SHORELINE STABILIZATION RECOMMENDATIONS FOR PLAYA DEL SECRETO MAYA RIVIERA, Q.R., MEXICO

NOVEMBER 2007 PHOTOGRAPH LOOKING SOUTH ALONG PLAYA DEL SECRETO

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April 2009

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1.0 Introduction

This report presents the results of field investigations that were performed in January and November 2008 to investigate 200 meters of existing shoreline and nearshore environment at Playa del Secreto, located in Quintana Roo, Mexico. This report present alternatives for both short-term and long-term shoreline protection solutions.

2.0 Location

The Playa del Secreto project site is located approximately 45 kilometers south of Cancun, on the eastern coast of Mexico between Puerto Morelos and Playa del Carmen, in the area known as the "Mayan Riviera". Refer to the Overall Location Map in Figure 1, and the project location shown in Figure 2.

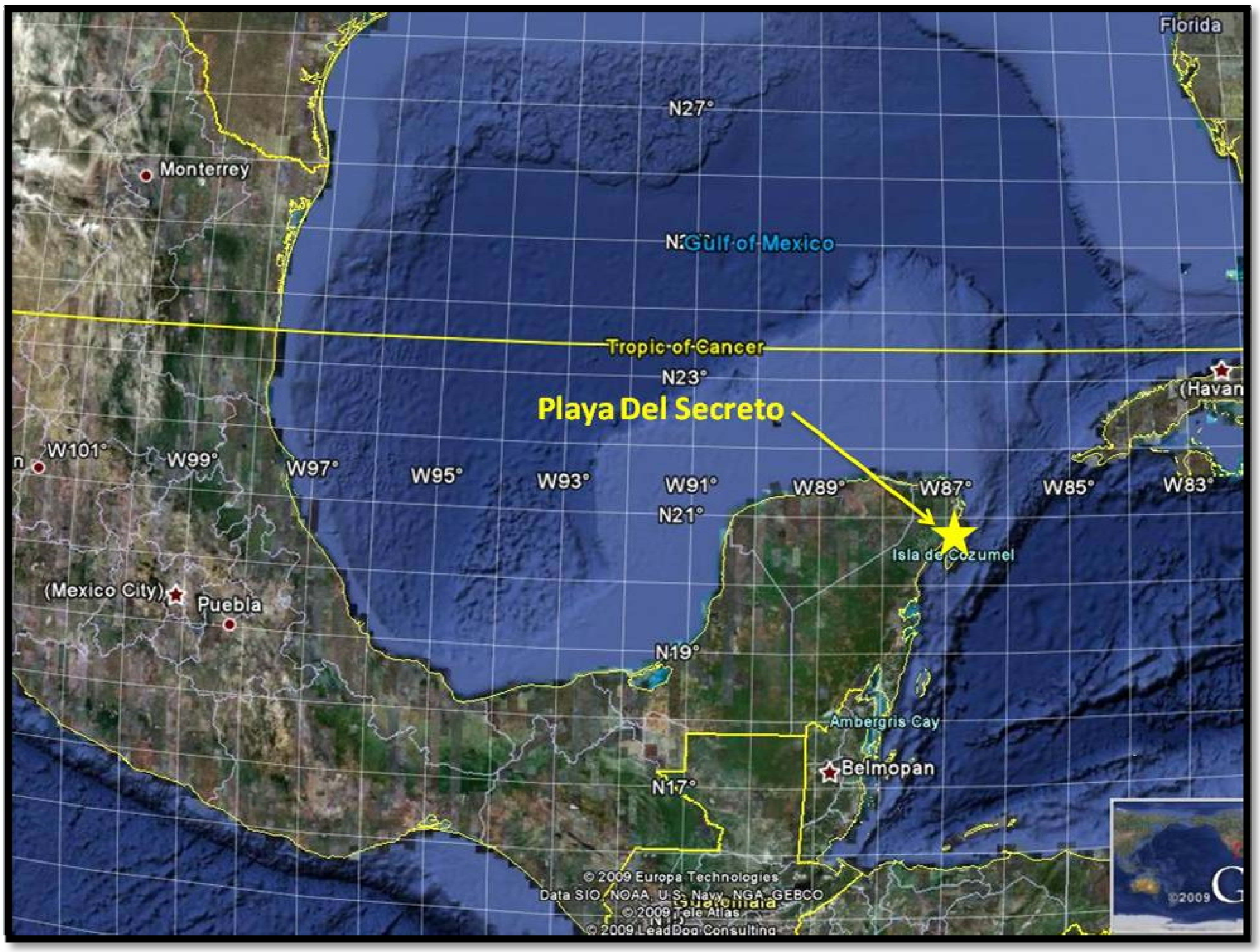

Figure 1. Overall Project Location Plan (Google Earth)

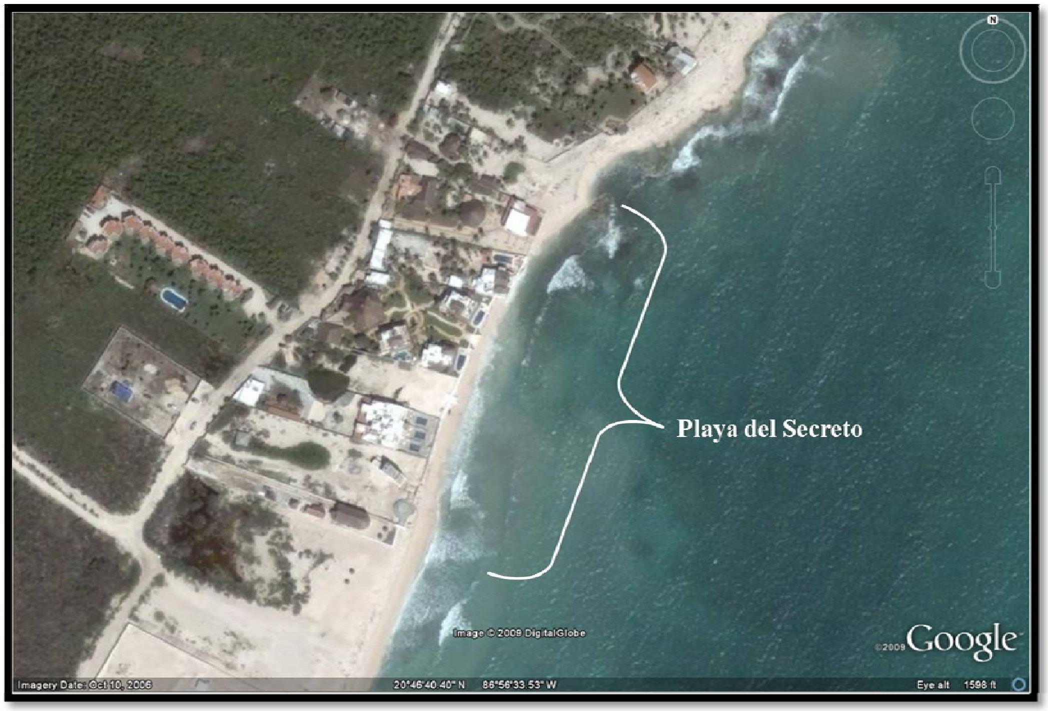

Figure 2. Playa del Secreto Site Project Location (Google Earth)

The project shoreline is approximately 200 m in length and is shared by five (5) private properties located along the oceanfront as shown in Figure 3. This is a high energy wave environment; all five properties have a vertical seawall. In addition, the beach has experienced severe erosion due to storms and hurricanes that have impacted the area in recent years. This has led to the erosion of the protective beach buffer, creating an emergency situation where significant wave energy is reaching the seawall, with the potential for high wave energy to impact the overall structures' stability.

Figure 3. Playa del Secreto Aerial (Photo date - November 2008)
(Photo courtesy of Casa del Secreto, www.playasecreto.com)

3.0 Existing Conditions

The existing conditions for the project area are presented in this section, which includes the meteorological and oceanographic conditions (winds, waves, tides, and currents) and the existing coastal geomorphology (beach topography and offshore bathymetry). As presented earlier, this section of shoreline includes vertical seawalls.

3.1 Oceanographic Conditions

The eastern coast of Mexico's Yucatan Peninsula is open to the Caribbean Sea, with complete exposure to waves coming from the east, northeast and southeast. There is considerable open ocean, with the winds capable of generating significant waves over fetch distances ranging from 200 km to over 2,000 km. In recent years the area has been subjected to several major tropical storms and hurricanes, which have greatly contributed to the beach erosion.

3.1.1 Winds and Waves

The Tradewinds provide a dominant wind pattern for the area, with winds coming from the east most of the time, except when the weather is influenced by the passage of frontal systems or nearby tropical systems. This area is open to the east; hence it experiences both locally generated wind waves and swell waves from storms further east in the Caribbean Sea. Tropical storms and hurricanes produce the strongest winds and largest waves for this area.

3.1.2 Ocean Currents

A major ocean current lies offshore of the area, with strong currents flowing from south to north. This current travels between Cozumel and the Yucatan Peninsula on its way up to Florida, where it becomes the Florida Current, which is part of the Gulfstream. This current is generally located further offshore so that it does not interact with the local beaches and coastal processes. Local longshore current can be produced by the winds and waves that affect the coast, which can produce longshore currents traveling in either direction.

3.1.3 Tides and Water Levels

Tides for the Caribbean coast of Mexico are semi-diurnal, with two high tides and two low tides per day. Predicted tides for Puerto Morelos during November 2008 are shown in Figure 4, which includes the date of the most recent survey for this report. The tide range is considered small, generally less than 0.3 m, but may reach 0.5 m or more during parts of the year. High water levels are possible and do occur due to tropical storms and hurricanes, that are able to produce storm surges that can greatly increase water levels.

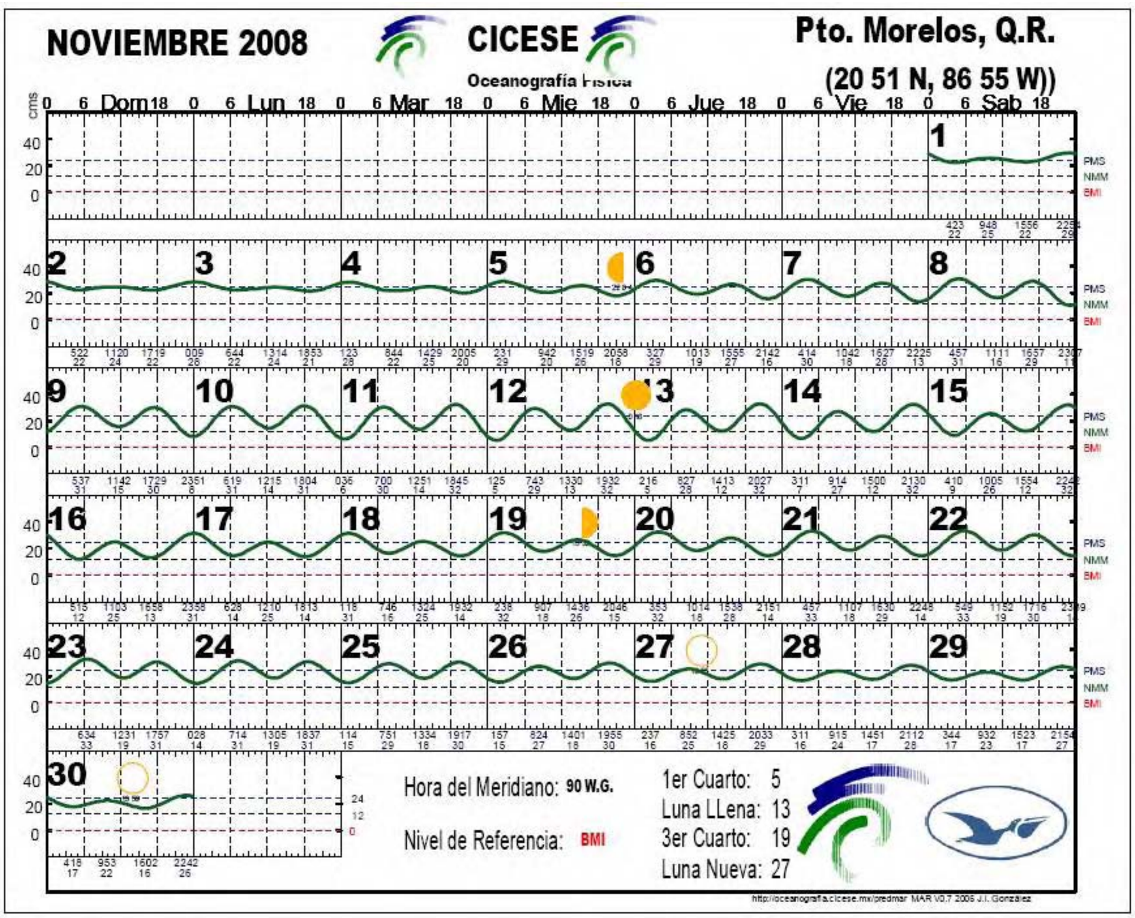

Figure 4. Predicted Tides for Puerto Morelos for April 2009

3.2 Beach Topography and Offshore Bathymetry

Two surveys of the beach and nearshore area were performed at Playa del Secreto in 2008. The first survey was performed on 21 January and consisted of 20 profile lines that extended from the existing seawall out to a water depth of 2m (6 to 6.5 feet). The profiles were spaced at approximate 10.5 meter intervals and covered a longshore distance of approximately 200 m. Figure 5 shows the locations of the profile lines. Figure 6 shows a graph of the distances and elevations for each profile from the existing seawall to a distance of 60 m offshore. Distances from the existing seawall to the waterline were measured at the time of the survey and vary from 1 to 4 meters at profiles 1 through 5, 12 through 15, and 19 through 20. For the remaining profiles, the waterline was measured at the seawall at the time of the survey.

Figure 5. 20 Beach Profiles surveyed in January 2008

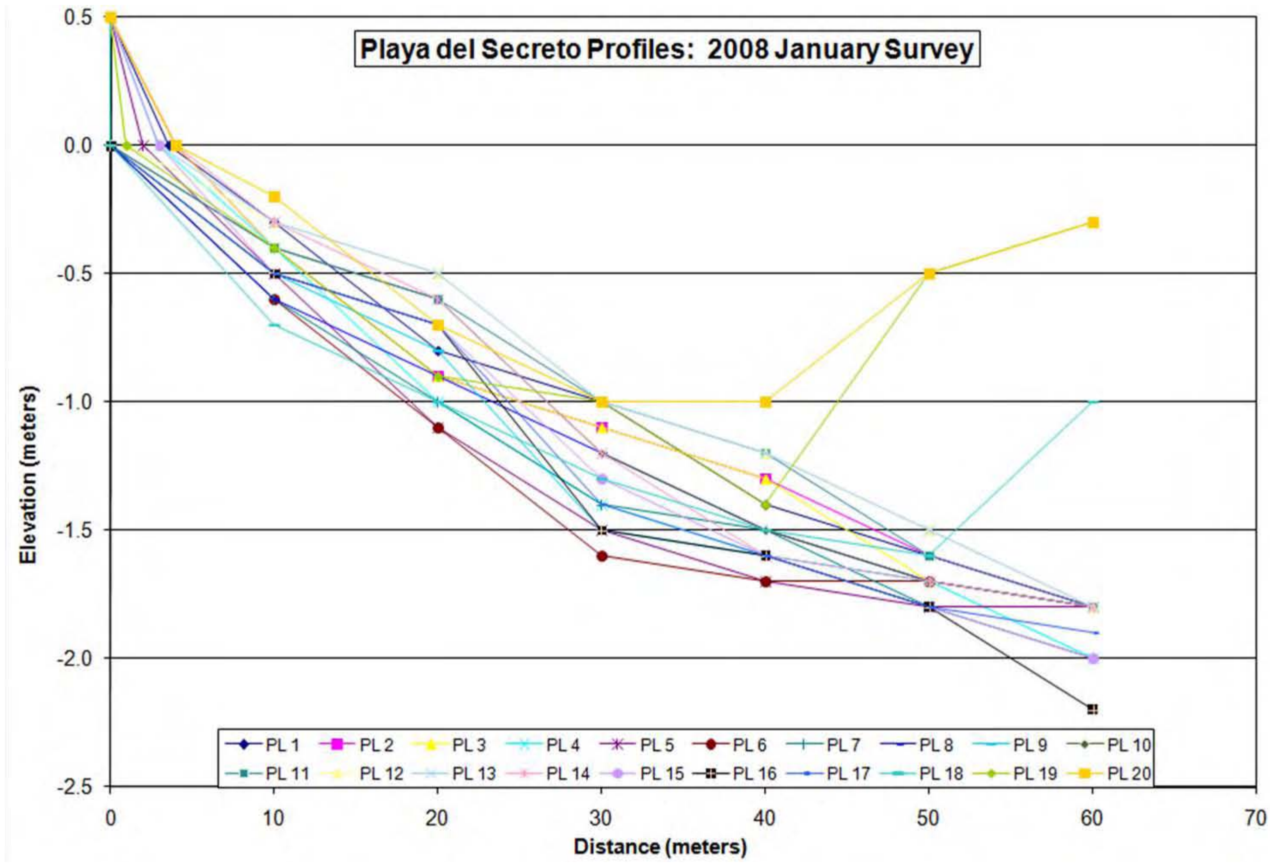

Figure 6. Graph of Beach Profile data (Jan-08)

The second survey was performed nearly 10 months later, on 4 November 2008, and consisted of 10 profile lines that extended from the existing seawall out to water depths of 1.2 to 1.8 m (4 to 6 feet), in order to focus on the area most suitable for an offshore breakwater. Figure 7 shows the location of the profile lines T-1 through T10, which are coincident with profiles PL-6 and PL-18 from previous survey performed in January 2008. Figure 8 shows a graph of the profiles lines from the shoreline seaward to the offshore area in which a breakwater is potentially being considered.

Figure 7. 10 Beach Profiles surveyed in November 2008

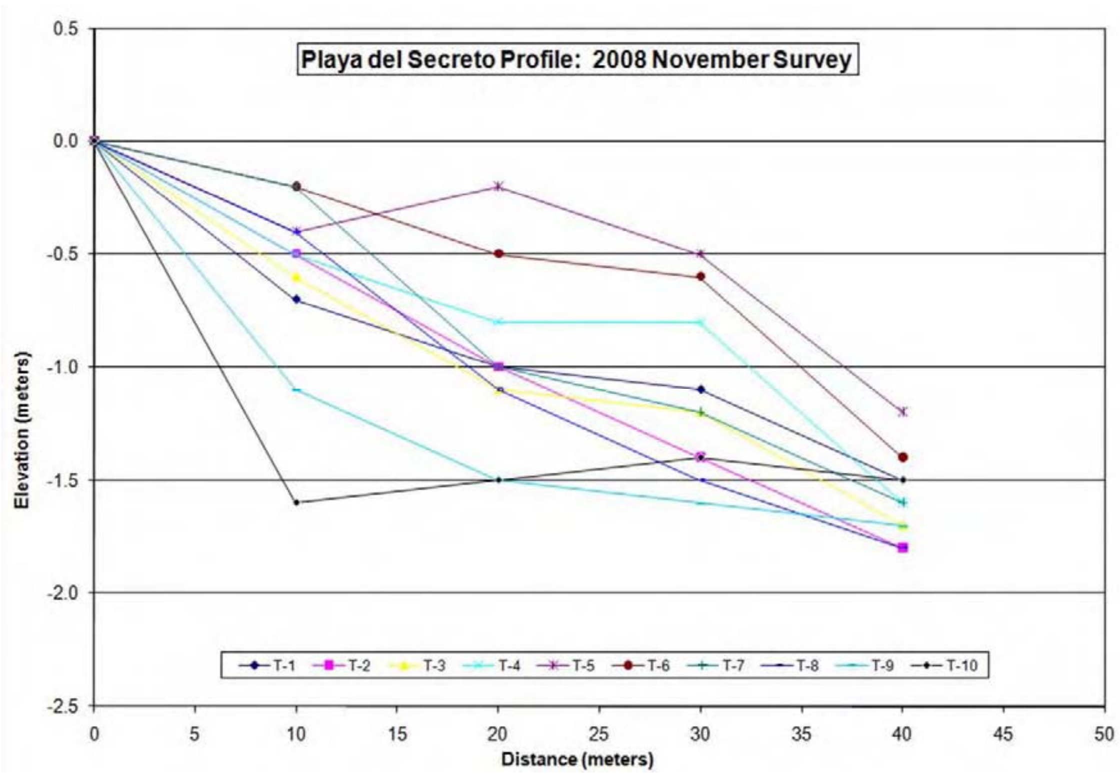

Figure 8. Graph of Beach Profile Data (Nov-08)

At the northern end of Playa del Secreto, there is a natural rock formation that extends from the shoreline, which was included e in the January 2008 survey, as shown on PL-20 of the survey data. Figure 9 shows the location and extent of the natural rock outcrop.

Figure 9. Exposed natural rock outcrops at the northern end of the beach

It is estimated that in September 2008, a property owner at the northern end of the beach (between profiles T-8 to T-10, and PL-16 to PL-19) installed a sand-filled geotextile container (Geotube), approximately 10 m seaward of the seawall, likely in an effort to alleviate the erosion problem. The Geotube dimensions are estimated to be 25 m long, 1.5 m wide and 0.9 m high.

In addition, due to the continued erosion of the beach seaward of the seawall, several property owners placed rocks at the toe of the seawall in an effort to reduce the scouring of the seawall , occurring as a result of increased wave action impacting the area. The photographs in Figure 10 and Figure 11 show the rocks along the seawall and in the nearshore area. Based on our observations, the sizes of these rocks are not sufficient for them to remain stable, with the smaller rocks being transported down the beach. In addition, a portion of the Geotube has been washed up onto the rocks, refer to Figure 10.

Figure 10. Rocks along the seawall, north end, November 2007 (Photo courtesy of reefball.org)

Figure 11. Rocks in the nearshore, November 2007 (Photo courtesy of reefball.org)

4.0 Proposed Shoreline Stabilization Options

This section of the report presents proposed alternatives to the beach area. This includes both short-term and long-term alternatives.

4.1 Short-term Alternatives

Short term alternatives include options that can be performed within a short time frame and to provide immediate relief, while the systems are monitored and more long term solutions are investigated. These options include:

- Scour Protection
- Minor beach nourishment
- Emergent breakwater using sand filled geotextile containers
- Submerged breakwater using sand filled geotextile container
- Submerged breakwater using Artificial Reefs

4.1.1 Scour Protection

The existing rocks were placed on the beach without any filter foundation; hence, they are expected to settle, and ultimately do not prevent the sand from being washed out behind or beneath them. It would be best to remove the small rocks that are out on the beach, leaving those that are up against the seawall. The building of the rock toe protection against the seawall using filter cloth and larger armor stones should be considered; however, this would require excavation of a trench along the seaward face of the seawall, installation of a filter cloth, placement of stones on top of the filter cloth, and placement of very large rocks on top as the armor layer. Each of the rocks in the armor layer should have sufficient weight to remain stable against wave attack, with a weight of each stone in excess of 2 tonnes = 2,000 kg (exact design weight based on the design wave height). The smaller rocks that have been placed on the beach can be used underneath the armor rock as foundation.

Toe protection is supplemental armoring of the beach surface in front of a structure, which prevents waves from scouring or undercutting it. Failure to provide toe protection invites almost certain failure (USACE). Refer to Figure 12, which shows toe scour and accelerated erosion seaward of a seawall both without toe scour protection (on left), and with the use of rocks on filter cloth as toe protection (on right). Note that the toe protection is needed up against the wall, and not out on the beach. Also note that filter cloth or use of small rocks as foundation is needed, with large armor rocks on top (not just small rocks placed on the sand). In order to maintain sand on the beach seaward of the seawall, the rocks should be installed in an excavated trench along the seawall, and buried with sand with the tops of the rocks below the desired beach level. The use of filters using graded rocks or a geotextile filter cloth is addressed in the following section.

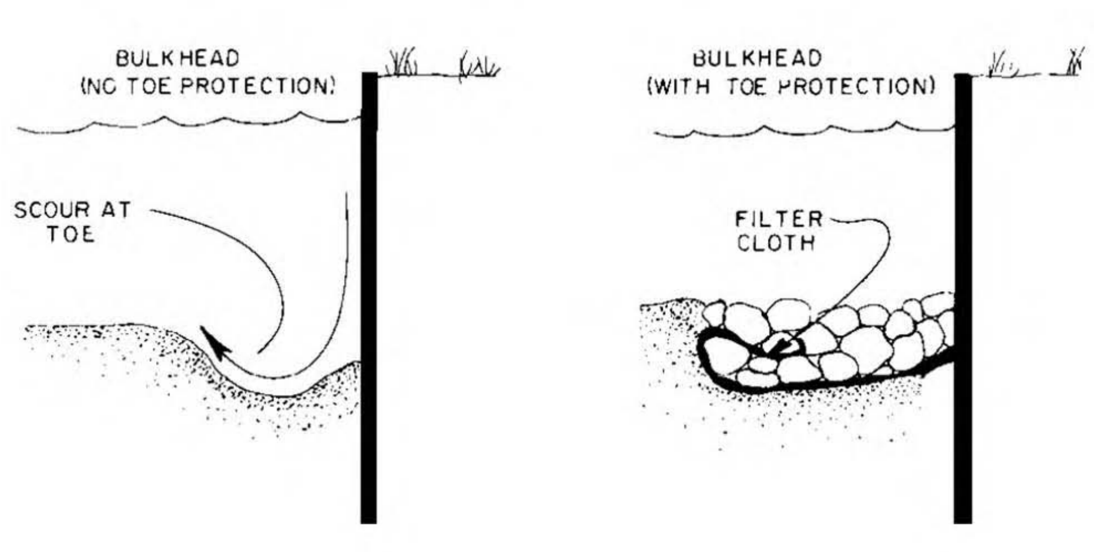

Figure 12. Toe scour seaward of a seawall (left); toe scour protection using rocks (right)
(From USACE)

Filtering, although one of the most important technical design details of shore protection structures, is probably the most neglected; and leads to more failures than any other cause (USACE). The consequences of not providing proper filtering are illustrated in Figure 13 (on left). Without filtering, the soil particles are easily transported through the armor layer of rocks, and the rocks continue to settle as the sand erodes. A properly designed filter blocks the passage of the soil particles while still allowing for hydrostatic pressure relief beneath the structure. As shown in Figure 13 (on right), the use of a graded stone filter or geotextile filter cloth is required to prevent the rocks from sinking into the sand, and to prevent sand from being eroded out from beneath the rocks. Filter cloth can also be used landward of seawalls, to prevent sand from being eroded out from underneath the seawall.

Since these seawalls are pre-existing, construction would be difficult and weather dependent, especially during high wave activity, as the water line is at the seawall location in some areas. Disturbance to the beach environment and the existing seawalls for structural enhancement purposes should also be considered as a long term solution.

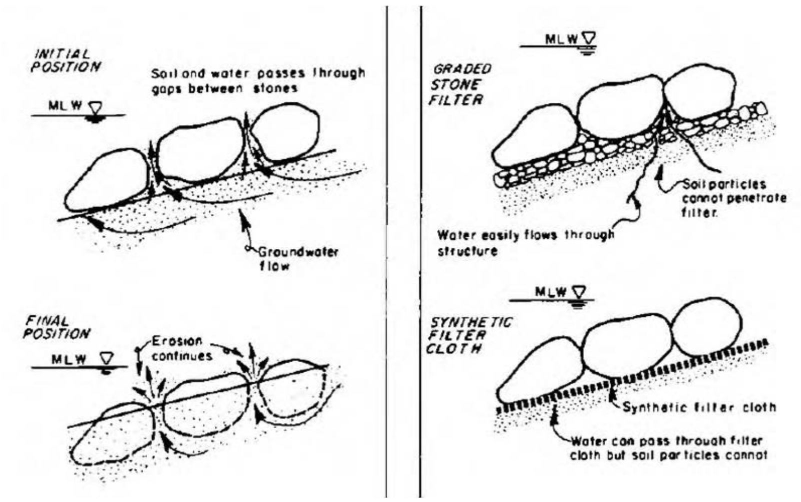

Figure 13. Erosion and rock settlement (left); Filter using graded stone or filter cloth to prevent erosion and settlement (right)
(From USACE)

4.1.2 Minor Beach Nourishment

Ideally, beach nourishment should be performed over a large area, and should be of sufficient volume to substantially increase the beach width to provide a buffer against erosion. Sand fill could be brought in either from an upland source or from offshore, but must be of sufficient grain size to be compatible and stable with the natural sand, as well as similar in color for appearances. Any sand placed on the beach at Playa del Secreto would be considered a temporary measure. The challenge with beach nourishment is locating a compatible offshore borrow area dredging; this is not recommended. If beach nourishment is permissible, then material should be transported in via dump trucks. Dredging should not be considered due to associated environmental impacts and costs.

4.1.3 Emergent Breakwater Using Sand-Filled Geotextile Containers

Traditional emergent breakwaters with the crests above the still water level can cause accretion in their lee, but also erosion of adjacent beaches. If the beach grows all the way out and connects to the breakwater (forming what is called a "tombolo") then the tombolo and breakwater will form a block to longshore sand transport, and deflect sand moving along the shore further offshore. Shoreline responses to offshore breakwaters are shown in Figure 14 with a specific example of erosion downdrift of an emergent breakwater at 32nd Street in Miami Beach, as shown in Figure 15.

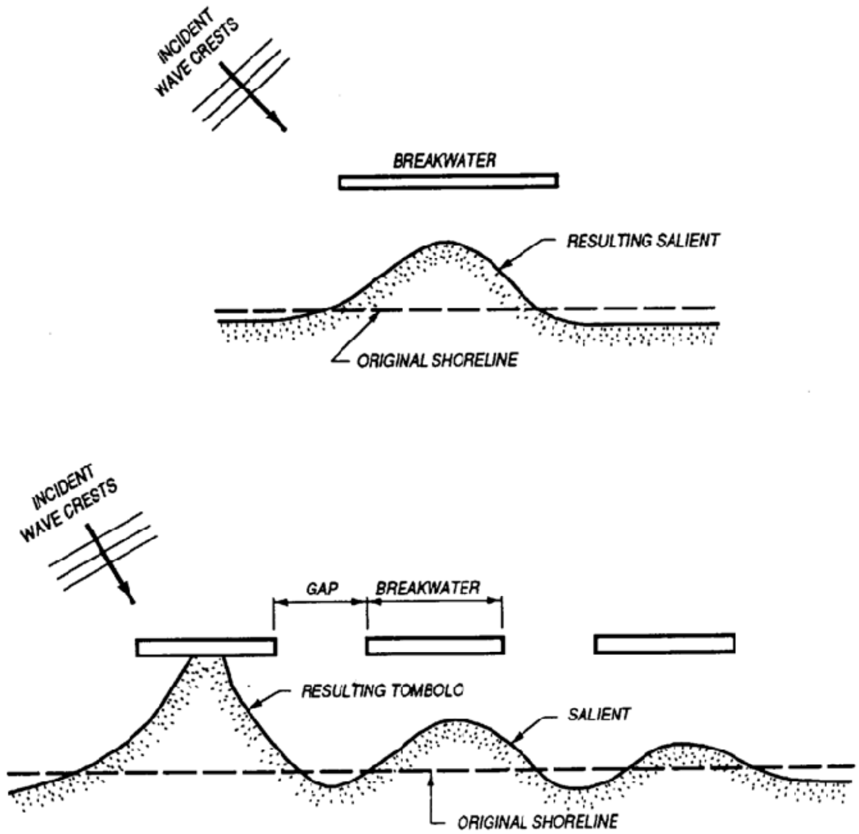

Figure 14. Shoreline Responses to Offshore Breakwaters (USACE)

Figure 15. Miami Beach 32nd Street Offshore Breakwaters (Google Earth)

In addition to the adverse effects on adjacent beaches, emergent breakwaters may not be acceptable in appearance. Examples of emergent breakwaters using sand-filled containers as offshore breakwaters may be found along beaches to the south of Cancun in the Riviera Mayan area, with numerous examples in the Playacar area located south of Playa del Carmen.

Ponding of water due to wave overtopping of the structures can increase the currents around the structures, causing rip currents that can erode the beach and are hazardous to swimmers. Algae growing on top of the containers makes them slippery, which is also hazardous. Moreover, this solution will require sediment and specialized construction in the nearshore zone. The following alternatives addresses advantages and disadvantages of geotubes.

4.1.4 Submerged Breakwater Using Sand-Filled Geotextile Containers

A submerged breakwater can stabilize the beach by decreasing the wave energy reaching the beach, but since it allows some of the wave energy to pass over the structure, a tombolo may not form, and sand may be able to continue to move along the shore landward of the breakwater. The beach landward of the breakwater may form what is called a "salient" which is a protrusion of the shoreline, due to less wave energy affecting the beach landward of the breakwater compared to the adjacent beaches. The effectiveness of submerged breakwaters in reducing wave energy depends on the degree of submergence of the structure (less depth above the breakwater results in more effective wave attenuation), and also the width of the structure (the wider the breakwater the more effective in wave attenuation).

Using sand-filled geotextile containers has both advantages and disadvantages. The advantages are that they can be deployed relatively easily on the existing sea bottom, and since they are constructed out of fabric, they can be easily removed. However, the major disadvantage is that since they are constructed using fabric, the materials are subject to puncture and tear by waterborne debris, as well as to damages due to vandalism. When part of a geotextile container is cut or torn, pieces of the fabric may break off and are transported offshore and down the coast. These fabric pieces are synthetic materials that can harm the environment, entangling and damaging reefs and wildlife. If this alternative is considered, the strongest possible materials should be used for the containers, with regularly scheduled inspections and repairs of any damages to the containers.

4.1.5 Submerged Breakwater Using Artificial Reefs

The use of artificial reef units for creating submerged breakwaters has been successfully used for beach stabilization in other parts of the Caribbean. Using hollow and/or porous breakwater units such as artificial reef units reduces the likelihood of ponding and creating rip currents that would increase erosion as compared to a more nonporous breakwater constructed using rocks or sand-filled geotextile containers. The reef units are constructed of non-toxic materials and are specifically designed to promote increased biological and environmental enhancement, including both benthic growth and fish habitat.

An advantage of using artificial reef units to construct a submerged breakwater is the ability to deploy the units in phases and the ability to easily modify the configuration of the units after they have been placed. In addition, the units can be removed with minimal effort should any adverse impacts be documented following the construction of the breakwater. In locations where a rock bottom exists, the artificial reef units can be stabilized by drilling into the substrate and pinning the units into the bottom. This has proved to be successful for breakwaters that have been exposed to direct impacts by major hurricanes (including Category 3 and 5 storms).

This solution also satisfies both short term and long term relief, refer to the following section for benefits and comparable projects that have successfully used the submerged artificial reef units.

4.2 Longer-term Alternatives

Long term alternatives will provide long term solutions to the erosion problem. The following solutions are often more costly, yet more successful than the short term measures. All long term alternatives will require a successful monitoring plan to assess their performance post construction. In addition, some options would require detailed engineering design and permitting, which will require more time for their implementation. Due to the emergency situation, which is time sensitive, some options are not viable; hurricane season is a mere two months away. Moreover, some long term alternatives will have environmental impacts. These options are intended to provide long term shoreline stabilization of the affected shoreline; however, it should be noted that none of these options will promote the natural accretion of the Playa del Secreto shoreline due to the littoral processes of this area. If no action is performed, then the beach will continue to erode, exposing and moving the existing rocks, with the potential for scouring of the seawall foundation, eventually damaging the upland properties. Long term alternatives include:

- Major Beach nourishment
- Groins to stabilize the new beach
- Emergent offshore breakwater using Rock Revetments
- Submerged offshore breakwater using Rock Revetments
- Submerged offshore breakwater using Artificial Reefs

4.2.1 Beach Nourishment

On a large scale, beach nourishment can provide shoreline protection from storms and significant wave action; however, as with all nourishment projects, periodic renourishment is required, and should be part of the design of a major beach nourishment plan. Renourishment intervals of projects vary from 2 to 10 years, but major storms often require the beach renourishment to be performed earlier than anticipated. The amount of time that the sand will remain on the beach depends on the wave action, especially that from tropical storms and hurricanes. Structures, such as groins and breakwaters, may be used in conjunction with the beach nourishment to aid in shoreline stabilization; these options are discussed in the following sections.

4.2.2 Groins

The use of shore perpendicular structures known as groins can trap sand and prevent the longshore transport of sand. As such, they can create extremely adverse impacts on adjacent beaches, by blocking the longshore transport of sand. Beach nourishment in addition to the groins would be required to create sufficient beach widths and to pre-fill the groin compartments to prevent erosion of adjacent beach areas. Shore perpendicular groins do not stop sand from being taken offshore from the beach, so that the use of T-head groins may be required. The T-head acts similar to an offshore breakwater, reducing wave action in its lee and helping to stabilize the sand on the beach.

4.2.3 Emergent Offshore Breakwater Using Rocks

Traditional emergent breakwaters with the crests above the still water level can decrease the wave energy reaching the beach, but also can cause a ponding where water due to overtopping of the structures can increase currents around the structures, causing rip currents that can erode the beach and are hazardous to swimmers. In addition to the adverse effects on adjacent beaches, emergent breakwaters may not be acceptable in appearance as they will be visible during low and high tide conditions.

4.2.4 Submerged Offshore Breakwater Using Rocks

A submerged breakwater can stabilize the beach by decreasing the wave energy reaching the beach. The effectiveness of submerged breakwaters in reducing wave energy depends on the degree of submergence of the structure (less depth above the breakwater results in more effective wave attenuation), and also the width of the structure (the wider the breakwater the more effective in wave attenuation).

The use of offshore submerged breakwaters constructed of large rocks can be costly to construct and would not be modified easily should it be necessary to remove or adjust the location of the rocks once they have been placed. To be effective in wave energy reduction, the submerged breakwaters will need to be placed so that the water depth is 0.3m (1 ft) above the structure, and be much wider than an equivalent emergent breakwater. A width 10m (33 ft) or more may be necessary to provide the desired wave attenuation.

4.2.5 Submerged Offshore Breakwater Using Artificial Reef Units

As discussed in Section 4.1, Short Term Alternatives, two of the primary advantages of using artificial reef units are:

1) the ability to deploy the units in phases; and

2) the ability to easily modify the configuration of the units after they have been placed.

In addition, the units can be removed with minimal effort should any adverse impacts be documented following the construction of the breakwater. In locations where a rock bottom exists, the artificial reef units can be stabilized by drilling into the substrate and pinning the units into the bottom.

Figure 14 shows the submerged breakwater constructed using 5 rows of Reef Ball artificial reef units offshore of the Marriott on the west coast of Grand Cayman in 2002. This system has stabilized the beach, and provides environmental enhancement and a snorkeling attraction for the tourists. The before and after photographs shown in Figure 15 and Figure 16 show the successful beach stabilization result, even following the passing of Hurricane Ivan in 2005, and wave impacts from more distant storms during the busy 2004 Hurricane season.

Figure 14. Grand Cayman Marriott Five-Row Reef Ball Submerged Breakwater

Figure 15. Grand Cayman Marriott before and after Reef Ball Breakwater Installation
Fall 2002 on the left, February 2003 on the right

Figure 16. Grand Cayman Marriott – November 2006 (L) and February 2007 (R)

5.0 Conclusions and Recommendations

The severe erosion and increased wave energy impacting the shoreline at Playa del Secreto presents a major problem to the individuals with oceanfront property, and for pedestrians using this stretch of shoreline. The consistent waves from the east and the potential for severe property damage along the shoreline make this project a necessity, and to provide the best option for the stabilization of the eroded shoreline.

The shoreline stabilization options for Playa del Secreto were considered and assessed for both short-term and longer-term measures. The solutions provided herein are intended only to stabilize the immediate existing shoreline; any construction of structures must consider the effects on the adjacent shorelines. Proper foundation for any structure is required, which can be accomplished by using a properly designed foundation that resists scour and settlement. Careful consideration of these alternatives and proper construction techniques are required in order to prevent any further damage to the already eroded beach area, and avoiding any adverse effects on neighboring beaches and the environment.

5.1 Short-term Recommendations

5.1.1 Phase I - Submerged Breakwater Using Reef Ball™ Artificial Reef Units

The recommended short long term alternative is the submerged artificial reef breakwater utilizing the Reef Ball™ artificial reef units. The reef units are stronger and more porous than the rock breakwaters or sand-filled containers, which gives this option the advantage of longevity, lack of rip currents, and environmental enhancement. Since the reef units are constructed of concrete, they are not subject to puncture and tear. However, they must be fabricated using special concrete and additives to increase the strength of the units and resistance to breakage. They also must be adequately anchored to prevent movement during large waves.

The design layout for the artificial reef breakwater should consist of constructing two structures of approximately 50 and 75 m long for a combined length of 125 m and be separated by a small gap of 5 to 10 meters. The structures should be placed along the -1.5 m contour as determined by the bathymetric surveys, and should tie in to the existing natural rock formation at the north end of the site. By following the -1.5 m depth contour, the breakwaters would be located approximately 40 to 50 meters offshore. The design of the submerged artificial reef breakwaters are shown in Figure 17 and Figure 18. Figure 17 includes the beach profile data and a general cross section for the proposed breakwater. Figure 18 is a plan view location for the proposed breakwater, the survey profiles are also shown. The purpose of the submerged breakwater is for wave attenuation, i.e. to absorb wave energy.

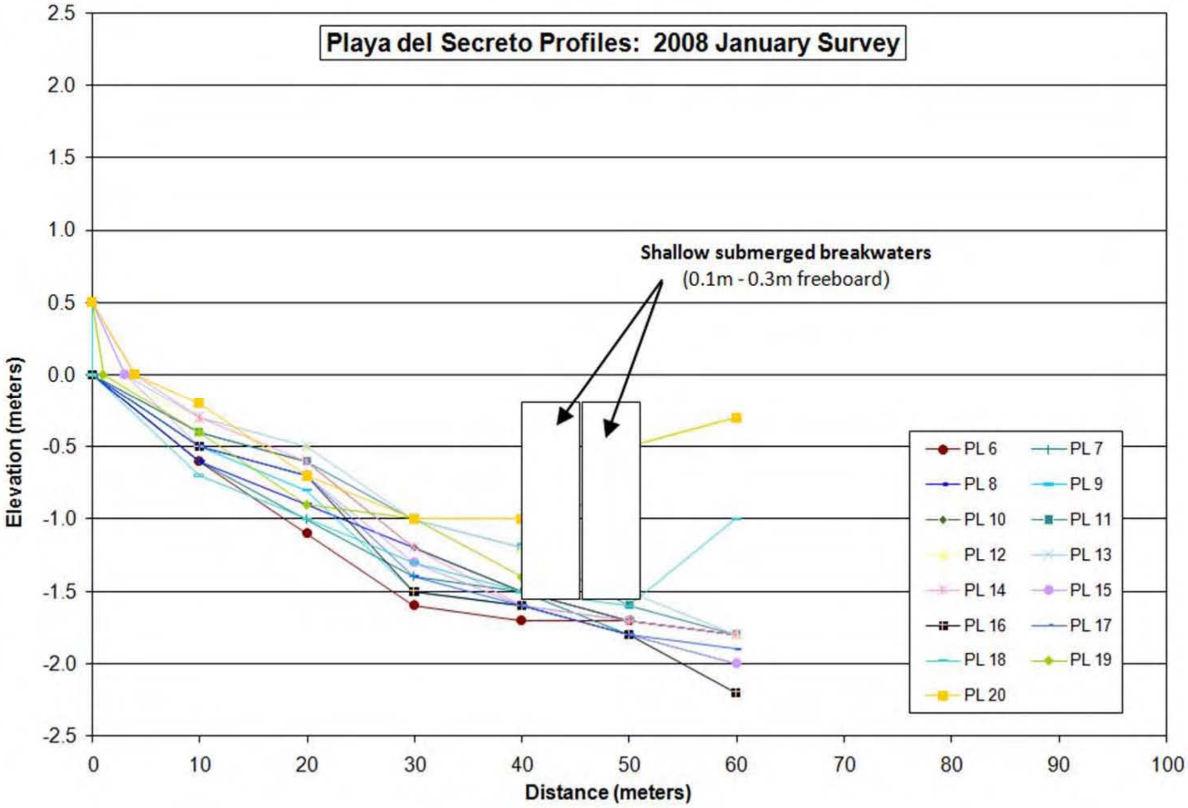

Figure 17. Profile View of Proposed Submerged Artificial Reef Breakwaters

Structure Heights are equal to 1.31 and 1.37m (4.3 and 4.5 ft)

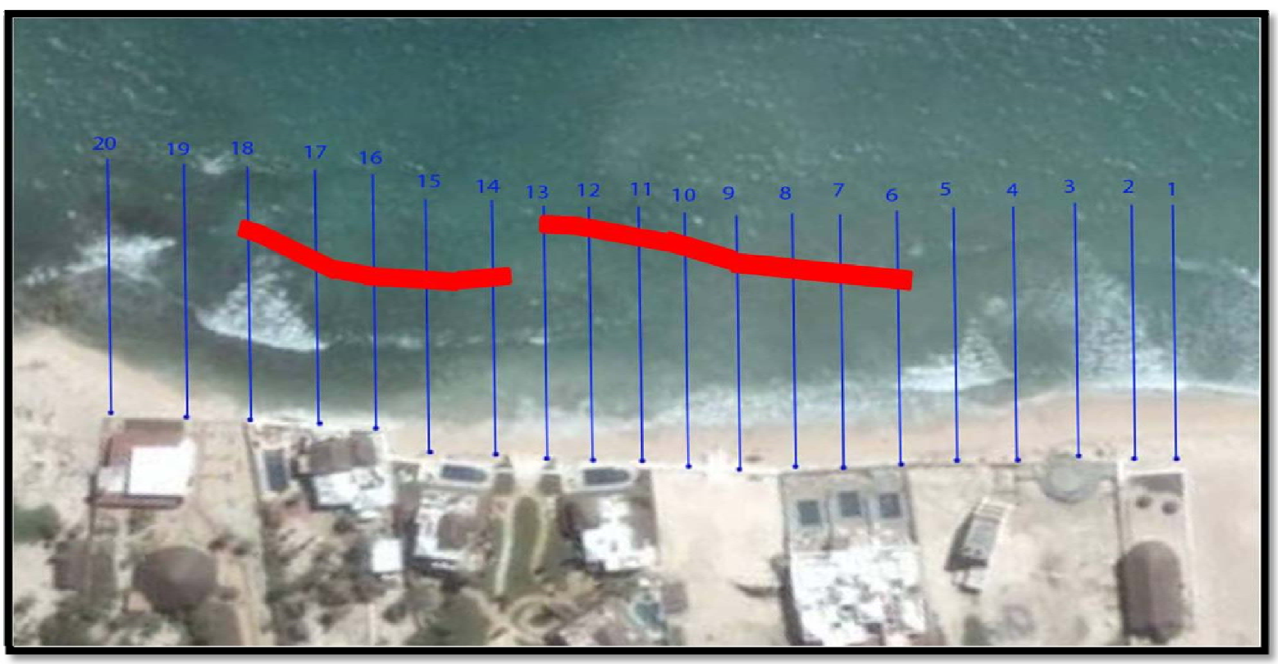

Figure 18. Plan View of Proposed Submerged Artificial Reef Breakwater

Each structure will consist of a minimum of three (3) rows of Reef Ball units, the outer row will use the larger Super Ball and the two inner rows will use the Ultra Ball, for an average width of 5.5 meters (See Table 1 for unit dimensions). The crest height of the breakwaters should be submerged a minimum of 0.1 m and a maximum of 0.3 m below the median tide level, which means that the crests should be visible during the lowest astronomical tide level so that significant wave attenuation is achieved. The units will be individually secured to the bottom (minimum of 20 centimeters penetration) using a minimum of two rebar anchors oriented at a 45° angle.

Table 1. Reef Ball Dimensions

Reef Ball Unit	***Width***	***Height***	***Weight***
Super Ball	1.83 m / 6 ft	1.37 m / 4.5 ft	1,818 – 2,727 kg / 4,000 – 6,000 lbs
Ultra Ball	1.68 m / 5.5 ft	1.31 m / 4.3 ft	1,591 – 2,045 kg / 3,500 – 4,500 lbs

5.1.2 Beach Nourishment

Nourishment of the beach could be performed after the construction of the breakwater is complete to provide a sand beach for recreational purposes. Beach compatible fill may be placed at the site but must be of sufficient grain size to be compatible and stable with the natural sand, as well as similar in color for appearances. Again, it is recommended that sand is placed via trucks, not by dredging.

5.2 Longer-term Recommendations

5.2.1 Phase II –Submerged Breakwater Using Reef Ball™ Artificial Reef Units

An advantage of using artificial reef units to construct a submerged breakwater is the ability to deploy the units in phases and the ability to easily modify the configuration of the units after they have been placed. In addition, the units can be removed with minimal effort should any adverse impacts be documented following the construction of the breakwater. Upon installation of the first phase of Reefball units (minimum of three rows), the system will be monitored to determine whether additional rows and/or modifications are necessary. The following section describes the monitoring plan that is recommended

5.2.2 Monitoring Program

A Monitoring Plan is necessary to evaluate potential impacts associated with the placement of submerged breakwaters along the Playa del Secreto shoreline and monitoring the interaction between the natural coastal processes, stabilization structures and shoreline. The following plan outlines various components of the monitoring to measure the nearshore area of Playa del Secreto.

The plan is separated into phases and utilizes beach profiles as the primary tool to measure and monitor changes in the coastal resources over time in the vicinity of the project site. Monitoring should be conducted for the pre-construction, construction, and post-construction phases of the project. Comparisons can then be made, identification of possible trends in shoreline changes, and more importantly, the effects of erosion operating on a beach, over a period of time can be monitored. Also, it is possible to determine whether measures should be implemented to modify or adjust the proposed breakwater configuration or location.

5.2.2.1 Pre-Construction Monitoring

The purpose of pre-construction monitoring is to establish a baseline of the existing beach conditions immediately prior to project construction and establish background trends existing within the project site and coastal areas adjacent to the beach nourishment site. This is done so that the construction and post-construction conditions can be evaluated based on the baseline conditions. It is imperative that beach and nearshore profile surveys will be tied in to survey monuments that are referenced to horizontal and vertical datum prior to the initiation of the proposed breakwater construction. The profiles will be surveyed along a predetermined azimuth that will be utilized in subsequent surveys in order to perform repeatable profiles from the reference monuments. Profile surveys should begin at the seawall to ensure a stable starting point for the life of the project and extend a minimum of 60 m offshore or to the -2 m depth contour, whichever is greater. The spacing of the profile lines along the shoreline should be no greater than 30 m (100 ft). Tidal elevations should also be recorded to relate the vertical control to mean low water. Permanent benchmarks should be installed for post construction monitoring surveys, and profile data should be plotted so that future monitoring surveys can be compared with the pre-construction surveys in order to assess the beach response.

5.2.2.2 Post-Construction Monitoring

The purpose of the post-construction monitoring is to collect physical data to assess project performance in regards to shoreline changes and movement of the artificial reef units. Post-construction monitoring includes beach profile surveys that will be performed at the locations established as part of the pre-construction baseline survey. All profiles shall be run at the same grid azimuth along the previously surveyed profiles to allow comparison of the survey measurements.

An immediate post-construction survey shall be performed following completion of construction to document as-built conditions of the newly placed structures. Continued monitoring of the project will occur at the 3 month intervals following the immediate post-construction survey during the first year. Additional surveys should be conducted following extreme storm events to assess performance of the submerged breakwaters and the response of the shorelines adjacent to the project area.

5.2.2.3 Data Analysis and Reports

The monitoring data collected will be analyzed to determine volume and shoreline changes in the project area to assess project performance. The following analyses shall be performed, at a minimum:

- Profile comparison plots,
- Breakwater performance assessment.

The results of the measured changes in the profiles, conducted semi-annually during the second year, will aid in the determination of the need for ameliorative measures should they be necessary.

5.2.2.4 Project Performance Evaluation

The implementation of the monitoring plan will provide project performance data to evaluate the breakwater performance and longevity data based on measurements of physical parameters following project construction and to identify work requirements for project maintenance. Shoreline stabilization within the project area is dependent on the effectiveness of the stabilization structures, background erosion rates, longshore losses due to natural processes and the occurrence of severe storm events.