Diagnosis of the Erosion Processes in the Caribbean Sandy Beaches

March 2003

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UNEP GPA

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Layout and cover design: Jeannette Haenel

For additional information contact:

The Global Programme of Action for the Protection of the
Marine Environment from Land-based Activities, GPA Co-ordination Office
Kortenaerkade 1
2518 AX The Hague
The Netherlands
Tel: +31 70 311 4460
Fax: +31 70 345 6648
Email: gpa@unep.nl
Website: www.gpa.unep.org

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Environmental Agency
Ministry of Science, Technology and Environment of Cuba, CITMA

Authors:

Dr. José Luis Juanes Martí
Lic. Ernesto Tristá Barrera
Engineer Miguel Izquierdo Álvarez*
Engineer Vladimir Caballero Camejo*
Dr. Alfredo Cabrera Hernández**
Engineer Adán Zuñiga Ríos***

Collaborators:

Professor Maurice Schwartz
Professor Guillian Cambers
Dr. Georges Vernette
Engineer Oscar Manuel Ramírez
Lic. Carlos García Hernández*

Translating: Lic. Martha Rivero*

* **Institute of Oceanology of CITMA**

** **Office of the Investor for the Recovery of Varadero Beach, CITMA**

*** **Center of Marine Ecosystems of Cayo Coco, CITMA**

Havana, Cuba, March 2003

I INTRODUCTION

Antecedents

The interventions of the Caribbean States in different international organizations in the last years have permitted to highlight, with increasing force, the meaning of Tourism in their national economies and the challenge that it represents from the environmental, cultural and social point of view to reach a sustainable development.

The results of the Second World Climate Conference held in 1990, contributed to lay the foundations for the creation of the Alliance of Small Island States (AOSIS), as a political organization of the United Nations aimed at coordinating the actions of those states before the threats of Global Climate Change, and the challenges of tourist development.

In 1992, during the United Nations Conference on Environment and Development (Rio Summit), the creation of the organization of Small Island Developing States (SIDS), was recognized. It was conceived to claim a greater attention on the part of the International Community to their problems related to sustainable economic development and management of coastal areas.

The Global Conference for Sustainable Development of the Small Island Developing States (SIDS), and the summit meeting of constitution of the Association of Caribbean States took place in 1994 and 1995, respectively. In them, tourism was ratified as an economic activity of high-priority attention, and it is recognized the need to join and increase the actions for a sustainable development.

In the official statement of the fourth meeting of Heads of States and of Governments of the Alliance of Small Island States (AOSIS), held in Johannesburg in September 2002, in the framework of the World Summit for Sustainable Development, the International Community is alerted on the circumstances in which the members of the SIDS face their development, and that 10 years after Rio it is still insufficient what has been done at international level to assist the Small Island Developing States in the solution of the environmental problems they face.

As custodians of enormous oceanic areas and resources, the Heads of States of the AOSIS affirm the need for greater attention from the International Community to sustain investigations and assistance to support the SIDS in their efforts to avoid or mitigate a greater environmental degradation.

Among the topics of interest for SIDS revised by the Heads of States of AOSIS, those regarding the vulnerability of those territories, capacity building, Climatic Change and sea level rise, energy sources for sustainable development, Tourism, marine resources and reefs, trade and finances stood out, among other.

In correspondence with what was expressed in the official statement of the AOSIS, the Implementation Program of Johannesburg Summit in its chapter IV. “Protecting and managing the natural resource base of economic and social development”, it is pointed out the need to advance in the implementation of the Global Program of Action (GPA) for the Protection of the Marine Environment from the Land-Based Activities, with emphasis in the Physical Alteration and Destruction of Habitat, which was adopted by 108 governments in November 1995.

As part of the activities developed by the Coordination Office of the GPA in its Work Program 2002-06 and with the support of the Regional UNEP Office, a meeting of experts took place on June 16-18, 2002. Its objective was to examine some of the problems assisted by the project "Physical Alteration and Destruction of Habitat" in the Caribbean region.

In this sense the debates in the meeting were good to reaffirm the significant role played by Tourism in the economy of the countries in the area, and in particular in those belonging to SIDS. Likewise, it was manifested the importance of beaches as the main natural resource on which the tourist activity is sustained in those countries.

In contrast with the expansion of tourism along the beaches, erosion processes take place with more frequency, causing severe damages to hotel facilities and the environmental deterioration of the coast.

The accelerated erosion observed in the Caribbean beaches is the result of the combination of complex natural phenomena related to sea level rise, intensification of tropical storms, deficit in the natural production of sands, and current tectonic adjustments of the Earth's crust.

The identification of the causes of the erosion in a beach is even more confused when it receives the direct impact of man's thoughtless actions, such as moning of beach sand, construction of roads and hotels on the dunes, damming or deviation of rivers, and establishment of marinas and ports that alter the coastal dynamics.

According to the different factors that intervene in the erosion of a beach, the actions to mitigate it require not only of scientific investigations that explain the phenomenon appropriately, but also of the implementation of regulations and laws that assure the correct Coastal Zone management and of the appropriate engineering techniques to recover and protect the damaged sectors.

The participants in the meeting coincided in recognizing that different Environmental Programs and Agencies, deal with the problems of coastal ecosystems such as mangrove swamps and coral reefs, while the problem of beaches is not particularly focused yet.

Likewise it was noticed that in many countries of the area it is inadequate or insufficient the legislation required to regulate actions in the Coastal Zone and to implement measures to mitigate environmental impacts.

In this point, the participants recognized the Cuban experiences in the development of research projects in the field of marine sciences, the scientific concepts used for the definition of the Coastal Zone in the Decree-Law 212, for "Coastal Zone Management", as well as the results reached with the projects for the recovery and creation of beaches.
It was also pointed out in the meeting the insufficient investigation and documentation with respect to the economic value of natural resources exploited by the tourist activity, making it difficult to quantify the negative impacts of tourism in economic terms in most of the cases.

In correspondence with the issues analyzed in the debates, the participants agreed to propose to GPA and UNEP/ROLAC, to develop three immediate actions directed to obtain a diagnosis of erosion processes in the Caribbean beaches, a comparative evaluation of the environmental legislation of the countries in the region regarding Coastal Zone, and a review of the available tools for the economic assessment of marine and coastal resources.

The proposed actions are aimed at the elaboration of proposals and recommendations that contribute to prevent and control the degradation of the marine and coastal environment, as well as to the recovery from impacts caused by land-based activities.

The present Report includes the results of the work developed in the elaboration of the Diagnosis of the Erosion Processes in the Caribbean Sandy Beaches.

Organization of the Work

Through a Memorandum of Understanding signed between the Environmental Agency of the Ministry of Science, Technology and Environment of Cuba and UNEP/GPA, the Agency assumed the commitment of elaborating the Report: "Diagnosis of the Erosion Processes in the Caribbean Sandy Beaches", as part of the UNEP/GPA Project: "Physical Alteration and Destruction of Habitat".

By means of a Contract, the Environmental Agency assigned to the Institute of Oceanology the development of the necessary tasks to elaborate the Report: "Diagnosis of the Erosion Processes in the Caribbean Sandy Beaches". At the same time, specialist from the Center of Coastal Ecosystems in Cayo Coco and from the Office of the Investor for the Recovery of Varadero Beach, institutions belonging to the Ministry of Science, Technology and Environment, participated in this task. The work was conceived in three stages:

a) Obtaining and processing information

At national scale, it was proceeded to the study and review of scientific publications, reports from the Ministry of Tourism, documents from the Institute of Physical Planning, Ph.D. and Master Theses, Executive Projects, as well as unpublished documents from different institutions. On the basis of the processed information, some conclusions are reached on the extension and intensity of erosion processes in Cuban beaches, and the main causes are identified. It stands out the fundamental actions developed in the country to mitigate the phenomenon of erosion, not only from the point of view of Coastal Zone management, but also of the engineering actions.

In the region, the group equally developed an intense search for information through the collaboration requested from specialists of: Jamaica, Santa Lucia, Guyana, St John's, Antigua and Barbuda, British Virgin Islands and Barbados.

The information obtained by Cuban specialists in works carried out in the Dominican Republic, Haiti, Mexico and Guatemala is incorporated to the results of this search.

A fundamental source of information is the collaboration of three specialists that have stood out for their works in the Caribbean region:

Professor Maurice Schwartz. Wersten Washington University. USA
Professor Guillian Cambers. University of Mayaguez, Puerto Rico.
Dr. George Vernette. University Bordeaux-1, France.
Assistant director at INVEMAR, Colombia.

Taking into account the revised information and the contributions of the foreign specialists, it was considered appropriate to develop a characterization of the problem of erosion of the Caribbean beaches by means of the presentation of CASE STUDIES by country or by group of countries. Likewise, it was deemed convenient to differentiate the problems of the continental beaches in the Caribbean basin from the beaches in the islands.

The gathered information becomes a preliminary inventory of the problem of Caribbean beaches directed to obtain an evaluation on the extension, intensity, and causes of the erosion phenomenon in the region, differentiating those that respond to natural phenomena from those induced by the land-based human activity.

With the objective of highlighting the incidence of natural phenomena like sea level rise, intensification of storms, tectonic movements, and deficit in the natural production of sand on the evolution of the coastal zone, this topic is included. Considering the interest that the beaches of white sands formed by carbonated remains of marine organisms have for tourism, the particularities of their formation and development processes are pointed out.

Furthermore, the obtained information allows the elaboration of a chapter directed to evaluate the main regional experiences in the application of engineering actions for the control of erosion, pointing out both positive and negative results.

It is also included a chapter with reflections on the way in which the tourist development takes place in the region, and on the implementation of regulatory measures to minimize the impacts.

For a better understanding of what tourism means for the Caribbean region it is presented a brief analysis of the development of that activity from the economic point of view.

b) Development of a meeting of experts

As part of the process to elaborate the information, a meeting of experts took place in Havana in February 5 to 8. It had as objective to analyze and discuss the information obtained and elaborated so far and to subject to the consideration of the experts the content of the report and its proposals and recommendations.

As it may be appreciated in the content of the meeting program, (Annex 1), the presentations were conceived to approach four main topics:

1. Incidence of natural phenomena in the erosion processes in the Caribbean Beaches.

    This topic included Professor Maurice Schwartz's special conference, “Effects of Sea Level Rise in the Processes of Beach Erosion. Impact on the Caribbean Beaches", which served as motivation to introduce the analysis of other natural factors.

2. The second topic of the meeting was focused on the presentation of CASE STUDIES directed to demonstrate the widespread character of beach erosion in the Caribbean, including evaluations on its extension and intensity, as well as the analysis of the causes.

3. The third topic of the meeting was guided to evaluate the experiences of the region in the application of measures to counteract beach erosion. Professor Schwartz made a special presentation on the application of the artificial nourishment of sand in beaches of the United States; and the results of the application of that technique in Varadero beach, Cuba, were shown.

4. In the fourth topic of the meeting, it was deepened in the evaluation of the regional capacities to develop not only the necessary scientific investigations, but also the actions to implement measures to mitigate the erosion of the beaches.

The list of participants in the meeting appears in Annex 2.

c) Elaboration of the final document

In this stage, the information has been completed and it has been proceeded to its elaboration and arrangement according to the objectives of the report.

The ideas and proposals presented during the debates of the meeting in Havana were fundamental for the final conformation of the document.

II EROSION IN THE CARIBBEAN BEACHES

1. CUBA CASE STUDY

The Cuban Archipelago is located between 23º 17' 07" and 19º 49' 36" latitude North and 74º 07' 52" and 84º 57' 54" longitude West. It is composed of the Island of Cuba, the Isle of Youth and more than 1200 smaller islands and keys grouped in four sub-archipelagos, with an extension of 110 922 km^2. (fig. 1).

Fig. 1. Cuban Archipelago, (the Island of Cuba, the Isle of Youth and more than 1200 smaller islands and keys grouped in four sub-archipelagos).

The Cuban insular shelf is mainly formed by submarine plains of shallow waters that contain the four chains of keys and reef crests, covering an extension of 67 831 km^2.

From the external border of the shelf the bottom falls to great depths through a steep slope that leads to the basins of the Caribbean Sea, the Gulf of Mexico and the Straits of Florida and Bahamas. These deep abysses constitute Cuba's true geographical limits.

In general it may be said that Cuban coasts are constituted in 40% of their extension by low mangrove swamp sectors, in 30% by carbonated rocky terrace, in 16% by sandy beaches and in 14% by cliffs composed of rocks of different origins.
In order to achieve a better understanding of the physical evolution of the coasts of the Cuban Archipelago, it is important to take into account the following particularities:

1. The biological processes associated to the formation of coral barriers, the mangrove swamps and the production of biogenic sands are decisive in the conformation and stability of Cuban coasts.

2. The trade winds of the Atlantic, the tropical hurricanes and the cold fronts of the Gulf of Mexico are the main meteorological events responsible for the generation of the wave that models Cuban coasts. The different directions and intensities that mark the occurrence of these events every year add complexity to the evolution of the coastline and hinder the prediction of its response before the introduction of coastal actions.

3. The existence of large shelves of very shallow waters and extensive sectors of low coasts make sea level rise, associated to global climate change, become a risk factor not only for the physical conservation of the coasts, but also for the different marine ecosystems.

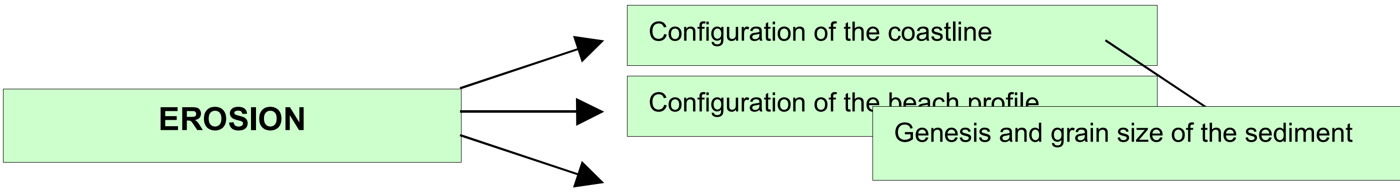
According to the importance of tourism for the national economy at present, the increase in the erosion processes in Cuban beaches has become one of the main problems to reach a sustainable development.

According to the "Program for the Development of International Tourism" elaborated by the Institute of Physical Planning in 1990, 25 tourist areas were classified as "Beaches on the Coast" and 18 as "Beaches in Keys", for a total of 43 new areas for tourist development that occupy 400 km of beach sectors along the whole Archipelago.

The beaches that integrate the tourist areas are located in coastal sectors directly exposed to the waters of the Gulf of Mexico, the Atlantic Ocean or the Caribbean Sea, receiving the denomination of "External Beaches".

The analysis of the extension, magnitude and causes of the erosion that affects the Cuban sandy coasts is based on the inventory of 171 beaches, 103 on the north coast (78 external and 25 inner), and 68 on the south coast (52 external and 16 inner).

In the inventory, the magnitude of the erosion in each beach was related to the following factors:



Likewise, the magnitude of erosion was related to the geographical location of the beach on the north or south coast and whether it was an inner or an external beach.

The erosion indications used to evaluate the occurrence of the erosive process were scarps in the dune, rocky outcrops and fall of trees and facilities under the effect of wave. (Picture 1).

Picture 1: Scarps in the dune, rocky outcrops and fall of facilities

The main anthropogenic activities identified as causes of erosion were the occupation of dunes, not only by houses but also by tourist facilities and the mining activity both in the submarine slope and on the own beach and the dune. According to the extension and intensity of the activity the affectation was classified as intense or moderate.

The inventory shows that of the total 171 beaches evaluated, 153 present indications of erosion for 90% of beaches affected by erosive processes in the country.

In Table 1 the data have been grouped to show the possible relationship between the geographical location of the beaches and the erosion, being noticed that on the north coast the percentage of external beaches that are eroded is 92%, while in the south it is a little lower with 79%.

It is significant that in the case of inner beaches, protected from the oceanic wave by the chain of keys and islands that surround the Cuban insular shelf, it is proven that not only on the north coast but also on the south coast, 100% of them are affected by erosive processes.

The widespread character of erosion in inner beaches may be understood when observing in Table 2 that in all them anthropogenic causes of erosion have been identified, mainly related to urban settlements on the coast.

TABLE 1
Number and percentage of beaches with erosion indications according to their geographical location

External beaches

	Inventoried	**Eroded**	**%**
North Coast	78	72	92
South Coast	52	40	79

Inner beaches

	Inventoried	**Eroded**	**%**
North Coast	25	25	100
South Coast	16	16	100

TABLE 2
Number and percentage of beaches according to the causes of erosion

External beaches

	Eroded	**Natural causes**	**%**	**Anthropogenic causes**	**%**	**Natural and anthropogenic causes**	**%**
North Coast	72	28	39	20	28	24	33
South Coast	40	25	63	12	30	3	7

Inner beaches

	Eroded	Natural causes	%	Anthropogenic causes	%	Natural and anthropogenic causes	%
North Coast	25	0	0	3	12	22	88
South Coast	16	0	0	0	0	16	100

As regards the external beaches, the data shown in Table 2 suggest some differences if compared to the results described for inner ones.

First, it should be highlighted that although the percentage of eroded beaches is high (92% and 79% for the north and south coasts respectively), the inventory shows 17 sectors where erosion does not take place.

Secondly, it can be proven in Table 2, that contrary to what happens in the inner beaches, where the anthropogenic activity is a cause of erosion in all the beaches, in the external ones the natural causes prevail.

Keeping in mind that in the distribution of eroded beaches no correspondence with the geographical location or morphological characteristics of the coast is noticed, it was considered convenient to investigate the possible relationship of the erosion phenomenon with the characteristics of the sources of sediment input.

According to the preliminary information comprised in the inventory of Cuban beaches and to the origin of the sand, beaches may be classified in biogenic (formed by calcareous remains of marine organisms), oolitic (formed by the precipitation of calcium carbonate), and terrigenous (formed by minerals dragged by the rivers). In some cases it is observed the mixture of these types of sand, combining the names to suit the case.

TABLE 3

Show the relationship among the eroded beaches, the cause of erosion and the origin of the sand for external beaches of the North and South coasts

Beaches inventoried according to sediment type and causes of erosion.

External beaches of the north coast

Type of sediment	Without erosion	Eroded	Natural causes	Anthropogenic causes	Natural and anthropogenic causes	Total
biogenic	4	61	22	16	23	65
terrigenous	2	4	0	4	0	6
oolitic - biogenic	0	7	6	0	1	7
Total	6	72	28	20	24	78

External beaches of the south coast

Type of sediment	Without erosion	Eroded	Natural causes	Anthropogenic causes	Natural and anthropogenic causes	Total
biogenic	1	21	18	1	2	22
terrigenous	11	13	1	11	1	24
oolitic - biogenic	0	6	6	0	0	6
Total	12	40	25	12	3	52

In the north coast it becomes evident the prevalence of sectors of biogenic sand representing, together with the oolitic-biogenic sectors, 93% of the beach extension in the northwestern part of Cuba and the whole Sabana-Camaguey Archipelago, and even good part of the northeastern coast of the island. The few beaches of terrigenous sediments on the north coast are located toward the northeastern end of the island, where the contribution of rivers that run through mountainous areas guarantees the sand supply.

The evaluation of the behavior of erosion and its causes in the beaches of the north coast, allows to notice that the coastal systems where it prevails the input of biogenic and oolitic-biogenic material, the erosion for natural causes is a widespread phenomenon, indicating alteration in the sedimentary balance of those systems.

In the case of terrigenous beaches, it stands out the fact that the only identified cause of erosion is the anthropogenic activity, and that in absence of man's erosive actions the beaches conserve their dynamic balance, leading to the idea that in coastal systems with terrigenous inputs the sedimentary balance remains stable.

In the south coast, the littorals formed by biogenic and oolitic-biogenic sands prevail in the whole western part of the Island of Cuba, the Isle of Youth, Los Canarreos Archipelago, and Jardines de la Reina Archipelago. While the sectors of terrigenous material constitute almost the only beach type in the whole eastern part of the Island.

Table 3, demonstrates that 21 out of the 23 biogenic beaches registered are eroded, 19 of them for natural causes and 2 for natural and anthropogenic causes; while all oolitic-biogenic beaches show erosion for natural causes.

Likewise, what is observed for the north coast, the external cumulative sectors formed by biogenic and oolitic-biogenic sediments in the south coast are also eroded due to natural causes.

For the cumulative sectors of terrigenous material, it is observed a relatively high number of beaches without erosion indications, also standing out the fact that in the eroded ones it is only identified the anthropogenic erosion, similarly to what occurs in the north coast.

Based on these results, it may be stated that the external biogenic and oolitic-biogenic beaches, that is to say those formed by materials coming from the sea, predominate in number and extension both in the north coast and the south coasts; and the phenomenon of erosion for natural causes is widespread in them, showing alterations in the sedimentary balance of the coastal systems characterized by sources of inputs of marine sediments.

As natural causes of beach erosion in these systems they are identified sea level rise and the deficit in the inputs of organogenic carbonated sands, phenomena frequently associated to Global Climate Change.

As an example, in the picture 2 it may be appreciated the presence of relicts of roots of coastal vegetation in the intertidal area and even in the submarine slope of the beach Las Canas, north coast of Pinar del Rio, as a consequence of a significant retreat of the coastline. However, man's direct actions have not taken place in this sector.

Picture 2: Retreat of the coastline. Las Canas beach, north coast of Pinar del Río.

In the case of beaches supplied by terrigenous sources, the data demonstrate the low percentage of eroded beaches, and that erosion only occurs in those beaches where the anthropogenic activity has been the cause. The capacity that the sources of terrigenous sands still have to supply the beaches sufficiently is evidenced in these systems.

In the case of inner beaches, the information with respect to the origin of sediments was obtained for 25 of the 41 beaches inventoried. In those beaches the composition and genesis of sediments was varied, since materials of two large sources intervene in their formation, the production of marine biocomponents of diverse nature and the terrigenous influence of the emerged areas (Table 4).

TABLE 4
Inventoried beaches according to sediment type and causes of erosion inner beaches

Type of sediment	Without erosion	Eroded	Natural causes	Anthropo-genic causes	Natural and anthropo-genic causes	Total
biogenic	0	12	0	0	12	12
terrigenous	0	10	2	0	8	10
terrigenous - biogenic	0	3	0	0	3	3
Total	0	25	2	0	23	25

During the analysis done so far, few references are made to the magnitude with which the erosion occurs in the beaches studied.

In Varadero beach, main tourist area of the country, systematic measurements of the morphological variations of the beach profile during more than 15 years have allowed to establish a rhythm of erosion of 1.2 m/year for that beach.

Using as reference the measurements in Varadero and comparing the erosion indications, it was considered reasonable to establish as an index of moderate erosion the values estimated below 1.2 m/year and of intense erosion for rhythms above that value.

According to the results of the inventory of Cuban beaches, most of them present a moderate erosion rhythm, although there exists a group of beaches with higher values.

Studies based on aerial pictures and field trips demonstrate that between 1983 and 1993 the erosion rhythm in the beaches of Cayo Paraíso and Cayo Moa was 3 m/year, and the phenomenon is associated to the deficits in the natural inputs of sand and to the occurrence of strong storms in that period.

Similar erosion rhythms were estimated for the beaches Veneciana and Guanabo, east of Havana City, being identified the intense occupation of the beach by tourist facilities as the main erosion cause.

In the external beaches of the south coast, it stands out the intense erosive process that affects the beach of Cayo Largo del Sur, where the impacts of hurricane Michelle in 2001 and hurricanes Isidore and Lili in 2002 caused the almost total disappearance of the sand along 20 km of beach.

In the inner beaches south of Havana, it has been possible to appreciate erosion rhythms higher than 2.5 m/year, being noticed the incidence of natural and anthropogenic causes. Maybe the most illustrative example in this process, is that of La Pepilla beach (picture 3), where the sandy fringe practically disappeared as a result of an erosion rhythm of 2.5 m/year (fig 2), causing considerable damages to facilities located near the coast.

Picture 3. Beach erosion. La Pepilla beach, in the south of Havana.

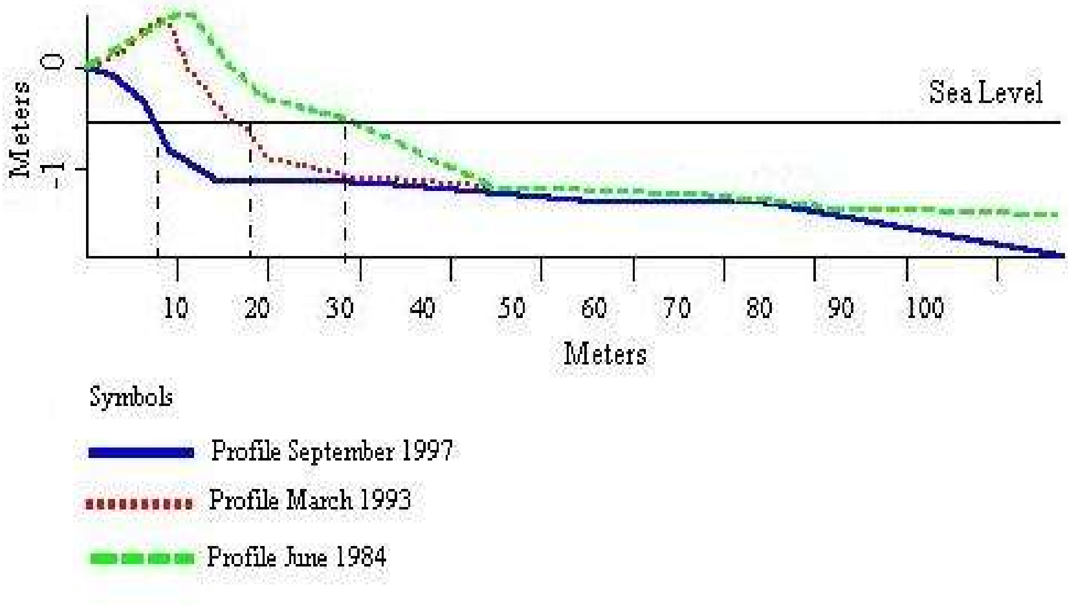


Fig. 2. Rate erosion of 2.5 m/year. (La Pepilla beach).

Based on the presented evaluation on the erosion in Cuban beaches, it is possible to synthesize the following basic ideas:

1. Most of the beaches of the country are distributed along the external coasts of the Cuban Archipelago where the sectors with greater potentials for the tourist activity are also located. However, although the inner beaches are not included in the group having the best potentials for tourism, they constitute an important recreational option for our population, being located in them numerous human settlements. These facts render them a high social significance.

2. Most external beaches are formed by biogenic and oolitic-biogenic material and the erosion for natural causes is generally noticed in them, being evident alterations in the sedimentary balance of the coastal systems characterized by the prevalence of the sources of inputs located in the sea. In the case of the inner beaches of Cuba, they are predominantly constituted by biogenic sediments. Two large sedimentary sources intervene in their formation: the production of marine biocomponents of diverse nature and the terrigenous influence of the emerged areas.

3. The intensity of erosion is moderated in most Cuban beaches, what implies rate erosion not higher than 1,2 m/year.

4. The beaches of terrigenous sediments do not present indications of erosion for natural causes. However, in a considerable number of them the anthropogenic activity causes moderate erosion.

5. In the case of beaches located in inner waters of the shelf it appears in a widespread manner the erosion due to the combination of man's inappropriate actions with sea level rise and the intensification of storms.

Not only in the case of the external beaches formed by terrigenous material, but also in the inner beaches, it is possible to notice that the single application of measures directed to the elimination or decrease of the anthropogenic erosive agents may lead to the recovery and stabilization of those beaches.

Nevertheless, the identification of the predominance of beaches formed by biogenic and oolitic-biogenic material in the Cuban coasts, and the generalized presence of erosion due to natural causes in them, confirms the need to analyze more thoroughly the particularities of functioning of coastal systems characterized by the input of marine sediments.

2. CASE STUDY - THE SMALL CARIBBEAN ISLANDS

The analysis presented on the erosion problem in the Small Caribbean Islands, includes part of the contribution "The Caribbean Islands, Ecology of the Coasts and Geomorphology", presented by Professor Gillian Cambers to the "Encyclopedia of the Coastal Sciences" whose edition is being elaborated by Professor Maurice Schwartz at present.

Morphology of the beaches. (Cambers, in press).

The beaches in the Caribbean Islands vary from lineal beaches that extend along several kilometers, like the one on the east coast of Barbados (from East Coast Road, north of Bathsheba, until Long Pondand Greenland), to small pocket beaches a few hundreds of meters long, limited by cliffs or beach heads, such as Lime Kiln Bay on the west coast of Monserrat.

There is an endless variety of beaches not only for their form and geomorphology, but also for the sediment type and its grain size, and for the presence or absence of rivers. The characteristics of the wave and the existence or not of reef barriers constitute other important factors in the control of coastal geomorphology.

Beach Material. (Cambers, in press).

The word "beach" in the Caribbean Islands is generally used to refer to sandy beaches. However, from a geologic point of view, beaches may be formed by other sizes of particles (clay, slime, sand, gravel, pebbles and blocks). In this article, according to the importance of sandy beaches and tourism, the word "beach" implies a sandy beach, unless for some reason it is specified otherwise.

The sand color regularly reflects its origin. In Anguilla, the beaches are mostly formed by calcareous sand of white color with patches of seashells, which comes from the reefs or from the fragmentation of the calcareous rock that forms the island. In Dominica, many beaches are composed of black sand with olivine and magnetite grains incorporated to the coast by the rivers and by the abrasion of volcanic rocks. The erosion of the sedimentary rock in the northern mountain range produces the yellow silicate sand along the north coast of Trinidad.

Not all the beaches are constituted by sand, a great range of grain sizes that goes from gravel to block appears in many beaches of the volcanic islands, as it happens in Argyle, on the east coast of St. Vincent, where the beach is composed of boulders and blocks. Coral boulders and blocks form many of the exposed beaches on the south coast of Tórtola, in the British Virgin Islands.

Geology and wave energy determine the type of beach material. The action of the strong waves washes the sand particles toward the submarine slope of the beach profile, as it is frequently found in the beaches of the Atlantic coast, while the conditions of calm frequently correspond to the deposits of fine sand and the soft slopes.

Many beaches present different types of materials according to the season of the year. Such is the case of the leeward beaches in the Lesser Antilles, which are pebble beaches during the winter months between October and April, with the greatest wave energy; while during the months of calm in summer, the sand is moved toward the coast covering the thicker material.

A rocky formation that appears in many Caribbean beaches, both on the beach itself and in its submarine slope, is the one known as beachrock, which consists of grains of sand and other beach materials, including pebbles, that are cemented by calcium carbonate.

The beachrock is formed with the body of the beach, below the sand surface and near the water level. Once the sand covering has been eroded, the beachrock formation appears as a hard rock. The beachrock outcrop is an indicator of beach erosion (Cambers, 1998).

Changes in the Beach. (Cambers, in press).

The coastlines are areas of continuous changes where the natural forces of waves and wind interact with the land. These changes have been occurring during millennia. History shows the example of Cockburn Town in the Turks and Caicos Islands, where Back Street has been renamed as Front Street at the beginnings of the XX century as an example of erosion.

Changes in the beaches have been measured in many of the Caribbean Islands since the 80's, as part of the regional program "Coastal and Beach Stability in the Caribbean Island Project", promoted by UNESCO and the Sea Grant College of the University of Puerto Rico. (This monitoring is recognized by the initials COSALC, Coastal and Beach Stability in the Caribbean Island Project, or as it has been recently renamed "Managing Beach Resources and Planning for Coastline Change, Caribbean Islands").

In the Caribbean Islands beaches change seasonally. In many of them a pattern can be distinguished with beaches eroding during the winter months, from October to April, as a result of big waves associated to the Trade winds and long storm waves from the North Atlantic, and some beaches growing in the summer months when the wave energy is lower. However this pattern may change for the different coasts, thus it is not advisable to generalize it.

An initial analysis of beach monitoring results (Cambers 1997[a]) showed that 70% of the beaches has eroded, and that 30% has increased. The annual mean erosion rhythm varies between 0.27 and 1.06 m/year. Both natural as well as anthropogenic factors have been identified as erosion causes. The natural factors include long winter waves, tropical storms and hurricanes, and sea level rise. As for anthropogenic factors, mining activity on the coast, facilities very near the beach area, incorrect location of coastal defenses, and destruction of reef barriers are identified as the most important.

Of the natural factors, hurricanes constitute that of more erosive impact. For example, in Dominica in 1989, intense erosion took place at the pass of Hurricane Hugo (Cambers and James, 1994), which was followed by accretion in 1990 and 1992. However, the beaches never recovered the pre-hurricane size before the pass of the following hurricanes that impacted Dominica in 1995.

During 1995 three tropical storms impacted the Eastern Caribbean Islands during a period of three weeks: Tropical Storm Iris, Hurricane Luis and Hurricane Marilyn. They caused considerable damages to infrastructure as well as to the environment, and particularly with the occurrence of intense beach erosion.

The COSALC database was used to measure the extension of erosion behind the beach that took place as a result of these events. The dunes in the north coast of Anguilla retreated up to 30 m due to the effect of Hurricane Luis. Erosion rhythms were much lower outside the trajectory of the hurricane center.

During the late 1990's the islands in the Lesser Antilles, from Dominica to Anguilla, experienced severe tropical storms and hurricanes, producing serious erosion.

This number of high-energy events appeared to introduce certain vulnerability to the coastal system making its recovery slower and less sustained.

The sand dunes. (Cambers, in press).

The dunes are sand ridges frequently formed behind the active part of the beach. In the Caribbean Islands, they vary from very low formations of 0.3-0.6 m in height, to sand hills that rise up to 6 m high. Several lines of parallel dunes may appear.

The dunes are formed when the sand is transported by the wind from the beach dry area toward the inner land behind the beach. When the wind finds some obstacle like vegetal formations, it diminishes its speed and the sand is deposited. A significant sand movement may take place when wind speeds over 6 m/s occur at a height of 1 m from the surface, (Bagnold, 1954).

In the Caribbean Islands, the mean wind speed is the same or exceeds this value in June and July, and from December to March. During the storms/hurricanes, dunes are frequently eroded and the sand is deposited in the submarine slope; while after the storms the sand is moved again toward the beach and the slow process of dune reconstruction is restarted.

As a result of Hurricane Luis, the dunes in Anguilla showed an average retreat of 9 m and it is expected that their recovery will take decades, if it occurs completely, (Cambers, 1996).

At the meeting of experts held in Havana on February 5 – 9, 2003, Professor Cambers presented a summary of the changes occurred in the Caribbean beaches during the period 1985-1994, (Table 5).

It should be pointed out that the accretion tendency appreciated in the case of the island of Montserrat is related to the significant input of material to the coast that took place as a result of the volcanic eruption in 1995. The retreat of the coastline in several Caribbean islands as a result of the pass of Hurricane Luis in 1995, appears reflected in Table 6.

TABLE 5
Summary of changes in the Caribbean beaches, 1985-`1994

Island	Observation Period	Total of sites measured	Number of sites with erosion	Number of sites with accretion	Mean change in the beach width, (m/year)
Antigua	1992-1994	30	24	6	-0.85
British Virgin Islands	1989-1992	44	32	12	-0.36
Dominica	1987-1992	23	21	2	-1.06
Granada	1985-1991	40	26	14	-0.31
Montserrat	1990-1994	10	2	8	1.07
Nevis	1988-1993	17	13	4	-0.85
St. Kitts	1992-1994	35	22	13	-0.27

TABLE 6
Coastline retreat in 1995 as a result of the pass of Hurricane Luis

Island	Distance to the center of Hurricane Luis, (km)	Coastline retreat, (m)
Barbuda	5	18
Anguilla	28	9
Antigua	40	5
St. Kitts	70	4
Nevis	90	5
Montserrat	90	4
Dominica	180	3

In the case of the island of Anguilla, Professor Cambers reports the following impacts:

- In the mangrove swamps: a mortality of 68-99% in the red, black and white mangroves.
- In the seagrass beds: reduction of the bottom covering in 45%.
- In the Reefs: 61% of living reefs (hard and soft corals) degraded to rocky fragments.
- In the beaches: reduction of their volume in 40%.
- In the sandy dunes: mean retreat of 9m.

As it may be appreciated in Table 6 and in the example of the island of Anguilla, a single erosive event may produce an intense coastline retreat and important environmental impacts, being evident the role of tropical hurricanes in the evolution of the Caribbean coasts.

The results obtained through "Managing Beach Resources and Planning for Coastline Change, Caribbean Islands" show the widespread character of erosion processes in the Caribbean sandy beaches and evidence the tendency to the increase in erosion rhythms.

The natural processes that cause the physical alteration of the coasts are in many cases accelerated by the direct incidence of human activities.

In Professor Cambers’s contribution it stands out how, together with economic development and employment for many, tourism also brought environmental problems, particularly in its beginnings in the 70’s and 80’s, when its growth took place in an uncontrolled manner. The precedent created by that situation brought about that in the early 80’s environmental controls began to be kept in mind, when many of the damages had already been caused. Islands like Barbados already presented serious pollution problems and impacts to their coastal reefs; Jamaica traded with the exclusivity of its beaches, so that local residents did not have access to the coast in long distances, and even small islands like Montserrat experienced a boom of the construction industry and increased sand mining in their beaches.

Unfortunately, sand dunes are frequently viewed as the first places for sand mining. Many dune areas have disappeared completely as a result of the extraction of material, as it has happened in Josiah'Bay in Tortola, in the British Virgin Islands, and in Diamond Bay in the east coast of St.Vicente, where the extensive dunes of black sands higher than 6 m no longer exist. In La Isabela, on the north coast of Puerto Rico, the mining activity has taken place in the last two decades, leaving only a scarcely a narrow fringe of residual dune that is often destroyed during storms, (From Cambers, in press).

Jackson (1984), (cited by Blommestein and col., 1996), observes that most of the tourist facilities are concentrated within 800 m starting from the line of maximum sea penetration. Frequently it is an extremely shorter distance. For example, in Jamaica it is found that 60% of the facilities is located at less than 15 m from the line of maximum sea penetration, (Government of Jamaica, 1992). However, the existence of these focuses on the coastal area does not mean that tourism is already extended along all the coasts. For example, in Jamaica 90% of hotels concentrate on four localities along the north coast, (Government of Jamaica, 1992). A similar pattern may be found in the other Caribbean islands (Blommestein and col. 1996).

In his report: “Tourism and Degradation of Coastal Resources in the Wider Caribbean” (1996), Bruce Potter synthesizes:

The impacts of Tourism in the Wider Caribbean are extremely diverse, depending on the big differences in the economy of the States, the relative and absolute size of the tourism sector, its growth rhythm and the nature of the tourist facilities involved.

The effects of the environmental degradation of tourist facilities in the coastal areas are generally small, frequently dispersed, punctually critical and having multiple causes.

3. CASE STUDY - MAYAN RIVIERA, MEXICO

PLAYA DEL CARMEN COASTAL SECTOR

Playa del Carmen tourist destination, in the Mayan Riviera, Quintana Roo, Mexico, is having an accelerated growth both urban and of hotel infrastructure. However, its beaches, main natural resource to which this development is associated, suffer the effects of coastal erosion, considered a generalized phenomenon in the Caribbean region.

In the face of the responsibility of stopping the physical deterioration of this important tourist area, the General Directorate of the Urban Management and its Directorate of Environment of the Honorable City Council of Solidarity, have started a program to conciliate actions among public and hotel officials and the users to coordinate an appropriate management of the beaches comprised in the municipal domain.

In the framework of this action, it was carried out a field trip with the objective of evaluating the current state of the beaches. Its main results are expressed in the present report.

Characteristics of Tres Ríos-Calica coastal sector

Tres Ríos-Calica coastal sector covers about 18.4 km of coast, 14 km of them correspond to beach areas and about 4.3 km to low terrace abrasive coast (Fig. 3).

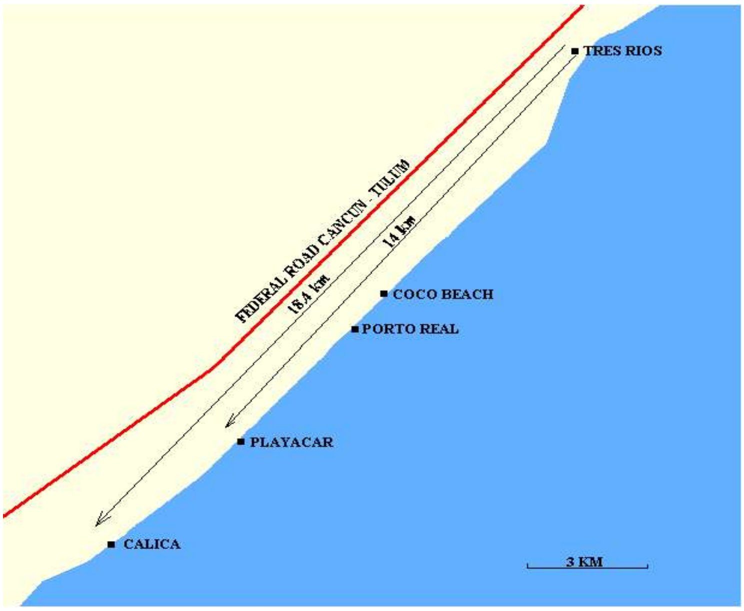


Fig. 3. Location of Tres Ríos-Calica coastal sector, Playa del Carmen.

According to the erosive state of the beaches and the level of urban occupation, this coastal sector may be divided in four coastal tracts:

A tract that extends from Tres Ríos to Coco Beach (Fig. 3), about 8.5 km long, including the beaches Mandarín, Capri, Capitan Lafite, Caracol Village, and Punta Esmeralda (Picture 4, Table 7), where it is appreciated in general a reduced fringe of emerged beach of about 5-10 m in the wider places, with a scarcely developed dune of variable height that does not exceed 1 m. Scarps of erosion frequently appear cutting the coastal dune. They mark the retreat of the coastline that is progressively happening in this coastal tract, accompanied by wide rocky surfaces that appear in the intertidal area.

The hotel and services facilities that exist in this tract have been built totally or partially on the coastal dune, eliminating the main sand reserve that the beach possesses for its natural functioning before severe hydrometeorological events.

Picture 4. Tres Ríos-Coco Beach coastal sector.

The second tract, bordering the previous one, extends along 1.3 km, from Coco Beach to Porto Real (Fig. 3), including the beaches Shangrilá, Las Palapas and Tucán (Picture 5, Table 7). This tract presents a wider emerged beach, with around 20-30 m regularly. However, the dune presents little development, also occupied by constructions very near the shore, and erosion scarps 0.30 - 0.40 m high are appreciated on the berm and the beach face.

Picture 5. Coco Beach-Porto Real coastal sector.

The third tract extends from Porto Real to Playacar, with about 4.3 km of longitude (Fig. 3). The hotel area of Playa del Carmen appears here, with a high density of coastal occupation (Picture 6, Table 7), where the coastal dune was totally eliminated. The fringe of emerged beach does not exceed 10 m in width. In several places the wave is impacting directly on the protection walls or the foundations of the facilities, including extensive areas where rock emerges. In various places, groynes and breakwaters have been built with sandtainers, which have been insufficient to control the erosion processes that are happening there.

Picture 6. Porto Real-Playacar coastal sector.

The fourth tract extends from the end of Playacar to Calica, along 4 km (Fig. 3). The main characteristic of this tract is the presence of a high terrace rocky coast, where sand accumulations do not exist on the littoral (Picture 7). This tract includes the shipment area of minerals located in Calica

Bay and Xcaret Natural Park.

Picture 7. Playacar-Calica coastal sector.

TABLE 7
The current state of the beaches in Playa del Carmen area

Coastal sector	Longitude	Genesis of the sediment	Current state
Tres Ríos – Coco Beach	8.5 km	Biogenic-carbonated	➢ Reduced beach fringe ➢ Scarcely developed dune ➢ Erosion scarps cutting the coastal dune ➢ Rocky outcrops
Coco Beach– Porto Real	1.3 km	Biogenic-carbonated	➢ Scarcely developed dune ➢ Constructions near the shore ➢ Erosion scarps
Porto Real– Playacar	4.3 km	Biogenic-carbonated	➢ High density of coastal occupation ➢ Coastal dune eliminated ➢ Rocky outcrops ➢ Presence of walls, groynes and breakwaters
Playacar– Calica	4 km	Biogenic-carbonated	➢ Absence of sand accumulations

As a synthesis, it may be pointed out that the beaches in Tres Ríos–Calica coastal sector present a remarkable degree of deterioration as a consequence of the sand loss. In general, it is appreciated a reduced fringe of emerged beach, with a scarcely developed dune under 1 m of height. The main erosion indications are the scarps that reach up to the coastal dune, marking the continuous retreat of the coastline, and the rocky surfaces that emerge on the shore and the submarine slope.

Keeping in mind the scarce information available regarding this coastal sector, it is indispensable to develop a research program that allows to deepen in the knowledge of the dynamics and evolution of the beach, and to better interpret the phenomena and processes that affect Playa del Carmen at present. On the basis of the results of these investigations, it will be possible to conceive a planning program that ensures the sustainable use of coastal resources, minimizing the impacts of land-based actions.

CANCUN BEACH

By initiative of the Mexican government and with the objective of opening a source of income of foreign currencies to the country, the vertiginous development of Cancun, one of the most important tourist areas in the world begins in 1970.

At present, Cancun has more than 20,000 rooms and 3 million visitors per year that generate over 2,000 million-dollar revenues and guarantee employment for a population of 300,000 residents.

Although the region has incalculable environmental and historical values that fully justify its tourist potentialities, the natural attractiveness of the beach was the main incentive that attracted the attention of national and foreign investors.

The decision of basing the hotel development on the exploitation of the beach resource caused that the tourist facilities near the sea were quickly extended along the island, disregarding the natural laws that govern the dynamic behavior of sandy coasts.

Cancun beach extends lineally along 12 km., covering the east side of an island with northeast-southwest orientation on the Caribbean coast of Yucatan Peninsula.

Cancun is structurally a barrier island formed during an intense production and accumulation process of calcareous sand of marine origin probably occurred about 15,000–20,000 years ago, under suitable climatic conditions for the occurrence of such processes.

The voluminous deposition of sand gave origin to a beach profile characterized by a potent dune and an extensive berm in the emerged part, and several sandy barriers in the submarine slope, (Picture 8).

Picture 8. Northeast sector of Cancun barrier island in 1974, at the beginning of the tourist development.

The sand transported outside of the beach during the extreme waves was compensated by the input of new material supplied by the skeletal remains of marine organisms (algae, mollusks and foraminifer, among other), maintaining the sedimentary balance of the system.

In recent times and as a consequence of global climate change, it is noticed the decrease in the production of biogenic sands that, together with the continuous sea level rise, has caused a negative unbalance leading to the disappearance of these beaches.

This process is manifested through the erosive scarps in the dunes, which become an important source of supply to the beach at present, with their potent sand reserves.

The analysis of a sand sample taken in front of Gran Oasis Hotel allowed verifying that the sand in Cancun is classified as very fine and of homogeneous grain. The surface of the particles is so refined that it becomes difficult to identify the components, being evident that it is an “old sand", probably coming from the dune.

However, the density of tourist facilities on Cancun coastal front causes that the current input of sand from the dune is very reduced, worsening the erosion problems that occur in front of the hotels.

The current erosion occurring in the beaches caused by the deficits in the natural sand inputs and the sea level rise has been considerably accelerated in Cancun, as a consequence of the negative effect on the sedimentary balance of the substitution of natural dunes by tourist facilities.

This reality was manifest when the strong waves associated to hurricanes Gilbert in 1988 and Roxanne in 1995 caused considerable damages to hotel facilities and the almost total disappearance of the beach.

After several years and in spite of some measures adopted in certain areas, the narrowness of the sun strip, the rocky outcrops and erosion scarps are clear evidences of the erosive tendency in this coast, (picture 9).

Picture 9. Rocky outcrops and occupation of the dune by tourist facilities.

At present, the recovery of the recreational and aesthetic conditions of the beach, as well as the creation of an effective defense for its hotel facilities, constitutes an imperious necessity of Cancun tourist area. Therefore, the corresponding authorities as well as the Association of Hotel Owners of Quintana Roo State carry out the necessary actions to achieve this objective.

The impact of hotel development in Cancun on the beach erosion processes constitutes one of the more notorious examples of destruction and physical alteration that man generates when developing Tourism without an appropriate environmental planning.

4. CASE STUDY - GUATEMALA-BELIZE

THE BEACHES OF GUATEMALAN CARIBBEAN

The Republic of Guatemala is one of the countries of more interest in the continental region of the Wider Caribbean, given the favorable conservation of its natural and cultural patrimonies, as well as its high potentiality to become a tourist destination of international quality.

Nevertheless, the deterioration that Guatemalan beaches generally suffer endangers the tourist development strategy in this Caribbean region; unless concrete actions are implemented at short, medium and long term, leading to obtain scientific–technical information and to execute and control coastal actions in order to strengthen and develop a sustainable sun and beach tourism.

Based on reports provided by the Guatemalan Institute of Tourism (INGUAT) and the information collected in a field trip to the beach areas, the following review of the general characteristics of Guatemala's Caribbean coast has been elaborated.

Characteristics of the Coasts and Beaches

The Caribbean coast of Guatemala has an extension of 170 km, 90 km of which correspond to beaches. The rest of the coast is conformed by 53 km of mangrove swamps or thick vegetation without beach, 3 km of rocky area, 9 km of urbanized areas (Puerto Barrio and Livingston), 4 km of port areas (Santo Tomas Port) and 10 km of cliffs (Cerro San Gil and Monte de Oro).

The typology of the beaches in the Caribbean coast is closely related to the physical-geographical regions to which they belong and according to their location inside the Amatique Bay or toward the Gulf of Honduras. The association of these two factors determines three beach types:

a) Beaches belonging to Izabal depression or valley (Fig. 4).

In the western end of Lake Izabal a constant deposition of alluvial sediments takes place, transported mainly by Polochic River. These terrigenous deposits supply the beaches of the Lake, among which stand out San Felipe and Dorada for receiving a greater affluence of swimmers. The waters of the lake pass by means of Dulce River to Amatique Bay, carrying in this journey meteorized minerals that are deposited in the Bay.

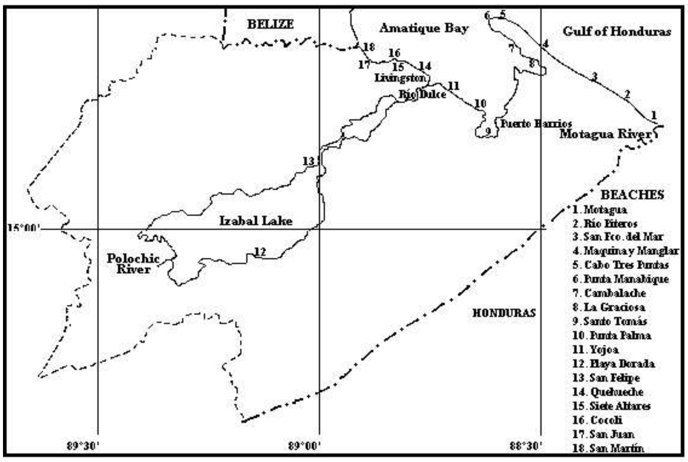


Fig. 4. Location of the beaches in the Guatemalan Caribbean.

The beaches that are formed in this region are relatively narrow, 3 to 4 m wide, although strong waves do not take place for being an area of calm waters. The sand that constitutes these beaches is of fine uniform, sub-angular and sub-rounded grain, predominantly of quartz and feldspath. Although there also appear fragments of rocks and of ferriferous minerals whose color varies from grayish-orange to yellow-grayish. These beaches have an approximate extension of 27 km, alternating with cliffs.

The following beaches belong to this area: Santo Tomás, Punta Palma, Yojoa, Dorada, San Felipe, Quehueche, Siete Altares, Cocolí, San Juan and San Martín (Fig. 4).

b) Beaches belonging to the Motagua depression.

The Motagua River has built an extensive flood plain formed by alluvium of the Quaternary, well-developed meanders, abandoned and fossil, with vast deposits of terrigenous sediments that supply significant volumes of sand to the beaches in the region through its mouth to the Gulf of Honduras, being responsible for the formation of the sand bank that separates Amatique Bay from the Gulf of Honduras.

The beaches in this area are characterized by presenting fine sand formed by sub-rounded and sub-angular minerals: quartz, feldspath, mica, with the presence of dark minerals: serpentine, magnetite and hematite, coming from the river's dragging from continental areas. The combination of these minerals provides to the sands a soft olive-gray color. These beaches are wide as a result of the significant contribution of sediments through the river, reaching about 35–40 m and in some places up to 100 m of width, specifically in front of the river mouth and tidelands. They extend continuously for 50 km from Punta de Manabique to the Motagua River mouth.

The following beaches belong to this area: Motagua, Piteros, San Francisco del Mar, Máquina, Manglar, Cabo Tres Puntas (Fig. 4).

c) Beaches of Punta Manabique,

Located in the Amatique Bay. They belong to the Motagua depression; however they have combined characteristics of both physical-geographical regions.

The beaches are narrow (2 to 4 m), like those in the coasts of Izabal depression, although they are wider (between 8 and 20 m) in some places. Their sands are of fine, uniform, sub-angular and sub-rounded grains. They have a strong presence of quartz and feldspath; but also micas, magnetite and hematite, minerals that provide a pale yellowish, grayish-orange and soft olive-gray color to the sand.

The following beaches belong to this area: Punta Manabique, Cambalache and La Graciosa (Fig. 4).

The general characteristics, as well as the current state of some of the beaches in the Caribbean coast of Guatemala, are summarized in Table 8.

TABLE 8
Diagnosis of the current state of the beaches in the Guatemalan Caribbean

No	Beach	Description	Current State
1	Motagua	10 km of extension. Fine, olive-gray sand. 50% of fragments of serpentine, magnetite and hematite. 50% quartz and feldspath.	➢ Absence of direct anthropogenic activity ➢ Old erosion scarps
2	Piteros River	4 km of extension. Fine, olive-gray sand. 60 % of quartz and feldspath, 40% of fragments of hematite, magnetite and serpentine.	➢ Absence of direct anthropogenic activity ➢ Old erosion scarps
3	San Francisco del Mar	6 km of extension. Fine, olive-gray sand. 60 % quartz and feldspath, 40% of fragments of hematite, magnetite and serpentine.	➢ Absence of direct anthropogenic activity ➢ Old erosion scarps
4	La Máquina and Manglar	10 km of extension. Fine, olive-gray sand. 70 % quartz and feldspath, 25% of fragments of serpentine, hematite and magnetite, 5% remains of seashells.	➢ Absence of direct anthropogenic activity ➢ Old erosion scarps
5	Cabo Tres Puntas	10 km of extension. Fine, olive-gray sand. 70 % quartz and feldspath, 25% of fragments of serpentine, hematite and magnetite, 5% remains of seashells.	➢ Absence of direct anthropogenic activity ➢ Old erosion scarps
6	Punta Manabique	2 km of extension. Sand of fine to medium-size grain, yellow pale. 60 % quartz and feldspath, 30 % magnetite and 10% of rock fragments	➢ Lack of planning and of territorial development policies ➢ Coastal erosion associated to the construction of groynes.
7	El Cambalache	1 km of extension. Fine to mean sand, grayish-orange. 70 % quartz and feldspath, 20 % hematite and magnetite, 10% fragments of serpentine.	➢ Reduced beach fringe ➢ Constructions next to the shore ➢ Erosion scarps
8	La Graciosa	1.6 km of extension. Fine, olive-gray sand. 80 % quartz and feldspath, 20% fragments of rocks and hematite.	➢ Dense occupation of the coast by constructions ➢ Reduced beach fringe ➢ Erosion scarps
9	Santo Tomás	1 km of extension. Artificial beach constituted by terrigenous material of mean to thick grain	➢ Polluted waters ➢ Occupation of the coast by service facilities ➢ Reduced beach fringe ➢ Erosion scarps
10	Punta de Palma	5.5 km of extension. Sand of fine grain, grayish yellow, with 95% of sub - rounded quartz and fragments of metamorphic rocks.	➢ Erosion scarps, emerging tree roots ➢ Illegal appropriation of public beach space ➢ Sand mining
11	Yojoa	9 km of extension. Grayish-yellow fine sand. 95 % quartz and feldspath, 5% fragments of rocks and hematite.	➢ Reduced beach fringe ➢ Erosion scarps
12	Playa Dorada	2 km of extension. 70% quartz, 20 % hematite, 10% of rock fragments	➢ Reduced beach fringe ➢ Occupation of the coast by service facilities ➢ Erosion scarps

13	San Felipe	1 km of extension. 65 % quartz, 20 % hematite, 15% of rock fragments	➢ Erosion scarps ➢ Reduced beach fringe
14	El Quehueche	2 km of extension. Grayish-yellow fine sand. 90 % quartz, 10 % fragments of seashells and magnetite.	➢ Constructions next to the shore ➢ Erosion scarps
15	Siete Altares	1 km of extension. Dark gray, mean sand. 60% of volcanic ashes, 20% of angular quartz, 20% of seashells.	➢ Limited access ➢ Reduced beach fringe
16	Punta Cocolí	Three bays separated by small cliffs, 1.3 km of extension. Fine, grayish-orange sand. 90% quartz and feldspath, and 10% of seashells and magnetite.	➢ Limited access ➢ Reduced beach fringe
17	Playa San Juan	0.45 km of extension. Mean-grain, white sand, with 95% quartz and feldspath, 5% fragments of seashells and rocks.	➢ Limited access ➢ Absence of direct anthropogenic activity ➢ Erosion scarps
18	San Martín	0.3 km of extension. 95% quartz, 5% fragments of seashells, rocks and hematite.	➢ Erosion scarps ➢ Reduced beach fringe

Among the main problems that the beaches in the Caribbean coast of Guatemala present, it is distinguished the lack of territorial planning and of development policies at medium and long term, what results in an anarchical use of the coastal zone, fundamentally by the private sector.

The disproportionate and uncontrolled occupation of the coast by service facilities and summer resorts, as well as the construction of groynes and other obstacles that retain the sand transported along the coast, obstructing its input to the neighboring beaches, are the main causes that generate significant erosion processes.

Sand mining from the beaches is another serious problem identified in Guatemala's coasts. This incorrect human action, if continued, will endanger the existence of valuable sandy coasts of wide social and recreational use.

A very sensitive problem is the pollution of beaches by solid waste and direct discharges, or through the rivers, by domestic wastewater or agro-chemical waste. This problem is more marked in the Santo Tomas Public Beach, for its location in the inner lobe of Amatique Bay and the proximity to polluting focuses generated by the port activity.

Based on the results of the evaluation of the current state of the beaches, two basic ideas can be synthesized:

- ➢ The beaches in the Guatemalan Caribbean are constituted by terrigenous sediments, being the rivers and tidelands the main ways for sand input to the coastal zone.
- ➢ Beach erosion appears as a widespread phenomenon whose main indication is the retreat of the coastline accelerated by the construction of groynes, facilities on the coastal dune and sand mining.

THE COASTS OF BELIZE

The information available on the coasts of Belize allows us to refer to those aspects related to the constitution of Belize's sedimentary facies, mainly for their linkage, at regional level, to Guatemalan coasts and the Mayan Riviera, in Mexico.

Ascending northward along the continental Caribbean coasts from Guatemala to Cancun, Mexico, a succession of sediment types according to their genesis may be observed. The sediments of the coast of Guatemalan Caribbean are predominantly terrigenous; in Belize there appear terrigenous sediments accompanied by biogenic-carbonated ones, giving way to mainly biogenic-carbonated sediments in the coasts of the Mayan Riviera, in Mexico.

Keeping in mind the sedimentological variability of Belize's coasts and its relation to possible erosive events that affect mainly the beaches, this topic is briefly approached as basic information of the diagnosis of erosion in the Caribbean sandy beaches.

Belize's continental margin is the result of the friction movement of the North American and the Caribbean Plates. These tectonic movements have determined the current configuration of the coastline, the extension of the shallow water area, and the distribution of sedimentary facies in individual environments (Fig. 5).

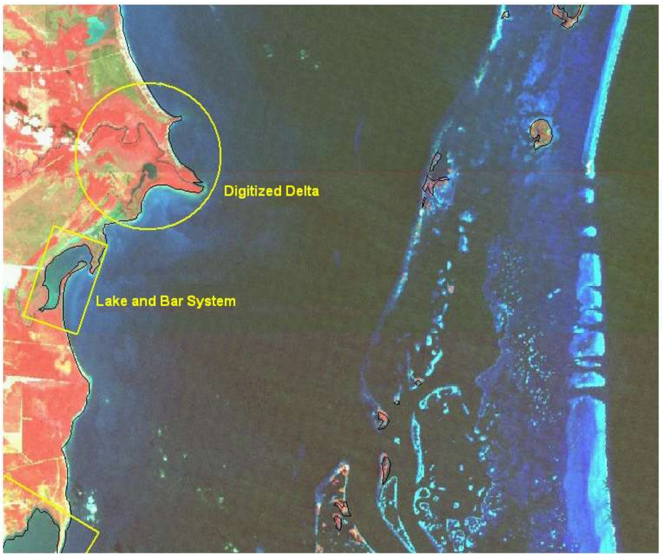


Fig. 5. Partial aerial view of the coastal forms and the reef barrier.

The sediment distribution in the coasts of Belize is due to the combination of the forms of relief produced by tectonic movements and the input of materials not only from terrigenous sources but also from the calcareous remains of marine organisms associated to the reef barrier. Although it should also be added the effect of dissipating the wave energy that produces the great barrier reef.

Belize waters are over-saturated by minerals like calcite and aragonite, what causes that most of the sediments in the submarine slope and next to the reef barrier are carbonated, both from chemical as well as biogenic origin. The terrigenous sediments concentrate mainly on the areas near the coast and are the result of the input of siliceous sediments coming from the rivers and distributed along the coastline by littoral currents (Fig. 6).

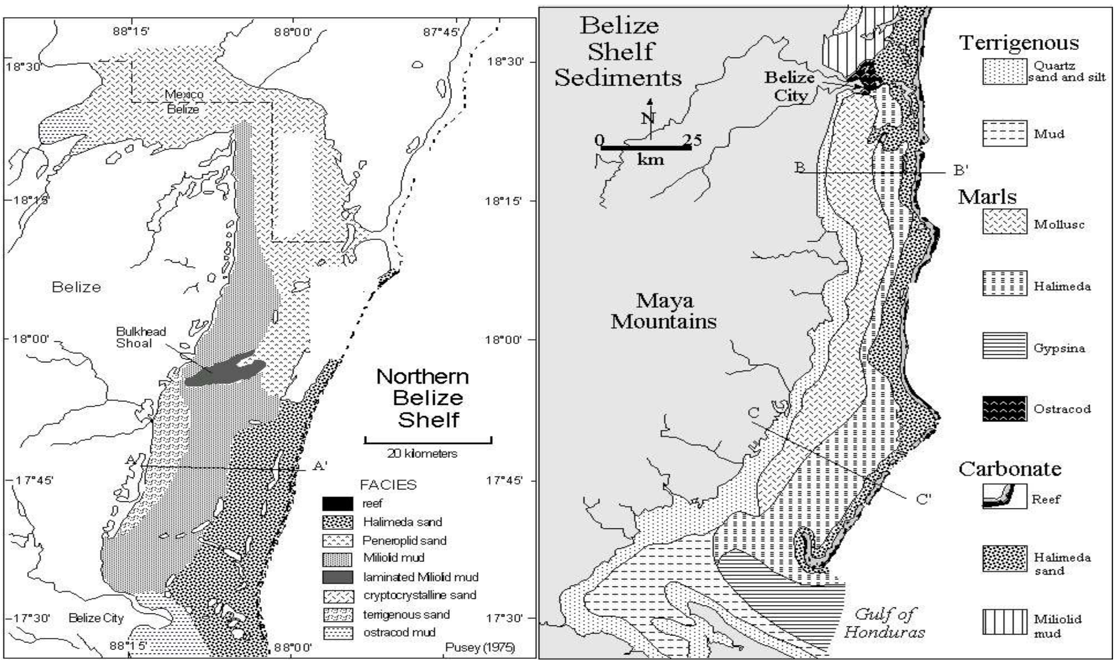


Fig. 6. Distribution of superficial sediments on Belize coast, lagoon and reef barrier.

The characteristics and location of the sediment types that form Belize margin, allow to define three sedimentary strips (Fig. 6):

1. A strip of terrigenous sediments next to the coast, composed of quartz-containing sand and mud.

2. A strip of biogenic-carbonated and terrigenous sediments in the Lagoon area, composed of quartz, mollusks, Halimedas, corals and foraminifers.

3. A strip of biogenic-carbonated sediments next to the reef barrier, constituted by mollusks, Halimedas, corals and foraminifers.

Although no precise information is available on the magnitude and extension of erosion in Belize beaches, there is reference of its existence, fundamentally due to the impacts caused by the occurrence of severe events, like hurricanes, generated in the Gulf of Honduras with a high frequency.

Hurricanes occur in this region with a return period of 2.5 years, causing significant impacts on the continental coasts and the keys for the winds and wave, in spite of the protection provided by the reef barrier. The height of the maximum wave reported for the region up to 1990 is 10 m with a period of 12.7 s, occurred during hurricane Greta in 1978.

5. CASE STUDY - COLOMBIA.

The information corresponding to the erosion problem in Colombian Caribbean Coast was presented by Professor Georges Vernette at the meeting held in Havana in February, and it is the result of research works developed by the Institute of Marine and Coastal Investigations of Colombia, INVEMAR.

In the south of the Caribbean Sea, the Colombian coast is limited to the southwest by the frontier with Panama (Cabo Tiburón, 8º 04’ No, 77º 19’ West), and to the northeast by the frontier with Venezuela (Cabo Castillete, 11º50’North, 71º18’West); with an approximate extension of 1,600 km (Fig. 7).

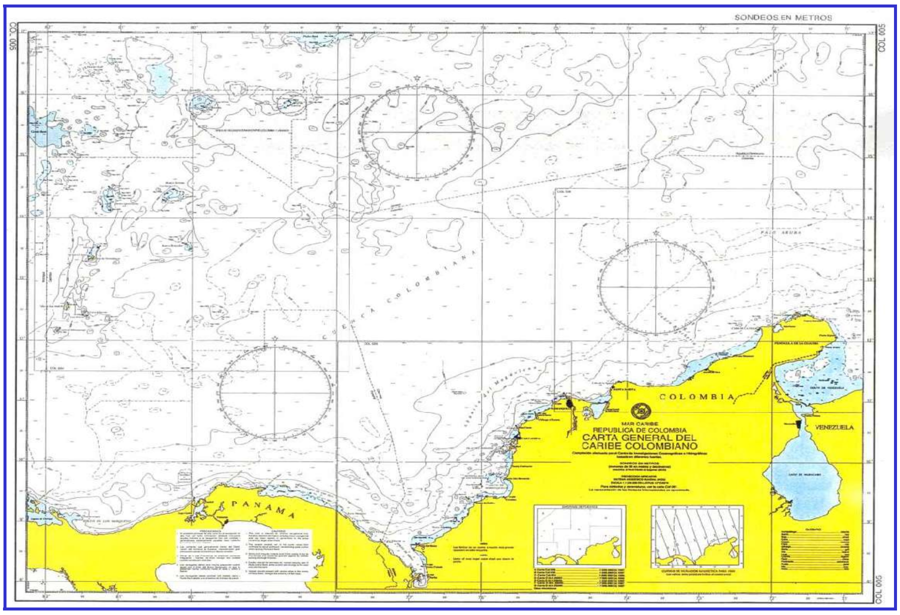


Fig. 7. Colombian coast in the south of the Caribbean Sea.

The beaches, that is to say the mid-littoral fringe constituted by sandy sediment, extend for more than a thousand kilometers; mainly in La Guajira, between Santa Marta and Cartagena, the Gulf of Morrosquillo, and up to the Gulf of Urabá. In the mountainous sectors (Sierra Nevada de Santa Marta), the beaches are narrow, of little extension and separated by rocky cliffs. Among the gulfs of Morrosquillo and Urabá, the coastal zone corresponds to littoral terraces constituted by unconsolidated formations (mainly sandstone and argillaceous sediment) and, consequently, the beaches are narrow, although of long extensions.

Marine erosion has been the dominant historical tendency along most of the beaches with predominant erosion rhythms between 0.5 and 5 m/year (Picture 10). The variations of the coastline in the last four decades have reached more than a kilometer in some sectors (mainly between the gulfs of Morrosquillo and Urabá), at average retreat speeds up to more than 40 m/year that may be considered exceptionally high, even at global scale.

Picture 10. Erosion scarps as a source of sand input to the beaches.

Picture 11. Erosion caused by inadequate use of coastal defenses.

Among the causes for the erosion of these coasts it may be considered the relative changes in sea level, associated to natural geotectonic movements (particularly neotectonic and diapirism of muds). Marine erosion in the above-mentioned sectors is also facilitated by the geologic conformation of coastal cliffs, mostly composed of fractured and meteorized argillaceous sediments, and by unconsolidated sediments of mainly sandy constitution. However, in most of the settlements, the natural erosive tendencies have been strongly accelerated by human interventions: exploitation of sands and gravel on the coast, construction of dams that work as sediment traps, incorrect location of groynes and inadequate defense works (Picture 11).

The main sources of sands for the beaches are:

- coastal erosion and the wind for La Guajira coastal sector;
- inputs of Magdalena river for the sandy coastal fringe between Santa Marta and the mouth of Magdalena river;
- inputs of Magdalena river and coastal erosion for the littoral between the mouth of Magdalena river and Cartagena;
- sandy substrate for the gulf of Morrosquillo;

- inputs of Sinú river and coastal erosion for the littoral between the mouth of Sinú river and the gulf of Urabá;
  - inputs of Atrato river for the coasts of the gulf of Urabá.

As it may be appreciated, the sandy sediments that constitute the beaches mainly arrive at the Coastal Zone through the rivers, following the pattern that characterizes continental areas.

In the Colombian Caribbean, tourism on the coasts is directly associated to urban areas, standing out the cities of Cartagena and Santa Marta. Barranquilla, on the margin of Magdalena River, near its mouth, may be also considered.

Cartagena and Santa Marta are tourist sites, as well as the localities of Tolú and Coveñas in the gulf of Morrosquillo. Other tourist places correspond to the narrow bays (Taganga, Neguange, Concha, Parque Tayrona) in the rocky coast to the foot of the Sierra Nevada de Santa Marta.

It should be highlighted that Colombia has an entire sector of islands (San Andrés, Providencia and Santa Catalina) and keys (Albuquerque, Quitasueño, Roncador, Serranilla) in the central Caribbean that could be included in the present report as part of the insular Caribbean.

III ECONOMIC IMPORTANCE OF THE BEACHES

Through the Case Studies it has been demonstrated that beaches constitute an important natural resource not only for the continental States of the Wider Caribbean, but also for the Small Island Developing States. However, for the Small Islands, the lack of other resources like fuels and minerals and scarce availability of water resources cause that the tourist exploitation of the coasts becomes a fundamental economic activity.

It should also be highlighted that due to their condition of small islands, the coast receives in a very direct way the influence of the whole social and economic activity of the country. This constitutes a factor of additional environmental risk that demands special attention to the Coastal Zone on the part of the whole society. As García and Juanes (1996) point out “the planning and management of coastal resources is essentially synonymous of the planning and management of national resources”.

Thus, although the man's activities that cause environmental degradation of the Coastal Zone are the same for both the continental area of the Caribbean and the islands, the dependence that the latter have on tourism suggests a peculiar analysis of them.

In Table 9 it may be observed theas high percentage that represents the service sector with regard to agriculture and industry in all the Island States.

What tourism means for those economies can be better appreciated through its contribution to the GDP, (Gross Domestic Product), (Table 10). In the case of the Small Islands, with the exception of Martinique and Trinidad and Tobago, tourism represents percentages that vary between 13.2% in Jamaica and 61.2% in Turks and Caicos. As an average, for the Caribbean as a whole, tourism revenues represent 24.31% of the gross domestic product of the region.

TABLE 9
Main macroeconomic indicators of the Caribbean

CARIBBEAN COUNTRIES	SECTORS OF ECONOMY (%)			COMMERCIAL BALANCE (*)	
	Agriculture	Industry	Services	Exportation	Importation
Anguilla	4.0	18.0	78.0	4.5	57.6
Antigua & Barbuda	4.0	12.5	83.5	38.0	330.0
Dutch Antilles	1.0	15.0	84.0	276.0	1500.0
Aruba	n.d.	n.d.	n.d.	2200.0	2500.0
Bahamas	3.0	7.0	90.0	376.8	1730.0
Barbados	4.0	16.0	80.0	260.0	800.3
Bermuda	1.0	10.0	89.0	56.0	739.0
Cuba	7.0	37.0	56.0	1800.0	3400.0
Dominica	21.0	16.0	63.0	60.7	126.0
Granada	9.7	15.0	75.3	62.3	217.5
Guadeloupe	15.0	17.0	68.0	140.0	1700.0
Haiti	32.0	20.0	48.0	186.0	1200.0
Cayman Islands	1.4	3.2	95.4	1.5	507.6
British Virgin Islands	1.8	6.2	92.0	6.2	220.0
U.S. Virgin Islands	n.d.	n.d.	n.d.	n.d.	n.d.
Jamaica	7.4	35.2	57.4	1700.0	3000.0
Martinique	6.0	11.0	83.0	250.0	2000.0
Monserrat	5.4	13.6	81.0	1.5	26.0
Puerto Rico	1.0	45.0	54.0	3800.5	2700.0
Dominican Republic	11.3	32.2	56.5	5800.0	9600.0
Santa Lucia	10.7	32.3	57.0	68.3	319.4
St. Kitts & Nevis	5.5	22.5	72.0	53.2	151.5
St. Vincent & Grdnes.	10.6	17.5	71.9	53.7	185.6
Trinidad & Tobago	2.0	44.0	54.0	3200.0	3000.0
Turks & Caicos	n.d.	n.d.	n.d.	4.7	46.6

(*) In millions $. Source: World Factbook 2002.

TABLE 10
Tourist revenues as part of the GDP per capita

DESTINATION	GDP (in millions $)	GDP per capita	Tourism Revenues (in millions $)	% of the GDP	Population	INDEX
Dominican Rep.	48300.0	5628.40	2483.2	5.1	8581477	289.37
Puerto Rico	39000.0	9905.22	2325.8	6.0	3937.316	590.71
Cuba	27274.0	2425.76	1952.0	7.2	11243500	173.61
Bahamas	4500.0	15108.17	1582.9	35.2	297652	5314.38
Jamaica	9700.0	3638.91	1279.5	13.2	2665636	480.00
US Virgin Is.	1800.0	14728.63	954.9	53.1	122211	7813.54
Aruba	2000.0	28568.57	773.5	38.7	70007	11048.00
Barbados	4000.0	14528.21	666.2	16.7	275330	2419.64
Bermuda	2100.0	33069.30	479.1	22.8	63503	7544.53
Cayman Is.	930.0	26177.27	439.4	47.2	35527	12368.06
Martinique	4390.0	10491.00	404.0	9.2	418454	965.46
St. Lucia	700.0	4425.39	311.1	44.4	158.178	1966.77
Antig. & Barb.	533.0	7958.88	290.0	54.4	66970	4330.30
Trin. & Tobag.	11200.0	9575.25	209.6	1.9	1169682	179.19
St. Vinc & Gren.	322.0	2777.25	78.9	24.5	115942	680.51
St. Kitts & Nevis	274.0	7069.87	70.4	25.7	38756	1816.49
Granada	394.0	4415.70	66.6	16.9	89227	746.41
Anguilla	96.0	7912.96	56.5	58.9	12132	4657.11
Dominica	290.0	4096.86	48.8	16.8	70786	689.40
Turks & Caicos	128.0	7063.62	23.0	61.2	18122	1313.21

Montserrat	31.0	4092.95	10.7	34.5	7574	1412.73
Dutch Antilles	2400.0	11400.00	N.D.		212226	

Index: gross tourist revenues per capita. Source: World Factbook 2002.

The rhythm with which tourism development takes place in the Caribbean islands may be appreciated in Table 11 that shows the percentages of growth for this economic activity between 1990 and 1994. Another form of evaluating the growth in this activity is through the number of visitors per year. As it may be observed in Table 12, from 1990 to 1999 the great majority of countries maintained positive average growth rates and in some cases with high values, such as Cuba (18%), Guadeloupe (10%), and Turks and Caicos (12%). The growth in the Dominican Republic was also important with a rate of 8.2%.

TABLE 11
Tourism growth in the Wider Caribbean, 1990 - 1994

NS	Surinam	-30%	SC	St. Kitts &Nevis	24%
BF	Bahamas	-3%	DO	Dominica	25%
BB	Barbados	-2%	AC	Antigua & Barbuda	28%
HA	Haiti	0%	GJ	Granada	33%
VC	St. Vincent. & Grenadines	2%	AR	Aruba	34%
NA	Dutch Antilles (North)	6%	CJ	Cayman Islands	35%
NA	Dutch Antilles (South)	13%	TD	Trinidad & Tobago	37%
MH	Montserrat	14%	AV	Anguilla	40%
DR	Dominican Republic	15%	MB	Martinique	49%
JM	Jamaica	16%	VI	British Virgin Islands	50%
VQ	US Virgin Islands	17%	BH	Belize	51%
RQ	Puerto Rico	19%	ST	St. Lucia	58%
Carib	Caribbean	20%	GP	Guadeloupe	65%
			TK	Turks & Caicos	69%
			GY	Guyana	76%
			CU	Cuba	81%

Source: Growth Percentage calculated by the Caribbean Tourism Organization, 1994.

TABLE 12
Tourist arrivals to the Caribbean, 1990-1999, (figures in thousands).

Destinations	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**TPC**
Anguilla	31.2	29.7	30.4	37.7	43.7	38.5	37.5	43.2	43.9	46.8	4.6
Antig. & Barb.	205.7	204.7	217.9	249.4	262.9	220.0	228.2	240.4	234.3	239.6	1.7
Aruba	432.8	501.3	541.7	562.0	582.1	618.9	640.8	646.0	647.4	683.3	5.2
Bahamas	1561.1	1427.0	1338.9	1488.7	1516.0	1598.1	1633.1	1617.6	1527.7	1577.1	0.1
Barbados	432.1	215.4	385.5	396.0	425.6	442.1	447.1	472.3	512.4	517.9	2.0
Bermuda	432.7	385.3	373.5	412.5	416.0	387.5	389.6	379.7	368.8	354.0	-2.0
Bonaire	41.3	49.5	50.6	55.1	55.8	59.4	65.1	62.8	61.7	61.5	4.5
Cayman Is.	253.2	237.3	245.9	278.6	314.4	361.4	373.3	381.2	404.2	394.5	5.0
Cuba	340.3	424.0	460.6	544.1	617.3	762.7	1004.3	1170.1	1415.8	1602.8	18.0
Curazao	207.7	205.7	206.9	214.1	226.1	223.8	214.3	205.1	198.6	198.3	-0.1
Dominica	45.1	46.3	47.0	51.9	56.5	60.5	63.3	65.5	65.5	73.5	5.5
Granada	125.7	85.0	87.6	93.9	109.0	108.0	108.2	110.8	115.8	125.3	0.0
Guadeloupe	288.4	132.3	340.5	452.7	555.6	640.0	625.0	660.0	693.0	711.0	10.0
Haiti	120.0	119.0	89.5	76.7	70.3	145.4	150.2	148.7	146.8	143.4	1.9
Jamaica	840.8	844.6	1057.2	1105.4	1098.3	1147.0	1162.5	1192.2	1225.3	1248.4	4.4
Martinique	281.5	315.1	320.7	366.4	419.0	457.2	477.0	513.2	548.8	564.3	8.0
Montserrat	18.7	19.2	17.3	21.0	21.3	17.7	8.7	5.1	7.5	9.9	-6.0
Puerto Rico	n.d.	n.d.	2753.9	2923.2	3112.7	3053.9	3127.7	3378.5	3492.3	3228.4	2.2
Dominican R.	n.d.	n.d.	1523.8	1636.4	1766.9	1775.9	1925.6	2211.4	2309.1	2649.4	8.2

Saba	4.9	7.3	18.1	16.4	14.1	10.0	9.8	10.6	10.6	9.3	9.5
St. Eustatius	n.d.	n.d.	12.9	9.5	10.7	8.8	8.2	8.5	8.6	9.2	-4.0
St. K & Nevis	75.7	83.9	88.3	88.6	94.2	78.9	84.2	88.3	93.2	84.0	1.1
St. Lucia	138.4	159.0	177.5	194.1	218.6	232.3	235.7	248.4	252.2	260.6	7.2
St. Martin	564.7	548.0	568.7	520.2	585.7	479.7	364.7	439.2	458.5	444.8	-2.0
St. Vincent & Grenadines	53.9	51.6	53.1	56.7	55.0	60.2	57.9	65.1	67.2	68.3	2.6
Trin & Tobag	194.0	219.7	234.7	248.0	265.6	259.8	265.9	324.3	347.7	358.8	7.0
Tur. & Caicos	41.9	54.6	52.0	66.8	70.9	77.8	86.5	92.3	105.9	117.6	12.0
Virgin I UK	160.1	136.4	116.9	200.2	238.7	219.5	243.7	244.3	279.1	285.9	6.6
Virgin I US	370.0	376.4	487.3	549.5	540.5	454.0	372.6	392.9	422.3	483.8	3.0
Cancun	n.d.	n.d.	n.d.	1979.4	2044.4	2195.1	2311.6	2621.3	2664.2	2818.3	6.0

Source: Summary of the Caribbean 2001. Caribbean Tourism Organization.
Other data relating to growth in the number of hotel rooms and arrival of cruises to the Caribbean could be useful to reaffirm the high significance of tourism for the region.

However, it should be pointed out that the economic importance of tourism, and particularly of the one developed in the Coastal Zone, does not constitute an exclusivity of the Caribbean. In fact, travel and tourism is the world's largest economic activity, contributing $ 3.5 trillion to the world's GDP in 2001 and presenting an average growth of 9 % per year since 1985, (data from the World Tourism Organization, taken from Houston 2002).

In correspondence with what happens worldwide, in the USA travel and tourism economy contributes $ 1.2 trillion to the GDP, what represents 11.6% of U.S. output, the largest of all the branches of economy, (Travel and Tourism Council, 2001b, taken from Houston 2002). Likewise Houston (2002) highlights what this activity means as a source of employment, export values, federal and local tax collection, among other economic aspects.

Coastal states in the U.S. receive about 85% of tourist-related revenues because beaches are tremendously popular (World Almanac 2001, in Houston 2002). Although there are many interior attractions from Yellowstone to the Grand Canyon and from Las Vegas to Branson, Missouri, the popularity of beaches dominates tourism.

For example, Miami Beach alone, with 21 million tourists a year, receives almost twice as many tourist visits as the combined number of tourist visits to Yellowstone (3.4 million), the Grand Canyon (4.5 million) and Yosemite (3.4 million) (National Park Service 2001, in Houston 2002).

It is estimated that each year approximately 180 million Americans make 2 billion visits to ocean, gulf and inland beaches (Clean Beaches Council 2001, in Houston 2002).

Houston (2002) points out that beaches are the leading tourist destination (USA Today 1993, Carlson Wagonlit Travel Agent Poll 1998, Washingtonpost.com Poll 2001, Chivas Poll 2001). Seventy-five percent of summer travelers plan to visit beaches (Morgan 2000).
Beach erosion is the number one concern that Americans who visit beaches have about beaches (Hall and Staimer 1995, in Houston 2002). With 33,000 km of eroding shoreline and 4,300 km of critically eroding shoreline, beach erosion is a serious threat to the national economy, (U.S. Army Corps of Engineers 1994, in Houston 2002).

Beach nourishment has been the most used engineering alternative in the USA, to return to the beaches the tourist attraction affected by the erosion processes.

The project executed in Miami Beach in the late 1970's meant a quick recovery of the physical conditions of the beach and brought about the economic recovery of that important tourist location.

Beach attendance increased from 8 million in 1978 to 21 million in 1983 (Wielgel 1992), and the number of foreign tourists visiting Miami increased from 2.3 to 5.6 million from 1980 to 2000 (Lang 2001). (Houston 2002).

The annual foreign revenue from tourists at Miami Beach of $ 2.4 billion is about 50 times the $52-million cost of the Miami Beach beach-nourishment project that has lasted over 20 years. It is estimated that for every $1 that has been invested annually to nourish the beaches at Miami Beach, Miami Beach has received almost $500 annually in foreign exchange (Houston 2002).

But the investments to preserve and improve the physical conditions of beaches used by the tourist industry in important centers of Europe and Japan are even higher than those executed in the USA. Also, in Australia and other Asian countries actions are carried out toward the protection and restoration of beaches linked to tourism.

The effort to maintain the physical conditions of the coasts has led to the current existence of a world economy in beach tourism that gives consumers ample choices.

If Florida beaches become run down for any reason, German tourists can choose Spanish beaches, and if Hawaiian beaches decline, Japanese tourists can choose Australia's Gold Coast (Houston 2002).

Likewise the other tourism centers in the world, the Caribbean is exposed to that increasingly competitive market.

The Caribbean still presents as unbeatable advantages its beaches with exceptional natural conditions and a climate that supports outdoor activities in any season of the year.

However, beach erosion caused by natural phenomena as well as by man's diverse activities, and the insufficient legal and scientific-technical training to implement the regulative and engineering measures required for beach maintenance and recovery, constitute immediate threats to the sustainable development of tourism in the Caribbean.

IV APPLICATION OF NORMATIVE AND REGULATIVE MEASURES TO CONTROL BEACH EROSION

The identification of man's inappropriate actions as causes of erosion and in many cases of critical erosion, allows to understand that only through the application of regulative measures for the use of the Coastal Zone it is possible to reduce its physical deterioration significantly.

As the topic of legislation with respect to the protection of the Coastal Zone in the Caribbean region is developed by another work group, it will only be approached in this report with the objective of underlining the importance of the implementation of an Integrated Coastal Zone Management, (ICZM).

Usually, the first challenge of an ICZM is the definition of the physical limits of the Coastal Zone in which it will be applied, by means of legal bodies, the regulations for environmental protection.

In this sense, the most widespread problem in existing regulations is that the landward limit of the Coastal Zone is established at a fixed distance measured from the line of maximum sea penetration. That definition ignores the significant differences that exist among the different types of coasts and their dynamic processes. This means, for example, that a facility can be located at the same distance to the sea in a cliff as in a beach, without keeping in mind the erosive effect that the facility may cause in the case of the beach. In the Caribbean there are many examples of facilities incorrectly located on the dune and that, however, fulfill the limits established in the regulations effective in those countries.

A novel treatment to the topic of Coastal Zone limits may be found in Decree-Law 212 for the Management of the Coastal Zone, in force in Cuba since 2000, in which the landward limits are established according to the morphological and dynamic differences of the different types of coasts. Furthermore, it establishes a Protection Zone for the Coastal Zone whose landward extension also depends on the coast type.

For example, in the case of beaches with dunes, the landward limit of the Coastal Zone is the inflection of the dune in its inner side, independently of the dune dimensions. With the limits established this way, the protection of coastal ecosystems is guaranteed, and land use becomes more rational, (Fig. 8).

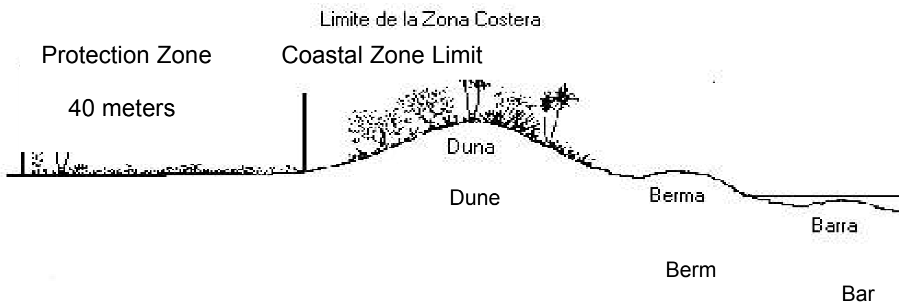


Fig. 8. Limit of the Coastal Zone and the Protection Zone in a beach with dune.

Once defined the limits of the Coastal Zone and the Protection Zone, the regulations for the use of both sectors are established, specific prohibitions are pointed out and the criteria of contraventions are determined.

Having an appropriate legal instrument to approach the Coastal Zone issue is an essential starting point to implement the ICZM.

Cambers (1996) highlights how the implementation of the ICZM constitutes a relatively novel activity in the Small Caribbean Islands, what may be extended to the whole region. According to the analysis on the challenges that the countries of the region face in order to develop the ICZM, Cambers (1996) presents the following recommendations:

1. To develop closer links between professionals in Caribbean academic institutions and government Coastal Zone Management agencies and to develop applied research projects for specific solutions to specific problems facing coastal managers.

2. To develop a cooperative approach between the Coastal Zone Management agencies, academic institutions and lending institutions to prepare quantitative coastal resources inventories.

3. To encourage technical cooperation between developing countries.

4. To develop tools which will convince politicians and senior administrators of the need to consider the longer term view point.

5. To strengthen physical planning in the small island states.

6. To encourage lending institutions to make equipment more readily available.

In a summarized manner, Professor Cambers' recommendations are included in the recommendations of the present report.

Understanding that the experiences reached in Varadero beach, with the implementation of an action program coordinated among government authorities, the Ministry of Tourism and the environmental institutions of the Ministry of Science, Technology and Environment, may serve as reference for other countries in the region, it has been considered convenient to include a description of the above-mentioned action program.

Integrated Action Program for the Recovery, Maintenance and Improvement of Varadero Beach. Example of an action in favor of achieving an Integrated Coastal Zone Management.

Antecedents

Varadero Beach constitutes a very particular coastal sector from the socioeconomic and environmental point of view, motivated by the tourist development that it experiences at present and its vicinity to big urban and industrial centers like Havana City, Matanzas and Cárdenas. Moreover, an intense oil extraction activity is developed in its surroundings, which is very important for Cuban economy, but potentially aggressive to the environment and thus to the tourist activity.

Since the 1970's the beach began to evidence, mainly in the urbanized sector, a violent erosion process, as well as certain level of danger of water and air pollution for the increase in oil exploitation in the area.

Starting from investigations carried out by the Institute of Oceanology, it was possible to identify the causes that originated the physical deterioration of the beach. Actions in favor of its recovery began to be undertaken, mainly directed at restituting the natural vegetation, totally prohibiting the sand mining, and demolishing walls and facilities on the dune.

Following this action line, in 1986 the National Institute of Tourism, (INTUR) and the Institute of Oceanology elaborated a plan of measures intended in three fundamental directions:

1. Increase the sand inputs to the beach balance artificially

2. Restore the beach and dune profile

3. Control environmental pollution.

In spite of all the measures adopted, in 1996 the beach once again presented a critical situation with a visible degradation of its natural environment. It is in this period when the Investor Office for the Recovery of Varadero Beach is created. Its fundamental objective is to direct and organize the funds devoted to the recovery and maintenance of this coastal sector, as well as to promote projects and investigations related to this topic, becoming an interface between the Ministry of Tourism (MINTUR) and the institutions in charge of providing and executing the solutions to existing problems.

From this moment on, and in coordination with diverse organizations and institutions, new measures are carried out, such as the protection to facilities, guidance to investors for the micro-location of new tourist and public works; regeneration, monitoring and periodic maintenance of the beach mainly using the Artificial Sand Nourishment; rehabilitation of the dunes and their natural vegetation, and environmental training actions.

Taking into consideration these actions and the need to achieve an integral view of them, at the end of 2000 the Investor Office for the Recovery of Varadero Beach and the Center of Environmental Services in Matanzas, decide to create a multidisciplinary group to carry out a "Physical–Environmental Diagnosis of Varadero Beach" that allowed to identify the problems and with these results, to elaborate and put into practice an "Integrated Action Programs for the Recovery, Maintenance and Improvement of the Beach", which we will explain briefly.

Theoretical – methodological framework and basic principles on which the program is sustained.

The essential theoretical conception on which this program is sustained is that the beach is a coastal system of high natural ecological significance, because it is exactly where land and sea meet with their multiple interactions; and of high economic, social and environmental significance, because it constitutes the main support of the recreational tourist activity that distinguishes this geographical space.

In accordance with this theoretical–methodological framework, three basic principles are followed:

1. The beach is a coastal system rich in elements, resources, fragile ecological and natural processes that requires an integrated approach in its protection, management and rational exploitation.

2. It is required a wide agreement and cooperation among all the levels and sectors that participate, condition or influence the protection, management and rational exploitation of this coastal system.

3. The identification of environmental impacts and problems that result from human activities constitute the starting challenge in the conformation, practical implementation and continuous improvement of the program.

Objectives of the program:

Based on all the above exposed, the program has the following objectives:

- Protect and manage the coastal system, its elements, resources and processes as natural basis of all the tourist exploitation to which the zone is subject.
- Recover and improve the beach sectors that currently present an unfavorable situation as regards their ecological-environmental functioning and their aesthetic-scenic view.
- Contribute to the success of the tourist activity that takes place in the peninsula at present, offering a favorable image of its natural environment.
- Contribute to the environmental education and training of investors, construction workers, tourism workers, decision-makers and general public, in topics related to the functioning, exploitation and protection of the coastal zone.
- Monitor and control by means of effective measures the levels of environmental pollution in the area.

Main problems identified during the diagnosis stage

Knowing the framework, principles and objectives that sustain the program, it was carried out the diagnosis aimed at identifying the problems that occur in Varadero Beach and looking for the most favorable ways to implement the action program.

In synthesis the problems detected may be classified in three big groups very related among themselves:

1. Damages to the physical environment due to erosion problems.

a. Existence of points where the erosive processes to which the beach is subjected are manifested with more intensity.
b. Erosion problems due to bad pluvial drainage in some intersections, terraces and roofs of facilities.

2. Environmental deterioration of the coastal fringe.

a. Dune areas very degraded as for their vegetation and poor reforestation of some sectors.
b. Existence of small dumping sites.
c. Presence of animals of riding in the beach area.

d. Problems of environmental planning and lack of staff's training.

e. Cut on the dunes for the access to the beach of cleaning vehicles or of other nature.
f. Existence of great quantity of permanent facilities in the dune yet.
g. Poor conservation state and incorrect design of some temporary facilities.
h. Existence of facility remains in the beach area.
i. Poor state of the delimiting fence in the sectors where it exists and need to extend it to other sectors.
j. Nonexistence of a signaling system in the coastal zone with the objective of regulating its use, guiding and educating the swimmers.
k. Insufficient training of the staff that works related to the beach area in some aspects concerning the topic.

Structure of the program

Once finished the diagnosis, and already with all the necessary elements, it is decided to guide the actions divided in seven subprograms, each with its concrete tasks, as it is shown in Figure 9.

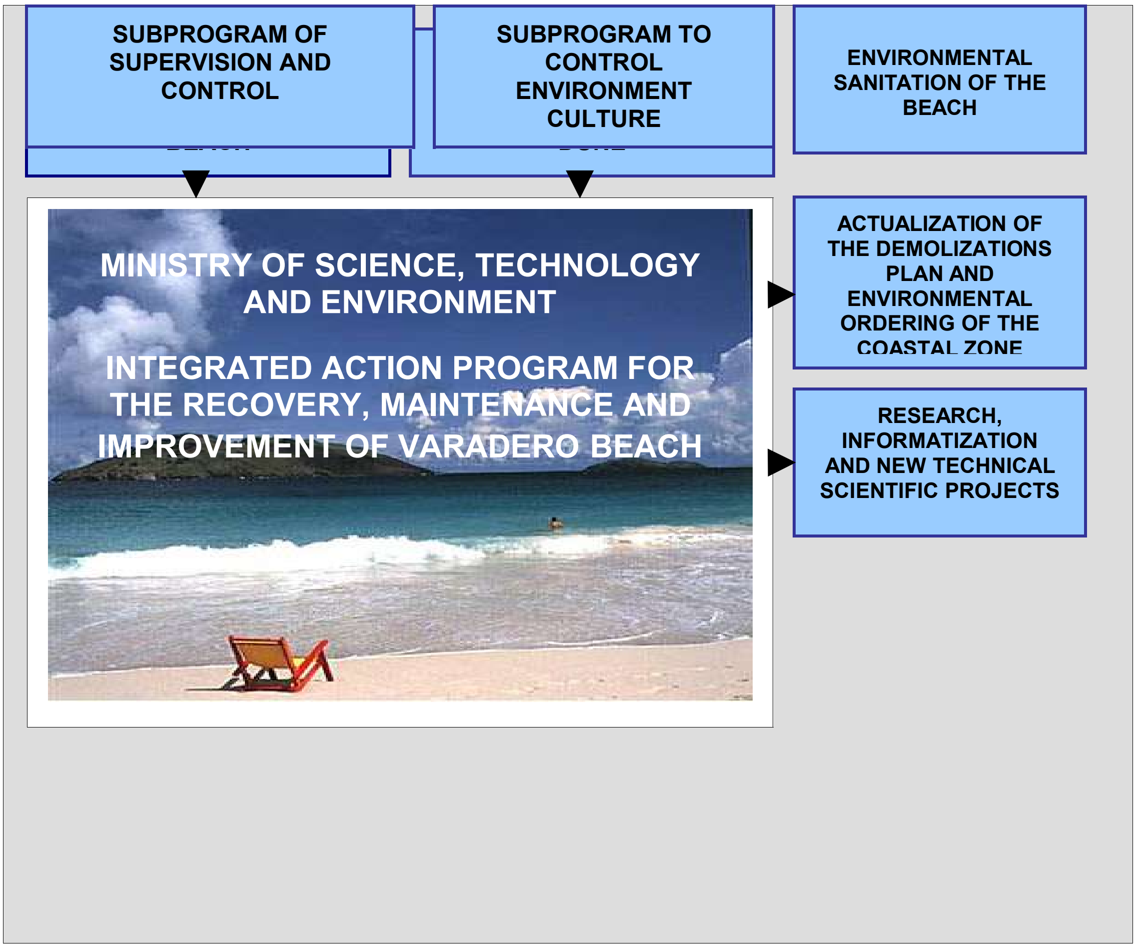


Fig. 9. Subprograms that compose the Integrated Action Program for the Recovery, Maintenance and Improvement of Varadero beach.

Functional Structure and Evaluation of the Program

The starting put into practice and continuous improvement of this program is the responsibility of a board that is coordinated by the Investor Office for the Recovery of Varadero Beach. The organizations and entities that are linked to the topic in one way or another are represented in this coordinating board, whose current structure is shown in Figure 10.

This board meets each quarter, to evaluate and activate the execution of the program and an annual workshop is carried out that constitutes the moment to balance the work carried out, where new ideas and practices are approved for the continuous improvement. This moment also allows presenting results and interacting with Government instances in the territory and at higher levels. Besides, a diagnosis of the beach is carried out every year, which permits to modernize and re-focus the fundamental actions of the whole program.

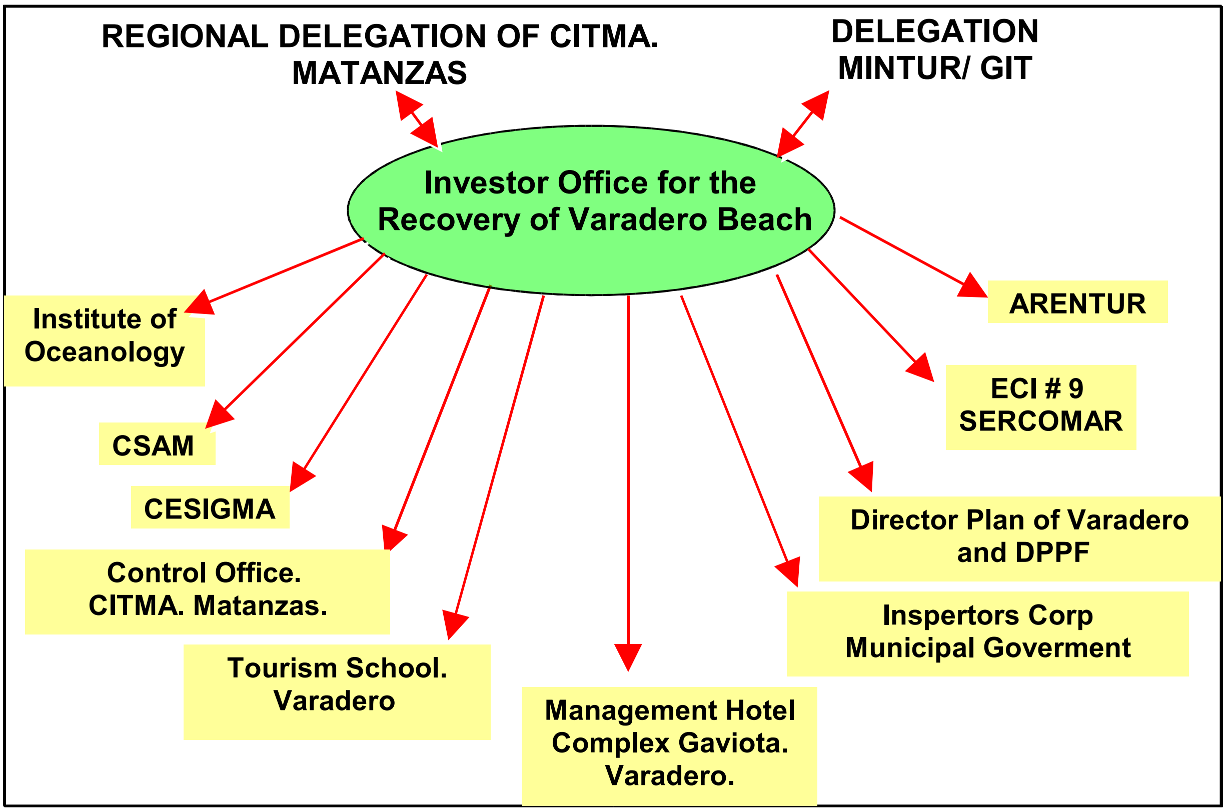


Fig. 10. Structure of the Coordinating Board of the Integrated Action Program for the Recovery, Maintenance and Improvement of Varadero beach.

V APPLICATION OF ENGINEERING MEASURES TO CONTROL BEACH EROSION

So far, after little more than two years of work, it is already possible to see the results, being achieved a greater coordination and effectiveness in the coastal zone planning actions; environmental education, monitoring and maintenance of the beach; environmental cleaning, restoration and recovery of environmentally degraded spaces, all which forces to a continuous improvement in the program's structure to achieve a greater effectiveness in Coastal Zone Management.

Peña (1994), during the "Hispanic-Cuban Seminar on Management and Actions in the Coast", highlights how the habit of coastal engineers to project port protection led to the idea that a coastal work necessarily had to include robust groynes calculated following the model of port protection dikes. This tendency generalized in the world in the 50's and 60's led to many failures, occurred not only because of the inefficiency of the works to solve beach erosion, but also for their negative influences on bordering sectors and the landscape deterioration of the coast.

Opposed to this tendency, since the 1970's the use of artificial sand nourishment has been increasing. Although its application has not had satisfactory results in all the cases, it is unquestionably advantageous in what concerns the conservation of the beach natural conditions.

In the specialized literature, when referring to these two forms of approaching the solution to beach erosion in coastal engineering, it is frequently spoken of "hard" and "soft" solutions.

In fact, practice demonstrates that the success does not depend on the hard or soft character of the work, but on the need that the engineer has to base his solution on the knowledge of the coastal system operation and to act when strictly necessary.

Establishing as a philosophy in coastal engineering the reduction to the minimum of actions to mitigate beach erosion and giving priority to regulative and planning activities that reduce or eliminate the erosive agents, is not an easy task if one keeps in mind that there exist strong managerial interests behind those coastal actions.

However, in the last two decades the application of Artificial Beach Nourishment has become the most widespread alternative worldwide. Professor Maurice Schwartz, during his conference in the experts meeting in Havana, explained that on the East Coast, the Gulf Coast and the Great Lakes of the United States, 1305 sand deposition or re-deposition actions have taken place in an extension of 6000 km at a cost of $2 500 million.

The Army Corps of Engineers began the largest beach restoration project in the United States in 1979-1980 in Miami Beach, in the Dade County. The project consisted in the deposition of 13.5 million cubic yards in 9.3 miles of coast to create a new beach 300 feet wide. Additionally, some 211 000 annual cubic yards are required to maintain the desired beach width. The original project had a cost of $62 million, (University of West Florida, 1985).

In general, engineering actions in the Caribbean have been characterized by responding more to the initiative of isolated proprietors than to a properly based program of coastal actions financed by the governments.

In her contribution, Professor Cambers highlights how in the Small Caribbean Islands the growing development, together with the current erosive processes, has caused that many private proprietors and government agencies build structures to diminish or stop erosion. These structures include piers, walls, groynes and breakwaters. Different degrees of success have been achieved in them.

Some islands like St. Martin and Anguilla have tried to restore their beaches by nourishing them with sand transported from the submarine slope. Again these measures have had different degrees of successes. In Maunday ' Bay in Anguilla, the beach was fed three times during the period 1995-1999 only to restore the sand washed away by the high-energy events and hurricanes in 1997, 1998 and 1999.

Before the challenge of restoring the beaches of tourist and social interest, the biggest and more successful projects of Artificial Sand Nourishment in the Caribbean have been developed in Cuba in the last 10 years. For their economic and social significance, as well as to the magnitude of the projects and high degree of effectiveness, the description of two of the main projects executed in Cuba is presented below.

1. CASE STUDY - VARADERO.

Varadero Beach occupies the north part of Hicacos Peninsula, which is located in the northwest coast of Cuba about 130 km east of Havana City. With a length of 22 Km., a maximum width of 500 m and a projection of 70º of azimuth, it constitutes a natural barrier that separates the low bottoms of Cárdenas Bay from the waters of Florida Straits. (Fig. 11).

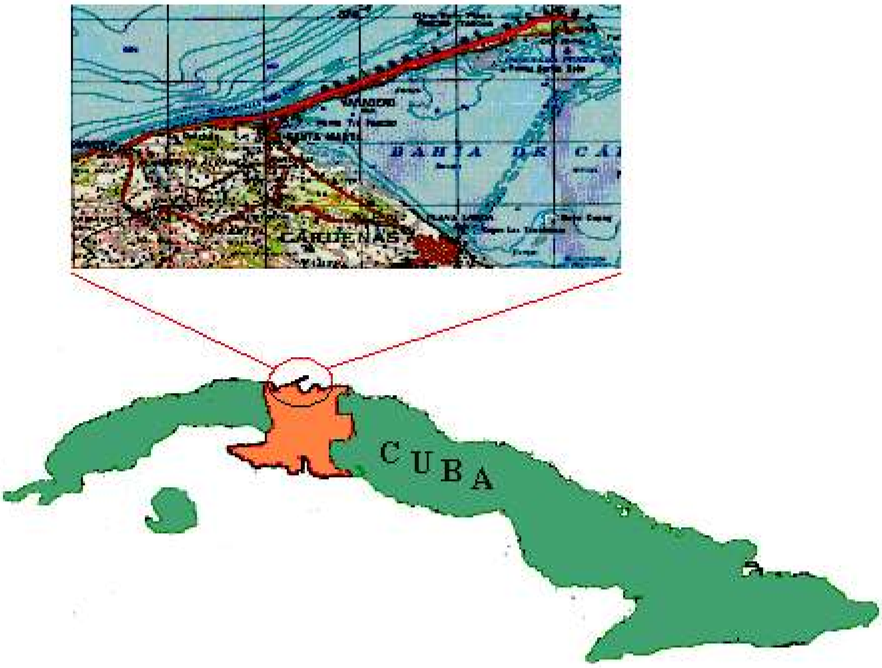


Fig. 11. Location of Varadero Beach.

The growing appearance of rocky surfaces in the beach area, scarps on the dune and the destruction of facilities under the wave action, constitute the best indications of the erosion that Varadero Beach has suffered in the last decades.

The investigations that the Institute of Oceanology carries out since 1978 demonstrate that Varadero presents an irreversible erosive tendency at present, with an average sand loss of 50,000 m^3/year, (Juanes 1996).

Among the causes of erosion it stands out:

1. The existence of more than 150 houses and hotels on the dune along 5 km of beach in the so-called “historical Varadero”, what favors the erosive action of the waves and currents during extreme storms, accelerating the sand loss process. It also hinders the reestablishment of the natural beach profile in the period of recovery after the storms.

2. The extraction of 990,000 m^3 of sand for the construction industry between 1968 and 1978 in areas of the submarine shelf, as well as the estimated volume of 1,000,000 m^3 before that date, including extractions in the dune. This practice caused the decrease in sand reserves in the sources of natural supply and non-quantifiable damages to sand-producing ecosystems.

3. The groynes at the entrance of Paso Malo channel that are projected seaward about 110 m, deviating the littoral transport of sediments toward greater depths, what is favored by the ebb current generated in the own channel. In turn, the groynes prevent that part of the material transported westward by the coastal drift supply the beach of the Oasis - Channel sector.

4. The sea level rise associated to Global Climate Change, the increase in the occurrence and intensity of erosive events related to climate variability, and the deficit in the inputs from natural sources have an impact on the erosion processes in Cuban beaches, as in many beaches worldwide.

It is understandable that actions to solve the erosion problems are aimed at the elimination of the factors that generate them and the execution of works to recover the eroded beach sectors.

The selection of the artificial nourishment as advanced technique for the maintenance of natural beaches was done based on its renowned ecological and aesthetic advantages with regard to other techniques. (National Research Council 1995)

In a first stage of "Recovery", the plan contemplated the fill of 1,000,000 m^3 of sand in a 4-year period at a rate of 250,000 m^3 per year, but around 700,000 m^3 were deposited from 1986 to 1992.

The evident improvement in the aesthetic and recreational conditions of the beach and the protection provided to tourist facilities in the 1987 - 1995 period, and particularly during the strong waves of the meteorological phenomena in February 1992 and March 1993, have been the best demonstration of the effectiveness of the method selected, even when the sand fills carried out were not executed in the most effective way and in the volumes required.

However, already in October 1996 the incidence on Varadero of the strong waves associated to hurricanes Josephy and Lili caused serious impacts in the area of Punta Blanca, causing the partial destruction of several tourist facilities (Pictures 12 and 13).

Pictures 12 and 13: Severe impacts to the beach and tourist facilities caused by hurricane Lili at its pass through Cuba in October 1996. Punta Blanca, west sector of Varadero.

Before the situation created by effect of Hurricane Lili, the fill of 1,087,835 m^3 of sand was executed in the summer of 1998. Its fundamental objective was to restore the aesthetic and recreational conditions of the beach and to reinforce the dune's foot to minimize the erosive effect of storm waves, thus protecting the tourist facilities that will inevitably remain exposed at least in the dune for a 5-year period.

Synthesis of the project

Place: beach sector between Punta Chapelín and Punta Blanca beach, Varadero.
Longitude: 12 km.
Sand volume: 1,087,835 m^3.
Mean density of sand per lineal meter of beach: 103.8 m^3

Native sand: Md. 0.26 mm. Biogenic composition.

Sand borrow area: Mono basin.

Mean depth: 10 m.

Mean distance to the borrow area: 19 km.

Introduced sand: Md. 0.38 mm. Biogenic composition.

Sand fill period: June 29 - August 26.

Dredging equipment: Trailing suction hopper dredger Alpha-B. Holland.

Duration of the work: 58 days.

Expected results:

- Recovery and conservation of the beach recreational and aesthetic conditions for a 5-year period.
- Guarantee of the protection to tourist facilities located on the beach front.

The cost of the work was of $5 millions.

Once concluded the artificial sand fill, it was started the monitoring of the behavior of the artificially deposited sand, with the objective of investigating the natural processes that rule its distribution and evaluating the effectiveness of the project executed.

Monitoring.

The effectiveness of the project is confirmed when it is demonstrated that the evolution of the beach and the sand borrow area satisfies the needs of the tourist activity and the environmental protection that led to its execution.

In order to know the evolution followed by the beach, researches were directed to obtaining quantitative information on the:

- Sand volume retained.
- Reduction or increase in beach width.
- Behavior of sand in the submarine slope.
- Possible sand loss toward the interior of Paso Malo channel.
- Changes in the grain-size composition of the sand.
- Behavior of the meteorological conditions.

➢ In the borrow area, studies were guided toward obtaining criteria relating to:
➢ Capacity of recovery of the sand volumes in the basin.
➢ Control of the sand quality.

Measurements of the sand volume

As a result of these measurements, the systematic control on the volume changes in the beach has been maintained. Figure 12 shows the sand volumes quantified in each survey developed from August 1998 to June 2002.

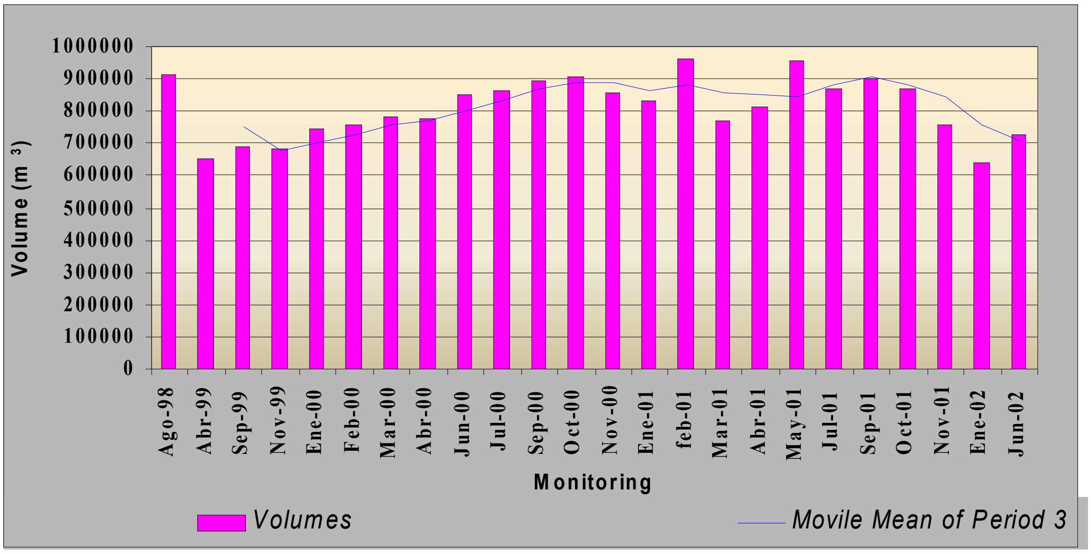


Fig. 12. Behavior of the sand volumes in time.

During the first year of monitoring it was observed a decrease in sand volume, what may be understood as a result of the natural rearrangement process of the material to conform an equilibrium profile, according to the mechanical characteristics of the sand and prevailing wave conditions.

In the succeeding controls, and independently of the alternation of erosion and accumulation periods, it took place a gradual increase in the retained volumes, reaching values higher than those initially calculated in February and May 2001. These high volumes respond to the fact that in this period the hydrometeorological conditions were favorable to the accumulation, what propitiated the reincorporating of sand to the emerged part of the profile and the submarine bars near the shore.

Measurements done in November 2001, 25 days after the pass of Hurricane Michelle, demonstrated that along the whole benefited sector the sedimentary balance showed a sand loss of 149,626.61 m^3. This volume constitutes 16.44% of the total filled in the summer of 1998, in such a way that by that date the beach conserved 83.56% of the initial volume. In the survey of June 2002, the beach conserved 729,732.00 m^3 of sand, what represents 80.16% of the volume quantified when concluding the regeneration works.

However, the sand volume behavior has not been the same along the whole benefited area, where there are sectors with significant losses in the volume filled for the tract.

In June 2002, five critical sectors were identified, which constitute 22% of the whole area benefited with the sand fills. Those sites of the beach where the first erosion indications begin to appear are identified in the specialized literature as “hot spots” (Erosional Hot Spots, according to Dean *et. al.,* 1999). Their behavior responds to a combination of the wave and bathymetry conditions with the influence of the facilities on the dune and groynes at the entrance of Paso Malo Channel.

With the interest of detecting the sand transport toward the submarine slope and beyond the second bar, the monitoring includes bathymetric transects and measurements of sand levels until the limit of the sandy bottom with the rocky surface.

In most of the monitored area there are two levels of submarine bars very well developed, with sand reserves that would play a decisive role in the protection of the beach in the event of occurring severe storms, as indeed it happened with Hurricane Michelle.

Since before the execution of the regeneration works and until November 2001, the dynamics in the submarine slope was not intense and relief forms such as bars and valleys had hardly suffered any variations.

With the pass of Hurricane Michelle, modifications took place in the morphology of the beach profile associated to the strong waves caused by the meteor. Controls carried out show that at depths greater than 8 m (closing depth of the active profile) there was a displacement of considerable sand volumes offshore. (Fig.13).

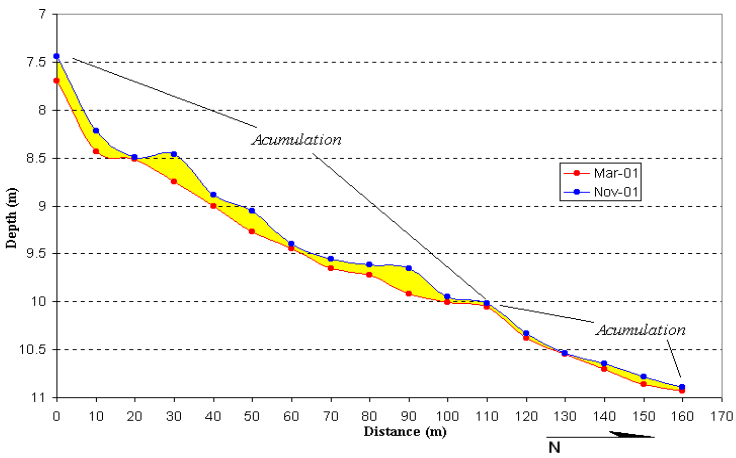


Fig. 13. Sand accumulation in the submarine slope for the action of storm waves.

The evidence that toward depths greater than the closing depth moved significant volumes of sediment permits to affirm that Hurricane Michelle caused losses due to sand escapes outside the beach system, thus unrecoverable for the profile.

At the same time, measurements of sand accumulation are carried out in Paso Malo Channel with the objective of quantifying the material deposited in its interior, (Picture 14).

Picture 14. Paso Malo Channel.

Keeping in mind that the tendency of sediments transport in the peninsula takes place from east to west, it should be expected that, under strong transport conditions generated by Hurricane Michelle, part of the suspended sand was trapped inside the channel.

However, in the control carried out after the pass of Hurricane Michelle no changes of consideration were registered in the levels measured. Therefore, it may be stated that no important sand losses have not taken place this way.

Reduction or increase in the beach width

As a complement to the analysis of profile evolution, sand volumes and beach state in general, Figure 14 shows the behavior of the mean beach width achieved regarding the one existing before the sand fills, which has stayed above 18 m after the pass of Michelle, regarding the beach width that existed before the sand fill, with an absolute mean width of 52 m, what represents a sun strip area of 572,000 m^2.

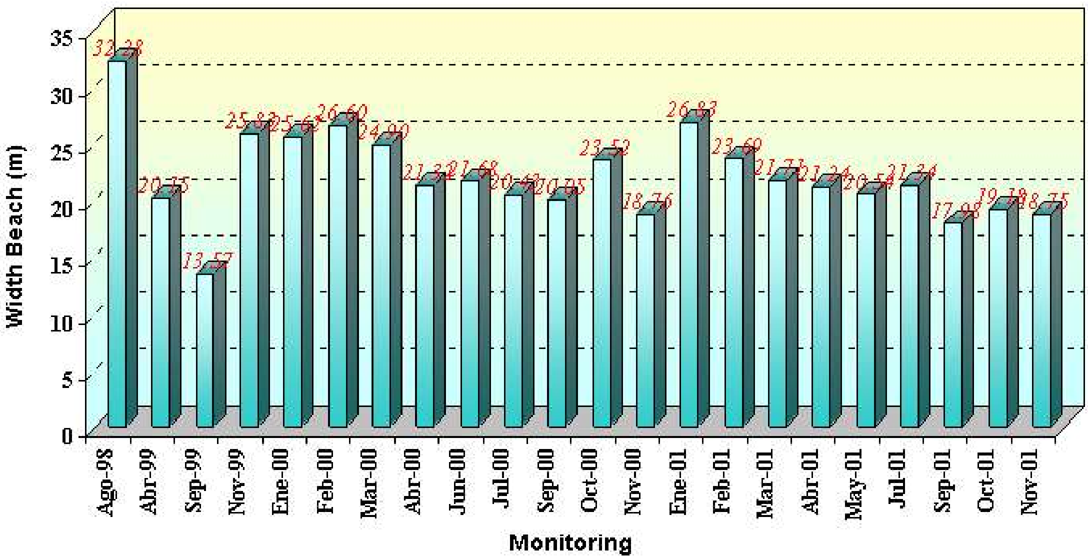


Fig. 14. Beach width by profiles compared to the one existing in May 1998.

In practical terms this means that, assuming an excellence norm of 10 m^2/tourist, Varadero has, in that sector, a sun strip area so that 57,200 tourists can take sun baths at the same time, each having 10 m^2 of beach at his disposal.

Changes in the grain-size composition of the sand

The systematic realization of sedimentological samplings has also been included as part of the monitoring program, with the objective of knowing the grain-size characteristics of the beach and evaluating the extent in which the characteristics of the introduced sand have been modified.

Since the execution of the sand fills and up to the pass of Hurricane Michelle, an important part of the regenerated beach had not suffered substantial changes in its grain-size yet. The analysis of sediments collected in January 2002 (two months after Michelle) indicated significant changes in the grain-size of sediments.

Figure 15 shows the evolution of the sand grain by profiles along the whole sand fill sector.

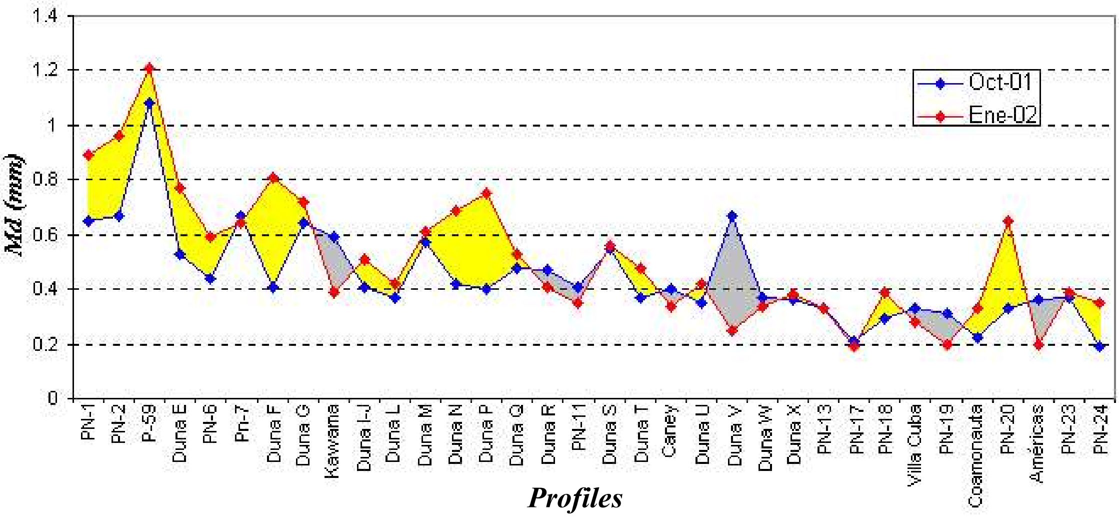


Fig. 15. Sand grain-size along the sand fill area. Sampling point, facebeach.

As it is observed, there was a widespread increase in the mean sand-grain diameter, in correspondence with what happens at the pass of hurricanes.

Capacity of recovery of sand volumes in the basin and control of the grain-size composition

As part of the monitoring program it was included the realization of bathymetric profiles and measurements of sediment thickness inside the area of 1.7 km^2 corresponding to the borrow area, with the objective of evaluating its recovery process.

The studies comprise sedimentological sampling and measurement of sand thickness by means of autonomous diving at 30 stations, as well as the realization of bathymetric profiles with a view to registering the evolution of the bottom relief.

Previous to the beginning of the sand fills, the basin presented a sediment thickness over 2 m in all its parts, and the maximum depth was 12 m.

Once the sand mining concluded, measurements demonstrated that the basin conserved a thickness between 0.4 m and 1 m in the areas that had been more strongly affected by dredging, in which furrows 1.5 m deep were also perceived, formed by dragging the suction tube.

During the works after the pass of Hurricane Michelle, it could be confirmed that in 86% of the sampled stations the sediment thickness surpassed one meter, of which 69% was above 1.60 m.

The grain-size analysis of superficial sediments has allowed to observe how, after the widespread reduction in mean grain diameter caused by sand mining, a progressive increase in mean grain diameter has taken place, showing a tendency to the prevalence of sediments classified as medium sand. This coincides with the characteristics that existed before the extraction.

According to the thickness of the measured sediments and the sand composition, it is possible to affirm that the borrow area is in capacity to be used in future Artificial Sand Nourishment projects in Varadero Beach.

Conclusions

It is possible to state that given the beach physical and aesthetic conditions and the protection provided to tourist facilities before the strong waves caused by hurricanes Georges (September 1998) and Michelle (October 2001), the employment of artificial sand nourishment as an engineering alternative for the recovery of beaches has been effective.

2. CASE STUDY. EL SALTO-GANUZA.

El Salto-Ganuza coastal sector is located on the north coast of the central part of the Island of Cuba (Fig. 16), occupying a fringe near 4 km long, constituted by deposits of sandy-slimy sediments of marine origin. These deposits formed a ridge about 100 m wide, on which a road and more than 600 housings and facilities were built.

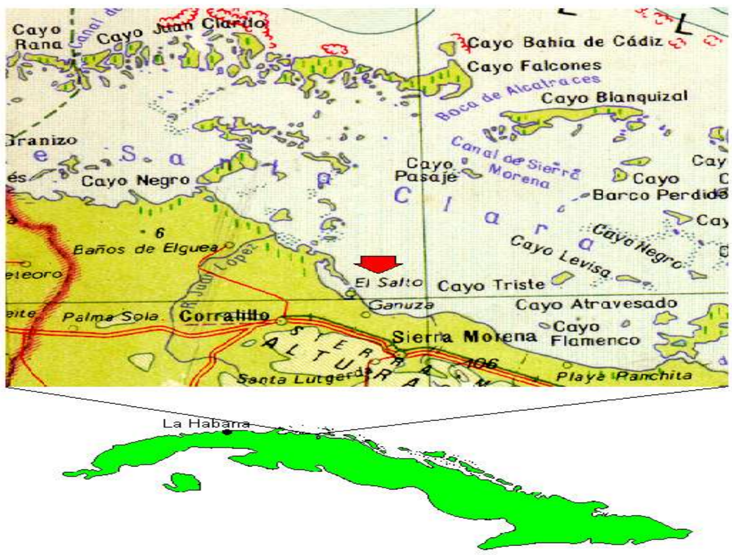


Fig. 16. Location of El Salto-Ganuza beach

In November 1985, the strong winds and wave that accompanied hurricane Kate significantly affected El Salto-Ganuza coastal sector. Some 200 facilities located next to the coast were destroyed and the beach was completely degraded.

The precarious conditions that characterized El Salto-Ganuza at the pass of the hurricane increased the use problems of the coast as a natural and tourist resource. This promoted the idea of the environmental, aesthetic, and functional recovery of this coastal sector on the north coast of the country.

According to the wide development of investments foreseen for El SaltoGanuza coastal sector, with the construction of two comfortable lodging facilities located one kilometer away from the coastline, it was essential to elaborate a project that allowed to establish the scientific-technical bases for the correct management, development and conservation of the coastal area.

In 1987, it began to be executed the research program directed to obtain basic information to evaluate the feasibility of creating the artificial beach and in 1988, based on the information obtained, it was elaborated the executive project where the engineering alternatives to be implemented are designed. The execution of the project concluded in 1989, with the spill of 60 000 m^3 of sand.

Physical-geographical considerations of the territory

The analysis for the characterization of El Salto-Ganuza coastal sector starts from the concept of beaches as a harmonic system that comprises three fundamental elements, on which their existence depends naturally:

1. A source of sandy material.
2. An appropriate relief in the coast and submarine shelf so that the sediment deposition occurs.
3. A hydrodynamic regime that guarantees the capacity to transport sediments from the supply sources toward the beach.

When conceiving the project of the artificial beach, it was fundamental to identify which parts of the system were present naturally and which should be created by man.

Characteristics of the relief

The topographic profiles that appear in figure 17 describe soft and regular slopes that do not surpass 2% in the submarine part. The calculated maximum slope is 1.6%, for a maximum longitude of l00 m, being 1% the most generalized value in the area.

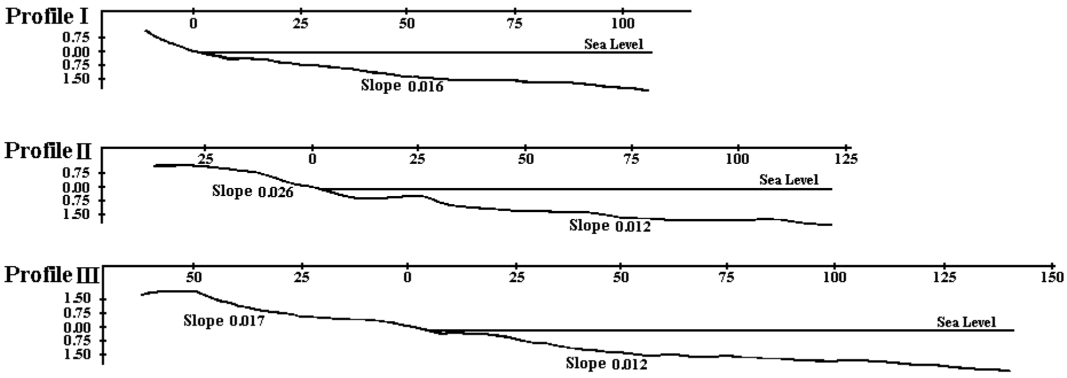


Fig. 17. Topographic profiles of El Salto-Ganuza beach.

Zenkovich (1967) affirms that when the slope is < 1% as an average, the material moves in the shallow waters toward the coast forming the coastal bars. The existing accumulative forms are in correspondence with the low values of slopes of the beach profiles, demonstrating the prevalence of accumulative processes over the erosive ones, under a normal wave regime.

Characteristics of the hydrodynamic regime

Figure 18 shows the trajectories of four drift bodies launched in different positions and distances from the coastline, with winds of north-northwest, north, north-northeast, and east-northeast directions, and speeds between 4.6 and 7.7 m/s, fundamentally associated to the occurrence of winter storms. The experiments were also carried out during the flow and ebb of the tide.

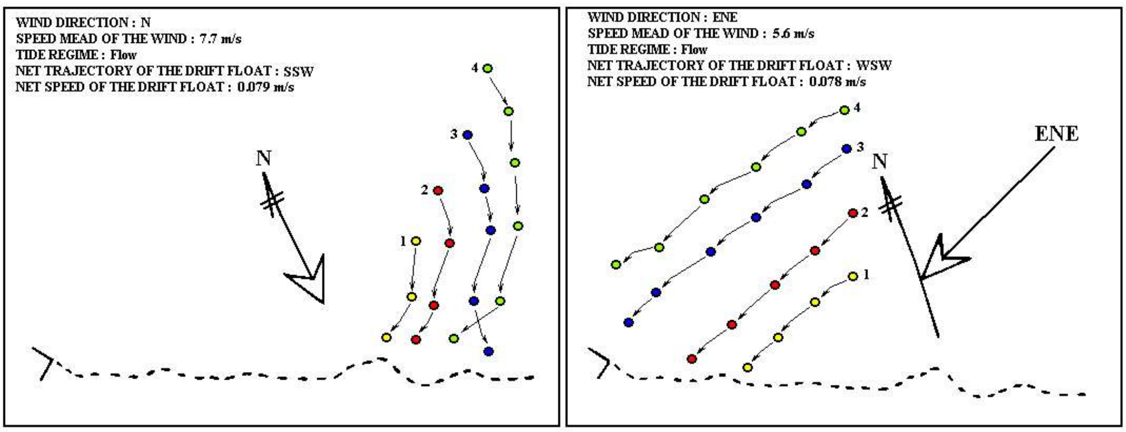


Fig. 18. Schemes of two of the coastal drift experiments in El Salto-Ganuza beach

As a result of the follow up of the buoy trajectories, a mean speed of the littoral current of 0.074 m/s was determined.

In general, the coastal drift experiments allow deducing that both the direction and speed of the drift currents are in direct correspondence with the variations of wind direction and intensity, with little influence of tide changes. Besides, the net speed values of the buoys do not surpass 1 m/s; therefore they describe coastal currents of low energy, at least under the occurrence of wind speeds lower than 10 m/s.

According to these results and considering that the winds with higher percentage of occurrence are those from the northeast with 32%, followed by the winds from the north-northeast with 11 %, and the east-northeast ones with 8% (Atlas Nacional de Cuba, 1978), it can be pointed out that the general tendency of sediment transport in the coastal area follows an East-West direction, in correspondence with the predominant winds in the region.

Characteristics of the sediment sources

The results of the textural processing of the native sediment allow differentiating that 58% of the samples corresponds to Sands, 38% to Slimy Sands, and 4% to Sandy Slimes.

The main components of the sediment correspond to calcareous fragments of benthic organisms, among which there is a prevalence of mollusks (4l%), foraminifers (25%), and calcareous algae (l6%). The results of the benthos sampling carried out near the coast demonstrate that the marine flora is represented by 2l species, seven of which are sand-producing calcareous algae; and the fauna is mainly composed of mollusks, sponges and corals.

Although 58% of the samples taken in the submarine slope belongs to Sands, the presence of 42% of Sand-Slime indicates that the sediments of the region present a significant component of fine material, inappropriate for the natural conformation of the beach as a source of supply of unconsolidated sediments. If it is also taken into consideration that the emerged part of the coast practically does not have sand, it should be understood that the creation of El Salto-Ganuza beach requires of an artificial source of sand supply.

Design of the artificial sand nourishment. Conformation of the beach profile

The design of the artificial sand nourishment was based on the analysis of the erosion-accumulation oscillations, during seven years, of a profile north of Punta Molas, in Varadero beach, with slope values and stability regime very similar to those of the profiles of El Salto-Ganuza coastal sector.

The obtained measurements permitted to establish the range of the variations of the beach width and height, being these 26 m and 0.76 m respectively. These values mean that the beach profile to be conformed should have a length and thickness of sand that admit variations in that order, without the occurrence of rocky outcrops or the crash of waves against rigid structures in the inner part of the profile.

This way, the profiles for the construction of the beach are designed (Fig. 19), taking into account the above exposed criteria, and also considering that:

a) The profile admits a cyclic erosion-accumulation evolution similar to that of a natural beach profile.
b) The range of the slopes is conserved, keeping in mind that those of the original relief fulfill the accumulation condition.
c) The volume of sand used is rationally required for the creation of the beach, thus avoiding unnecessary expenses.

The design of profiles for the creation of the beach, (Fig. 19), conceives a sun strip of 30 m of mean width, with a sand fill 0.30 m thick. In the area nearer the sea, where greater seasonal variations in the profile are expected, it is projected the extraction of the native material in a fringe l0 m wide and 0.50 m thick along the whole coast, with the purpose of achieving thicker sand fills precisely in that area. This way, a berm 0.70 m thick with soft slopes will be conformed.

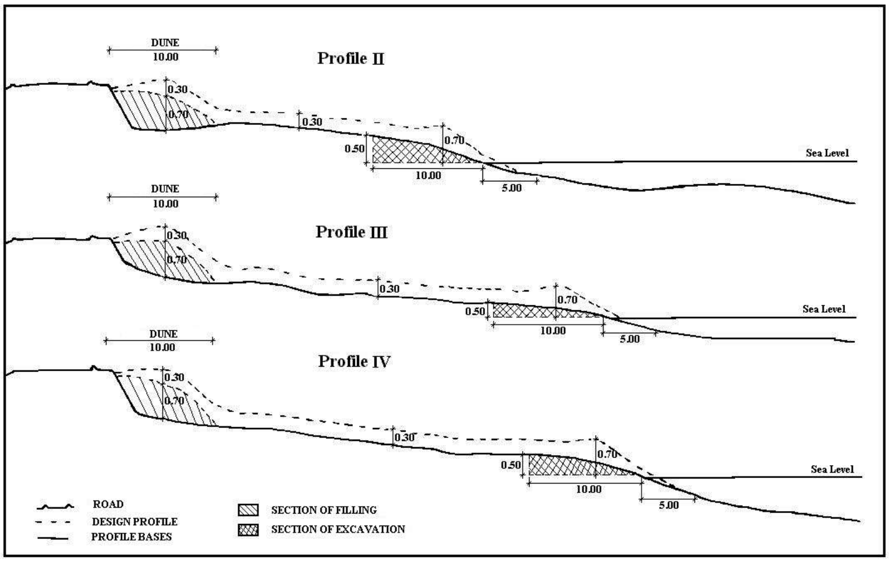


Fig. 19. Design profiles for the sand nourishment

Toward land and at a distance of around 40 m from the coastline, it is conceived the creation of a dune conformed with filling material in its core and a sand layer 0.30 m thick on top. This dune, likewise the natural ones, will be covered by typical beach vegetation that, besides having an aesthetic function, will contribute to the retention of the wind-blown sand.

The comparison of the design profiles with those of the original relief permitted to calculate a sand volume of 60 000 m^3 to be filled for the conformation of 2 km of beach, with a density of 30 m^3 per lineal meter.

Definition of sand borrow area. Calculation of the optimum volume to be filled

As a result of an exploration in areas of the submarine shelf of Villa Clara northern keys, two sand borrow areas were located with enough volumes for the fill works in El Salto-Ganuza beach (Fig. 20). The practical problem consisted in choosing which of them was the most appropriate for sand extraction, considering the characteristics of the sediment, conservation of the natural environment, and the execution costs of the dredging and transportation.

The borrow areas present sediments with different grain size characteristics, the sand from borrow I has a medium size of 0.20 mm (medium sand), and that of borrow II is 0.50 mm (thick sand). Calcareous remains of marine organisms form the sand found in both places.

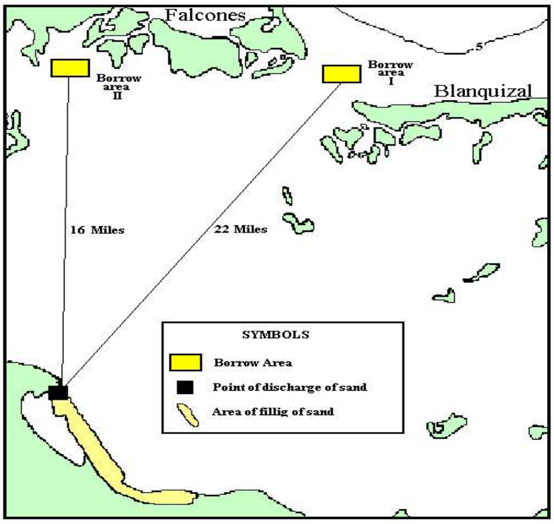


Fig. 20. Location of the sand borrow areas

Starting from the expression of the equilibrium profile adjusted to the characteristics of the inner beaches, $\mathbf{h(x)=A_p x^{0.56}}$, it is used the methodology of Dean (1990) with respect to the calculation of the optimum sand volume to be filled to maintain the equilibrium conditions of El Salto-Ganuza beach (Fig. 21).

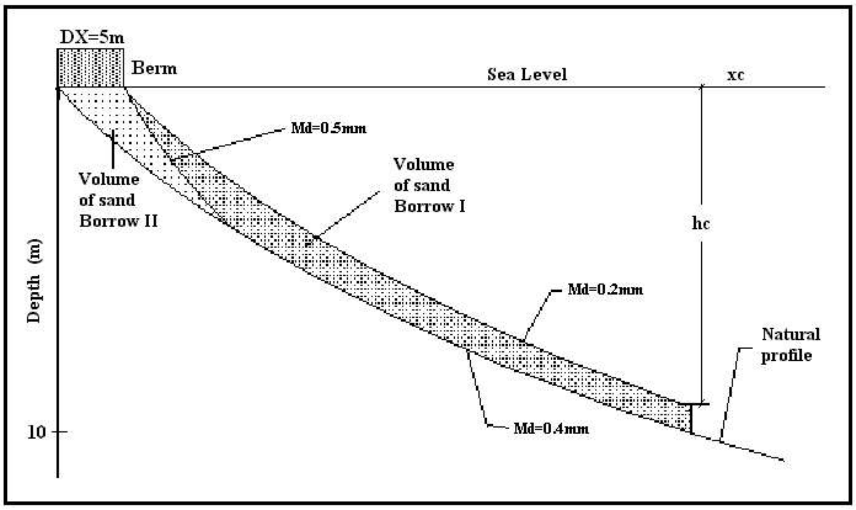


Fig. 21. Design profiles according to the mean diameter of the sand to be poured

The equilibrium profiles represented in Figure 21 are calculated for **Md**=0.20 mm (Borrow area I) and **Md**=0.50 mm (Borrow area II), when planning to elevate the benchmark of the berm (**B**) to a maximum height of 1 meter and an a 5-meter advance (**DX**), starting from the coastline to be regenerated. The shaded area, defined between the native beach profile and the corresponding calculated equilibrium profiles, shows the volume of sand to be poured per lineal meter of coast in each case, that is to say the optimum volume, considering that each profile represents the equilibrium conditions once the sand fill has been carried out.

The values of the profile closing distances and the optimum volume for each case are shown in Table 13.

TABLE 13
Technical parameters for the sand fill in El Salto-Ganuza beach

Sand	Mean diameter (mm)	Closing distance of the dynamic profile (m)	Volume (m^3/ lineal m)
Native	0.40	143	-
Poured Borrow (I)	0.50	119	6
Poured Borrow (II)	0.20	194	54

The results obtained through the calculation of the optimum volume lead to decide the use of the borrow area I, considering the following aspects:

a) Smaller extension of the sand fill toward the submarine slope.
b) Lower volume of sand to be extracted.
c) Minimizing negative impacts on the marine bottoms due to dredging operations.
d) Reduction of sand fill works on the beach.
e) Guarantee of the equilibrium conditions required for maintaining the natural, aesthetic and functional characteristics of the beach.

This way, with the use of the sandbanks in the borrow area I, it was guaranteed the source of supply for the creation of the artificial beach.

Evaluation of the effectiveness of the project

The systematic monitoring of the morphological and sedimentological variations of the topographical profiles obtained starting from 15 points distributed along the beach, from June 1989 to October 1995, has allowed to evaluate the evolution of the beach and to calculate the sand loss volumes.

Through the comparison of the beach profiles it was determined a mean width of the lost sand fringe of 1.7 m, and the volumes of net losses do not surpass 0.95 m^3 per year per lineal meter of beach in a period of six years and four months.

The evaluated losses are lower than 5% of the total volume of sand poured, what validates the effectiveness of the executed works and demonstrates the high stability of the beach.

Pictures 15 and 16 show the changes occurred in El Salto-Ganuza coastal sector with the execution of the project to create the artificial beach.

Pictures 15 and 16.
View of the beach before and after the execution of the artificial sand nourishment project.

Conclusions

1. The characteristics of the relief and the hydrodynamic regime are favorable for the creation of the beach, however the source of sand supply does not guarantee its natural conformation, being defined the application of the artificial sand nourishment.

2. The erosion-accumulation oscillations of a monitoring profile in Varadero beach and its adaptation to the physical-geographic characteristics of El Salto-Ganuza coastal sector, constituted a valid empiric model for the design of the beach artificial nourishment.

3. The 95% of retention of the sand poured in El Salto-Ganuza artificial beach, after more than 10 years of its creation validates the effectiveness of the project and demonstrates the high stability of the beach.

VI CONCLUSIONS

1. The evaluation of erosion in the Caribbean beaches demonstrates the widespread character of this phenomenon in the coasts of the region, with an intensity that varies between erosion rhythms of around 9m/year, although there are reports reaching up to 40m/year.

2. The causes of erosion in the Caribbean beaches are both natural and anthropogenic.

   The natural causes are manifested in the whole region, and it may be noticed that they are related to a higher frequency and intensity of tropical storms, sea level rise, the deficit in the sand inputs, and tectonic phenomena. Investigations on these processes are insufficient and disperse, not permitting to establish a more direct cause-effect relationship between them and the coastal erosion.

   The anthropogenic causes are clearly related to mining on the dunes, beaches and rivers; destruction and occupation of dunes by tourist facilities; construction of marina; incorrect location of coastal protection works, and the damage to coral reefs and seagrass beds, important sources of production of marine carbonated sand.

The anthropogenic causes are widespread and dispersed, but locally intense. The direct relationship between erosion and man's incorrect actions is observed in all the main tourist areas of the Caribbean, what demonstrates the unsustainable character of that tourist development model.

3. The Caribbean exhibits a great variety of beaches regarding the composition and origin of their sands, as well as in their geomorphology and geologic structure. Inside that diversity of beaches, those formed by marine carbonated sand, very demanded for the tourist activity, deserve to be highlighted. The formation and development processes of those beaches present particularities exclusive of tropical areas, and they should be treated in a special way when evaluating engineering alternatives to mitigate erosion.

4. The tourist industry is vital for the countries of the region, especially for the Small Islands Developing States. In turn, the tourist activity is sustained by the beach resource. The Caribbean faces an increasingly competitive Tourism market, in which the maintenance of the beaches has become a first-order commercial factor.

5. It is noticed that the environmental legislation regarding Coastal Zone protection, and particularly of the beaches, is still insufficient; and that it is required the implementation of Integrated Coastal Zone Management Programs that assure the sustainable development of Tourism in the region.

6. The engineering actions to mitigate erosion have had, in most of the cases, a punctual and spontaneous character, responding to the interests of isolated proprietors and not to a program of coastal actions led by environmental authorities. The applied solutions and techniques have responded, in many cases, to the interests of building companies and not to the results of a project sustained on the results of scientific investigations. Different examples show that the actions to protect the beaches have had an impact more negative than positive.

7. Although there exist in the region scientific institutions and agencies with professionals qualified for the development of research projects on coastal processes and the implementation of Coastal Zone Management and Environmental Education Programs, it is insufficient the availability of research means and equipment, the required funds, and the necessary regional arrangements for such projects and activities.

VII RECOMMENDATIONS

Taking into consideration the aspects discussed, the following ideas may be synthesized:

The information obtained regarding the assessments of the conservation state of Caribbean beaches permits to detect the need to establish a conceptual and methodological work line at regional level that guarantees the correct interpretation of coastal processes and the appropriate selection of the measures adopted to protect the beaches.

In the region, and in different institutions, there are work groups able to develop the investigation lines required to evaluate the physical processes of the beaches and propose management measures. However, it is not similar the degree of training of these groups, nor the complexity of the territorial problems they face, being necessary to propitiate an appropriate framework for the systematic transfer of technologies and exchange of results and experiences.

The growing demand for coastal actions, and especially for beach preservation projects in the region, suggests the convenience of a regional coordination that contributes to the optimum use of the technical and financing resources devoted to this activity.

Taking into account the ideas pointed out above, it is recommended the establishment of a **Regional Beach Preservation Program.**

General Objective of the Program

Contribute to the formulation of the National Policies of the Caribbean States regarding beach protection and uses to assure the development of a Sustainable Tourism.

Scientific-Technical Objectives.

1. Carry out a more precise assessment of the intensity and extension of beach erosion in the region by means of a regional monitoring network using compatible methodologies

2. Develop investigations with a view to identify and quantify with more precision the causes of beach erosion, distinguishing those associated to natural phenomena from the ones caused by man's activity.

3. Develop investigations to evaluate more effective and lasting engineering solutions, opening the field to non-conventional technologies.

4. Monitor the results of beach recovery projects executed in the region, with a view to evaluating their effectiveness.

5. Elaborate a Beach Protection Manual with scientific and engineering approaches that respond to the particularities of the Caribbean region.

6. Increase the human and material capacities of the organizations and institutions linked to the Program.

7. Encourage regional workshops to exchange experiences and organize the Regional Conference on Beach Preservation.

8. Contribute to environmental education for beach protection and conservation.

These actions may be developed by Regional Investigation Centers, with the collaboration of Scientific Institutions from developed countries through the coordination of UNEP's GPA.

Practical objectives

1. Propose solutions for the critical coastal sectors of greater socioeconomic interest in the region.

2. Offer technical supervision in the elaboration and execution of coastal protection and beach recovery projects, as well as in the implementation of national programs of Integrated Coastal Zone Management.

For these actions, it is proposed to create a "real-time response" task force group, preferably integrated by specialists from the region, which will respond to the interests of the Program.

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ANEXO 1.
PROGRAMA. REGIONAL MEETING: DIAGNOSIS OF THE EROSION PROCESSES IN THE CARIBBEAN SANDY

5 - 8 FEBRUARY 2003

ACUARIO NACIONAL. HAVANA, CUBA

February 5 (Wednesday)

8:30 **Accreditation.**

9:00 Welcome.
Lic. Guillermo García Montero. Director of the National Aquarium of Cuba and Chairman of the National Oceanographic Committee.

9:20 Global Action Program for the marine environmental protection from man made land activities, (PGA), UNEP
Ing. Oscar Ramírez, Regional Office (UNEP).

9:40 Contents and Scope of the Diagnosis of the Erosion Processes in the Caribbean Sandy Beaches in the frame of PGA (UNEP).
Dr. José Luis Juanes Head of the Coastal Processes Department. Institute of Oceanology.

10:00 **Break.**

10:30 Conference: Sea Level Rise Effect in the Beach Erosion Processes. The Impact in the Caribbean Beaches.
Professor Maurice Schwartz. Western Washington University.

11:30 Conference: Beach Erosion in the Small Caribbean Islands. Natural and Anthropogenic causes.
Professor Gillian Cambers. UNESCO Consultant, Caribbean Small Islands Shores Affairs.

12:00 General Debate. Recommendations to the Report "Diagnosis of the Erosion Processes in the Caribbean Sandy Beaches"

13:00 **Lunch in the Aquarium Restaurant.**

14:00 General Debate. Recommendations to the Report "Diagnosis of the Erosion Processes in the Caribbean Sandy Beaches"

15:00 Beach Erosion in the Caribbean Major Islands. Negril Beach, Jamaica. Causes and Magnitude of the Erosion Processes. Necessary Research and Monitoring.
Dr. José Luis Juanes Head of the Coastal Processes Department. Institute of Oceanology.

16:00 Visit to the Aquarium areas.

February 6 (Thursday)

9:00 The Erosion in the Caribbean Continental Shores. Colombia. Case Study. Evaluation of the Natural and Anthropogenic causes.
Professor George Vernette, Deputy-Chairman INVEMAR / Bordeaux-1 University.

10:00 The Erosion in the Caribbean Continental Shores. Guatemala, Belize and Quintana Roo (Mexico), Case Study. Evaluation of the Natural and Anthropogenic causes.
Lic. Ernesto Trista. Specialist of the Coastal Processes Department. Institute of Oceanology.

11:00 **Break.**

11:30 The Beach Erosion in the Caribbean Major Islands. Cuba, Case Study. Causes and Magnitude of the Erosion Processes. Necessary Research and Monitoring.
Dr. José Luis Juanes Head of the Coastal Processes Department. Institute of Oceanology.

12:30 General Debate. Recommendations to the Report "Diagnosis of the Erosion Processes in the Caribbean Sandy Beaches"

13:00 **Lunch in the Aquarium Restaurant.**

14:00 Conference: Potentialities of the Marine Ecosystems Center of Cayo Coco to Develop Researches on Beach Erosion Processes in the Caribbean Region.
Ms. Adán Zuñega. Specialist of the Marine Ecosystems Center (Cayo Coco)

15:00 Conference: Experiences of the Coastal Management Program in Varadero Beach.
Dr. Alfredo Cabrera. Chairman of the Investment Office for the Varadero Beach Restoration.

16:00 Visit to the Oceanology Institute.
Meeting with the Director of the Institute MSc. Roberto Pérez.
Visit to the Coastal Processes Department.

February 7 (Friday)

9:00 Conference: Engineering Actions for Beach Restoration. The Experience in the Caribbean Small Islands.
Professor Gillian Cambers. UNESCO Consultant, Caribbean Small Islands Shores Affairs.

10:00 Conference: Engineering Actions to Create an Artificial Beach. The Case of "El Salto – Ganuza" (Cuba).

Lic. Ernesto Trista. Specialist of the Coastal Processes Group of the Oceanology Institute.

11:00 **Break.**

11:30 Conference: Engineering Actions for Beach Restoration in the United States of America.
Professor Maurice Schwartz. Western Washington University.

12:30 General Debate. Recommendations to the Report "Diagnosis of the Erosion Processes in the Caribbean Sandy Beaches"

13:00 **Lunch in the Aquarium Restaurant.**

14:00 Conference: Engineering Actions for Beach Restoration. Design , Execution and Monitoring of the Artificial Beach Nourishment Project in Varadero Beach.
Ing. Miguel Izquierdo, Specialist of the Coastal Processes Group of the Oceanology Institute.

15:00 General review of the meeting sessions. Discussion of the recommendations to the final report: Diagnosis of the Erosion Processes in the Caribbean Sandy Beaches"

16:00 Closing words
Ing. Oscar Ramírez, Regional Office (UNEP).

February 8 (Saturday)

FIIELD TRIP TO VARADERO

8:30 Departure from Copacabana Hotel

10:30 Welcome in the Investment Office for the Varadero Beach Restoration

11:00 Visit to the Beach Areas benefited by the Artificial Beach Nourishment.

13:00 Lunch in the Restaurante "Albacora"

14:00 Visit to the new tourism development areas in "Punta Hicacos"

16:00 Return to Havana.

ANEXO 2 - LIST OF PARTICIPANTS

No	Participants	Institution	Adress	Phone, Fax and e-mail
1	Dr. José Luis Juanes Martí	Instituto de Oceanología (Jefe de Departamento Procesos Costeros)	Calle 1era No 18406 % 184 y 186 Reparto Flores, Playa, Ciudad Habana. CUBA	(0537) 2716008 y (0537) 2711424 mariaelena.miravet@infomed.sld.cu costa@oceano.inf.cu
2	Lic. Ernesto Tristá Barrera	Instituto de Oceanología (Especialista Departamento Procesos Costeros)	Calle 1era No 18406 % 184 y 186 Reparto Flores, Playa, Ciudad Habana. CUBA	(0537) 2716008 y (0537) 2711424 costa@oceano.inf.cu
3	Lic. Carlos García Hernández	Instituto de Oceanología (Especialista Departamento Procesos Costeros)	Calle 1era No 18406 % 184 y 186 Reparto Flores, Playa, Ciudad Habana. CUBA	(0537) 2716008 y (0537) 2711424 costa@oceano.inf.cu
4	Ing. Miguel Izquierdo Álvarez	Instituto de Oceanología (Especialista Departamento Procesos Costeros)	Calle 1era No 18406 % 184 y 186 Reparto Flores, Playa, Ciudad Habana. CUBA	(0537) 2716008 y (0537) 2711424 costa@oceano.inf.cu
5	Ing. Vladimir Caballero Camejo	Instituto de Oceanología (Especialista Departamento Procesos Costeros)	Calle 1era No 18406 % 184 y 186 Reparto Flores, Playa, Ciudad Habana. CUBA	(0537) 2716008 y (0537) 2711424 costa@oceano.inf.cu
6	Dr. Georges Vernette	INVEMAR Asistente de Dirección	Punta Betin, Santa Marta A.A. 1016. COLOMBIA	4312963 Fax : 4315848 g.vernette@invemar.org.co
7	Dr. Maurice Schwartz	Universidad de Bellingham Departamento de Geología	Dept. Of Geology, Western Washington University Bellingham, WA 98225	coastal@cc.www.edu
8	Dr. Gillian Cambers	Universidad de Puerto Rico	P.O. Box 783, Rincón, PUERTO RICO 00677	Tel.1 787 823 1756 Fax: 1 787 823 1774 gilliancambers@aol.com
9	Ing. Oscar Manuel Ramírez Flores	UNEP/ROLAC/GPA	Blud. de los Virreyes # 155 Col. Lomas de Virreyes 11000, México. MÉXICO.	Tel.: (5255) 52024841 ext 312/316 Fax: (5255) 52020950 omramirez@rolac.unep.mx
10	Dr. Juan Alfredo Cabreras Hernández	Oficina Recuperación Playa Varadero. Director	Calle 52 y Avenida Playa. Varadero. CUBA	Telefax: (05345) 614712 marioluis@enet.cu
11	Ing. Adán Zúñiga Ríos	Centro de Investigaciones de Ecosistemas Costeros Investigador	Cayo Coco. Morón. CUBA C.P. 69400	Tel.: (05333) 301161 Fax: (05333) 301151 dinamica@ciec.fica.inf.cu
12	Lic. Guillermo García Montero	Acuario Nacional de Cuba Director	Avenida 3ra y Calle 62. Miramar. Ciudad de la Habana. CUBA	Tel.: (0537) 2036401-06 Fax.: (0537) 2049987 ggarcia@ama.cu