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Feasibility Study of Island Development at the Pacific Entrance of the Panama Canal

Final Report

Volume 1 of 4

Sites Characterization Studies

May 2004

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1 INTRODUCTION

This report presents the results of engineering feasibility and environmental studies for the development of an artificial island on the west side of the Pacific-entrance navigation channel. The island would be constructed from excavated material generated by the construction of the proposed new set of Post-Panamax locks to be located west of Miraflores Locks, and also using material from the deepening of the Canal Pacific entrance channel.

Depending on the final alignment selected for the locks and the location of the proposed water savings basins, the total materials volume available for disposal will be from 40 to 70 million m3. At this time, the most probable alignment is designated as P1-M and would generate approximately 69.5 million m3.

Following internal discussions within the Panama Canal Authority (ACP) in 2001 with regard to the potential beneficial use of the excavated and dredged material, a preliminary study[1] examined the commercial, technical and environmental issues related to the use of this material to create a new island at the Pacific entrance to the Panama Canal. The terms of reference of this first study limited island development options to maritime related or port activities, such as container terminals, other cargo terminals, bunkering facilities, distribution centers and trade related activities.

The study, which was completed in December 2001, concluded that it is technically feasible to use the material to construct an island located west of the Pacific entrance to the Panama Canal. Furthermore, the initial financial analyses showed that the square meter cost of the island and infrastructure appears to fall within acceptable ranges for international port and port related facilities.

This report now takes the analysis to feasibility level in order to generate a higher level of confidence in the cost estimate and to identify key issues related to the permitting process. In turn, these engineering feasibility studies and environmental assessment establish the foundation for future detailed engineering design for construction and provide the basis for the formal environmental permitting process.

[1] Preliminary Study of Island Development at the Pacific Entrance of the Panama Canal, Moffatt & Nichol and Louis Berger Group for ACP, December 2001

In parallel with the study, ACP has also prepared an evaluation[2] of other disposal sites for material to be removed from the Locks and also from the proposed deepening and widening of Gaillard Cut. This study includes an assessment of transportation costs, environmental impacts, value added potential and cost estimates for some 17 sites, one of which is the Artificial Island that forms the subject of this study.

Environmental field work for the Disposal options study was coordinated with the requirements of the Feasibility Study and has been as a basis for a number of the conclusions in this report. Appendix E presents the results of the analyses that were extracted from the Disposal Study investigations and incorporated in this report.

One important consideration arose from the ACP Workshops that were held to discuss the various disposal sites and options for the entire group of Pacific Side Canal Capacity Expansion projects. Given the aesthetic considerations and potential socio economic or environmental implications of maritime related development on the island, it was suggested that the long term development of the island and one other marine site under consideration should not necessarily be limited to port and port related uses.

Consequently, this feasibility study offers a broader panorama of potential uses for the artificial island.

[2] Pacific Site Excavation & Dredging Material Disposal Alternatives Evaluation, Moffatt & Nichol, Louis Berger Group and Golder Associates, October 2003

2 BACKGROUND

2.1 Materials Disposal Sites Screening Process

The selection of the candidate sites to receive all of the dredged and excavated material from the Locks and other Canal deepening and widening projects was developed from a number of reports to ACP from December 2001 to October 2003, and also from a series of ACP Workshops.

The sources for the sites evaluated over this period were:

- Projects identified before 1993 in various studies and ACP documents
- Sites listed in the Panama Canal Alternatives Study (1993)
- Existing or Proposed ACP materials Disposal Sites
- Abandoned US Dept of Defense Firing Ranges within the former Canal Zone
- Listing of Sites considered by ACP during a Workshop in November 2001
- Pacific Site Excavation & Dredging Material Disposal Alternatives Study, October 2003.

The initial screening identified some 59 sites that had been proposed or suggested over the past 20 years or so for materials disposal, reclamation or fill. The elimination of those sites that were essentially at the same location, although presented in separate reports reduced the number of locations to 29 sites.

The criteria for passing to the next level in the screening process were:

- The site should accommodate all of the material from the Third Locks Project (approximately 70 million m^3)
- Sites should be within an “economic” haul distance, considered to be 20 km.
- Those sites with obvious land use, environmental or other critical conflicts would be eliminated.

This then reduced the options to six basic alternatives that could potentially hold all the material from the Locks excavation and these were presented to the ACP for discussion and consideration at a Workshop on September 27, 2002. One of the first comments from the participants was the suggestion that it was not necessary to exclude sites that could not hold all the material from the Locks excavation work, since several sites could be combined to accommodate the full volume of material.

A second key consideration was that the consultants should emphasize opportunities for beneficial use of the materials, which could well involve the use of relatively small amounts of material at some of the smaller sites.

It was also suggested that consideration should be given to the use of material for the potential construction of a new reservoir at a site identified as the Trinidad Dam. Due to the preliminary nature of the engineering evaluation of this project, it was decided that only the transportation costs of moving material to this location should be evaluated at this time.

Finally, it was recommended that cost estimates and preliminary evaluation should include the disposal of material from the Pacific entrance dredging and also for the Third Locks excavation using traditional deep water disposal methods. The primary intent of this scenario was to use the baseline cost of deep water disposal to act as a benchmark against the potential transport and development cost of other options having added-value or potential beneficial use.

Based on the deliberations of the Workshop participants and the modifications to the listing of candidate sites as noted above, the sites shown in were selected for evaluation as candidates to receive materials from the three Capacity Expansion Projects. However, this list of 17 sites includes disposal locations for the Gaillard Cut and Pacific entrance channel projects. Since they are not sites that could economically be used to receive material from the Pacific Side Locks project, they are omitted from the final list of candidate sites shown in Table 2-1.

Figure 2-1: Location of Potential Disposal Sites for Pacific Side Capacity Expansion Projects

Use old Fig 3-1 from PFR.

Table 2-1: List of Sites under Consideration for Pacific Side Locks Project

Site Ref	Designation	Former Name (from earlier studies)
Terrestrial Sites		
T6	UXO Area	UXO
T7	Miraflores West Bank	Area East of Alignment P1
T8	1939 Third Locks Expansion	1939 Third Locks Expansion
T9	Rodman/Horoko	1993 Study Site 2
T10	El Arado	El Arado- Site 13 Sea Level Canal Study
Marine Sites		
M1	Panama Bay Fill	Ciudad Marina et al.
M2	Chorrillo Bay Fill	
M3	Amador Causeway East	Widen Amador Causeway
M4	Farfan/Palo Seco	
M5	Artificial Island	
Others		
M6	Site M6 - Offshore Open Water Disposal	
A1	Site A1 - Trinidad Dam Project	

2.2 Results of the Evaluation

Throughout all of the discussions on the candidate disposal sites the possibility of beneficial use of the excavated materials through the construction of an artificial island was an important consideration.

The results of the recently completed Dredge Disposal Options study concluded that:

"The key issue related to this study is the selection of one or more sites to receive some 90 million m3 of material from the Third Locks Project. If the El Arado site is discounted for the reasons noted earlier, only the UXO area and the Artificial Island remain as sites that could receive all of the fill material. The combined capacity of all of the other acceptable sites does not meet the project needs. Hence the basic choice comes down to the selection of one of these two options."

Given the potential for public objections, national government issues, environmental and other concerns associated with any or all of the three sites indicated above, transportation costs were also computed for simple disposal of the Locks material at a deepwater site. This cost also provides a benchmark for the assessment of value added potential.

The comparative transport costs presented in the Disposal Study for the three final sites and the deep water disposal option are presented in Table 2-2, below.

Table 2-2: Estimated Costs of Transport of Excavated Materials to Candidate Sites for Locks Project

Ref No.	Site	Unit cost of Materials Transport (B/m3)	Comments
T6	UXO Site	3.43	Includes UXO clearance & site restoration
T10	El Arado	5.96	Includes land acquisition & site restoration
M5	Artificial Island	4.25	Dry materials, includes marine site preparation costs
M6	Open Water Disposal	5.08	Assumes dumping in water 20 m deep

As can be seen from the results presented above, the disposal of material to the UXO site appears to be the most cost effective, mainly because the center of the site is less than 7 km from the center of the excavation area. However, as noted above, there are a series of important issues associated with all of the sites listed, and there are no assurances at this time that any one of the sites could be readily approved and prepared to receive the material in time for the commencement of the excavation work at the Pacific Side Locks project.

However, these unit costs are a critical element in the financial comparison of any proposal to use the excavated material for the construction of an artificial island.

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3 MATERIALS CHARACTERISTICS

3.1 Excavation Quantities

The recently completed Pacific Locks concept study examined various alignments for the entrance and exit channels and the new Locks. While the results of this study have still not been officially released, it is understood that the recommended alignment is extremely close to the routing known as P1 and shown in Figure 3-1. It is understood that the recommended alignment is designated as P1-M and will require from 50 to 69.50 million m3 of excavation, depending on the channel width selected.

Exact quantities of excavation are not available for all of the alignments under study at this time. However, as part of earlier studies on the Locks project, excavation quantities were computed for two alignments for the Locks project by Harza Associates in 2000[3]. These computations were checked by the consultants using terrain modeling provided by ACP. At the same time, the consultants incorporated a number of modifications to the cut profiles to accommodate adjusted side slopes and increased working areas around the main locks construction zone.

As a result, the total volume of material to be removed from the excavation area is calculated to be 69.35 million cubic meters (m^3), before the application of any coefficients for bulking and compaction at the disposal site. Since this figure represents the upper volume limit for the Locks project, and is very close to the numbers expected from the modified P1 alignment, it is reasonable to use it as a basis for this study.

Two potential disposal sites[4] within the Locks construction working area could potentially hold up to 9.5 million m^3 of this material and adjustments to the final alignment of the channels could further reduce the total quantity. However, it is recommended that the above figure should be adopted for all island fill and transportation cost calculations, in order to ensure sufficient disposal capacity for all potential scenarios.

[3] Evaluation of Lock Channel Alignments, Harza Associates for ACP, August 2000

[4] Sites T7 and T8, Pacific Sites Disposal Alternatives Study, November 2003.

Figure 3-1: Proposed Alignment of Pacific Side Locks Project

3.2 Materials Classification

3.2.1 Introduction

Dredging, conventional dry earth moving methods and drill-and-blast excavation methods will be used to remove the materials from the Locks area and the approach channels, with the expectation that most of the material will be excavated under dry conditions. The ultimate selection of the excavation methods and equipment will be the responsibility of the contractor, but ACP may place reasonable constraints on the contractor in order to optimize the beneficial use of the excavated materials or coordinate with the overall construction program.

Options for transport of the excavated materials from the work area to the proposed offshore island include truck haul, a dedicated rail line, barge transport and a conveyor system or a combination of systems.

This section of the report presents the following information to support the transportation system and cost modeling efforts:

- Characterization of material to be excavated through analysis of available geologic and geotechnical data and observations made at the site.
- Evaluation of suitability of excavated material in artificial island construction as armor stone, underlayer stone, underwater rock fill, compacted rock fill, compacted soil fill, and hydraulic fill.
- Review and refinement of geologic plan and profiles to support computations of available quantities of each material type.
- Recommendation of bulking/shrinkage factors for each geologic unit.
- Comments on the size, shape and specific gravity of the excavated rock.

A more detailed discussion on the materials characteristics evaluation is presented in Appendix A to this report.

3.2.2 Source Information

Data and information available for this study included the following:

- Panama Canal Authority Preliminary Study of Island Development at the Pacific Entrance of the Panama Canal: Final Report, December 2001 (Moffatt & Nichol Engineers);
- Selected Panama Canal Company boring logs completed from 1939-1945 (Third Locks Studies);

- Panama Canal Authority boring logs completed during 2001 (Third Locks Investigation);
- Test results for soil and rock from borings advanced in 2001 (Third Set of Locks Project, Summary of Test results on Rock formations, August 2001);
- 2002 Panama Canal Authority geologic map/ boring location plan (Third Locks Investigation)
- 2002 Panama Canal Authority geologic profiles (Third Locks Investigation)
- Transactions of the International Engineering Congress, 1915: Volume 1-The Panama Canal, Paper No. 3: Outline of Canal Zone Geology.
-

A summary list of boring logs utilized by the consultants in this study is also found in Appendix A.

3.2.3 Methodology

The following steps were taken to evaluate the geotechnical characteristics of the material from the proposed third locks excavation:

- Available data was compiled and analyzed.
- Construction needs were recognized.
- Material properties and behavior were generalized.
- ACP geologic map and profiles were reviewed.
- Suitability of each material type for construction purposes was evaluated.

3.2.4 Geology

Rock

Five rock formations are represented on geologic plans and profiles prepared by ACP following extensive borehole investigations in the excavation area for the third locks project. Figure 3-2 shows the Basaltos, Pedro Miguel Formation, La Boca Formation, Cucaracha Formation, and Culebra Formation. The complexity of the geology has been influenced by faulting and igneous activity along the alignment.

Figure 3-2: Geologic Mapping of Excavation Area

11x17

Use 11 x 17 version of Mapa Geologico with less detail. Show general formation extents and boreholes, plus Locks Alignment.

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As indicated on the geologic map and profiles, the Basaltos, Pedro Miguel, and La Boca Formations are most common in the excavation area, while the Cucaracha and Culebra Formations are encountered less frequently. Zones of fault gouge are also anticipated within the excavation area. This material is relatively insignificant compared to the rock in which it occurs; therefore, in this report, it is treated as having the same characteristics as the rock types in which it occurs. Generalized characteristics and behaviors of the rock formations, as deduced from analysis of the available boring logs, are described in

Table 3-1.

3.2.5 Overburden

The rock formations are overlain in most areas by overburden consisting of weathered rock, residual soil, and/or fill material from previous canal excavations. According to the boring logs, the thickness of the overburden ranges from 0 to 52 meters. The overburden soils are quite variable in respect to their particle size, consistency, moisture content, plasticity, and dry strength.

The logs indicate that the fill material is commonly gravelly and often contains boulders. Fill consisting primarily of hard basalt boulders has been noted in several borings, with zones ranging in thickness from 3 to 12 meters.

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Table 3-1: Characteristics of Materials in the Excavation Area

11x17

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3.2.6 Material Suitability for Construction Elements

The various material and rock types encountered in the study area may be divided into the following four categories:

- Basalt
- Agglomerate
- Sedimentary Rocks
- Overburden

Based on this initial assessment, Table 3-2 indicates the potential suitability of the four categories of material for the various construction elements of the island project.

Table 3-2: Suitability of Excavated Materials for Island Construction

Island Construction Element	Category of Excavated Material
Primary Armor Stone	Basalt[1] or Off-Site Quarries[2]
Underlayer Stone	Basalt[1] (with processing)
Underwater Rock Fill	Basalt[1], Durable Agglomerate
Compacted Rock Fill	Basalt[1] & Durable Agglomerate (with limited processing)
Compacted Soil Fill	Non-durable Agglomerate, Sedimentary Rocks, Overburden
Waste (Unsuitable Soils)	Overburden, dredged material

1 - Additional testing is required to confirm durability of basalt for armor protection.

2 - Joint spacing of the basalt is unlikely to yield sufficient size of rock pieces for primary armor on exposed faces of the island.

Basalt

A large portion of the excavation area is composed of the Basaltos Formation, consisting of sound, strong to very strong, basalt and diabase. Although diabase has been identified as a component of the Basaltos Formation on boring logs and geologic plans and profiles, it is considered to behave similarly to the basalt. Therefore, these rock types are treated as one geotechnical unit (basalt) in this report. Excavation of basalt is projected along the alignment from approximately Station 1+500 through 2+900 and Station 5+000 through 10+000.

The typical spacing of joints in the Basaltos Formation is moderately close to close (0.06 to 0.6 meters). It is expected that well-designed blasts will produce angular pieces that typically grade from a few millimeters to 0.6 m although some pieces larger than 0.6 m should be expected. These units may be used in the underwater rock fill up to the size that can be handled by the equipment and in areas where piling will not be driven. Alternatively, they may be set aside for use as armor stone or broken down further by blasting or hoe-ramming. However, it is not likely that the largest pieces will be of sufficient size for primary armor on exposed faces of the breakwater or revetments. Data on specific gravity of the basalt is provided in Table 3-1.

Field data and test results indicate that the basalt has high strength. The average strength resulting from point load tests performed by ACP was approximately 70 MPa. High strength is typically indicative of durable material. Core logs indicate that zeolites are locally present along fracture surfaces within the basalt. Zeolites can weather and expand over time, resulting in degradation of rock particles that appear to be sound when excavated. However, since zeolites were only identified along joint surfaces and not within the rock matrix, this type of degradation is not considered likely.

Based on discussions with ACP specialists it is expected that testing will show the basalt is durable. Hence it is most probable that the basalt may be used directly, without processing to adjust the gradation, in underwater rock fill. With limited processing to remove oversize material, it should also be suitable in compacted rock fill. Basalt that is found to be non-durable can be used for above water fill. Test blasts are recommended in the early stages of the excavations in the basalt to determine the blast hole spacing and powder factor that yield a gradation suitable for the fills and that provide a level of rock fragmentation that is acceptable to the contractor.

Given the expectation of joint spacing noted above, it is most probable that the underlayer stone may be obtained by processing the shot rock. However, it is not expected that the excavation process will generate a high yield of basaltic material large enough for primary armor stone on exposed faces of the island.

Agglomerate

Excavation of agglomerate is projected along the alignment from Station 1+500 through 7+000, approximately. The sound agglomerate of the Pedro Miguel Formation is medium strong to strong, and its durability varies. The matrix of the agglomerate can locally be more tuffaceous; hence, it will be more erodable and less durable. The average strength resulting from point load tests performed by ACP was approximately 30 MPa. The typical joint spacing of the agglomerate is close to wide (0.6 to 2.0 meters).

Several boring logs indicate that the agglomerate exhibits a tendency to hydrate, swell, and disintegrate upon exposure to air. However, ACP geologists[5] consider that these comments on the logs are questionable. Additional testing is therefore recommended in order to obtain a better understanding of its durability:

It is expected that well-designed blasts will produce angular pieces that typically grade from a few millimeters to one meter with some pieces larger than one meter. Data on specific gravity of the agglomerate is provided in

Table 3-1. If further testing confirms the expectations that the agglomerate is durable, these larger pieces may be used for primary armor. Alternatively, they may be used for underwater rock fill up to the size that can be handled by the equipment or broken down further by blasting or hoe-ramming.

Test blasts are recommended in the early stages of the excavations in the agglomerate to determine the blast hole spacing and powder factor that yield a gradation that is suitable for the fills and provides a level of rock fragmentation that matches the construction requirements for the island and transportation system adopted by the selected contractor.

Any agglomerate that is found to be non-durable can be fragmented by blasting or broken down during handling and used as compacted soil fill, rail bed fill material or above water fill material in the island.

Sedimentary Rocks

Sedimentary rocks will be derived from several formations in the excavation area. Interbedded sandstone, siltstone, conglomerate, and tuffaceous beds of varying thickness comprise the La Boca Formation. The Cucaracha Formation is predominantly shale with local sandstone or conglomerate layers. The Pedro Miguel Formation sporadically contains tuff layers. Excavation of sedimentary rocks is projected along the alignment from approximately Station 1+000 through 4+000, Station 6+000 through 6+400, Station 6+900 through 7+600, and Station 8+300 through 10+000.

The sedimentary rocks within the excavation area are typically soft to medium soft and of weak to moderate strength. The average strength resulting from point load tests performed by ACP was approximately 10 MPa. In addition, they exhibit a tendency to hydrate, swell, and disintegrate upon exposure to air. It is expected that the sedimentary rocks will be excavated primarily by ripping. Locally harder or more massive zones of conglomerate and sandstone may require blasting. Particle sizes from the excavation operations are expected to range from a few millimeters to a meter. With handling and exposure to moisture, the smaller particles are likely to breakdown further into silt and fine sand sizes.

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[5] Discussions with ACP geologist Pastora Franceschi

The poor durability of these materials will limit their use in construction to above water fill or access corridor fill. They should be treated like soil materials and compacted in layers less than 300 mm thick. This will require the removal or fragmentation of pieces larger than 150 mm.

Overburden

Overburden materials include weathered rock, residual soil, and fill material derived from previous canal excavation. Since these are surface materials, they will be the first to be removed in the excavation process and cannot be moved to the island construction site until the fill process is well advanced.

Through consideration of the plastic limit as an approximation of optimum moisture content, soil samples 10% wetter than optimum moisture content are likely to be unsuitable for use as compacted fill. Based on this criterion, an estimated one-third of the overburden will be unsuitable for construction purposes. It is anticipated that the unsuitable soil types that will be encountered most frequently during excavation are silts, sands, and clays of high moisture content. These soils will serve no practical use in construction of the artificial island. However they can serve as base material for landscaping or site restoration where natural revegetation is to be used.

Some of the overburden may also be excavated by dredging. Because of its high moisture content, dredged material will not be suitable for use in the artificial island and should be considered waste material. However, as noted above, it may be used as surface cover for re-vegetation and natural growth erosion protection purposes.

3.3 Materials Volumes

The approximate lateral extents of basalt, agglomerate, and sedimentary rocks beneath the overburden are presented on Figure 3-2. In addition, approximate vertical extents of these materials and of overburden soils may be inferred from the ACP geologic profiles. The expected in situ[6] volume of each of the major categories of material is presented in Table 3-3, below. A more detailed explanation of the calculation process and computations is presented in Appendix A of Volume 3 of this report.

[6] Volume before application of bulking or shrinkage factors are applied.

Table 3-3: Estimated Volumes of Primary Excavation Materials Categories

Material Classification	Expected Volume (m3)
Basalts	19,110,426
Agglomerates	18,476,429
Sedimentary Rock	7,018,950
Overburden	24,744,194
Total	69, 350,000

3.4 Bulking and Shrinkage Factors

Prior to excavation, in situ rock typically has a density similar to the specific gravity of the rock as it has little to no air space within the rock mass. Upon blasting or ripping, the rock mass breaks into discrete particles of rock which are piled randomly against each other. This causes bulking of the material, as there are voids between contact points of the rock fragments. For this project, bulking factors are expected to be on the order of 30% to 40% for the basalt and agglomerate. For the sedimentary rocks, which will break down into smaller pieces more readily, the bulking factors should be in the range of 10% to 20%.

Volume decreases are expected for the overburden material. Factors affecting the amount of shrinkage include the relative density between the borrow and fill materials, losses of material during transportation, and settlement of the material. No project-specific data is available for estimating shrinkage factors, but based on experience on other projects, shrinkage in the range of 15 to 20%, is expected, excluding losses due to settlement.

3.5 Excavation Program

At this time, the detailed schedule for preparation of the final designs, acquisition of finance, approvals, and construction of the new Locks has not been finalized. In discussions with ACP project staff, it was agreed that transport productivity rates would be computed on the expectation that the excavation program would cover a five year period.

Within this time period, it was also considered that the excavation sequence would be undertaken to respond to the following priorities.

1. Removal of Overburden material and surface clearance in the Locks area
2. Immediate Locks construction zone
3. Water savings basins areas
4. Entrance and Exit channels to new locks
5. Final cuts to Gaillard Cut and Pacific Entrance reaches

Elements 1 through 4 would all be accomplished in the dry, while the final linking of the locks to the main Canal reaches would be undertaken by marine equipment. According to earlier reports, this then implies that approximately 90 percent of the total volume of material would be excavated under dry conditions.

This schedule and extended length of the overall excavation zone then dictates that the materials transport system will need to serve multiple work faces and different materials at the same time, without interference with the main construction elements of the project.

If it is assumed that work would commence on the Locks project by late 2005, filling of the island should then be completed by approximately 2010, unless material was to be placed in a large stockpile and re-handled at a later date.

Finally, it should be noted that for any land based transportation system, a haul corridor must be prepared and installed before any significant quantities of material can be removed from the excavation area. This then places the selection and design of the disposal area on the critical path for the overall Locks project.

4 SITE CHARACTERIZATION STUDIES

Landside and marine field investigations were carried out to cover the potential locations for the island and also the corridor expected to be used to move materials from the excavation site to the island.

In all cases, the field work was undertaken by ACP directly with assistance and coordination by the consultants. Specific field work campaigns described in the following sections included:

Land side Investigations

- Topography of proposed rail or haul corridor
- Trial pits and boreholes along haul corridor

Marine Site Characterization Studies

- Bathymetry of study area
- Current metering and tidal measurements
- Geophysical and side scan surveys of study area

In addition to these investigations, the consulting team also carried out marine environmental sampling and socio economic field work for the Disposal Study mentioned earlier. The results of these field investigations are pertinent to this Island Study and included:

- Water Quality and sediment sampling for marine sectors
- Socio economic evaluation fields trips

4.1 Bathymetry

As shown in Figure 4-1, the usually considered Southern limits of the Gulf of Panama are Punta Mala on the West and Punta Piñas to the East. The line between these two points is very close to the 7.5^{o} N Latitude line, and has an approximate length of 200 km. At this location the depth is approximately 200 m. Southwards the depth increases steeply to 1000 m. and more, right outside the Gulf entrance. Northwards, a gradual decrease of the depth is broken by Las Perlas Islands. At the western part of the Gulf extensive mud flats with small slopes can be observed.

4.1.1 Inshore Bathymetric Surveys

Three bathymetric campaigns were undertaken in the area of interest for the Artificial Island. The first two surveys were taken by ACP in 1999 and 2000 as part of the evaluation of the Anchorage areas, but did not fully extend to the western limits of the area under consideration for the island construction.

The third survey was undertaken in January 2003 as part of the geophysical survey discussed below with the instrumentation cross linked to the side scan sonar and seismic reflector equipment to ensure consistency of each element of the survey.

The results of the three surveys were also compared with data from the navigation charts and in general, a close approximation was observed between the published data and the ACP survey results.

Figure 4-2 shows the bottom contours of the inshore study area, according to the bathymetry generated during the geophysical survey work carried out in 2003. It is seen that the bottom slopes gently and consistently from the shoreline with maximum depths of approximately 20 m below MLWS to be encountered close to the northern shores of Taboga island.

Figure 4-1: Bathymetry of Panama Bay

11x17

Use Fig 3-1 from Hydro Baseline Study

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Figure 4-2: Bathymetry of Island Study Area - January 2003.

Use bathymetric figure from Golder Geophysical survey

4.2 Topography

A preferred route was identified for the corridor from the excavation area to the proposed causeway connection point as part of the Preliminary Study carried out in 2001. However, this analysis was based on topography from aerial photography and some inconsistencies were noted during the early field visits, particularly in areas of heavy tree cover.

ACP therefore undertook a topographical survey of the entire route, covering a width of 200 m either side of the preferred centreline, in order to provide a basis for the evaluation of alternative transport systems.

The coverage of the topographic survey is indicated in Figure 4-3 on the following page. Further details of the results of the survey are presented in the discussions on transportation alternatives and concepts for the materials transportation and stockpiling systems.

All mapping and computation for the transportation corridor to the island are based on the results of the 2003 topographic survey carried out by ACP.

Figure 4-3: Coverage Area - Topographic Survey of Materials Transport Corridor

4.3 Geophysical

4.3.1 Introduction

A key factor in the location and cost computations for the island is the understanding of the bottom and sub bottom conditions within the area of interest for the project.

The general nature of the shoreline, Taboga Island and the rocky islands in the study area are an indication that rock will be encountered at varying depths below the sea bed in the study area. Work contracted by the Panama Canal Commission (PCC) along the Pacifi channel in 1999[7] indicated that andesites and basaltic rock could be encountered at depths of approximately 15 m below MLWS[8]. Earlier work on the construction of the Port of Vacamonte[9] also indicated that similar material is encountered at depths of 7.00 to 10.00 m below MLWS and these two boundary conditions were used as a basis for preliminary geotechnical and cost computations for the Preliminary Study report prepared in 2001.

At this feasibility study level, a higher level of confidence is required in order to optimize the island location and to compute dredging and other costs. Consequently ACP, in conjunction with the consultants, prepared a program of wash probes and boreholes to obtain a characterization of the sea bed and sub bottom materials in the project area.

Unfortunately, the cost proposals for this work were extremely high and it was decided that a geophysical survey would provide a more detailed mapping of the sub bottom materials at a much reduced cost. Since ACP already owned a sub bottom profiler and other equipment, the marine geophysical investigations were undertaken as a joint exercise using ACP equipment and personnel, in conjunction with equipment and senior geophysical specialists from Golder Associates.

Following an initial training period of one week in early January 2003, the field work was undertaken by ACP personnel from January 9th to February 6th, 2003 and covered some 125 km^2 as shown in Figure 4-4. Data analysis was performed concurrently with the field program, in order to modify survey techniques or identify areas of special interest. Full data acquisition followed the survey work by approximately two weeks. The data were analyzed by GAI geophysicists at their Redmond, Washington office.

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[7] Seismic Survey Panama Canal Buoy 1 to 21, Coastal and Inland Marine Services Inc for Panama Canal Commission, November 1999

[8] Mean Low Water Spring Tides

[9] Field Investigations for Vacamonte Fishing Port, Livesey & Henderson, 1974 to 1976

Figure 4-4: Geophysical Survey Coverage Area

Insert coverage map from Golder Report

4.3.2 Survey Objectives

The specific objectives of the marine geophysical survey were to:

- Provide detailed characterization of physical features of the seafloor.
- Map the thickness of unconsolidated sediment overlying bedrock.
- Provide general characterization of the nature of the unconsolidated sediment.
- Map the depth to the top of bedrock.

4.3.3 Field Operations & Instrumentation

The marine investigation used the following geophysical methods to achieve the project objectives:

- Precision echo sounding
- Side scanning sonar
- Seismic reflection profiling

The site is approximately 12 km in length (north to south) and 10 km in width (east to west). The data were obtained on a grid pattern, consisting of a series of survey transects, spaced at an interval of 250m over the entire site.

The survey was conducted on board a 10m hydrographic survey vessel, owned and operated by ACP which also provided navigation and echo sounding equipment. The navigation and bathymetric data were obtained with an integrated and automated hydrographic system that provided real-time on-line navigation and positioning of the survey vessel. The hydrographic instrumentation consisted of a Trimble 4000SE Differential GPS receiver, Coastal Oceanographic Hypack navigation software and Odom Echotrack precision echo sounder.

The differential global positioning system (DGPS) was used to determine the vessel's location in real-time, and to plot the position along the survey lines. The pre-plotted survey lines, and the actual survey lines traversed by the vessel, were displayed in real-time on a video monitor. The navigation computer transmitted event marks to the geophysical recording instruments every 60 seconds. The navigation data, and event marks were digitally recorded and used to produce the survey trackline maps needed for the data analysis task.

Geophysical Instrumentation

The geophysical instruments were installed on the survey vessel at the ACP marine dock located near the Bridge of the Americas. Calibration and checkout of the instruments was done in the harbor prior to beginning survey training and operations on the following day. There was no loss of survey time resulting from failure of the seismic reflection instrumentation and the overall quality of the data was very good to excellent.

Sidescan Sonar

Sidescan sonar produces an acoustic image of the seabed that is analogous to an aerial photograph on land. The plan view image provides aerial information on the nature of seabed sediment (silt, sand, gravel); identifies the presence of rock or other features, including cultural artifacts, that project above the seabed, and provides information on potential geohazards such as submarine slides or fault lineaments.

The sidescan sonar data were acquired with a Klein 3000 system operating at a frequency of 100 kHz. The sidescan transducer was suspended from a davit located on the port side of the survey vessel and lowered 2 to 3m below the sea surface. The data were stored digitally and also displayed in real-time on a thermal graphic recorder.

Subsurface Reflection Profiling Systems

A subbottom profiler and a seismic reflection system were used to characterize and map the thickness of the marine sediment. The difference in the acoustic characteristic of these two instruments provides a means to qualitatively characterize the nature of the sediment and to maximize resolution and subsurface penetration.

Subsurface reflection profiling uses acoustic pulses, emitted at regular intervals by an acoustic energy source, to image subbottom stratigraphy and geology. The transmitted acoustic pulses reflect from the seabed and underlying geology or stratigraphy and are received by either a transmitting transducer (subbottom profiler, SBP) or a surface-towed hydrophone (high-resolution seismic reflection profiler). The transducer or hydrophone converts the acoustic pressure waves into electrical signals that are processed and displayed on a graphic recorder on board the survey vessel. This display, the seismic reflection record, is an acoustical profile of the seabed and subbottom stratigraphy or sediment layers along the survey trackline.

The lateral and vertical distribution of fine to medium-grained sediment was mapped with a Klein subbottom profiler. This system, which operates at a frequency of 3 to 5 kHz provides very high-resolution (able to image thin layers of sediment) information but only achieves limited subsurface penetration in medium or coarse-grained sediment (less than 1 to 2 meters). The transducer was suspended from a davit on the port side of the survey vessel and deployed approximately 2 to 5 meters below the water surface.

High-resolution seismic reflection data were collected with an Applied Acoustic Engineering Model 500 system. This relatively low frequency system (800Hz to 2 KHz)) is capable of much deeper penetration than the SBP, particularly in coarse-grained sediment. At this site the maximum subsurface penetration achieved with this system was estimated to be 28 m below the seabed.

Hydrojet Probing Calibration

A hydrojet probe, using a Honda high-pressure water pump and lightweight pipes was used to verify the interpretation of the geophysical reflection data. Seven sites were selected for probing to determine the thickness of unconsolidated sediment overlying bedrock. The results from the probing were compared with the sediment thickness values on the isopach map at each of the probe stations.

4.3.4 Geophysical Interpretation of Results

Bathymetry

Although ACP had carried out recent bathymetric surveys of the study area, the on board equipment for the geophysical survey provided new information that was integrated with the other data inputs from the project.

As can be seen in Figure 4-5, the water depth in the survey area ranged from approximately 1m to 18m across the survey area with the presence of occasional bedrock pinnacles or small islands. The seafloor gradient is extremely low having a maximum value of 1:250. With the exception of the small pinnacles or islands and the dredge disposal zone shown in the figure, there were no abrupt changes in the seafloor gradient that might have indicated former channels, zones of subsidence or submarine slides. Some of the mounds in the dredge disposal zone have a maximum of 1 to 3m of relief above the seabed as shown in Figure 4-5.

Sidescan Sonar

In general the sonar images suggest that the seabed sediment consists of fine to medium-grained material (silt to sand size particles) with no unusual bedforms. The exceptions to this are several small areas of rock, a few small islands or pinnacles and the area located near the center of the site identified as a dredge disposal zone. This zone exhibits considerable seabed roughness resulting from the uneven discharge of dredged material.

Subbottom Profiler and Seismic Reflection

The subbottom profiler and seismic reflection data were used to produce the sediment isopach map shown in Figure 4-7 and to provide additional information for developing the surficial features map. The sediment thickness data was summed with the bathymetric data to produce the depth to top of bedrock map indicated in Figure 4-6.

Figure 4-5: Bathymetry in Study Area

Figure 4-6: Depth to Bedrock in Study Area

Figure 4-7: Thickness of Sediments in Study Area

The SBP equipment is only capable of obtaining good subsurface penetration in fine-grained sediment. Consequently, evidence of significant subsurface penetration can be interpreted as evidence of fine-grained (clay or silt) sediments. This qualitative interpretation suggests that the eastern and southeastern area of the site is covered with fine-grained material since the SBP was able to penetrate up to 16m of material. The western area of the site appears to be characterized by fine to medium-grained sediment, based on the acoustic characteristic of the reflection pattern, and the reduced depth of penetration.

Over nearly the entire site the seismic reflection system was able to penetrate the entire unconsolidated sediments down to bedrock. In some areas, such as in very shallow water or in the zone of dredge spoils, the contact between the unconsolidated sediment and the top of bedrock was difficult to identify. These acoustically opaque zones result from the scattering of the acoustic signal by the coarse-grained surface materials or the presence of very dense sediment such as weathered rock or cobbles.

As seen in Figure 4-7, the thickness of unconsolidated sediment ranges from approximately 1 to 10m across most of the site. The exception to this is the significant deposit of material that fills the linear, channel-like feature that runs along the east side of the site parallel to the ship channel. The trench-like appearance of the feature is morphologically similar to a tectonic structural feature termed a graben. A graben is a linear structural block, relatively long compared to its width that has been downthrown along normal-slip faults that form its margins. This type of tectonic feature generally forms in an extensional tectonic environment. There is no evidence of this feature on the bathymetric map or the sidescan sonar data.

4.3.5 Summary & Conclusions

A summary of the results of the geophysical investigation are presented below:

- The water depth ranged from 1.0 m to 12.0 meters below MLWS. The seafloor has very little relief, with the exception of several small rock pinnacles and islands and a localized dredge disposal zone.
- The interpreted sidescan sonar data suggests that the seabed is mantled with fine to medium-grained sediments, i.e. clay or silt to sand. A qualitative classification of the sediment in the dredge disposal area is not possible because of the ruggedness of the seabed.

- The interpreted SBP data identified a large zone of fine-grained (silt or clay size) sediment, 4 to 12m thick, that covers the southeastern area of the site. A large area of the center and western edge of the site is covered with fine to medium-grained sediment, 1 to 3m thick. The remainder of the site is covered with either medium to coarse-grained material, dredged disposal material or has exposed weathered rock.
- The subsurface penetration on the seismic reflection data, which represents the total thickness of unconsolidated sediment, ranged from 1 to 10m across most of the site. The exception to this is the thick sediment deposit (10 to 26m) located in a trench-like feature that is located on the eastern edge of the survey area.
- The trench-like feature that is adjacent and runs parallel to the western edge of the canal may be fault related. Although this feature could be the result of stream erosion during lowered sea level its persistent linear nature suggests that it is structurally controlled. Onshore, Quaternary-age faults have been mapped northwest of Panama City (U.S. Geological Survey, Open-File Report OFR 98-779) as well as further offshore that project through this area. Most of the 31 seismic events recorded in Panama are concentrated within and along the southern projection of the Quaternary-age faults. The events are within 50 km of the survey area.
- There is a potential risk to proposed structures if the trench-like feature is located on an active fault. Motion that could produce significant displacement of the seabed during an earthquake event may result in excessive ground motion and/or the generation of local tsunami.

4.4 Geotechnical Studies

4.4.1 Marine

It was hoped that a number of boreholes could be driven to assist with the characterization of the soft materials and the transition from weathered rock to the hard materials that are encountered over the entire study area. Unfortunately, as noted above, the mobilization cost of the work was out of proportion to the quality of the specific data that could be obtained. The geophysical survey was then selected as the preferred approach until more definite location for the island could be determined. At this time, a more specific geotechnical site investigation can be developed, with the characterization of the soft materials being a high priority for the program.

In the meantime, the design and cost estimating for this study are based on the determination of the depth of the soft materials, the results of bottom samples from the environmental field work and the results of the geophysical survey, together with anecdotal information or earlier work undertaken for the Vacamonte[10] fishing port project in the 1970s.

Bottom samples were also taken to support an application[11] for a sand extraction concession south of Isla Tortola and within the island study area. Three soil samples were taken within the proposed concession area, and were identified as fine sands with approximately 90 and 65 percent passing the #4[12] and #10 sieves respectively. According to the laboratory analysis of the samples, the material would be classified as being a coarse sand.

However, there is no indication in the report of the depth at which the samples were taken, and any conclusions of the consistency of the material could well be suspect.

At this feasibility level of study, the results of the geophysical survey give an acceptable understanding of the depth of soft material overlying the hard rock base. However, it is known that the soft silts change to sand deposits at approximately the 12 m contour, and the geophysical work does not clearly differentiate between fine sands and silts over this area. The survey was also unable to give any indication of the shear strength of the soft materials, except for the fact that the jet probes used to calibrate the seismic reflection results met little or no resistance to depths of about 5.00 m below the mud line.

Figure 4-7, presented in the previous section, shows the depth of soft sediments or sands over the study area. However, as noted above, no conclusions can be made at this time as to the extent, characteristics and strength of each soil type.

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[10] A member of the study team directed site investigation and design work for the Vacamonte Port. The field studies included boreholes, rock core extraction, wash-probes and seismic reflector surveys of the port area and approach channel.

[11] Estudio de Impacto Ambiental II, Solicitud de Concesión Minera para la Extracción de Arena Submarina, Panama Environmental Services S.A. for Energy Consultants S.A., November 2000

[12] ASTM sieves #4 and #10 have openings of 4.75 mm and 2.00 mm respectively.

4.4.2 Landside Geotechnical Conditions

In conjunction with the topographic surveys noted above, a series of boreholes and trial pits were taken by ACP geotechnical staff along the proposed transport corridor. In general terms, trial pits were taken to a depth of approximately 2.5 m at intervals of 500 m, with boreholes being taken at all major stream crossings or potential bridge sites. Figure 4-8 shows the borehole and trial pit locations for the investigation.

A total of eight boreholes were taken over the corridor. Between five and nine samples were taken at each borehole location for a total of 56 samples. Soil samples from the SPT sampler were stored in plastic bags while rock samples were sealed with paraffin and transported to the laboratory for storage. In the laboratory all samples were removed from the bags and dried in the work area. Index tests to test water content, Atterberg Limits and specific gravity as well as a sieve analysis were conducted on each soil sample to determine the classification of the material. Strength tests including unconfined compression, point load, and triaxial tests were performed on intact rock samples having a nominal diameter of 2.6 inches. Table 4-1 and Table 4-2 show typical results obtained from these analyses.

Table 4-1: Summary Results of Index Tests – Boring RTP-6

AUTORIDAD DEL CANAL DE PANAMA
DIVISION DE INGENIERIA
SECCION DE GEOTECNIA

SUMMARY RESULTS OF INDEX TESTS

Project: Railroad to Artificial Island
Location: Pacific Side

Borehole	SPT No.	Depth (m)	Blows (N)	Specific Gravity Gs	Moisture Content (%)	Passing No. 200 (%)	Liquid Limit LL	Plastic Limit PL	Plastic Index PI	Classific. U.C.S.	Name	Color
RTP-6	1	0.00-0.45	1-3-2		30.23	40.18	43	30	13	SM	Silty sand	Light brownish gray
RTP-6	2	1.50-1.95	5-5-5		49.73	33.77	+	+	+			
RTP-6	3	3.00-3.45	3-3-5		42.3	47.88	68	33	35	SC	Clayey sand	Pale brown
RTP-6	4	4.50-4.95	3-4-6		41.6	38.55	59	31	28	SM	Silty sand	Light brownish gray
RTP-6	5	6.00-6.45	11-46-50		29.95	32.16	26	23	3	SM	Silty sand	Light yellowish brown

Remarks: (+) means "insufficient material"
Tested By: C. Rodriguez, and X. Rios
Date: 08/08/2002
File: RTP
Prepared By: Xenia Rios
Checked By: Gustavo Guerra B.

Table 4-2: Summary Results of the Point Load Strength Index of Rock – Boring RTP-1

AUTORIDAD DEL CANAL DE PANAMA
DIVISION DE INGENIERIA
SECCION DE GEOTECNIA

SUMMARY RESULTS OF THE POINT LOAD STRENGTH INDEX OF ROCK
Project: Railroad to Artificial Island

Location: Pacific Side

	Boring	Depth (m)	Sample No.	Point Load t. Is_{50} (Mpa)	Estimated Unconf. Comp. σc (Mpa)	Type of Rock
1	RTP-1	12.67-12-90	m-1	0.27	6	sandstone
2	RTP-1	13.80-14.07	m-2	0.21	5	sandstone
3	RTP-1	15.25-15.45	m-3	0.3	7	sandstone
4	RTP-1	16.45-16.62	m-4	0.47	10	sandstone

Remarks: rock color: sandstone light olive gray

Tested and prepared By: R.Lam, X. Rios and G. Guerra 09/15/2002

Seven pits were excavated in total. Each pit measured approximately 2.5 m deep, 4.0 m long and 2.5 m wide (see Figure 4-9). The excavations were accomplished by using a D6 to remove standing overgrowth and a backhoe to dig the pit. Two samples were recovered from each pit, properly packaged and tagged and sent to the laboratories for analysis. Laboratory index tests included dry density, wet density, specific gravity, moisture content, maximum liquid limit, plasticity limit and passing tests.

Table 4-3 summarizes the results for each sample.

A full report on the field work and laboratory results is presented in Appendix C of this report.

Table 4-3: Summary Results of Index Tests – All Pit Locations

PANAMA CANAL AUTHORITY

ENGINEERING AND PROJECTS DEPARTMENT

ENGINEERING ENGINEERING DIVISION

SOILS AND MATERIAL LABORATORY

SUMMARY RESULTS OF INDEX TESTS

Project: Artificial Island Proposed Railroad Alignment
Location: West Bank

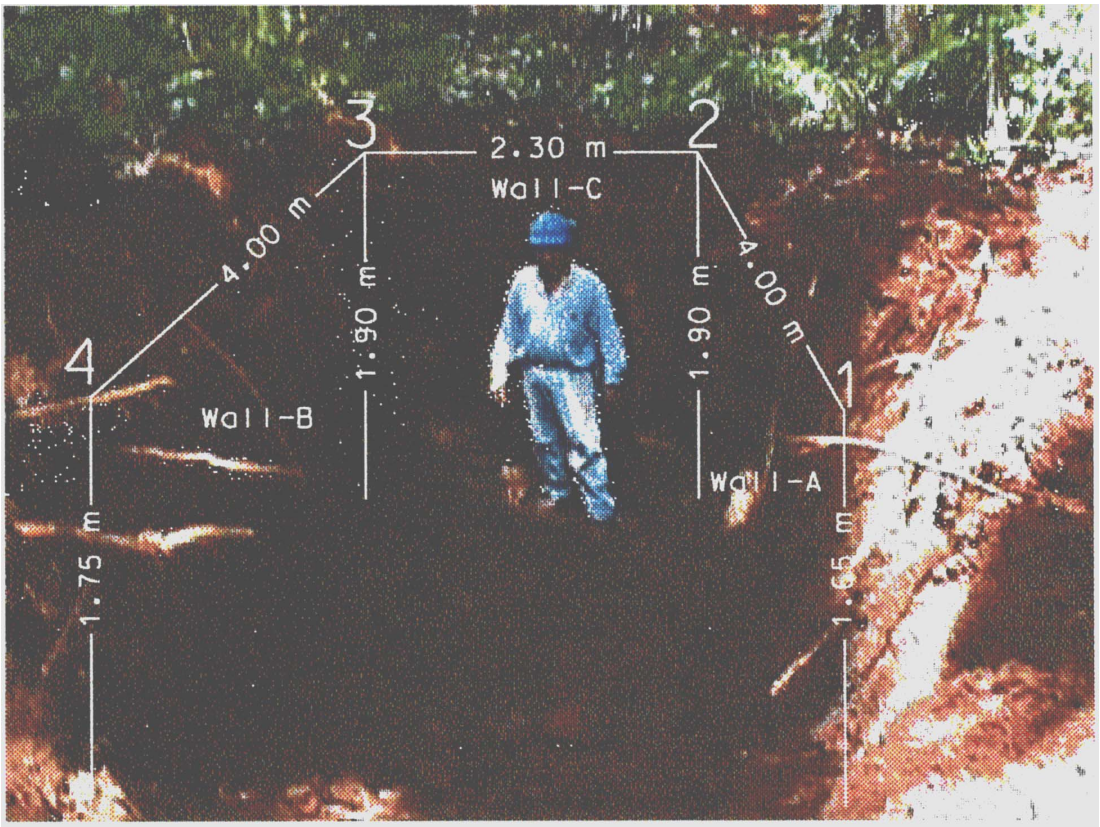
PIT No.	Sample	Depth m	Wet Densinty (lb/ft^3)	Dry Density (lb/ft^3)	Specific Gravity Gs	Moisture Content (%)	Passing No. 200 (%)	Liquid Limit LL	Plastic Limit PL	Plastic Index PI	Classific. U.C.S.	Name	Color
PIT-1	A	1.00	121	91	2.53	32.89	56.97	73	35	38	MH	Sandy elastic silt	Reddish brown
PIT-1	B	0.80			2.53	30.95	56.97	73	35	38	MH	Sandy elastic silt	Reddish brown
PIT-2	A	0.70	112	84	2.57	33.21	25.4	59	36	23	SM	Silty sand	Reddish brown
PIT-2	B	1.00			2.57	33.51	25.4	59	36	23	SM	Silty sand	Reddish brown
PIT-3	A	1.00	119	90	2.55	31.86	28.37	64	36	28	SM	Silty sand	Brown
PIT-3	B	1.20			2.39	32.61	28.92	66	36	30	SM	Silty sand	Brown
PIT-4	A	0.90	127	97	2.42	30.4	32.65	60	32	28	SM	Silty sand	Light Brown
PIT-4	B	0.80			2.42	29.5	32.65	60	32	28	SM	Silty sand	Light Brown
PIT-5	A	1.50	119	85	2.32	40.67	60.39	78	34	44	CH	Sandy fat clay	Brown
PIT-5	B	0.86			2.2	52.06	51.49	73	43	30	MH	Sandy elastic silt	Light yellowish brown
PIT-6	A	1.82	122	98	2.49	25.06	32.84	47	27	20	SC	Clayey sand	Light gray
PIT-6	B	1.30			2.64	37.14	13.44	69	39	30	SM	Slity sand	Reddish brown
PIT-7	A	1.10	116	100	2.39	16.34	30.07	54	28	26	SC	Clayey sand	Light reddish brown
PIT-7	B	1.34			2.57	17.7	34.69	54	31	23	SM	Silty sand	Reddish brown

Tested By: Carlos Rodriguez and Xenia Rios.
Prepared By: Xenia Rios
Checked By: Gustavo Guerra B.
File: Pits Isla Artificial
Date: 07/24/02

Figure 4-8: Location of Boreholes & Test Pits - Corridor Geotechnical Investigations

Use Railroad to Artificial Island Map at the end of the ACP Lab Testing Program Report (Sept. 2002)

Figure 4-9: Typical Test Pit – Geotechnical Investigations



4.5 Wind Data

Average wind speed and direction for the study area are available at Balboa FAA station from the period 1985-2002. Table 4-4 presents the monthly average speed and wind directions at that station.

Table 4-4: Average Wind speed & direction at Balboa FAA

Station Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Avg. Wind Speed (m/s)	2.17	2.42	2.45	2.26	1.80	1.56	1.73	1.66	1.56	1.55	1.64	1.75
Avg. Wind Direction	333.4	338.6	341.9	336.4	299.2	296.6	308.3	308.8	263.9	255.4	296.0	325.0

During the rainy season months in Panama of May to November, the dominant wind direction is from the West – Southwest. Wind speeds during this period are slightly smaller than during the rest of the year. From December to April (dry season) the predominant winds are from the North-Northwest, when the northeasterly (trade) winds blow with more intensity.

Hourly winds were also available at Balboa for the period May – July 2002 when ACP measured water levels and currents in Panama Bay. Time series of wind speed and direction for this period are presented in Figure 4-10.

Surface wind data are available at Howard Air Force Base from the period 1973-1995. Table 4-5 presents the prevailing wind direction, monthly mean wind speed, maximum peak gust and highest-pressure altitude at this station.

Table 4-5: Average Wind speed & direction at Howard Air Force Base

Station Name	Units	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Pvlg. Wind Direction	16 pts	N	N	N	N	NNW	NNW	NNW	NNW	NNW	S	NNW	NNW
Mean Speed (Pvlg Dir)	kts	8	8	9	7	6	5	6	6	5	7	5	6
Mean Speed (All Obs)	kts	7	8	7	6	4	3	4	4	3	3	4	5
Max Peak Gust	99.95%	31	32	34	31	56	35	45	41	35	36	31	56
Pressure Alt	ft	295	281	300	304	300	286	276	284	292	284	292	339

Source: Howard AFB Panama; Prepared by: AFCCC/DOS, Oct. 1996; Period: Jan 1973 – Dec 1995

The dominant wind direction from May to November is North- Northwest. These wind speeds are again slightly smaller than during the rest of the year. From December to April the predominant winds are from the North.

Figure 4-10: Balboa FAA - Wind Speed and Direction Data (May to July 2002)

Use Fig 3-4 from Hydro Baseline Report.

4.6 Tides & Currents

As seen in Figure 4-11, the Gulf of Panama is about 200 km wide (E-W direction) and 170 km long (N-S direction). There are two main groups of natural islands in the Gulf. The first group includes the islands of Taboga and Taboguilla, located 15 km. south of Panama City, while the second group, Archipelago de Las Perlas, is located in the middle of the Gulf at a distance of 90 km South East of the Canal Pacific entrance.

The entrance of the Gulf located at an approximate Latitude of 7.5^{o} N (East of Punta Mala, at the Azuero Peninsula) has depths in the order of 200 m. South of the entrance, depth increases very rapidly reaching values between 2000 to 3000 meters at a latitude of 6° N.

The area of interest of the present study is located in Panama Bay and it is limited by the Coast of Panama along the North and West, the entrance channel to the Panama Canal on the East and Punta Chame and Otoque island on the South. The depth in this area varies from 0 to around 50 m.

4.6.1 Tides

Tides in Panama Bay are semidiurnal with two high waters and two low waters per day and with an approximate period of 12.25 hours. The average tidal range at the entrance of the Gulf of Panama is 1.5 m during neap tide and 3.4 m during spring tide. The tidal propagation along the Gulf follows a standing wave pattern. The tidal range amplifies from south to North due to the reflection of the tidal wave on the closed boundary at the North of Panama Bay. At Balboa the average tidal range is approximately 2.7 m during neap tide and on the order of 5.0 m during spring tide. The tidal propagation in the Gulf of Panama is described with more detail in Bennett (1965).

Figure 4-11: Study area for Wave and Hydrodynamic Modeling Studies

Use Fig 2.1 from baseline Hydro report

4.6.2 Currents

The currents in the Gulf of Panama are generated by tidal effects, oceanic currents and wind. A discussion of each system follows.

Tidal Currents

The tide-generated currents are associated to the tidal variability discussed in the previous section. During the filling of the bay (transition from low water to high water) the flood current's direction is to the north while during the emptying of the bay the direction of the ebb current is approximately south. The magnitude of the tidal currents varies with the tidal range presenting the highest values during spring tide and the lowest during neap tide.

Oceanic Current

The Oceanic currents in the Eastern Pacific are very complex and they are associated to the global wind patterns related to the position of the Inter-tropical Convergence Zone (ITCZ). The main currents affecting the Gulf of Panama are:

- The Westerly moving North-Equatorial current, which is a direct result of the Trade Winds. This current moves west from Panama Bay at about 12°N.
- The Easterly Equatorial Counter Current moves in the opposite direction to the prevailing wind direction between 4° and 10° N. It is generated by the horizontal pressure gradient in the water surface elevation between the West and East Pacific, produced by the trade winds. The effects of the Equatorial counter-current disappear between 90° to 85° W where it is partially incorporated into the circulation of the Gulf of Panama. The tropical waters of the Gulf are displaced south by the Trade Winds forming a cyclonic (counterclockwise) circulation known as Gulf of Panama or Colombia current (Forsbergh, 1969; Bennett, 1965). The intensity of the current varies with the intensity of the trade winds, being highest during the months of December to April, and lowest from May to June.

Estimation of the net current in the Gulf of Panama has been presented in a number of publications. The Atlas of Pilot Charts presents the net average current for each calendar month. Figure 4-12 presents the currents chart for May and July (first and last month of the calibration period presented in this report).

Figure 4-12: Net Currents in Panama Bay (Atlas of Pilot Charts)

Use Fig 2-2 from Baseline Hydro Report

The currents presented in the charts shown in Figure 4-12 have the highest values during the months of April, May and June being 0.5 knots (0.26 m/s) south of Taboguilla Island, 0.7 knots (0.36 m/s) west of Punta Cocalito and 1 knot (0.51 m/s) west of Punta Mala. The net average flow throughout the year at the northern end of the Bay is in the order of 0.3-0.5 knots (0.15 – 0.26 m/s).

The net current of the Gulf of Panama was also estimated in Bennett, (1965) using current data collected by the former United States Navy Hydrographic Office in the western Gulf of Panama from late August to early October 1958. The measurements were taken at five locations as shown in Figure 4-13 and at three depths. Bennett calculated the net current to be about 0.35 knots (0.18 m/s) inshore at a depth of 55 ft (17 m) and 0.7 knots (0.35 m/s) offshore at approximately 100 ft (30 m) of depth.

Wind Generated Currents

When winds blow across the ocean surface, kinetic energy is transferred from the wind to surface water as a result of the friction between the two. Kinetic energy transferred to the ocean surface sets the surface layer of water in motion and generates both waves and currents. Current patterns can also be affected by the local wind climate, especially in the shallow water. However, previous studies at Panama Bay concluded that the local wind has a very small impact on the magnitude and the pattern of the currents at the North end of Panama Bay (Delft Hydraulics, 1999).

Figure 4-13: Currents in Panama Bay (Bennett, 1965)

Use Fig 2-3 from Baseline Hydro Report

Tides

In support of the hydrodynamic modeling work presented later in this report, tidal and current readings were taken at the limits of the study area from May to July 2002. Additional readings were also taken at the Pacific Entrance to the Canal in December 2003. Tidal readings were made at Taboga island, the Mine Dock on Amador Causeway and also at Contadora island, as indicated in Figure 4-14. As current readings were taken over Spring and Neap tides at the three locations shown in Figure 4-15, defining the boundaries of the model and conditions at the expected island location. The work was undertaken by ACP staff with transect locations and initial field work assistance from the consultants.

Typical output from the measurements is presented in Figure 4-16 and Figure 4-17, on the following pages. The full results of the tidal and current measurements are presented in Appendix D to this report.

Figure 4-14: Location of ACP established Tidal Stations

Use Figure 3.2 from Baseline Hydro Study

Figure 4-15: Location of Current Measurements (2003)

Use Figure 3.3 from Baseline Hydro Study

Figure 4-16: Typical Results of Current Metering - June 2002

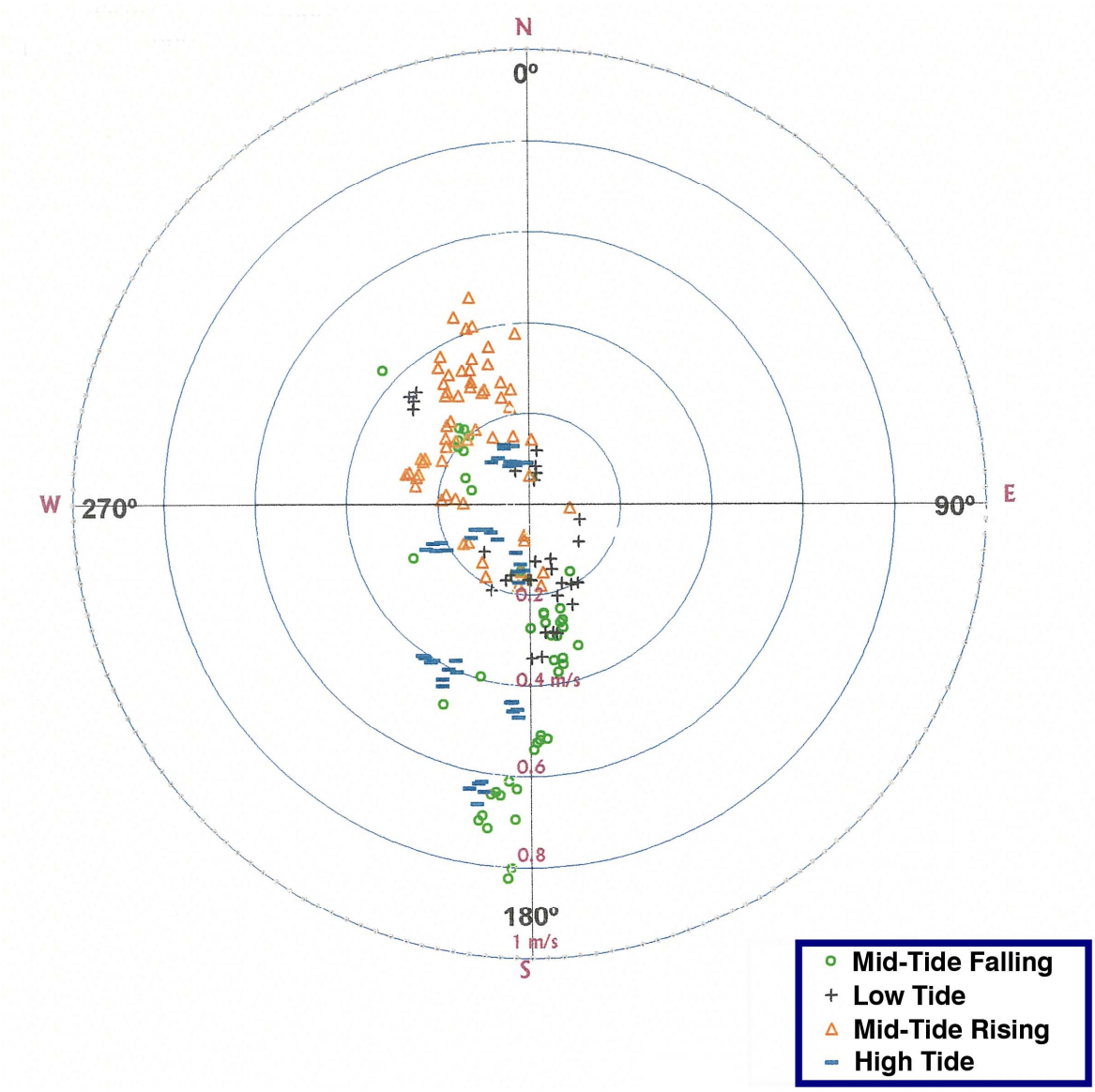
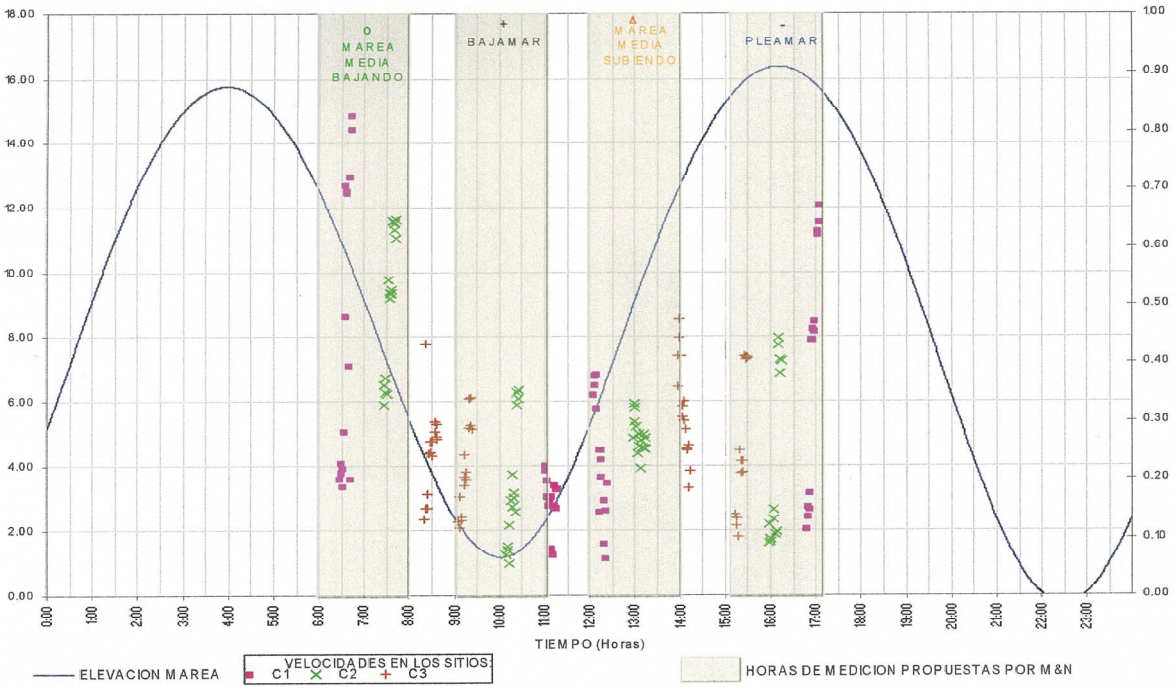


Figure 4-17: Typical Current Velocities Observed at Western Limits of Study Area



Tidal Prediction Stations

A number of NOAA tidal stations are available in the Gulf of Panama. Balboa is the only primary station and the tidal predictions for the other locations are calculated from the constituents at Balboa using some amplitude and phase corrections. A number of these stations throughout the Gulf of Panama are presented in Table 4-6. The location of these stations is shown earlier in Figure 4-14.

Table 4-6: NOAA Tidal Prediction Stations in Panama Bay

Station Name	Station Type	Long. (deg. W)	Lat. (deg. N)	Mean Tide Range (m.)	Spring Tide Range (m.)	Mean Tide Level (m.)
Bahia Piña	Secondary	78.18	7.57	3.20	4.18	2.07
Punta Garachine	Secondary	78.42	8.08	3.32	4.33	2.13
Isla del Rey	Secondary	78.90	8.30	3.26	4.24	2.10
Rio Chepo	Secondary	79.12	8.98	3.81	4.94	2.47
BALBOA	Primary	79.57	8.95	3.84	5.00	2.50
Naos Island	Secondary	79.53	8.92	3.78	4.75	2.38
Taboga	Secondary	79.55	8.80	3.81	4.94	2.47
Bahia de Chame	Secondary	79.75	8.68	3.81	4.94	2.47
Punta Mala	Secondary	80.00	7.47	2.47	3.20	1.58

4.6.3 Water Level Observations

ACP installed four tidal gages in Panama Bay in order to record the water level variation during the months of May to September. Coordinates and temporal extent of the measured record for each station are presented in Table 4-7. The measurement locations are shown in Figure 4-14.

Table 4-7: Water level stations

Station Name	Measurement Period	Longitude (deg. West)	Latitude (deg. North)
Otoque	07/08/02 – 09/12/02	79.61	8.61
Taboguilla	07/08/02 – 09/12/02	79.52	8.81
Mine Dock	05/01/02 – 09/12/02	79.54	8.92
Contadora	06/25/02 – 09/12/02	79.04	8.63

4.6.4 Current Measurements

During the period May-June 2002, ACP personnel carried out five current measurement campaigns in Panama Bay (ACP, 2002). Currents were measured in a number of points along three different transects: A – Rio Pacora, B – New Island and C – Punta Chame. The measurement locations along each transect are shown in Figure 4-15. The campaigns were designed with the aim of measuring the currents in the Bay at different tidal phases. Table 4-8 provides the date and the tidal phase covered by each of the measurement campaigns.

Table 4-8: ACP Current Measurement Campaign, (2002)

Date	Tidal Phase	Tidal Range at Balboa (m.)	Transects measured
12,13 and 14 May, 2002	Small Spring Tide	4.65	A, B and C
19,20 and 21 May, 2002	Neap Tide	3.40	A, B and C
27 May, 2002	Spring Tide	5.26	B
3, 4 and 7 June, 2002	Neap Tide	2.56	A, B and C
23, 24 and 25 June, 2002	Spring Tide	4.98	A, B and C

During each measurement series, the objective was to observe the currents at each location for High. Ebb, Low and Flood tide stages. In addition, currents were measured near the surface at each location and at mid depth and near the bottom. At each depth, the current speed and direction were measured five times, with a minute separation between consecutive measurements. The mean and standard deviation was then computed from the five measurements, thereby providing a better estimate of the current conditions measured than a single value.

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5 ENVIRONMENTAL CHARACTERIZATION

5.1 Background

In order to establish a baseline condition for the environmental assessment of various island locations and long term development options, a data search was made of previous reports, papers and publications on the area within and surrounding the study area of interest. In addition, a water quality and marine sediments field sampling program was undertaken in early 2003 to provide benchmark values for the environmental assessment of a series of marine disposal options under the Pacific Side Excavation and Dredging Material Disposal Study mentioned earlier.

The information provided under this parallel study is directly pertinent to the environmental evaluation of the Artificial Island project and is therefore described in the following sections. For a more detailed explanation of the Marine Field studies and results of the analyses, the reader is referred to Appendix E of this report.

5.2 Environmental Field Investigations

Environmental baseline studies of the marine area were undertaken as part of the Disposal Options study in parallel with the island study. The field work undertaken for the project was carried out in early 2003 and included water quality sampling, bottom samples and laboratory analyses at the locations indicated in Figure 5-1.

5.2.1 Water Quality and Marine Data Collection

The marine team conducted coastal intertidal and offshore studies of the potential areas for marine disposal. In intertidal areas the studies included:

- Collection of benthic organisms
- Collection of water quality parameters
- Observations of the general coastal characteristics of the study areas.

In open water areas the environmental studies consisted of collections of zooplankton , phytoplankton and benthic organisms. Samples were obtained at six sampling stations, selected to typify conditions outside and within the study area.

Diurnal and nocturnal collections were conducted at all of the six areas identified in Figure 5-1. At each sampling station a minimum of three zooplankton samples, three phytoplankton samples, and two water quality samples were obtained. A total of 48 samples were obtained.

These surveys included:

- Surface plankton samples (zooplankton and phytoplankton)
- Surface and subsurface water quality samples
- Benthic and sediment samples

The collected samples were preserved in-situ and sent to laboratories at the University of Panama for analysis.

Due to the limited timeframe of the Disposal Alternatives Study, only results of environmental conditions during the dry season were evaluated. Should the island project move ahead beyond this feasibility level of analysis, it is important that this initial information collection program be extended to cover the rainy season as part of the environmental impact assessment (EIA) study for the project.

5.2.2 Marine Habitat Evaluation

Marine habitat evaluation was conducted visually in coastal areas of Palo Seco, Kobbe, El Chorrillo, and Farfan during low and high tides, via the analysis of sediment granulometry and existing secondary data. Coastal habitat evaluations included rocky and sandy intertidal areas.

A marine sampling program was also undertaken, with the location of the sampling sites designed to characterize the area covering all of the alternative locations for the marine disposal options identified at the time the surveys were being undertaken.

Figure 5-1: Location of marine sampling stations

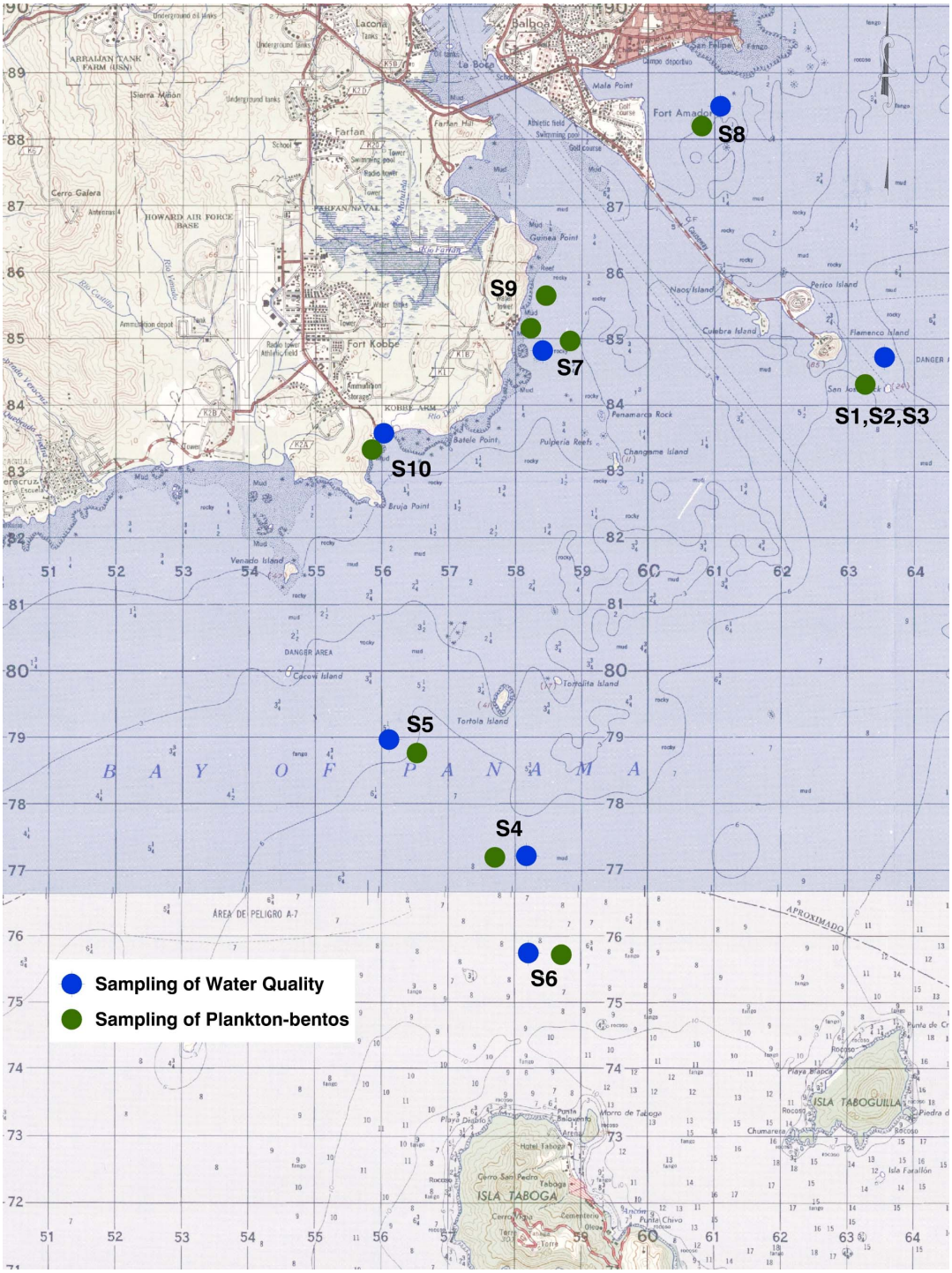


Table 5-1:: Area and date of data collection of the first study.

AREA	DATE OF DIURNAL DATA COLLECTION	DATE OF NOCTURNAL DATA COLLECTION
Causeway	28/01/03	07/02/03
Site 2	29/01/03	06/02/03
Chorrillo	28/01/03	07/02/03
Site 15	30/01/03	07/02/03
Artificial Island	29/01/03	06/02/03
Fishing Site	30/01/03	07/02/03

The second study included six stations of diurnal and nocturnal data collection during the month of February, at similar locations and following geographical coordinates (Table 5-2). The position of the data collection stations was determined using a GPS (Global Positioning System) with a precision of 50 to 100 meters.

Table 5-2: Area and coordinates of data collection for the second study

LOCATION	COORDINATES (UTM)	
	EASTING	NORTHING
Causeway	662321	984382
Site 15	659565	977170
Artificial Island	655906	980695
Fishing Site	658061	974411
Site 2	658507	9844009
Chorrillo	661088	987809

5.3 General Characterization of Panama Bay

As described in Section 4.5, Panama Bay and nearby areas are located within the zone of influence of north winds. These winds move across the isthmus during the dry season, breaking the stratification of the water column and bringing deep waters, characterized by their low temperature, high salinity, high concentration of nutrients, strong reduction in transparency and reduced levels of dissolved oxygen, to the surface. This leads to a high level of biological productivity and stimulates plankton production. During the rainy season, run-off waters and drainage from the rivers and streams draining into the Bay produce an increase in water temperature, reduction in the levels of salinity and elevation of nitrates and silicates.

The high level of contamination from organic matter in front of Panama City and near the entrance to the Canal presents a strong biochemical oxygen demand (BOD), reducing the levels of dissolved oxygen. This is in addition to the presence of hydrocarbons and contamination resulting from wastewater discharges from around the study area.

Important marine communities in Panama Bay include coral reefs, mangroves and benthic or pelagic fishing communities. According to recent research by ANCON and the Universidad de Panamá, there are no known sea-grass prairies in the Pacific coast of the Panama Canal.

Coral Reefs

Until recently, coral communities existed close to the entrance to the Panama Canal near the islands of Taboga, Urabá,Taboguilla and Otoque. However, the pollution in the area, as well as the increase in suspended sediments and the consequent deterioration of the water quality have caused continuous harm to the coral reef population. In the area around the Canal, only a few representative communities remain around Taboga and Urabá islands. Currently, the only coral reef population known in the Eastern Pacific, and endemic to Panamá, is the species *Siderastrea glynni*, which has been observed around the Island of Urabá.

Mangroves

Typical mangrove communities are located in Perequete, Caimito, Veracruz, Balboa, and Juan Díaz. These are important ecosystems that attract local marine species like *anchovetas* and *camarones peneidos*. Among the communities associated with these mangroves are algae, invertebrates, birds, mammals, larva and young fish.

Mangroves offer protection and source of nourishment for the biotic community previously mentioned. Studies conducted by D'Croz et al. (1976), D'Croz, L., and Kwiecinski, B. (1980), indicate the presence of eight species of shrimp inhabiting among its roots.

According to D'Croz, the species known as white shrimp or prawns (*Penaeus occidentalis, P. stylirostris,* y *P. vannamei*) are the most abundant in the mangroves. The young stages remain there for a long time, and as adults they migrate to deeper waters of Panama Bay.

Other common species in the mangroves include the *mojarra* (*Eucinostomus californiensis*), the *anchoveta* (*Anchoa panamensis*), and the false *anchoveta* (*Cetengraulis mysticetus*) that is used for fish flour production (Bayliff, 1966). The young stages of the false *anchoveta* get nourishment mainly food filtered in the pelagic zone, while the adult phases are mostly *iliófagos*, but also feed on plankton (Bayliff, 1966). The *anchoveta* is known for spawning in front of the coast of Juan Díaz and Panamá Viejo (D'Croz,).

The economic importance of the mangrove ecosystems was estimated by D'Croz, L. and Kwiecinski, B. (1980). Anchoveta fishing and shrimp fishing were estimated to produce $65,164 per km and $26,350 per km, respectively. Other common species in artisan fishing include corvine Iona (Micropogon sp.), pargos (Lutjanus sp.) and robalos (Centropomus sp) and were each estimated to produce $3,100 per km. While these values are expressed in 1980 currency, their purpose is to demonstrate the economic significance of the mangroves in the Panama Bay.

Coastal birds and marine mammals

Information obtained from Adrián Carrillo (Office of the National Authority of the Environment in Taboga) in an interview on June 26, 2002, reveals that the coastal life around the island of Taboga is very rich and includes a 252 hectare wildlife refuge with 55,000 to 70,000 birds which nest in the southwest corner of the island. The majority of these birds include pelicans and paticuervos. Both species feed in the Bay waters and near the entrance to the Panama Canal. Mr. Carrillo also indicated that humpback whales come close to the island between June and September, but do not stay longer due to the presence of humans and ships to the east, which generate noise disturbances. Other marine mammals present in the zone include dolphins.

Benthic organisms

The factors that influence the water quality may also have a negative effect on plankton larvae communities, whose adult stages are also of economic importance. Some examples are the post-larvae shrimp such as *Penaeus occidentales, P. stylorostis* and *P. vannamai.*

The most common benthic organisms found in sediment samples of the Canal area include the polychaets, crustaceans and molluscs; which comprise almost 90% of the biological communities in these habitats. Many of these organisms are commonly used as biological indicators in environmental studies.

5.4 Water Quality and Marine Data Studies

Two marine sampling studies were performed in the overall study area. The first session took place during 2002 while the second was carried out between February and March of 2003. Diurnal and nocturnal collections were conducted at the areas identified in Figure 5-1 for the collection of water quality, zooplankton and phytoplankton samples. Water quality and zooplankton data are available for the first study, while water quality, zooplankton and phytoplankton data are available for the second. Benthic and sediment samples were taken at the same open water sites indicated in Figure 5-1 but also included sites at Palo Seco and Kobbe Beaches.

The collected samples were sent to laboratories at the University of Panama for analysis. At the laboratory, the samples were homogenized and a sample-drop deposited over a microscope slide for analysis. The equipment used included an Olympus differential contrast microscope (Model BX50) with an attached 35mm Olympus camera and PM-30 exposure control. All identified species were recorded. Those with no clear identification were photographed and preserved for further analysis. Water quality sampling did not include biological oxygen demand or nutrients, since these are evaluated by ACP on a regular basis. Due to the limited timeframe of this study, only results of environmental conditions during the dry season were evaluated. This information should be complemented with an additional set of samples to be collected during the rainy season as part of the environmental impact assessment (EIA) study if required.

A full report with detailed results of each study is presented in Appendix E to this report.

5.4.1 Water Quality Sampling

First Study

Physical and chemical parameters of the study sites are provided in Table 5-3 The diurnal surface temperature varied from 24.4 ºC at the Causeway to 25.05 ºC at the Fishing Site. The greatest amount of suspended solids (34.06 mg/L) and the greatest degree of salinity (35.1 0/00) were also found at the Fishing Site.

Table 5-3: Physical-Chemical Parameters at the Data Collection Sites.

Site	Diurnal Temperature (°C)	Salinity (o/oo)	Suspended Solids (mg/L)
Causeway	24.40	34.05	33.13
Site 2	24.27	34.24	33.30
Chorrillo	24.84	33.89	33.01
Site 15	24.83	34.94	33.92
Artificial Island	24.53	34.09	33.17
Fishing Site	25.05	35.10	34.06

Note: No nocturnal physio-chemical data was collected during the first set of field studies.

Second Study

Based on the data from the physical-chemical parameters provided by the collection group, (Table 5-4), the surface temperature cited during the day for the entire study area ranged from 25.1 ºC at Site 2 to 27.9 ºC at the Causeway. At night, the temperature fluctuated between 24 to 25 ºC. These values were recorded at the Artificial Island and at El Chorrillo, respectively. The highest turbidity was registered at Site 2 during the day (10.2 NTU), and the lowest turbidity was obtained at night at the Fishing Site (2 NTU). The highest oxygen levels were also obtained at the Fishing Site (8.5 mg/L). The extreme salinity records ranged from 31‰ at Site 2 during the day to 37‰ at El Chorrillo at night.

Table 5-4: Physical-Chemical Parameters at the Data Collection Sites.

Site	Type of Collection	Temperature (ºC)	Turbidity (NTU)	Oxygen Level (mg/L)	Salinity (‰)
Causeway	Diurnal	27.9	2.6	5.9	34.0
Causeway	Nocturnal	25.6	4.7	6.1	36.0
Site 15	Diurnal	26.7	1.7	6.7	35.0
Site 15	Nocturnal	25.0	1.9	7.8	33.1
Artificial Island	Diurnal	26.4	2.5	6.9	32.0
Artificial Island	Nocturnal	24.0	4.3	6.4	31.9
Fishing Site	Diurnal	26.3	2.1	6.9	33.0
Fishing Site	Nocturnal	25.2	2.0	8.5	33.4
Site 2	Diurnal	25.1	10.2	5.2	31.0
Site 2	Nocturnal	24.7	8.3	6.4	31.2
Chorrillo	Diurnal	26.8	3.1	6.8	35.0
Chorrillo	Nocturnal	25.8	10.0	5.3	37.0

Summary and Conclusions

The values for temperature, salinity and suspended solids obtained during the first study were homogeneous throughout the entire study area and cannot be used to characterize each site and establish a correlation to the collected organisms at each site.

The decrease in temperature, increase in salinity above 30 ‰ and the elevated concentration of oxygen shown in the second study are typical patterns caused by upwelling in the study area. D'Croz *et* al (2003) show that upwelling in the Gulf of Panama occurs in waves, 70% of which takes place between January and February.

Previous studies have indicated that the changes caused in the plankton communities during upwelling are affected by the temperature and assimilation of chemical species (nutrients). This is consistent with the abundance of organisms (copepods, in particular) recorded in the study area.

5.4.2 Zooplankton

First Study

Table 5-5 shows the average density of zooplankton organisms at each site. The greatest density was recorded during the night at El Chorrillo (5,987,826.00 org/m^3). The greatest diurnal density also occurred at El Chorrillo (249,753 org/m^3).

Table 5-5: Density of Organisms (org/m^3) N=1

Site	Type of Collection	Density (organisms/m^3)	
		Mean	±SEM
Causeway	Diurnal	55,252.46	3,665.40
Causeway	Nocturnal	279,171.30	1,499.87
Site 2	Diurnal	2,824.11	107.72
Site 2	Nocturnal	33,936.12	1,153.10
Chorrillo	Diurnal	249,753.10	24,169.65
Chorrillo	Nocturnal	5,987,826.00	17,957,430.00
Site 15	Diurnal	12,467.06	2,067.88
Site 15	Nocturnal	3,841,729.00	104,999.00
Artificial Island	Diurnal	49,724.23	14,311.54
Artificial Island	Nocturnal	38,431.39	17,848.89
Fishing Site	Diurnal	6,262.93	517.12
Fishing Site	Nocturnal	2,576,471.00	311,307.70

A total of 26 taxa were identified. Copepods represented approximately 58.19 % of the total density of organisms collected during the day, with the greatest number recorded at El Chorrillo during the night. Calanoid copepods were the most abundant group and the dominant species, followed by Cladoceros and Chaetognatha. The Fishing Site had the widest variety of taxa, where a total of 15 taxa were found.

The density of fish eggs at night was highest at Site 15 (811,169.01 org/m^3). This value is an order of magnitude greater than diurnal values of fish egg density. The greatest density of fish larvae during the diurnal and nocturnal collections was recorded at El Chorrillo (3,718.41 org/m^3). At the Artificial Island, a total of 385 larvae were recorded during the day. In the rest of the collection sites, no fish larvae were reported during the day. The most abundant larvae were Scianidae, Engraulidae, Gobiidae and Haemulidae.

The mean biomass values at each site are represented in Table 5-6. The nocturnal biomass samples ranged from 0.26 mg/m^3 at Site 15 to 3.96 mg/m^3 at El Chorrillo. The diurnal biomass samples ranged from 0.12 mg/m^3 at Site 15 to 1.64 mg/m^3at the Causeway.

Table 5-6: Biomass Values for Diurnal and Nocturnal Collections.

Site	Type of Collection	Dry weight (mg/m^3)
Causeway	Diurnal	1.64
Causeway	Nocturnal	3.92
Site 2	Diurnal	0.32
Site 2	Nocturnal	1.38
Chorrillo	Diurnal	0.38
Chorrillo	Nocturnal	3.96
Site 15	Diurnal	0.12
Site 15	Nocturnal	0.26
Artificial Island	Diurnal	0.42
Artificial Island	Nocturnal	3.78
Fishing Site	Diurnal	0.52
Fishing Site	Nocturnal	0.80

Second Study

Table 5-7 shows the average density of zooplankton organisms and the mean biomass at each site surveyed in the second study. The greatest density was recorded at night at El Chorrillo (302,044.65 org/m^3) and is far greater than those at other sites. The greatest diurnal density occurred at Site 2 (123,076.33 org/m^3). The mean dry biomass for nocturnal samples was between 0.13 and 1.50 mg/m^3. The greatest biomass was obtained during the nocturnal period at El Chorrillo (1.50 mg/m^3). The mean biomass for diurnal samples was between 0.37 and 0.52 mg/m^3. The greatest diurnal biomass was recorded at the Artificial Island.

Table 5-7: Properties of Planktonic Organisms (org/m^3) N=3

Site	Type of Collection	Density (organisms/m^3)		Dry weight (mg/m^3)		Ash weight (mg/m^3)	
		Mean	± SEM	Mean	± SEM	Mean	± SEM
Causeway	Diurnal	33,790.65	6,852.03	0.37	0.07	0.07	0.02
Causeway	Nocturnal	149,756.18	49,115.26	0.67	0.04	0.17	0.02
Site 15	Diurnal	18,816.15	1,332.25	0.47	0.04	0.10	0.02
Site 15	Nocturnal	4,421.55	913.24	0.11	0.01	0.05	0.02
Artificial Island	Diurnal	73,049.28	18,729.28	0.52	0.04	0.11	0.01
Artificial Island	Nocturnal	15,572.77	3,067.96	0.27	0.02	0.79	0.46
Fishing Site	Diurnal	21,983.83	7,688.89	0.47	0.03	0.13	0.02
Fishing Site	Nocturnal	5,228.61	1,480.94	0.13	0.02	0.03	0.01
Site 2	Diurnal	123,076.33	66,738.75	0.50	0.07	0.12	0.01
Site 2	Nocturnal	35,162.04	10,591.48	1.07	0.16	0.28	0.08
Chorrillo	Diurnal	22,934.36	4,094.61	0.38	0.04	0.08	0.01
Chorrillo	Nocturnal	302,044.65	107,848.50	1.50	0.01	0.31	0.01

A total of 31 taxa were identified, where copepods represented approximately 66.4% of the total density of organisms collected during the day and 65.0% of that collected at night. The site with the widest variety of taxa during nocturnal sampling was the Causeway (18 taxa). Site 2 and El Chorrillo had the widest variety of taxa during diurnal sampling, each containing 13 taxa. Site 2 had the greatest diurnal density of organisms, and El Chorrillo had the greatest nocturnal density.

The density of fish eggs and fish larvae at night was greatest at El Chorrillo (25,711 org/m^3). During the day, the highest density of fish eggs and larvae was recorded at Site 2 (5,833 org/m^3). At Site 15 and the Fishing Site no fish larvae were reported. This could be attributed to timing in sampling. At the Causeway, the larvae identified were Engraulidae (anchovies), Gobiesocidae (a typical reef group), Polynemidae and Paralichthydae (soft bottom group). At El Chorrillo and the Artificial Island the larvae were Engraulidae.

At Site 2, the reported larvae were Carangidae and Gobiidae. The presence of species of various habitat types (pelagic, reef bottoms, sandy bottoms) is an indication of the coastal dispersion of these larval stages.

Summary and Conclusions

In the first study, the greatest concentration of zooplankton seems to have occurred at El Chorrillo. However, some values at the collection sites do not agree with values obtained for the zone in other studies. For example, the number of larvae was expected to be greater at night than during the day, but the data showed the opposite. The discrepancy in the data could be due to several factors, among them being error in the measurement of the flux meter. The collected samples were also saturated with phytoplankton, indicating that a net was probably used to collect the zooplankton. Furthermore, the small sample size of the study may have also distorted the interpretation of the results.

In the second study, the majority of organisms found at the collection sites was common for the coastal region and consistent with the continental platform and with those reported in other studies. The greatest percentage of density of zooplankton was calanoid copepods. Cladoceros copepods and chaetognatha were the most abundant organisms, specifically during the day at Site 2 and at night at El Chorrillo. Both of these sites are located in coastal areas and provide an insight on the importance of coastal hydrological processes and their potential influence on commercial fisheries. Sites near the coast showed to be more productive than sites offshore given the former's greater density of zooplankton. Conversely, during the day, the density of zooplankton at sites near the coast was lower than the density of sites offshore. However, the number of organisms was higher for the sites near the shore both during the day and at night.

The consistent values for dry biomass (0.37 to 0.52 mg/m^3) found at all collection sites can be the result of the uniformity in the physical-chemical parameters of the area. However, these values are very low compared to those presented by Morales (2002, in press), which shows that the total dry biomass of zooplankton for the summer season in the Gulf of Nicoya, can be between 18.2 and 22. 69 mg/m^3. It is likely that the low biomass values found in this study can be strongly related to the quality of the plankton, the season and the type of net used at the time of collection.

The low number of taxa reported in the second study is an indication that the zooplankton fauna is relatively poor when compared to more productive areas in the region. The predominance of copepods is consistent with studies conducted by Morales & Brugnoli (2001) indicating that copepods were the most abundant group of zooplankton in the area of Punta Morales.

The differences between zooplankton communities in a region may be due to the fact that the structure of a community (Gómez *et al*., 1995) varies as a function of hydrographic region and seasons (McGowan & Miller, 1980). Therefore, the distribution, diversity, and density of organisms in zooplankton communities depend on seasonal variations and the tolerance of these organisms to environmental factors (Hernández-Trujillo, 1989c).

The reduction or absence of fish eggs and larvae at Site 15 and the Fishing Site may be attributed to the sites' proximity to the area of ship transit in the Panama Canal. The density of eggs found in the Causeway coincides with the figures reported by Gómez (1994) in a station near the entrance to the Canal, where the density was low due to the high salinity of the area (34 and 36%). Simpson (1959) indicates that Engraulidae *Cetengraulis mysticetus* lays eggs in areas with low salinity where the Panama Canal enters the Pacific Ocean, and their abundance is greater during the rainy season.

From an analysis of diversity indices, each site demonstrated homogeneity in its individual population of zooplankton macro-fauna. When comparing taxa found across sites, the sites appeared to be divided into two groups. Site 15, the Artificial Island, the Fishing Site, and Site 2 constitute one group considered to be oceanic in nature. The Causeway and El Chorrillo compose the second group defined by coastal characteristics. Statistical differences were found in the density of zooplankton organisms across the interaction of sites and collection periods. This suggests that the zooplankton community residing in the Panama Bay is typical, demonstrating vertical movement and migration concentrated at coastal sites.

5.4.3 Phytoplankton

Second Study

During this study, 115 microalgae taxa were identified, 91 of which were diatoms (Bacilloriophyceae) divided into 39 genera. In addition, 24 taxa of dinoflagellates grouped into 10 genera were also identified. Table EA-5 and Table EA-6 in Appendix E show that the most common species among diatoms were: *Chaetoceros anastomosans*, *Chaetoceros lorenzianus*, *Chaetoceros socialis*, *Coscinodiscus* spp, *Proboscia alata*, and *Pseudonotzschia pungens*. *Pyrophacus horologium, Noctiluca scintillans*, *Peridinium* cf. *granii*, *Ceratium furca* and *Ceratium tripos,* are the taxa dominating the dinoflagellates present in the samples.

In general, the frequency in diatoms was not specific to a certain collection period. On the other hand, dinoflagellates showed higher frequencies and more cells per species in diurnal samples than in nocturnal samples, except for *Pyrophacus horologicum*, which showed high frequencies in nocturnal samples taken from the Causeway.

Table 5-8 compares the number of species collected at certain sites and collection periods across seasons (winter and summer). The average number of species found in the summer samples was slightly lower than the average number of species found in the winter samples. In contrast, studies conducted in the same geographic area during winter months showed lower numbers of organisms than those samples collected during the summer.

Some species abundant in the summer samples such as *Pyrophacus horologium*, *Noctiluca scintillans*, *Chaetoceros anastomosans* and *Chaetoceros socialis*, were not observed in the winter samples, while other species were equally abundant in the summer and winter. The analyses of the samples collected during the month of February showed a higher number of species and of individuals per species than samples collected during the month of January

Table 5-8: Number of Species Collected in Summer (January-February) and Winter (June-August) at Common Sampling Sites

Site/Samples	Number of Species	
	Winter	Summer
Causeway diurnal (ACP 4)	37	42
Artificial Island diurnal (ACP 5)	42	39
Artificial Island nocturnal (ACP 6)	32	35
Fishing Site diurnal (ACP 7)	46	35
Fishing Site nocturnal (ACP 14)	51	34

Species present at most of the sampling sites for this study included Coscinodiscus spp, Proboscia alata, Pseudonitzschia pungens, Chaetoceros curvisetus, Pseudosolenia calcar avis, Ceratium furca, Noctiluca scintillans and Pyrophacus horologium. In general, all samples contained diatoms or dinoflagellates.

5.4.4 Benthos

Background

In marine coastal zones environmental parameters vary widely due to factors such as proximity to land or altered levels of salinity and water clarity resulting from periods of rain and drought. Among the environmental parameters frequently affected is water clarity. The reduction in water clarity produces alterations in the structure of biotic communities.

On one hand, phytoplankton is favored by the presence of nutrient-rich suspended particles. At the same time, an increase in the phytoplankton populations reduces the penetration of sunlight in the water column.

At the deepest portions of the water column, an elevated concentration of suspended sediments may also modify the benthic communities; mainly because of the negative effect suspended sediments have on the filtering organisms. If the re-suspension of sediments is elevated and the filtering organisms are unable to eliminate the excess particles on their filtering organs, it could adversely affect the biological communities at all trophic levels. On the other hand, if the re-suspended sediments contain a high concentration of organic material (mainly from domestic waste) or contaminated compounds (hydrocarbons, pesticides, industrial, etc) environmental risk increases. Decomposing organic material requires the consumption of oxygen, creating anoxic zones that hamper the development of macroscopic life. These conditions allow only for organisms adapted to living in those conditions making them typical bio-indicators of adverse environmental conditions. Some of these organisms include polychaets (*Capitella capitata*, *Heteromastus filiformis*) and *ulvanean* macroalgae.

The Panama Bay constitutes the most severe case of marine contamination in the country due to the untreated waters from the city producing elevated concentrations of fecal coliforms. In some areas there are levels that are 496 times higher than those established for water consumption and public recreation, and 50 times higher than those established for the proliferation of wildlife (D´Croz *et al*., 1991).

Study Area

The sampling sites were situated near shore and in oceanic areas. The sites near shore included west and east sides of Palo Seco Beach as well as Kobbe Beach. On Kobbe Beach and on the west side of Palo Seco samples were collected at high and low tides while on the east side of Palo Seco they were collected only during high tides. The samples were taken on January 9 and 10, 2003.

The sites located in open waters included the Causeway, Site 15, the Artificial Island, the Fishing Site, Site 2 and El Chorrillo. The oceanic samples were collected on February 10 and 11, 2003.

Methodology

At the beach, six sediment samples were taken, at each site with a 0.005 m diameter core sampler, obtaining a sample of approximately 6.25×10^{-4} m^3 of sediment. The material collected at each station was set in a plastic bag, labeled, and transported to the laboratory. The replicates were sifted through filters of 1.0 and 0.5 mm openings, where the organisms from the benthic macro fauna were separated, counted, and identified. The collected organisms were identified with a *stereoscopic* Nikon SM2-10ª microscope.

Results and Conclusions

A complete compilation of the results of the benthic collections can be found in Tables EA-7 through EA17 in Appendix E.

Overall, the sites offshore consisted of more diverse macro fauna than the sites on the beach, although the latter experienced higher densities of macro fauna. The 10 most abundant taxa found at the beach sites belonged to the Polychaet, Mollusc, or Crustacea group, all of which comprised nearly 80% of all the samples collected at the beach. Eight of the ten most dominant taxa found at the offshore sites were Polychaets, a group specialized in feeding off organic material from sediment. Polychaets are used as bio-indicators of pollution and/or physically perturbed areas. Additional studies during the EIA phase of this project will require extensive sampling of these organisms to obtain a clearer interpretation of the numbers found. The highest number of these organisms was found at the Artificial Island, the Fishing Site, Site 2, and East Palo Seco.

A detailed description of the macro fauna collected at each site is provided in Table 5-9. The Artificial Island had the widest variety of macro fauna with a reported 7 phyla and 28 taxa. The highest number of organisms was found at Site 2 (232). Polychaets were the most abundant group during low tide at the West Palo Seco station as well as at the Causeway, Site 15, the Artificial Island, Site 2 and El Chorrillo. Molluscs dominated the population of macro fauna at Kobbe Beach both during low and high tide. The majority of macro fauna at West Palo Seco during high tide and at East Palo Seco fell into the Crustacea group.

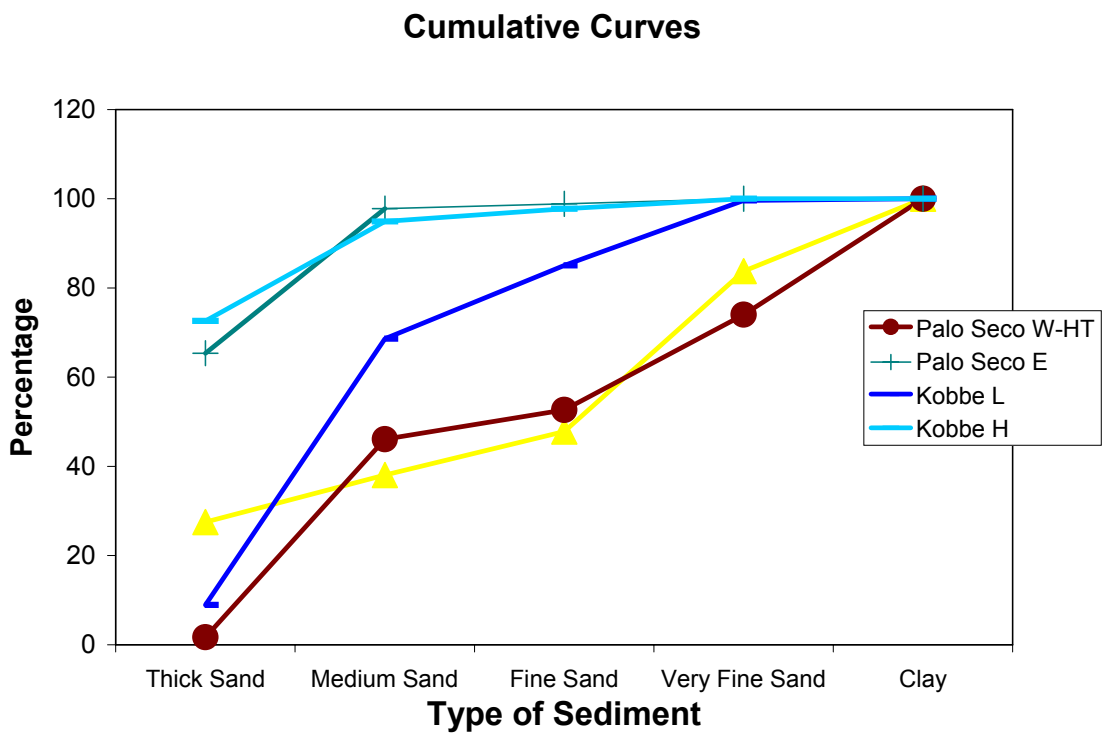
Through standardization of the results, samples collected at sites on the beach and offshore were easily compared. On average, the sites located at the beach had a density of 1,547 organisms per m^2 while sites offshore had a density of 490 organisms per m^2. The highest concentration of organisms was found at Kobbe Beach during high tide (2,633 org/m^2), and the lowest density of organisms occurred at Site 15 (201 org/m^2).

Table 5-9: List and abundance of the macrofauna collected at the 11 stations included in this study.

TAXA	Causeway	Site 15	Artificial Island	Fishing Site	Site 2	Chorrillo	W. Palo Seco-LT	W. Palo Seco - HT	E. Palo Seco	Kobbe-LT
Nematods		4	19	15	15	6				
Polychaets	34	26	96	69	194	45	14	4	15	6
Molluscs	7	4	4	2	29	14	3	11	16	27
Crustacea	7	11	9	31	22	3	6	23	18	8
Echiuras			8	4	4	2				
Equinodermata	2		1							2
Chordata			1			1				
TOTAL	51	45	138	122	232	72	23	38	49	43
TAXA	15	15	28	14	24	12	10	7	8	12

5.5 Marine Habitat Evaluation

The study of the granulometry of the sediment samples collected in Palo Seco and Kobbe Beach provides an insight into the biological abundance and specific taxonomic groups found in those areas.



The method for the granulometric analysis was based on the Webthmore scale. Thick sand corresponds to grain size ranging from 1.0 mm to 0.5 mm in size; medium sand 0.49 mm to 0.25 mm; fine sand 0.24 mm to 0.125 mm; very fine sand 0.124 mm to 0.062 mm; and clay particles smaller than 0.062 mm.

The analysis of sediment shows the presence of significantly larger grain size at Kobbe Beach and smaller clayish grain size at Palo Seco. This could be due to lower flow of currents in the protected area of Palo Seco Beach and the action of dredge material deposition and suspended sediment being carried “downstream” from the Canal.

Soft silts and muddy clays with rock outcrops typify the area surrounding the proposed artificial island site and neighboring islands. The soft silts serve as habitats for bottom-dwelling fish while the rock outcrops harbor marine life such as shrimp.

5.6 Area Fisheries

The fishing industry in Panama is very active on the Pacific coast, involving more than 10,000 persons. The predominant fishing resources include shrimp, *anchovetas* and *arenques* which produce yields that vary significantly from year to year (D'Croz *et al.*, 1994). These fluctuations have been attributed to variations in the density of annual water movement in the Gulf of Panama, or to the El Niño phenomenon, which affects all of the Gulf area. (Kwiecinski *et al.*, 1988).

At the icthyological level, plankton samples showed the presence of fish larvae (icthyioplankton) including *engraulidos, carangidos, mugilidos*, and *cianidos*, all of which are commercial species. Of importance to this project is the massive spawning of *anchovetas* (*Cetengraulis mysticetus*) that occurs in coastal areas in front of Juan Díaz and Panamá Viejo (Bayliff, 1966). The life cycle of this species is also directly associated with the presence of mangroves, which serves as spawning habitats for anchovetas. Consequently, the biological cycle of this species is completed in waters far away from the coast between Isla Melones and the entrance to the Canal, as well as in the areas of Punta Chame, where the adult stages congregate to feed on planktonic organisms found in the zone.

Studies of upwelling of algae and water mass movements in the Panama Bay (D'Croz, et. al. 1991), indicate that during the raining season there is a warm mass of water with a salinity of 30 $^{0}/_{0}$, low concentration of phosphates and chlorophyll, and low density of phytoplankton. In the dry season, there is an increase in the concentration of the these components. These changes are also evident in higher trophic levels accompanied by an increase in *anchoas, carangidos* and *escómbridos* fish schools, and marine birds such *pelícanos* and *cormoranes* (Glynn, 1972).

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6 REGIONAL ARCHAEOLOGICAL SETTING

6.1 Background

Important themes in Panamanian archaeology include:

- Paleoindian migration through the isthmus, ca. 13,000 cal BP, as evidenced by Clovis-like stone tools
- Forager adaptations to early Holocene environments
- Origins of tropical agriculture
- Development of chiefdoms
- Early Spanish colonial settlements and trade routes

The results of the recent STRI survey in the ROCC (western basin of the canal) (Griggs et al. 2001) indicate the kinds of Archaeological sites that can be anticipated in central Panama and the topographic settings where they are most likely to be identified. The most numerous sites found in the ROCC survey are small hamlets (caserios) dating from the Late Ceramic Period (AD 750-1650). Sites containing a newly recognized type of late prehistoric/early colonial period pottery (Limon ware) were concentrated along the Rio Cocle del Norte and Rio Toabre. One site with Limon ceramics was identified on the Rio Indio.

Another site located near the Rio Indio was Cantera Grande, Cp-62. Here, biface thinning flakes of chert indicate lithic reduction during the Paleoindian or early Preceramic periods (11,000-7000 radio-carbon bp). Also situated on the Rio Indio is Pn-53, a late Preceramic site with C^{14} dates of ca. 6600 cal BP on carbonized seeds. Small lithic flakes found in association with the dated material may have been used to process tubers.

Prehistoric Archaeological sites of this region are classified broadly into three topographic types:

- rockshelters
- hamlets located on upland flats and hilltops or gentle slopes near rivers or creeks (quebradas)
- extraction or processing sites located near deposits of valued stone (e.g., quartz) or gold. Some of the earliest colonial sites also occur near gold deposits.

6.2 Sites of Interest in the Study Area

Larger sites associated with late prehistoric chiefdoms have been found on the Pacific slope of Panama. It has been suggested that in the late prehistoric period a socio-political network called "Gran Cocle," centered in Cocle province, linked the populations of the Caribbean and Pacific slopes. The eastern boundary of this interaction sphere has been set (somewhat arbitrarily) about 50 km west of the Canal Zone. However, the Venado Beach site, located in the former Howard Air Force base, seems to have been related to the Cocle culture. Here was found evidence of a specialized workshop for manufacture of ornaments from marine shells (*Spondylus*). Unfortunately, more than 360 graves equipped with shell ornaments, gold artifacts, and painted pottery at Playa Venado were unsystematically excavated in the 1950s by members of the "Panama Archaeological Society."

Similar shell ornaments have been found by Cooke at the Cerro Juan Diaz site, located 200 km to the west, on the Azuero Peninsula. They are dated there to ca. AD 550-700. In both areas, the ornaments are associated with painted pottery of the Cubita style. Cooke et al. (2000) hypothesize that the manufacture of ornaments of subtidal inshore reef shells peaked during this period, and that this industry somehow was involved in the spread of the Gran Cocle tradition along the coast and on the islands in Panama Bay.

It should be noted that the corridor connecting the Excavation sites to the Artificial Island may pass through or adjacent to the Venado Beach area. Locations of ancillary facilities on this route should be investigated for archaeological resources prior to construction.

Although additional prehistoric sites were discovered on Engineer's Hill and other locations on the west bank of the canal in the 1970s, they have not been intensively investigated. Cooke (personal communication) regards the western edge of the canal as an archaeological *terra incognita*. No systematic surveys have ever been conducted there. In his opinion, it would be particularly important to recover prehistoric material from intact, datable stratified contexts in this area.

The submerged areas of the coastal shelf may be archaeologically significant since some 50 km of former dry land along the southern shore of Panama Bay has been inundated since the end of the Pleistocene era by rising sea levels. Relatively intact prehistoric sites may well be located offshore in the Gulf of Panama. Their degree of presentation would depend on various factors, such as the speed of inundation, nature of overlying sediments, strength and variability of local currents, etc. However, this inundated zone is so vast that the small potentially affected areas offshore are unlikely to contain uniquely significant sites that would merit the extraordinary effort needed to properly excavate them.

It should be noted that the “San Jose,” a Spanish treasure ship that sank in 1631 has been discovered recently near the Islas de Perlas. Other ships following the same route from the Peruvian ports may have gone down closer to shore. Lost gold-laden vessels have doubtless been the subject of both documentary research and exploratory dives for more than 300 years. However, vessels laden with more mundane cargoes, which have not been so strenuously sought after, may also lie undiscovered on the sea bottom in the general project area.

Side-scan sonar results from the geophysical surveys taken in January 2003 might be analyzed for signatures of wrecks in the project area. The data records did show materials deposited in the ACP dredged materials disposal sites and it is possible, though unlikely, that sonar might allow recognition of submerged shell middens associated with prehistoric occupations. Unfortunately, due to problems with the side scan equipment, it was not possible to obtain a full profiling of all of the survey tracks.

6.3 Summary

Once a preferred site has been selected for the island, it is recommended that the side scan sonar records be reviewed more closely in order to identify any areas or items of potential archaeological or cultural interest within the project area.

The area surrounding Playa Venado also warrants particular attention, because the rich graves found there probably were a ritual focus for people living in hamlets and villages in the vicinity around AD 600.

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7 METEOROLOGICAL & OCEANOGRAPHIC STUDIES

7.1 Pacific Ocean Wave Studies

The wave climate in the region of the potential island construction due to Pacific Ocean waves was evaluated using existing information in order to determine wave protection requirements and potential ship motion characteristics for marine terminal options. This analysis involved the development and evaluation of the offshore metocean data and the transformation of the offshore wave climate to the study region. An overview of the results of the evaluation is presented in this section and the reader is referred to Appendix F for a more complete discussion on the offshore and near shore wave climates.

Hindcast Methodology

A 31 year wave hindcast was obtained for the project from Oceanweather Inc., covering the period from early 1970 through the end of the year 2000. The hindcast process involves the collection of historical wind and wave data from a number of locations and the transfer of the wave data to a given site, based on wind data, bathymetry and physical characteristics of the study zone.

The hindcast used Oceanweather's Global Reanalysis of Ocean Waves (GROW) model to produce a time series of wave parameters at a location just offshore of the entrance to the Gulf of Panama. The global oceans covered in the GROW model are divided into a 0.625 by 1.25 degree latitude/longitude grid with wave and wind fields archived every three hours. In order to determine the offshore deepwater wave condition, the hindcast wave data were obtained for GROW2000 model grid point 30275, located at 6.875° latitude and 280.0° longitude, just offshore of the Gulf of Panama as shown in Figure 7-1 The model output included a time series of significant wave height, wave direction, and wave period every three hours for the entire 31 year period (1970-2000). This point was selected because it is located in an area that captures the wave climate from the predominant directions expected to impact the site.

Figure 7-1: Location of Deep Water Wave Model Grid Point

To allow for more direct analyses, the raw wave hindcast data were summarized by counting the number of occurrences of particular events within defined bins, or specific ranges of values. The wave data were grouped in 0.25 meter bins, the wave period data in 2 second bins, and the wave direction data in 5 degree bins. The frequency of occurrence of specific events was summarized monthly and annually. The monthly data consisted of the total occurrences of a particular event during a given month over the 31-year time series. The annual data were for all occurrences of a particular event over the entire 31-year time series. By grouping the data this way, it was possible to calculate percent occurrence and percent exceedance values for the different wave conditions.

Joint frequency tables are provided in Appendix F-Part A for the whole period of hindcast for the following pairs of variables:

- Significant wave height (Hs) by peak wave period (Tp)
- Peak wave period (Tp) by mean wave direction (degrees clockwise from North)
- Significant wave height (Hs) by mean wave direction

Offshore Wave Climate

As seen in Figure 7-1, wave energy can only reach the entrance to the Gulf of Panama from a restricted direction due to the geometric shape of the Gulf itself and the surrounding geography. The only significant wave energy that can affect the project site is from a window extending from south to west-southwest (180°–247.5°). The offshore fetch to the south is limited by the west coast of Ecuador which blocks some of the large swells that originate near the Antarctic. The Azuero Peninsular at the western edge of the entrance to the Gulf of Panama limits wave energy from the northwest to west.

The Pearl islands and other islands within the Gulf and the geometric configuration of Panama Bay also provide additional shelter from offshore waves. Consequently, any waves at the site generated from these restricted directions will primarily be the result of local winds, likely resulting in shorter period waves of limited height and energy.

Significant Wave Height

Figure 7-2 shows the percent occurrence of significant wave height monthly and annually. The graph illustrates that most significant wave heights are between 0.5 and 2.5 meters. Predominant wave heights are centered around 1.00 -1.25 m for the months of December to April and 1.50 -1.75 meters for the months of July to November.

Figure 7-2: Percent Occurrence of Significant Wave Height

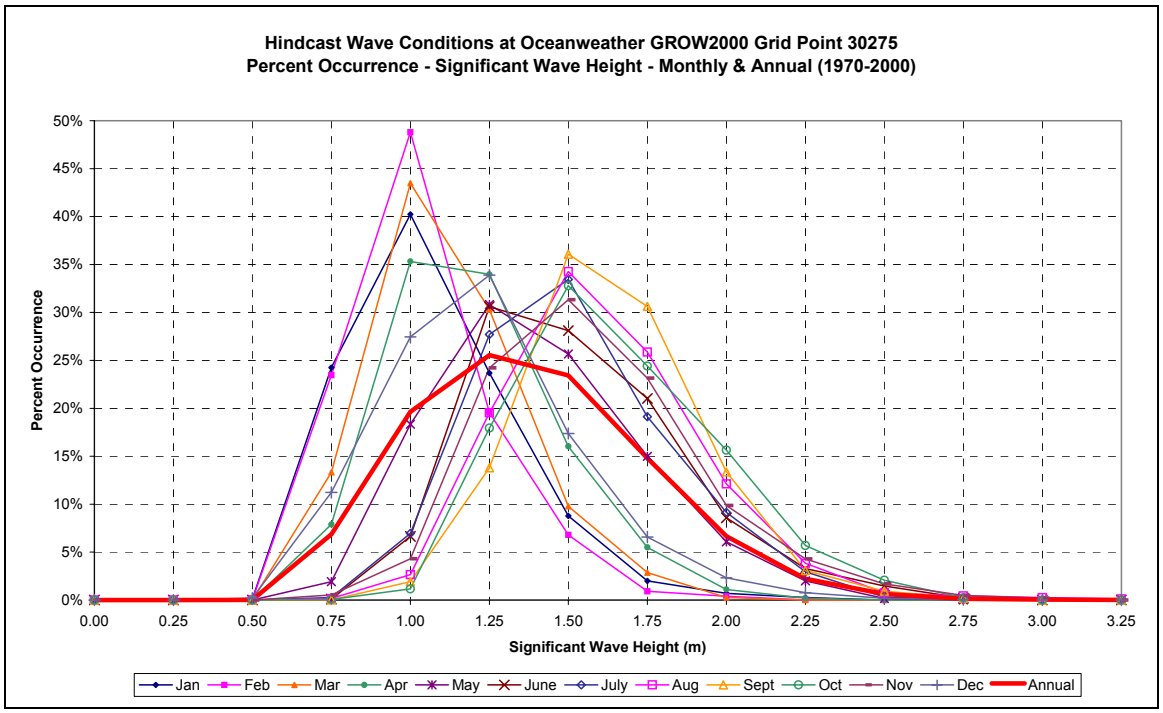
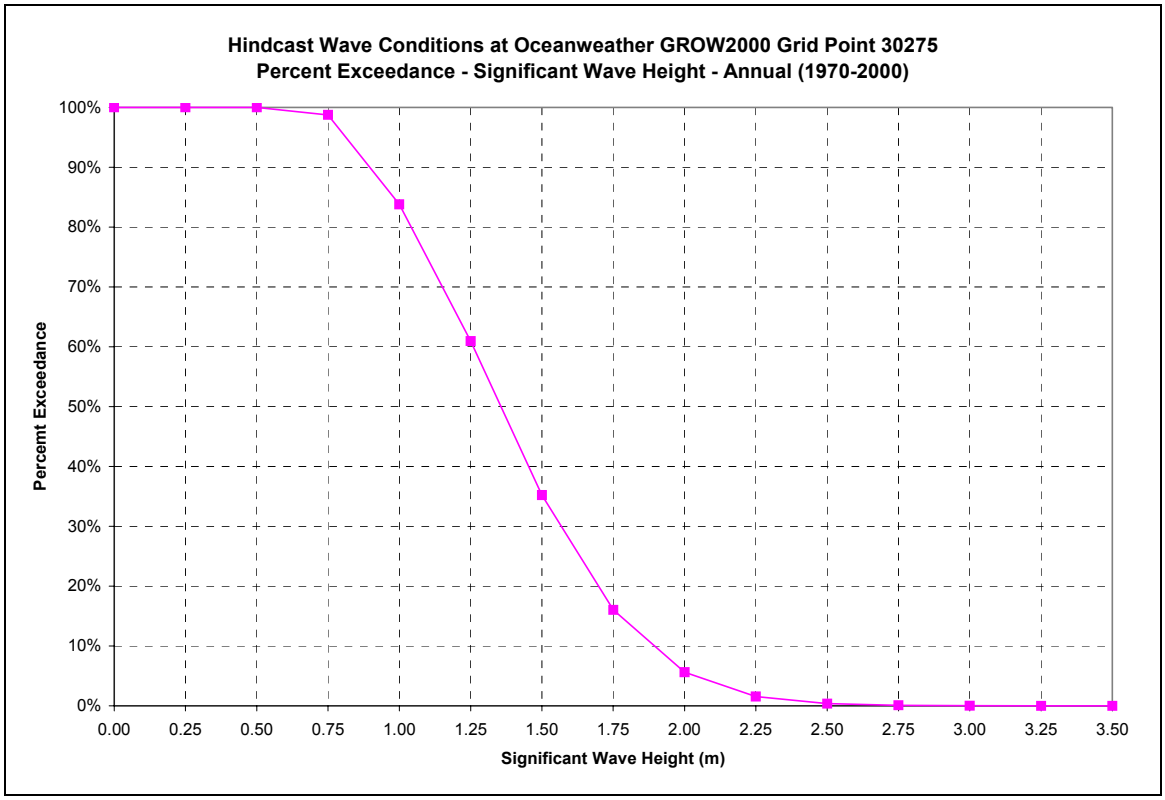


Figure 7-3 provides the deepwater wave exceedance curve for significant wave heights. From the figure, it can be seen that the offshore wave climate is relatively mild, with significant wave heights rarely exceeding 2 meters.

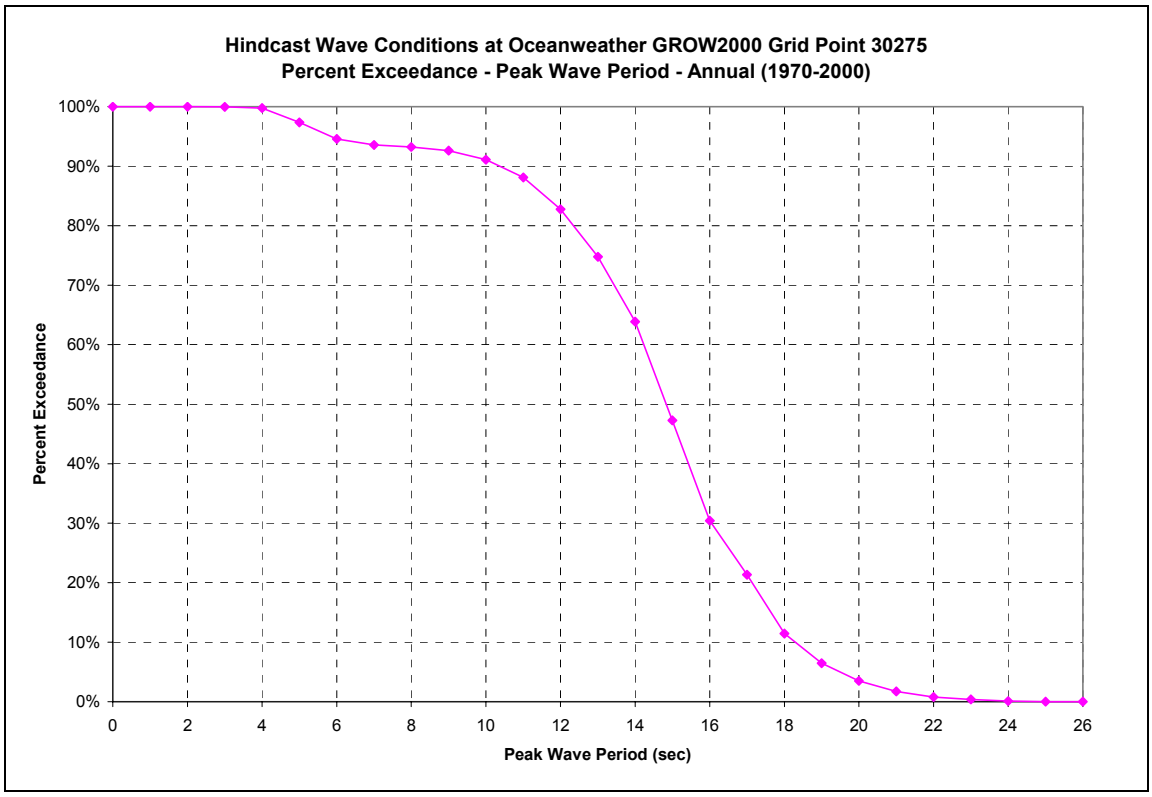
Figure 7-3: Percent Exceedance of Significant Wave Height



Wave Period

Figure 7-4 illustrates the percent exceedance of wave periods within the 31-year hindcast record. From the graph, it can be seen that over 80% of the peak offshore waves are of periods between 10 and 18 seconds.

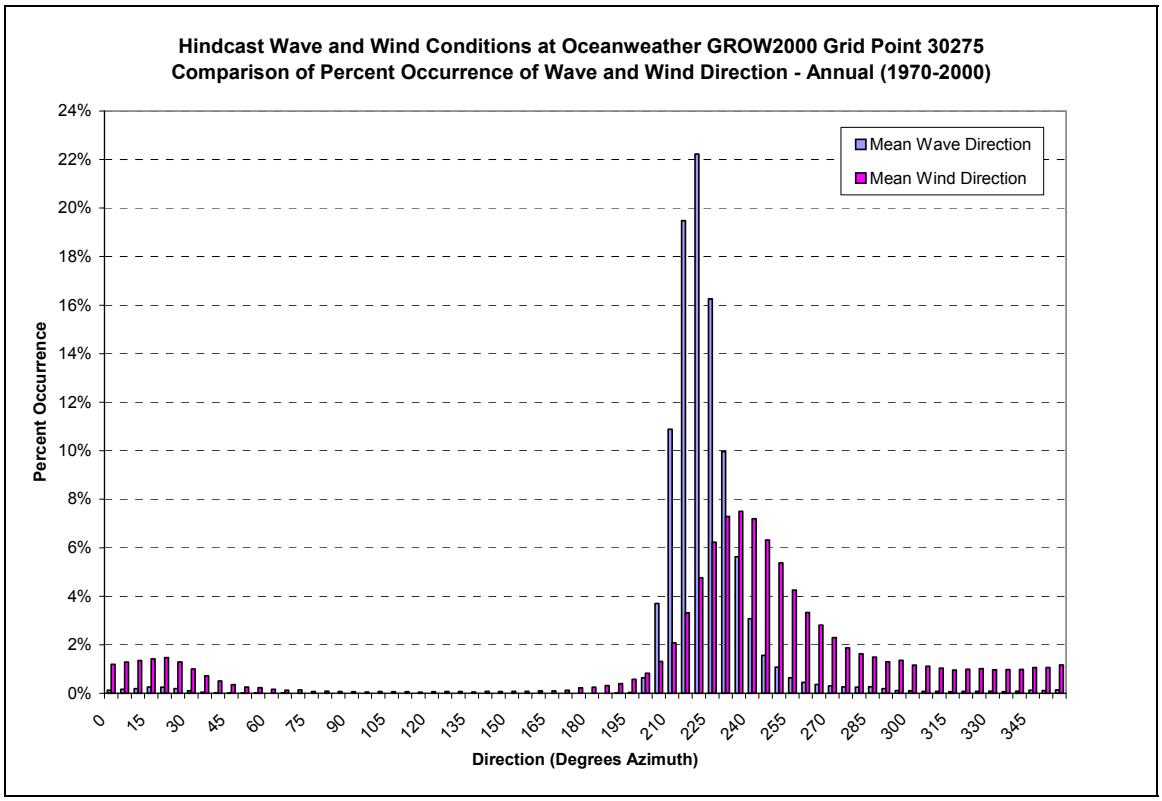
Figure 7-4: Percent Exceedance of Peak Wave Period



Wave and Wind Direction

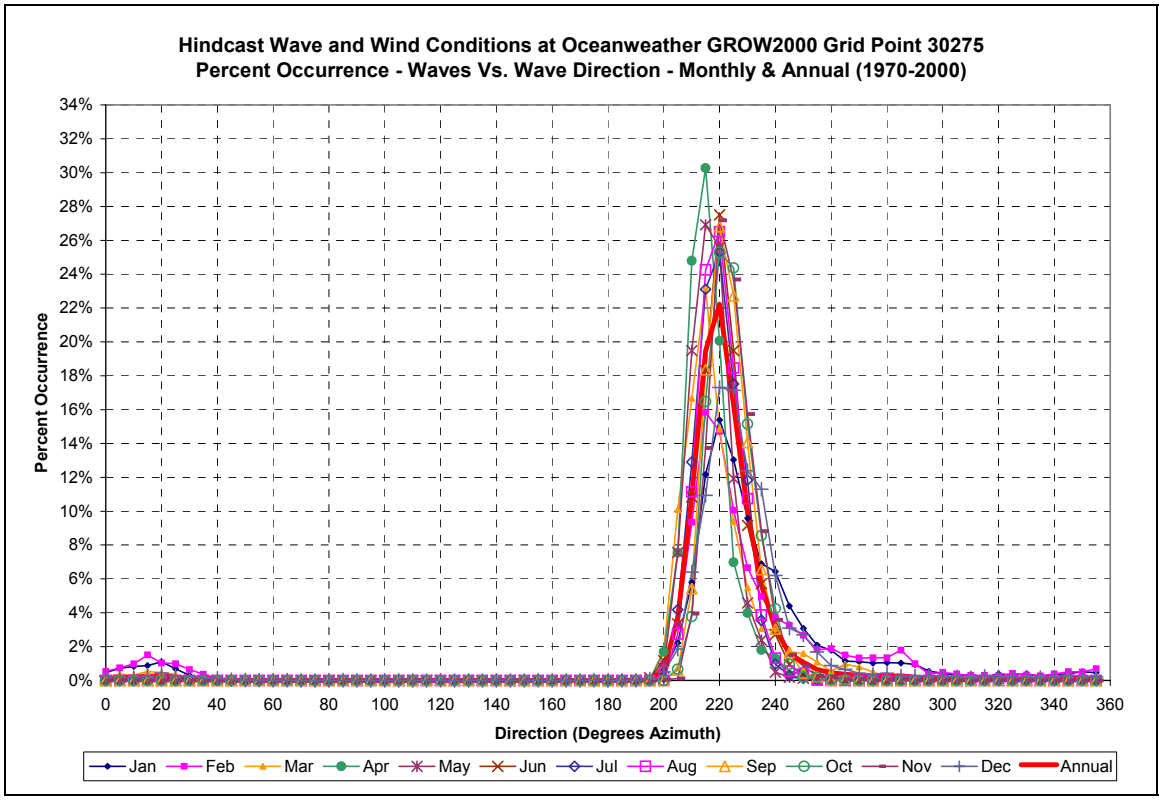
The relatively small range of offshore wave directions, limited by the geographic configuration of Central and South America, is clearly illustrated in Figure 7-5. Most waves arrive at the entrance to the Gulf of Panama from 200 to 250 degrees. The offshore hindcast wind field is slightly shifted from the mean wave directions and is more distributed. The wind is not constrained by the land configuration in the same manner as waves.

Figure 7-5: Percent Occurrence of Waves and Wind by Direction



The percent occurrences of waves by mean wave directions are graphed for monthly and annual conditions in Figure 7-6. This graph reveals little seasonal variation in the offshore wave direction.

Figure 7-6: Percent Occurrence of Waves vs. Wave Direction



Tides

Tidal ranges for stations within the Gulf of Panama were obtained from the British Admiralty Tide Tables and are presented in Table 7-1. The overall tidal range within the Gulf is approximately 4 to 5 meters.

Table 7-1: Astronomical Tide Level Characteristics within the Gulf of Panama

Location	LAT N	LONG W	Mean High Water Springs (MHWS)	Mean High Water Neap (MHWN)	Mean Sea Level (MSL)	Mean Low Water Neap (MLWN)	Mean Low Water Spring (MLWS)
Rio Chepo*	8°59'	79°07'W	4.8	3.9	2.5	1.2	0.2
Balboa*	8°57'	79°34'W	4.9	3.8	2.6	1.1	-0.1
Punta Garachine	8°05'	78°25'W	4.2	3.3	2.2	1.1	0.2
San Telmo Bay	8°18'	78°54'W	4.2	3.3	2.1	1.1	0.2
Bahia Pina	7°34'	78°11'W	4.1	3.2	2.1	1.1	0.2
Punta Malla	7°28'	80°00'W	3.3	2.4	1.7	0.9	0.1

*Permanent Tidal stations closest to project region

Tide levels referred to Chart Datum (m).

For this study, the wave transformation model was run at both MHWS and MLWS, with the high and low tidal elevations taken to be 4.8 meters and 0.2 meters respectively.

Extremal Wave Analysis

Return periods of 2, 5, 10, 20, 50 and 100 years were computed for significant wave height. The extreme analysis shown in Table 7-2 was based on annual maximum significant wave heights for the 31 year hindcast record and used a Type I (Gumble) distribution approach.

Table 7-2: Return Periods and Wave Heights

Return Period (years)	Significant Wave Height (m)
2	2.6
5	2.8
10	3.0
20	3.2
50	3.4
100	3.6

7.2 Wave Transformation Analysis

7.2.1 Methodology

As deepwater waves propagate toward shore and into shallower water, they are modified both in direction and height, due to interaction with the sea floor. It is important to quantify these transformation effects so that a deepwater wave climate may be adapted to describe the nearshore climate at the site of interest. A wave model was required to transfer the offshore wave climate to the project region (proposed vicinity of the artificial islands). Regional grids were developed to take waves of various periods from deepwater to the near-shore project region.

Using the offshore hindcast data, the waves were transformed to the project site to account for refraction, diffraction and shoaling effects from changes in the bathymetry as waves propagate from offshore to the shallower near-shore project region. The wave transformation processes of shoaling, refraction, and diffraction depend on the period of the wave. Refraction and diffraction also depend on the incident wave direction.

The process of diffraction around Punta Mala at the western edge of the entrance to the Gulf of Panama and diffraction around the islands prior to the study region plays a significant role in proper representation and modeling of the wave energy reaching the study area. It was therefore critical that a model was selected with the capabilities of accounting for diffraction. As a result, the Danish Hydraulic Institute, MIKE21 Parabolic Mild-Slope Model (PMS) was used for this study.

The MIKE21 Parabolic Mild-Slope Model (PMS) model is a parabolic linear refraction / diffraction model that takes into account the effects of refraction and shoaling due to varying depth, diffraction along the perpendicular to the predominant wave direction and energy dissipation due to bottom friction and wave breaking. It is based on a parabolic approximation to the elliptic mild-slope equation governing the refraction, shoaling, and diffraction of linear waves propagating over a gently sloping bathymetry.

The parabolic approximation simplifies the computation and is obtained by assuming waves travel in the x-direction and by neglecting diffraction along this direction. The parabolic approximation limits the allowable angle between the direction of wave propagation and the x-axis. Several techniques allowing for larger deviations in wave angle up to 60 degrees from the predominant wave direction are available within the PMS model (Padé's model and Kirby's Minimax model). The solution to the wave parameters is determined on a rectangular Cartesian grid using Crank-Nicolson finite difference techniques.

7.2.2 Bathymetry

The bathymetry data for the inshore wave analysis was obtained from nautical charts (Admiralty – Chart 1929: "Gulf of Panama" and Chart 1401: "Approaches to the Panama Canal") and the recently completed hydrographic survey of the study region[13]. Current data with higher resolution of the bathymetric information in the study region, especially near the site where the water depths are shallower and wave interaction with the seafloor is increased, provides improved results for wave transformation calculations. The bathymetry for the Gulf of Panama and study region was digitized from this data. All vertical data was referenced to Chart Datum, approximately Mean Low Water Springs (MLWS). From the bathymetry of the Gulf, a smaller model region was extracted as shown in Figure 7-7.

[13] ACP – January 2003

Figure 7-7: Inshore Wave Model Limits

INSERT FIGURE 3-1 from wave report

7.2.3 Modeling Approach

In order to transform the deepwater waves to those representing the nearshore wave climate at the site of interest, the offshore waves were divided into representative period-direction pairs. Each pair was propagated and transformed to calculate the wave climate within the study region. Refraction, shoaling, and diffraction were solved numerically over the model area by digitizing the bathymetry into an x-y grid and solving the governing equations at each grid point

The main output data are integral wave parameters such as wave height, peak wave period, and mean wave direction. A normalized unit incident wave, specified by wave period and direction, was modeled for each period-direction component. Grid spacing was selected to provide adequate resolution of the bathymetry and the waves within reasonable computer storage and processing requirements.

7.2.4 Modeled Wave Conditions

Wave model runs were performed for water depths corresponding to Mean Low Water Spring (MLWS) and Mean High Water Spring (MHWS), taken as 0.2 m and 4.8 m, respectively, above bathymetry datum (chart sounding datum). Based on the previous offshore wave climate analysis, wave periods from 6 to 20 seconds and wave directions from 200 to 240 degrees were chosen for the wave transformation model runs.

Unit wave heights were modeled for each wave period-direction pair with wave periods taken every 2 seconds and with a directional interval of 5 degrees. In order to provide relatively smooth model results and to more closely represent the natural variation of actual wave conditions, JONSWAP spectra with minor frequency and directional spreads were used to represent the offshore boundary wave conditions.

7.2.5 Modeling Region

As shown in Figure 7-7, the bathymetry grid for the modeling region was approximately 60 by 168 kilometers. From the larger Gulf of Panama bathymetry grid, a computational grid with uniform spacing in both the x and y-directions of 30 x 30 meters was interpolated and used to calculate transformation of the waves with periods of 14 to 20 seconds. This provided a minimum of 10 grid points per wavelength in deepwater and adequate resolution as the wavelengths are reduced in shallower water. The 12-second models were run using the bathymetry grid with a higher resolution of 20 X 20 meter grid spacing.

Figure 7-8 shows the initial model grids and the reduced bathymetry grids for the 6-10 second model runs, relative to the original modeling region. The length of the model grid was chosen based on diffraction behavior and the wave angle with respect to Punta Mala. For the shorter period waves, the grid was shortened a point in line with the shielding afforded by Punta Mala and where the water was still deep with respect to the wavelength (no refraction), thus allowing the offshore wave conditions to be representative at the boundary.

Figure 7-8: Model Grids for Wave Study

INSERT FIGURE 3-2 from wave study

Table 7-3 lists the grid size used for the entire matrix of model runs. As shown in the table, some of the steeper angle model runs were eliminated. Based on the PMS results for the 12-20 second waves, it was found that the steeper directions did not result in significant energy reaching the proposed site. In the event that less than 1% of the offshore wave height remained near the site for the 12-second model runs, all lower period model runs were eliminated (e.g. 235°- 240 °). The 6-8 second model runs were likewise eliminated for the 225° -230° directions, based on the 10-second wave results.

Table 7-3: Grid size used for Wave Model runs

Wave Direction (degrees)	Wave Period (sec)							
	6	8	10	12	14	16	18	20
200	10 m	10 m	10 m	20 m	30 m	30 m	30 m	30 m
205	10 m	10 m	10 m	20 m	30 m	30 m	30 m	30 m
210	10 m	10 m	10 m	20 m	30 m	30 m	30 m	30 m
215	10 m	10 m	10 m	20 m	30 m	30 m	30 m	30 m
220	10 m	10 m	10 m	20 m	30 m	30 m	30 m	30 m
225			15 m	20 m	30 m	30 m	30 m	30 m
230			15 m	20 m	30 m	30 m	30 m	30 m
235				20 m	30 m	30 m	30 m	30 m
240				20 m	30 m	30 m	30 m	30 m

7.2.6 Model Results & Discussion

The typical wave climate due to ocean waves in the area of the proposed artificial islands is relatively mild with the geometry of the Gulf of Panama and South America limiting the directions of waves entering the region. The 100-year return period significant wave height was computed to be 0.7 meters with a 17 second period. These long period swell waves generated by storms in the Pacific occasionally reach the area, however, these long period waves can cause considerable movement of a vessel at an unprotected or partially protected berth. This in turn can lead to accelerated fender damage, inefficient or restricted cargo operations and other operational difficulties. The placement of the artificial islands especially with respect to the shielding provided by the near-shore islands of Isla Taboga and Taboguilla will greatly determine the amount of protection required for container vessel operations. The gap between these islands and the deeper water it contains provides a path for wave energy to get behind the islands into the proposed project region.

The full results of the PMS modeling are presented in Appendix F of this report. Design wave conditions and wave protection requirements for each of the island locations evaluated are presented later in this report, since they are specific to the alternatives under consideration.

7.3 Locally-Generated Waves

7.3.1 Fetch Direction and Distance

Following the analysis of the ocean waves that would impact the project sites, an evaluation of locally-generated waves was performed to assess how wind waves generated within the Bahia de Panama would dictate design conditions. The island sites are exposed to relatively long fetches over deep water to the east and southwest (see Figure 7-9). The fetch distance to the east is over 70 km; to the southwest the fetch distance is about 24 km. Water depths to the east range from 20 to 40 m; to the southwest from 10 to 14 m. The island sites are sheltered from long fetches over deep water from the north, northwest, west, south, southeast, and northeast directions.

Figure 7-9 Radially Averaged Fetches within Panama Bay for Island Sites

7.3.2 Wind Speed and Direction

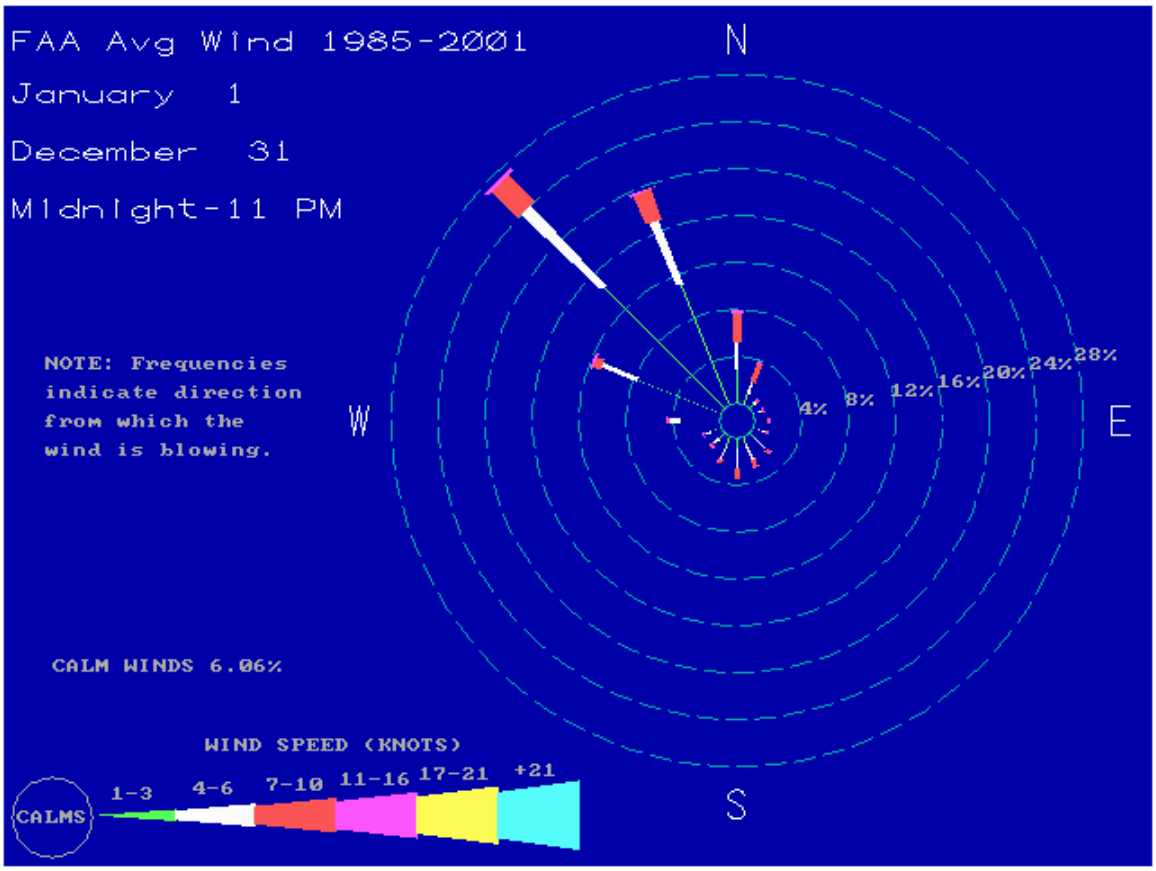
Wind speed and direction data were obtained from the Balboa FAA records for the period 1985 through 2001. These data were then used to hindcast the locally-generated waves that would impact the various island locations. The hourly average wind data are presented in Table 7-4 as a frequency distribution and Figure 7-10 presents a wind rose graph developed from the same data. The data are presented for sixteen directions and six wind speed ranges, and show that almost 67 percent (66.93) of the winds that have been recorded over the 17-year record most winds are from the WNW to N directions. The records also show that maximum hourly average wind speeds from any direction are generally less than 16 knots, with slightly less than one percent (0.94%) of the recorded winds in the 11 to 16 knot range, which is typical of the tropical coastal conditions.

Table 7-4: Balboa FAA Hourly Average Wind Data 1985-2001

Frequency Distribution

Direction	Speed (knots)						
	1-3	4-6	7-10	11-16	17 - 21	> 21	Total
N	0.029856	0.022474	0.024823	0.001899	0.000000	0.000000	0.079052
NNE	0.010375	0.010932	0.016032	0.001429	0.000000	0.000000	0.038768
NE	0.005805	0.003006	0.001335	0.000081	0.000000	0.000000	0.010227
ENE	0.005999	0.002704	0.000497	0.000013	0.000000	0.000000	0.009214
E	0.007207	0.004402	0.000986	0.000027	0.000000	0.000000	0.012623
ESE	0.005456	0.006422	0.001604	0.000027	0.000000	0.000000	0.013509
SE	0.006402	0.013730	0.003550	0.000040	0.000000	0.000000	0.023722
SSE	0.006342	0.014730	0.006134	0.000047	0.000000	0.000000	0.027252
S	0.009590	0.016898	0.007261	0.000067	0.000000	0.000000	0.033815
SSW	0.010133	0.011079	0.002946	0.000054	0.000000	0.000000	0.024212
SW	0.007778	0.006228	0.001765	0.000060	0.000000	0.000000	0.015831
WSW	0.010314	0.004765	0.000778	0.000047	0.000000	0.000000	0.015904
W	0.035003	0.008147	0.001758	0.000107	0.000000	0.000000	0.045015
WNW	0.078072	0.031366	0.007194	0.000705	0.000000	0.000000	0.117336
NW	0.145850	0.094554	0.031332	0.003664	0.000000	0.000000	0.275400
NNW	0.110874	0.058712	0.026863	0.001087	0.000000	0.000000	0.197536
Total	0.485055	0.310148	0.134858	0.009355	0.000000	0.000000	
FREQUENCY of CALM WINDS = 0.060584							

Figure 7-10: Balboa FAA Hourly Average Wind Data 1985-2001 Frequency Distribution Wind Rose



7.3.3 Wave Hindcast Computations

Using the above data, wind-generated wave calculations were completed for the southwest and east directions. In accordance with procedures recommended by the U.S. Army Corps of Engineers (USACE), Coastal Engineering Manual (CEM) (USACE 2001), a radially averaged fetch distance was computed for the two directions (70 km from east and 24 km from southwest as stated above). Wave conditions were hindcast along these fetch directions for the maximum hourly average winds observed over the period of record. Water levels were evaluated using MHWS over the average water depths within the radial fetch window. Average water depth to the east is about 30 m; to the southwest about 12 m. Waves were hindcast for a 16 knot (8 m/s) wind speed using methods published in the CEM.

Hindcast results are presented in Table 7-5 for significant wave height (H_s), maximum wave height ($H_{2\%}$), and peak spectral wave period (T_p), respectively. Hindcast results predict significant wave heights of about 1.0 m from the east and 0.6 m from the southwest. These wave heights are comparable to those from the Pacific Ocean that have been reduced due to protection from the islands as shown in the wave modeling discussed above.

Note that the water is too deep at the site (10 m at MLWS) to cause these hindcast waves to break prior to reaching either a breakwater or dike/revetment structure.

Table 7-5: Locally-generated Significant Wave Heights (m), Maximum Wave Heights ($H_{2\%}$), and Peak Spectral Wave Periods (sec)

Wave Direction	H_S	$H_{2\%}$	T_P
East	1.0	1.8	4.1
Southwest	0.6	1.1	3.1

7.4 Conclusions

The wave analyses show two separate sets of dynamics controlling the wave conditions within the study area. Panama Bay is well protected from ocean swells generated in the Pacific Ocean, which limits the expected 100 year significant wave height at the island site to 0.70 m from the south or south west, with a 17 second period. However, the locally generated wind waves are higher at 1.0 m from the east, with a 4.1 second period. The maximum wind generated wave height from the same direction is computed to be 1.8 m, also with a 4.1 second period.

The difference between these two wave dynamics is of particular importance to the long term development alternatives proposed for the study. In general terms, any wave period in excess of 7 seconds is considered to be “long” and problematic from a ship motion standpoint. Long period waves are known to have caused significant ship motion problems for Pacific Coast ports from San Antonio in Chile to Los Angeles and Long Beach, regardless of the wave height and these could be of great concern for container handling installations located without full breakwater protection at the artificial island.

According to the wind data used for this analysis, the 1.8 m maximum wind generated wave is of very short duration. However for the purposes of breakwater design or shore protection for the island, should be taken as the design wave, given that the combination of a short duration storm with long period regular waves from the Pacific and the high tidal range at Panama could cause significant damage to inadequately protected shoreline structures in a short period of time.

8 HYDRODYNAMIC MODELING

Hydrodynamic models of the study area were constructed in three phases during the study. This section presents the results of the baseline model that was used to test a series of alternative island locations and configurations.

8.1 Numerical Model Description

Models for this study were developed using the Delft3D modeling system. The system includes the DELFT3D-FLOW hydrodynamic model that solves the Navier Stokes equations for an incompressible fluid, under the shallow water and the Boussinesq assumption. Vertical accelerations due to buoyancy effects and sudden variations in the bottom topography are not taken into account.

The model equations are solved on a staggered grid (Arakawa C-grid). The horizontal grid is an orthogonal curvilinear grid with the water level points in the middle of each cell. This type of grid is topologically rectangular but is continuously distorted to match certain boundaries. Two significant advantages of this type of grid are that the grid lines can be made to approximately line up with the natural boundaries and that the grid spacing can be varied in order to concentrate on regions of interest. In the vertical direction a scaled coordinate, the so-called σ-coordinate is used. This coordinate system is boundary fitted both to the bottom and to the moving free surface. The number of layers is constant over the horizontal computational area, and therefore a set of coupled conservation equations is solved for each layer.

The model uses an Alternating Direction Implicit (ADI) numerical method for the shallow water equation. This method splits the computation of one time step into two stages (the two horizontal directions). In addition, the model uses a fully implicit method to solve the equations in the vertical. The model allows the wetting and drying of tidal flats.

The system also includes a model that solves the transport of dissolved substances or heat using an advection-diffusion equation in the three coordinate directions. This equation is formulated in a conservative form in orthogonal curvilinear co-ordinates in the horizontal and σ-coordinates in the vertical. The equation is solved using a Cyclic method (Stelling and Leendertse, 1991) which is a finite difference scheme that conserves large gradients without generating artificial oscillations. The method is based on an implicit time integration and does not impose a stability condition. To ensure that the total mass is conserved, the transport equation is solved in a mass conserving flux form.

Since the horizontal and vertical grids are usually too coarse and the time step too large to resolve the turbulence scales of motion in the model, a closure model is needed. The horizontal processes are represented by the Reynold's stresses which are determined using the eddy viscosity effect. In the vertical the k-ε turbulence model is applied. In this closure model, transport equations for both the turbulent kinetic energy, k, and for the energy dissipation, ε, have to be solved.

8.2 Hydrographic Data

8.2.1 Bathymetry

The bathymetry data was obtained from nautical charts[14] (see Figure 4-1) and the recently completed ACP hydrographic survey of the study region. Depths were converted from Mean Low Water Springs (MLWS) to Mean Sea Level (MSL) using available tidal correction at the primary NOAA station BALBOA located at the Pacific Canal entrance.

Offshore data not covered by the aforementioned charts were obtained from the seafloor data of Smith and Sandwell, (1997) which has also been included in NOAA's ETOPO2 database. These data were derived from satellite altimetry observations combined with carefully, quality-assured shipboard echo-sounding measurements. The data is global and is gridded at 2-minute (latitude-longitude) resolution, which in the Gulf of Panama area is in the order of 3.5 km.

8.2.2 Tidal Boundary

The model tidal boundaries were obtained from the TPXO.5 (TOPEX/Poseidon Global Inverse Solution) data set from Oregon State University. TPXO.5 is a global model of ocean tides, which best fits, in a least-squares sense, the Laplace Tidal Equations and track averaged data from 232 TOPEX/Poseidon orbit cycles. All available track data are averaged to the chosen data sites. The methods used to compute the model are described in detail by Egbert, Bennett, and Foreman, (1994). The tides are provided as complex amplitudes of earth-relative sea-surface elevation for eight primary harmonic constituents (M2, S2, N2, K2, K1, O1, P1, Q1), on a 720x335, 1/2 degree resolution, grid between latitudes of 85.75oS and 81.75oN. TPXO.5 reduced the RMS error of the Topex/Poseidon data from 0.348 m (no tidal correction), to 0.1108 m.

[14] Admiralty – Chart 1929: "Gulf of Panama" and Chart 1401: "Approaches to the Panama Canal"

8.3 Regional Model

In order to propagate the tidal variability from deep water to the entrance of Panama Bay, a Regional model was first created. The model is limited by the Gulf of Panama and the coast of Colombia and at the South by the latitude of 5.5^{o}N and at the west by the Longitude 81°W (see Figure 4-1).

8.3.1 Model Grid and Bathymetry

The hydrodynamic model is built on a rectangular grid with a grid size of 2,750 x 2,750 meters and approximately 14,800 computational points. The model grid is presented in

Figure 8-2. The model bathymetry has been created from the sources of data already described in section 8.2.1.

Figure 8-3 shows the model bathymetry.

8.3.2 Boundary Conditions

Tidal conditions at the two open boundaries have been obtained from the sea-surface elevation for eight primary harmonic constituents (M2, S2, N2, K2, K1, O1, P1, Q1) from the TPXO.5 data source introduced in section 8.2.2. The two boundary conditions (South and West) are indicated in

Figure 8-2. Time series of predicted tides were constructed at the three extreme points of the boundaries. Along each open boundary, the model interpolates between the two specified values in order to prescribe the water level at each point of the open boundary.

Figure 8-1: NOAA Charts 1929 and 1401

Use Figure 3.1 from HB report

Figure 8-2: Regional Model Grid

Use Figure 3.5 from HB report

Figure 8-3: Regional Model Bathymetry

Use Figure 3.6 from HB report

8.3.3 Regional Model Verification

In order to verify the validity of the model to provide correct boundary conditions for the local model, the results have been compared with the field observations. Time series of water levels have been extracted from the model results and compared to the observed water levels at the ACP stations identified earlier.

Figure 8-4 and Figure 8-5 show the comparison of the observed and simulated time series of water levels. Very good agreement is obtained at all the stations and therefore it can be concluded that the regional model accurately reproduces the tidal variability in the Gulf of Panama and can therefore be used to generate tidal boundaries for the detailed model.

Figure 8-4: Calibration of Regional Model Tides (Contadora & Taboguilla)

Use Fig 3-7 from HB report

Figure 8-5: Calibration of Regional Model Tides (Otoque & Mine Dock)

Use Fig 3-8 from HB report

8.4 Local Model

As described in the previous section, a Regional Gulf of Panama Model was used to generate boundary conditions for a local model with finer resolution at the vicinity of the project area. Model Grid and Bathymetry

In order to meet the model objectives, the boundary of the local model was established at Punta Mala on the Azuero Peninsula, and approximately followed the Latitude 7°28' N, as shown in

Figure 8-2.

A curvilinear grid was created with approximately 44,000 nodes. The model grid was defined with the aim of having fine resolution at the project area and at the same time covering Panama Bay to the previously described boundary. More than half of the nodes are located within a 15 km. from the shore, which represents less than 10% of the total model area.

The largest grid size is in the order of 5.5 km., while at the vicinity of the project the grid resolution is in the order of 130 m., which was considered enough to accurately represent the different project alternatives that will be simulated as part of the study.

Figure 8-6 presents three different views of the detail model grid, where the high resolution at the project area can be observed. Model bathymetry has been created using the available data sources described earlier in this report. Figure 8-7 presents two different views of the detail model bathymetry.

Figure 8-6: Local Model Grid

Use Fig 3-9 from Hydro Baseline Report

Figure 8-7: Bathymetry in Local Model area

Use 3-10 from Hydro baseline report

8.4.1 Boundary Conditions

The boundary condition for the model is prescribed as the superposition of the tidal variability extracted from the regional model and a variation of the water level along the boundary that will account for the Gulf of Panama current. This variation of the water level was modified until a net current pattern similar to the one presented in the Atlas of Pilot Charts, (2001) and Bennett, (1965) was obtained. In addition, the model was calibrated to actual observed currents (ACP, 2002) generated by the tidal, oceanic and wind generated currents.

8.4.2 Wind Forcing

In order to account for the effect of winds on the current pattern the Local model was forced by local winds measured at Balboa. The model computes the wind shear stress that acts on the water surface using the density of air, the wind speed and the wind drag coefficient (Cd).

8.4.3 Local Model verification – Existing conditions

Water levels

Simulated water levels from the Local Model were compared with predicted tides at the primary and secondary stations. In addition, the simulated water levels were compared to water levels measured by ACP at the Mine Dock, Balboa, Taboguilla and Rio Chepo stations. Figure 8-8 and Figure 8-9 show that good agreement was obtained between observed (predicted) and simulated water for all the stations and it is concluded that the Local model can be used to accurately simulate the water level in Panama Bay.

Figure 8-8: Local Model Tide Calibration (Mine Dock & Balboa)

Use Fig 4-1 from Hydro Base report

Figure 8-9: Local Model Tide Calibration (Taboguilla & Río Chepo)

Use Fig 4-2 from Hydro Base report

8.5 Currents

In order to verify the ability of the model to simulate current patterns in Panama Bay, model results were compared to available data. The depth-averaged currents computed by the model are compared to a similar observed variable. It was assumed that the Gulf of Panama Current remains constant during the entire simulation. This assumption is based on the small monthly variability observed in (Atlas Pilot charts, 2001) and other studies such as Bennett, (1965) and Delft Hydraulics, (1999), which also consider a mean net current in Panama Bay and disregard the possible variability of this current in time.

First, the simulated current patterns in the northern part of the Bay were compared to the depth-mean currents computed in Bennett, 1965 for the maximum spring range. Figure 8-10 and Figure 8-11 present simulated current patterns during the spring tide event of May 27th 2002 together with the estimated currents by Bennett. Bennett's currents are approximately represented as a net current of 0.35 knot (0.18 m/s) at the inshore stations and 0.7 knots (0.35 m/s) at the offshore stations and the model reproduces quite accurately the magnitude and direction of the currents at all the observation points. Some discrepancies in the direction of the flood current are observed at point A and for the flood and ebb currents at point E. At point E the direction of the simulated current seems to be influenced by the net current and this is not observed in Bennett's estimated currents. Based on these results it can be concluded that the model is able to reproduce quite accurately the tidal and oceanic currents in Panama Bay described by Bennett, (1965). Figure 8-12 and Figure 8-13 present the flow patterns in the project area for spring and neap tide conditions. The flow patterns are presented at four stages of the tide: low water, peak flood, high water and peak ebb. The influence of the Gulf of Panama current to the flow patterns in the project area is easy to be observed especially during low and high water conditions.

In general it can be concluded that the model can accurately reproduce the average tidal and flow conditions in Panama Bay particularly during conditions when the Gulf of Panama current is close to the estimated average. The baseline model may therefore be used as an analytical tool for investigating the impacts that different artificial islands alternatives will have on the hydrodynamic conditions of Panama Bay.

Figure 8-10: Comparison of Local Model Current Patterns with Bennett (1965) - 1

Use Figure 4-3 from Hydro base report

Figure 8-11: Comparison of Local Model Current Patterns with Bennett (1965) - 2

Use Figure 4-4 from Hydro base report

Figure 8-12: Spring Tide Flow Patterns at the Study Site

Use Figure 4-5 from Hydro Baseline Study

Figure 8-13: Neap Tide Flow Patterns at the Study Site

Use Figure 4-6 from Hydro Baseline Study

9 SOCIO ECONOMIC BACKGROUND

9.1 Introduction

The construction of an artificial island within the general study area will have positive and negative socio economic impacts on the communities surrounding the project area and also on those social groups deriving income or recreational uses of the location.

Based on the results of the Pre-Feasibility Report, it was determined that the following locations or communities, also shown in Figure 9-1, will be impacted or could potentially benefit from the construction of the artificial island:

- Taboga and Taboguilla Islands
- Amador Causeway
- Bique Beach
- Vacamonte City
- Port of Vacamonte
- Veracruz Community

9.2 Methodology

An initial assessment was made of the baseline socio economic conditions on communities surrounding or potentially impacted by the construction of an artificial island within the general study area. Members of the study team visited each of the communities discussed in the following paragraphs but no direct contacts were made to community leaders or local residents, due to the very preliminary nature of the studies and a desire to avoid unnecessary public reactions to alternatives that might be discarded later in the study process.

All of the data presented in the following paragraphs was obtained from public sources and through observations of the study sites. Additional information was also obtained from the Panama National Comptroller's office (Contraloría de la Republica de Panama).

Figure 9-1: Communities Included in Socio-Economic Overview

9.3 Community Characterization and Baseline Conditions

9.1.1 Taboga Island

Location & Description

The island of Taboga is a popular weekend or daily tourism destination for residents of Panama City, with frequent ferry service from the Port of Balboa. It is also a popular daily or short term anchorage for recreational boaters from the Panama area. The island is located 12 km south west of Panama City as shown in Figure 9-3, is located within Taboga county and has a surface[17] area of 8.53km^2.

Taboga has two main beach areas, two hotels, numerous vacation properties, a condominium building and a number of smaller lodgings or hotels.

Governmental and public district services in the island include the office of the Mayor, Municipal Courts, Health Center, National Police, offices from The National Environmental Authority (ANAM), the Panama Maritime Authority (AMP) and the Electoral College.

Aquatic transportation is the only means of goods and passenger transfers to and from the island. Locals go to Panama City by ferry for supplies, schooling and employment and also to adjacent Taboguilla to work at recently constructed fuel bunkering installations and a small fish meal plant.

[17] Panamanian National Atlas, 1988.

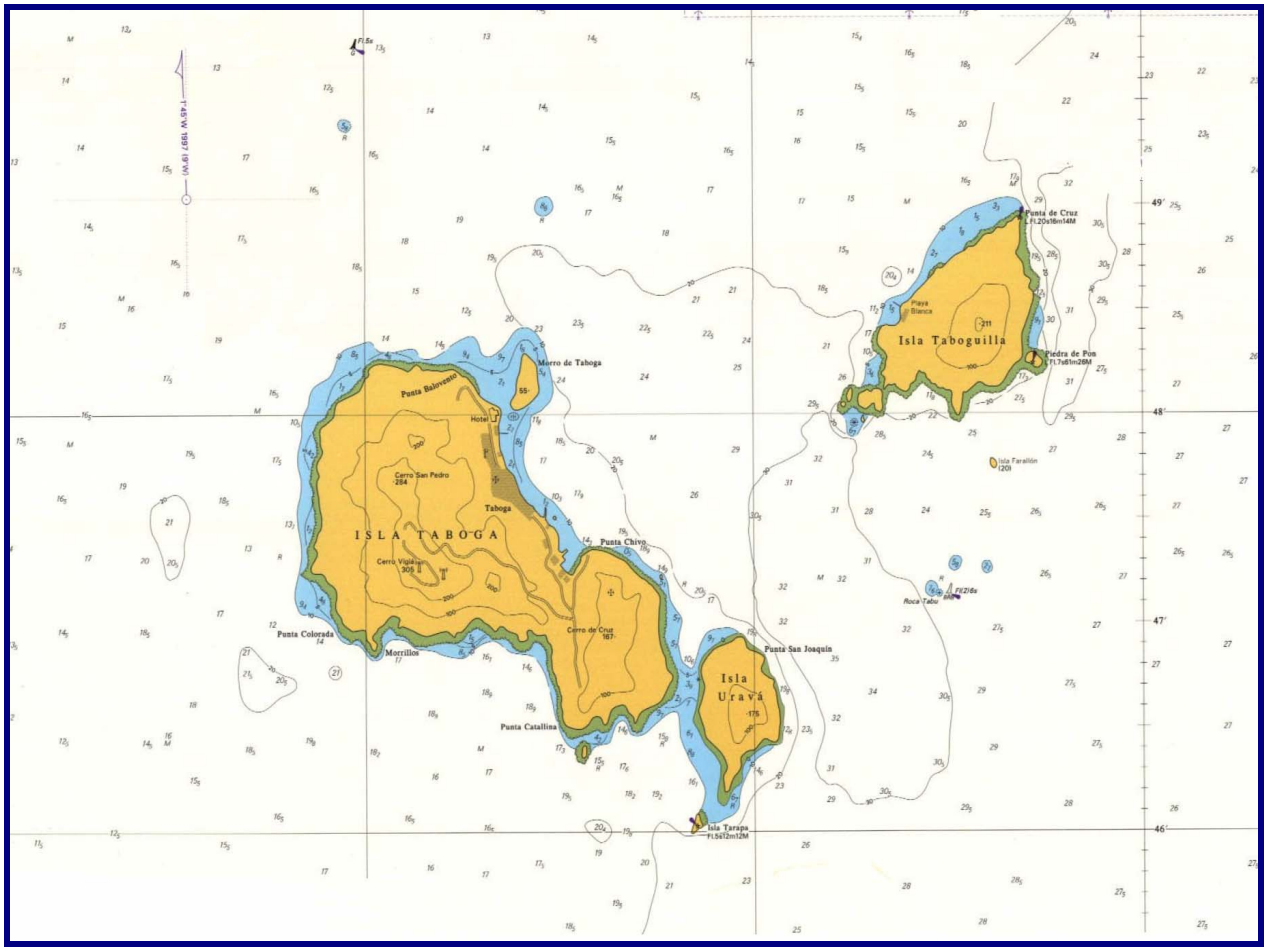
Figure 9-2: Berth and Ferry between Panama City and Taboga

Population & Housing

The population is distributed in the Barrio Esquivel, Barrio José Agustín Arango, Barrio Santa Rosa, Barrio Pueblo Nuevo, Barrio Congreso Arriba, Barrio La Teñidera and the Restinga neighborhoods. From Table 9-1, it is seen that the population[18] of the island was recorded as 908 inhabitants in 2000, distributed in 231 houses. The island contains the largest population of the three cities comprising the District of Taboga, housing 64.8% of the district's inhabitants. According to the same source, 56% of the population (509) is male and 44% (399) is female.

[18] Population and housing census by the Panamanian National Comptroller, year 2000.

Figure 9-3: Taboga & Taboguilla Islands



Approximate grid size 3,650 m

Table 9-1: Population & Housing in Taboga Island (1980 – 2000)

Data	1980	1990	2000
Population	1003	1199	908
Housing	222	249	231
Density per km^2	117.5	140.5	106.8

Source: Data from the population and housing census by the Panamanian National Comptroller, year 2000.

Table 9-2 summarizes additional socio-demographic information characteristics of the island in 2000 as obtained from the Panamanian National Comptroller.

Table 9-2: Socio-Demographic Indicators in Taboga Island (2000)

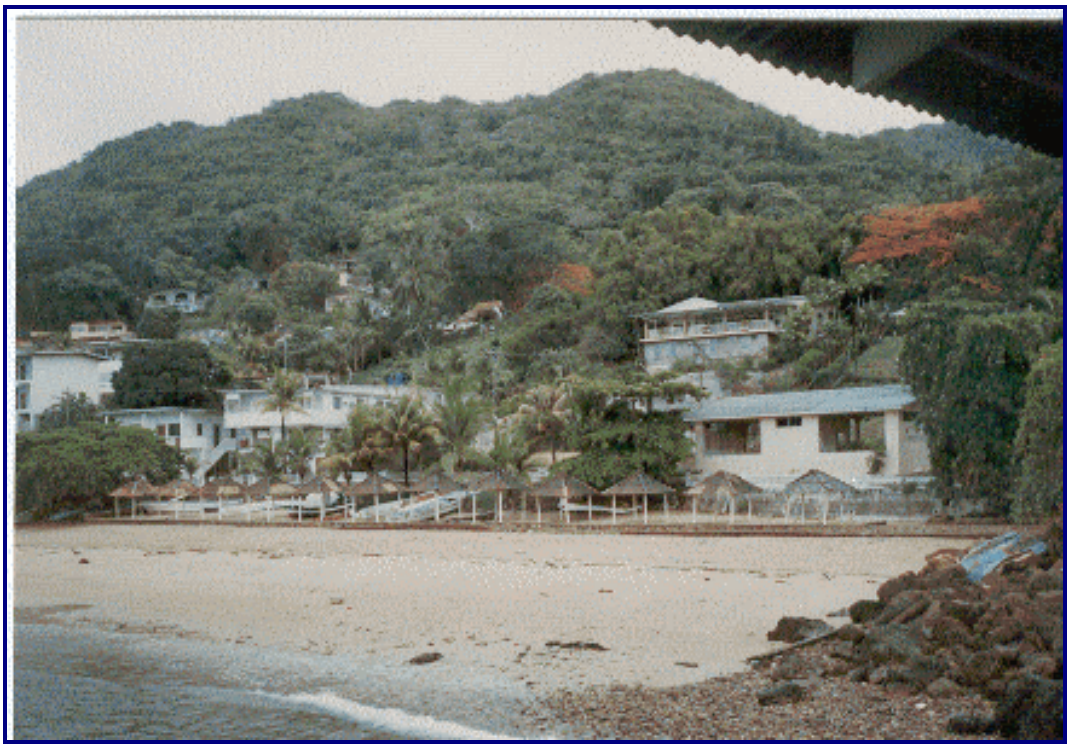
Average Number of Members per Household	3.7
Percentage of Population Under 15 Years of Age	21.3%
Percentage of Population Between 15 and 64 Years of Age	66.1%
Number of men per 100 Women	127.6
Average Age in Total Population	32
Percentage of Households with Male Householder	79.2%

Source: Data from the population and housing census by the Panamanian National Comptroller, year 2000.

Economy

Fishing, agriculture, and tourism play important roles in the economy of the island. While some island inhabitants travel to Panama City for employment, fishermen can make a living from the varied selection of marine life found off the coast of the island. Likewise, farmers cultivate crops such as pineapples, ñame, yucca, and mangos on small parcels of land. Tourism from both foreigners and residents of Panama City also provides jobs for locals. Island inhabitants also travel to Taboguilla to work at fuel bunkering installations and a small fish meal plant.

Figure 9-4: Houses on Taboga Beach



Infrastructure

The road network on the island consists of small, narrow, steep streets. Potable water is accessed through local wells and distributed by sectors. Wastewater is dumped into the ocean, and a collection service provided by the Taboga Municipality disposes of solid waste. The construction of a wastewater treatment plant is currently underway.

Taboga Island also has small parks, an elementary school, a health care center, a church, and two hotels.

Social Patrimony in Taboga Island

The island of Taboga has an important historic and natural patrimony. The wildlife refuge, created on October 21, 1984, is considered to be a sanctuary for 75,000 to 85,000 migratory birds.

Figure 9-5: Paved Road and Souvenir Stand Close to Ferry Landing in Taboga

9.1.2 Amador Causeway

While not specifically a community in the same manner as the others examined in this section, the development and use of the Amador Causeway is an important factor in the assessment of alternative locations and long term uses for the artificial island project.

The recent development of the Amador Causeway has been extremely successful and the area is now one of the more attractive recreation and commercial development areas in the City of Panama.

Combined public and private investments[19] to the end of 2002 were the order of $70 million with a further $320 million proposed in the future or committed in 2003. The future projects include three or four new marinas, commercial and residential development, hotels, restaurants, and a new golf course.

[19] Strategic Plan for Tourism Development – EDSA, 1996, et al.

Figure 9-6: Amador Causeway, West side looking north

As a result of the increased attractiveness of the area, it has become extremely popular and offers uninterrupted views of Panama Bay to the east and the west. To date, the only interruptions to this view are the Canal and ships passing into or out of the Pacific entrance channel.

It therefore follows that any proposal to construct an artificial island within the views from the Amador Causeway could well have significant socio economic impacts on the users of the area and the public and private sectors investing in its development.

Figure 9-7: View from Amador Causeway to Island Sites

9.1.3 Bique Beach

Location and Description

As seen in Figure 9-1, Bique Beach is an underprivileged fishing community located along the shoreline of the Panama Bay, near the Veracruz community. Access to Bique village is via a dirt road through the Gambotti family estate. The residents of Bique Beach are dependent on neighboring villages for employment, goods, and services.

Population and Housing

According to data from the Panama National Comptroller, the community reached a population of 350 inhabitants distributed in 86 houses in the year 2000, steadily increasing from 1980 (216 inhabitants) and 1990 (216 inhabitants). The data in Table 9-3 also indicates that Bique Beach has a large young adult population, making up nearly half of the total population of the island.

Table 9-3: Socio-Demographic Indicators in Bique Beach (2000)

Average Number of Members per Household	**4.10**
Percentage of Population Under 15 Years of Age	42.0%
Percentage of Population Between 15 and 64 Years of Age	54.9%
Number of Men per 100 Women	112.1
Average Age in Total Population	19.0
Percentage of Households with Male Householder	86.1%

Source: Data from the population and housing census by the Panamanian National Comptroller, year 2000.

Figure 9-8: Bique Beach and Mangroves

Economy

The economy of Bique Beach relies heavily on the fishing industry. The inhabitants of Bique Beach travel to neighboring villages including Alto Bonito, Arraiján, Vista Bella, Vacamonte Port, Chumical de Veracruz and Chumical de Vacamonte to sell fish. Others find seasonal work at shrimp processing factories in Vacamonte Port or work as domestic employees. Some also travel to Panama City, Chorrera and Vista Alegre for other types of permanent or temporary work. Still a few work the lands in the Gambotti family estate.

Figure 9-9: "Panga" Boat Used by Artisan Fishermen

Infrastructure

A turbine-powered well distributes potable water to the houses on Bique Beach. Although most households have latrines, there is no system to handle the disposal of solid waste. Bique Beach has a church and a school providing 1st to 3rd grade education to local children.

9.1.4 Vacamonte City

Location and Description

Vacamonte City is a relatively recent but rapidly-growing city located in Vista Alegre County. As can be seen in Figure 9-1, it is situated northwest of Vacamonte Port. A relatively new community started as an urban project, Vacamonte City consists largely of inhabitants from other provinces who took advantage of the affordable housing being offered to settle in Vacomonte City following the construction of the Vacamonte Fishing port in 1978. Inhabitants have access to goods and services within the city or in neighboring cities in Alegre County. Most residents continue to work outside the city, mainly in Panama City.

Population and Housing

According to the census provided by the Panama National Comptroller, Vacamonte City reached a population of 25,281 inhabitants distributed in 6,425 houses in the year 2000, comprising nearly 65% of the total population of Alegre County in 2000. This demonstrates a considerable increase from the 232 inhabitants reported in 1990 in Vacomente City. This growth can be attributed to urban developments made within the last decade directly to the city of Vacomente as well as to the intense growth of areas surrounding the city including the emergence of several villages including 16 de Octubre, Los Guayacanes, 13 de Febrero, 2000, Omar, Rogelio Paredes, Loma Cobá, 7 de septiembre, Cristal, and La Paz.

Figure 9-10: Main road in Vacamonte City

Table 9-4 shows that the majority of the population is between the ages of 15 and 64 with a large emerging population under 15 years of age.

Table 9-4: Socio-Demographic Indicators in Vacamonte City (2000)

Average Number of Members per Household	3.90
Percentage of Population Under 15	34.1%
Percentage of Population Between 15 and 64	63.6%
Number of Men per 100 Women	92.80
Average Age in Total Population	26
Percentage of Households with Male Householder	77.4%

Source: Data from the population and housing census by the Panamanian National Comptroller, year 2000.

Economy

As mentioned earlier, the majority of the residents of Vacamonte City commute to Panama City and other provinces for employment. A select few (less than a third) are involved in the fishing industry, working on fishing ships and selling fish at the Port of Vacamonte.

Infrastructure

The residents of Vacamonte City enjoy a wide range of public services including telephone, cable TV, electricity, sewage, pharmacies, clinics, private and public transportation and elementary schools and high schools for local children. The road network includes access to the Panamá-Chorrera Highway and the Panamerican Highway, the two main highways in the country. This connects Vacamonte City to Panama City and other provinces, facilitating the commute for workers.

9.1.5 Port of Vacamonte

Location and Description

The Port of Vacamonte is located in Vista Alegre county 20 km southwest of Panama City, 8 km south of the Panamerican Highway, and 20 km southeast of the International Port of Balboa as can be seen in Figure 9-1.

There are 252 companies within the port area dedicated to exporting and processing shrimp, chicken, turkey and pork. White and red shrimp (or pawn) are the main products exported to the United States, Mexico, Venezuela and Spain.

Governmental and public district services at the port include the offices of the Red Cross, Consult and Ship, Marine Resources, Customs, Ministry of Health, and Solid Waste Collection, as well as a branch of the Panama National Bank and the Occupational Health Clinic provided by the Social Security Agency. The Occupational Health Clinic provides a full range of medical services to workers at the port. The Port of Vacamonte also has a fire station, a restaurant, a center for gasoline distribution for ships, and a shipyard.

Economy

There are 57 companies located in the port area, ranging from small to mid-size. These include companies specializing in the sale of fuel, construction materials and ship repair, as well as seafood processing plants and seafood export companies. Approximately 250 shrimp ships, 20 of which also fish dorado and shark, arrive at the Port of Vacamonte. These ships sell their catch directly to export companies located at the port, supermarkets, retail or to the association ASOCEPROM which sells seafood to neighborhoods, houses, on streets and at local restaurants. Artisan fishermen and bucketeers also sell their catch at a local level.

The port employs 5,220 people directly and 25,000 people indirectly. Direct permanent employees include the crew of the fishing fleet, which comprises approximately 20% of the total work force. Temporary employees comprise 20% to 40% of the total work force. The work force consists of residents of the Port of Vacamonte as well as residents of neighboring areas including Nuevo Emperador, Santa Clara, Bique, Rio Indio, Vista Alegre, La Revertida, Omar Torrijos, Burunga, Chumical, Chorrillito, Vacamonte City, Chorrera and Panama City.

9.1.6 Veracruz Community

Location and Description

The Veracruz community is the main urban settlement of Veracruz County in the south Arraiján District and the closest significant community to Panama City. This community is located along the shore of the Panama Bay.

Commerce and fishing, are Veracruz's main economic activities. Veracruz has three elementary schools, a health care center and many local stores and pharmacies. The Ministry of Family, the Youth and Children, the District Attorney, and the National Police all have offices in Veracruz.

Population and Housing

According to the 2000 Census, the Veracruz community reached a population of 14,936 inhabitants, distributed in 3,232 houses. Among them, 7,715 were men and 7,221 were women. Table 9-5 shows the high growth rate for the population in the last 20 years. The data shows increases of 49.5% and 121.5% between 1980 and 1990 and between 1990 and 2000, respectively.

Table 9-5: Population and Housing in the Veracruz Community (1980-2000)

Data	1980	1990	2000
Population	4,511	6,744	14,936
Housing	929	1,454	3,232

Source: Panamanian National Comptroller, year 2000.

The county of Veracruz has a surface area of 13.8 km^2, a population of 16,748 inhabitants (year 2000 census), and a density of 1,213.6 inhabitants per km^2. The Veracruz community comprises 89.2% of the total county population.

Other socio-demographic indicators are shown in Table 9-6.

Table 9-6: Socio-demographic Indicators in Veracruz (2000)

Average Number of Members per Household	4.5
Percentage of Population Under 15	33.9%
Percentage of Population Between 15 and 64	62.0%
Number of Men per 100 Women	106.8
Average Age in Total Population	23
Percentage of Households with Male Householder	77.1%

Source: Data from the population and housing census by the Panamanian National Comptroller, year 2000.

Economy

Veracruz is an urban community where commerce and services are the major economic activities. Most of the population is employed in the public and private sector. According to data provided by the Office of the General Comptroller, there are 134 companies in the Veracruz area specialized in fishing, mining and excavation, manufacturing, commerce, hotels, restaurants, transportation, storing, communication, construction, and social and health services.

These companies employ 239 people and generate an income next to 12.3 million Balboas per year. The activities that generate the most profit (74.6% of the total income) are retail commerce, hotels, restaurants, and manufacturing. They also account for 51.5% of the total employment of the area. Artisan fishing produces 8,400 pounds of fish per month, generating a monthly income of approximately 5,200 Balboas. Other companies related to the fishing industry specialize in ship repair, equipment sales and fish flour processing. While the tourism industry is not a main contributor to the economy of Veracruz, locals have established food services along the beaches to accommodate weekend visitors.

Infrastructure

The road infrastructure in Veracruz consists of concrete roads in urgent need of repair. A public bus system transports residents to Panama City and Arraijan. Potable water is available and provided by IDAAN, but the service is intermittent due to water scarcity. A solid waste collection service is available and disposes of waste at a landfill in Chorrera.