Access to Information Act have resulted in the release of a set of supporting documents,[2] which, combined with information from official government presentations, now make it possible to infer the general characteristics of project, as outlined below:

- Timing: The project has two development phases. Core sampling to set the stage for Phase 1 is underway at the time of writing. Minister Davies estimates that it will take approximately four years until the project is completed and transhipment activities begin (Davies 2014).

- Location: Development in Phase 1 is planned for the area on and around the Goat Islands, connected by a causeway to an area immediately inland that extends from the coast to Highway 2000. Planned development in Phase 2 is focused in the Hellshire Hills area (Shirley 2014; Figure 2). Dredging may occur up to 20 kilometres (km) out to sea (authors' measurements from CHEC/CCCC Water Transportation Consultants 2014; Figure 3).

- Size: The size of the lots planned for development in Phase 1 is approximately 3,400 acres (~14 km^2). A slightly smaller additional area is considered for Phase 2, such that total lot area is approximately 6,400 acres (~26 km^2) (Shirley 2014; Figure 2). The port itself will occupy approximately 2,200 acres (~9 km^2) (authors' estimate based on CHEC/CCCC Water

[1] These documents include the Memorandum of Understanding (MOU) between CHEC and the Port Authority of Jamaica, the Addendum to the MOU, and CHEC's proposal for the port.

[2] Documents released include the Amendment to the Beach License (NEPA 2014), and the Statement for Changing of Engineering Survey & Geotechnical Investigation (CHEC/CCCC Water Transportation Consultants 2014).

Transportation Consultants 2014; Figure 4), including the Goat Islands and reclamation between and around them. The remaining area is to be occupied by large industrial estates on the mainland.

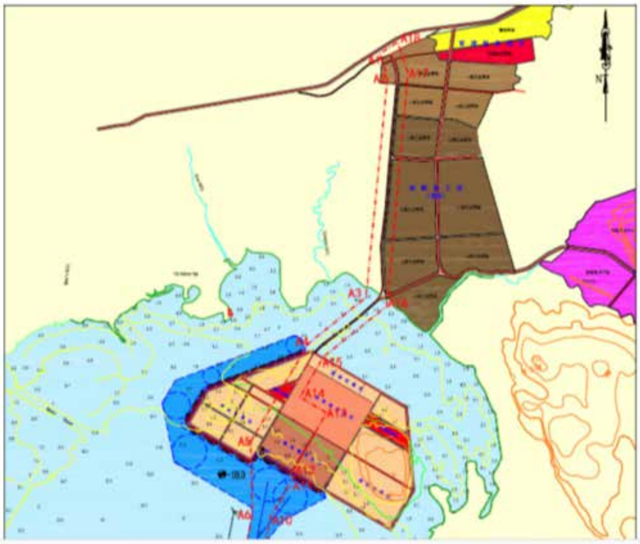
Figure 2: Proposed location and lots to be used on and around Goat Islands

Source: Shirley 2004

Figure 3 *(right)*: Full scope of the planned facility (Phase 1)

Source: CHEC/CCCC Water Transportation Consultants 2014

Figure 4: Schematic design and layout of proposed facilities



Source: CHEC/CCCC Water Transportation Consultants 2014

- Facilities: In Phase 1, the following will be built: an industrial park, support infrastructure, a container terminal, berths, a portside logistics zone, and a coal-fired power plant (Davies 2014). Industrial activities are eventually likely to include an assembly plant for gantry cranes, a steel fabrication plant (JIS 2013), a cement plant, and manufacturing facilities (van den Akker et al. 2013). Following recommendations from an in-depth study by Delft Technical University (van den Akker et al. 2013) that included interviews with CHEC, we estimate that approximately 2.6 km^2 of the port is for transhipment (served by 4.5 km of quay length) and 6.3 km^2 is for industry within or immediately adjacent to the port (served by 2 km of quay length).

- Dredge depth: Drawings of the proposed facility indicate a dredge depth of 18 metres (m) for transhipment areas (CHEC/CCCC Water Transportation Consultants 2014), which is sufficient to accommodate Post-Panamax vessels. It is reasonable to assume that this is the near-term objective. Minister Davies has also stated that berths are to be of sufficient width, length, and depth to accommodate Super Post Panamax Vessels (Davies 2014). We take this to indicate a longer-term interest.

While it is encouraging that some details about the planned development have recently been made public, we believe that if decisions are to reflect what is in the best interest of Jamaicans, information about a far broader range of issues should be generated and shared. In the absence of such information, debate will necessarily be along the lines of whether Jamaica's development needs or environmental legacy should be sacrificed. At the present, it is not at all clear that that is the appropriate question, or, if it is, how stark the trade-offs are.

This report focuses on one of several fundamental questions that need to be assessed in order for Jamaicans to make an informed decision: are there suitable alternative sites that would reduce environmental and social risk to Jamaica without imposing undue financial costs on the developer? If such sites exist, Jamaica could avoid significant social and environmental costs and risks to the nation, without diminishing the business case for the new port. The core of our analysis is therefore an assessment of the costs of construction at Goat Island as compared to alternative sites.

We add to the cost comparison by considering the following additional important questions:

1. What is the value of the environmental services and associated livelihoods that may be put at risk through development around Goat Island, and how does this value compare to values at alternative sites? Estimating this contribution in economic terms and comparing it to values put at risk at alternative sites provides a means to ensure that the environment is part of Jamaica's cost-benefit calculations in deciding what is in the nation's best interest.

2. Of the jobs and economic activity potentially created, what fraction will go to Jamaicans? Beyond jobs created, can any additional benefits be expected, for instance related to cheaper energy, better roads, or better coastal protection? How do potential benefits to Jamaica vary across sites? To the extent that there is uncertainty around economic benefits to Jamaica, greater caution is merited in putting other values at risk.

3. Beyond immediate environmental and social impact, what negative consequences can Jamaica expect from building on Goat Islands as compared to alternative sites? Of particular importance is Jamaica's international reputation and the relevance of that reputation to the country's tourist industry, the source of over 50 percent of the country's foreign exchange earnings and about one-fourth of all jobs (GTTP, accessed 2014). Any negative impact on relationships with development banks, the United Nations, and other international agencies (many of whom have provided millions of dollars in financial and other support for the PBPA and similar areas) would also be important.

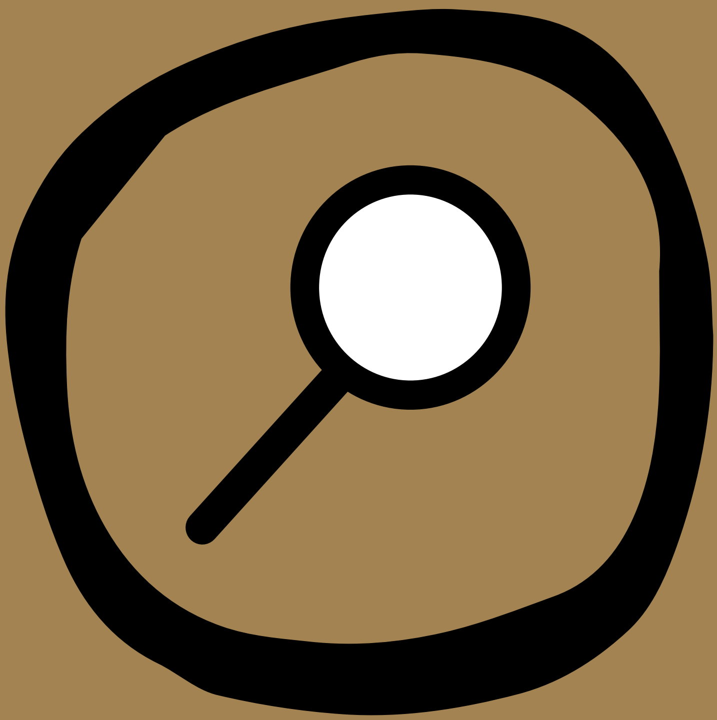
It is important to note that various third parties have already suggested alternative sites for consideration. The most frequently mentioned is Macarry Bay, on the basis that sea currents, dredging requirements, flat ground for building, and other characteristics may be more favourable than those at Goat Islands, while environmental impact would be far less (Chin 2013). The most comprehensive scoping of alternatives to date found three potentially viable alternatives to Goat Islands (Macarry Bay, Jackson Bay, Little Bay) according to a balanced set of criteria related to financial cost, economic benefit to Jamaicans, and environment (van den Akker et al. 2013).

To date, however, the Port Authority of Jamaica and CHEC have not publicly considered these or other alternatives. We assume that this is due, at least in part, to the fact that none of the suggestions so far have included specific cost comparisons of multiple sites.[3] We therefore build on the suggestions mentioned above, but seek to make our work as amenable as possible to transparent consideration in the decision-making process by providing a clear comparison of the major financial costs and related factors that will distinguish each site.

Our cost assessment is necessarily done at a high level. We cannot know how CHEC and the Port Authority would choose to develop alternative sites, nor is it appropriate to make specific suggestions in this regard from a rapid scoping. Furthermore, our analysis is not intended to replace due public process of detailed comparison of alternatives where investments of this magnitude are considered. Instead, results are intended simply to provide clear evidence of whether more detailed assessment of alternative sites is merited. Our results are also intended to add to the transparency of informed public debate.

The methodology used is described in Section 3. Analysis carried are presented in Section 4, with results given in Section 5. Section 6 concludes.

[3] TUDelft (Van den Akker et al. 2013) did in fact estimate costs in their full report; however, this information was not included in the publically released summary (Smith Warner International 2013). To the best of our knowledge, the full report is not in wide circulation.



Methodology

The overall framework for the analysis carried out in this report is Cost-Effectiveness Analysis (CEA). CEA refers to a comparison of the costs two or more alternative means to achieving a common outcome. The outcome itself is frequently non-monetary, and can range from saving lives to protecting species to building a particular length of road. This approach is common to examining policy options where the intended outcome is already selected, does not depend per se on return on investment, or where it is inappropriate, difficult, or unnecessary to value the outcome in monetary terms. In other words, CEA seeks to support selection of the best approach to achieving a pre-determined goal, as compared to Cost-Benefit Analysis (CBA), which can additionally offer information on whether a particular investment is worth making at all.

Given that the Government of Jamaica has committed to developing a logistics hub and transhipment port facility with CHEC as part of its push to prominence in global logistics, a CEA of multiple options for developing such a facility is appropriate. This approach addresses the question of which option is most cost-effective, rather than whether any of the options are likely to generate a net benefit to Jamaica or how to maximize that benefit for the greatest number of Jamaicans. Given the high stakes, we do not believe the latter question should be taken as given, but assessing it is beyond the scope of this report. However, we note that important doubts have been raised.[4]

CEA requires a common outcome that can be used to ensure that the costs of each option can be fairly compared. In this case, the common outcome is a logistics hub/transhipment port/industrial area meeting the specifications given publically by Minister Davies and Port Authority Chairman Shirley, as well as those that can be discerned from relevant documents as outlined in the previous section. The options compared are different potential locations, rather than, for instance, different industrial production technologies that might affect the area required.

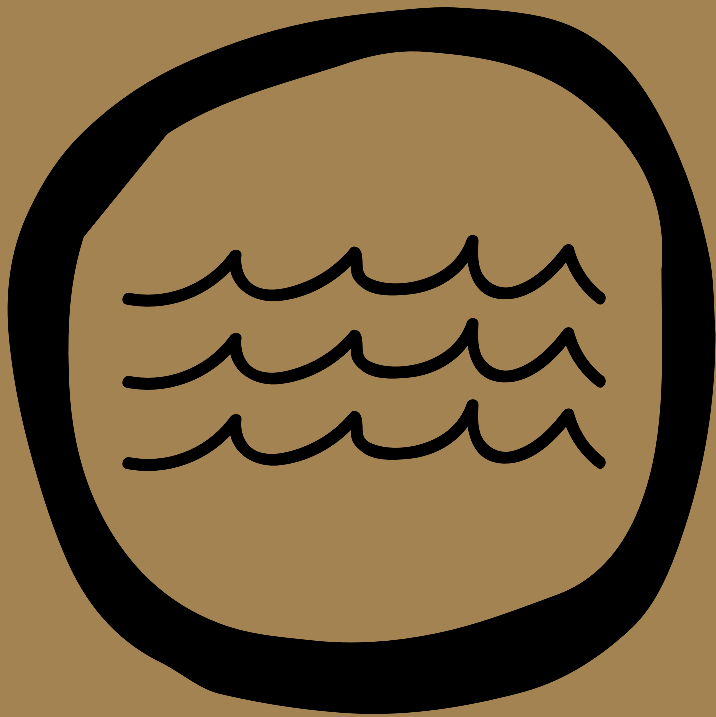
The basic product of the CEA is a comparison of the financial costs of building at each location included in the analysis. This category of costs is also referred to as "internal" costs, in that they are typically paid directly by developers and/or government, and are therefore of obvious importance. Internal costs are generally the core of any CEA. We assess internal costs here by designing a reasonable port layout for potential sites based on wave environment and relevant geophysical characteristics (geology, topography, and bathymetry). Layouts and local cost data are then used to calculate the major construction requirements that differentiate the sites.

[4] As this report was being finalized, CaPRI (2014) published a study concluding that there are fundamental hurdles to overcome if Jamaicans are to benefit substantially from the logistics hub. The Economist (2014) suggests that Jamaica is already significantly behind potential competitors seeking to capture Post-Panamax vessel transhipment traffic. Witter (2013) also provides a useful discussion of the shortcomings in terms of benefits to Jamaicans of the bauxite, banana, and tourism industries.

As noted, we extend the analysis to consider several related issues. We include quantifiable environmental damage by considering external costs (or “externalities”), for instance related to lost fisheries production or opportunities for tourism development. This category of costs is typically not paid by developers, and is therefore frequently not included in CEA, although in theory it should be because external costs nonetheless represent real losses to society. To provide a monetary estimate of these losses, we use a benefit transfer function (as explained below) to value the expected habitat directly destroyed at each site based on port layouts. Finally, we describe and compare several major additional differences between the sites, including factors potentially relevant to both operations and to indirect benefits and costs to Jamaica. These factors are not quantified, but are relevant given that for developments at the scale considered here, it is not possible to design facilities that are exact equivalents in everything but cost.

Within the CEA framework, we focus on major differences between sites. Relevant financial costs in this context include the cost of dredging, excavation, reclamation and breakwaters, rather than the cost of planned facilities such as the gantry crane assembly plant or steel plant whose costs will be roughly the same across all locations.

Analysis was carried out in the following steps: 1) Selection of the two most promising alternatives to Goat Islands for inclusion in the CEA; 2) Analysis of key determinants of layout and cost at the selected alternative sites and at Goat Islands (i.e., wave environment and relevant geographical, geological, and topographical characteristics); 3) High-level design of port layouts at alternative sites; 4) Calculation of key costs at all sites; 5) Valuation of ecosystem services that would be lost or put at risk at each site; and 6) Qualitative comparison of other major differences between sites.

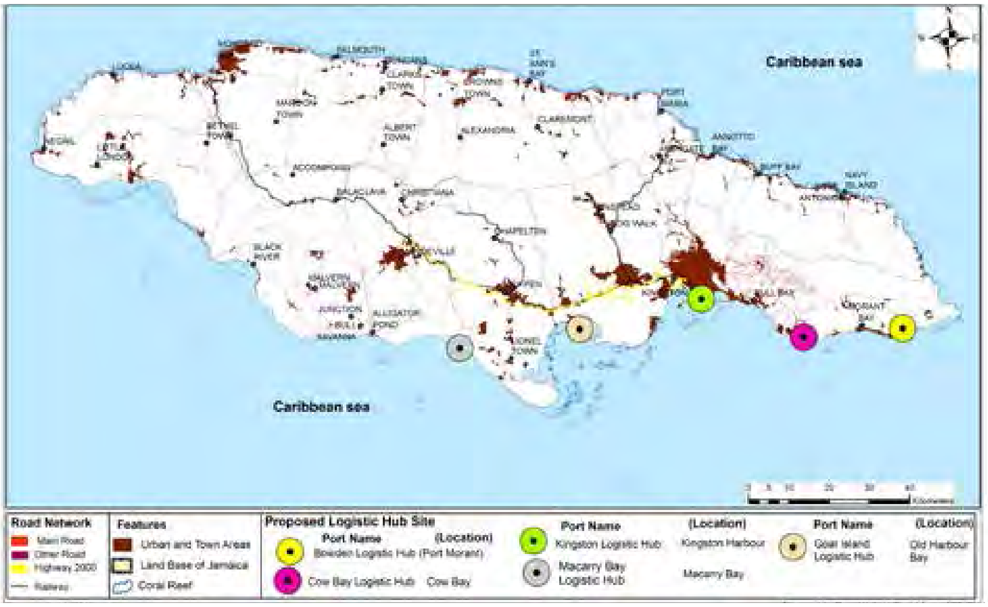


{ Analysis

4.1 Selection of alternative sites for inclusion in analysis[5]

This step considered only potential port sites relatively close to Kingston, on the understanding that proximity to the capital city is an explicit priority for CHEC (van den Akker et al. 2013). The set of sites that appeared potentially viable considering this requirement and the specifics of the planned facility were Macarry Bay, Kingston Harbour, Cow Bay and Bowden Bay (Figure 5).

Figure 5: Location of the four alternative sites scoped prior to the CEA; Goat Islands shown for reference



Source: Wallace 2014

To select the most promising of these alternatives for analysis in the CEA, we considered existing maps and a similar scoping exercise carried out by Delft Technical University (van den Akker 2013). We also carried out a site visit to see potential sites and talk to local experts first hand. Criteria for evaluation included:

- Wave environments as indication of the extent and configuration of any breakwaters which might be required to provide sheltered berths;
- Land area available;
- Water depths;
- Lengths and orientation of entrance channel;

[5] Sections 4.1-4.4 are based on analyses performed by Niras Fraenkel Ltd. (NFL). Full detail is available in Niras Fraenkel (2014).

- Navigation, turning area and berthing;
- Allowance for future expansion and increasing vessel depth;
- Access and communications; and
- Littoral drift (transportation of sediment along the coast).

Qualitative description of the advantages and disadvantages of each site are as follows:

Macarry Bay

Advantages

- A large flat area of land available inshore of the port allows space for the full proposed development including ports and industrial estates in one site.
- The location puts the population centres of Mandeville, May Pen, Kingston, Spanish Town and Old Harbour potentially within commuting distance; by comparison to Goat Islands, the first two are closer, while the latter three are somewhat farther.
- Shallow water in the vicinity of site reduces wave heights particularly for hurricane conditions, reducing the volume and size of armour units of breakwaters that would otherwise be needed
- Some shelter from trade wind waves is offered by the location and wide shallow foreshore, although no natural breakwaters exist.

Disadvantages

- Shallow water in vicinity of site requires a long approach channel to be dredged and maintained.
- The site is exposed to hurricane waves (although these are reduced in height by the wide foreshore as mentioned above.
- It is likely to require long breakwater(s) for protection.

Kingston Harbour

The Fort Augusta area in Kingston Harbour is not considered due to CHEC's previous rejection of the site on the grounds that it allowed insufficient area for industrial activities. We consider here the possibility of building a new port area on land reclaimed on a large shoal in the shallow southern portion of Kingston Harbour to the north of the existing airport runway and Port Royal mangrove swamps, and connected to the Palisadoes Peninsula.

Advantages

- The location on the Palisadoes Peninsula puts the population centres of Kingston, Spanish Town and Harbour View within easy commuting distance. Due to the presence of the existing container terminal, it may be assumed that this site is the most accessible to Jamaica's skilled port labour.

- The location within a natural harbour provides protection from waves without the need for breakwaters.
- Most of Kingston Harbour's existing East Channel is deep enough for Chinamax vessels (requiring dredging to 27m) to be accommodated in addition to post-Panamax vessels that require dredging to only 18m.

Disadvantages

- The existing approach channel to Kingston Harbour is a single channel that is congested under the current traffic volumes. To accommodate the proposed traffic it would need to be widened to two lanes. This would require a significant amount of dredging, particularly in the vicinity of Port Royal.
- The project would involve a major reclamation effort involving a large volume of fill. If the material obtained in the course of dredging for the berths and approach channel can be used for this purpose, costs would potentially be manageable. The composition of the strata forming the shoal (and hence most of the dredge material) is therefore very important but is unknown at the time of writing.[6]
- While it is possible to reclaim sufficient land for the port complex, there is no suitably large area of land for the associated industrial estates available in the vicinity. Kingston can therefore only be included if transhipment and industrial activities can be separated, with the transhipment port built in Kingston Harbour, and the industrial port and associated industrial estates built elsewhere.

Cow Bay

Advantages

- Deep water close inshore means little or no approach channel needs to be dredged.
- Some shelter from trade wind waves due to location.
- Relatively close to Kingston.

Disadvantages

- The site is exposed to hurricane waves
- Deep water close to shore will require expensive breakwaters.
- High ground inland of the site severely limits availability of dry area near to port.

[6] Nearby locations include both sand (most of the Palisadoes peninsula) and mud (the north eastern part of the harbour)

Bowden Harbour

Advantages

- Bowden Bay is a natural harbour with natural reefs on either side of the entrance, so that breakwaters would be in shallow water and fairly short or not required at all.
- Large flat area of land available to the east of the port allows space for the proposed industrial estates on land contiguous with port facilities built on the eastern side of the harbour.
- Deep water just outside of the harbour results in a very short approach channel which limits the volume of dredging required. Because the entrance is short, a two-way channel would not be required, further reducing the scope of dredging.

Disadvantages

- The site is only large enough to accommodate the transhipment port quay length if it is located at the eastern side of the harbour and if the eastern side of the harbour is extended inland by dredging. The full length of the eastern side of the harbour would need to be utilised and this would require breakwater protection of the southern (seaward) end of the quay. Using the eastern side of the harbour for the transhipment port requires the industrial port to be located on the western side where there is sufficient space for it, but this would separate it from the only available large land area for the industrial estates.
- While the volume of dredging is less than for most of the other options, the geology of the area suggests that a significant quantity of soft rock (mainly sandstone and coral) may be encountered, making suction dredging much less likely and therefore significantly increasing the unit cost of dredging
- A localised area of high ground adjacent to the eastern side of the harbour severely limits size of the available dry land immediately adjacent to the port. This area appears to consist of a mixture of soil and fairly soft sandstone such that levelling it and using the material as fill for reclaimed areas is a practical possibility.
- The location near the eastern end of the island is not ideal in terms of proximity to major population centres. The road link to Kingston is by winding coastal road with improvements only on the last few kilometres between Bull Bay and Kingston.

In light of the considerations above, Cow Bay was eliminated easily because of size constraints, hurricane exposure, and a foreshore width of only around 500 m such that waves reaching the site may well be higher than those offshore. Siting the entire proposed facility in either Kingston Harbour or Bowden Bay was similarly eliminated due to space constraints.

The CEA therefore considered Goat Islands, Macarry Bay, and an option that divides the required facility between Kingston and Bowden, including a transhipment port at Kingston Harbour and an industrial port and shore side industrial complex on the eastern side of Bowden Harbour.[7] Potential differences in the efficiency of this design are discussed in the later sections.

4.2 Assessment of wave environment

Once the most potentially viable sites were selected, we carried out a more detailed assessment of factors influencing design and costs. Topography, bathymetry and geology affect costs by determining the extent of excavation, reclamation and dredging, what material needs to be moved, and need for any soil treatment, among other issues. Of particular relevance here, dredging or excavating sand or other soft material is far less expensive than carrying out the same operation for an equivalent amount of rock; similarly, using sand removed from nearby for reclamation offers significant savings over either importing fill or quarrying it from nearby. This is particularly significant in a case where the sand has already been dredged as part of the process of dredging channels or berths and would need to be disposed of whether or not it was utilised as fill, so only the difference between the cost of utilising the dredged material as fill and that of disposal, had it not been utilised, need be considered. Available map data and in person conversations were sufficient to understand these issues at all three sites

Wave environment determines three factors of relevance to costs:

1. Are berths adequately sheltered to avoid excessive wave induced downtime? Are breakwaters required to provide shelter?
2. Are the approaches to the port adequately sheltered for attachment of tugs, or does the pick-up point need to be in the shelter of breakwater?
3. What are the extreme waves which the works will have to withstand?

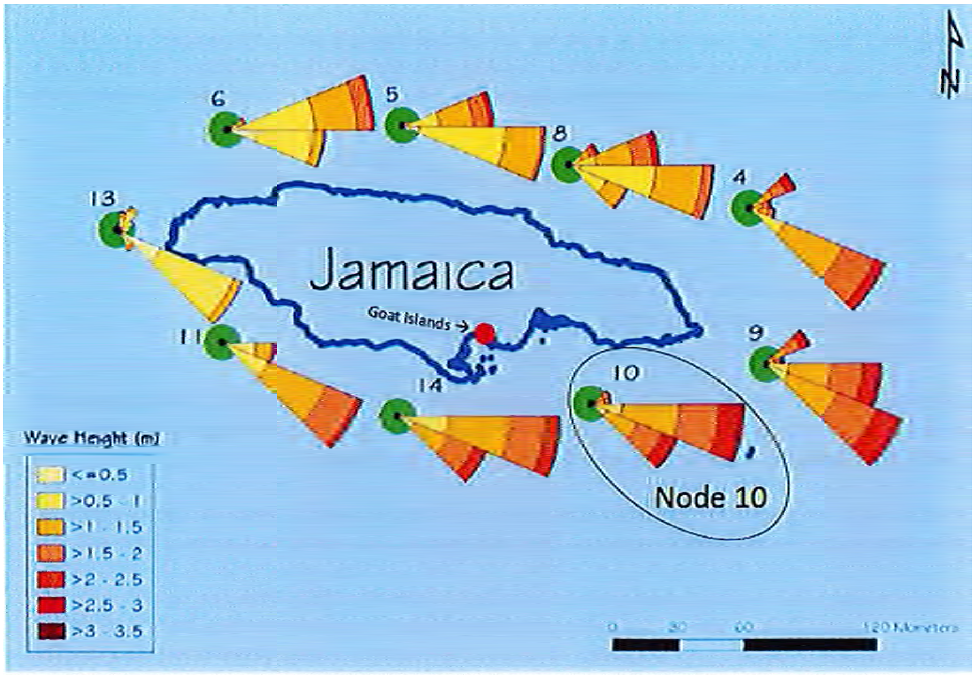
The influence of waves on these factors requires understanding both offshore waves in deep water and wave transformations in shallowing water. The wave environment could not be adequately understood from existing maps or related information, and was assessed by Niras Fraenkel (2014) as described below.

[7] Another option for constructing the industrial estates would be on land north-east of Hunts Bay, adjacent to the north-east part of Kingston Harbour. This would require a transport link to the port area, probably by means of barges. As Hunts Bay is very shallow an additional approach channel would need to be dredged but since barges have shallow draft, this channel would not need to be particularly deep. There would need to be significant ongoing maintenance dredging as there is heavy siltation in Hunts Bay. We do not consider this option further at this stage.

4.2.1 Offshore Waves

Van den Akker et al. (2013) provided wave roses based on United States National Oceanic and Atmospheric Administration (NOAA) data for nine locations around Jamaica (Figure 6). Location 10 is typical of waves approaching the south coast, with offshore waves predominantly from two 22.5 sectors, E–ESE and ESE to SE. Niras Fraenkel (2014) checked this wave analysis against other long-term data (Hogben et al. 1986) and found them to be consistent, estimating a three hour trade wind storm in deep water to have wave heights of 3.3 m and 3.2 m from E-ESE and ESE-SE, respectively, with a wave period of 10 seconds.

Figure 6: Wave Roses around Jamaica



Source: van den Akker et al. (2013), p211

With regard to hurricane waves offshore, NFL's analysis of wave height data showed a split at around a wave height of 3–3.5 m, with the family of high waves above 3.5 m likely to be from hurricanes. Van den Akker et al. (2013) undertook an analysis of all hurricanes occurring within 300km of Jamaica since 1855. This produced estimates of the once in 200 year extreme waves from each of five directions. Extreme wind speeds and deep water wave lengths were also derived. Based on review by NFL that found these wave height values to be compatible with other relevant sources of data, we use van den Akker et al.'s reported figures, as presented in Table 1.

Table 1: Waves resulting from once in 200 year hurricane extreme in deep water

	Angle of waves				
	90°	135°	157°	180°	225°
Wave Height (m)	16.21	12.38	11.32	11.28	14.09
Wave Period (s)	19.08	16.1	15.22	15.19	17.47
Wind Speed (m/s)	65.25	37.62	36.39	36.56	29.6

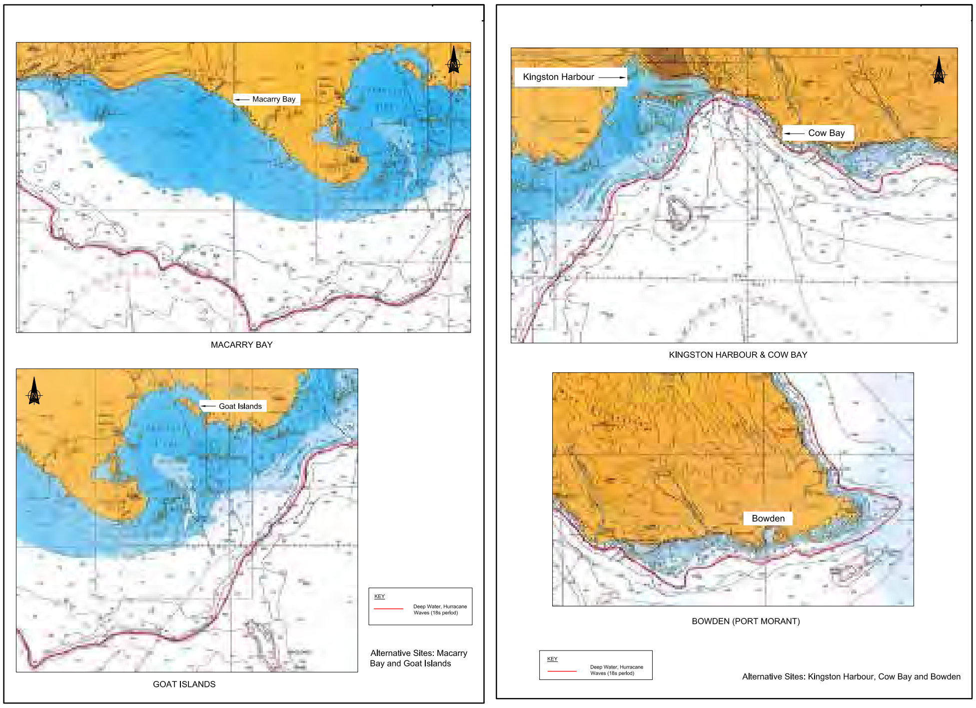
Source: van den Akker et al. (2013)

4.2.2 Wave transformation in shallowing water

Waves in deep water are largely unchanged through interaction with the seabed until the water depth reduces to around half the wave length. Based on estimated wave lengths of 156 m and 505 m respectively, depth limits for deep water Trade Wind and Hurricane waves are estimated at 75 m for trade wind waves and 250m for Hurricane waves.

Figure 7 shows the water depth contour lines to seaward of Macarry Bay, Goat Island, Kingston Harbour, and Bowden Bay. Because the seabed generally slopes gradually down from the shore out to the 30 m contour and then drops rapidly down to depths of 500 m or more, the two limiting depths for deep water waves are on the steep slope and are almost coincident at the scale of the maps.

Figure 7: Water depths at alternative port sites considered. The red lines mark where the 250 m limiting depth for hurricane waves is located. The 75 m limit for Trade Wind waves has not been plotted but is almost the same.



Source: Niras Fraenkel (2014)

As is notable, the foreshore widths reduce on moving from west to east along the coast, being widest Macarry Bay (12-14 km), narrowing at the approaches to the Goat Islands (6-8 km), then much narrower at Kingston Harbour (2-4 km) and Bowden (1.5 km). Specific effects of this and other conditions on the processes of wave transformation at each site are taken into account in design and discussed in detail in Niras Fraenkel (2014), but one general result is that friction plays an important role in reducing wave heights in both Macarry Bay and Goat Islands.[8]   An overview of wave transformation processes is provided in Annex 2.

4.2.3 Description of wave exposure at the sites considered

Macarry Bay: Macarry Bay is sheltered from the direct approach of the Trade Wind waves from E to ESE and from ESE to SE. Some activity from ESE to SE could reach the site after refraction around Portland Point, which separates Macarry Bay from Portland

[8] Detailed modelling by TUDelft confirms this effect, showing that friction plays an important role in reducing hurricane waves of 12-16 m in deep water to 6 m to seaward of the reefs which shelter the Bight.

Bight. The site is open to the hurricane waves from 157°, 180° and 225°, with the latter two seen as more likely. Waves from west can also reach the site, but the foreshore width is 40km or more from that side, which would greatly lower the height of hurricane waves reaching the port.

Goat Islands: The Goat Islands site is partially sheltered from open sea by a string of cays which act as breakwaters. There is a 300 m wide channel through the cays, with depths down to 20 m. There are also several minor channels. The Bight is open to waves from deep sea from E through S to SSW. Wave modelling by TUDelft established that both Trade Wind storm waves and Hurricane waves can reach the port site. Waves reaching the cays can be expected to be higher than those reaching a port in Macarry Bay as the foreshore width is less, but the cays will provide some protection against them progressing towards the Goat Islands themselves. Also of note, the Bight has a diameter of 5 km or more, wide enough for noticeable waves to be generated locally by high winds.

Kingston Harbour: The site considered is virtually separated from the sea by the string of connected cays forming the Palisadoes. Some wave activity from seaward could reach the site around the western end of the Palisadoes, but the waves are likely to be very low. The predominant waves will be locally generated by winds from the east blowing along the length of Kingston Harbour.

Bowden Bay: Port Morant, the inlet in which the Bowden site is situated, has a relatively narrow foreshore width, at around 1.5 km, so waves nearing the entrance are be expected to be higher than at the other sites. The entrance to Port Morant is restricted by cays extending out from the headlands on either side, with a 200 m wide channel between the lines of cays. This channel is significantly less wide than the 500 m wide channel leading to the Goat Islands. Thus although higher waves reach the entrance to Port Morant than at Portland Bight, the narrower channel may offset to some extent wave heights at the port site itself. The area of Port Morant available for the generation of local waves is negligible.

4.2.4 Quantitative comparison of wave exposure

Each of the relevant conditions and transformations was investigated. Computer wave modelling by van den Akker et al. (2013) for Goat Islands provides more sophisticated analyses for that site than were possible for the other sites in this study. We therefore used their modelled outputs for Goat Island, with two adjustments. First, an important issue related to van den Akker et al.'s estimates of wave period was identified and corrected. In particular, Niras Fraenkel (2014) found that longer period waves were likely to reach the site than those modelled.[9] Second, van den Akker et al.'s modelling was conducted prior to release of information on the actual design planned by CHEC. The updated layout shown in CHEC/CCCC Water Transportation Consultants (2014) extends further seaward, covering several cays and extending out to the 10 m depth contour. The seaward face of the works therefore now extends out into deeper waves than originally considered.

For the other three sites, wave transformation from deep to shelter water was performed using graphical aids from the US Army Corps of Engineers' Shore Protection Manual (1984) and the US Army Corps of Engineers' Coastal Engineering Manual (2006). The results are not as rigorous as those from the computer modelling and the resulting wave height should be considered valid only to the nearest metre. However, at the scale of analysis carried out here, this approximation is seen as acceptable.

Storm surge in hurricane conditions, which has the effect of raising the equivalent still water level about which the waves oscillate, was also considered. Storm surge is caused by the very low atmospheric pressure associated with a hurricane, raising the sea level locally and causing water to be piled up by wind and wave action against the shore. The latter effect is significantly influenced by the geography of the shoreline with long narrow inlets tending to trap water and locally increase the height of the surge. Considering 50-year storm surges, the Caribbean Disaster Mitigation Project (CDMP) finds higher surges in the inner (northern) areas of Portland Bight and Kingston Harbour than in either the more open coastline at Macarry Bay or the smaller harbour at Bowden (Niras Fraenkel 2014).

Table 2 presents results for a 1 in 200 year return period event (columns 1 and 2). These are used to calculate the required seawall height above still water (Rc, column 3) for each location, based on methods given in the US Army Corps of Engineers' Coastal Engineering Manual (2006). An allowance for storm surge is shown in column 4, and an allowance for tide and sea level rise due to global warming (GW) is included in column 5. The final column shows the sum of the components (Rc + GW & Tide + Surge), which is the final height of the structure that would have to be built above still water level.

[9] The output data from TUDelft modelling combines waves from seaward and locally generated waves. NFL calculated that the output is a mixture of the long periods offshore and the shorter period locally generated waves. In fact, these are waves of two dominant periods know as a twin peaked spectrum. One peak at the offshore wave period and one at the short inshore period. The longer period wave is of significance to the final design of the works since longer period waves have higher energies than shorter..

Table: 2: Impact of wave environment on necessary structure height at each site

Port Site	Wave travel Direction (Degrees)	Wave Height (m)	Rc Height (m)	Surge Height (m)	Global Warming and Tide allowance (m)	Final height above still water level * (m)
Bowden Bay	180	3	5	0.5	0.25+0.45	6
Kingston	90	2.7	2.1	1.3	0.25+0.45	4
	225	1.75	1.5	1.3	0.25+0.45	4
Macarry Bay	180	4.4	6.6	1.5	0.25+0.45	9
	Inside Breakwater	0.5	0.7	1.5	0.25+0.45	3
Goat Islands	225	4.8	6.6	2.3	0.25+0.45	10

* Rounded to the nearest metre to reflect data resolution. Sources: Storm surges: Niras Fraenkel using CDMP data, except for Goat Islands from TUDelft; Design significant wave height (Hs): Niras Fraenkel, except for Goat Islands from TUDelft; Global Warming and Tide: Niras Fraenkel

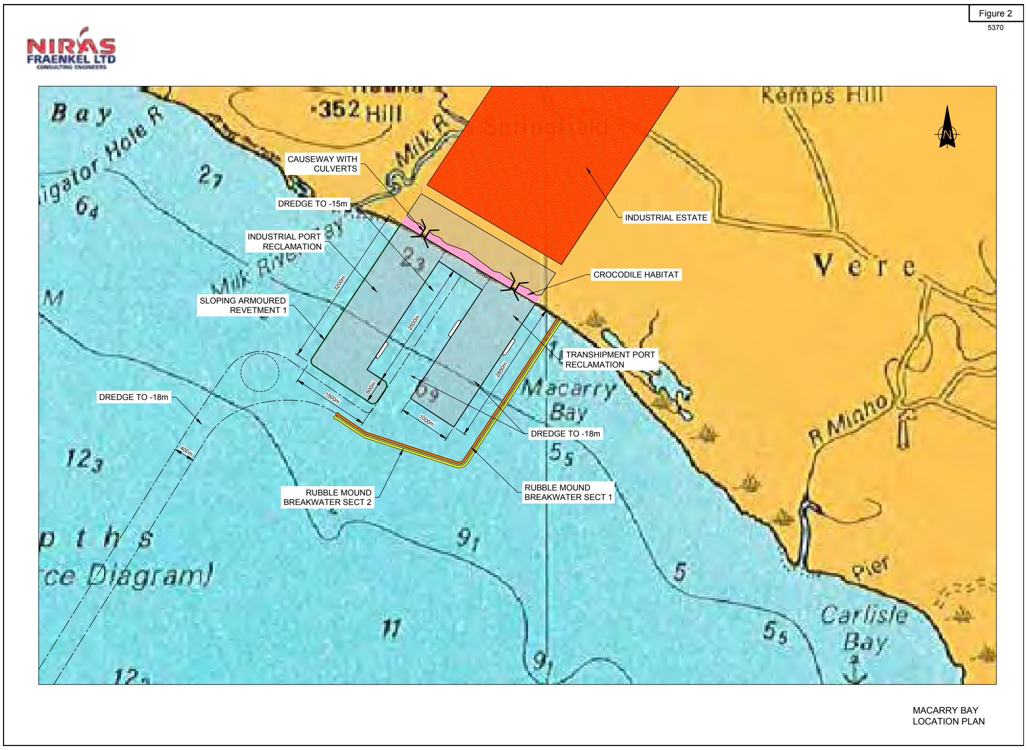
4.3 Port layouts

Niras Fraenkel (2014) combined the results of their analysis of wave environments with data on topography, geology, bathymetry, and environmentally important features to design high-level layouts of port facilities at each alternative site. The Goat Islands layout was taken as given in CHEC/CCCC Water Transportation Consultants (2014).

4.3.1 Macarry Bay

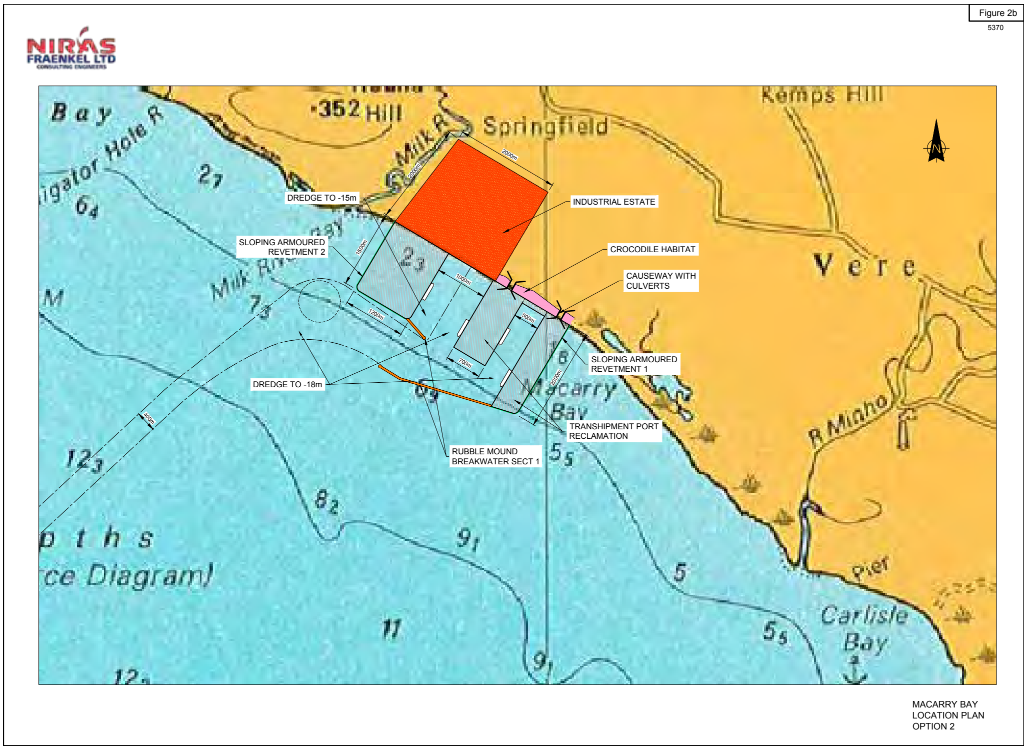
Two layouts were considered. The first is an optimum layout that is best for both efficiency of transhipment operations and in terms of minimising environmental impact (Figure 8). The transhipment port consists of a single rectangular reclaimed peninsula with straight berthing faces on both sides, enclosed within a breakwater to give protection to the quay area including any stacked containers awaiting transhipment in the event of a hurricane. The entire port facility is built on reclamation formed by sand dredged in the course of the construction of the port and its approach channel and is connected across the narrow strip of swamp (crocodile habitat) behind the beach by means of one or more short causeways to proposed industrial estates in the scrub area behind.

Figure 8: Macarry Bay design prioritizing efficiency and reduced environmental impact



The second is a lower cost layout that reduces the seaward extension of the port and hence breakwater length and fill volume by utilising some of the beach and swamp area as part of the industrial port (Figure 9). It also reduces the length of the transhipment port peninsula, resulting in the need for additional quay length to be built on reclamation inside the breakwater. This matches the overall quay area and berth length of the proposed Goat Islands development, but does not provide a layout as efficient as the single peninsular layout above. Crocodile habitat would also be destroyed.

Figure 9: Macarry Bay low-cost design



4.3.2 Combined development at Kingston Harbour and Bowden

As described, this is a combined development in which the transhipment port is located in Kingston Harbour and the industrial port and associated industrial estates are located at and adjacent to the eastern side of Bowden Harbour. The height of the reclamation fill in Kingston Harbour has been taken as 3 m, which is similar to the height of the existing Kingston Container Terminal reclamation. This is lower than the 4 m height stated in Table 2, but the highest waves in the harbour approach in a line almost parallel to the berthing face and thus have less tendency to overtop it. There is also less distance over water for the wind to generate waves from the eastern end of the harbour, so waves should be lower than is the case with the existing container terminal. The layouts are shown in Figures 10 and 11.

Figure 10: Transhipment port layout in Kingston Harbour

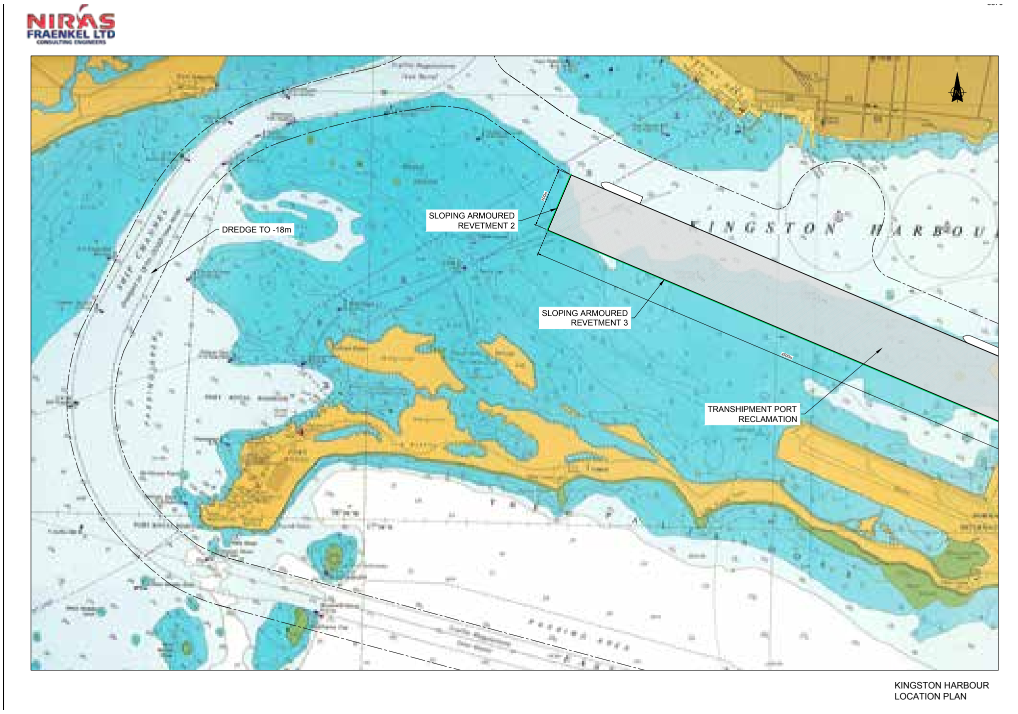
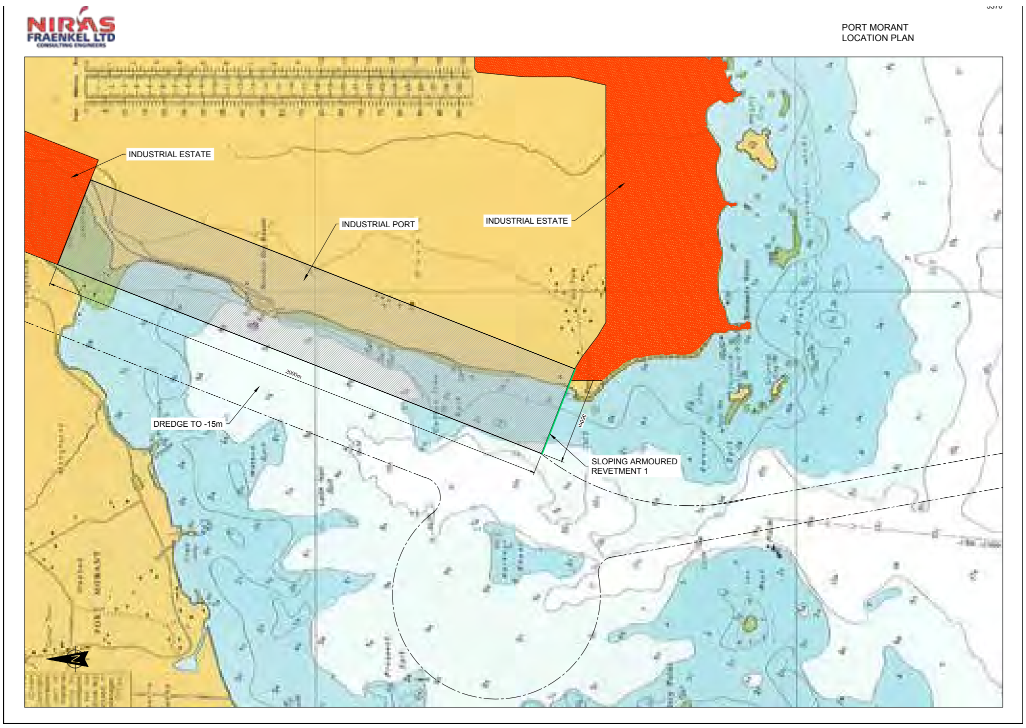


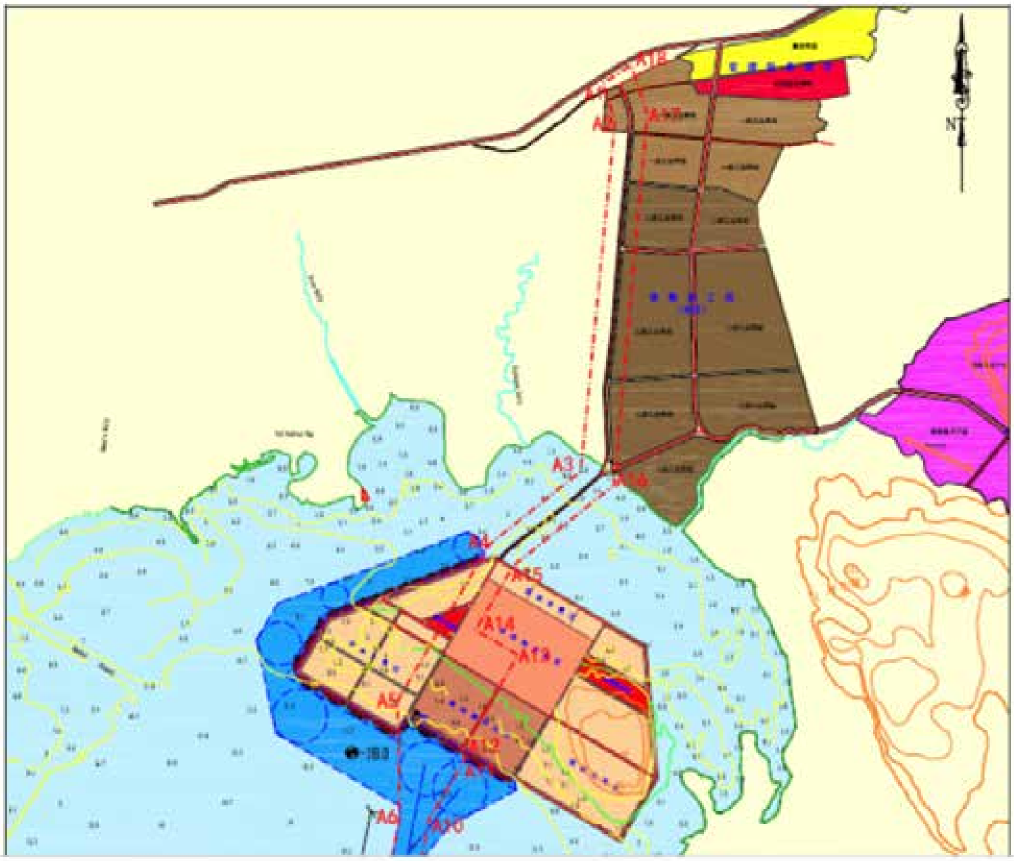
Figure 11: Industrial port layout in Bowden Bay



4.3.3 Goat Islands

The proposed development at Goat Islands is the benchmark against which the two alternative designs are compared. Design is taken as given in CHEC/CCCC Water Transportation Consultants (2014; figure 12). A 7m Chart Datum (CD) fill level is assumed as the highest practical quay height, although wave calculations made here suggest the quay would need to be significantly higher or have breakwaters if hurricane damage to stored containers and equipment was to be avoided. Consideration of breakwaters versus quay height versus acceptable downtime or hurricane damage would therefore seem to be important, but we are not aware of such analyses having been carried out. Breakwaters were not included in cost estimates as they were not shown CHEC's design.

Figure 12: Goat Island design according to CHEC/CCCC Water Transportation Consultants (2014)



Results

5.1 Costs

Costs for excavation, reclamation, dredging, and breakwaters were calculated for each design, based on the volume of material involved, its composition, and unit costs[11]. Volumes for excavation, reclamation and dredging were estimated as the difference between average depth or height and the proposed layout, including appropriate design specifications[12]. The volume of each type of material needed for breakwaters was based on the relevant wave environment and, again, an appropriate design specification. Causeways were necessary only in in Goat Islands and Macarry Bay, and were assigned an indicative cost only, as they were not seen to represent a major determinant of feasibility in any case.

The composition of material at each site could be assumed with some confidence, except in the case of Kingston Harbour. To accommodate this uncertainty, NFL conducted sensitivity analysis around material composition for Kingston/Bowden. Per unit costs were largely based on locally quoted prices in 2014 (values used are given in Annex 3). Given that it is particularly hard to estimate the degree to which costs for levelling and using the material for the Goat Islands would approximate local prices, a sensitivity analysis around costs was conducted for Goat Islands. Sensitivity analysis was not seen to be necessary for Macarry Bay.

The main issues that account for differences in costs between sites are reviewed below (summary in Table 3):

Macarry Bay (optimal)
A large volume of dredging is required (~70 million m3), both inside the port and to create the long approach channel. However the material to be dredged is confirmed sand, so unit cost is reasonable (estimated at $7/m3), with total dredging cost estimated at $500 million. Significant reclamation is also necessary but costs per m3 are minimal due to possibility of using sand dredged from nearby as part of marine works such as the approach channel and berth excavation. Two large breakwaters are also required, each over 20 m in height and having a volume greater than 2 million m3. These cost $250 million together. The total differential cost of this option is $931 million.

Macarry Bay (cost minimizing)
Utilising some of the beach and swamp area inland as part of the industrial port and reducing its seaward extend reduces the need for dredging and reclamation. The largest cost savings in this layout is from the elimination of a breakwater at a savings of $100 million. Total differential cost is $731 million.

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[11] Breakwaters includes revetments, i.e., structures backed by the port on one side rather than sea on both sides
[12] For instance related to dimensions of approach channels or necessary armour on breakwaters

Kingston/Bowden

Total volume of dredging at Kingston and Bowden combined is approximately half that at Macarry Bay. However, the small amount of dredging required in Bowden Harbour (8 million m3) is likely to require removing soft rock at a far greater unit cost than dredging sand ($50/m3). Total estimated dredging cost in Bowden is therefore $400 million. Excavation at Bowden will be more costly for the same reason, totalling approximately $250 million despite a comparatively small volume.

The total area needed for reclamation in Kingston and Bowden combined is also relatively small in comparison to some of the alternatives, similar to that for the low cost Macarry Bay layout. However, there is a key unknown cost in this layout related to the material underlying the proposed site in Kingston Harbour. Two scenarios are considered:

Scenario 1: The site is primarily founded on mud, in which case the dredged fill from the adjacent berths and channel deepening has been assumed to be unsuitable for use as hydraulic fill. Fill would need to be imported, and additional soil treatment would be necessary in order to provide a stable platform for port operations and this has been allowed for in the cost estimate. In this case, the combination of fill and ground improvement is estimated to cost $850 million, accounting for imported fill at $31/m3 (purchased, delivered, spread, compacted, levelled) and $80/m2 for ground improvement on 2.3 km2. Total differential cost of this scenario is $1.7 billion

Scenario 2: The site is primarily founded on sand, in which case the dredged fill from the adjacent berths and channel deepening has been assumed to be suitable for use as hydraulic fill. No additional soil treatment would be necessary. In this case, reclamation costs drop by nearly $700 million, putting total differential cost at $1 billion.

Goat Islands

The volume of dredging required is approximately equivalent to that at Kingston/Bowden. Assuming the material is sand or alluvium, total dredging costs are $215 million, calculated at the same rate as for Macarry Bay. The significant majority of costs comes from the need to excavate over 80 million m3 to level Goat Islands to 7 m, and to reclaim an area requiring a similar volume of material between and around the Goat Islands to accommodate the proposed transhipment and portside industrial areas. These activities are complementary in that the excavated material can likely be used as fill, but they are still costly.

The main unknowns are the rates at which CHEC can expect to do the necessary quarrying, and the suitability of material dredged in the vicinity of the port for use as fill. Three scenarios have been considered to allow for sensitivity to these costs:

Scenario 1: Fill and armourstone is obtained from the islands at similar rates to those for purchasing equivalent materials from a local quarry with only a nominal transportation cost to reflect moving materials within the site area. If the combined cost of excavation and reclamation is estimated as the costs of obtaining fill from a local quarry plus mark up and placed/compacted in situ (estimated at $22/m3), reclamation and excavation alone would cost ~$1.8 billion. Total differential cost is $2.1 billion.

Scenario 2: Fill is primarily dredged material pumped into position, with excess excavated material from the process of levelling the islands being disposed of. We assume that excess material whether dredged or quarried/excavated can be economically disposed of, but that there is a cost for excavating material from the islands whether it is ultimately used as fill or just cut to level the terrain. There appears to be no scope for savings under this scenario given the need to level the Goat Islands regardless to accommodate the proposed design. Total differential cost is $2.3 billion.

Scenario 3: Fill and armourstone is obtained from the islands at reduced rates. Given that the implied total costs under both scenarios above are far higher than the publically stated $1.5 billion, it is also useful to consider the possibility that our cost estimates are higher than those expected by the developer. For convenience, we consider a cost scenario in which costs faced by CHEC are 50% of the estimated commercial rates (i.e., combined excavation/reclamation costs $11/m3). This brings estimated reclamation and excavation to an estimated $900 million, with total differential costs of $1.15 billion. Some support for the idea that costs in this range are indeed expected is found in van den Akker et al. (2013), who estimate that differential costs make up approximately two thirds of total costs, implying total overall costs in the range of $1.5 billion.

We cannot know the exact costs that CHEC expects. However, we note carrying out excavation and reclamation at $11/m3 may be optimistic. Prices ex-quarry for granular fill and armourstone are $3.60 and $5.80 per tonne, respectively, at a local quarry. Assuming this is a reasonable estimate of the marginal cost of excavation, extraction and short haul moving of fill and small armourstone will cost approximately $10 and $17.70 per m3 at reasonable estimates of density and including $1/tonne for short haul transportation by normal truckload. Excavation cost alone would therefore likely be greater than $11/m3.

Table 3: Summary of the main characteristics driving costs at each site/scenario

	Macarry Bay (optimal)	Macarry Bay (low-cost)	Goat Islands Quarry fill rates	Goat Islands 50% Quarry rates	Goat Islands dredged fill	Bowden/ Kingston import fill	Bowden/ Kingston dredged fill
Areas (km²)							
Dry area for transhipment	2.85	2.05	2.5	2.5	2.5	2.25	2.25
Wet area for transhipment	1.75	2	1.74	1.74	1.74	2	2
Dry area for industrial*	6.3	5.8	6.3	6.3	6.3	0.7**	0.7**
Wet area for industrial	1.75	0.75	0.88	0.88	0.88	0.8	0.8
Total Area excluding channel	12.65	10.6	11.42	11.42	11.42	5.75**	5.75**
Lengths (m, thousands)							
Quay length for transhipment	5.35	4.5	4.35	4.35	4.35	4.5	4.5
Quay length for industrial	2	2	2.2	2.2	2.2	2	2
Approach channels	15	15	5	5	5	7	7
All break-waters and revetments	10.1	7.7	7.4***	7.4***	7.4***	5.55	5.55
Volumes (m³, millions)							
Total volume of dredging	72	65	31	31	31	33	33
Total volume of reclamation	42	25	79	79	79	23	23
Total volume of excavation	0	0	2	2	35	20	21
Costs (USD, millions)							
Total Costs	**931**	**731**	**2,103**	**1,159**	**2,295**	**1,683**	**1,015**

Source: Niras Fraenkel 2014

* Sum of designed area plus extended land area to give matched Goat Islands total industrial area.
** Does not include areas to the south-east and north-east of the industrial port to be used as industrial area, see Figure 11.
*** Net of any material subsequently used in reclamation or breakwaters.

5.2 Value of damage to ecosystems

To complement the financial analysis presented so far, this section considers the quantifiable economic value of ecosystems that would be destroyed or put at risk at each site. The environmental importance of the natural resources of the Goat Islands, Hellshire Hills, Galleon Harbour, and the Portland Bight Protected Area (PBPA) more broadly have been well-documented (e.g. C-CAM 2014). In addition to their intrinsic importance, these natural resources provide a range of valuable ecosystem services (ES) that contribute to the livelihoods of the people living in and around the PBPA. Services include the following (Cesar et al. 2000):

- Food, including a range of fish and shellfish;
- Materials, including fuel wood, charcoal, and poles for use in construction;
- Non-timber forest products, including honey, orchids, and medicinal plants;
- Protection from storm surges and coastal erosion;
- Treatment of waste;
- Maintenance of fisheries productivity through serving as a nursery for juveniles of numerous fishable species;
- Controlling climate change through absorbing carbon;
- Tourism;
- Safeguarding globally important biodiversity; and
- Importance for local culture, including pride and a way of life

Two previous studies have estimated the ES values provided by the entire PBPA. Cesar et al. (2000) estimated that effective park management would generate between $55 and $70 million for Jamaica (Net Present Value – NPV –over 25 years at 10% discount rate; inflated to 2013). This value is mostly provided by improved fisheries productivity, a growing tourism industry, and continued international investment in the protection of Jamaica's endangered species. Of note, all of these values accrue to Jamaicans.

Guingand (2008) complements analyses in Cesar et al. (2000), most notably by carrying out a primary study of PBPA's fisheries and the net returns to local fishers from higher levels of sustainable catch as fisheries recover under good management. Using the same NPV parameters, Guingand (2008) estimates that effective management of PBPA would generate benefits between $75 and $95 million, with fisheries, tourism, carbon sequestration and waste treatment generating the majority of value. Again, almost all values accrue locally or to Jamaicans more broadly, with the exception of carbon sequestration.

These valuations provide an important indication of value of protecting PBPA, and by extension the value that Jamaica would put at risk in choosing to develop the Goat Islands site. However, because neither study disaggregates sources of value within PBPA, and because there is no similar existing research for the other port locations considered in this study, additional analysis is needed.

We take a first step towards this by carrying out a benefit transfer analysis. This approach relies on data and findings from existing studies to estimate the monetary cost or benefit of a new policy. With appropriate caution, benefit transfer is an acceptable and frequently used approach in cases where time and budget are limited (Smith et al. 2002) and is in fact the basis of the analysis by Cesar et al. (2000) reviewed above.[13] Best results from benefit transfer are obtained using function transfers, that is, using an algorithm to adjust estimated values from existing studies to the particular characteristics of the policy site (Kaul et al. 2013).

We found only one suitable benefit transfer function. It estimates total value of ecosystem services produced by wetlands (Ghermaldi et al. 2010), based on a function derived from analysis of 170 rigorous valuation studies from around the world. Key model parameters determining the per acre value of wetlands include the following:

- Overall size of the wetland;
- Level of pressure;
- Human population;
- Relative abundance of other nearby wetlands; and
- Which goods and services are provided to people.

The values from wetlands alone do not represent the full value of services provided at each site. However, due to lack of suitable data and/or benefit transfer functions for other ecosystem (notably dry forests, coral reefs, and sea grasses), we chose not to estimate their economic value. Instead, we include qualitative consideration of differences in impact to other important terrestrial and marine systems in the following section (5.3).

Applying the wetland valuation model given by Ghermaldi et al. (2010), we find the following per acre values of expected losses: The lowest per unit area value is found at Goat Islands and Macarry Bay, in the range of $7,000 - $8,000 per acre (NPV over 25 years, 10% discount rate). These values are driven mostly by relatively lower levels of pressure and larger total wetland extent than at the other sites. Per acre value at Bowden Harbour is slightly higher, estimated at $10,000 NPV per acre. Per acre values are highest in Kingston Harbour at NPV $67,000, due to high intensity of human activity nearby, small area of remaining intact wetland in the area, and the absence of several

[13] Benefit transfer is also the most common valuation method used to compute benefits and costs of environmental regulations by the United States Environmental Protection Agency (EPA, 2010).

uses like recreational hunting that tend to be associated with lower value wetlands. Values used along with the relevant parameters of the wetland valuation function are presented in Annex 4.

On the other hand, in terms of area impacted at each site, we find that building on the Goat Islands would directly destroy an area of wetlands more than five times larger than at Macarry Bay, and approximately 20 times larger than at the combined Kingston/Bowden site. Overall, development at Goat Islands would generate the greatest economic losses due to wetland destruction at an NPV of $6.8 million, followed by Kingston/Bowden, and then Macarry Bay. Results are summarized in Table 4.

Table 4: Net Present Value (25 yrs., 10% discount rate) of wetland ecosystem services at each site

	Macarry Bay **	Goat Islands	Kingston/Bowden
Area directly destroyed (acres)*	185	1,010	55***
Ecosystem benefits per acre	$8,000	$7,000	$67,000/$10,000
Total value lost (NPV, millions)	$1.5	$6.8	$1.9

Source: authors' calculations based on Ghermaldi et al. 2010

*In the direct footprint of port construction only

**The two Macarry Bay designs are presented together here as the difference in area of wetland impacted is very similar. The major distinction in environmental impact is not quantified but relates to preservation of a strip of important crocodile habitat along the coast.

***Approximately seven hectares of land classified "a section of wetland" in Kingston Harbour has been included in this category

Our value estimates for Goat Island and Macarry Bay are not directly comparable to results from Cesar et al. (2000) and Guingand (2008), because they consider neither the full area of the PBPA nor the full suite of ecosystems. Considering how results relate is nonetheless useful. To provide an indicative comparison, we run the benefit transfer function again for the entire PBPA. The necessary modelling adjustments suggest lower per acre values, putting the total wetland NPV of PBPA at $58 million. This value is on the lower end of total value estimates by Cesar et al. (2000) and Guingand (2008), which is reasonable given their inclusion of a larger set of ecosystems.

It must be noted that the calculations above are also conservative in that they include only the area of wetland directly destroyed by the footprint of port construction. In reality, indirect and spill-over effects related to pollution, increased vehicular traffic, migration of people working at the port, and others are likely to significantly increase the area of natural habitat destroyed. For instance, a recent study of the impact of dredging on coral reefs in Australia showed that reefs closest to the sediment plume from dredging (i.e., near but not in the dredged channel itself), had two-fold higher incidence of disease and six-fold increase in signs of compromised health as compared to corals with little plume exposure (Pollock et al. 2014). With regard to pollution, in a single instance in 2009, 300 tons of sulphuric acid were accidentally spilt into the Kingston Harbour from a leaky container (JIS 2009). It is impossible to accurately predict these effects. However, it seems reasonable to assume that if indirect effects and the value of additional ecosystems are considered, the true value of damage at each site will be significantly higher than estimated above.

5.3 Other major differences between sites

Analyses presented to this point aim to ensure that the major costs that distinguish the sites are calculated and included. However, in CEAs of investments at the scale considered here, important differences in the outcome as well as unquantified costs and benefits often remain. Their existence does not undermine the validity of the analysis, but it is important to ensure they are clearly described and their relative importance is at least qualified.

We present major differences in two areas:

5.3.1 Differences related to operations

Accessibility to Jamaican Labour: CHEC has stated its interest in locating the port close to Kingston for the purpose of being accessible to qualified labour and providing a source of socio-economic benefit to Jamaica (van de Akker et al. 2013). Among the relevant factors to consider in assessing accessibility to each site are population centres nearby, distance to Kingston via existing roads, and length of road that would need to be constructed or improved to reach major roads from the port site.

Kingston Harbour itself excels in all of these criteria. Second best is Goat Islands, which is relatively close to Highway 2000, putting the population centres of Kingston, Spanish Town, May Pen, and Old Harbour within easy commuting distance. Macarry Bay is also within commuting distance of those population centres in addition to Mandeville, although it is not as close as the Goat Islands and requires greater effort in road improvement to access the highway. On the other hand, two accessibility-related factors add value to building at Macarry Bay. First, Mandeville has supplied much of the workforce of two alumina plants that have closed in recent years, such that unemployment of skilled industrial workers is high. Second, to the extent that air transportation links are needed, Vernam Field is close by and could in principle be developed for that purpose (Chin 2013). Bowden is a clear last according to these issues: the location near the eastern end of the island is not ideal in terms of proximity to major population centres, and it is linked to Kingston by a winding coastal road that has not had any major improvements in recent years, with the exception of the last few kilometres between Bull Bay and Kingston.

Efficiency of design: The potential port layouts generated for this analysis are not sufficiently detailed to examine this issue in depth. However, it is reasonable to note that the optimum Macarry Bay option in which the port is built entirely on reclamation seems to offer an excellent option, with the transhipment port consisting of a single rectangular reclaimed peninsula with straight berthing faces on both sides providing an orthogonal layout for container movement. Because the causeways are short and over a sand stratum, they can be made wide enough to provide good continuity between the port and industrial estates. On the other hand, sand is especially susceptible to being moved by wave action: this would have to be considered in conjunction with the potential negative effects of maintenance dredging of the approach channel, particularly just after a hurricane. The Goat Islands port would likely be somewhat less efficient due to the need for a comparatively long causeway between the port and shore and possibly due to the quay alignment as well. The Kingston/Bowden option has a clear downside in that it requires dividing transhipment and industrial activity, although the extent to which this is a problem would need to be determined directly by CHEC and the Port Authority.

Adaptability: CHEC has highlighted the importance of both potential for future expansion and potential to accommodate larger vessels such as Chinamax. In terms of expansion, there is more relatively flat land at both Macarry Bay and the Goat Islands site. Farming is the principal use of this land in both cases, although further expansion around Goat Islands would likely also include dry forest areas and therefore have additional impacts on globally important wildlife habitat. By contrast, expanding in Kingston Harbour would be significantly more complex.

In terms of accommodating Chinamax vessels, the required 27 m draft would mean significant additional work at all sites. Kingston Harbour and Bowden would likely require the least. In Kingston, much of the existing East Channel is already deep enough for Chinamax vessels, while deep water just outside of Bowden Harbour results in a very short approach channel. In Macarry Bay, a very substantial additional amount of dredging would be required, although it is likely to be in sand. Deepening the channel into Portland Bight will also require a very substantial amount of additional dredging as neither the naturally available channel into Portland Bight nor existing shipping channels for the alumina industry are deep enough. The presence of hard limestone on and in the vicinity of Goat Islands means that there is a higher risk of encountering rock than in Macarry Bay.

5.3.2 Differences related to broader impact

Environmental impact and international reaction: Beyond the ecosystem service value potentially lost at each site, building on Goat Islands will clearly be the worst of the options in terms of possible negative domestic and international reaction. In addition to the wetlands damage valued above, a Goat Island port would damage a far greater area of coral reef and dry forest area than at any other site, putting at risk decades of work and one of the world's great conservation success stories. Additionally, the site is the only one of the alternatives entirely within a national protected area (annex 1). Building in Macarry Bay is likely to be seen as acceptable given that it is environmentally far better than the current alternative, in particular if the optimized layout or a similar design consciously avoids an area of vital crocodile habitat is used. Building in either Kingston or Bowden would presumably be seen in a particularly positive light given the small area of natural habitat that would be destroyed and the clear development objectives being served.

Jamaicans have already shown a significant negative reaction to the Goat Island site. Predicting the likelihood of meaningful international response to building on Goat Island is harder. Considering tourists, while Jamaica's reputation and draw includes its natural beauty, further work would need to be done to assess the likelihood that tourists would change their choice of destination based on environmental concerns. It is clearer that building on Goat Islands would entail a significant foregone opportunity in terms of tourism potential: the South Coast Sustainable Development Study identifies the Goat Islands and Hellshire as priorities for sustainable tourism based on potential for day trips from Kingston, the location of Taino sites, and the potential for yachting and low key adventure hiking (Halcrow 1998).

We consider it possible that international aid agencies and development banks might also react negatively, for instance if their own previous investments in Jamaica are undermined, unwise major financial choices are made, or poor public procurement process is followed. The degree to which a negative reaction would translate into economic losses for Jamaica is hard to predict, with the exception of a likely reduction in international biodiversity conservation investment. A more in depth comparison of potential environmental impacts at all sites considered is provided in Annex 5.

Impact on the local economy. It is difficult to predict the extent to which jobs created by the port will go to local residents at the port site, although serious doubts have recently been raised (Tufton et al. 2014; also see Witter 2013). To the extent that numerous local people do not find employment at the port, the area where the greatest economic losses would be caused is Goat Island, due to the large number of fishing families based in Old Harbour. On the flip side, the Kingston/Bowden site offers several potential benefits. Necessary widening and possible deepening of the existing channel in Kingston Harbour could add significant benefit to other activities in the Harbour. In the case of Bowden, if the port project (or even as an additional, complementary contract) included improvement of the road to Kingston, significant additional benefit would be provided in the form of improved connectivity between Kingston and centres of population to the east and Port Antonio to the north.

Conclusions

This document assessed the possibility that there are cost-effective alternatives to building the proposed port associated industrial area on and around Goat Islands. We find strong evidence to justify serious consideration of at least one or possibly both sites.

Building at Macarry Bay appears to compare favourably to Goat Islands from a construction cost standpoint. Our high-cost scenario at Macarry Bay costs over $200 million less to construct than an optimistic, low-cost scenario at Goat Islands. These differences are driven in large part by the necessity to excavate and fill areas requiring more than 80 million m3 of material including rock in the Goat Islands case, versus a Macarry Bay design that relies on less expensive dredging of sand and using it to reclaim land nearby. Furthermore, due to storm surge, locally generated waves, and an orientation that permits Trade Wind waves to enter the Bight, Goat Islands faces a more challenging wave environment than might be assumed based on location, while Macarry Bay is less challenging than would initially be assumed due to the prevailing direction of Trade Wind waves and a long, shallow foreshore that significantly reduces deep sea wave heights before they reach the port.

Quantified environmental damage to wetlands from building on Goat Islands is more than three times higher than that from building in Macarry Bay. Considering non-quantified characteristics, Maccary Bay is superior to Goat Islands except with respect to its access to the road network and Kingston, and likely in terms of the need for maintenance dredging of the approach channel, especially after hurricanes. Macarry Bay appears better in all other characteristics considered, including environmental impact to important species and habitats, efficiency of transhipment port layout, ability to expand activities on land and deepen the access channel, likely international reaction, and local economic impact.

Building at Kingston/Bowden presents an obvious challenge. However, the combination of sites may offer an opportunity to maximize benefit for Jamaicans from the port development, helping to further Kingston Harbour's competitive advantage in transhipment and at the same time significantly improving road access for thousands of people. If these gains are deemed potentially worth some complication in design, it would be a relatively simple matter to further investigate whether dividing the proposed facility between Kingston and Bowden is cost-competitive.

In conclusion, we find significant likelihood that there is at least one option for building a transhipment port and logistics hub at lower cost and with less environmental damage than building at the currently proposed Goat Island site. Investigating alternative sites including Macarry Bay transparently and in due detail is clearly in the best interest of Jamaicans. If findings are confirmed, there will be no need to sacrifice a world class conservation site to build a world class port.

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Annexes

Annex 1: Legal protection and international designations of PBPA. Source: C-CAM and Jet (2013)

TABLE 2: LEGAL PROTECTION UNDER JAMAICAN LAW				
Year Declared	**Type of Protected Area**	**Legal Instrument**	**Names of Areas**	**Reasons for Protected Status**
1999	Protected Area	Natural Resources Conservation Authority Act (1991) (Section 5)	Portland Bight Protected Area	Protection of ecosystem services and biological diversity.
1996	(2) Forest Reserves	Forest Act	Peake Bay and Hellshire Forest Reserves	Conservation of forests, soil, and water resources, provision of parks and other recreational amenities, protection and conservation of endemic flora and fauna.
Various years (1994-2004)	(6) Game Sanctuaries	Wildlife Protection Act	Little Goat Island, Great Goat Island, Amity Hall, West Harbour-Peake Bay, Cabarita Point, Long Island	Protection of wildlife from hunting, the taking of eggs and the introduction of predators such as dogs.
2009	(3) Fish Sanctuaries	Fishing Industry Act	Three Bays, Galleon Harbour, Salt Harbour	Protection of fish spawning and nursery areas from fishing, in order to allow fish populations to recover.

Sources: (NEPA 2011) (GOJ 1991) (Forestry Department 2013)

TABLE 3: INTERNATIONAL DESIGNATIONS FOR THE PORTLAND BIGHT PROTECTED AREA				
Year	**Type of Area**	**Organisation**	**Name of Area**	**Rationale / Purpose for Designation**
2006	Wetlands of International Importance	Ramsar Convention	Portland Bight Wetlands and Cays	Internationally important for conservation of biological diversity, particularly waterfowl. To promote conservation of habitat (spawning ground, nursery, and/or migration path on which fish stocks depend).
2009	Important Bird Area	BirdLife International	Portland Bight IBA	Areas of habitat for globally threatened birds, thus priority conservation areas.
2010	Alliance for Zero Extinction site	Alliance for Zero Extinction	Hellshire Hills	Survival of globally threatened species, especially the Jamaican Iguana
2011	Key Biodiversity Areas in the Caribbean Islands Biodiversity Hotspot	Critical Ecosystems Partnership Fund	Braziletto Mountains, Portland Ridge and Bight, Hellshire Hills	Areas where globally threatened species of wildlife occur, as defined by IUCN. Conservation strategy is to integrate biodiversity conservation into landscape and development planning and implementation.
2012	Biosphere Reserve (conditional approval)	United Nations Educational, Scientific, and Cultural Organization (UNESCO)	Portland Bight Biosphere Reserve	To conserve biodiversity in terrestrial and coastal ecosystems while allowing sustainable use.

Sources: (Levy 2008), (BirdLife International 2009), (BirdLife International 2013), (CEPF 2011), (IUCN 2013), (NEPA 2011), (UNESCO 2013)

Annex 2: Wave Properties

Waves reaching locations at the shore can be of two types, both generated by winds. Waves produced by high winds over deep water can approach from seaward, and winds can generate waves locally around a site. For example at the Goat Islands site in Portland Bight, waves can come from seaward through the gaps between the reefs (locally known as cays) and waves can be generated by local winds blowing across the Bight.

Waves are quantified with reference to their height and period. The wave height is the vertical distance between the crest of the wave and its proceeding trough. The wave period is the time taken for successive crests to pass a fixed point. Another wave parameter is wave length which is the horizontal distance between successive crests and depends on the wave period and the depth of water. Longer period waves in deeper water have longer wave lengths.

In very deep water where the depth is more than half wave length of the waves, the waves are unaffected by the seabed over which they travel. On moving into shallower water the waves are transformed in several ways which can affect both the wave height and the wave direction. As waves travel over shallowing water inshore the deep water depth limit are affected by five processes which are: Refraction, Shoaling, Friction Loss, Breaking, and Diffraction.

Refraction

The speed at which waves travel towards the shore varies with the depth of water. They are slower in shallower water and faster in deep water. When a wave crest is at an angle to the depth contours its deeper end moves more quickly than its shallower end, so it turns to become more parallel with the contours. As it turns the wave heights tend to fall. The figure at the end of this annex shows the effects of refraction of Hurricane waves travelling towards Bowden. The red lines show the directions in which the waves are travelling. The wave crests are locally at right angles to the lines which are called wave rays or wave tracks.

Shoaling

As water depths decrease the wave motions below the water surface are squashed and energy is transferred to the wave height, which typically increase (the process is much more complex than this and the wave height actually falls at some offshore depths). Often in coastal studies shoaling is a dominant factor increasing wave heights well above their height in deep water. For water which is deeper than 0.06 of the wave length of the waves in deep water there is hardly any effect. For depths less than this, the wave height increases markedly with decreasing depth until limited by wave breaking. The period does not change. For the extreme hurricane waves shoaling has little effect until the depth decreases to 30m.

Sea Bed Friction

Wave height reduction due to friction at the seabed is often ignored. It is only important where there are extensive areas to seaward where water depths are shallow compared with the deep water wave. The width of the foreshore between the deep water wave limit and the coast line provides an indication of the influence that friction at the seabed plays on the heights of waves. The wider the width to seaward of the coast the greater the effect of friction and the lower the wave height reaching the coast or cays.

Breaking

As depths decrease the wave height may increase and the wave length decreases. Consequentially the wave profile becomes steeper and more pointed and due to instability the waves break. As a guide waves break when the wave height is 0.78 of the water depth. Waves with heights more than the threshold break and lose much of their energy in turbulence. Waves with heights less than the threshold do not break and continue towards the shore. Again their periods remain largely unchanged. The highest waves after breaking are those which are just lower than 0.78 of the depth. These are known as depth limited waves.

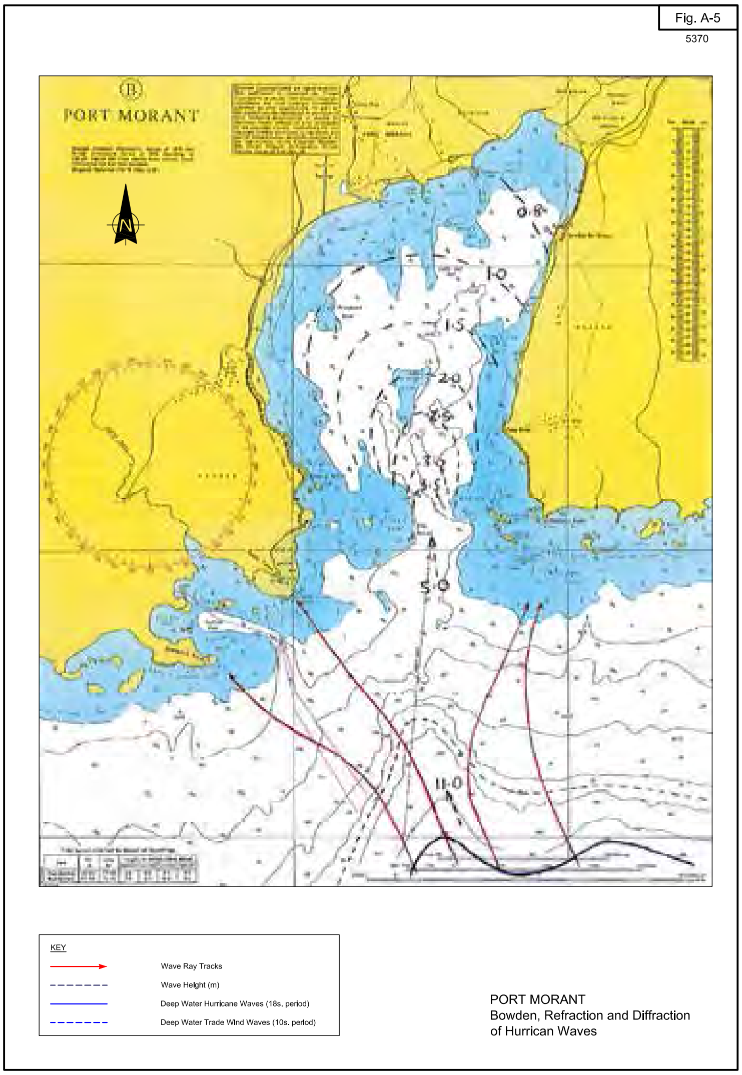
Diffraction

When waves squeeze through a narrow entrance they spread throughout the area beyond the entrance. The heights of the waves tend to fall as they radiate from the entrance. The figure at the end of this annex shows the effects of diffraction in the Port Morant inlet at Bowden. The numbers show how wave heights are reduced from the 5 m wave height nearing the entrance through the process of diffraction.

Locally Generated Waves

Winds produce local waves over the areas of water in which the sites are situated. The heights of the waves increase with the speed of the wind and the length of water over which the wind blows. For example, higher waves are developed over the broader expanse of Portland Bight where the Goat Islands site is situated than in Port Morant where the Bowden site is.

Figure: Refraction and diffraction of hurricane Waves at Bowden Harbour.



Annex 3: Per unit costs considered

	Cost Estimations - NFL	USD $*	Comment
1	Dredging/m³ Sand or alluvium	7	For the dredging and disposal of material
2	Dredging/m³ Soft rock	50	e.g. Sandstone (no blasting assumed)
3	Dredging/m³ Hard rock	150	e.g. Limestone (blasting required)
4	Reclamation/m³ - hydraulic fill	7	For the dredging and use of soft (e.g. sand) material taken from a alternative site
5	Reclamation/m³ - hyd fill already dredged	2	Extra over cost for the use of already dredged material (e.g. sand/mud) for reclamation
6	Reclamation/m³ - imported fill	$31	e.g. Mud being dredged (Fill to be imported by trucking)
7	Reclamation/m³ - Goat Island fill	$22	Quarried from island itself, not imported
8	Reclamation/m² - ground improvement	80	e.g. Mud substrate/fill (Consolidation to be allowed for/mitigated by ground improvement)
9	Breakwater/m³ - Large stones Kingston	$83	Limestone from local quarries
10	Breakwater/m³ - Large stones Maccary	$63	Limestone from local quarries
11	Breakwater/m³ - Large stones Goat Is	$73	Limestone quarried on Goat Island
12	Breakwater/m³ - Small stones Kingston	$70	Limestone from local quarries
13	Breakwater/m³ - Small stones Maccary	$56	Limestone from local quarries
14	Breakwater/m³ - Small stones Goat Is	$71	Limestone quarried on Goat Island
15	Breakwater/m³ - Core Kingston	$60	Limestone from local quarries
16	Breakwater/m³ - Core Maccary	$46	Limestone from local quarries
17	Breakwater/m³ - Core Goat Is	$48	Limestone quarried on Goat Island
18	Excavation/m³ Soil	8	Soft material e.g. soil/sand/mud
19	Excavation/m³ Soft rock (Gl or Bowden)	12	e.g.Sandstone (assumed rippable, no blasting required)
20	Excavation/m³ Hard rock (Goat Is)	18	Taken as ex-quarry rate for boulders

* Per m³ (volume) or m² (area)

Annex 4: Parameters and values used at each site to apply the function transfer model for wetland values specified by Ghermaldi et al. (2010)

Variable	Coefficient	PBPA	Macarry	Goat Islands	Kingston	Bowden
Year of publication	-0.041	40	40	40	40	40
Marginal	0.713	0	1	1	1	1
HABITAT TYPES						
Estuarine	0.27	1	1	1	1	1
Marine	0.754	1	1	1	1	1
Riverine	0.38	0	0	0	0	0
Palustrine	-0.48	0	0	0	0	0
Lacustrine	0.332	0	0	0	0	0
Human-made	1.023	0	0	0	0	0
Wetland size (ha) *	-0.234	8200	824	4,643	399	1,832
WHICH ES ARE PRESENT						
Storm control/flood buffering	0.432	1	1	1	0	1
Surface and groundwater supply	-0.099	0	0	0	0	0
Water quality improvement	0.727	0	0	0	0	0
Commercial fishing and hunting	0.266	1	1	1	0	1
Recreational hunting	-1.007	1	1	1	0	1
Recreational fishing	-0.082	1	1	1	1	1
Harvesting of natural materials	-0.202	0	0	0	0	0
Fuel wood	-0.968	1	1	1	1	1
Nonconsumptive recreation	0.67	1	1	1	1	1
Amenity and aesthetics	0.529	1	1	1	1	1
Natural habitat, biodiversity	1.143	1	1	1	1	1
PRESSURE						
Medium-low human pressure	0.572	1	1	1	0	0
Medium-high human pressure	1.243	0	0	0	0	1
High human pressure	1.992	0	0	0	1	0
CONTEXT						
GDP per capita *	0.358	8,890	8,890	8,890	8,890	8,890
Population in 50 km radius, 1000s *	0.399	1,541	879	1,541	1,493	343
Wetland area in 50 km radius, ha *	-0.058	8,200	7,865	8,087	6,449	1,954
Constant	-0.681	1	1	1	1	1

* Ln transformed

Annex 5: Summary comparison of some potential environmental impacts of port and logistics hub at the four sites *(Contributed by Ann Sutton)*

The following is a brief, qualitative, preliminary comparison of some of the potential short-term and long-term environmental impacts of the construction and operation of the proposed transshipment port and logistics hub at the four sites that were assessed in the main report. As in the main report, only the relative impacts are considered here. Impacts that are likely to be similar across all the sites are not included in this discussion. The comparison is based on the designs provided by Niras-Fraenkel (shown overlaid on maps of benthic habitats and important locations for endemic species in Figures 1-4 at the end of this annex).

The comparison shows that the environmental impacts of developing the port and logistics hub on Goat Islands are likely to be much more extensive, severe and harder to mitigate than at the other sites.

Ecosystems/habitats

a. Port development

All the sites include vulnerable and ecologically important habitats. However the Goat Islands are located in a relatively undisturbed area, of outstanding ecological importance because of its contribution to the local economy and Jamaica's global obligations to protect its biodiversity. Loss, infilling and disturbance to mangroves and dry forest are of particular importance at Goat Islands (Table 1). In this area, impacts on marine productivity, wildlife habitat, scenic areas, coastal protection and impacts of storm surge could be compounded by changes in drainage and water circulation patterns.

Table 1: Qualitative comparison of relative extents of major ecosystems likely to be destroyed by port development at the 4 sites

	Goat Islands	Macarry Bay	Kingston Harbour	Bowden
Wetlands	High	Low	Low	Low
Old growth dry forests	Medium	None	None	None
Inshore lagoons	Medium	None	None	None
Rivers and streams	Medium	None	None	None
Coral reefs	Medium	None	Low	Low
Mud, rubble and sandy bottoms	Medium to high depending on design	High	High	High
Seagrass (including patchy seagrass and corals)	Medium	High	Low	Low
Sandy beach	Medium	Medium	None	Medium
Agricultural land	High	High	None	Medium

The impacts of dredging and operation of the expanded shipping channel include sedimentation (and disposal of spoil), groundings, spills and introduction of invasive alien species. The Goat Islands site has the highest potential for damage to surrounding areas down-current because the shipping channel runs through or close to several other vulnerable habitats. The risk of grounding (with consequent damage to benthic habitats and risks of spills) is highest in Kingston Harbour and Goat Islands.

b. Logistics hub

The logistics hub will be constructed on adjacent lands, which for expediency are likely to be lands that are already owned by the government. Table 2 compares the areas of natural habitats that are likely to be damaged or destroyed. Kingston Harbour and Bowden are excluded from this table.

Table 2: Qualitative comparison of major ecosystems likely to be destroyed by associated logistics hub development at Goat Islands and Macarry Bay

	Goat Islands	Macarry Bay
Wetlands	High	None
Old growth dry forests	High	None
Inshore lagoons	Low-High (depending on hub location)	None
Rivers and streams	Medium	Low
Coral reefs	None	None
Mud, rubble and sandy bottoms	Medium	None
Seagrass	Low	None
Sandy beach	None	None
Agricultural land	High	High

Threatened and endangered species

Hellshire Hills are of outstanding global importance for threatened and endangered species. Destruction of Great Goat Island and development of the logistics hub on or near the Hellshire Hills will have major impacts on these species. The proposed development of the Goat Island port appears likely to include removal of all or part of the Great Goat Island, which is currently a dry limestone forest; functionally part of the Hellshire Hills. It has long been identified as the only possible location for a predator-free site for the re-establishment of wild populations of Jamaican Iguanas and other endemic species. The locations suggested by the Government of Jamaica for the logistics hub lie on the northwest of the Hellshire Hills. These include the scenic and ecologically important Salt Island Lagoon as well as the Devil's Race area.

Any increase in disturbance and access to western Hellshire potentially threatens the

Jamaican Iguana with extinction in the wild (B. Wilson, pers. comm.). It would also threaten important populations of the endemic Jamaican Hutia (Geocapromys brownii) and several lizards, snakes and a frog that are also endemic only to the PBPA i.e. they are not found anywhere else in the world.

These and other threatened species that will be more affected by development of the port at Goat Islands than at other sites are summarized in Table 3. Manatees will be particularly badly affected by disturbances in Galleon Harbour, which is one of the few locations where they are regularly seen. The impact on sea turtles will also be severe, partly because of changes to feeding habitats, and partly because of the impacts of increased light pollution over an extended area, which could reduce survival of hatchlings at many sites. Portland Bight is currently one of the most important sites in Jamaica for nesting Hawksbill Turtles.

It is important to note that ecosystems and wildlife habitats in the Goat Islands area are highly irreplaceable, as no equivalent areas exist anywhere in the island, and options for habitat restoration are very limited.

Impacts at the other sites are far less severe (Table 3).

Table 3: Relative importance of sites for globally threatened and endemic animal species

	Goat Islands and Hellshire Hills	Macarry Bay	Kingston Harbour	Bowden
Jamaican Iguana	High	None	None	None
American Crocodile	High	Moderate	Low	?
Other threatened species (frogs lizards plants)	High	Low	None	Low
Jamaican Hutia	High	None		
West Indian Manatee	High	Low	None	Low
Sea turtles	Moderate	Moderate	None	Low
West Indian Whistling Duck	Moderate	Low	None	Low

Ecosystem services

The impact on ecosystem services of port development at Goat Islands will also be higher than for other sites (Table 4). This is due, among other factors, to the much greater loss and disturbance of natural ecosystems (see Table 1). The loss of mangroves at Goat Islands is of particular importance. Already, suggestions are being made that the Galleon Harbour Special Fisheries Management Area should be undeclared. However, it seems unlikely that there will be any major changes there (Figure 1). Other economically important wild species that will be disproportionately affected by port development in the Goat Islands area include game birds (columbids) and crabs. Two gun clubs currently have shooting rights in western Hellshire. More than 1,000 people reportedly harvest land crabs in western Hellshire, during the season. However, port construction at Macarry Bay potentially disrupts long-shore sediment transport and natural replenishment of beaches.

Table 4: Comparison of risk to selected ecosystem services

	Goat Islands	Macarry Bay	Kingston Harbour	Bowden
Fish nurseries	High	None	None	None
Coastal protection	High	Moderate	Low	Low
Carbon sequestration	High	Low	None	Low
Food supply	High	Low	Low	High
Local climate (likely reduction of rainfall in upper watershed)	High	Low	Low	Low
Materials and medi-cines	High	Low	None	Low
Game bird habitat	High	Low	None	Low
Migratory bird habitat	High	Low	Low	Low
Long-shore sediment transport	Low	High	Low	Low

Potential damage from pollution

Pollution risks arise in all phases of port development and operation. They include temporary and permanent point sources of air, water and ground pollution as well as pollution events. Table 5 compares the vulnerability of adjacent ecosystems and human settlement to pollution that might arise.

Table 5: Comparison of impacts from pollution

	Goat Islands	Macarry Bay	Kingston Harbour	Bowden
Air pollution (risks to adjacent human populations)	High	Low	High	Moderate
Damage to adjacent ecosystems down current	High	Moderate	Moderate	Moderate
Invasive species	High	Moderate	Moderate	Moderate

Landscape, viewsheds and heritage

Landscape is part of our heritage and an essential component of our tourism product. Development at any of the sites will impact landscape and viewsheds, but the impact of Goat Islands development will be much greater because it will significantly alter a landscape of great natural beauty and be visible across the bight and from the surrounding hills as far as Newcastle. Development in Kingston Harbour would be visible but less impactful because the surroundings are already developed. Development at Goat Islands would involve destruction of major Taino, English and WW2 heritage sites.

Table 6: Comparison of impacts on landscape and heritage

	Goat Islands	Macarry Bay	Kingston Harbour	Bowden
Impact on landscape of outstanding natural beauty	High	High	Moderate	High
Impact on viewshed	High	Low	Moderate	High
Severity of visual impact	High	High	Moderate	High
Risk of destruction of heritage sites	High	Low	None	Moderate

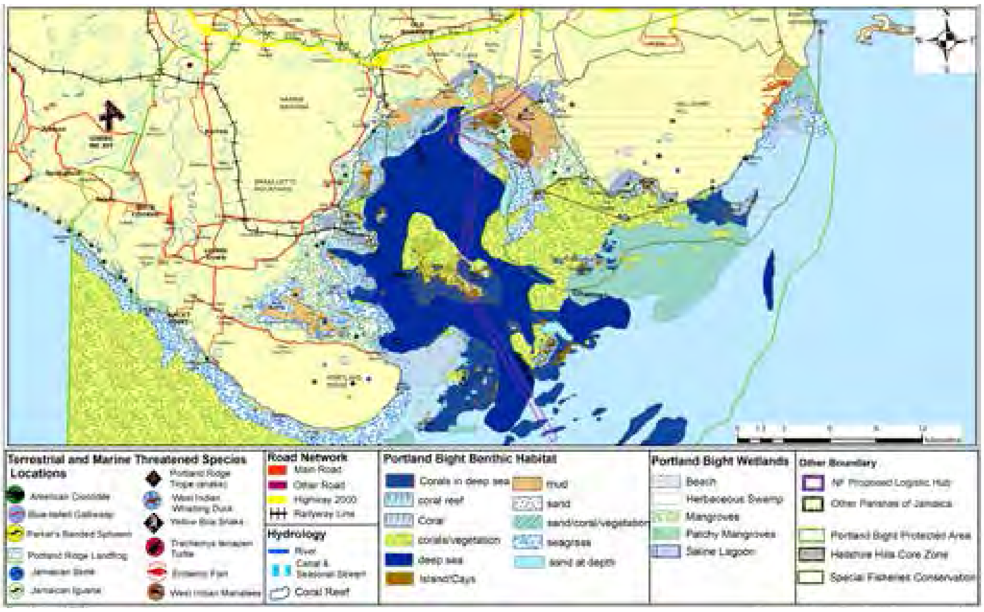
Loss of Options

Development of Goat Islands has the highest impact in loss of options, particularly due to impacts on artisanal fisheries, and of sites that have potential for tourism (Table 7). The industrialization of Goat Islands will negatively impact the potential for growth of nature-based and heritage tourism in the whole of the PBPA, because of the loss of one of the PBPA's most important sites, the increased risk of pollution, changes in accessibility, and adverse perceptions of the area.

Table 7: Comparison of some losses in options

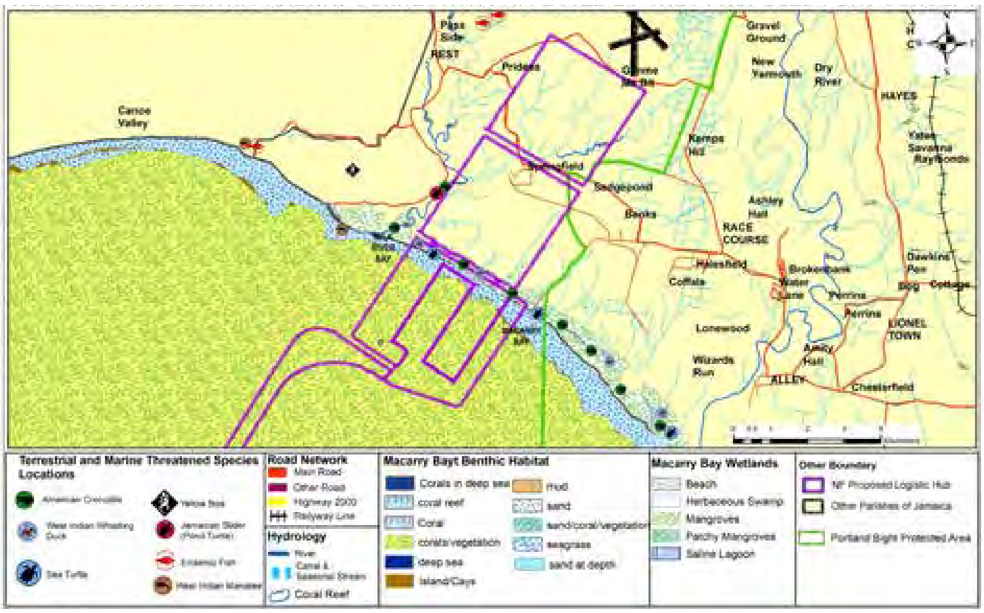
	Goat Islands	Macarry Bay	Kingston Harbour	Bowden
Nature-based Tourism	High	Moderate	Low	High
Heritage tourism	High	Low	None	Low
Fishing and related livelihoods	High	Low	Moderate	High
Agriculture	High	High	None	High
Hunting	High	Low	None	Low
Blue carbon	High	Low	Low	Low

Figure 1: Goat Islands: port development, habitats and threatened species



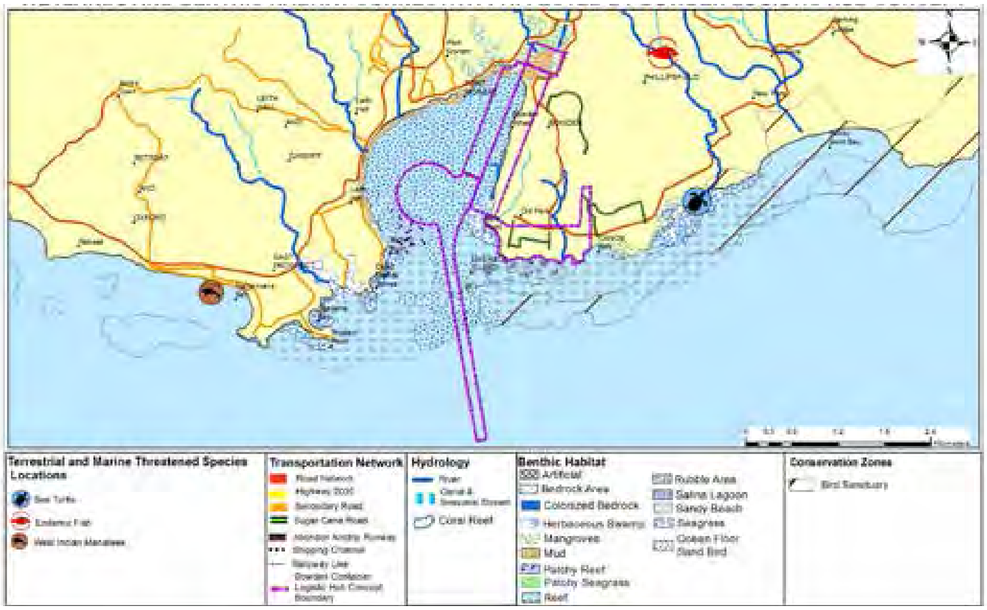
Source: Wallace (2014)

Figure 2: Macarry Bay: Port development, habitats and threatened species



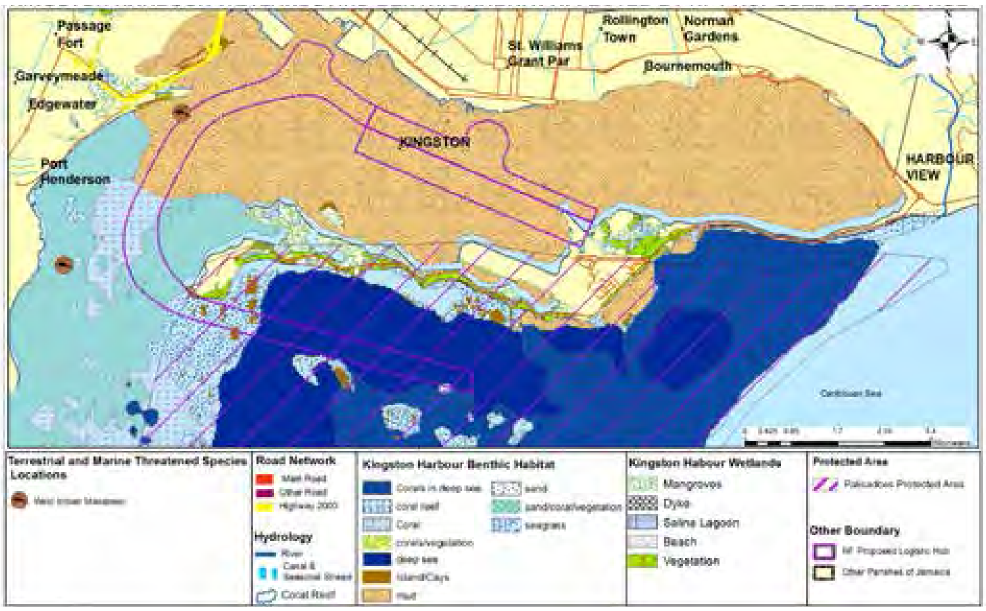
Source: Wallace (2014)

Figure 3: Bowden: Port development, habitats and threatened species



Source: Wallace (2014)

Figure 4: Kingston Harbour: Port development, habitats and threatened species



Source: Wallace (2014)

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Front cover photo: Paulette Coley, a resident of Old Harbour Bay, holds up the day's catch. © Robin Moore

Back cover photo: Wetlands and sea complex of Hellshire Hills. © Robin Moore

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