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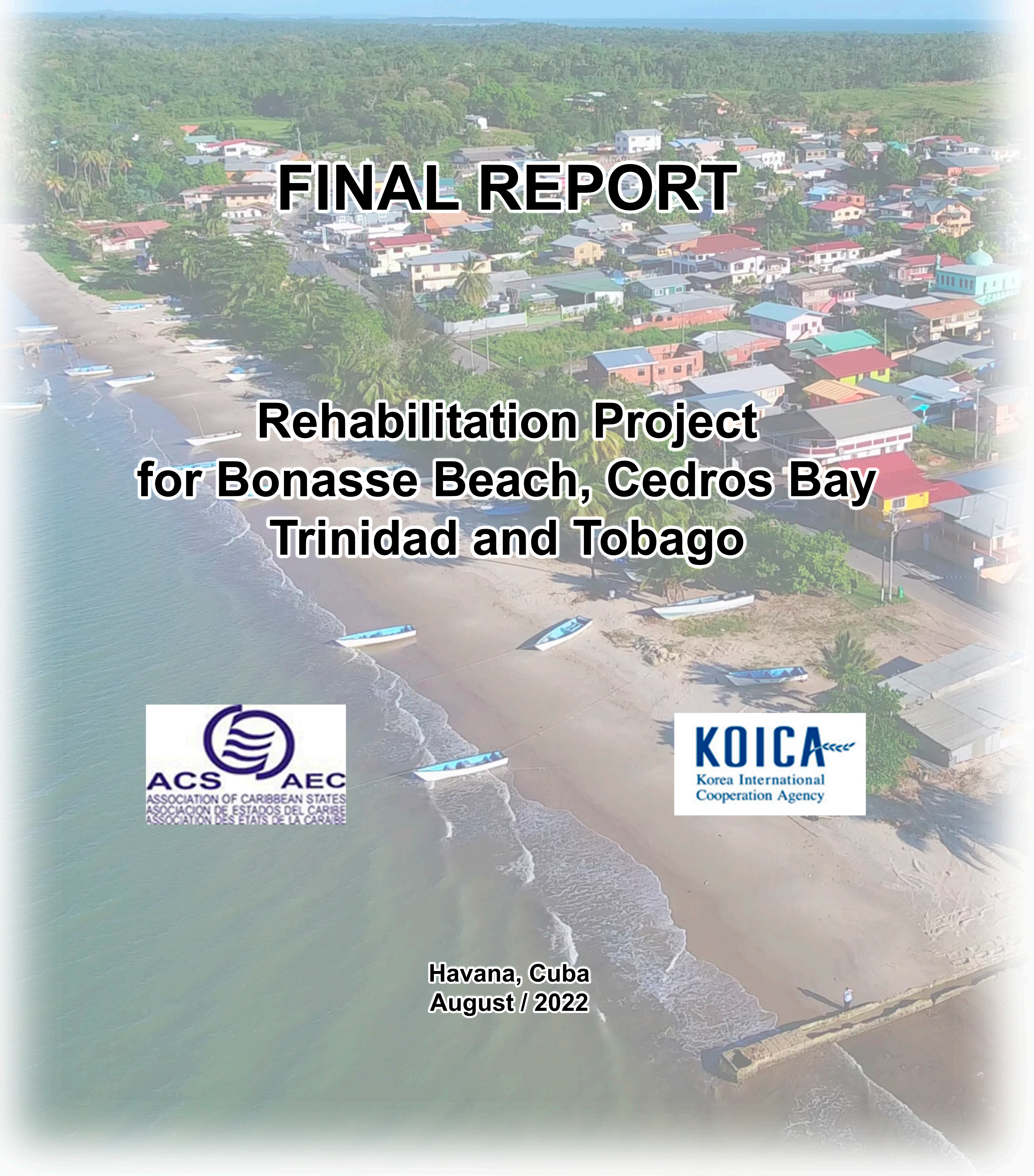

FINAL REPORT

Rehabilitation Project for Bonasse Beach, Cedros Bay Trinidad and Tobago

ACS AEC
ASSOCIATION OF CARIBBEAN STATES
ASOCIACION DE ESTADOS DEL CARIBE
ASSOCIATION DES ETATS DE LA CARAIBE

KOICA
Korea International Cooperation Agency

Havana, Cuba
August / 2022

“IMPACT ASSESSMENT OF CLIMATE CHANGE ON THE SANDY SHORELINES OF THE CARIBBEAN: ALTERNATIVES FOR ITS CONTROL AND RESILIENCE”

REHABILITATION PROJECT FOR BONASSE BEACH, CEDROS BAY, TRINIDAD AND TOBAGO

August 2022

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REHABILITATION PROJECT FOR BONASSE BEACH, CEDROS BAY, TRINIDAD AND TOBAGO

FINAL REPORT

I. INTRODUCTION

In January 2021, Contract 2/DECS/2021/01SS was signed between the Association of Caribbean States (ACS) and the company Inversiones GAMMA SA, belonging to the Cuban Ministry of Science, Technology and Environment, for the preparation of three executive beach rehabilitation projects in Viento Frío, Colón, Republic of Panama; Runaway Bay, Antigua and Barbuda; and Bonasse, Cedros Bay, Republic of Trinidad and Tobago.

In May 2021, Supplement No. 1 to the Contract was signed, with the aim of modifying the start date of the field work, scheduled for March 2021, moving it to September 2021.

In July 2021, it was agreed between the ACS and GAMMA to prioritize remote work between GAMMA specialists and the Focal Points, beginning the exchange of information and arrangements for logistical support of the field expeditions to start in Panama.

Also in July 2021, GAMMA delivered the Service Inception Report to the ACS, as well as a Contingency Plan aimed at dealing with the existing difficulties, imposed by the health situation affecting the countries involved in the project and its impact on international flights, which reduced the possibilities of starting the fieldwork of the projects on the scheduled dates.

In accordance with the Contingency Plan and as a result of GAMMA's arrangements with the airlines, on March 28, 2022, GAMMA project manager for Trinidad and Tobago arrived in the country to coordinate the logistics and necessary assurances for the execution of the field work and the postgraduate course. Due to the country's health regulations, since Cuban anti-Covid vaccines were not recognized, an exception was necessary to enter the country, issued by the Ministry of National Security, in addition to spending 7 days of mandatory quarantine.

The group of specialists who participated in the fieldwork and in the delivery of the postgraduate course arrived in Trinidad and Tobago on April 17, 2022, and also had to spend 7 days of mandatory quarantine, after the extension of a letter of exception to enter the country, issued by the Ministry of National Security.

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The fieldwork conceived in the Technical Task, included in the Contract to prepare the executive project for the rehabilitation of Bonasse Beach, was successfully completed on June 14, 2022.

Among the main results of this stage, the following stand out: determination of the coastal system functioning, topographic leveling of the beach profile, bathymetric surveys of the beach front and the sand borrow area, sediment sampling of the beach and the sand borrow zone, grain size analysis at the laboratory of the Institute of Maritime Affairs (IMA) of all the sand samples collected, study and determination of marine sand deposits for possible use as a borrow area in the rehabilitation and protection of Bonasse Beach.

This report presents the results of the tasks carried out during the field and laboratory work, as well as the complete study and design of the proposed solutions for the rehabilitation of this coastal sector, thus fulfilling the commitment to the ACS.

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II. PROJECT JUSTIFICATION

Coastal erosion is a global and irreversible phenomenon, especially in the current climate change context, being of particular concern for the countries in the Caribbean basin, whose economies are mainly based on the exploitation of their natural resources, especially their beaches.

Caribbean coasts have been subjected a continuous erosion process, which has been a source of concern and discussion at the different heads of state summits of the Association of Caribbean States (ACS), as well as in other international forums.

The loss of territories due to coastal erosion, the effects on agriculture, infrastructure, communities, and the deterioration of the conditions to offer a high-quality tourism product, which for many of these states is their main source of income, constitute a problem that becomes of maximum priority for their own subsistence.

Understanding this problem, the Association of Caribbean States (ACS), with the assistance of Korea International Cooperation Agency (KOICA) and the technical supervision of Korea Institute of Ocean Science and Technology (KIOST), develop the project "Impact Assessment of climate change on the sandy shorelines of the Caribbean: Alternatives for its control and resilience", which includes, under Component 4, section 4.1 Beach Rehabilitation Projects.

Thus, within the framework of this project, the ACS summoned the countries participating in the project, through their Focal Points, to present candidate beaches for the preparation of three executive beach rehabilitation projects, being selected the beaches: Viento Frio, in Panama; Runaway Bay, in Antigua and Barbuda; and Bonasse, in Trinidad and Tobago.

According to the "Third National Communication of the Republic of Trinidad and Tobago to the United Nations Framework Convention on Climate Change", citing the National Tourism Policy of Trinidad and Tobago (2010), the government of Trinidad and Tobago recognizes the impacts of global warming due to climate change and its potential to negatively affect the tourism industry. The climate change effects can manifest in the form of beach erosion, coral bleaching, water and food shortages, ecosystem collapse, sea level rise and extreme weather events.

Unlike most Caribbean nations and territories, which rely heavily on tourism, Trinidad and Tobago's economy is primarily industrial, with an emphasis on oil and petrochemicals. Tourism, specifically "sun, sea and sand" modality, has its greatest development on the island of Tobago.

Bonasse Beach, selected by the ACS Technical Advisory Group, is located on Cedros Peninsula, in the southern part of the island of Trinidad, where it is common to see small beaches on both coasts of the peninsula, with different levels of erosion extent and intensity. On the beach, signs of erosion can be identified, showing that it has been subjected to an erosion process, whose causes are the subject of a detailed analysis in the development of this project.

Given this scenario, the execution of a beach rehabilitation project should seek the main objective of improving its environmental, functional and aesthetic conditions, while also guaranteeing a more effective protection of the towns of Bonasse and Fullerton against the effect of climate change-induced sea level rise. With a better beach, the town can encourage leisure and recreation activities, creating new employment and income opportunities for its residents and the State.

The solutions that are proposed and designed in the current project respond to this objective, under the premise of not compromising the application of new actions to deal with the effects of sea level rise in future climate change scenarios. In addition, they are based on understanding the coastal system functioning and the application of environmentally friendly solutions based on scientific criteria.

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III. MATERIALS AND METHODS

Geodetic works carried out in Bonasse Beach were referred to two points with XYZ coordinates, belonging to IMA's network of reference points, provided by the Institute of Maritime Affairs (IMA), Table 1.

Table 1. Coordinates of IMA's reference points used for the topographic survey.

Benchmark	UTM Coordinates, Zone 20N (WGS-84)		
	Easting	**Northing**	**Height**
HUB1209	624349.512	1115875.088	9.207
Cedros01	624755.011	1115984.361	2.387

From these points and using a GS-14 GNSS Leica in RTK mode, Bonasse Beach baseline was. In total, seven new points were established, which in turn constituted the heads of the beach profiles that were subsequently measured (Photos 1-4). Table 2 presents the list of coordinates of the heads of the established profiles.

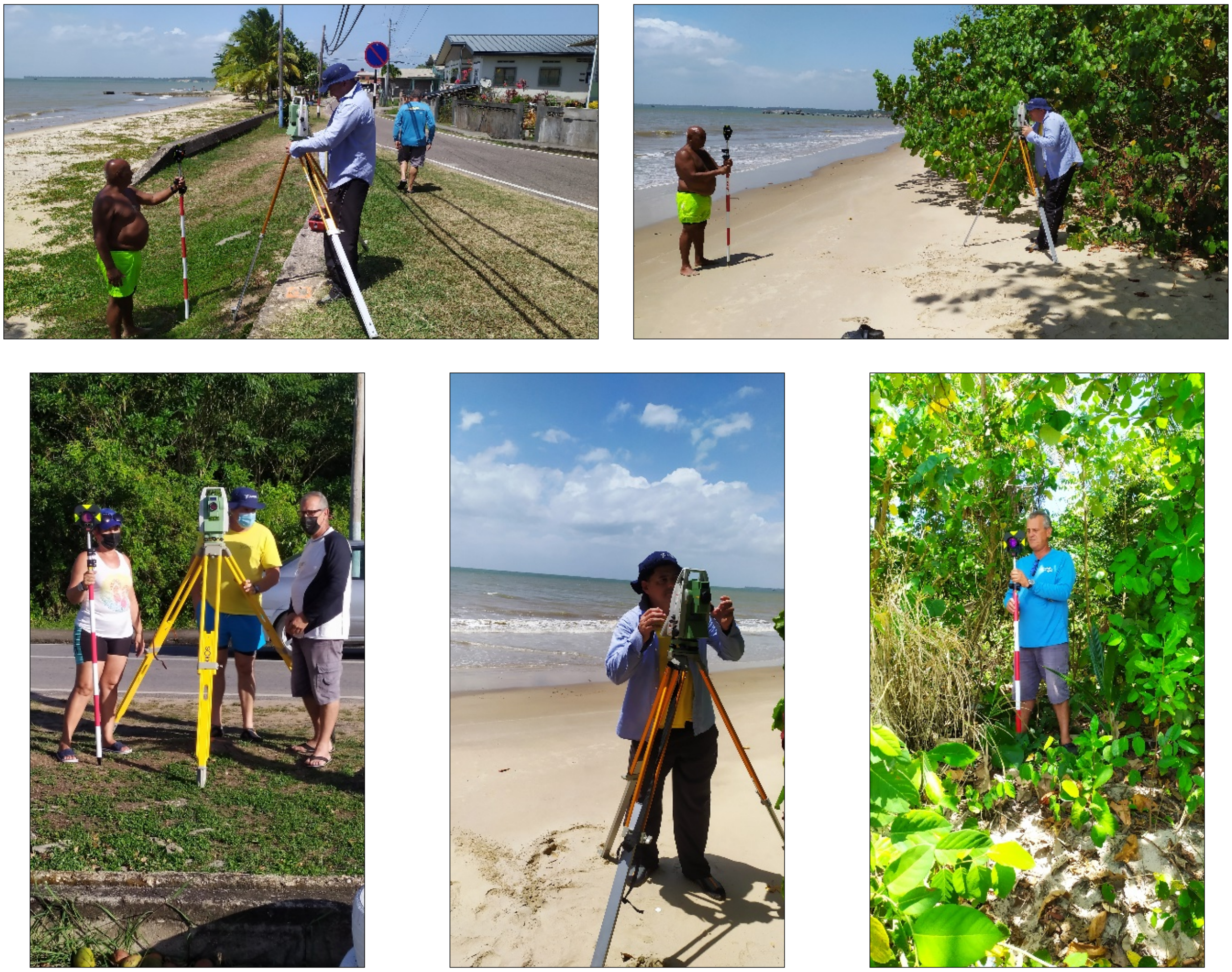
Photos 1 and 2. Installation of the base station at Bonasse Coast Guard facilities. Using GS-14 GNSS Leica in RTK mode.


Photos 3 and 4. Establishment of topographic points that serve as heads of the beach profiles for the characterization of the profile morphology.

Table 2. Coordinates of the heads of the profiles established during the topographic works.

Profile	**UTM Coordinates, Zone 20N (WGS-84)**		
	Easting	**Northing**	**Height**
Bonasse-1	622917.670	1115834.242	1.988
Bonasse-2	623216.440	1115844.097	2.053
Bonasse-3	623918.458	1115853.275	3.626
Bonasse-4	624491.019	1115919.843	2.541
Bonasse-5	624754.790	1115985.861	2.361
Bonasse-6	625186.846	1116065.828	4.238
Bonasse-7	625600.808	1116156.267	2.639

For the measurement of the seven beach profiles, a Leica TS09 Plus Total Station was used, following the distance and slope method. (Photos 5-9) (Annex 1)



Photos 5-9. Measurement of beach profiles along Bonasse Beach with a Leica TS-09 Plus Total Station.

All the topographic information was processed using Leica FlexOffice Standard, Grapher 18 and Surfer 21 software. The cartographic materials are presented in the UTM Zone 20N coordinate system, WGS-84 datum.

For the bathymetric study, a Stonex SDE 28 D echosounder was used, and the positioning of the sounding lines was carried out with the Hemisphere GNSS VS1000. Sounding logs were made by connecting the equipment to a laptop and using HYPACK MAX 64 hydrographic software for processing. (Photos 10-13)

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Photo 10. Stonex SDE 28D echosounder .

Photo 11. Hemisphere GNSS VS1000.

Photos 12 and 13. Execution of the bathymetric survey with the HYPACK MAX 64 software.

During the sounding, the antennas were placed parallel to the center line of the boat, at a distance of 1.5 m between them, with the primary antenna towards the stern and the secondary one towards the bow. The echosounder transducer was mounted on the port side of the boat, at a depth of 0.60 m, away from the noise of the boat's engine. Before starting the measurements, the speed of sound in the water at the work area was determined using an AML sound speed profiler in the water column, which was used to correct the depth records in the post-processing stage (Photo 14).

Photo 14. AML sound profiler.

A general bathymetric survey of the beachfront and adjacent areas was carried out at a scale of 1:50,000 (additional sounding lines were carried out in areas of interest). In total, 24 sounding lines were carried out, 6 km long each, with a separation of 500 m between them, which means a total sounding length of 144 km to cover an area of 60 km^2 (Figure 1).

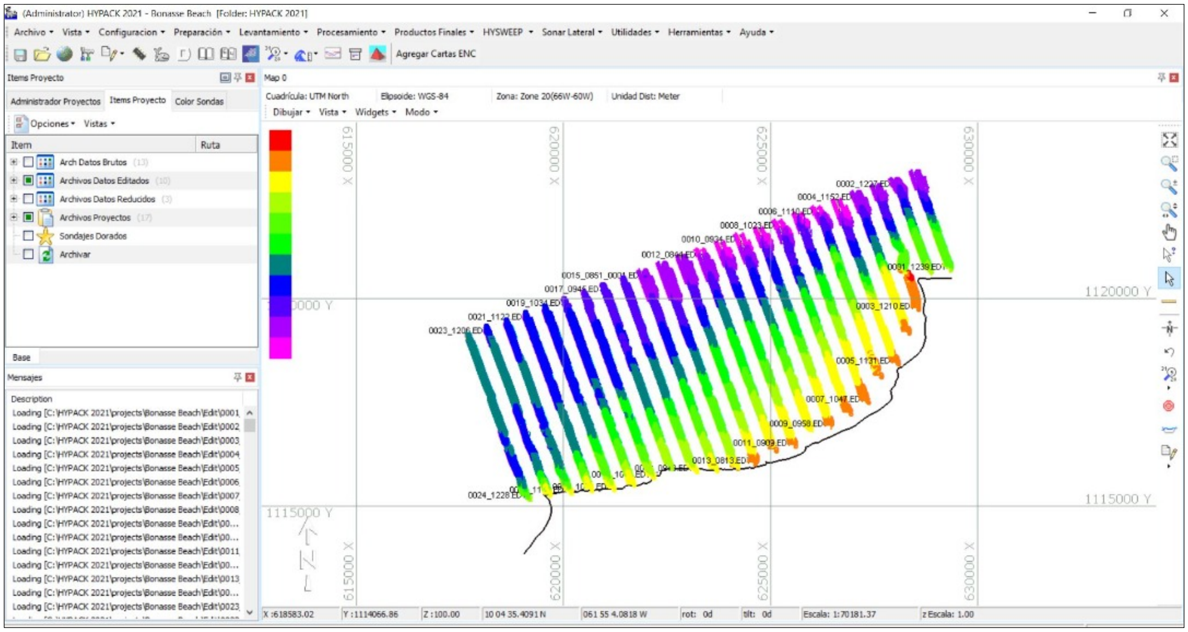

Figure 1. Screenshot of the HYPACK MAX 64 software used for echosounder data collection. Sounding lines of the general bathymetric survey of the beach.

In addition, the detailed bathymetric survey of the beach at a scale of 1:5,000 was developed. A total of 114 survey lines of 3.5 km in length each were conducted, with a separation of 50 m between them, which represents a detailed survey length of 399 km, to cover an area of 19.6 km^2 (Figure 2).

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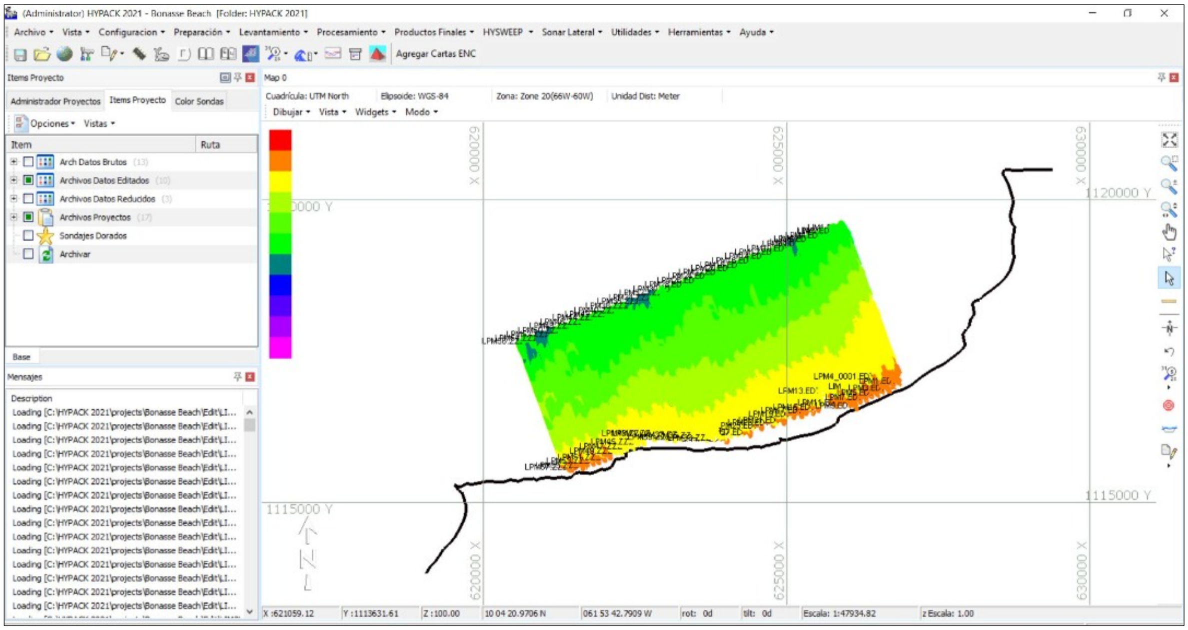

Figure 2. Screenshot of the HYPACK MAX 64 software used for echosounder data collection. Sounding lines from the detailed bathymetric survey of the beach.

The bathymetric records were processed with Surfer-21 software, whose bathymetric scheme is shown in Plan 1.

Sediment sampling was developed, both in the borrow area and on the beach.

For the grain size characterization of the sediments, samples were taken at each station in which the topographic leveling of the beach profile was conducted. The samples were taken manually from the foreshore of the profiles and stored in nylon envelopes. The sand samples collected at sea were taken with the help of a sampler and a winch, installed on the deck of the boat (Photos 15 and 16).

Photos 15 and 16. Use of sampler and winch to collect sand samples at sea.

The collected sand samples were dried in the open air under sunlight and sent to the IMA laboratory for grain size analysis.

In the sedimentology laboratory at IMA, the samples were dried in a Memmert Be20 oven for 24 hours (Photos 17 and 18).

Photo 17. Memmert Be20 oven used for drying the samples.

Photo 18. Sand samples dried in the oven for 24 hours.

Taking into account the sandy nature of the samples, the grain size analysis was carried out manually by dry sieving, using sieves with a mesh set of 0.063, 0.125, 0.25, 0.50, 1, 2 and 4 mm and an Endecotts Octagon sieve shaker. (Photos 19 and 20).

Photo 19. Set of sieves used for sifting the samples.

Photo 20. Endecotts Octagon sifter with set of sieves.

The weight data per sieve were processed with Gradistat Version 4.0 software developed by Simon Blott, from the Current Environments Research Group, Department of Geology, Royal Holloway University, London (Blott, 2001), obtaining the mean particle diameter (M) in mm and ø units, the standard deviation, and other parameters, by the method of moments and the Folk & Ward method. For sediment classification, it was used the one proposed by Wentworth (Shore Protection Manual, 1984) (Table 3).

Table 3. Wentworth's grain size classification (Shore Protection Manual, 1984).

Sediment type	Mean diameter M (mm)
Clay	0.00049 – 0.0039
Silt	0.0039 – 0.0625
Very fine sand	0.0625 – 0.125
Fine sand	0.125 – 0.250
Medium sand	0.250 – 0.500
Coarse sand	0.500 – 1.000
Very coarse sand	1.000 – 2.000
Gravel	2.000 – 4.000

The results of the grain size analysis, both of the samples collected on the beach and of those from the borrow area, are shown in Annex 2.

According to the methodology established in Gradistat, taking into account the logarithmic method of moments, the standard deviation, or the sorting degree (Ø) of the sand, the sediments are classified according the ranges indicated in Table 4.

Table 4. Classification ranges of the sorting degree of the sand according to the standard deviation value.

Standard deviation value range (Ø)	Classification
0.35 – 0.50	Well sorted
0.50 – 0.70	Moderately well sorted
0.70 – 1.00	Moderately sorted
1.00 – 2.00	Poorly sorted

Understanding that the wave generated during extreme erosive events and that, particularly, tropical hurricanes constitute the main erosive agents that affect the Bonasse coast, chapter IV includes a specific study of this topic, considering the methodological aspects. Other studies and mathematical models related to hydrodynamic characteristics and sediment transport are also included in this chapter.

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IV. PHYSICAL-GEOGRAPHICAL CHARACTERISTICS OF THE STUDY AREAS

IV.1. General Aspects

Trinidad and Tobago are the southernmost islands of the Lesser Antilles, located near the South American continental shelf. (Figure 3)

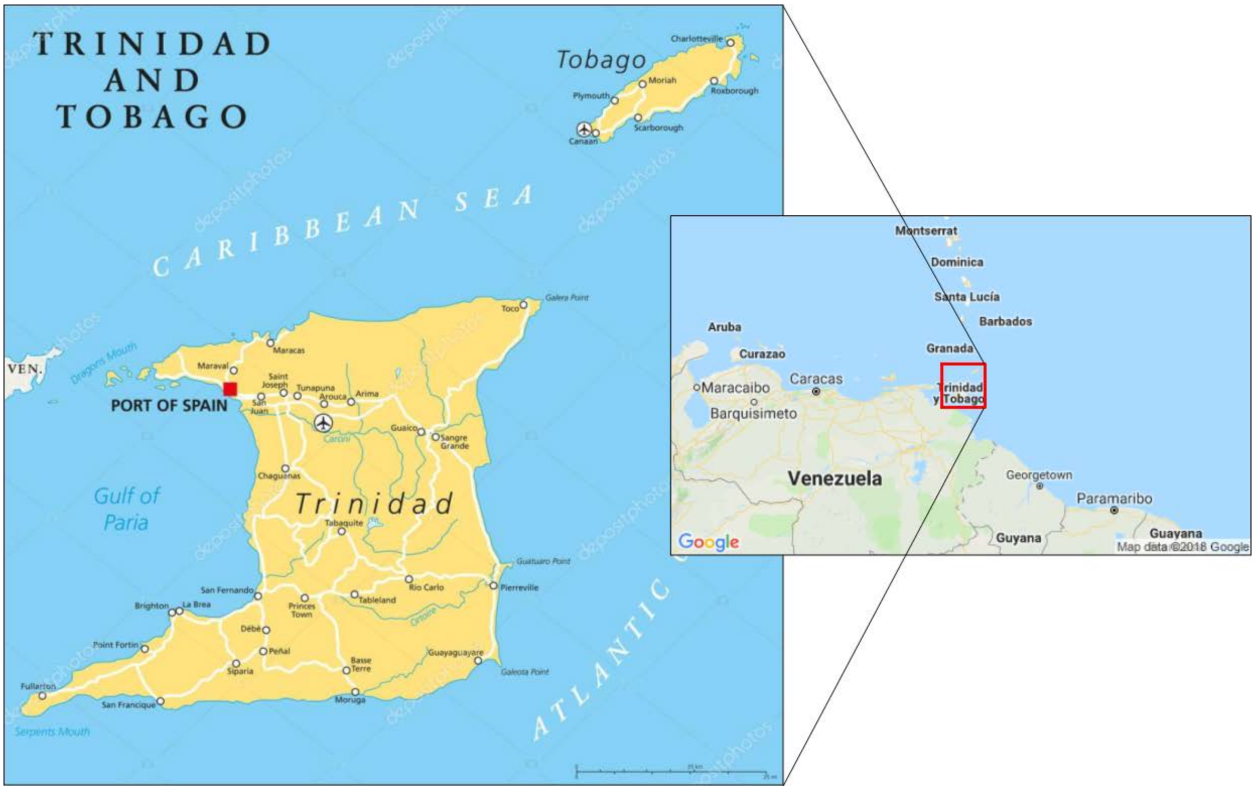

Figure 3. Geographic location of Trinidad and Tobago

Trinidad is located 11 km from the northeast coast of Venezuela and 130 km south of the Grenadines. It is 60 km long and 80 km wide at its maximum, and has an area of 4,828 km^2. Trinidad has a rectangular shape, with three protruding peninsular corners. Tobago is located 30 km northeast of Trinidad, from which it is separated by a channel 37 km wide; the island is 42 km long and 13 km wide, with a total area of 300 km^2. Tobago is cigar-shaped and has a northeast-southwest alignment.

The islands have a humid tropical monsoon-type climate. Rainfall reaches an annual average of 2,200 mm, being seasonal, with a wet season from June to November and a dry season from December to May. Temperatures range from 25-27°C, humidity from 50-100%, and average wind speeds from 20-28 km/h. Trinidad's landscape is characterized by rugged mountains, rolling hills and plains, and is endowed with highly varied shorelines, a good part of them covered by wetlands, and a highly diverse flora and fauna.

Currently, Trinidad and Tobago is the subject of much research in the field of climate change and sea level rise, which is why it is a signatory to the UN Framework Convention on Climate Change, whose objective is to achieve a drastic reduction in emissions of CO_2 and other greenhouse gases.

Floods are the natural hazard most worrying the population, due to their frequency of occurrence and the magnitude of the resulting damage. This phenomenon is related to poor watershed management practices and poor discharge habits of the population, especially in urban areas.

Pollution is a growing problem across the country. The main water pollutants are urban, domestic and industrial waste, agricultural products and residues, sediments, petrochemical products and discharges from the oil and energy industries, waste from fishing vessels, boats and tourist facilities and yachts. Pollutants affect both inland freshwater resources and coastal water resources, including beaches and shorelines.

As in other countries, economic growth and development, along with population growth, is leading to environmental degradation of river basins, water resources and coastal areas. In the case of Trinidad and Tobago, an island state, coastal habitats and ecosystems take on greater significance. Coastal zones support a variety of ecosystems and valuable natural resources, and are home to major industries and economic activities. Like watersheds, these areas are subject to threats from various terrestrial activities.

The country experiences much of the gamut of environmental problems, from widespread pollution of its waterways and coastal areas, petrochemical spills, illegal dumping, deforestation, excessive soil erosion, overfishing, and the depletion of natural resources. These problems are attributed to poor land use and an inadequate legal and institutional framework for the management of river basins, water resources and coastal areas, which are also threatened by natural disasters (tropical storms, earthquakes, floods and droughts), as well as climate change and sea level rise.

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IV.2. General geological-geomorphological characteristics of Trinidad and Tobago.

Geologically, the islands are not part of the Antillean arc. Rather, Trinidad was once part of the South American mainland, and Tobago is part of a sunken mountain range related to the mainland. Today, the islands are separated from the South American mainland by the Gulf of Paria; a passage to the north of 19 km wide, the Dragon's Mouth, and another of 14 km to the south, the Columbus Channel, or Snake's Mouth, as it is also known.

Trinidad is an uplifted segment of the Orinoco Neogene platform, created largely by the Orinoco paleo-river and its delta. The sedimentary prism of the Atlantic-facing shelf margin has an internal clinoform morphology, with marine and non-marine sandy topsets and deep-water muddy slope deposits, containing turbidite channels and collapsed shelf-edge blocks.

The oldest rocks in Trinidad are phyllites, limestones and metamorphic quartzites from the end of the Jurassic; quartzites, phyllites, slates and limestones are associated to the Cretaceous. To the east of the island, there is an area with exposed volcanic rocks on the surface, including basalt, ash and breccia, and along the north coast, the phyllite slates; likewise, deposits of dark slates and quartzites, followed by argillites, are associated with the Cretaceous. During the Paleocene, calcareous and non-calcareous shale were deposited. In the Eocene, calcareous marls and schists were formed and the turbiditic flysch appears in the Cordillera Central. Clastic material and conglomerate marked a shift towards erosion in the elevated areas at the end of the Eocene. The Cordillera Central was raised in the Oligocene; although the deep-water clays and marls suggest a deepening of basins like the one in the north.

Oil sands are mostly associated with the Miocene, and this Era marks the return to deep-water clays, together with reef limestone and surface deposition, which prevailed in many parts of the island until the Pliocene, when the processes of ascent and descent became common after the main phase of the Andean orogeny ended to the south. Changes in sea level during and since the Pleistocene have played a key role in sedimentation.

IV.3. Geological environment of the study region.

The area of the works is located in the Orinoco Delta, near the northeast end of South America, associated with sediments belonging to the Late Miocene and Pliocene; despite the fact that the origin of the Orinoco River belongs to the Pliocene and that its flow changed from the north of the

Gulf of Maracaibo in the Miocene to the east, between the Andes of Mérida and the Cordillera del Caribe to the north, and the Guayana Shield to the south (Díaz de Gamero, 1996).

The Orinoco River and its delta migrated along the axis of the Eastern Venezuela Basin, to emerge towards the south of Trinidad at the end of the Miocene and large volumes of mud are still transported and deposited by coastal currents towards the northwest, along the inner shelf and in front of the Orinoco Delta, derived from the Amazon River (Aslan *et al*., 2003).

The sediments present in the study area are related to the Morne L'Enfer Formation, which outcrops on the southwestern coast of Trinidad, at Erin Bay and Cedros Bay, and is one of the best exposed formations on the island (Barr *et al*., 1958; Suter, 1960; Ablewhite and Higgins, 1968), supported by more than 1,200 m of core samples from drills in the west of the South Basin (Figure 4), guided by the geological map of Trinidad (Kugler, 1959), where the lower and upper members of Morne L'Enfer are well exposed.

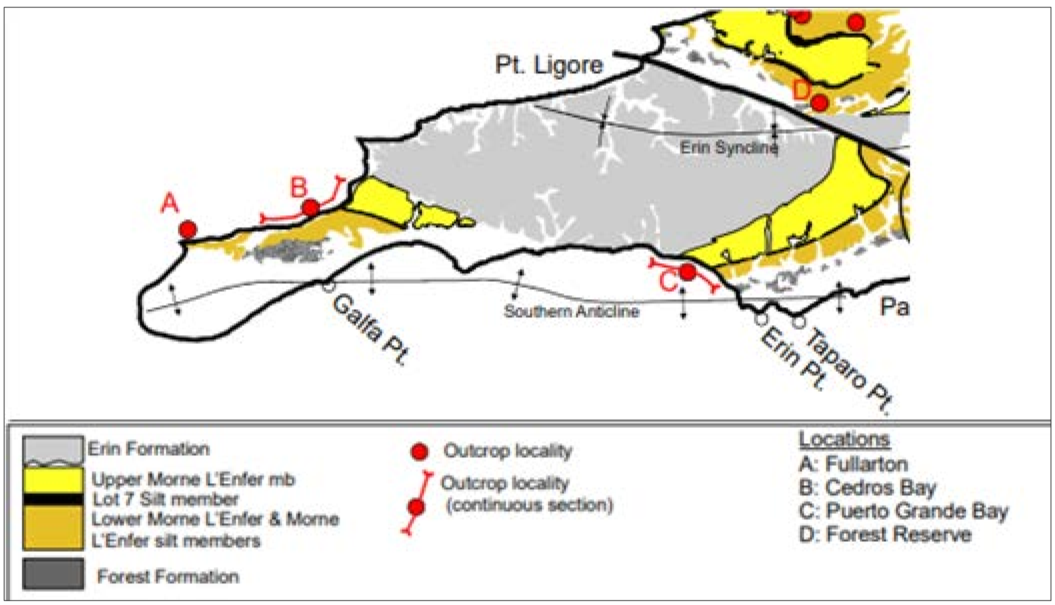

Figure 4. Geological map of southwest Trinidad showing the location of examined sections within the Morne L'Enfer Formation. (Source: Chen et al., 2014).

From the stratigraphic correlations of Puerto Grande and Cedros Bay along the coasts and outcrops further inland, it is observed that the lower and upper members of Morne L'Enfer are well exposed, where their physical and biogenic sedimentary structures were integrated with mineralogy and paleo-current orientations to obtain regional data on depositional patterns in this part of the South Basin.

At least seven sets of lithofacies can be distinguished along the Morne L'Enfer, each of which represents specific sedimentation processes and clogging stages of the basin. Sedimentary environments within the lower Morne L'Enfer member vary from silts and sandstones, the upper part is characterized by laterally channeled fills, tidal flats and floodplain deposits and swamps. The fluvial facies towards the top of this member may represent a key basal change in facies that is continuous in the Erin Formation.

IV.4. Morphological and sedimentological characteristics of Bonasse Beach.

Bonasse Beach is located in Cedros Bay and has a length of 3,300 m; it is linear, supported laterally by two cliffs, to the east the one located at Marie Point and to the west the one located on the coastal limit of Fullerton town, both with heights greater than 10 m (Figure 5, Photos 21 and 22).

Figure 5. Project study area.

Photo 21. Marie Point, cliff that limits Bonasse Beach to the east.

Photo 22. Cliff in Fullerton that limits Bonasse Beach to the west.

According to Saunders (1998), both cliffs are made up of unconsolidated intercalations of silt, clay and sandstone (Photos 23 and 24), which show a frank erosion process, evidenced by the scarped walls and the material accumulated at the foot of the cliff (Photos 25 and 26).

Photos 23 and 24. Intercalations of silt, clay and sandstone on the walls of the cliffs. Left: East limit cliff. Right: West limit cliff.


Photos 25 and 26. Material from a landslide at the foot of the cliff. Left: East limit cliff. Right: West limit cliff.

Due to the extension of the beach and its level of anthropization, the study area was divided into two (2) sectors (Figure 6):

- Sector 1: from the cliff of Marie Point to the east, to the Coast Guard pier, with a length of 1,500 m.
- Sector 2: from the Coast Guard pier to the cliff to the west in Fullerton, with a length of 1,800 m.

Figure 6. Subdivision of the study area according to the degree of anthropization.

Sector 1

The morphology of Sector 1 in its emerged part near the shore, is characterized in its eastern half by the presence of elevations approximately between 10-15 m high, regularly occupied by dwellings, as well as troughs between the elevations, where part of the pluvial drainage is evacuated towards the beach. On the other hand, the western half of the sector in its emerged part near the shore, has heights that do not exceed 3 m. This section is the most anthropized, where the population center of Bonasse town is located.

Two fundamental activities are carried out in this sector. On the one hand, it is the most used by bathers, due to the facilities created for this purpose, such as bathrooms, sales of light products and parking lots. On the other hand, it is used for the beaching and mooring of small boats, associated with fishing, which is the fundamental economic activity in the area. (Photos 27 and 28)

Photos 27 and 28. Basic uses of Bonasse Beach . Left: use in activities related to fishing. Right: recreational use, as a bathing area.

According to the beach profiles measured in this sector, Bonasse Beach has a gentle slope, where the emerged part is dominated by vegetation and buildings on the dune, with a marked influence of tidal cycles, which make Bonasse Beach about 60 m wide at low tide; being only 20 m wide at high tide, reducing the beach by 40 m, with a berm only about 7 m wide (Figure 7).

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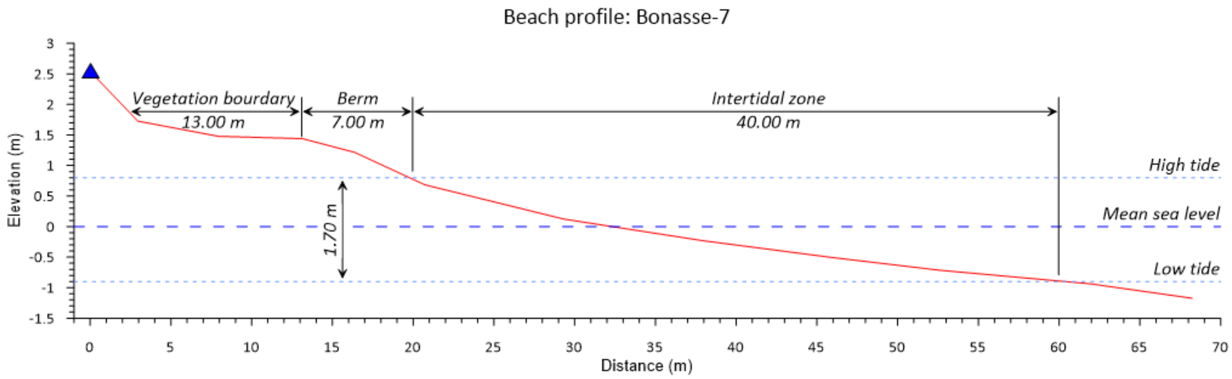

Figure 7. Typical beach profile of Bonasse Beach in Sector 1.

The sunbathing and bathing areas are made up of fine to very fine sand, brown in color, with a high content of terrigenous material. From a depth of approximately 1.20 m to about 100-120 m from the shore, the sediments change their texture to sandy-muddy, brown in color, with dark gray shades, until the sand disappears and the entire seabed appears covered with mud, integrating with the sediments present in the Gulf of Paria.

Taking into account the coastal geomorphology of the region, this distribution of the sediments along the profile allows us to establish *a priori* that the origin of the sediments that appear in the emerged part and the underwater slope of the beach are associated with the inputs from terrigenous sources, mainly from the existing cliffs upstream, which reach the beach transported by the currents, produced by the ebb and flow of the tides, and mainly by the coastal currents induced by the breaking of the waves that move very close to the shore.

In this sector there is evidence of environmental degradation, related to pollution and beach erosion, which are associated with human and natural causes.

Pollution problems are of anthropic cause and are linked to poor management of drainage and domestic discharges, which drag solid and liquid waste towards the coast, impoverishing the quality of the waters that wash the beach and the very sediments that make it up.

In the sector, domestic waste is dumped directly onto the ground and there are also concrete structures that channel wastewater and runoff into the sea, without prior treatment, which undoubtedly constitutes a source of pollution of beach water and sediments (Photos 29 -34).

Photos 29 and 30. Presence of a concrete structure that channels wastewater and runoff seaward. East end of Sector 1.

Photos 31 and 32. Presence of concrete micro-dumping sites and gullies on the beach that channel wastewater and runoff seaward. Central part of Sector 1.

Photos 33 and 34. Presence of a concrete structure that channels wastewater and runoff seaward. West end of Sector 1.

In relation to the signs of erosion, due to the gentle slope of the beach, in usual conditions the waves reach the shore completely dissipated. Therefore, the observed signs of erosion are not recent; they are long-standing and limited to extreme events, when some of the wave energy dissipates over the emerged part of the profile, leaving traces of its impact, in addition to the measures taken at the time by the residents and authorities to face similar future events (Photos 35 and 40).

Photo 35. Old erosion scarp, smoothed and covered by vegetation.

Photo 36. Retreat of the old erosion scarp. Dune and post-dune vegetation reached by the sea at high tide.

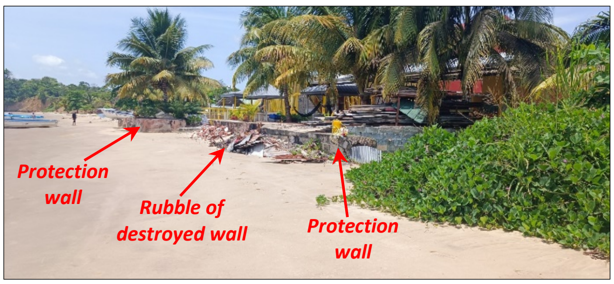

Photo 37. Protection walls and buildings on the beach and rubble from their destruction by the wave.

Photo 38. Abandoned house and protection wall on the beach.

Photo 39. Protection and containment wall that limits the beach and the road.

Photo 40. Remains of a destroyed pier that still rests on the beach.

Sector 2

The geomorphology of the sector in 80% of its extension is characterized by the presence of elevations approximately between 10-15 m high, which in some cases extend their slopes from the beach itself, and in others from a flat strip up to 20 m wide, covered by dense vegetation (Photos 41 and 42).

Photo 41. Elevations that rest their slopes on the beach itself.

Photo 42. Elevations that rest their slopes in areas of the beach dune.

Between these elevations, as in Sector 1, the presence of troughs can be observed, through which waters associated with the rainfall drain from the highest areas inland (Figure 8). These troughs during the dry periods, keep the outlets to the sea obstructed with the dragged garbage and the formation of berms; so that, in the rainy periods, with especially intense and continuous rainfall, permanent opening is required to avoid flooding in coastal sectors, especially the one located in the vicinity of the Fullerton boat mooring and repair area, where this practice is common (B in Figure 8) (Photos 43 and 44).

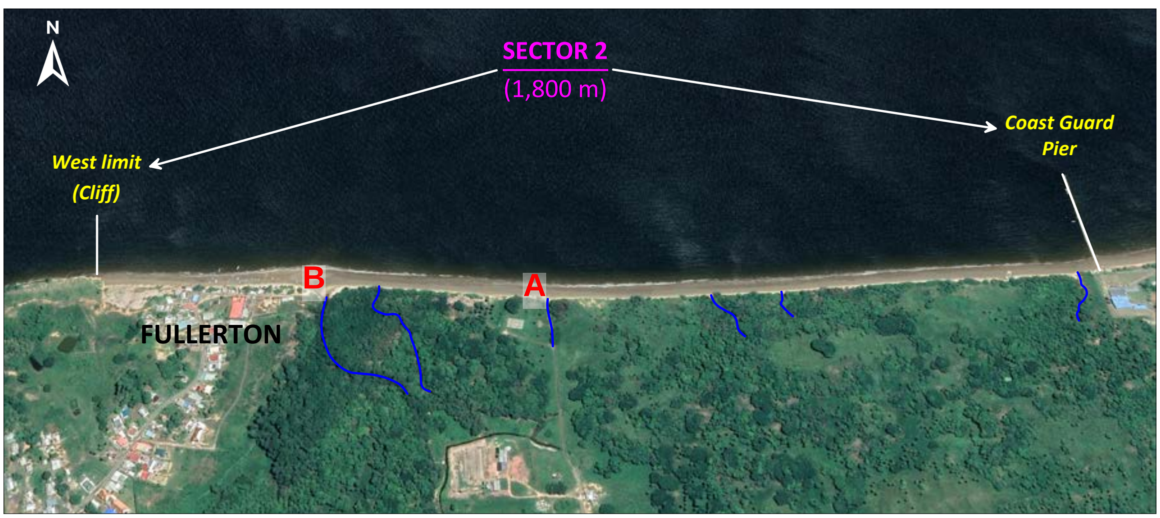

Figure 8. Troughs (blue curves) in Sector 2 that drain directly to the beach.

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Photo 43 and 44. Outlet to the sea of pluvial drainages through the valleys. (A and B according to Figure 8)

In this sector, despite being the longest, the main economic activity is fishing and it is limited to the 300 m stretch of beach in front of Fullerton town, so that in the remaining 1,500 m of beach in the sector no activity takes place. In fact, this entire beach length is completely virgin (Figure 8).

The beach is characterized by a reduced width of the sun exposure area, where at high tide the sea level can reach the vegetation and the slopes of the elevations; while at low tide this sun strip can reach up to 30 m wide.

In this section, the underwater slope is gentle but higher than Sector 1, which is due to the distribution of the bathymetric curves (Plan 1), where the isobaths are closer together and approach the coast, encouraging waves to dissipate their energy closer to the coast, both for usual and extreme conditions.

The sun exposure and bathing areas have similar characteristics to those described above for Sector 1, made up of fine to very fine sand, of terrigenous origin and brown in color, with gray hues, which are distributed to a depth of 1.20 m at about 100 m - 120 m from the shoreline approximately. As in Sector 1, from this depth the sand begins to mix with muddy sediments, until the sand disappears and the entire seabed appears covered with mud, integrating with the sediments present in the Gulf of Paria.

Although the sector conserves its natural state and there is no human intervention, a significant erosive process can be observed, where the main signs of erosion are the presence of erosion scarps, fallen trees, outcropping of old structures due to loss of sand and the marked retreat of the shoreline, evidenced by the presence of vegetation on the beachfront that normally, due to its natural zoning, belongs to dune and backdune areas (Photos 45-48).

Photo 45. Old erosion scarp, smoothed and covered by vegetation.

Photo 46. Falling of trees under the action of waves.

Photo 47. Retreat of the old erosion scarp. Dune and backdune vegetation reached by the sea at high tide.

Photo 48. Outcrop of old structures due to sand loss.

Summarizing, Bonasse beach, as a natural resource, presents a deterioration of its physical and environmental conditions, the result of pollution problems due to unprocessed discharges into the sea from storm drainage, and liquid and solid waste from domestic activity, fundamentally, to the detriment of sediment and seawater quality. Likewise, the existence of some abandoned concrete structures in the process of destruction can be observed, which unfavorably interfere with the aesthetic and functional conditions of the beach.

However, the main environmental problem, especially in the context of Climate Change and sea level rise, is related to coastal erosion that is observed along the entire beach, where there are signs of erosion that undoubtedly warn of the unequivocal presence of this phenomenon, with an intensity that can be classified as moderate.

The causes of erosion are mainly natural, associated with the sedimentary imbalance of the beach, as a result of the deficit in sediment inputs from the cliffs upstream, which causes more sediment to escape from the beach by the coastal currents than sediment that enters the beach from the cliffs, marking an irreversible erosive trend in a natural way.

Table 5 below summarizes the characteristics of the beach profile and the sediments present on the beach.

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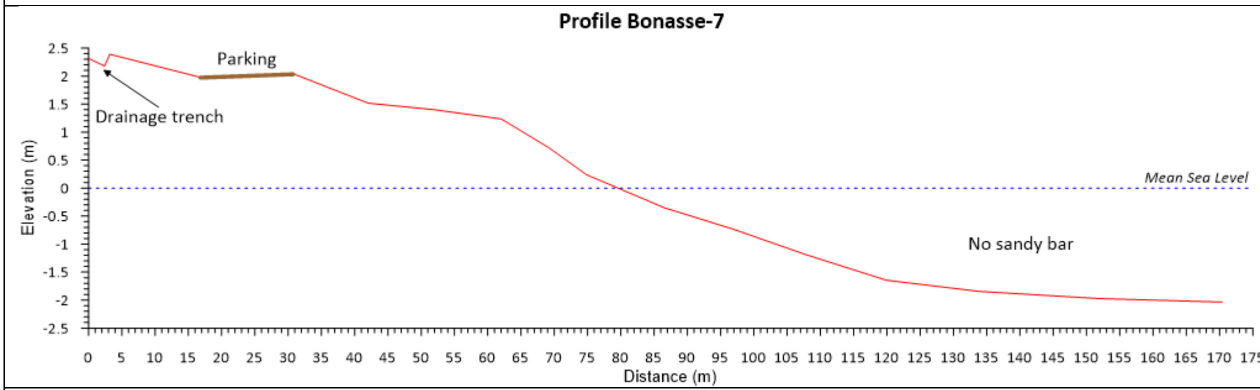
Table 5. Synthesis of the characteristics of the beach profiles and sediments in the coastal front of Bonasse Beach.

SECTOR 1

Profile: Bonasse 7.

Reference point coordinates

Easting	Northing	Height
625600.808	1116156.267	2.639



Sediment composition : _

Sample	Profile / Sector	Grain size composition		Grain size classification	Macroscopic description
		M (mm)	ϕ		
P-7	7/1	0.151	2.722	Fine sand Moderately well sorted	Terrigenous brown sand with gray hues. No calcareous remains.

Description:

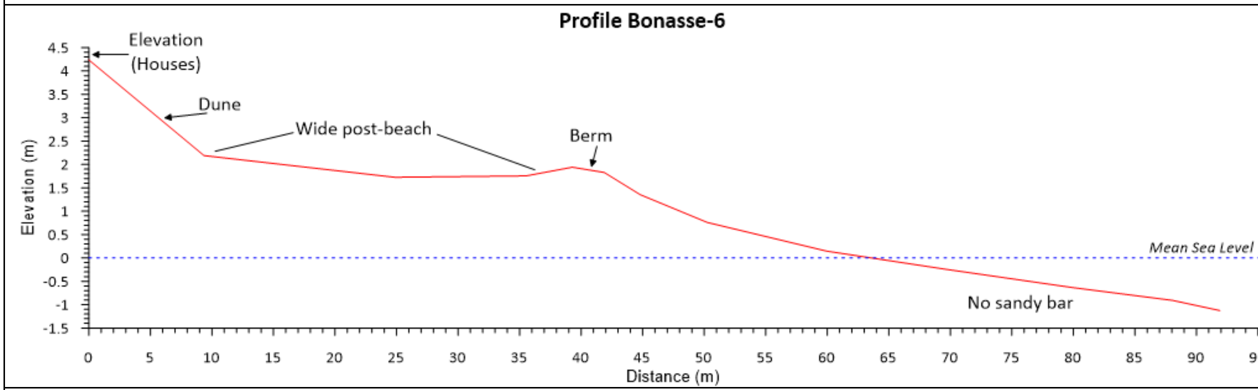
The profile records a good beach width, even at high tide the sun exposure area has a width of 25-30 m. No sandbars are observed on the underwater slope. Starting 120 m from the shore, the sand appears mixed with mud.

SECTOR 1

Profile : Bonasse 6.

Reference point coordinates

Easting	Northing	Height
625186,846	1116065,828	4,238



Sediment composition:

Sample	Profile / Sector	Composition grain size		Classification grain size	Description macroscopic
		M (mm)	ϕ		
P-6	6/1	0.159	2,656	Moderately well graded fine sand	Terrigenous brown sand with gray hues. No calcareous remains.

Description:

Profile with sun exposure area 30 m wide. Newly laid berm denoting a cumulative process. The dune covered with vegetation that connects with an elevation on which there are houses of settlers. No sandbars are observed on the underwater slope. Starting 120 m from the shore, the sand appears mixed with mud.

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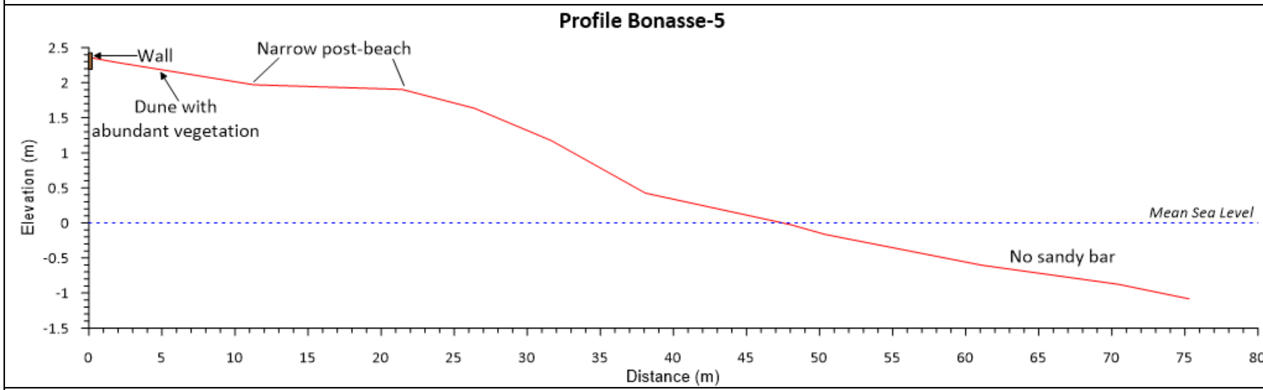
SECTOR 1

Profile: Bonasse 5.

Reference point coordinates

Easting	Northing	Height
624754.790	1115985.861	2.361



Sediment composition: _

Sample	Profile / Sector	Grain size composition		Grain size classification	Macroscopic description
		M (mm)	ϕ		
P-5	5/1	0.147	2.770	Fine sand Moderately well sorted	Terrigenous brown sand with gray hues. No calcareous remains.

Description:

Profile with sun exposure area 15 m wide. Narrow dune covered in vegetation and limited by a wall and the main Bonasse road. No sandbars are observed on the underwater slope. Starting 120 m from the shore, the sand appears mixed with mud.

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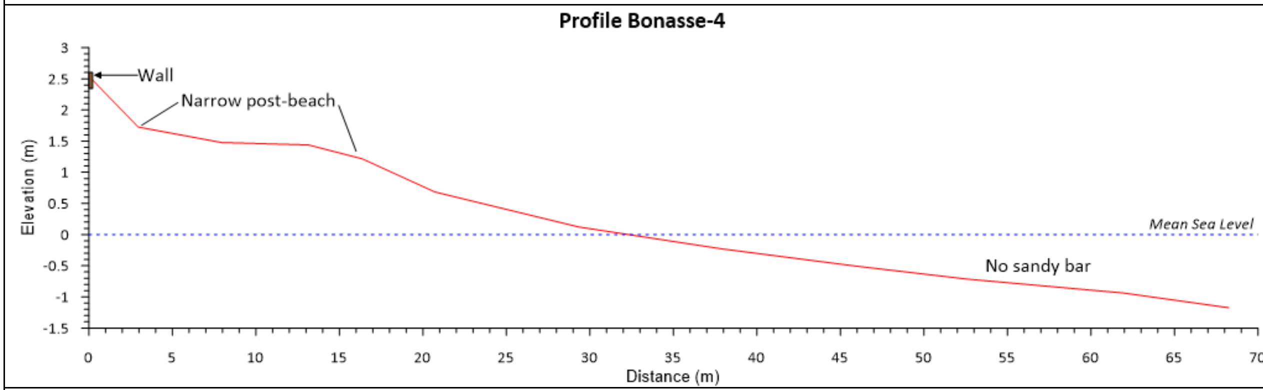
SECTOR 1

Profile: Bonasse 4.

Reference point coordinates

Easting	Northing	Height
624491.019	1115919.843	2.541



Sediment composition: _

Sample	Profile / Sector	Grain size composition		Grain size classification	Macroscopic description
		M (mm)	ϕ		
P-4	4/1	0.202	2,307	Fine sand Moderately well sorted	Terrigenous brown sand with gray hues. No calcareous remains.

Description:

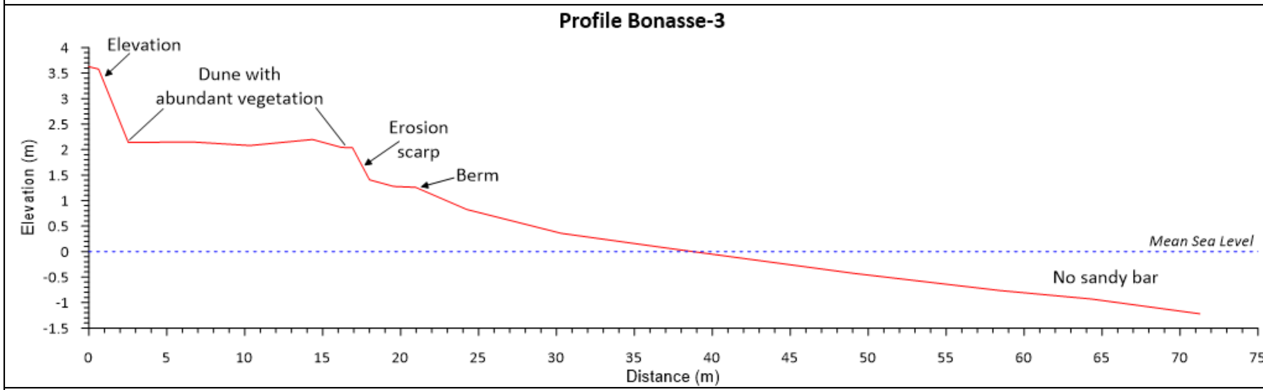
Profile with sun exposure area 10 m wide. There is no dune, instead there is a protection wall and the road that gives access to the Coast Guard facilities. No sandbars are observed on the underwater slope. Starting 120 m from the shore, the sand appears mixed with mud.

SECTOR 2

Profile: Bonasse 3.

Reference point coordinates

Easting	Northing	Height
623918.458	1115853.275	3.626



Sediment composition: _

Sample	Profile / Sector	Grain size composition		Grain size classification	Macroscopic description
		M (mm)	ϕ		
D-3	3/2	0.171	2.551	Moderately well graded fine sand	Terrigenous brown sand with gray hues. No calcareous remains.

Description:

Profile with 5-7 m width of the sun exposure area. Dune covered by abundant vegetation, which connects with an elevation also covered by abundant vegetation and without anthropogenic occupation. Presence of escarpment at the base of the dune of 0.50 m. No sandbars are observed on the underwater slope. Starting 120 m from the shore, the sand appears mixed with mud.

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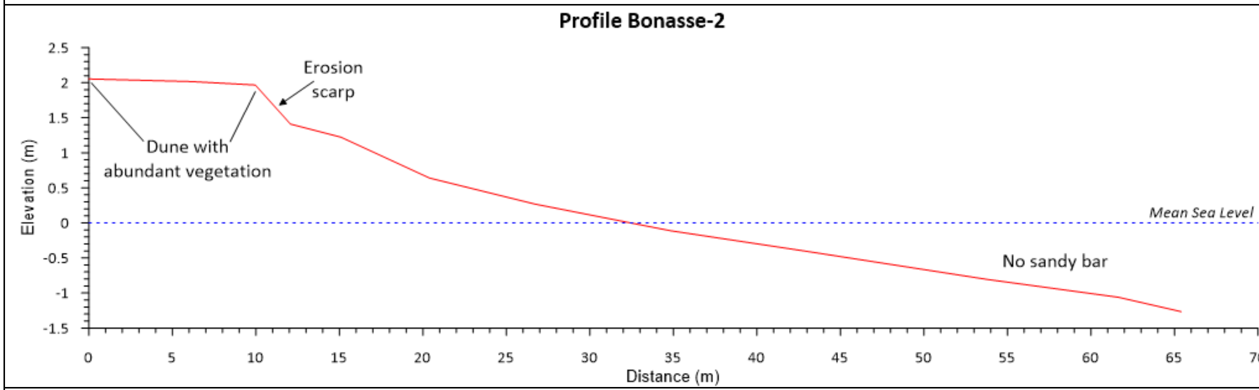
SECTOR 2

Profile: Bonasse 2.

Reference point coordinates

Easting	Northing	Height
623216.440	1115844.097	2.053



Sediment composition: _

Sample	Profile / Sector	Grain size composition		Grain size classification	Macroscopic description
		M (mm)	ϕ		
P-2	2/2	0.188	2.410	Well graded fine sand	Terrigenous brown sand with gray hues. No calcareous remains.

Description:

Profile with 5-7 m width of sun exposure area. Dune covered by abundant vegetation. Presence of escarpment at the base of the dune of 0.60 m. No sandbars are observed on the underwater slope. Starting 120 m from the shore, the sand appears mixed with mud.

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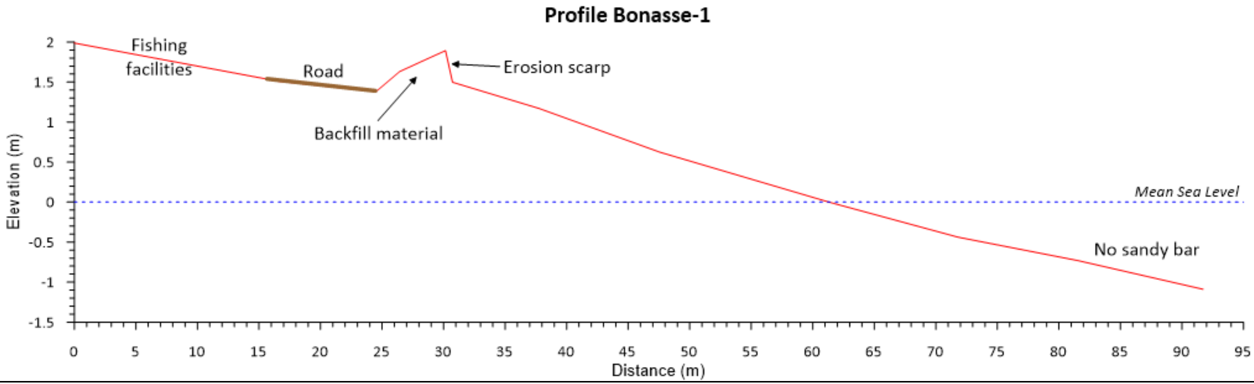
SECTOR 2

Profile: Bonasse 1.

Reference point coordinates

Easting	Northing	Height
622917.670	1115834.242	1.988



Sediment composition: _

Sample	Profile / Sector	Grain size composition		Grain size classification	Macroscopic description
		M (mm)	ϕ		
P-1	1/2	0.180	2.473	Well graded fine sand	Terrigenous brown sand with gray hues. No calcareous remains.

Description:

Profile with 5-7 m width of the sun exposure area. There is no dune, instead there is a road and facilities dedicated to the fishing activity of Fullerton town. Existence of filling material from the road. Escarpment can be observed at the base of the filling of 0.50 m. No sandbars are observed on the underwater slope. Starting 120 m from the shore, the sand appears mixed with mud.

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The description of the morphological characteristics and the sedimentology of Bonasse Beach profiles reveal the absence of sand bars along the coast, indicating that there is no significant onshore - offshore sediment transport.

Despite all the signs of erosion observed, these do not show a beach with intense erosion, whose effects are masked by the amplitude of the tide, where at times of low tide a beach of just over 30 m wide can be observed, in contrast with just 7-10 m wide at high tide.

According to work carried out at the Institute of Maritime Affairs (IMA), by the Department of Geomatics, using the Digital Shoreline Analysis System (DSAS) within Esri ArcGIS software to assess shoreline change, net shoreline movement along transects in Bonasse Bay was calculated, and a mean positive change of 0.29 m/year was measured throughout the period between 1994 and 2014. An analysis was also carried out to determine the rate of change of the shoreline for two periods: 1994-2007 and 2007-2014.

Bonasse Bay eroded at a rate of -0.15 m/year between 1994 and 2007 and increased at a rate of 0.33 m/year between 2007 and 2014. According to this study, the beach went from being in an erosion process to being in an accumulation process.

However, another IMA study based on the morphological analysis of two Bonasse Beach profiles for the period 2011-2018 (Figures 9 and 10), shows a decline in beach width between -0.80 and -0.44 m/year, respectively, so it can be said that for that period an average loss of beach width of -0.62 m/year was registered.

The results of both studies differ substantially. For our work, we assume a value of -0.62 m/year as the shoreline retreat rate.

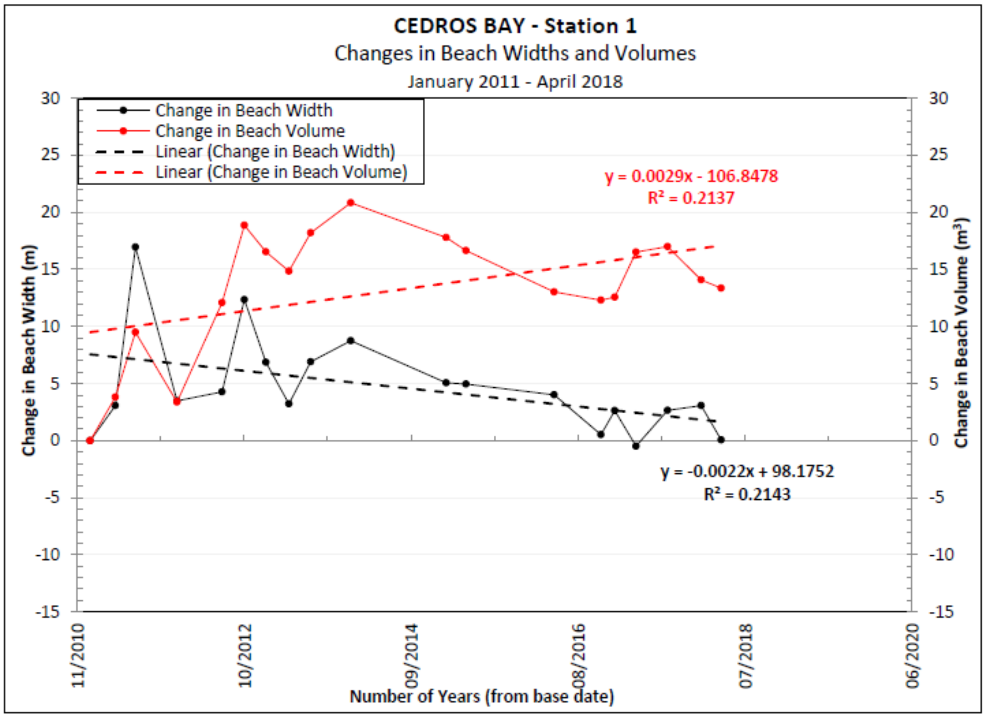

Figure 9. Evolution of the volume and width of the beach in the period 2011-2018. Station 1, Cedros Bay. Source: Institute of Maritime Affairs (IMA).

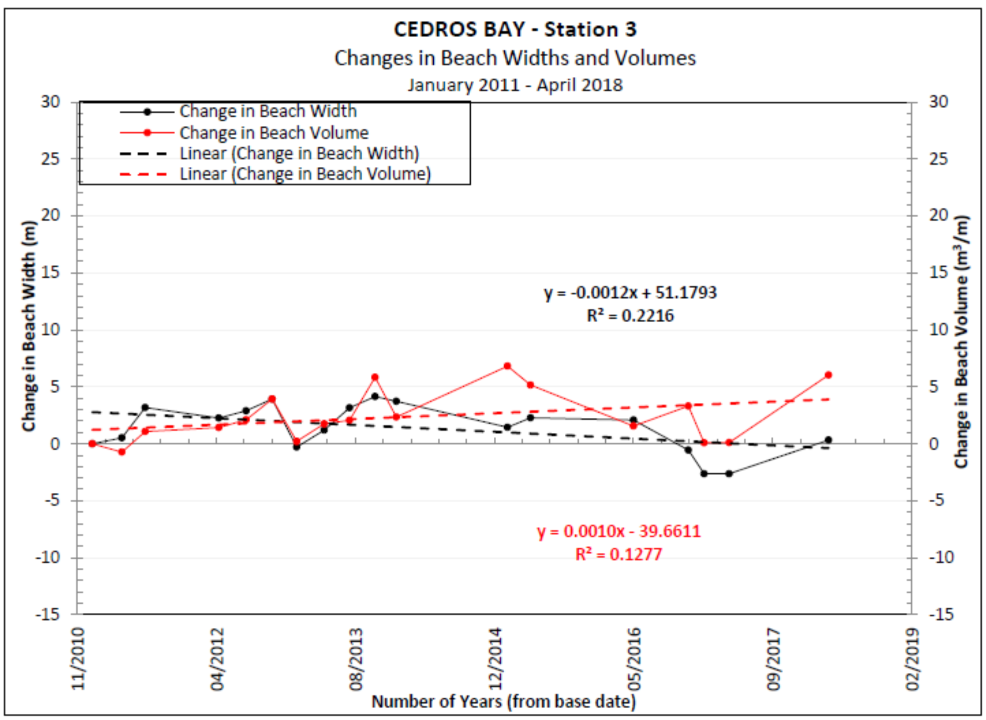

Figure 10. Evolution of the volume and width of the beach in the period 2011-2018. Station 3, Cedros Bay. Source: Institute of Maritime Affairs (IMA).

IV. 5. Characteristics of the hydrodynamic regime.

The morphology of the coastal zone that characterizes the study region, made up of cliffs, rocky ledges, beaches and bays, are the result of the interaction of waves, currents and tides (Park and Edge, 2011) and in doing so, they contribute to shoreline changes, such as erosion (Coelho *et al*., 2009). Anthropic actions, without a scientific foundation, have in some cases accelerated the negative impacts to which the coastal zone is subjected, regardless of the effect produced by the tides on the coasts, which has been well documented and identified as being responsible for the sediment transport in estuaries and tidal environments around the world (Masselink and Hughes, 2003).

The study area is influenced by a large anticyclonic gyre that characterizes its current patterns (Gopaul and Wolf, 1995) and a south-north residual flow fed by the Guiana Current (van Andel and Postma, 1954), and according to Oostdam (1982), the flows that occur through the Snake's Mouth register bottom velocities of 17 cm/s and are dominated by a flow pattern towards the north that moves towards the coast. Oostdam also states that the influx of the water through the Snake's Mouth partially returns south, both in the bottom layers and in the surface layers, in the form of an eddy. Coastal currents have a predominant direction towards the south and are generated by the waves.

Wave processes also play a fundamental role in sediment transport and, by extension, in the erosion of the study area, where the wave period presents cycles of less than 4 s, generated by the northeast trade winds that give rise to wind waves, oscillating between 0.39 m and 0.46 m (Deane, 1973). However, wave events that occur mainly in the hurricane season (June to November) generate waves with heights ranging from 0.76 m to 1.5 m (Deane, 1973). The tides are microtidal with a range of syzygy and quadrature of approximately 1.5 m.

The results of the grain size analysis of Bonasse Beach sediments (Annex 2) show that the beach is made up of fine to very fine grained quartz sands, with a low presence of light brown silt, and at a distance of about 100 m from the shoreline, it becomes completely clayey, coinciding with the mineralogical and sedimentological composition of the cliffs located upstream, which constitute the sources of origin of the sediments present on Bonasse Beach and the other beaches that are found downstream (Figure 11).

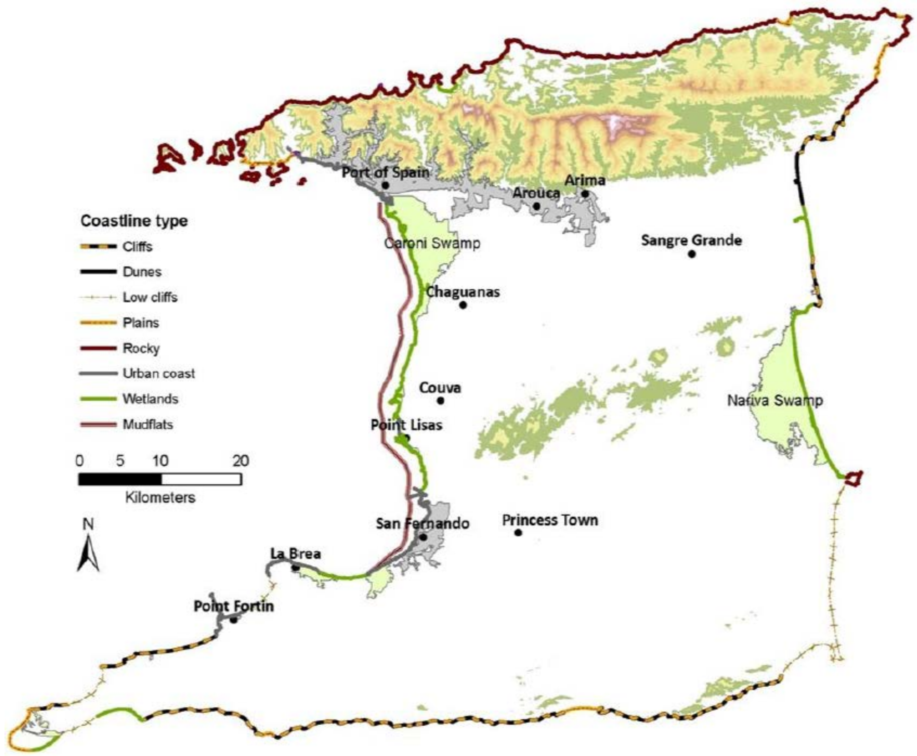

Figure 11. Classification of the type of coasts of Trinidad. Source: Report for Trinidad and Tobago on the beach surveillance network. Source: IMA (2021).

It must be considered that the region as a whole is part of a very dynamic system, due to its geographic and oceanographic environment, associated with the continuous erosion suffered by the cliffs, directly influencing the evolution of the shoreline.

The observed geomorphological indicators show that the most influential factors in the sediment transport of Bonasse and neighboring beaches are related to the wave regime, associated with the average annual conditions and extreme conditions during storm events, as well as with marine currents, mainly during the tidal ebb, with special attention to the coastal currents produced by the wave breaking, which are ultimately responsible for the nearshore sediment transport.

Trinidad and Tobago is under the permanent influence of the trade winds, which have a global nature and come from the first and second quadrants.

Part of the climatological information, with which the analyzes and assessments for this project were carried out, has been provided by the Trinidad and Tobago Meteorological Service (TTMS), through the Institute of Maritime Affairs (IMA).

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Daily hourly data was available from the Piarco and Chatham automatic stations, which have records of wind direction and speed, from the years 2001-2020 and 2016-2020, respectively.

Piarco automatic station is located at Piarco International Airport, 79 km from Bonasse Beach , and the Chatham automatic station is located 14 km from Bonasse Beach . Between both stations there are 68 km.

From the records of Piarco automatic station, the wind rose was constructed that collects the 20 years of measurements between 2001-2020 (Figure 12), after filtering the series to discard erroneous or lost data. Hourly data were averaged to reduce them to a daily data; in the case of wind speed, to determine the mean value, the arithmetic mean was calculated directly; and in the case of wind direction, to determine the mean value, the angular mean was calculated.

Likewise, Table 6 was developed, which summarizes the volume of observations broken down by classes (speed segments) and directions.

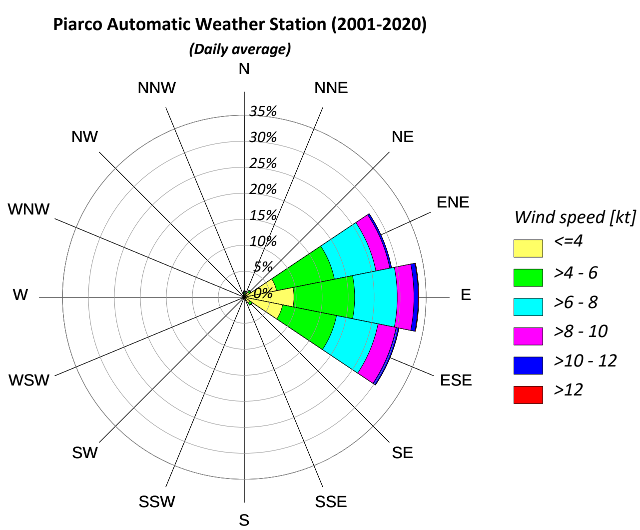

Figure 12. Wind rose for all directions. Piarco automatic station. Measurement period 2001-2020. (Data provided by IMA).

Table 6. Summary of winds by directions for Piarco automatic station

Directions	Wind speed (kt)						Frequency
	< 4	4 - 6	6 - 8	8 - 10	10 - 12	> 12	
N	44	24	10	7	2	0	1.22%
NNE	36	11	2	0	0	0	0.69%
NE	84	25	4	3	1	0	1.64%
ENE	453	812	582	194	25	1	28.91%
E	684	835	586	230	59	9	33.61%
ESE	538	756	583	253	38	4	30.38%
SE	95	3. 4	5	0	0	0	1.87%
SSE	19	1	0	0	0	0	0.28%
S	16	0	0	0	0	0	0.22%
SSW	10	0	0	0	0	0	0.14%
SW	11	1	0	0	0	0	0.17%
WSW	14	1	0	0	0	0	0.21%
W	14	1	0	0	0	0	0.21%
WNW	11	0	0	0	0	0	0.15%
NW	5	0	0	0	0	0	0.07%
NNW	15	1	0	0	0	0	0.22%
Total	2049	2502	1772	687	125	14	100.00%

According to the wind rose and the previous table, the winds coming from the East northeast to the southeast represent 94.77% of the total cases of the records, which demonstrates the marked influence of the Trade Winds on Trinidad and Tobago. The average wind speed recorded for Piarco was 5.31 kt (9.83 km/h), and the maximum was 96.00 kt (177.79 km/h).

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Despite the fact that the Chatham Automatic Station only has data between 2016-2020 (4 years), and that, in addition, there are several empty periods in the database, with the available information it was prepared the wind rose and the summary table of the volume of observations, broken down by segments of speed and directions. (Figure 13 and Table 7)

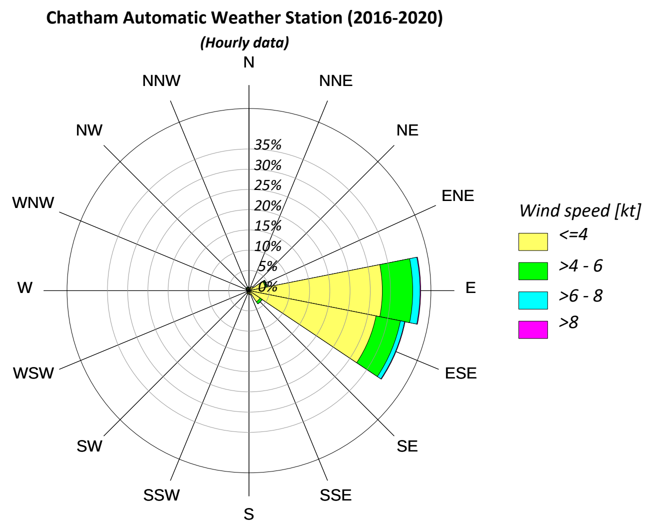

Figure 13. Wind rose for all directions. Chatham Automatic Station. Measurement period 2016-2020. (Data provided by IMA).

Table 7. Summary of winds by directions for the Chatham automatic station.

Directions	Wind speed (kt)				Frequency
	< 4	4 - 6	6 - 8	> 12	
N	200	7	1	0	0.75%
NNE	211	0	0	0	0.76%
NE	333	7	0	0	1.23%
ENE	1128	128	28	3	4.65%
E	9121	2081	500	47	42.48%
ESE	8860	1701	291	37	39.37%
SE	910	169	11	0	3.94%
SSE	282	2	0	0	1.03%

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Directions	Wind speed (kt)				Frequency
	< 4	4 - 6	6 - 8	> 12	
S	211	3	0	0	0.77%
SSW	232	10	0	0	0.87%
SW	158	3	3	0	0.59%
WSW	124	7	0	0	0.47%
W	135	10	2	0	0.53%
WNW	162	21	3	1	0.68%
NW	201	41	11	1	0.92%
NNW	198	57	7	0	0.95%
Total	22466	4247	857	89	100.00%

According to the wind rose and the previous table, the winds coming from the east northeast to the southeast, represent 90.44% of the total cases of the records, which is in correspondence with the behavior of the winds recorded by Piarco station. The average wind speed recorded for Chatham was 2.94 kt (5.44 km/h) and the maximum was 15.60 kt (28.89 km/h).

The winds that have the most influence on Bonasse Beach and the wave field that reaches its coast are those coming from the west to the northeast, which barely total 5.82% in the records of Chatham Automatic Station, and 4.20% in the records of Piarco Automatic Station, really low percentages that are probably the result of local meteorological situations generated and develop in the Gulf of Paria.

Taking into account the lack of instrumental information from meteorological stations or oceanographic buoys located in the Gulf of Paria, and with a view to filling the gap in the necessary information for a correct evaluation of the average annual hydrometeorological conditions in the gulf, wind and wave information was requested from ICOADS Series (International Comprehensive Ocean-Atmosphere Data Set), belonging to The Research Data Archive (RDA) of the National Center for Atmospheric Research in Boulder, Colorado, USA.

The ICOADS Series collects visual and instrumental meteorological and oceanographic information provided by ships en route, oil rigs and buoys. For our study, information from the Gulf of Paria was requested for the period 1912-2014.

After filtering the series to eliminate empty data or errors, with the wind speed and direction information, the wind rose was created (Figure 14) and the summary table of the volume of observations was prepared, broken down by speed segments and directions (Table 8), as was done for Piarco Automatic Station and Chatham Automatic Station.

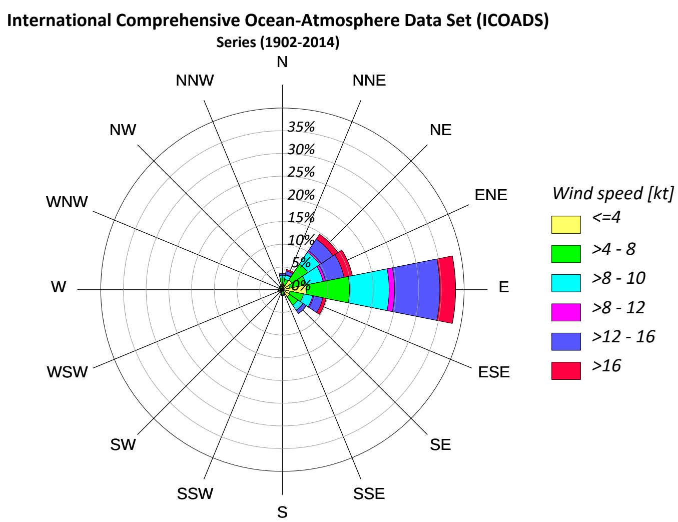

Figure 14. Wind rose for all directions. ICOADS 1902-2014 series, with information from ships en route and oil rigs in the Gulf of Paria.

Table 8. Summary of winds by directions. ICOADS series 1902-2014. Gulf of Paria.

Directions	Wind speed (kt)						Frequency
	<=4	4 - 8	8 - 10	8 - 12	12 - 16	>16	
N	278	203	97	10	63	17	3.59%
NNE	187	246	174	21	150	67	4.55%
NE	472	783	585	71	577	243	14.69%
ENE	303	688	705	99	778	347	15.71%
E	982	1765	1620	222	1854	646	38.14%

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Directions	Wind speed (kt)						Frequency
	<=4	4 - 8	8 - 10	8 - 12	12 - 16	>16	
ESE	316	562	382	45	381	138	9.81%
SE	348	413	247	11	150	10	6.34%
SSE	67	78	42	5	22	0	1.15%
S	99	93	36	4	14	0	1.32%
SSW	15	33	18	1	8	0	0.40%
SW	53	46	24	0	15	0	0.74%
WSW	23	35	8	4	4	0	0.40%
W	78	74	14	2	1	0	0.91%
WNW	27	34	8	1	2	0	0.39%
NW	71	74	31	1	10	0	1.01%
NNW	48	66	23	5	11	2	0.83%
Total	3367	5193	4014	502	4040	1470	100.00%

As can be observed in the wind rose and the table above, the highest percentage of occurrence of winds in the Gulf of Paria corresponds to the northeast to east southeast directions, which represent 78.35% of the total cases of the records, which is in correspondence with the behavior of the winds recorded for Piarco and Chatham stations. The average wind speed recorded for the Gulf of Paria, according to the ICOADS series, was 8.78 kt (16.26 km/h) and the maximum was 36.93 kt (68.39 km/h).

Taking into account the information provided by Piarco of and Chatham Automatic Stations, as well as that offered by the ICOADS Series, it can be stated that, in the study area, there is a predominance of easterly component winds, governed by trade winds, which have an occurrence of more than 87% of the registered cases.

However, due to the orientation of the coastline and its configuration, these wind directions have little influence on the hydrodynamic processes that take place near the coast of Bonasse Beach,

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where the wind and wave directions that could cause the greatest impact are those from the west to the northeast.

From the records of the ICOADS Series, and Figure 14 and Table 8, it can be observed that, 24.67% of the cases occur from west to northeast directions, which in terms of time means 2.96 months a year with winds from those directions.

The ICOADS Series also provides wave data (direction, period and height). Based on the results of the wind analysis, and taking into account the directions of interest for the study area, the series was filtered and reduced to these directions. Figure 15 shows the wave rose (Hs) for all directions and Figure 16, the wave rose (Hs) for the directions of interest. Summary tables present the volume of observations broken down by segments of speed and directions (Tables 9 and 10).

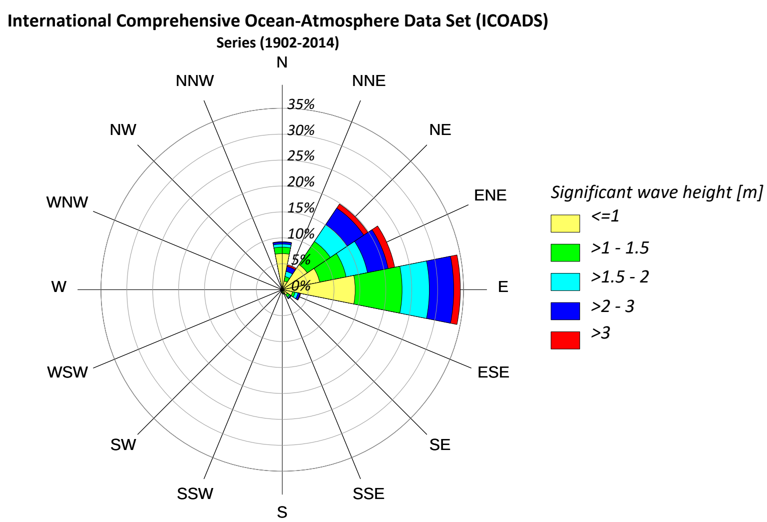

Figure 15. Wave rose for all directions. ICOADS 1902-2014 series, with information from ships en route and oil rigs in the Gulf of Paria.

Table 9. Summary of wave by directions. ICOADS series 1902-2014. Gulf of Paria.

Directions	Significant wave height (m)					Frequency
	<=1	1 - 1.5	1.5 - 2	23	> 3	
N	285	51	24	16	3	9.27%
NNE	70	36	41	40	12	4.87%
NE	238	219	160	157	39	19.88%

Directions	**Significant wave height (m)**					**Frequency**
	<=1	**1 - 1.5**	**1.5 - 2**	**23**	**> 3**	
ENE	301	213	172	166	53	22.13%
E	576	370	215	193	52	34.38%
ESE	83	20	24	16	5	3.62%
SE	48	22	9	5	2	2.10%
SSE	26	6	4	0	1	0.90%
S	12	10	2	3	0	0.66%
SSW	4	2	1	0	1	0.20%
SW	8	2	1	4	2	0.42%
WSW	5	4	2	1	1	0.32%
W	8	5	3	0	0	0.39%
WNW	1	6	1	3	2	0.32%
NW	5	0	1	3	0	0.22%
NNW	3	6	0	4	0	0.32%
Total	1673	972	660	611	173	100.00%

From the wave rose and the summary table referring to all directions, from the northeast to the east there is the highest percentage of occurrence of the wave that was recorded in the Gulf of Paria (76.39%), which is totally in correspondence with the results of the analysis of the wind series. Likewise, it is noted that for directions from the north to the northeast, 34.02 % of the cases were registered, wave directions that do have a direct influence on the coastal dynamics of Bonasse Beach.

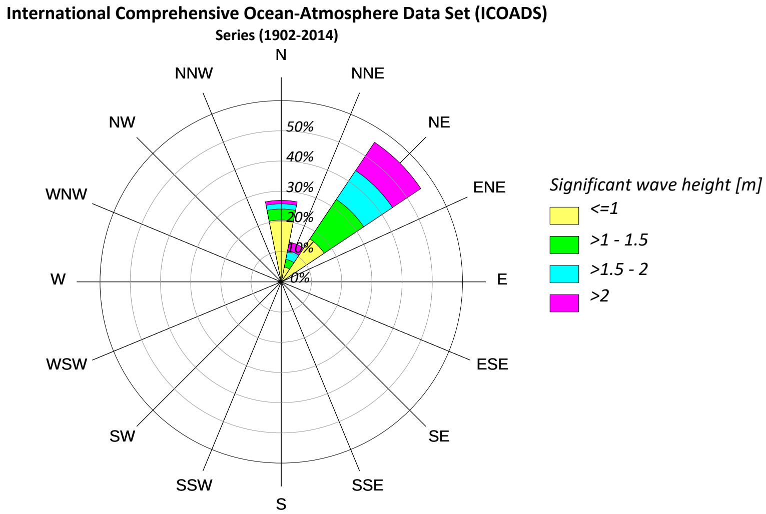

Figure 16. Wave rose for directions of interest. ICOADS 1902-2014 series, with information from ships on route and oil rigs in the Gulf of Paria.

Table 10. Summary wave by directions of interest. ICOADS series 1902-2014. Gulf of Paria.

Directions	**Significant wave height (m)**				**Frequency**
	<=1	**1 - 1.5**	**1.5 - 2**	**>2**	
N	285	51	24	16	26.99%
NNE	70	36	41	40	13.42%
NE	238	219	160	157	55.56%
WSW	2	2	2	1	0.50%
W	8	5	3	0	1.15%
WNW	1	6	1	3	0.79%
NW	5	0	1	3	0.65%
NNW	3	6	0	4	0.93%
Total	612	325	232	224	100.00%

The most significant result of the filtering of the ICOADS Series for the directions of interest, presented in Figure 16 and Table 10, is that for these directions, 95.97% of the cases belong to the directions from north to northeast. In addition, 64% of the significant wave heights (Hs) recorded do not exceed 1.5 m in height.

From the ICOADS Series filtered for the directions of interest, the mean annual regimes of the sea state parameters, significant wave height (Hs) and peak period (Tp) at indefinite depths were determined for the Gulf of Paria.

These mean regimes represent the mean annual wave conditions for the Gulf of Paria, where waves from tropical storms are not taken into account, considering the latter of interest to establish the extreme wave regime in the Gulf.

For the development of the mean regimes, the visual wave data described above have been used, which have been drawn on a maximal Gumbel probability paper (Figure 17 and 18), whose methodology is explained later in this chapter.

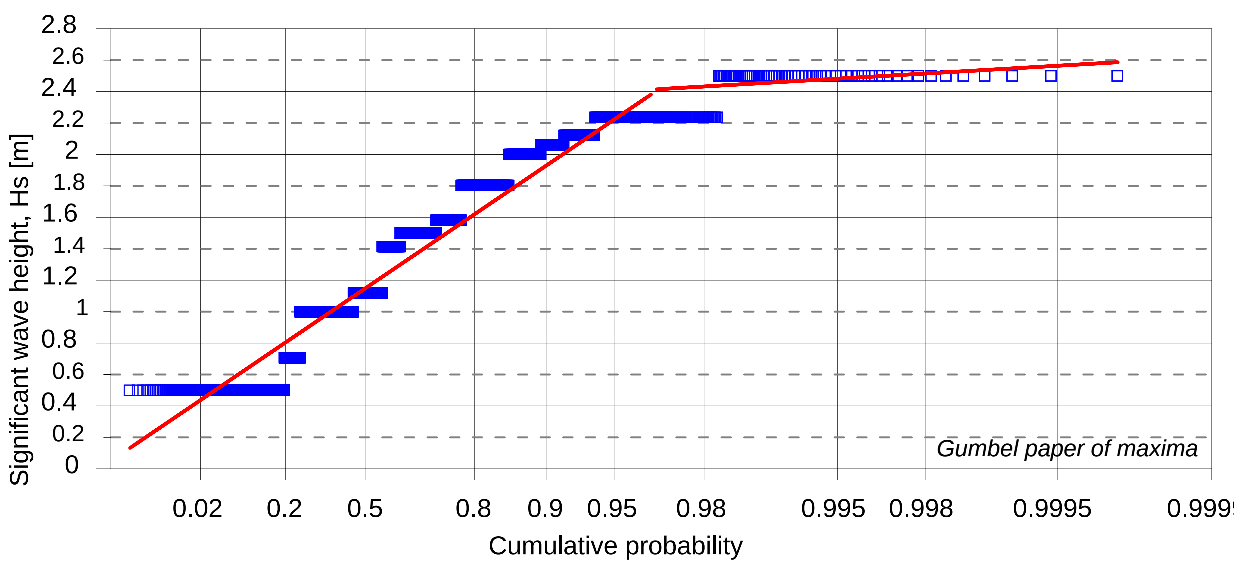

Figure 17. Mean significant wave height regime (Hs) for indefinite depths in the Gulf of Paria. ICOADS series 1902-2014.

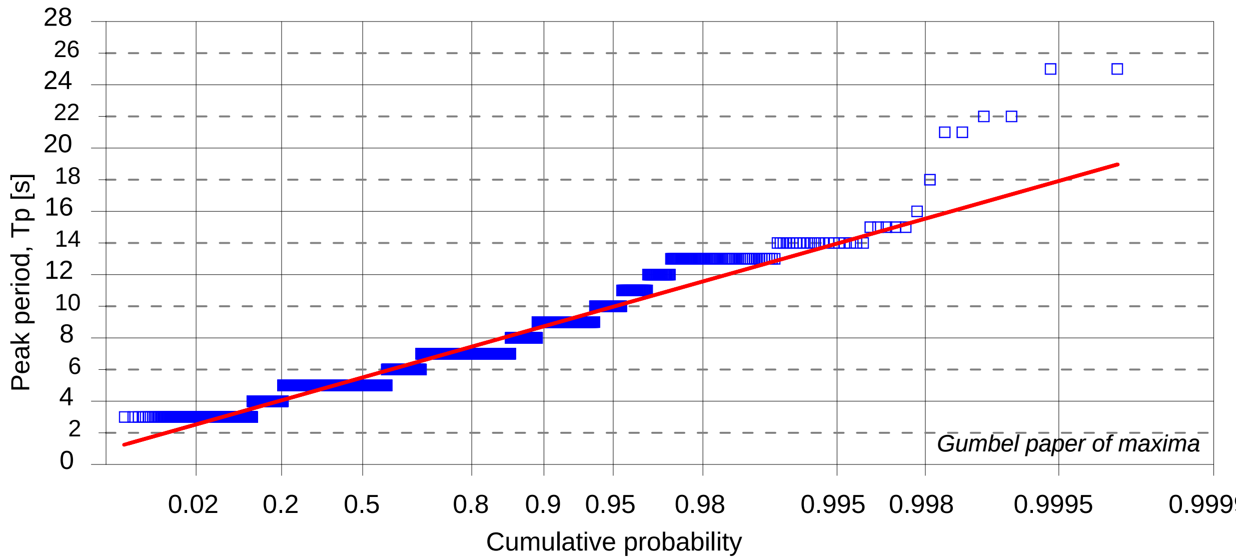

Figure 18. Mean regimen of peak period (Tp) for indefinite depths in the Gulf of Paria. ICOADS series 1902-2014.

Given the origin and limitations of the information sources used to characterize wind and wave, it has been decided to estimate the extreme wave regime from wind and atmospheric pressure data, associated with tropical organisms.

In this work, the trajectories of the hurricanes that affected Trinidad and Tobago between 1851 and 2021 were analyzed. Although some of them, when sliding through the vicinity of the national territory, had a lower category, from the engineering point of view, they can be considered as extreme erosion events.

The area of interest for the project, in particular, is confined within the Gulf of Paria, whose depths and extension constitute a natural obstacle, which prevents the development of storm waves generated by cyclonic organisms, in their displacement from east to west through the gulf, being limited by draft and fetch. The waves generated by storms that move through the Caribbean Sea near Trinidad and Tobago, must exceed the straits formed by the Dragon's Mouth, with which the waves that reach the study area through this route will also have limited development.

However, the phenomenon of storm wave or storm surges, associated with this type of events, does constitute an element to take into account in coastal actions, since it generates a sea level rise that brings about greater waves, which makes wave transformation process particularly important in different scenarios.

The storm surge is the rise in mean sea level due to the action of the winds from tropical cyclones on a region of the ocean. This tide lasts from 12 hours to 3 days; it can cause flooding in the low-lying areas, adjacent to the coast, and waves that impact on structures and buildings near the sea, as well as the removal of sand from the beaches by direct impact of waves and wave-induced currents. These impacts are increased when the high tide of the astronomical tide is combined with the storm tide.

The list of tropical organisms that affected the country between 2000 - 2020, was provided by the Trinidad and Tobago Meteorological Service, through the IMA, which was verified and expanded with information available on the US National Hurricane Centre website.

Trinidad and Tobago has historically been affected by 24 cyclonic events: 5 cases with the category of tropical depression (TD), 10 cases with the category of tropical storm (TS) and 9 with the category of hurricane (H), of which 7 were category 1 hurricanes (H1), 1 category 2 hurricane (H2), and 3 category 4 hurricanes (H4), according to the Saffir- Simpsom scale (Simpson, 1974), during the period 1851-2021 (Table 6).

Table 11. List of historical storms that have affected Trinidad and Tobago.

Month	**TD**	**ST**	**H1**	**H2**	**H3**	**H4**	**H5**	**Total**
June	-	1	1	-	-	-	-	2
July	1	1	1	-	-	-	-	3
August	3	5	1	-	-	-	-	9
September	1	2	2	1	-	1	-	7
October	-	-	2	-	-	-	-	2
November	-	1	-	-	-	-	-	1
Totals	5	10	7	1	0	1	0	24
Percentage	21%	42%	29%	4%	0%	4%	0%	100%

It can be concluded that:

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a) From the year 1851 to 2021, 170 years of storm records were completed, and only 24 storms have affected the country. The highest percentage (42%) corresponds to Tropical Storms, 92% groups storms between Tropical Depression and Category 1 Hurricane.
b) Only once was the country affected by a hurricane of great intensity, a category 4 hurricane (Hurricane Iván in 2004).
c) On only one occasion it has been affected by 2 or more cyclonic events in the same year, 1 Tropical Depression, 1 Tropical Storm and 1 Category 4 Hurricane in 2004.
d) The most dangerous months for the country are August and September, with 16 tropical organisms out of a total of 24 that have affected the territory. This means that 67% of the total damages occur in those months.
e) Specifically, the most intense hurricanes have occurred in the month of September. Hurricane Flora (H2) in 1963 and Hurricane Ivan (H4) in 2004.

In nature, cyclonic disturbances constitute random processes that, for planning and design, are based on future events, whose magnitude and frequency, in terms of intensity of winds, rains, waves or surge induced flooding, cannot be predicted. It is necessary to resort to studies of the probability and frequency of some of these parameters.

The return period of an extreme event is the frequency with which said event occurs, and its degree of magnitude is inversely related to its periodicity.

To calculate the return period of the tropical cyclones that affected Trinidad and Tobago, the wind intensity parameter was used, which is associated with the atmospheric pressure in the eye of the meteor, and defines the different categories expressed on the scale Saffir-Simpson.

For this, the Gumbel distribution was used to model the distribution of the maximum extreme values, whose results are represented in a maximal Gumbel probability paper (Figure 19, Table 12). The procedure was as follows:

1. Extraction of relevant information from the series of historical storms HURDAT in the period 1851-2021. (in total 1936 storms in 170 years).
2. Extraction of relevant information from the series of historical storms HURDAT in the period 1851-2021. (in total 24 storms impacted the coasts of Trinidad and Tobago in 170 years of records).

3. Ordering of the series of historical storms that affected Trinidad and Tobago, in descending order, using the maximum sustained wind speed parameter, to determine the return period and its corresponding probability of exceedance.
4. Fitting the data set to a Gumbel cumulative distribution of maxima to estimate the return period for tropical cyclones.
5. Representation of the data set in a maximal Gumbel probability paper.

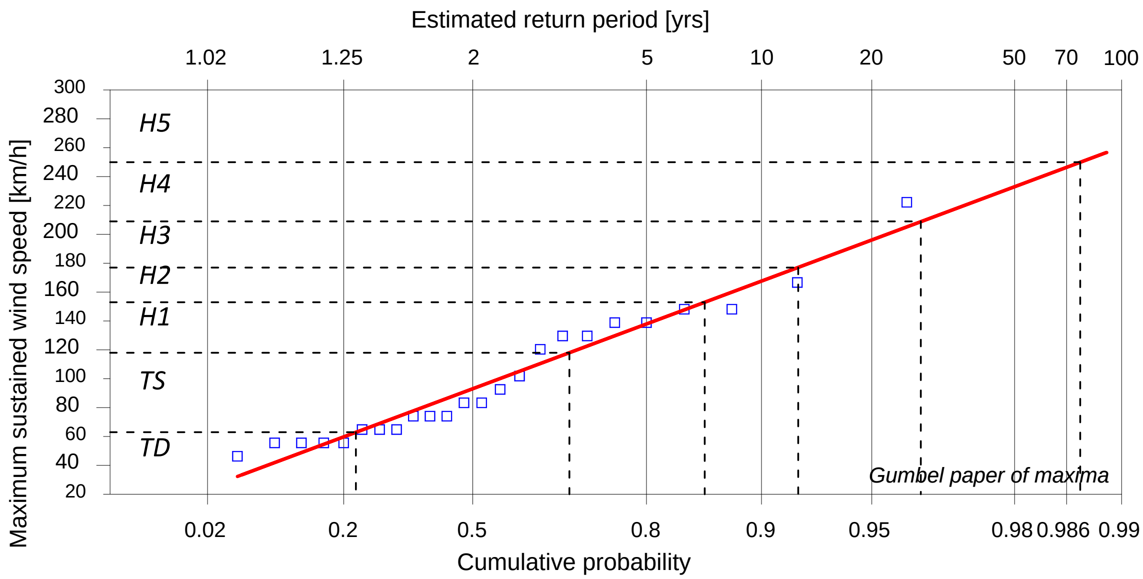

Figure 19. Representation of the return period of tropical storms by category for Trinidad and Tobago. Gumbel distribution of maxima.

Table 12. Return period and associated exceedance probability, for tropical cyclones that affected Trinidad and Tobago, from category TD to category H5 of the Saffir-Simpson scale.

Category	Return period (Years)	Probability (%)
TD	1.04	96%
ST	1.29	77%
H1	3.24	31%
H2	7.07	14%
H3	12.57	8%
H4	27.35	4%
H5	76.45	1%

Storm waves

To estimate the extreme regime that reaches the study area, we have started from the data of winds and pressure, associated with tropical organisms.

The procedure used to calculate the waves generated by hurricanes is described in the USA-CERC (1977), it is based on an empirical method proposed by Sverdrup, Munk and Bretsclineider (SMB method, described in the same source), which is solved for short fetch's and high wind speeds. (Bretschneider, (1959), according to Aldeco, J. and Montaño-Ley, Y., (1986))

The estimation of the significant wave height and period associated with it, at the point of maximum winds, was made using the following equations:

$$H_S = 5.03exp[R\,(P_N - P_O)/6271.6][1 + (0.152V_F/U_R)] \quad (1)$$

$$T_S = 8.6exp[R\,(P_N - P_O)/12543.2][1 + (0.076V_F/U_R)] \quad (2)$$

where:

Hs, significant wave height in deep water (m)

Ts, period corresponding to the significant wave (s)

R, radius of maximum winds (km)

P_N, usual pressure of 1013.25 mb

P_O, pressure in the eye of the hurricane (mb)

V_F, hurricane displacement speed (km/h)

U_R, maximum sustained wind speed (km/h)

The radius of maximum winds R, was calculated using the expression:

$$R\ =\ 0.0007exp[0.01156P_O] \quad (3)$$

where:

R, radius of maximum winds (km);

P_O, pressure in the eye of the hurricane (mb);

The values of P_O, V_F and U_R, were taken or calculated from the historical database of tropical storms in the Atlantic Ocean (HURDAT), developed by the US National Hurricane Centre.

Figure 20 shows the extreme regime of significant wave height obtained, adjusted to a Gumbel distribution of maxima.

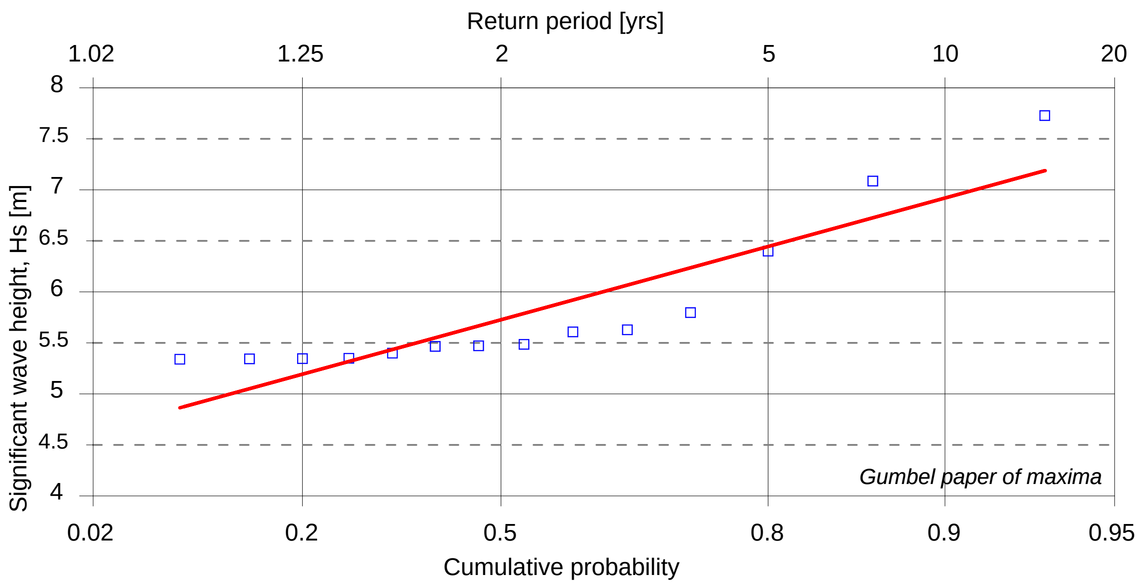

Figure 20. Extreme regime of significant wave height (Hs) at indefinite depths, associated with tropical storms off the coast of Trinidad and Tobago. Gumbel distribution of maxima.

Storm tide

The amplitude of the storm tide depends on several physical factors in the coastal zone, such as bathymetry, the shoreline and its location with respect to the path of the cyclone and the winds generated by it.

In deep waters it is of little importance; however, if the winds of the tropical cyclone occur over shallow marine regions, it acquires values of more than one meter. Such is the case of the study area, confined within the Gulf of Paria.

The most accurate storm tide calculation methods require bathymetric curves (isobaths). However, for this report there is no bathymetry of the Gulf of Paria, only the bathymetry carried out for Bonasse Beach and the sand borrow area, which is distant and does not connect with the bathymetry of the beach.

To obtain the values of mean sea level increase due to storm tide, it is required to simulate the mean sea level rise and the speeds caused by tropical cyclone winds over the ocean surface.

The simulation of mean sea level rise can be carried out by means of a software that solves the equations of water movement within a region exposed to the winds of the tropical cyclone. To achieve this, the wind field presented by the tropical cyclone at different times is taken into account, as well as detailed information on the seabed near the coast and the land topography. However, for a medium geographic scale, the highest level reached by the storm tide during the presence of the tropical cyclone can be estimated, with a suitable approximation and a simplified method.

The greatest mean sea level increase, caused by storm tide, can be calculated from the atmospheric pressure at the eye, the maximum sustained wind speed, and the radius of maximum winds.

To make these estimates, the parameters of real storms that hit Trinidad and Tobago were taken, which represent the most unfavorable scenarios, with the exception of category 3 and 5 hurricanes, for which there are no records in this regard; therefore, the characteristics of real storms that affected other Caribbean islands were taken (Table 13).

Table 13. Characteristics of the storms that were simulated to calculate the storm tide for different categories.

Name	Category	Pressure (mb)	R (km)	Ur (km/h)
Gonzalo (2020)	TD	1009	81.42	55.56
Brett (2017)	ST	1008	80.48	83.34
Emily (2005)	H1	991	66.12	138.90
Flora (1963)	H2	975	54.96	166.68
Keith[1] (2000)	H3	939	36.25	201.17
Ivan (2004)	H4	946	39.30	222.24
Dean[1] (2007)	H5	905	30.48	273.59

[1]It did not affect Trinidad and Tobago. It is only taken as a reference.

Based on the analysis of measurements on storm tide elevations of some tropical cyclones, and empirical expressions proposed in the United States and Japan, an expression was obtained to know the maximum amplitude of the storm tide due to a tropical cyclone:

$$h = (0.03R + 0.000119U_R^2 - 1.4421)F \tag{4}$$

where:

h, highest elevation (m) reached by the storm tide at sea near the coast,

R, radius of maximum winds (Km),

U_R, maximum sustained wind speed (Km/h)

F, corrective factor for wind direction.

The corrective factor (F) is determined from the angle "α" formed by the direction of movement of the tropical cyclone with respect to the coastline near the site of interest. This factor is determined by the expression:

$$F = \begin{cases} 0.6(1 + sen \propto) & si \;\; 0° < \propto < 180° \\ 0.6 & n \; other \; cases \end{cases} \tag{5}$$

From the application of the simplified method through formulations (4) and (5), the values expressed in Table 14 were obtained.

Table 14. Storm tide estimation results (m).

Category	**Storm tide**
TD	0.84m
TS	1.11m
H1	1.75m
H2	2.17m
H3	2.75m
H4	3.46m
H5	5.17m

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IV.6. Characterization of coastal dynamics through wave modeling

Wave propagation towards the coast produces transformations in the wave fronts, mainly caused by the phenomena of refraction, diffraction, breaking and dissipation by the seabed, which also causes alterations in the spatial distribution of wave energy.

To characterize wave dynamics, it is necessary to propagate wave fronts from deep waters in the Gulf of Paria towards the coast. These propagations have been carried out using the Wave Propagation Model Oluca-SP, of the Coastal Modeling System (SMC), developed by the Oceanographic and Coastal Engineering Group of the University of Cantabria, Spain.

Spectral waves were propagated, using a frequency spectrum of the TMA type (Texel Marsen Arsloe) (Bouws *et al*., 1985), that is applicable in areas close to the coast where the depths are reduced and waves are affected by the seabed, which is defined from a JONSWAP spectrum. Propagations were performed for the two scenarios indicated in Table 15, and the results are shown in the next section.

Table 15. Scenarios and parameters for wave modeling.

Parameter	Scenarios (Wave)	
	Usual	Tropical Depression
Significant height (Hs)	1.20m	4.86m
Peak period (Tp)	6s	9s
Directions	N, NNE, NE	NW, N, NE

Wave data used for model runs refer to mean directional and scalar regimes of sea state parameters at indefinite depths.

The usual wave scenario corresponds to the average annual conditions (50% probability) shown in Figure 17, which describes the average regime for the directions of interest that affect Bonasse Beach.

For extreme wave scenario, the most probable event was simulated, corresponding to a tropical depression with a return period of 1.04 years and a probability of occurrence of 96% (Table 12).

The graphic results of the modeling presented in this study are the isolines and wave direction vectors (significant wave height Hs), which will allow the spatial characterization of wave behavior on its way to the coast.

Annex 3 presents the results of the mathematical modeling carried out for the different scenarios. Next, the typical situations of the two modeled scenarios are discussed.

Usual wave scenario

The usual wave is the one that represents the average annual conditions, which are those produced by the trade winds. This scenario is one of those responsible for the cumulative stages on the beaches.

Figure 21 shows the result of the simulation carried out for the northeast direction, at Bonasse Beach, which is the predominant direction, and therefore, representative of this scenario.

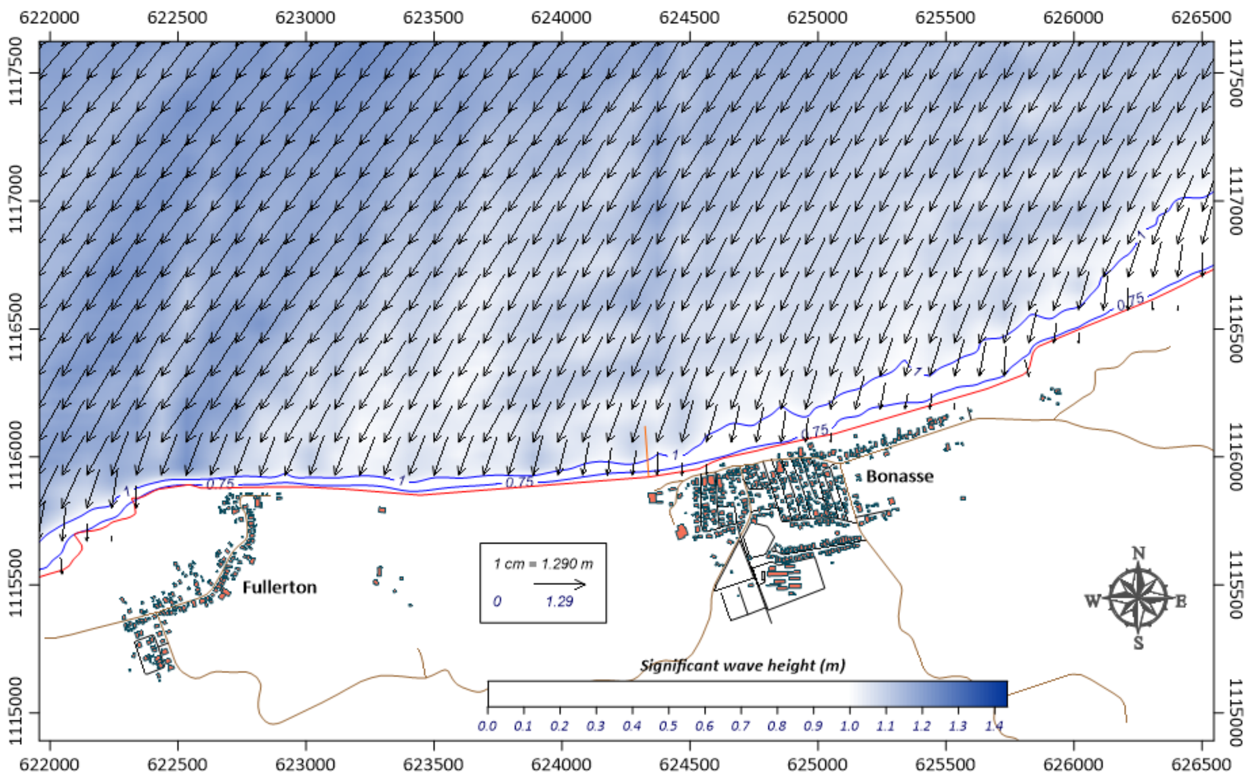

Figure 21. Distribution of isolines, vectors and magnitude of significant height for Bonasse Beach. Usual wave, northeast (NE) direction.

The analysis of the previous figure shows that for usual conditions the wave propagates through the Gulf of Paria with an angle of incidence of 45° with respect to Bonasse shoreline. As they approach the beach, the wave trains begin to suffer effects in the propagation direction, which are visible within the wave breaking zone. From this zone, and due to the processes of shoaling, refraction and diffraction, the height and direction of the wave fronts undergo the greatest transformations, producing a rapid dissipation of wave energy in a narrow strip very close to the shore, which will not produce sand movements of considerable magnitude.

In the eastern half of the beach, limited by the Coast Guard breakwater, the isoline with a significant wave height of 1 m is further from the shore. This means that wave breaking occurs farther from the shore, which is in correspondence with the disposition of depths, and explains why in this half of the beach the width of the sun exposure area is greater than for the western half of the beach, where it is narrower with a reduced sun exposure area.

Extreme wave scenario

It has been shown in various studies, under certain circumstances, that sand loss and the total disappearance of beaches have one of their direct causes in storm waves associated with extreme weather events, such as tropical storms and hurricanes.

Figure 22 shows the simulation carried out for the impact of a tropical depression with the characteristics described above, selecting the northeast direction, as this is the direction that all the wave fronts will adopt once they approach the coast.

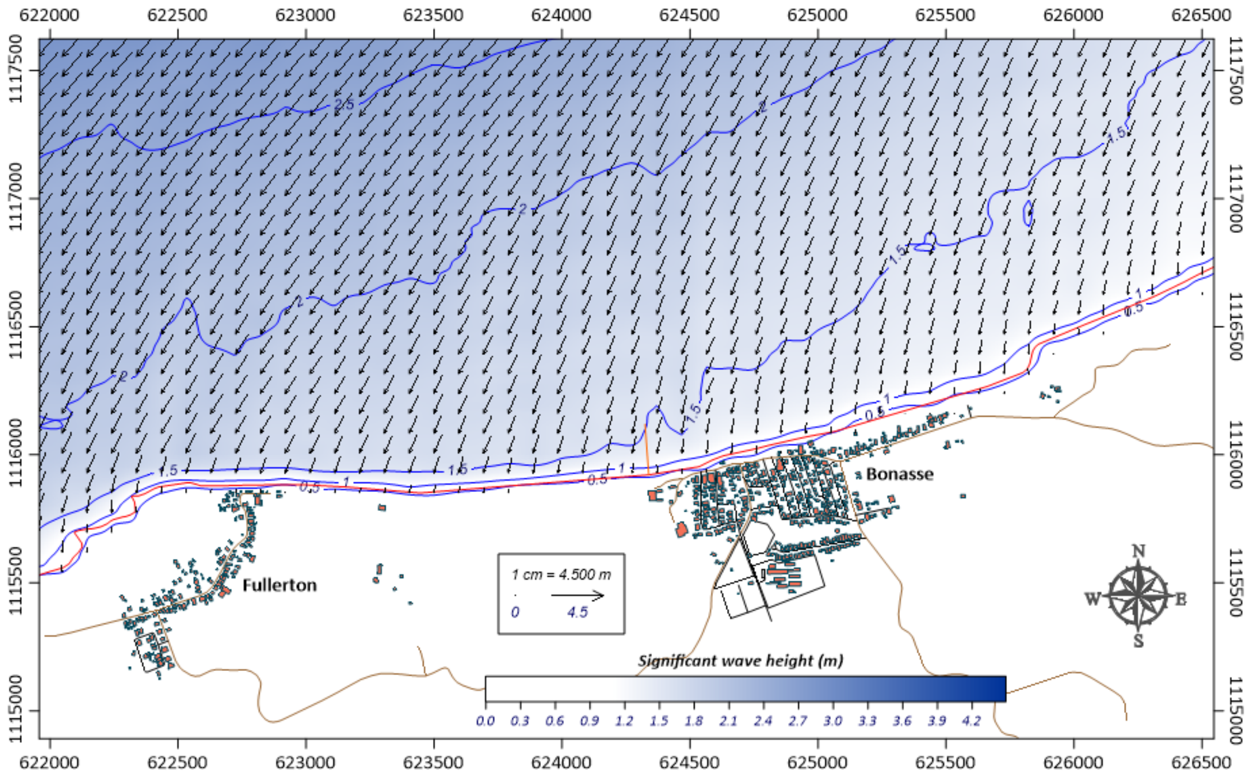

Figure 22. Distribution of isolines, vectors and magnitude of significant height for Bonasse Beach. Extreme waves, northeast (NE) direction.

Under these circumstances, the generated wave trains adopt a propagation scheme similar to that generated under usual conditions, with the particularity that hurricanes are low pressure centers and produce an increase guaranteeing that wave trains greater than usual arrive with hurricane energy on the coast.

As can be observed, wave dissipation through shoaling and breaking processes begins more than 1 km from the shore, occurring in a quasi-uniform manner along the entire coast. Since there are no significant sandbars, practically on the shore, 1m-high broken waves are capable of reaching less than 100 m from the shoreline. However, there are longitudinal variations in the bathymetry, which divide the beach into sectors, as already mentioned above in the analysis of usual conditions. Towards the western half of the beach, between Bonasse and Fullerton, where the bathymetry is more abrupt, waves reach the shoreline with greater energy, showing that the 1.5m isoline of significant wave height is aligned along the entire length of the beach, less than 100 m from the shore. This is contrary to the eastern sector of the beach, where the 1.5 m isoline of significant wave height gradually moves away to the east, placing the wave breaking zone farther

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from the shore, which constitutes a level of natural protection for this sector under a storm scenario.

This wave propagation distribution scheme, similar to, but greater in magnitude than that produced for usual conditions, determine the circulation system and sediment distribution along the coastal strip of the study area.

Circulation system

Within the breaking zone, wave breaking generates a series of currents, which depend on the angle of arrival at the coast and the wave height. These currents, called longshore or wave breaking currents, are of special importance in the disposition of the equilibrium of a beach, and more specifically, in its shape in plan, given the sand transport capacity.

Wave breaking currents occur in the wave breaking zone, in an area where the sediment is in suspension and is easily transported by the effect of these currents. In this way, for a certain shape in plan to be in equilibrium, it is necessary that either there are no longshore currents, or that, even if they exist, the transport gradient generated by them is null.

To determine these wave breaking currents, the COPLA model, developed by the GIOC of the University of Cantabria, Spain, was used. The modeling carried out appears in Annex 3.

As an example, Figure 23 shows the simulation carried out for waves produced by a tropical depression with a northeast direction, with similar behavior for the other modeled scenarios.

Wave transformation and breaking generates a circulation pattern governed by a longshore current from east to west, for both usual and storm conditions, a pattern that is in correspondence with the distribution of sandy sediments observed the along the coast, which is presented in a narrow strip attached to the coast, as projected by the circulation system shown in Figure 23.

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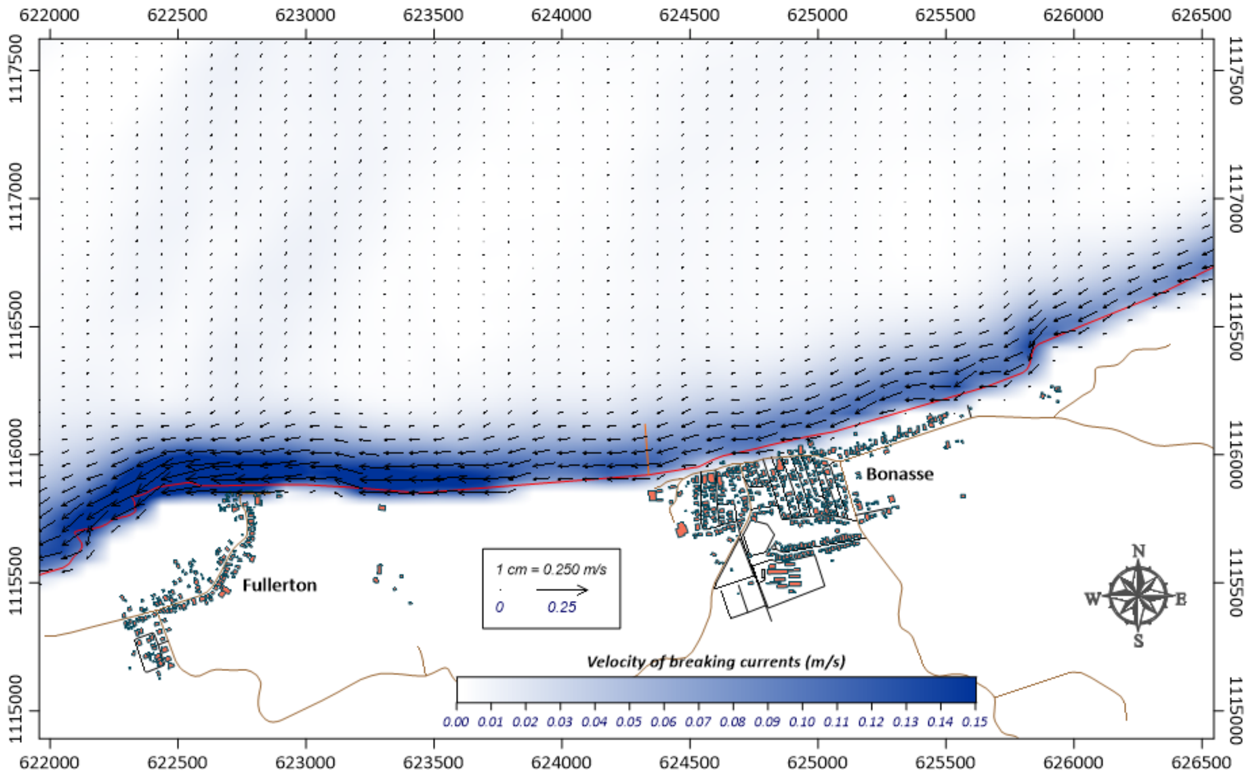

Figure 23. Vector distribution and magnitude of wave breaking currents for Bonasse Beach. Extreme waves, northeast (NE) direction.

IV.7. Sediment transport

Sediment distribution of on a beach is closely linked to its current system. For sediment transport to exist, two actions are necessary: a mechanism that puts the sediment in suspension, and an element that serves to transport it.

These two actions occur simultaneously within the breaking zone of a beach. On the one hand, the wave breaking the puts sediments in suspension, and on the other hand, the currents induced by the breaking are responsible for transporting this sediment.

Annex 3 presents the modeling carried out for propagated wave situations, for which we used EROS model, developed by the GIOC of the University of Cantabria, Spain.

EROS solves the sediment flux equations within the breaking zone, as well as the changes in bathymetry associated with spatial variations in sediment transport. It takes as input data, the wave output data calculated by the Oluca -SP model, and output data of the field of wave breaking currents calculated by the Copla-SP model. The model computes the total transport, the sum of the suspended transport and the bottom transport, using the formulations of Soulsby (1997) and Van Rijn (1997).

According to the modeling carried out, sediment transport near the shore is weak for all scenarios, which corresponds to the low intensity of the currents.

Figure 24 shows the simulation carried out for waves produced by a tropical depression in a northeast direction, which corresponds to the modeled scenario and shown in Figure 23, relative to the currents induced by said waves.

As already discussed, wave breaking generates a circulation pattern governed by a longshore current, heading west. This circulation system generates a potential sediment transport that follows this circulation pattern; however, the magnitude of the transport is low, for both usual and storms conditions, where a maximum potential transport of just 2.20 m^3/hour/ml is reported.

As can be observed in Figure 24, the largest transport vectors are located in the vicinity of Fullerton town, near the cliff that marks the western limit of the beach, which constitutes one of the morphological elements that provides the greatest sediment input to the system of beaches found downstream.

This pattern of sediment transport could be verified on the beach through its different morphological elements, both in profile and in plan, where the non-existence of sand bars and the narrowness of the sediment strip on the seabed near the shore, denote a weak sediment transport, of little intensity.

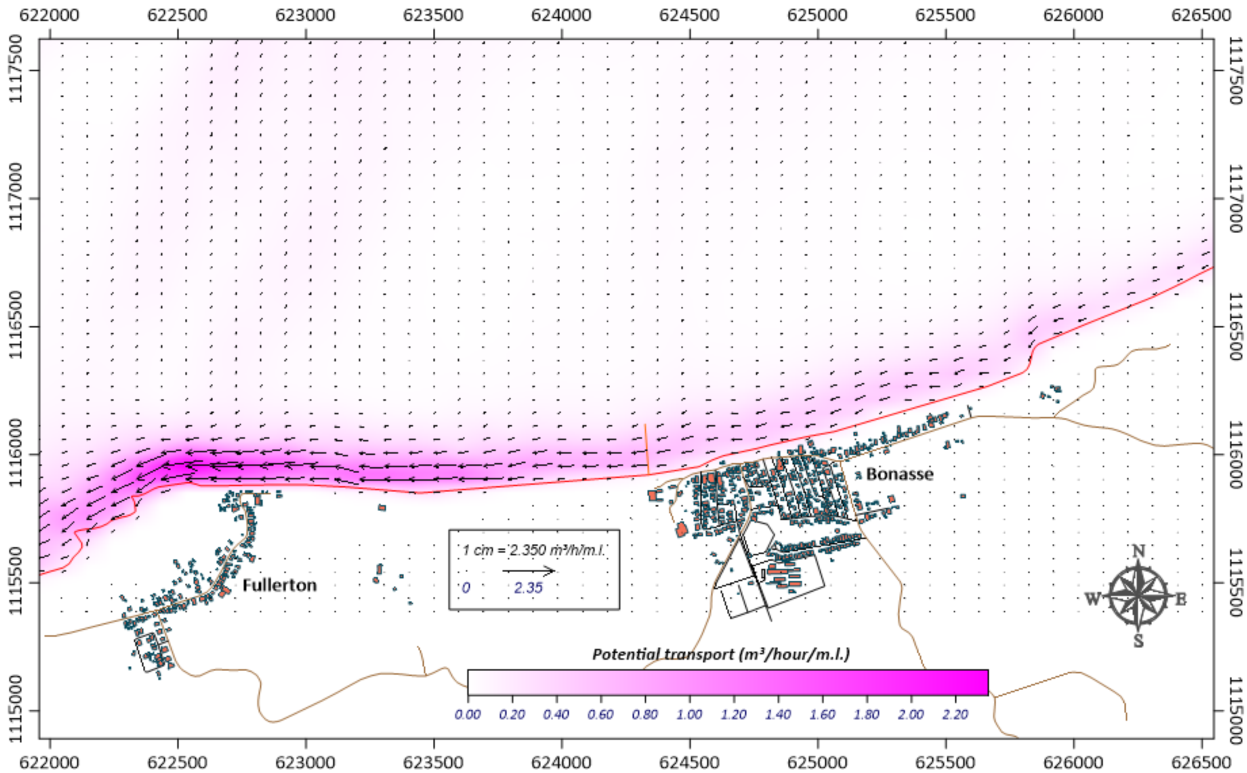

Figure 24. Distribution of vectors and magnitude of sediment transport for Bonasse Beach. Extreme waves, northeast (NE) direction.

IV.8. Morphodynamic functioning scheme.

The coastal system in which Bonasse Beach is located has an active dynamic, dominated by the physical processes that take place in the Gulf of Paria.

"Geologically, the Gulf of Paria is a tectonic basin, and its hydrographic characteristics, as well as the composition of sediments, have received the attention of numerous researchers over the years, who determined that the dynamics of the gulf is controlled by the estuarine circulation, the temporal variability of tides, coastal processes and the local wind system. The current speed within the Gulf of Paria varies between 15-33 cm/s (Moore and Todd 1993) and the tides are of the semidiurnal mixed type (Gade 1961). Benitez and Okuda (1976) point out that the amount of water that comes from the Orinoco and other rivers that flow into the gulf produces a significant reduction in the surface salinity of the water. Therefore, salinity is the main factor controlling density and circulation in the gulf." (Salcedo, R. and Barrios, W. 2020)

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Gade (1961), cited by Salcedo, R. and Barrios, W. (2020), developed a scheme of current patterns in the Gulf of Paria (Figure 25).

Figure 25. Current patterns in the Gulf of Paria. (Gade 1961).

According to this pattern, the currents coming from the Atlantic enter the gulf through Culumbus channel, or Snake's Mouth, located between Cedros Peninsula and the Orinoco Delta. Within the gulf, during the tidal flow currents move to the north following the configuration of the west coast of Trinidad, exiting the Caribbean Sea through the Dragon's Mouth, between Paria Peninsula, in Venezuela, and Chaguaramas Peninsula in Trinidad. During ebb, when tides reverse, currents within the gulf change direction to the south, forming a kind of counterclockwise eddy that marks the general pattern of the circulation system within the Gulf of Paria.

This circulation system is responsible for transporting part of the muddy sediments discharged by Orinoco River to the Gulf of Paria, which are carried in suspension during tidal flows.

However, along with this general circulation system of the Gulf of Paria, there are other coastal processes near the shore that are independent of tides, and are basically responsible for the transport of sediments (sand) that input the existing beaches. These coastal processes are the result of the interaction of local winds with the sea, capable of producing waves that, during the breaking processes, generate the coastal currents carrying sandy sediments from the production areas to the beaches.

In chapter IV, an exhaustive review of the interaction of these processes is done, based on the results of the mathematical modeling that appear in Annex 3.

Figure 26 graphically shows the morphodynamic functioning scheme in Bonasse Beach, which is the result of the interpretation of different processes that take place in the breaking zone, validated with geomorphological and sedimentological indicators observed along the beach, and the results of mathematical simulations.

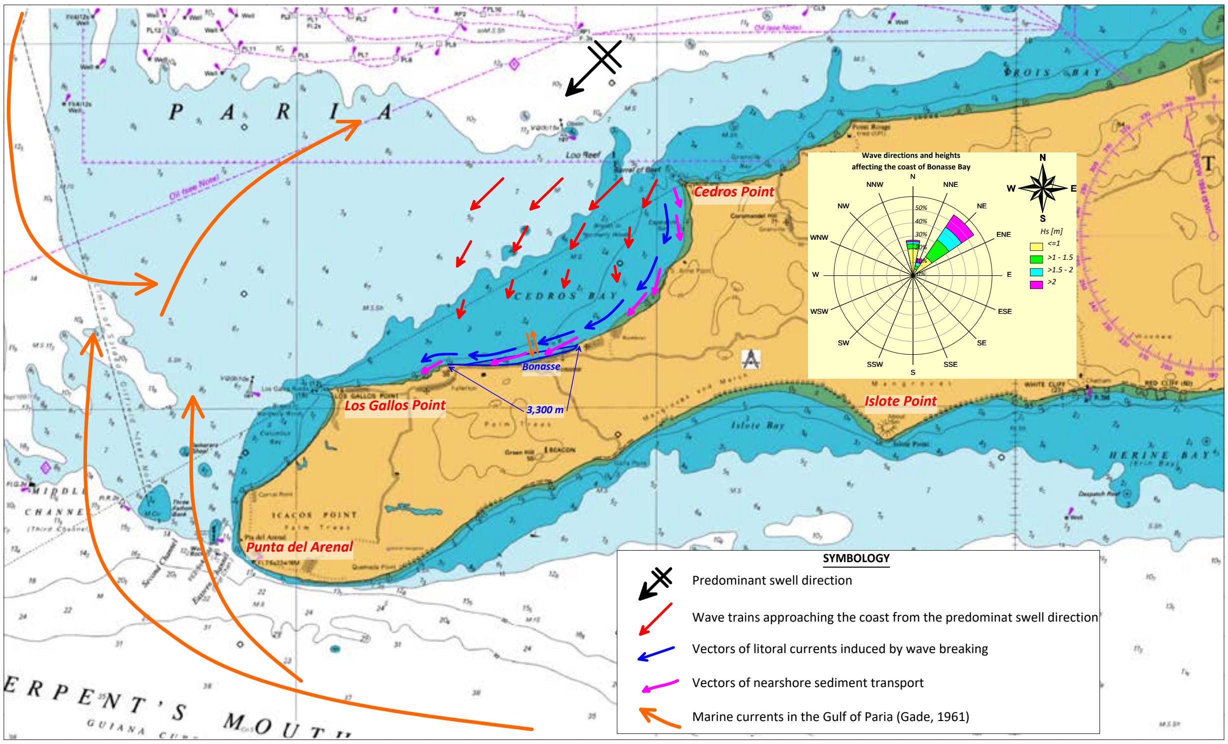

Figure 26. Morphodynamic functioning of Bonasse Beach.

V. STRATEGY BEACH RECOVERY AND PROTECTION

To evaluate the recovery and protection measures for Bonasse Beach, we reviewed the results of the work published by Wong (2018), entitled "Coastal Protection Measures - Case of Small Island Developing States to Address Sea-level Rise".

Reviewing the latest National Communications (NC), Wong (2018) presents a summary table with the topographical characteristics of the coastal zone and the types of solutions most commonly applied and proposed in the 35 countries of the Small Island Developing States (SIDS), which in the case of Trinidad and Tobago are shown in Table 16.

Table 16. Topographic characteristics and existing and proposed adaptation measures in Trinidad and Tobago only. (Extracted from Wong, 2018).

SIDS (last NC)	**Significant topographic characteristics (pages)**	**Existing adaptation measures (pages)**	**Proposed adaptation measures and options (pages)**	**Comments on EBA[2] and other aspects**
Trinidad and Tobago	Mountainous islands, coral reefs, beaches, mangrove swamps (6, 80, 89)	Dikes, groynes (84)	Protection of coastal ecosystems (89)	Scope of the EBA (coral reefs, mangrove swamps)

After describing the types of solutions applied, Wong (2018) produced the first classification of coastal protection technologies for small island states (Table 17).

Table 17. First Cut Classification of Coastal Protection Technology for SIDS. (Wong 2018).

Protection technology	**Assessment for SIDS**
A. Hard structures Dams and revetments Dikes Breakwaters and groynes	Expensive; implemented for critical structures; for "no retreat" options; revetments within the reach of the richest SIDS
B. Soft structures beach nourishment sandbags	Short term; for selective use, e.g. on tourist coasts

[2] EBA: Ecosystem-Based Adaptation.

Protection technology	Assessment for SIDS
C. Hybrid structures living coasts	Scope for SIDS, but generally restricted to lower energy coasts. Research is required for its implementation on the coasts with the highest energy. It is currently the best and has a wide reach for SIDS; can be combined with hybrid structures; more research required.
D. EBA Mangrove swamps Coral reefs Dunes	
E. Topography/height Claiming Save some islands	Expensive, but may be more permanent than category "A" technology.
F. Floating Fixed/elevated dwellings Floating/amphibious dwellings Floating islands	Should be considered more seriously in the light of new materials and technologies.
G. Imitate nature Build with nature Live with the water	Research needed for application in SIDS.
H. New and innovative ideas	It will be updated periodically based on new materials and technologies that appear in the future.

In Trinidad and Tobago there is a predominance of low-lying coasts with elevations very close to the shoreline, where beaches, coral reefs and mangroves are found, characterized by marine-coastal ecosystems with important biodiversity values and essential for the development of tourism and fishing. The adaptation measures applied with the use of hard structures (retaining walls and groynes) have been of very little magnitude and the proposed adaptation measures and options are aimed at protecting coastal ecosystems.

In recent years, in the wake of the climate crisis expected due to Climate Change and sea level rise, which are expected to increase the risks of erosion, flooding and extreme storms in coastal regions around the world, the scientific community has suggested the idea of nature-based solutions or ecosystems.

Ecosystem-based solutions refer to a set of actions or policies that harness the power of nature to address some of our most pressing societal challenges, such as the growing risk of natural disasters or Climate Change. These solutions involve protecting, restoring and sustainably managing ecosystems in ways that increase their resilience and capacity to address these societal challenges while safeguarding biodiversity and enhancing human well-being.

This approach has gained momentum in various parts of the world over the past two decades, deriving in various policies and guidelines aligned to the incorporation of natural processes in engineering, e.g. Shoreline Management Plans (UK, 2006), Building with Nature (Netherlands, 2012), Living shorelines (USA, 2016) and Nature- based solutions in Program of the International Union for Conservation of Nature, recently renewed in 2021.

In particular, an ecosystem-based alternative for flood and erosion risk mitigation is "green infrastructure". After its implementation, this infrastructure seeks to conserve, or recover if necessary, the mass and energy flows that enable connectivity between ecosystems, their functioning and resilience.

The selection of a successful solution will depend on an adequate diagnosis that includes a resistant, resilient and site-specific design, given the complexity of coastal processes, as has been done in this Project.

Within the green infrastructure solutions, there is the so-called **"Ecosystem Enhanced Engineering".**

In this type of green infrastructure, traditional protection measures, both rigid and soft, are modified to change physical processes (e.g., wave intensity and sediment transport), producing benefits to natural processes that are maintained or adapted to imitate natural ecosystems. For example, beach nourishment and revegetation of coastal dunes with native plants are measures of this type that have demonstrated to be effective, which will be implemented in the present project.

Taking into account the pollution problems detected and described in the Project, measures for their control and mitigation are also proposed, which are part of the package of adaptation measures aimed at the rehabilitation and protection of the coastal ecosystem where the Bonasse beach is located.

The proposed package of measures can be classified as:

- Short-term measures (<3 years)
- Medium-term measures (3-7 years)

- Long-term measures

According to this time scale (short, medium and long term), actions are proposed for each scale.

V.1. Short- and medium-term measures

The solution to the environmental problems detected on the beach is based on the implementation of **coastal management actions** and the application of **engineering measures** with low environmental impact, which allow the rehabilitation and protection of the beach as a whole.

Coastal management actions should be aimed at eliminating all sources of pollution, as well as ensuring the physical integrity of the coastal environment, preventing new construction on the dunes and the beach, and removing all the remains of abandoned concrete structures that currently exist and that, due to their nature, are incompatible with the proper functioning of the beach.

These sources of contamination affect the aesthetics and functionality of the beach as a seaside resort, in addition to being potential generators of diseases, due to the increase of microorganisms harmful to human health in the water and sediments.

Likewise, these management actions will give way to the implementation of engineering measures such as those proposed in the Project, which are aimed, on the one hand, at mitigating the effects of erosion and restoring the morphological, aesthetic and functional conditions of the beach, and on the other, to face the challenges imposed by climatic changes and sea level rise.

It is understandable that actions to solve erosion problems should be oriented towards the elimination and/or mitigation of the causes that generate them and the execution of works that allow for the rehabilitation of eroded beach sectors.

As has been identified, the fundamental cause of erosion is due to the deficit in sediment inputs to the beach, with losses being greater than inputs, marking an irreversible erosive trend in a natural way.

It is evident that the solutions to be implemented for the rehabilitation of the beach must contribute to restore the sediments lost over the years, restoring the volumes of sand and the width of the beach, allowing the protection of infrastructure and real estate against extreme weather events and the increase in sea level caused by climate change.

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Among the most popular solutions, often developed by private initiatives, without a scientific basis, are the construction of breakwaters, groins and seawalls, among others; rigid solutions that far from solving erosion problems, contribute to aggravate them, these structures do not produce sediments that meet the deficits of the beach, being their function the dissipation of wave energy or the interruption of the longitudinal transport of sediments, so this type of solutions are dismissed in this project.

The short and medium-term actions of the project are conceived in two (2) groups of actions:

1st. Coastal management actions.

2nd. Enhanced engineering actions with the use of ecosystems: artificial beach nourishment and dune revegetation.

The selection of artificial beach nourishment as a state-of-the-art technique for the maintenance of natural beaches was made on the basis of its recognized ecological and aesthetic advantages over other techniques (National Research Council, 1995).

These actions are addressed and developed in detail in the Project.

This type of actions, carried out jointly, have demonstrated a high level of effectiveness, since through their application the beaches are designed with a double function, for recreational use and as coastal zone protection works, almost instantly restoring the deficit in the volume of sediments required for the recovery of its conditions:

- Morphological: conforming a well-developed and complete profile, with the presence of the different morphological elements typical of its structure (mainly submarine bars, berms and dunes, the latter revegetated with typical species of Caribbean beaches), and a remarkable increase in the sun strip width.
- Aesthetics: advancing in the gradual restoration of the natural aesthetic and landscape values of the original ecosystem, through the rehabilitation of the sandy profile and corresponding coastal vegetation, as well as the elimination of different polluting elements existing in the environment.
- Functional: conceiving a double use value for the recovered beach:
    - Recreational: to whose conditioning the achievement of the previously mentioned precepts will contribute, relative to the conformation of a profile with adequate sun strip

and carrying capacity, and an attractive natural image. Representing new opportunities for the promotion of the tourist and fishing activity, the valuation of the lands and the generation of employments.

- Coastal defense: taking advantage of the essentially dissipative nature of beaches, with sufficient sand volumes to form extensive, gently sloping profiles, with the presence of submerged bars, berms and powerful dunes, conceived under appropriate design parameters, which guarantee an efficient dissipation of wave energy generated by extreme weather events, contributing to the confrontation of sea level rise caused by climate change.

The actions stated and proposed for their execution in the short and medium term are also aligned with the implementation of the concepts of Sustainable Development, Sustainable Tourism, and Ecosystems-Based Adaptation to Climate Change.

In any case, regardless of the selected actions or strategies, the dynamic nature of a beach, especially in a sea level rise scenario such as the one predicted as a result of Climate Change, makes it necessary for its management to continue over the long term.

V.2. Long-term measures

The long-term strategy for the rehabilitation and protection of Bonasse Beach must take into account the expected effectiveness of the short- and medium-term measures that are proposed, for which the monitoring of the beach morphological and sedimentological variations, as well as other physical and chemical parameters, such as quality of bathing water and sediments, is essential for a correct diagnosis of the environmental quality of the beach.

This strategy must start with establishing an environmental baseline that serves as a reference for the definition of environmental indicators, which allow decision makers to adopt the necessary preventive measures.

The approach of the strategies of Small Island Developing States (SIDS) for confronting climate change is essentially adaptive. For many countries, adaptation basically involves the design of strategies for a gradual retreat from the most vulnerable areas, adjusted to the predicted rate of sea level rise and shoreline retreat.

However, Wong (2018) acknowledges that retreat, as an adaptation strategy, is not possible in many Small Island Developing States (SIDS) due to their small size, limited land, and low-lying nature.

Mean sea level rise will cause an adjustment of the equilibrium profile of the beaches, with its landward movement, which translates into a shoreline retreat (Bruun's Rule). One of the most effective measures to face and mitigate this phenomenon is to artificially provide the beaches with new volumes of sand, which guarantees raising the level of the profile and, therefore, the protection of the coastal zone.

The fact that Bonasse Beach is confined within the Gulf of Paria, where depths are shallow and mean annual wind and wave conditions do not produce important changes in the beach profile, guarantees that, although there is a deficit in sediment input to the beach, the sediment input through the application of Artificial Beach Nourishment is maintained over time with a low loss rate, which should reach a maximum at times of extreme weather events that have low probability of occurrence. Therefore, the periodic application of Artificial Beach Nourishment is not an essential element in the long-term management strategy to face the effects of erosion in the study area.

Taking into consideration that the erosion in Bonasse Beach is essentially triggered by natural causes, and to a lesser extent by anthropogenic causes, as well as the possible climate change effects in the medium and long term, the long-term management strategy can be synthesized into the following elements:

- Creation of a legal framework that promotes and guarantees the implementation of strategies and actions, aimed at the sustainable use of the coastal zone, with emphasis on beaches.
- Monitoring of the effectiveness of the actions carried out as part of the short- and medium-term strategy, and in general, of beach evolution, to define the moment when new actions are required.
- Integrate the beach morphological and sedimentological monitoring into the national monitoring program led by IMA, with at least four (4) beach profiles.
- Other actions, such as those aimed at pollution control, dune maintenance and protection and its vegetation cover, will also be assessed, designed and executed as appropriate.

VI. DESIGN OF PROPOSED PROTECTION MEASURES

VI.1. Coastal management actions

Bearing in mind that the environmental effects suffered by Bonasse Beach are not only related to the deficit in the natural input of sand, but also that they are a consequence of inadequate management practices in the coastal zone, the recovery of the beach will start from the execution of coastal management actions, which due to the social impact that such actions may have, will be divided into two packages of measures, to be developed in the short and medium terms:

(A) Actions in the Short Term.

Coastal cleaning and sanitation. Drainage management.

These actions must be executed immediately and will be permanent.

It refers to the removal of all those elements that can be considered "garbage" (organic and inorganic waste, remains of fishing gears, fallen trees, sargassum accumulations, etc., found on the emerged part of the beach), as well as loose debris from destroyed structures and facilities (Photos 49 and 50).

Photo 49. Debris and vegetation residues on the beach.

Photo 50. Inappropriate practice of burning garbage on the beach.

Regarding the management of drainage at this stage, it refers to the elimination of micro-dumps (Photos 51 and 52) of sewage, as well as sanitation through the removal of contaminated sediments in micro-dump sites. Also included in this point is the strict control of discharges from fishing boats that are stranded/docked on the beach, both at Bonasse and Fullerton.

Photo 51. Sewage discharges through micro-dumps directly onto the beach.

Photo 52. Group of black vultures attracted by the discharges from the micro-dumps on the beach.

(B) Actions in the Medium Term.

Removal of rigid structures. Drainage management.

These tasks must be carried out as part of the beach preparation actions, for the execution of the Artificial Beach Nourishment.

They include the demolition and removal of all half-destroyed rigid structures with no use value, present in the submerged part of the beach, whose removal will make possible the execution of the sand filling tasks and allow the reconstruction and restoration of the beach plan and profile, returning its natural and environmental conditions for a stable and sustainable functioning (Photos 53 and 54).

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Photo 53 and 54. Remains of the old groyne located in Bonasse town.

Added to this point is the clearing and elimination of those trees that are in danger of falling.

Drainage management at this stage will have two action fronts. On the one hand, monitoring the elimination of micro-dumps that have not yet been removed and, on the other hand, the execution of solutions for the control and sanitation of drainage discharges that are evacuated through the concrete structures (canals) present at both ends of Bonasse town, which discharge directly into the sea without any type of treatment.

The establishment of waste treatment plants, as well as a drainage system by means of main conductors and submarine outfalls, should be the object of assessment and projects that would make up the Bonasse Coast Master Plan.

VI.2. Artificial Beach Nourishment (Medium term)

Within the actions implemented worldwide in coastal engineering, there is a wide range of measures whose main purpose is to DEFEND, PROTECT or REGENERATE beaches subject to an erosive process.

Shoreline defense and protection means fixing the coastline and stopping its retreat; while regeneration means restoring the conditions in which the beach was before the start of erosion and even improving them.

The actions are classified into:

- Hard (hard works), which consist of hardening a stretch of coast by building breakwaters or any other structure that stops the sand. It should be pointed out that this type of action does not produce sand.
- Soft (soft works), are those in which no resistant structures or elements are used. Artificial beach nourishment and dune regeneration or creation are included.
- Mixed (hard works + soft works), is the combination of both types of actions.

Until a few years ago, beach regeneration was not conceived without building breakwaters. But it has now been proven that, in many cases, especially on open beaches, this type of action, although it rarely meets its objective locally, produces erosion in adjacent areas, so that its implementation by itself is in disuse given the environmental problems it generates, its insertion in projects is recommended in such a way that hard works (hardening of a stretch of coast) and the soft works (artificial nourishment or bypass) are combined.

The most acceptable solutions to coastal erosion problems from almost all perspectives, but particularly from the environmental point of view, are those that have been called 'soft solutions', and among them, artificial beach nourishment.

In the last decades of the 20th century, the application of artificial beach nourishment began to become widespread, being preferred over the traditional rigid coastal defense works.

Juanes (1996) refers to 3 important examples in this regard:

- In the Republic of Georgia, by the Black Sea, the failure of various beach protection works through the construction of breakwaters and dikes until 1981 led to their replacement and the execution of artificial beach nourishment projects, which between 1983 and 1987 benefited 47.5 km of coastline, with the discharge of 9,224,600 m^3 of sand and gravel (Kiknadze , *et al*. 1990).
- In Spain, between 1983 and 1988, more than 300 actions were carried out on the coasts, with 70% of the budget allocated to beach rehabilitation projects through artificial beach nourishment (MOPU, 1988).
- In the United States, around 1988, there were reports of 60 beaches on the Atlantic coast, 35 on the Gulf coast, and 30 on the Pacific coast, which had been or were periodically benefited by the application of artificial beach nourishment. It was then estimated that these

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works had exceeded the order of 300 million m^3 of sand discharged for the recovery of more than 600 km of coastline (Leonard *et al*., 1990).

In the latter case, the example of Miami, Florida, is a remarkable reference. The breakwater field that existed there until the 1970s had to be demolished, giving way to the discharge of more than 10 million m^3 of sand between 1977 and 1982. The application of this technique in Miami has continued. In fact, in May 2022 a new project began to discharge some 600,000 m^3 of sand on 3,500 m of beach.

In the United States, artificial beach nourishment has become almost the only coastal defense procedure nowadays, after years of applying hard solutions that, far from recovering the beaches, caused the intensification of erosion processes, with very expensive projects to remove rigid structures placed on hundreds of kilometers of shoreline.

In most European countries such techniques have been used extensively and with notable successes that have been duly recognized.

In the Caribbean area, Cuba has been a pioneer in its application for the recovery of its beaches, being particularly noteworthy the example of Varadero, which has been subject to sand filling of more than 3.5 million m^3 between 1987 and 2020, highlighting the project executed in the summer of 1998 for 1,087,000 m^3 of sand along 12 km of beach.

The experiences of Varadero led, locally, to the implementation of an Integrated Coastal Management Strategy, which has also included the demolition of more than a hundred structures occupying the dune that contributed to beach erosion, the removal of Australian pines existing in the coastal zone, the reshaping and reforestation of several kilometers of dunes, and the construction of rustic wooden walkways to access the beach to guarantee the preservation of dunes and their vegetation, among other actions.

Likewise, the investment program for the recovery of Varadero Beach was one of the bases for the conception of the National Investment Program for Beach Recovery in Cuba, later integrated into the Cuban State Plan to Confront Climate Change (known Task Life). Adding this program and the initial experiences, more than 5 million m^3 of sand have been discharged on several of the country's main tourist beaches, occasionally resorting to the use of rigid coastal defense structures, in specific cases where research has indicated their need.

On Cancun Beach, in Mexico, it stands out the discharge of more than 5.2 million m^3 of sand between 2009 and 2010, in a project carried out to recover the beach from the effects of the passage of the powerful Hurricane Wilma in 2005. Around 2021, local sources pointed out the existence of four other projects, awaiting financing to begin their execution, for almost 7 million m^3 of sand to be discharged as a whole, for the recovery of the beaches of Cancun, del Carmen, others in the Riviera Maya and Cozumel Island.

Juanes *et al*. (2012) report the execution of four projects in 2006 for 1,300,000 m^3 of sand, on Long Beach, Dorada, Cabarete and Juan Dolio beaches, in the Dominican Republic.

Artificial Beach Nourishment, as an advanced technique for beach recovery and/or maintenance, has shown satisfactory results worldwide, due to its undeniable benefits and advantages over other engineering alternatives, with regard to the conservation of natural beach conditions.

It basically consists of providing new volumes of sand to the beach, from a nearby borrow area, which allows the sediment lost due to the effect of erosion to be returned to the system in a short period of time. In addition, it allows the creation and/or recovery of spaces destined for recreational use or related to fishing, as well as providing the beach profile with the volumes of sand and the space necessary for its dynamic operation, thus also serving as a coastal defense.

Among its most notable advantages is the speed with which the profile is restored and the non-introduction of new structures in the coastal area, this being a friendly solution in harmony with the environment, as well as being aesthetically superior to the creation of rigid structures, such as groynes, breakwaters or jetties. It should be noted that its implementation does not compromise the application of other measures in the future, if necessary, since the basic morphology of the coastal sector is not modified, nor are costly and difficult-to-remove elements introduced.

Among the most important elements in this type of project, the determination of design parameters of the beach to be shaped, and the identification and characterization of the borrow area stand out, from where the necessary input volumes will be extracted to satisfy the design requirements.

It can be asserted that the application of artificial beach nourishment for the recovery and protection of Bonasse Beach constitutes a viable engineering measure, due to the existence of marine sand deposits with suitable conditions as a borrow area, at an acceptable distance for the transportation of sediments, elements that will be dealt with below.

VI.2.1. Borrow area

For the conception of projects of this type, it is a priority to identify and characterize sand borrow areas, capable of satisfying the demand of the beaches, with the necessary quality and volumes, minimizing environmental impacts and guaranteeing their sustainable use and the capacity to self-recover over time.

To meet this objective, a work program was carried out aimed at exploring the submarine shelf around Cedros Peninsula, based on the analysis of the morphological characteristics observed in the available nautical chart; as well as conducting bathymetric surveys in front of the beach and in the possible borrow area (Figure 27).

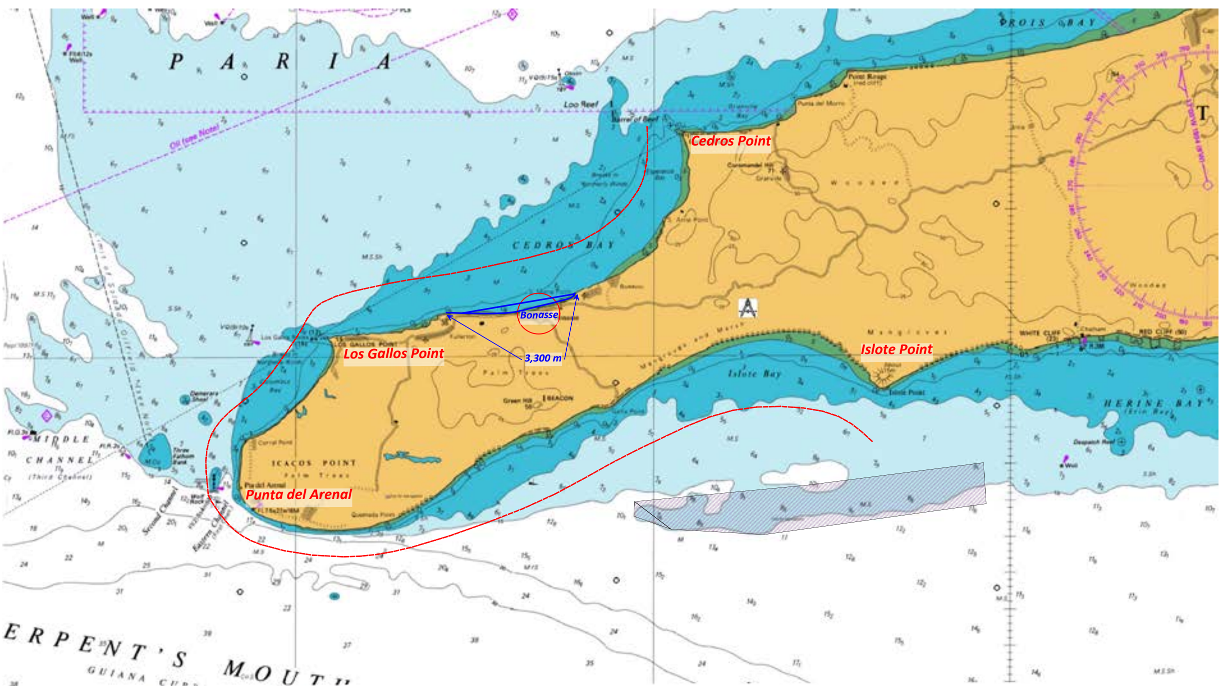

Figure 27. Set of tasks conceived in the work program for the exploration of the submarine shelf around Cedros Peninsula.

From the initial reconnaissance expeditions, the execution of the first autonomous diving stations, and interviews with residents and fishermen, three areas were delimited to explore potential sand borrow zones (Figure 28).

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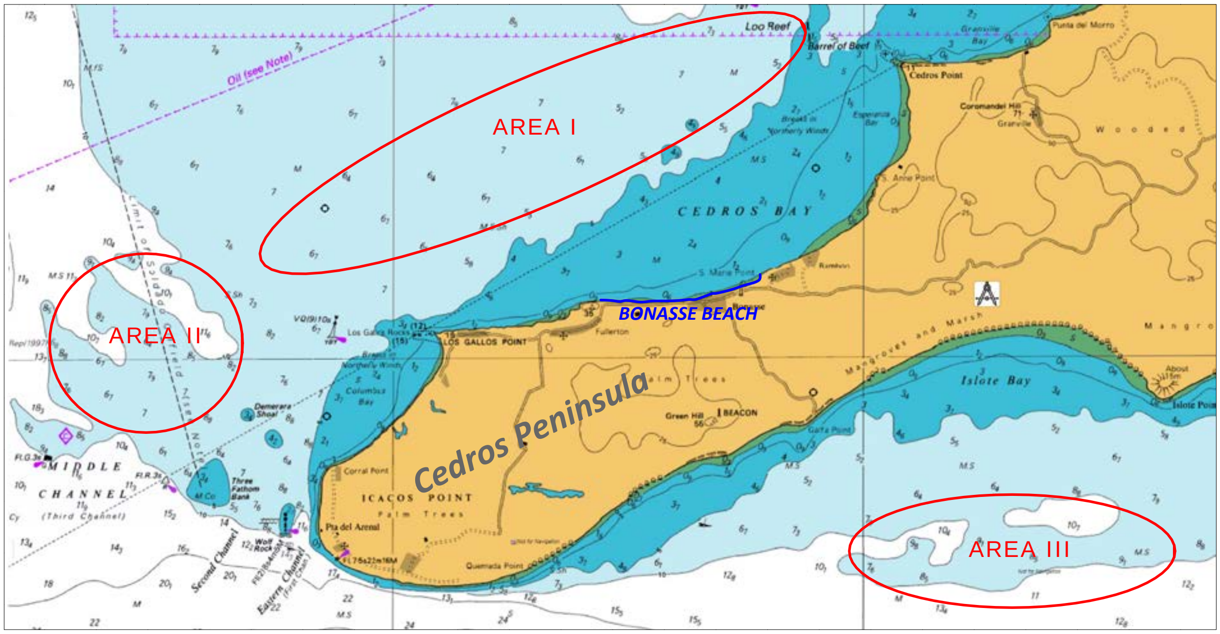

Figure 28. Areas explored during the search for the sand borrow area around Cedros Peninsula.

During the exploration work, due to maritime safety issues and the proximity to the beach, priority was given to research on the underwater slope of the Gulf of Paria, between Cedros Point and Icacos Point, a 15-km-long shoreline that encompassed only Areas I and II.

As a result of this work, 20 sedimentological sampling stations were carried out, showing that the presumed potential sand borrow areas located in the Gulf of Paria (Areas I and II) are composed of muddy, highly clayey sediments, which are probably the result of sediments carried by the flow currents from those transported by the Orinoco River from the continent and deposited in the gulf (Photos 55 and 56). Therefore, Areas I and II were dismissed.

Photos 55 and 56. Samples of muddy sediments from the seabed of the Gulf of Paria.

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Given that these works yielded negative results for the purpose of the project, it was necessary to locate a borrow area outside the Gulf of Paria. Through the interpretation of the available nautical chart, geophysical file information and the general scheme of water circulation around the island of Trinidad, specifically towards the south of Islote Bay, a potential area was located, which we call Area III (Figure 28).

Because Area III is in a dangerous area for navigation due to piracy and drug trafficking, the collaboration of the Coast Guard was necessary.

Following a communication from Dr. Rahanna Juman (Director of IMA), a meeting was held with Coast Guard officials. They were informed of the activities that the work team would be carrying out in Bonasse and the surrounding coastal area (Photos 57 and 58).

Photos 57 and 58. Information and collaboration meeting between GAMMA and IMA specialists with the Bonasse Coast Guard.

It was agreed that two divers from the Coast Guard would participate in the diving work, to accompany the team, in safety and protection functions, since it was intended to explore an area that is sensitive from the point of view of safety due to its geographic location.

With the collaboration of the Bonasse Coast Guard Service (Photos 59 and 60), in support of maritime safety, with a vessel with an armed crew and support divers, the diving and sand sample collection stations were carried out in the planned Area III, actions that were previously agreed with the personnel of the Coast Guard Service and IMA.

Photos 59 and 60. Coast Guard vessel support during geological prospecting and bathymetric survey work in Area III.

In the diving stations carried out (Photos 61 and 62), good quality sand was found. The conducted drillings yielded a measured sand layer thickness of 1.65 m. In all the drillings, the manual drill penetrated easily and quickly; therefore, a sand layer thickness greater than 2.00 m is estimated.


Photos 61 and 62. Execution of autonomous diving stations to collect sediment samples and carry out drilling of the seabed.

Because of the null visibility due to water turbidity and the strong speeds of marine currents, it was necessary to carry out the collection of samples using of a sampler and the winch, which allowed increasing the density of the sedimentological sampling. In total, 21 stations were executed with sediment sampling in 19 of them (Photos 63 and 64).


Photos 63 and 64. Collection of sediment samples with using a sampler and winch.

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The works were carried out in pre-defined stations, so that a large enough area was covered to ensure that the sand volume was sufficient to satisfy the needs of the beach rehabilitation project (Figure 29).

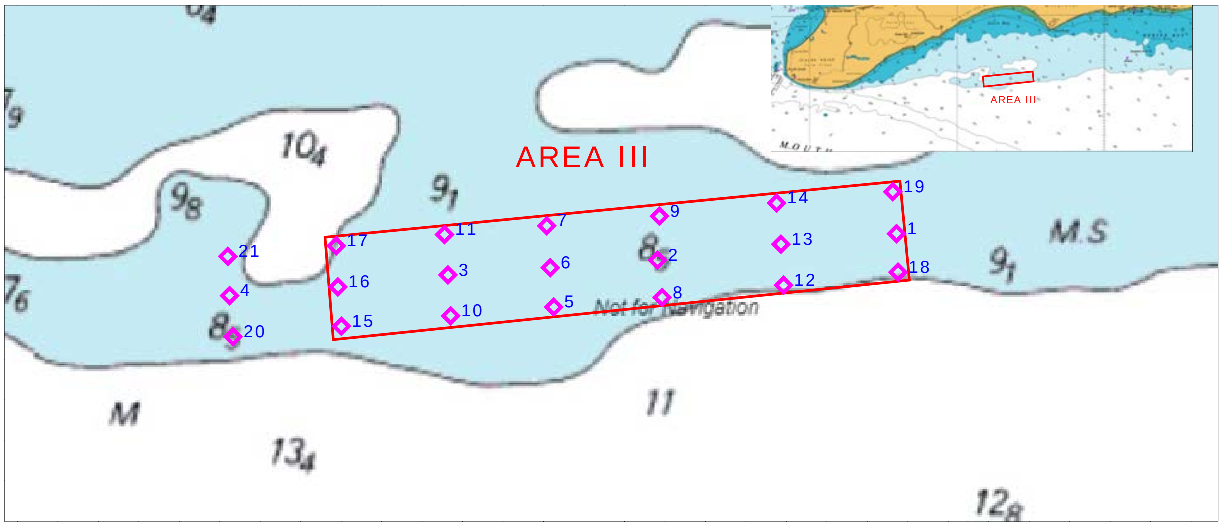

Figure 29. Sampling stations executed in Area III.

With the development of the diving stations, the drillings and the collection of sand samples in Area III, it was possible to delimit a surface of 1.43 km^2, with an estimated volume of **2,356,195.00 m^3** of sand, sufficient reserve to satisfy the needs of the present project and future ones that are developed in the region. Table 18 shows the coordinates of the vertices of the polygon that delimits the explored Borrow Area to the south of Islote Bay.

Table 18. Coordinates of the vertices of the Borrow Area to the south of Islote Bay. (Identified and measured block)

Vertex	Geographic coordinates (WGS-84)		UTM coordinates (WGS-84, Zone 20N)	
	Longitude	**Latitude**	**Easting**	**Northing**
A	-61.81810195	10.04845750	629520.165	1111003.240
B.	-61.79217170	10.05087264	632361.183	1111280.666
C	-61.79176311	10.04644675	632407.767	1110791.384
D	-61.81774498	10.04387885	629561.112	1110497.046

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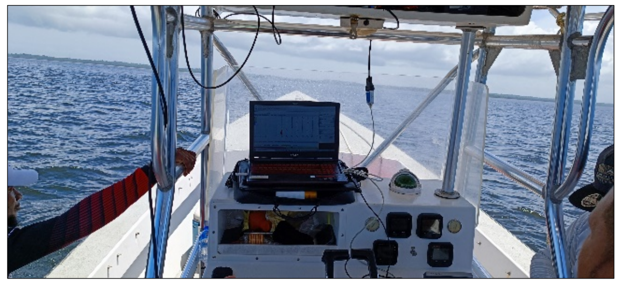
Due to maritime safety issues and bad weather conditions that occurred during the period of these works, it was not possible to extend or increase the density of the prospecting work in Area III, so that, prior to the project execution, it will be necessary to carry out a field campaign with the aim of checking and updating the data collected, an action that is normally always recommended before dredging.

Once sand sample collection was completed, the bathymetric survey of the possible borrow area was carried out, at a scale of 1:15000, including 22 sounding lines 500 m long, with a sounding sequence of 150 m, covering an area of 2 km^2 (Photos 65 and 66).



Photos 65 and 66. Execution of the bathymetric survey of the sand borrow area at a scale of 1:15000.

Depth distribution within the Borrow Area shows an average of 10.03 m, with maximum values of 12.03 m, and minimum of 9.15 m. (Plan 2)

The expanse of the Borrow Area constitutes a natural sink of 2,870 m in length by 500 m in average width, which extends between 10 m isobaths forming a small depression, ideal morphological conditions for sediments carried by waves and coastal currents to be deposited. The Borrow Area is located south of Islote Bay, 4 km from Islote Point, perfect for dredging and transportation work.

For the characterization of sediments, 19 sand samples were collected in the Borrow Area.

From a textural point of view, the grain size analysis shows that 73.7% of the samples are fine sand, distributed around the upper threshold of said classification, and 36.3% are medium sand, distributed around the lower threshold of said classification, which corresponds to the result of the type sample, with an average diameter of 0.216 mm, being classified as fine sand. (Table 19, Figure 30, Annex 2, Plan 3)

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Table 19. Results of grain size processing of the sample type of the Borrow Area.

Sieve Range								M		Stand Dev. (Ø)	Wentworth Classification
>4	4-2	2-1	1-0.5	0.5-0.25	0.25-0.125	0.125-0.062	< 0.062	(mm)	(Ø)		
2.839	3.642	4.276	5.868	17.386	59.610	6.148	0.219	0.216	1.929	1.139	Fine sand

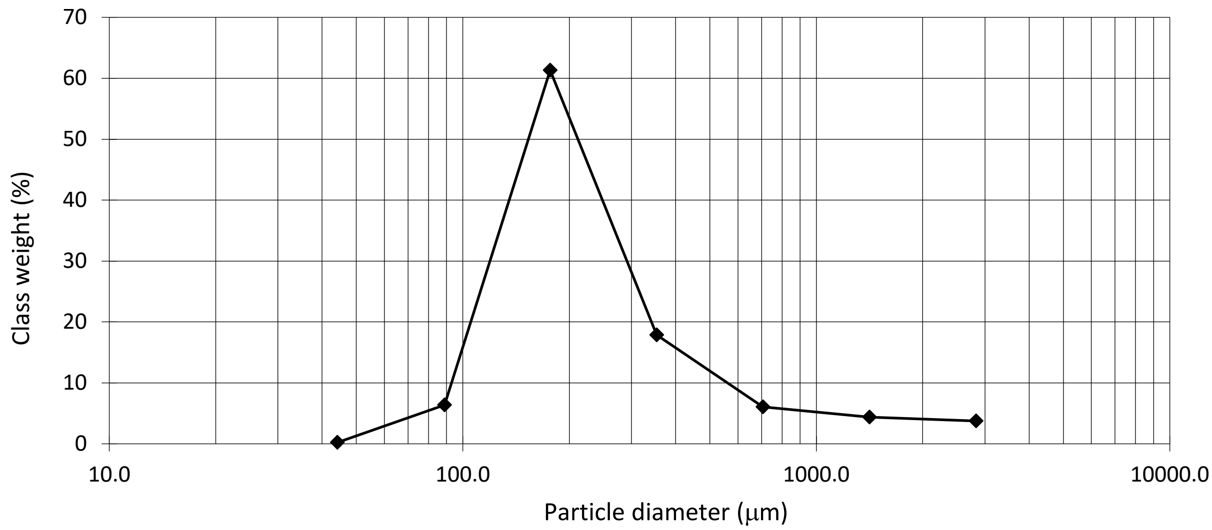

Figure 30. Particle size distribution of the type sample from borrow area.

VI.2.2. Suitability of the sand to be used

The sedimentological characterization, of both the area to be benefited and of the borrow area, is one of the essential elements in beach rehabilitation projects, where Artificial Beach Nourishment is applied. It allows establishing the grain size composition and the genesis of the sand. The results of these analyses make it possible to define the areas of the submarine shelf with the best possibilities to be used in dredging works.

Annex 2 presents the grain size results, from the analysis carried out on the sand samples from the beach and the borrow area, which are summarized in Table 20.

Table 20. Grain size of the type samples of the beach and the borrow area.

Type sample of beach				**Type sample of borrow area**			
M (mm)	**M (ϕ)**	**Stand. Dev. (ϕ)**	**Classification –**	**M (mm)**	**M (ϕ)**	**Stand. Dev. (ϕ)**	**Classification –**
0.170	2.556	0.545	Fine sand	0.216	1.929	1.139	Fine sand

By analyzing the values shown in Table 20, it can be concluded that in both the type sample of the beach and in that of the borrow area, the values of mean particle diameter (M) classify as fine sand, being slightly higher in the borrow area where M = 0.216 mm, while on the beach M = 0.170 mm.

This increase in mean diameter of the sand from the borrow area, with respect to that on the beach, is appropriate to achieve greater stability of the sand grains when filling in Artificial Beach Nourishment works, according to the recommendations of the Shore Protection Manual (1984).

Precisely this sand stability, from the engineering point of view, is a determinant when evaluating sand suitability, and therefore, in the selection of the borrow area.

The results of the geological exploration in the borrow area, as well as the existing similarity in the results of the grain size analysis between the sands on the beach and the borrow area, allow us to affirm that the borrow area located to the south of Islote Bay fully meets the requirements of the project, in terms of sand volume and suitability.

When executing a filling work, part of the material is lost during the placement of the sand and later in the rearrangement process; this happens, basically, due to the washing of the sand and grain size differences between the sand on the beach (native) and the sand from the borrow area (introduced).

To compensate for these sand losses, it is necessary to adjust the sand volumes to be introduced, using a coefficient called the overfill ratio $R_{A,}$ proposed by James (1975), and adopted by the Shore Protection Manual (1984), Automated Coastal Engineering System (ACES, 1992), and by the Coastal Engineering Manual (2002).

James (1975) graphically determines the coefficient R_A using an abacus, considering that R_A is the value by which the filling volume of the project must be multiplied. This methodology is automated in the ACES software, collected within the graphic interface Coastal Engineering Design & Analysis System 4.0 (CEDAS).

The calculation of the R_A was carried out using the software Automated Coastal Engineering System (ACES, 1992), obtaining the results presented in Figure 31.

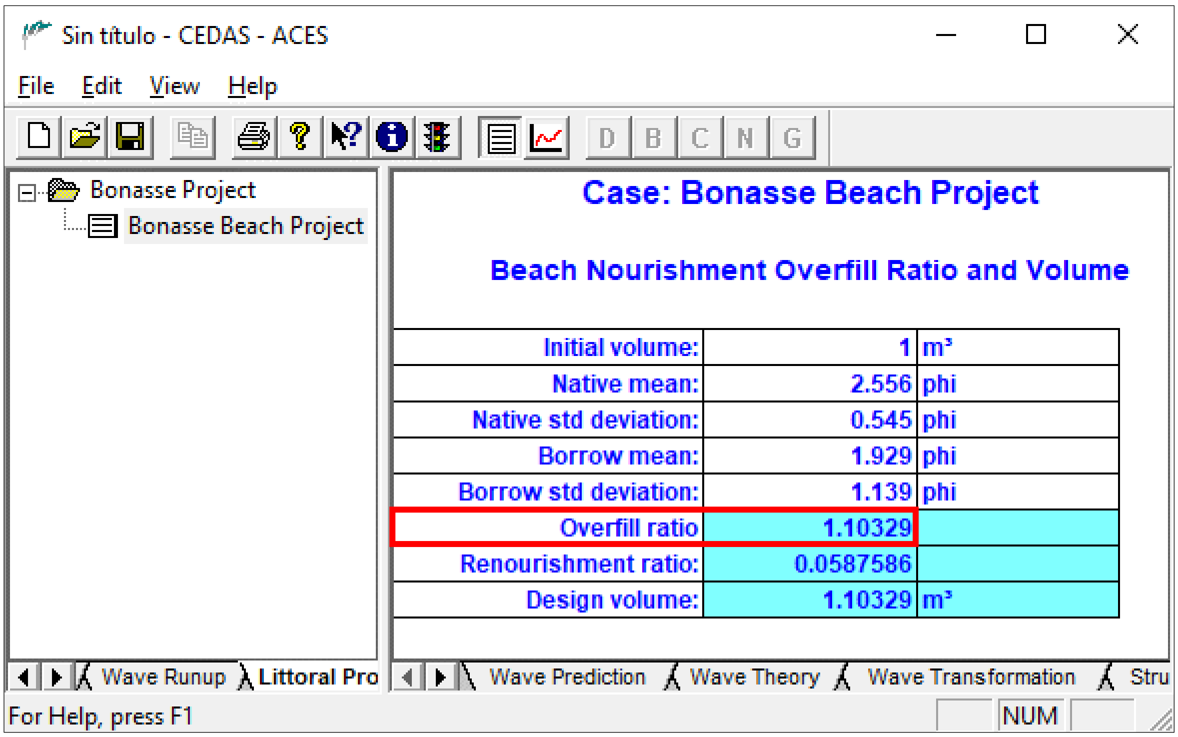

Figure 31. Graphic interface of the CEDAS-ACES software. Calculation of the overfill ratio for the borrow area.

This coefficient R_A =1.1, must be multiplied by the filling volume calculated for the project, which will mean an adjustment to this volume due to differences in grain size between the native and the introduced sand.

VI.2.3. Sand Volume Calculation

The section to benefit from Artificial Beach Nourishment will include the entire beach, 3,300 m long, whose limits are shown in Table 21 and in Figure 5 of chapter IV.

Table 21. Coordinates of the limits of the filling area.

Limit	Geographic coordinates (WGS-84)		UTM coordinates (WGS-84, Zone 20N)	
	Longitude	Latitude	Easting	Northing
West	-61.88084320	10.09273338	622626.990	1115875.344
East	-61.85156327	10.09671308	625834.072	1116326.569

Regarding the calculation of the filling volume, international experience shows that various criteria are used for its estimation, although there is agreement that the density of the fillings should not be less than 60 m^3 per linear meter of beach. (Juanes *et al.*, 1996)

For the design of any beach, in general, a formulation is used, which allows determining the equilibrium profile from wave conditions and a given sediment, recognizing as equilibrium profile the average profile around which the different seasonal or temporal variations occur in a centered manner. These are smooth algebraic curves with one or more sections and generally easy to handle and calculate.

There are several models of the equilibrium profile, which allow evaluating the sand volume required to guarantee an increase in beach width. Many of these models are based on the one proposed by Dean (1977, 1991).

Dean (1991) developed a method, which is used to determine the sand volume required for filling works to achieve a desired dry beach width.

The beach equilibrium profile is a fundamental concept in the design of a sand filling. One of the best known and most applied equilibrium profile formulations is the one proposed by Bruun (1954) and Dean (1977; 1991):

$$h(y) = A \times y^{2/3} \qquad (6)$$

Where:

h(y) = depth at a distance "y"

y = horizontal distance from the shoreline

A = dimensionless parameter related to sediment characteristics

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Dean (1987) showed that the parameter A is related to the particle settling velocity (w) by the expression:

$$A = 0.067 \times w^{0.44} \quad (7)$$

The settling velocity can be related to the sediment particle diameter by using the formulation of Hallermeier (1981a). For the case of beaches with sediment particle diameters in a range of 0.15 mm to 0.85 mm, this is reduced to the following ratio:

$$w = 14 \times D^{1.1} \quad (8)$$

Where:

D = mean diameter of the sand expressed in mm

w = particle settling velocity expressed in cm/s

Parameter A can be expressed as:

$$A = 0.21 \times D^{0.48} \quad (9)$$

Most beach engineering works are concentrated in the emerged part of the beach, that is, the dry beach. However, when artificial nourishment is performed, the injected sand is distributed throughout the entire profile within the breaking zone, to a depth known as the active profile closure depth (h*), obtained by Hallermeier (1981b) and later modified by Birkemeier (1985).

$$h* = 1.75 \times H_{S12} - 57.9 \times \left(\frac{H_{S12}^2}{g \times T_S^2}\right) \quad (10)$$

Where:

H_{S12} = Significant wave height exceeded only 12 hours per year.

T_S = Significant wave period associated with H_{S12}

If the size of the introduced sand is similar to that of the native sand, the post-filling beach profile should be equal to the pre-filling profile, but extended seaward, in a “reverse” manner to Bruun’s Rule (Bruun, 1962), which basically states that, for a given sea level rise, the shoreline will retreat uniformly to maintain a constant equilibrium profile. (Figure 32)

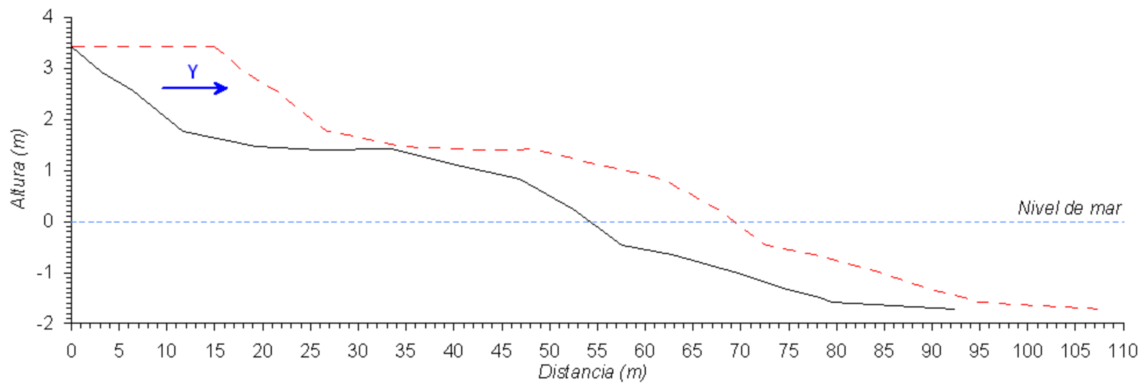

Figure 32. Off-shore displacement of the active profile as a consequence of the fillings.

Restoring the beach is, therefore, the reverse process where the profile will be rebuilt towards the sea. The Shore Protection Manual (1984) states that when the berm height is B and the closure depth is h* (Figure 33), to achieve a beach width Y, a volume V of sediment per linear meter of beach will be required, according to the expression:

$$V = (B + h*) \times Y \quad (11)$$

In the event that the grain size of the introduced sand differs from the native grain size, Dean's method (1991) allows determining the volume of sediments necessary to achieve a desired dry beach width.

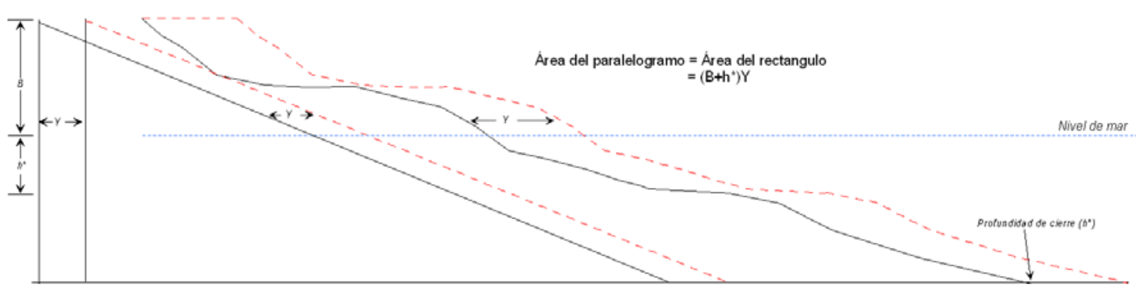

Figure 33. Volume of sand per length unit of beach resulting from beach filling.

This author defined three basic types of filling profiles. Depending on parameter A of the native material (A_N) and the filling material (A_R), it may happen that the filling intercepts or does not intercept the native profile before the closure depth, or that it is submerged.

To determine whether or not a filling profile intercepts the native profile, Dean (1991) arrives at the following inequalities:

$$Y\left(\frac{A_N}{H}\right)^{3/2}+\left(\frac{A_N}{A_R}\right)^{3/2}<1 \qquad \text{The profile is intercepted} \qquad (12)$$

$$Y\left(\frac{A_N}{H}\right)^{3/2}+\left(\frac{A_N}{A_R}\right)^{3/2}>1 \qquad \text{The profile is not intercepted} \qquad (13)$$

Where:

A_N = value of the scale parameter A of the native sand

A_R = value of the scale parameter A of the introduced sand

H = closure depth of the active profile

Y = beach width to be achieved

In the case of profiles that <u>do not intersect</u>, the sediment volume to be deposited is determined by the expression:

$$V = B \times Y + \frac{3}{5}H^{5/2}\left[\left[\frac{Y}{H^{3/2}}+\left(\frac{1}{A_R}\right)^{3/2}\right]^{5/3} A_N - \left(\frac{1}{A_R}\right)^{3/2}\right] \qquad (14)$$

Where:

V = volume of sediment in cubic meters per linear meter of beach

H = closure depth of the active profile

B = height of the berm

Y = beach width to be achieved

A_N = value of the scale parameter A of the native sand

A_R = value of the scale parameter A of the introduced sand

For profiles that do <u>intersect</u> (when inequality (7) holds true), the volume needed to obtain a determined beach width is given by:

$$V = B \times Y + \frac{\frac{3}{5} \times A_N \times Y^{5/3}}{\left[1-\left(\frac{A_N}{A_R}\right)^{3/2}\right]^{2/3}} \qquad (15)$$

To apply the methodology proposed by Dean (1991), it is necessary to define the closure depth of the active profile (h*), by expression (5), for which the parameters H_{S12} and T_S must be determined.

From the mean regimes in Figures 17 and 18, it is possible to determine the significant wave height and the peak period, exceeded only 12 hours per year, which correspond to the cumulative probability of 0.99863; therefore, H_{S12} = 2.50 m and T_S = 15 s, with these values and applying expression (5) it is obtained that h* = 4.21 m.

From (12) and (13), it is concluded that the filling profile intercepts the native profile before the closure depth.

Applying the corresponding expressions, it is possible to determine the volume necessary to obtain a dry beach 30 m wide, with a berm height of 1.75 m that guarantees to keep the backshore emerged at times of high tide, whose manual calculation yielded a volume of 105.8 m^3/m. These formulations are automated in the Coastal Modeling System (SMC).

Figure 34 shows the calculation window of the "Coastal Engineering Tutor" Module of the SMC, in which the input parameters and the results are collected, highlighting the filling volume that coincides with the one calculated manually (105.13 m^3/m) and the advance of the filling line, which means that to achieve a 30 m wide dry beach after reaching equilibrium, the filling must extend up to 46 m in its emerged part (Figure 35).

The calculated volume expresses the sand filling density, that is, the volume per linear unit of beach, which must be multiplied by the overfill ratio R_A to compensate for the losses due to the grain size differences between the introduced and the native sand. As the length of the beach to be regenerated is 3,300 m, the total filling volume is 381,150 m^3.

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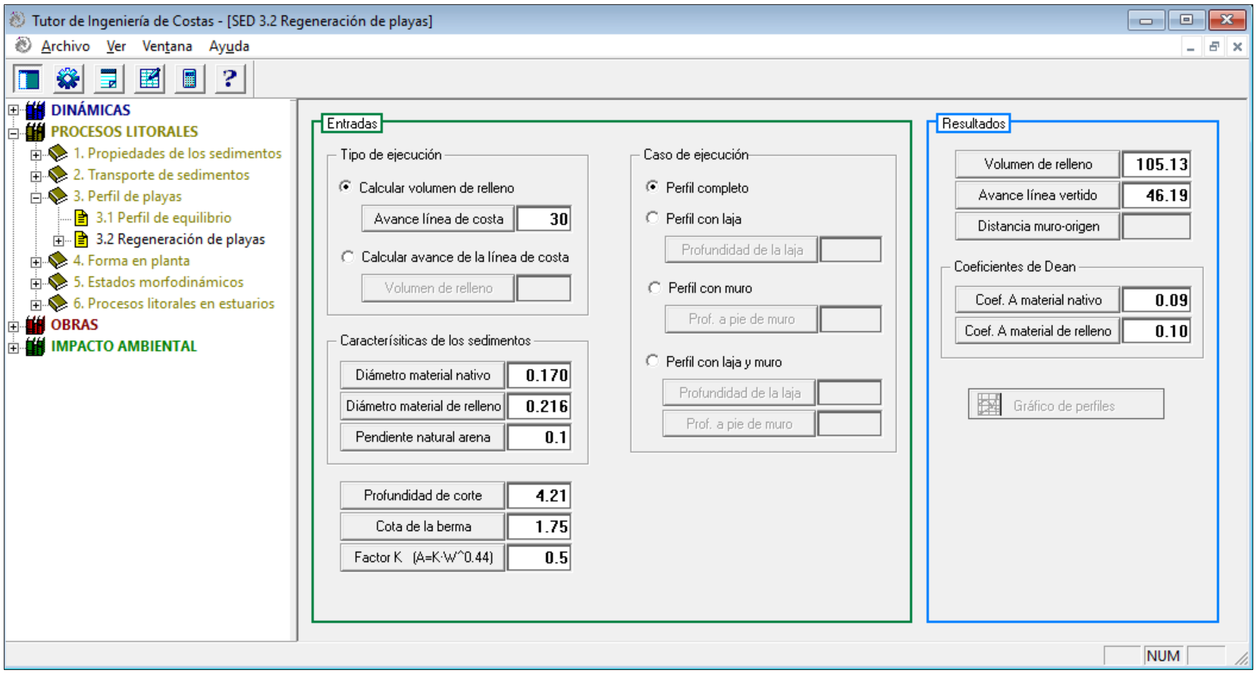

Figure 34. Calculation of filling density using the Coastal Engineering Tutor (TIC) of the Coastal Modeling System (SMC).

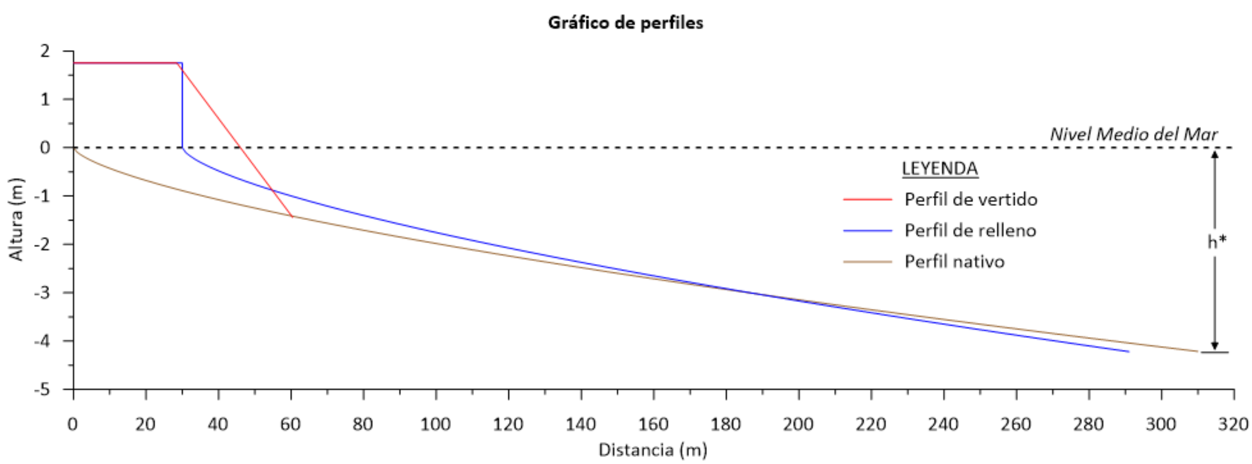

Figure 35. Representation of equilibrium profiles (native and filling) and filling profile.

Plan 4 shows the design profiles, which have been drawn based on the beach profiles measured during fieldwork, also considering that these are representative of the beach stretches where they are located. With the selection of these profiles, both the tasks of project execution oversight and subsequent monitoring are guaranteed.

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VI.2.5. Restoration of the beach dune system

From a functional point of view, dunes represent the sand reserves of the beaches, that is, the areas where during extreme episodes, such as hurricanes and extratropical lows, the sea takes the sand it needs so that the beach profile adjusts to the harshest conditions of the incident waves. This way, it strengthens the underwater bars and pushes wave breaking seaward, dissipating its energy away from the shore.

The role of coastal dunes acquires greater importance, given the challenges posed by the effects of climate change, since it confronts us, on the one hand, with a rise in the mean sea level, and on the other, with a greater frequency of occurrence of extreme weather events.

The objective of recovering Bonasse Beach dune is to restore the functional and aesthetic characteristics of the dune as an economically viable alternative to counteract coastal erosion.

However, as has already been described, Bonasse Beach has a series of particularities that require a sectorized analysis to rebuild and enhance the dunes, which are basically summarized as fallows:

- The beach does not have underwater sand bars along its length, a geomorphological indicator that denotes a poor or null "onshore-offshore" sediment transport; therefore, there is no exchange between the dunes and the bars.
- At times of storms when the dunes are attacked by the waves, the eroded sediments are suspended and transported from east to west by coastal currents, as shown by the modeling results that appear in Annex 3.
- 25% of the beach (600 m in Bonasse and 200 m in Fullerton) has dunes occupied by buildings that will prevent the sand volumes from being increased. (Case A) (Figure 36)
- In 42% of the beach (1,400 m of Sector 2) the dunes have been eroded, to such an extent that in some places the vegetation that normally occupies the dune and backdune is currently found in backshore areas, and in occasions, the waves reach it at high tide. (Case B) (Figure 36)
- Only in 33% of the beach (1,100 m) there is the possibility of enhancing the sand volumes in the dunes. (Case C) (Figure 36)

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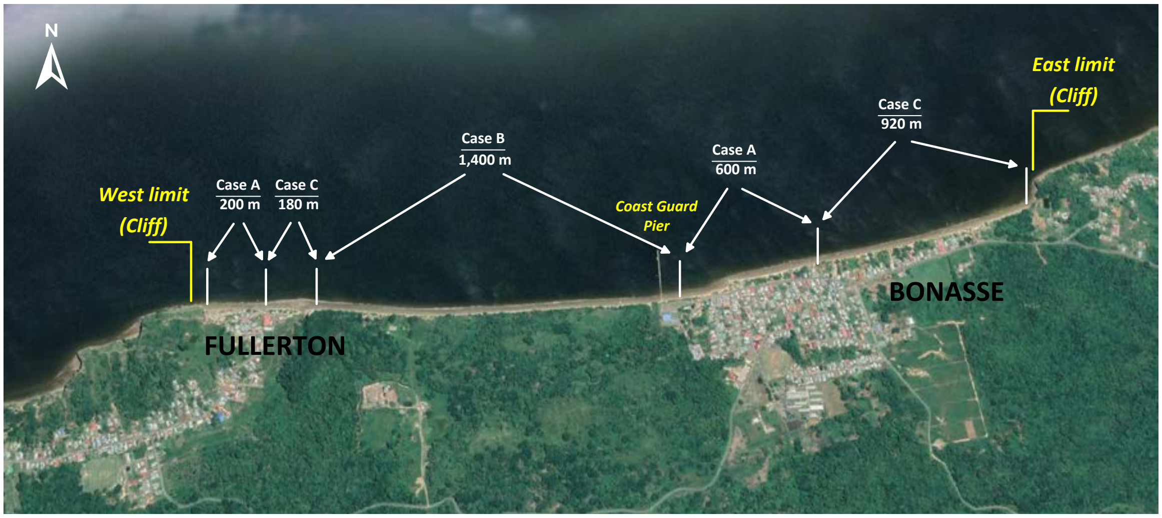

Figure 36. Zonation of dunes for the application of actions during the sand filling.

For this reason:

- In Cases A and B, the sand volumes will be deposited in such a way that the berm and backshore have a crest height of 1.75 m, which will guarantee a dry beach that will never be flooded by the sea at high tide. The sand volumes will be supported landward on the current dune (Plan 4). Operationally, in the stage of mechanical rearrangement of the sand volumes (profiling the beach), the current dune will be leveled to the extent that the vegetation and buildings allow it.
- Similarly, in Case C, the sand volumes will be deposited in such a way that the berm and backshore have a crest height of 1.75 m, which will guarantee a dry beach that will never be flooded by the sea at high tide. Sufficient sand volumes will be transported towards the current dune to form a dune belt 15 m wide, with a crest height of 2.50 m, and a density of 15 m^3/m, equivalent to 16,500 m^3 additional to the sand volume calculated in section VI.2.4., (Plan 4).

From the above, **the sand volume necessary for the rehabilitation and protection of Bonasse Beach is 397,650 m^3**.

Once the dune has been reshaped in the corresponding sections, its stabilization against wind transport will be achieved by planting coastal dune species that meet three fundamental requirements: that they are sediment fixers, that they have the ability to survive burial by sand and also to regenerate naturally after a storm event.

The species that will be selected to stabilize the reconstructed dunes will also contribute to restoring the minimum ecological conditions, for the gradual recovery of flora diversity in the area. This will guarantee a substantial medium-term increase in the self-recovery capacity of the vegetation, facing severe weather events or other types of damage.

The restoration strategy of dune vegetation takes into account the natural zonation of plant species that reflects the different levels of substrate salinity they tolerate, where herbaceous plants are those that withstand the highest levels of saline aerosol.

Specifically, on Bonasse Beach, in the sections where the dunes will be reshaped, dune restoration will be circumscribed to its front face and its back face.

For all practical purposes, the front face of the dune comprises its front slope from the base to the crest where the slope direction changes. It is divided into two parts: a 2 m strip at the very base (foot of the dune seaward), and the inclined plane from the front face to the top. For its part, the back face comprises the plane of the back slope of the dune, from the crest of change in slope to the back foot of the dune.

The species to be used in the different sectors of the dune are listed in Table 22, and images of these species are shown in Photos 67, 68 and 69. In view of the fact that the areas revegetate are not very extensive, in this first phase immediately after the filling, only one type of plant is proposed for each dune zone.

Table 22. Plant species by sectors to be used in dune rehabilitation.

Dune area	**Plant species**
foot of the dune seaward	Shoreline purslane (*Sesuvium portulacastrum*)
front face of the dune	Bitter panicgrass (*Panicum amarum*)
back face of the dune	*Beach morning glory* (*Ipomoea pescaprae*)

Photo 67. Herbaceous vegetation, Shoreline purslane (Sesuvium portulacastrum).

Photo 68. Herbaceous vegetation, Bitter panicgrass (Panicum amarum).

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Photo 69. Creeping vegetation, Beach morning glory (Ipomoea pescaprae) .

VI.2.6. Planting volumes by zones

Foot of the dune seaward, 2 m wide (2,200 m²)

Shoreline purslane (*Sesuvium portulacastrum*)

Sowing density: 25 pl/m²

Total Shoreline purslane: 55,000 plants

Front face of the dune, 7 m wide (7,700 m²)

Bitter panicgrass (Panicum amarum)

Planting density of 18 pl/m²

Total Bitter panicgrass: 138,600 plants

Back face of the dune, 6 m wide (6,600 m²)

Beach morning glory (*Ipomoea pescaprae*)

Sowing density: 15 pl/m²

Total Beach morning glory: 99,000 plants

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These plant volumes must be available in nurseries; therefore, they must be considered within the short and medium term strategy.

For the planting densities per square meter of dune, these values are based on the experience of the work carried out by the Cuban Institute of Marine Sciences and the Institute of Ecology and Systematics, in the recovery of dunes in Playas del Este (Eastern Beaches), in Havana.

VI.2.7. Conformation of containment barriers and sand catchment

Sand catchment systems are structures that manage to form accumulations thanks to the interception of windborne sand, by reducing its speed due to the friction they exert on the ground. These systems are used to stop sand transport towards the back of the dune, help filling gaps in the dunes and create entirely new ridges.

Thus, sand collectors replace the function that vegetation naturally performs in building coastal dune ridges, in those places where the vegetation has low density or is absent.

To rehabilitate the dunes in Bonasse Beach, it is recommended to employ support collectors, which are used in areas where the dune ridge is not totally degraded and are installed between the natural vegetation or the new revegetation. Their main objective is to protect of the vegetation against wind erosion and allow sand deposition while the plants reach their adult size, later assuming the function of stabilization and fixation of the mobile sand areas.

The location of the collectors on the ground depends on the objective pursued and the natural sediment dynamics of the system. In the case of the dune to rehabilitate in the indicated sections, the sensors must be placed near the top of the dune, on its seaward slope, in such a way that the height of the sensors is higher than the height of the dune. As the dune grows to the point of surpassing them, these systems are repositioned advancing seaward, thus allowing the dune to increase in size. Once the vegetation is stabilized, its permanence will be assessed.

The sand collectors are palisades, which can be built using wooden boards (sheet piles) or other materials, such as synthetic mesh (Photo 70). Regarding the dimensions, the collectors must have a minimum height of 1.20 m, and 1/3 of them must be buried. If wooden sheet piling is used, the vertical boards should be spaced about 25 cm apart (Figure 37).

Photo 70. Containment barriers and sand catchment implemented in El Paso Beach, Cayo Guillermo, Cuba.

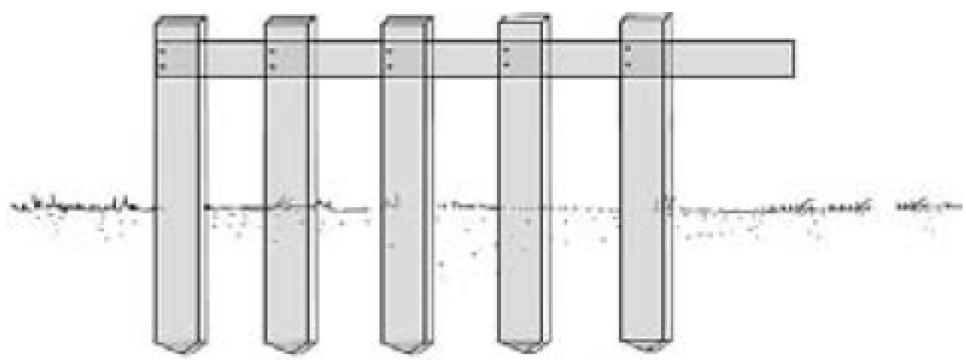

Figure 37. Diagram of the structure of sheet pile collectors.

VII. EXPECTED EFFECTIVENESS OF THE PROJECT

At the end of a sand filling, the material deposited on the beach is subjected to the action of waves, and of wave and wind-induced currents. As a result of the action of these agents, a sand movement is established, following a morphodynamic functioning scheme, which causes the natural rearrangement of sediments, remaining in a position called equilibrium.

The greatest interest when assessing the effectiveness of a project of this type is to know its durability or useful life. Commonly, this assessment is made on the basis of quantifying, in terms of shoreline retreat and/or loss of sand volume, the effects that the dunes and the backshore may suffer in the face of extreme erosive events.

In Bonasse Beach, under mean annual conditions, there are no large variations in the beach profile, due to the low energy of the waves that can reach the beach. However, the extreme conditions caused by storms are responsible for the maximum damage registered, leaving their mark on the backshore, dunes and buildings, such as what happened with Hurricane Ivan in 2004, when according to local residents, part of the beach sand was moved towards the main street, reaching elevated areas of up to more than 3 m high.

Although storms are directly responsible for the moments of greatest erosion on the beach, it should be noted that the frequency of occurrence of this type of event is low, so that, once the proposed solution is applied, it should be expected that the loss rate of the deposited sand maintains low values.

The greatest challenge for the current project is, therefore, to achieve the stability of the artificially deposited sands in the medium and long term, to maintain a beach with proper aesthetic and functional conditions, in the face of the challenges posed by climate change and mean sea level rise. Therefore, according to the shoreline retreat rate of -0.62 m/year described in chapter IV, and assuming that this rate is maintained over time, it can be estimated that at least 30 years must elapse for the beach to lose 60% of its width, provided that there are no hurricanes or other extreme hydrometeorological events that accelerate the sand loss process.

With the sand filling, an emerged beach of 46 m will be instantly achieved. However, the beach will begin to move sand from its emerged part towards the underwater slope, until the shoreline adopts its equilibrium position, achieving a backshore width of about 30 m from the base of the dune.

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It is important to point out that this reduction in beach width should not be understood as loss of sand from the beach; in any case, it should be interpreted as the natural rearrangement of sand along the profile, where some of the sand from the emerged part moves towards the submerged part.

It is recommended that, at the end of the sand filling works, regular monitoring of beach behavior is established, in order to identify critical sectors and plan preventive mitigation actions.

VII. FORM OF EXECUTION OF THE WORKS AND ESTIMATED TIME

VIII.1. Form of execution

The execution of the work must go through five stages, which will guarantee the success of the work:

(1) Preparation of the dredger connection and discharge pipeline

(2) Conditioning of the beach and preparation of works

(3) Sand filling

(4) Shaping the design profile

(5) Stabilization of the reshaped dune

(1) Preparation of the dredger connection and discharge pipeline

For the execution of the project, the use of a trailing suction hopper dredger is conceived for sand mining in the borrow area, its transport to the filling area and its pumping onto the beach (Photo 71).

Photo 71. Example of a trailing suction hopper dredger with ideal characteristics for the execution of the project. (Mario Oliva Pérez Dredger, Empresa Constructora de Obras Marítimas, Cuba)

One of the main actions during the mobilization to start the Artificial Beach Nourishment works is the preparation of the pipeline that will connect with the dredger, through which the sediments will be discharged onto the beach. To do this, a sector must be selected as close as possible to the beach with enough space to assemble the pipeline.

It is recommended to use a floating pipeline, since Bonasse Beach is made up of mud, and when placing the pipeline for discharge, it can get trapped in in the mud, resulting in a problem when changing pipeline position.

Once the pipeline is joined, according to the necessary length from the shore to the coupling points in the 7 m isobath, it is tossed into the sea and moved by sailing to the action area, where one of its ends is fixed in the coupling point of the dredger at sea, while the other end is taken to land and fixed to the bottom by means of anchors and dead weights.

Bearing in mind that sufficient space is needed for the collection of pipelines, the joint work of pipeline sections, in addition to the possibility of accessing the same coastal area, the configuration of the seabed facing the beach that allows the approach of tugboats to the vicinity of the shoreline, it is proposed that this area be Sector 2, between the Coast Guard pier and Fullerton town, an eastern section that meets the above characteristics. It can also be considered virgin, with 1,300 m in length (Figure 38).

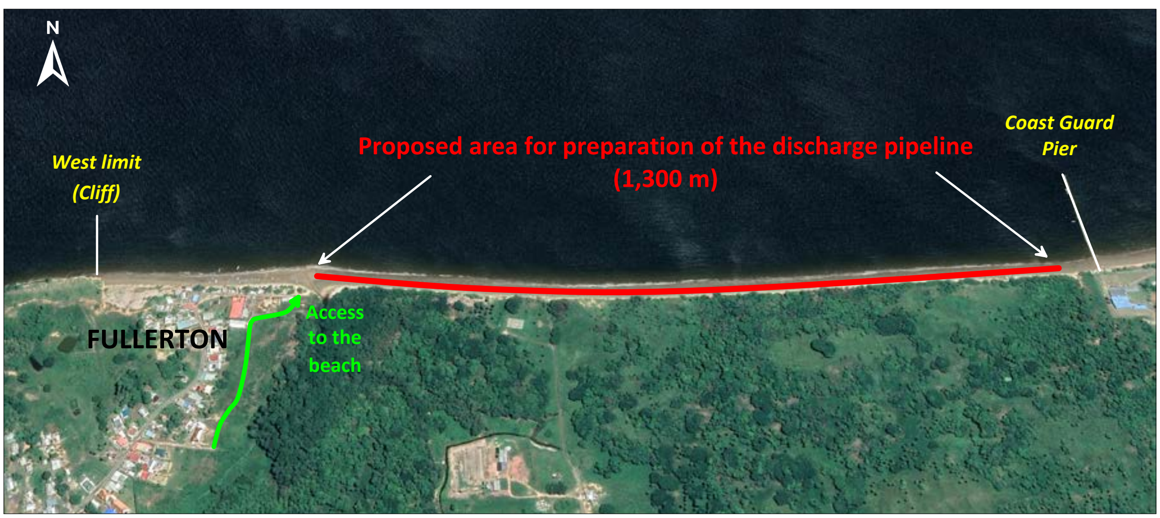

Figure 38. Location diagram of the preparation area for the discharge pipeline.

(2) Conditioning of the beach and preparation of works

At this stage, a series of actions must be undertaken to facilitate the execution of the works that will consist of the removal of all the obstacles in the beach area, which prevent the free movement of heavy equipment and the correct redistribution of the material during sand pumping and subsequent rearrangement.

At present, the beach is only exploited in a small sector for recreational use, but with very low intensity. Its major use is for the beaching/mooring of small vessels (boats) that is also limited to small sectors, so that, at the time of execution of the works, they must be temporarily removed.

Bonasse authorities must ensure communication to boat owners for the removal and protection of their boats and fishing gear that may be on the beach. Likewise, they must inform the inhabitants of the works that will be carried out, and take the pertinent security measures to avoid access to work areas and occurrence of possible accidents.

On the other hand, road and traffic permits will be requested, for the access of equipment to the pipeline assembling area, as well as for internal movements through the main and secondary roads that give access to the beach.

The necessary specifications will also be made for the rest of the support facilities, such as: access to the port, availability of fuel, food, equipment, workforce, among others, which will be defined after the negotiations with the executing agency. However, the water and fuel supply port is expected to be the seaport of Point Fortin, located 24 km north of Bonasse.

(3) Sand filling

The main problem posed by the project is the distance that the trailing suction hopper dredger must travel in order to pump the sand from the different coupling positions onto the beach. As can be observed in Plans 1 and 5, the 7 m isobath is located at a maximum distance of 3,200 m from the shore, so the dredger to be used must be able to overcome this pumping distance.

Due to the characteristics of the beach and its bathymetry, as well as the distance to the borrow area, a suction dredger must be used, capable of navigating in shallow depths between 7 and 8 m, a hopper capacity between 2,000 and 5,000 m ^{3}, power to pump the water/sand mixture up to a maximum distance of 3,500 m, as well as sufficient pipes to reach said distance (Plan 5).

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Filling works will begin at the eastern limit of the beach, advancing west towards Fullerton town. The placement of two docking points is planned, one for each sector of the beach limited by the Coast Guard pier (Plan 5).

The beach will be shaped in its underwater and backshore slope, with an average density of 105 m^3/m, and an average density for dune sectors of 120 m^3/m, according to the design profiles that appear in Plan 4.

Plan 5 and Table 23 show the location of the coupling points of the dredger.

Table 23. Coordinates of the coupling points of the dredger.

Point	Geographic coordinates (WGS-84)		UTM coordinates (WGS-84, Zone 20N)	
	Longitude	Latitude	Easting	Northing
1	-61.87329255	10.11725762	623445.064	1118590.186
2	-61.88352932	10.11245323	622325.181	1118055.039

All the equipment to be used for moving pipes, hauling the deposited sand and shaping the design profiles, must be reached through the access points located at both ends of the beach (Plan 5).

The sand mining will take place while the dredger remains sailing within the limits of the borrow area. Once positioned within these limits, the dredger deploys the suction arm until it makes contact with the seabed and begins dredging while moving at low speeds, between 2 and 4 knots (Figure 39).

Figure 39. Representation of a trailing suction hopper dredger mining sand with the extended arm.

The commanding officers of the dredger, together with the investor's representative and the designer, must select the dredging routes that guarantee controlled exploitation of the deposit.

Dredging will always be carried out within the Borrow Area delimited by the coordinates shown in Table 18, represented in Plan 2. Dredging will be done along straight lines, following the headings 85° - 265°, parallel to the isobaths, in the longitudinal direction of the borrow area.

After the sediment has been extracted from the seabed, it is accumulated in the hopper, and once loaded, the dredger will move to its coupling points with the discharge pipe, following the routes suggested in Plan 5. Table 23 shows the coordinates of the dredge coupling points, and maximum distance to the discharge area (Plan 5).

The dredging and pumping cycle ends when the dredger is connected to the discharge pipe, through which the sand will be propelled by hydraulic processes to the beach to shape the final profile with the support of mechanical equipment, according to the design (Figure 40).

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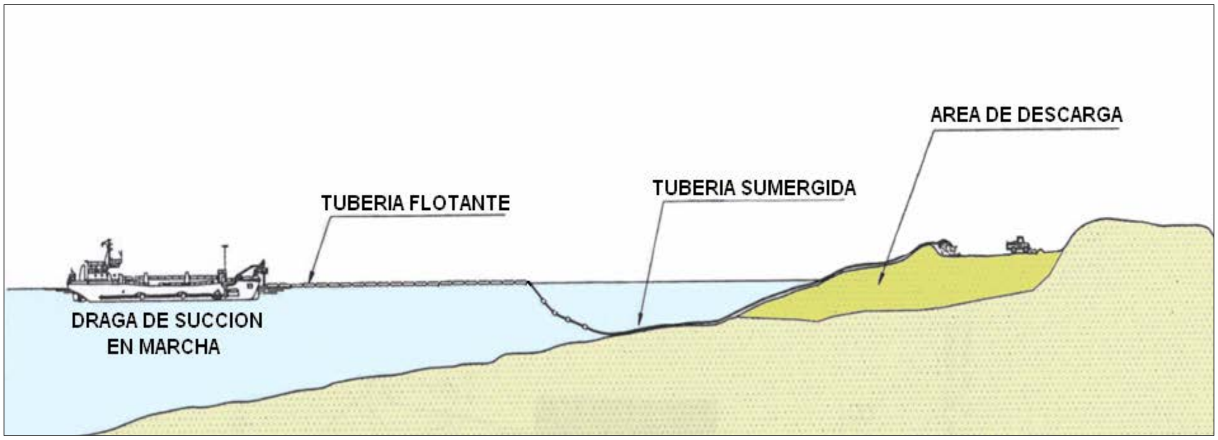

Figure 40. Representation of the trailing suction hopper dredger connected to the discharge pipe through which it pumps a mixture of water and sand onto the beach to be regenerated, where mechanical equipment shape the profile.

To calculate the mined volume, the dredger's hopper has measurement points through which the capacity and volume are obtained, according to the table offered by the manufacturer and certified by competent institutions. Despite the confidence offered by the certification issued, before the start of the work a verification is carried out with an empty hopper, with the participation of the captain and the investor's representative.

Dredging works with this type of equipment can be considered as a series of continuous simple dredging cycles. Each cycle consists of different phases executed successively. The different phases that comprise a dredging cycle are shown in Figure 41.

It should be noted that the diagram in Figure 41 shows the phases for both the discharge using a pipeline and opening the hopper. In the case of this project, the discharge will only be carried out through pipes directly onto the beach.

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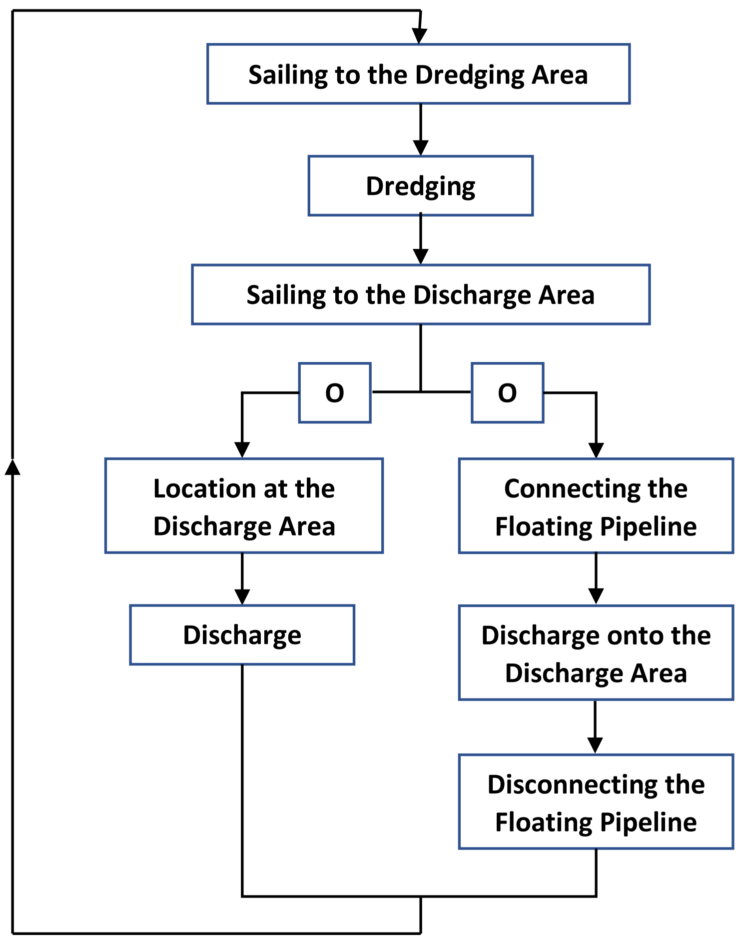

Figure 41. Phases of the dredging cycle.

The length of each advance from one discharge point to the next will be calculated based on the volume measured in the dredger's hopper in each cycle, so that the design discharge density is preserved in the sector in question.

Before each discharge, the mechanical equipment on land will position the pipe at the corresponding point, raising it from 2 m to 3 m above ground level (Photo 72). The construction or not of containment dikes for the sand around the discharge point contributes to the management of densities, and must be assessed in each case by the representatives of the executor and the designer on the ground.

Photo 72. Backhoe placing the end of the pipe at the discharge point.

Once the dredger is connected to the discharge pipe, it is started the pumping of water to clean the line, and later, of the sand and water mixture (Photo 73). During the discharge, the mechanical equipment will remain ready to operate in case their intervention is required to contribute to the seaward drainage of water from the spilled mixture. This is particularly necessary if a larger capacity dredger is used.

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Photo 73. Sand discharge on the beach.

(4) Shaping the design profile

This stage refers to the work that must be carried out once the sand has been deposited on the beach, in order to comply with the design parameters established in the project.

For the conformation of the design profiles with the proposed densities (Plan 4), it will be necessary to carry out an intense work of hauling the sand, with the use of heavy equipment (bulldozers, backhoes and/or front loaders), which starts from the moment the dredger unloads (Photo 74).

Photo 74. Leveling and shaping of the beach profile by mechanical equipment.

The way of executing this work to carry and rearrange the material must be supervised by the designer, within the project oversight actions (also called Author's Control), since the correct execution of this action will guarantee minimizing the losses of the fine fractions of sand due to the washing of the material itself. It should be noted that the dredger pumps a mixture of water/sand with a 70/30 ratio, which is decisive in ensuring that the density and volume that actually remain on the beach are as close as possible to what is projected.

Once each discharge is finished and the density per pipe section is met, new pipe sections are connected or the same one is dragged, thus advancing in the direction of the filling, leaving behind the recently benefited beach, which still does not comply with the morphology of the projected profile.

At this point, the beach is being prepared to receive the new trip of the dredger, while under the supervision of the designer, the newly filled beach is shaped following the parameters established in the design profiles.

Once the new beach is being shaped, free from the obstacles of the filling tasks, the Site Engineer in charge of Author's Control tasks performs the certification of the beach.

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Plan 6 summarizes the existing beach conditions and measures to be implemented for its rehabilitation.

VIII.2. Estimated time

Assuming a loading capacity of the trailing suction hopper dredger of 2,500 m^3 of sand, and that the borrow area is located at an average distance of 40 km (21.6 nautical miles) from the filling area, it is estimated that the dredger is capable of making 4 trips per day, with an average daily volume of about 10,000 m^3.

With this average performance, to complete the 397,650 m^3 required by the project and adding 6 days for changes and placement of pipes, the estimated execution time is 45 days.

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IX. COSTS

The budget that appears in the following table has been prepared on the basis of experience in similar works carried out in Cuba and in the Caribbean region. Therefore, the calculations are estimates, reflecting the items that are commonly taken into account in the costs sheets prepared by the executing companies, which allows to have an order of magnitude of the cost of artificial beach nourishment works. To obtain more precise calculations, it is necessary to carry out a bidding for these works.

Table 24. Estimated Costs for Bonasse Artificial Beach Nourishment Project.

ITEM	UNIT	UNIT PRICE	AMOUNT	WORTH
DIRECT COSTS				
Dredging, filling and shaping design profiles	USD/m^3	$7.50	397,650.00	$2,982,375.00
Mobilization and demobilization of dredger				$1,500,000.00
SUB-TOTAL DIRECT EXPENSES				**$4,482,375.00**
GENERAL EXPENSES				
Utilities			5%	$224,118.75
Administrative expenses			3%	$134,471.25
Insurance and sureties			two%	$89,647.50
Liquidation to workers			1.5%	$67,235.63
Pension and retirement			1.5%	$67,235.63
Supervision and Author's Control			5%	$224,118.75
Contingencies			1%	$44,823.75
SUB-TOTAL GENERAL EXPENSES				**$851,651.25**
GRAND TOTAL				**$5,334,026.25**

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The reduction in execution costs for the artificial beach nourishment solution will depend to some extent on the location of the dredge in relation to the work area, which will determine the mobilization and demobilization costs, as well as the cost per m^3 of sand. In the table above, despite performing the calculation with a price of 7.50 USD/m^3, according to the overall value of the service, in terms of cost per m^3 of sand, the project would have a cost equivalent to 13.41 USD/m^3 of sand, which corresponds to the experience in the region.

As part of the preparations to face the execution of this type of project, a bidding process is carried out in which international dredging companies participate, offering a turnkey execution proposal that includes dredging, maritime transport, discharge, hauling and beach profiling, as well as the hiring of labor, fuel, lubricants, water and food, etc. in the country.

The bidding process will involve variables such as the world price of fuel, the geographic location of the dredge that determines the price of mobilization and demobilization, the volume of sand to be dumped, the demand of other projects in the area, etc., elements that contribute to form the unit price per m^3 of sand and determine the overall price of the project.

Inversiones Gamma SA is in a position to provide technical assistance in the purchase and bidding process, and to provide consulting services for the supervision and author's control of the works.

In order to have a reference on the execution costs, in the following table we list some projects executed by international dredging companies, both in Cuba and in the Caribbean region.

Beach	Volume (m^3)	Country	Year	Mobilization (% of total)	Overall price /m^3
Varadero	1,087,000	Cuba	1998		$ 4.59
4 Beaches	1,300,000	Dominican Rep.	2006		$ 13.84
Cancún	2,700,000	Mexico	2006		$ 6.40
Cancún-Cozumel-Del Carmen	7,000,000	México	2009		$ 9.43
Varadero-Holguín	834,500	Cuba	2012	33.65%	€ 9.79
El Paso-Flamenco	630,000	Cuba	2016	29.20%	€ 11.42
Dunas	150,000	Cuba	2017		€ 9.51
Larga	267,500	Cuba	2018		€ 9.38

$ - USD € - EUR

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X. PROPOSED MONITORING PROGRAM

The objective of the Monitoring Program is to develop measurements and field studies that ensure the updating of the magnitude, extension and trend of the erosion process in Bonasse coastal front. However, it should be noted that there is already a National Monitoring Program in place, led and executed by IMA specialists, and that Bonasse Beach has just been incorporated, but with a single beach profile. It is necessary to add more profiles, which should coincide with those established in this project, thus allowing to also monitor the evolution of the deposited sand volumes once this project is executed.

In the particular case of Bonasse Beach, the monitoring tasks constitute an extension in time of those developed in this project, taking advantage of the established baseline.

With the results of the monitoring, the necessary information will be obtained to evaluate the effectiveness of the applied recovery and protection measures, allowing the introduction of corrective measures or new decisions making in the medium and long-term management plans.

Tasks of the Monitoring Program.

Task 1. Establishment of the methodology and procedure for the development of field and office work .

Objective: Establish the material basis and qualified personnel in Trinidad and Tobago to ensure the execution of the Program tasks.

Description:

The work protocol for the monitoring network development is drawn up, taking as a reference the one used in the project “Impact Assessment of climate change on the sandy shorelines of the Caribbean: Alternatives for its control and resilience”, currently being implemented by the Association of Caribbean States (ACS). It includes training and qualification actions for the personnel.

Results: Work protocol drawn up and personnel trained for the development of the monitoring network.

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Task 2. Topographic leveling of the beach profile.

Objective: Spatial-temporal assessment of changes in the shoreline and beach profile morphology.

Description:

The topographical leveling of the beach profile will be repeated at the points of the established baseline, with measurements at least twice a year and after the occurrence of extreme erosive events. Monitoring techniques using high-resolution satellite images will also be introduced.

Results: Annual reports with topographic records of changes in the shoreline and beach profiles, with calculations of the erosion rate, expressed in m/year, and the volume of material removed from the coast.

Task 3. Sedimentological sampling.

Objective: Spatial-temporal assessment of variations in sediment composition.

Description:

The sedimentological sampling will be repeated to detect the variations in grain size and mineralogical composition of the material, at the same stations established in the baseline, at least twice a year and after the occurrence of extreme erosive events.

Results: Annual reports with records of the space-time changes in grain size and mineralogical composition of sediments.

Task 4. Meteorological study.

Objective: Evaluate the spatial-temporal variations of the characteristics of wind and atmospheric pressure, for a better understanding and interpretation of hydrodynamic and morphodynamic processes.

Description:

Maintain detailed control of hourly variations in wind direction and speed, through records from the Chatam Automatic Weather Station, as well as the barometric pressure record.

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Results: Annual report with hourly records of wind speed and direction, as well as barometric pressure, which are useful for applying mathematical modeling in the interpretation of hydrodynamic and morphodynamic processes.

In the framework of a project for the monitoring of the evolution of Bonasse shoreline, it is essential to establish a high-precision tide gauge, which should be incorporated into the Caribbean Program to study sea level rise in response to climate change. The information provided by this tide gauge would also be especially useful for regional seismic studies.

In this Monitoring Program, the tasks that have been identified directly guarantee the information required to evaluate the effectiveness of measures to be executed, as well as to have adequate information available in case other protection measures are required.

However, it must be taken into account that, as mentioned above, a broader program requires qualified personnel, laboratory equipment, computer equipment, vessels, adequate infrastructure and logistical support, which entails a significant budget.

For now, something rational has been proposed that uses the already installed meteorological base of Trinidad and Tobago Meteorological Service, and takes advantage of the network of beach profile monitoring stations established by this project.

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XI. ASSESSMENT OF POSSIBLE ENVIRONMENTAL IMPACTS

The preliminary assessment of possible environmental impacts that the proposed solution, Artificial Beach Nourishment, would generate in the medium term took into consideration the positive and negative environmental, socio-cultural and economic impacts expected for the phases of preparation, execution, operation and eventual abandonment of the work.

In addition to the possible positive and negative impacts, mitigating factors are considered, and the adoption of some measures is recommended to minimize the expected negative impacts.

Tables 25 and 26 summarize the evaluations carried out.

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Table 25. Possible environmental impacts, mitigating factors and mitigation measures.

Phase	Positive Impacts	Negative Impacts	Mitigating Factors	Mitigation measures
Preparation and Execution	Recovery of the beach natural conditions.	Suspension of fine sediments during dredging.	The negative impacts will be limited to the dredging area, being punctual in space and time.	Negative impacts can be minimized by requiring compliance with the technical standards established for the equipment to be used.
	Recovery or enhancement of coastal dunes.	Gas emission as a result of fuel combustion.	The borrow area, and its surroundings, have a low presence of marine organisms.	
	Removal of destroyed rigid structures that affect the beach environmental quality.	Risk of micro-spills of petroleum, oil, etc., due to the use of machinery.	Recovery in the short and medium term of the affected populations in the borrow area is to be expected.	Include recovery and monitoring of the borrow area, as part of the beach management strategy.
	Dune revegetation.	Noise pollution.		
	Eradication of micro-dumps.			
Functioning	Adequate dynamic functioning of the beach. Increase in the resilience capacity of the beach against the impact of tidal waves.	-	-	Implement an Integrated Management Program for Bonasse Beach, with emphasis on monitoring and execution, and readjustment of strategies in the medium and long term.
Abandonment	-	Gradual progress of the erosion process. Possible return to conditions similar to those existing before the execution of the project.	The foreseeable negative impacts are limited only to the deterioration of what has been achieved with the execution of the project, as a result of the absence of management in the medium and long term.	The Management Program must be transcendent in time, and could serve as a model for its extension to all the coasts and beaches in the country.

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Table 26. Possible socio-economic impacts, mitigating factors and mitigation measures.

Phase	Positive Impacts	Negative Impacts	Mitigating Factors	Mitigation measures
Preparation and Execution	Job creation.	Minimal risk to the health of workers on site, due to noise or gas emissions. Risks for the safety of workers due to the use of heavy machinery.	-	Requirement of compliance with adequate protection measures and standards.
Operation	Benefits of the beach as a coastal defense work, protecting buildings and properties. Benefits of the beach as a natural resource for recreation and tourism. Increase in the value of properties in the beach area. Creation of a favorable environment for the development of small businesses of tourist services, gastronomy, etc.	**Observation:** The improvement of beach conditions could lead to its intensive use and affect dunes and vegetation, as well as generating possible sources of contamination by solid waste.	-	Implement an Integrated Management Program for Bonasse Beach, with an emphasis also on the protection of dunes and their vegetation, creation of access pathways, dissemination, waste management, and distribution of services. Evaluate tax collection options for beach exploitation, to ensure the sustainability of the management program.
Abandonment	-	Gradual progress of the erosion process. Possible loss of values added to the beach. Increased vulnerability of the coastal zone and properties located in it.	The foreseeable negative impacts are limited only to the deterioration of what has been achieved with the execution of this project, as a result of the absence of management in the medium and long term.	The Management Program must be transcendent in time, and could serve as a model for its extension to all the coasts and beaches in the country.

The identification of the project's expected positive and negative environmental impacts makes it possible to recommend its execution. However, it was considered useful to deepen the analysis, and advance in a Preliminary Environmental Impact Assessment.

For the assessment and prioritization of the environmental impacts associated with the process of mining, transport and discharge of the material resulting from dredging in the beach area, it was used the RIAM method (Rapid Impact Assessment Matrix; DHI, Water & Environment, (2000)), which provides for three sequential technical stages.

The RIAM method consists of the following steps:

- Identification of impacts.
- Classification by Physical-Chemical, Biological-Ecological, Socio-Cultural, or Economic-Operational components.
- Valuation based on criteria of Scope, Magnitude, Permanence, Reversibility and Accumulation.
- Weighting of the Impact and Classification by ranges.
- Construction of the RIAM Matrix and Impact Assessment.

The criteria assessment is carried out according to the scale shown in Table 27.

Table 27. RIAM method assessment criteria.

RIAM ASSESSMENT CRITERIA				
CLUSTER	**CRITERION**	**WEIGHT**		**QUALITATIVE SCALE**
A	Importance of the condition (A1)	4	=	Of National Importance / International Interest
		3	=	Of Regional Importance / National Interest
		2	=	Important for immediate outer area
		1	=	Important only for local condition
		0	=	Without importance
	Magnitude of change or effect (A2)	3	=	Highest positive benefit
		2	=	Significant improvement
		1	=	Improvement
		0	=	Without changes
		-1	=	Negative change
		-2	=	Significant Deterioration or Negative Change
		-3	=	Major Deterioration or Negative Change
B.		1	=	No Changes / Does not apply

RIAM ASSESSMENT CRITERIA				
CLUSTER	**CRITERION**	**WEIGHT**		**QUALITATIVE SCALE**
	Permanence (B1)	2	=	Temporary
		3	=	Permanent
	Reversibility (B2)	1	=	No Changes / Does not apply
		2	=	Reversible
		3	=	Irreversible
	Accumulation / Synergy (B3)	1	=	No Changes / Does not apply
		2	=	Non-cumulative / Simple
		3	=	Cumulative / Synergistic

The weighting of each variable is done by calculating the Score (ES), as:

$$ES = (A_1 x A_2) x (B_1 + B_2 + B_3) \tag{16}$$

While the rating by ranges is made based on the scale shown in Table 28.

Table 28: Ranges to rank the assessed impacts.

Ranges to rank the assessed impacts				
Score (ES)			**Class**	**Interpretation**
72	to	108	+E	Change / Major Positive Impacts
36	to	71	+D	Change / Significant Positive Impacts
19	to	35	+C	Change / Moderate Positive Impacts
10	to	18	+B	Change / Positive Impact
1	to	9	+A	Change / Slightly Positive Impact
	0		N	No change or importance
-1	to	-9	-A	Change / Slightly negative impact
-10	to	-18	-B	Change / Negative impact
-19	to	-35	-C	Change / Moderate negative impact
-36	to	-71	-D	Change / Significant negative impact
-72	to	-108	-E	Change / Major Negative Impacts

Additionally, it is possible to analyze the environmental impacts by stages, beginning with those derived from the incidence of natural factors and processes in the current situation, whose effect would extend indefinitely in the event of choosing the No Action option, allowing the continuity of the erosive process in the beach; and concluding with the impacts derived from the abandonment or non-implementation of a management program that gives continuity to the actions necessary to control the effects of erosion in the medium and long term.

This way, the analysis of environmental impacts was carried out for the current situation and the stages of execution, operation and eventual abandonment of the project:

- Current Situation (No Action decision).
- Execution (of actions defined for the short term).
- Operation (exploitation of the beach).
- Eventual Abandonment (abandonment or non-implementation of an integrated beach management program, in the medium and long term).

From the analysis summarized in Tables 25 and 26, the list of impacts was adjusted to RIAM method criteria, for the different stages and components (Table 29).

Tables 30 to 33 list and weight the evaluated impacts, highlighting the stage to which they correspond.

From this analysis, the matrices corresponding to each of the four stages analyzed were obtained (Tables 34 to 37), as well as their graphic outputs (Figures 42 to 45).

During the application of RIAM methodology, a total of 37 environmental impacts could be identified. From them:

- By components: Physical-Chemical 12; Biological-Ecological 6; Socio-Cultural 10; and Economic-Operational 9.
- Negative impacts: 20. However, 11 of them are typical of the current condition, being present as long as no action is taken, or after the execution of the proposed actions in the short term, 9 of them being able to occur again in the future, due to the non-implementation of a management program or its eventual abandonment.
- Positive impacts: 16. The concentration of positive impacts in the Operation stage (Use or exploitation of the beach) is remarkable. These impacts are achieved through the Execution of the proposed actions in the short and medium term and last in the long term, requiring a Management Program to guarantee their preservation.

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Table 29: List of environmental impacts identified for the different stages and components. The impacts derived from not acting, as well as from non-implementing or abandoning the management program in the long term are highlighted.

No.	Nature of the Impact	Stage	Action	Activity	Environmental impact	Character	Assessment	Permanence, Reversibility and Accumulation	Observation
1	PHYSICAL - CHEMICAL	CURRENT - ABANDONMENT	No Action – Non-Implementation of Management	Erosive Process	Gradual shoreline retreat	Negative	Moderate	Permanent, Reversible and Cumulative	With No Action, Permanent and Cumulative. With Action, Reversible.
2					Loss of beach resilience capacity	Negative	Moderate		
3		EXECUTION	Artificial Beach Nourishment (ABN)	Dredging	Alteration of the seabed in the borrow area	Neutral	Neutral	Temporary and Reversible	No practical effects. Naturally reversible.
4					Increased water turbidity in the borrow area	Negative	Low	Temporary, Reversible and Non-cumulative	Highly turbid waters with healthy (adapted) algae.
5				All Tasks	Risk of hydrocarbon micro-spills	Negative	Very Low		Avoidable with good technological practices.
6				Discharge	Increased turbidity in beach water	Negative	Very Low		Very little transcendent in time. Zone without benthic life.
7				All Tasks	Pollution by emission of combustion gases	Negative	Very Low	Temporary and Non-cumulative	Very limited effect.
8				Dredging	Noise pollution	Negative	Very Low		
9		EXECUTION - OPERATION	ABN and Complementary Actions (CA)	Discharge - Profiling - Other Tasks	Recovery of natural beach conditions	Positive	Moderate	Temporary and Reversible	Reversible without appropriate Management Program.
10					Increased beach resilience capacity	Positive	High	Temporary, Reversible and Non-cumulative	
11		EXECUTION - OPERATION - ABANDONMENT	CA	Demolition	Removal of sewage drainage channels	Positive	High	Permanent and Irreversible	Irreversible specifically in terms of structures.
12					Eradication of anthropogenic erosive agents (structures)	Positive	High	Permanent and Irreversible	Irreversible specifically in terms of structures.
13	BIOLOGICAL - ECOLOGICAL	CURRENT - ABANDONMENT	No Action – Non-Implementation of Management	Colonization of Invasive Plants	Damage to the ecosystem due to the colonization of invasive plants	Negative	Low	Permanent, Reversible and Cumulative	With No Action, Permanent and Cumulative. With Action, Reversible.
14				Erosive Process	Impacts on the vegetation due to erosion	Negative	Low		
15		EXECUTION	ABN	Dredging - Discharge	Damage to biodiversity in the borrow area	Negative	Very Low	Temporary, Reversible and Non-cumulative	Limited damage to borrow area. Resilient ecosystem.

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No.	Nature of the Impact	Stage	Action	Activity	Environmental impact	Character	Assessment	Permanence, Reversibility and Accumulation	Observation
16		EXECUTION - OPERATION	CA	Invasive Plant Control	Removal of invasive plants on the dune	Positive	Moderate	Temporary and Reversible	With No Action, Permanent and Cumulative. With Action, Reversible.
17			CA	Dune Reforestation	Rehabilitation of coastal vegetation	Positive	Moderate		
18			ABN and CA	Discharge - Profiling - Other tasks	Beach rehabilitated as a protective barrier for the ecosystem	Positive	High		
19	SOCIOLOGICAL - CULTURAL	CURRENT - ABANDONMENT	No Action – Non-Implementation of Management	Erosive Process	Loss of beach tourist and recreational use value	Negative	Very High	Permanent, Reversible and Cumulative	With No Action, Permanent and Cumulative. With Action, Reversible.
20					Damage to buildings in the coastal zone	Negative	Low		
21					Loss of beach natural aesthetic values	Negative	Moderate		
22		EXECUTION	ABN and Complementary Actions	All tasks	Employment generation during execution	Positive	Very Low	Temporary	During execution
23					Risk to the health of workers due to contaminants	Negative	Very Low		
24					Safety risk of workers due to the use of machinery	Negative	Very Low		
25		EXECUTION - OPERATION		Discharge - Profiling - Other tasks	Recovery of tourist and recreational use value of the beach	Positive	High	Temporary, Reversible and Non-cumulative	Reversible without apprpopriate Management Program.
26					Beach as coastal defense for the protection of buildings	Positive	High		
27					Beach aesthetic-environmental improvement	Positive	High		
28		OPERATION	Use and Management	Management Program	Generation of employment during Management	Positive	Very Low	Temporary	Management Program
29	ECONOMIC - OPERATIONAL	CURRENT - ABANDONMENT	No Action – Non-Implementation of Management	Erosive Process	Impact on the beach tourist potential	Negative	Very High	Permanent, Reversible and Cumulative	With No Action, Permanent and Cumulative. With Action, Reversible.
30					Loss of property values in the beach area	Negative	Low		
31					Unfavorable environment for services related to tourism and fishing	Negative	Low		
32					Increased cost of infrastructure maintenance	Negative	Moderate		

No.	Nature of the Impact	Stage	Action	Activity	Environmental impact	Character	Assessment	Permanence, Reversibility and Accumulation	Observation
33		EXECUTION	ABN and Complementary Actions	Investment	High cost of investment	Negative	High	Permanent and Reversible	High initial investment. Sustainable income management.
34		EXECUTION - OPERATION		Discharge - Profiling - Other tasks	Increase in beach tourist potential	Positive	High	Temporary, Reversible and Non-cumulative	Reversible without appropriate Management Program.
35					Revaluation of properties in the beach area	Positive	Moderate		
36					Creation of a favorable environment for tourism-related services	Positive	Moderate		
37					Reduction of infrastructure maintenance costs	Positive	Moderate		

An analysis by Stages is carried out below.

Current Situation (No Action Option)

The No Action Option entails the continuity and advance of erosion on the beach, so that only the manifestation and exacerbation of mostly moderate negative impacts (Class C) can be expected, in correspondence with the intensity of the erosive process.

Class E classifies the loss of tourist and recreational use value in its social component, and the impact on the beach tourist potential and its use for fishing, economically, both activities have an impact at the national level, given that this is one of the beaches most used by the population, especially in the southern region of Trinidad Island.

This analysis clearly expresses the need to act and implement the proposed strategy and actions defined in the short, medium and long term.

Table 30: Matrix of Impacts by Class. Current Situation (No Action Option).

Current situation / No Action											
Class	**-E**	**-D**	**-C**	**-B**	**-A**	**N**	**A**	**B**	**C**	**D**	**E**
PC	0	0	2	0	0	0	0	0	0	0	0
BE	0	0	0	2	1	0	0	0	0	0	0
SC	1	0	1	1	0	0	0	0	0	0	0
EO	1	0	1	2	0	0	0	0	0	0	0
Total	**2**	**0**	**4**	**5**	**1**	**0**	**0**	**0**	**0**	**0**	**0**

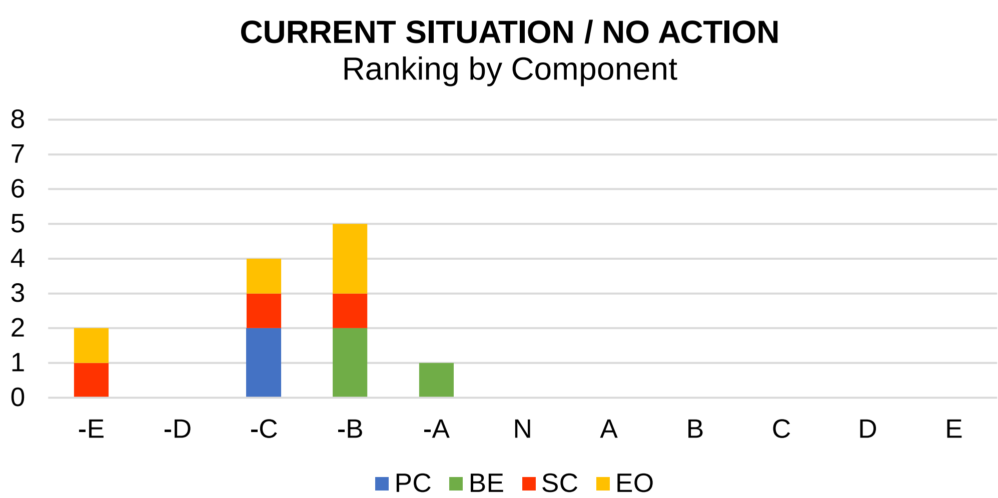

Figure 42: Graphic output of RIAM Matrix. Impacts by Class. Current Situation (No Action Option).

Execution Stage

This is the Stage with the most widespread foreseeable impacts. However, the benefits derived from an improvement in the morphological, aesthetic and functional conditions of the beach provide 13 positive impacts of class C (Moderate) and D (High), an expression of the desired reversal of the current state of the beach.

In contrast to the foreseeable negative impacts of this type of action, they are generally classified as Low or Very Low (Classes A and B), several are due to small impacts avoidable with good technological practices, except for the high cost of the initial investment; although the execution of coastal protection works of other types may have a higher cost.

Table 31: Matrix of Impacts by Class. Execution Stage.

Execution stage											
Class	**-E**	**-D**	**-C**	**-B**	**-A**	**N**	**A**	**B**	**C**	**D**	**E**
PC	0	0	0	1	4	1	0	0	1	3	0
BE	0	0	0	0	0	0	0	1	1	1	0
SC	0	0	0	0	2	0	1	0	0	3	0
EO	0	1	0	0	0	0	0	0	3	1	0
Total	**0**	**1**	**0**	**1**	**6**	**1**	**1**	**1**	**5**	**8**	**0**

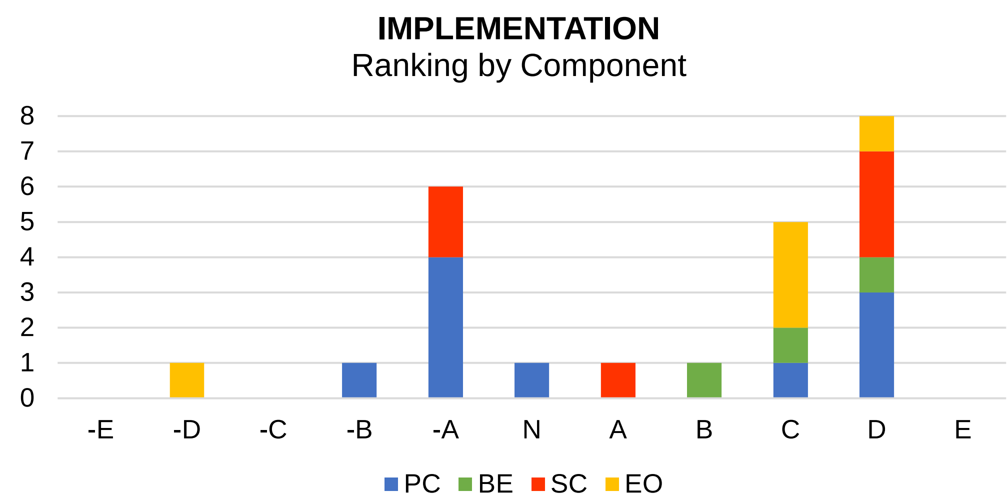

Figure 43: Graphic output of RIAM Matrix. Impacts by Class. Execution Stage.

Operation Stage (Use or Exploitation)

The objectives that will be achieved from the execution of artificial beach nourishment and other proposed complementary actions will allow that, once completed, the foreseeable impacts that will last on the beach will be positive in their entirety.

However, it should be noted that most are considered reversible, their sustainability depending on the implementation of a beach management program in the medium and long term.

Table 32: Matrix of Impacts by Class. Operation Situation (Use of the beach).

Operation stage (Use)											
Class	**-E**	**-D**	**-C**	**-B**	**-A**	**N**	**A**	**B**	**C**	**D**	**E**
PC	0	0	0	0	0	0	0	0	1	3	0
BE	0	0	0	0	0	0	0	0	0	1	0
SC	0	0	0	0	0	0	1	0	0	3	0
EO	0	0	0	0	0	0	0	0	3	1	0
Total	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**4**	**8**	**0**

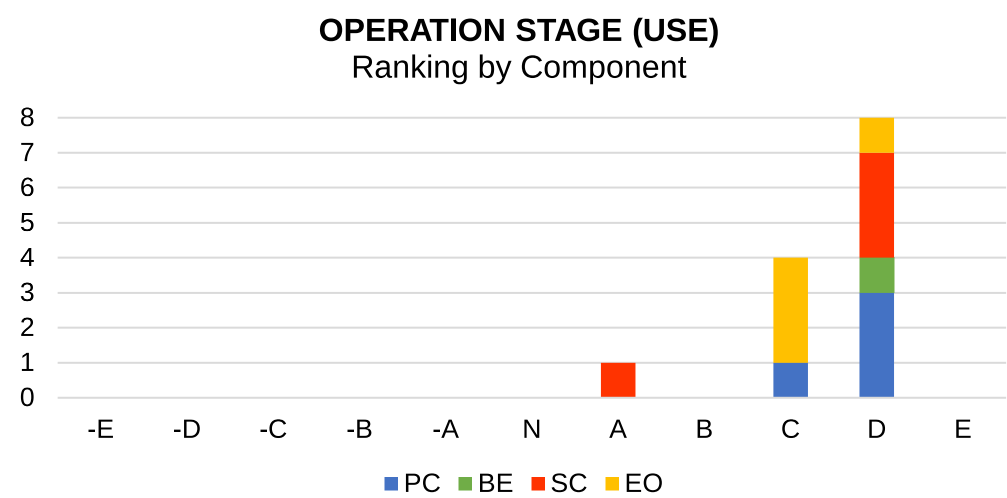

Figure 44: Graphic output of RIAM Matrix. Impacts by Class. Operation Stage (Use of the beach).

Eventual Abandonment (Non-implementation or Abandonment of Management Program)

Once the recommended actions have been carried out, if the beach management strategy is not continued in the medium and long term, the situation of the beach could be reversed once again, returning to a condition very similar to the current one, which can then continue deteriorating.

The benefit of the demolitions of buildings located in the coastal zone, which have been carried out, would hardly remain, in the case of buildings that have become erosive agents for the beach. This last impact, for the purposes of the project, has been considered permanent.

Table 33: Matrix of Impacts by Class. Abandonment (Non-implementation or abandonment of the Beach Management Plan in the medium and long term)

Abandonment (without monitoring plan)											
Class	**-E**	**-D**	**-C**	**-B**	**-A**	**N**	**A**	**B**	**C**	**D**	**E**
PC	0	0	2	0	0	0	0	0	0	0	0
BE	0	0	0	1	1	0	0	0	0	0	0
SC	1	0	1	1	0	0	0	0	0	0	0
EO	1	0	1	2	0	0	0	0	0	0	0
Total	**2**	**0**	**4**	**4**	**1**	**0**	**0**	**0**	**0**	**0**	**0**

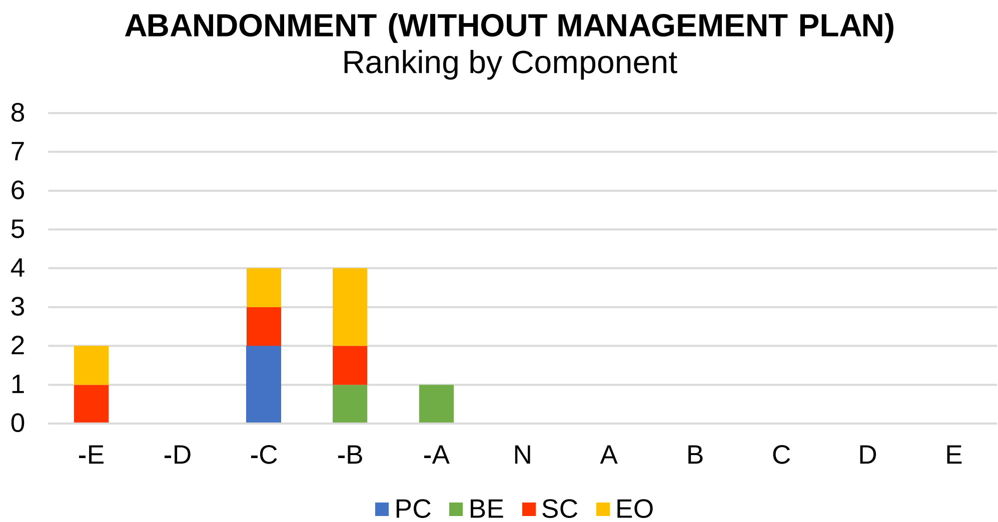

Figure 45: Graphic output of RIAM Matrix. Impacts by Class. Eventual Abandonment (Non-implementation or abandonment of the Beach Management Plan in the medium and long term).

Conclusions from the application of the RIAM Method

From the preliminary environmental impact assessment of the actions proposed for the rehabilitation of Bonasse Beach, it can be concluded that:

- The benefits of the project, in all the components, justify advancing in its execution and the implementation of a beach management strategy in the short, medium and long term.
- If no action is taken, it will imply greater damage to the beach due to the continuity of the erosive process and its effects.

- After the execution of the actions foreseen in the short and medium term, the non-implementation of a Management Program, once the foreseen period of effectiveness has elapsed, will return the beach to a condition similar to the current one and its deterioration will continue, progressively increasing the damage in all the components, and consequently, the costs of an eventual new intervention for beach rehabilitation.

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Other consulted documents provided by IMA:

- Trinidad and Tobago Response to request for technical and logistics info: Beach rehabilitation at Bonasse Bay, Cedros, Trinidad submitted by the Institute of Marine Affairs (IMA), Trinidad and Tobago. September 29, 2020.
- Report - Constanza Ricaurte
    - Annex 2. Executive Beach Rehabilitation Project Bonasse
    - Annex 3. Letter commitment Executive Beach Rehabilitation Project, Bonasse, Cedros Bay, Trinidad
    - Annex 4a. Cedros Bay - ACS -Beach profiles
    - Annex 4b. Cedros Bay - beach width and beach volumes - ACS – consultant
    - Annex 4c. Coastline change detection - Cedros bay
    - Annex 4d. Columbus Bay Tech Report March 2014
    - Annex 4e. Photographic memory of the field visit to Trinidad and Tobago

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ANNEXES AND PLANS

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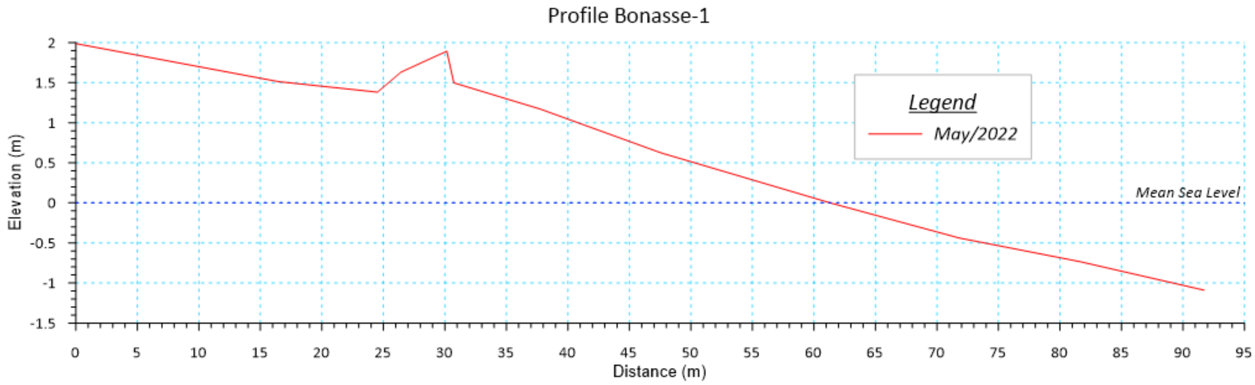
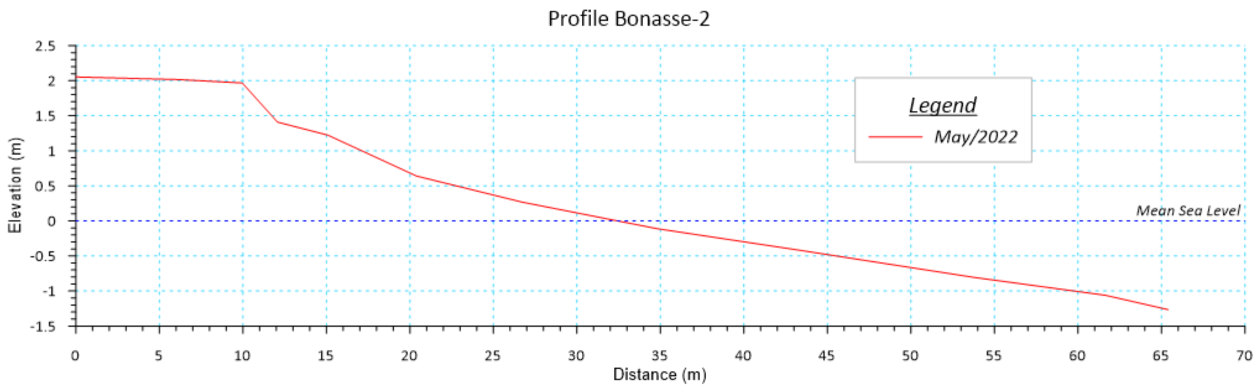
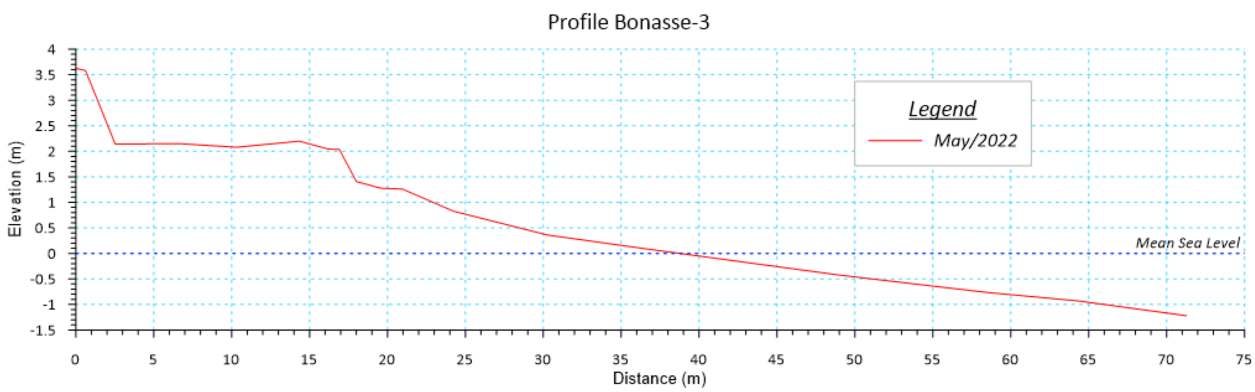
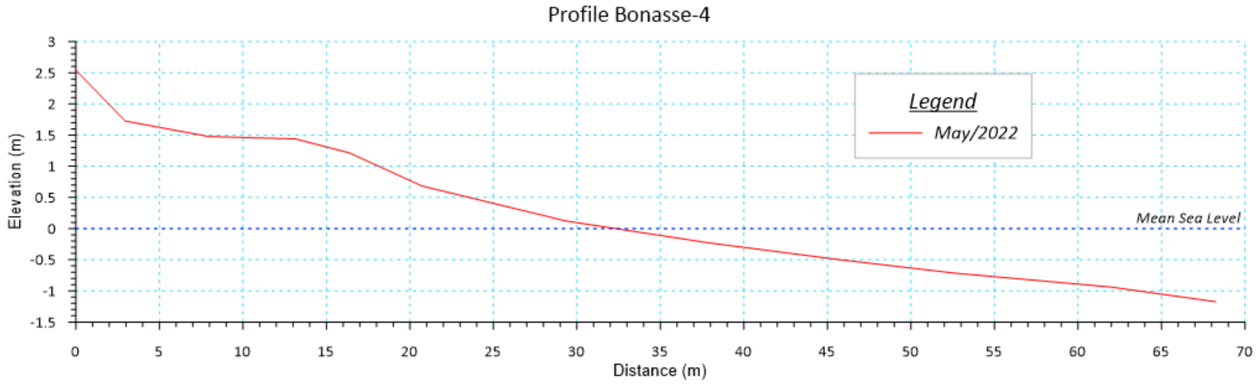
ANNEX 1

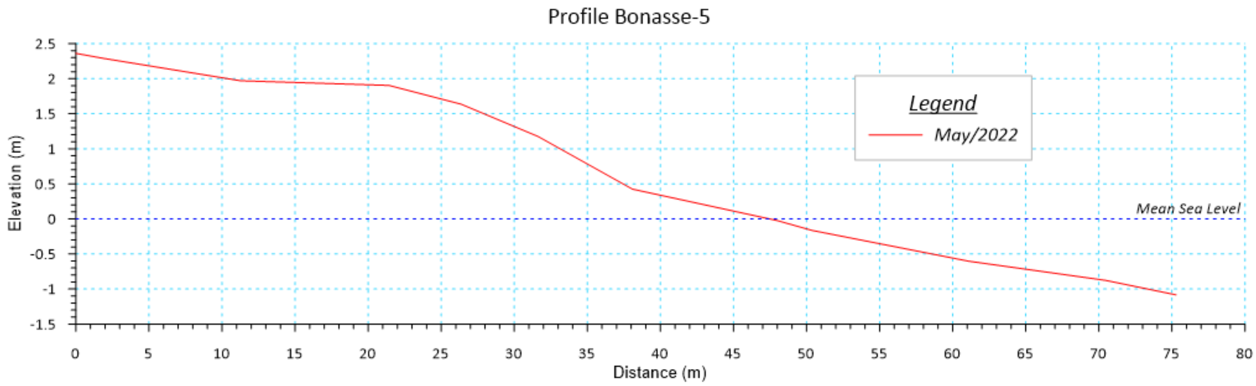
Beach profiles

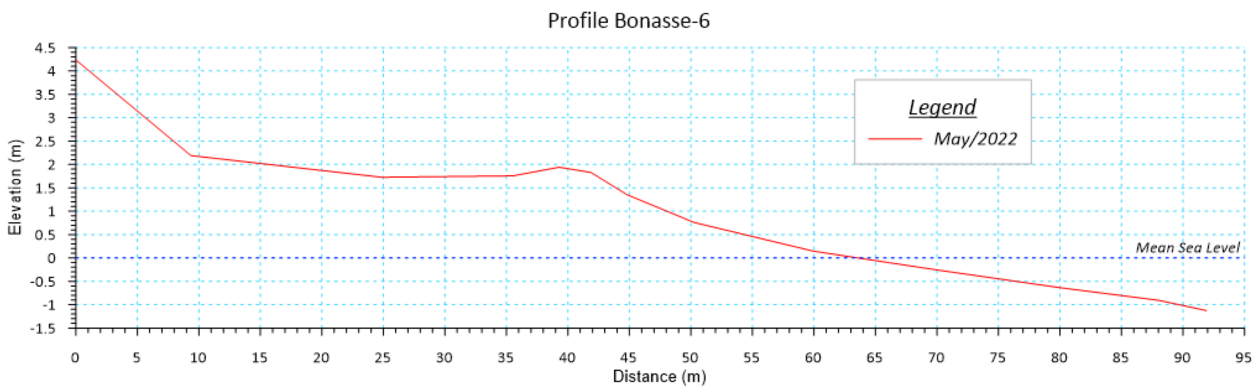

Profile Bonasse-1
Elevation (m)
Distance (m)
Legend
May/2022
Mean Sea Level

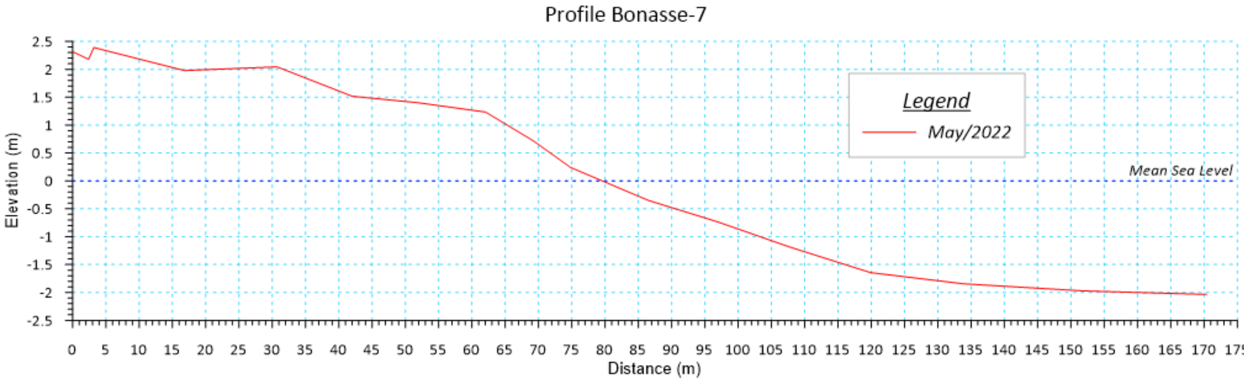

Profile Bonasse-2
Elevation (m)
Distance (m)
Legend
May/2022
Mean Sea Level


Profile Bonasse-3
Elevation (m)
Distance (m)
Legend
May/2022
Mean Sea Level


Profile Bonasse-4
Legend
May/2022
Mean Sea Level
Elevation (m)
Distance (m)


Profile Bonasse-5
Legend
May/2022
Mean Sea Level
Elevation (m)
Distance (m)


Profile Bonasse-6
Legend
May/2022
Mean Sea Level
Elevation (m)
Distance (m)


Profile Bonasse-7
Legend
May/2022
Mean Sea Level
Elevation (m)
Distance (m)
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115 120 125 130 135 140 145 150 155 160 165 170 175

ANNEX 2

Results of grain size analysis

SIEVING ERROR: -0.1%

SAMPLE STATISTICS

SAMPLE IDENTITY: **Perfil-1**

ANALYST & DATE: Miguel, Jun 8th 2022

SAMPLE TYPE: Unimodal, Well Sorted

TEXTURAL GROUP: Sand

SEDIMENT NAME: Well Sorted Fine Sand

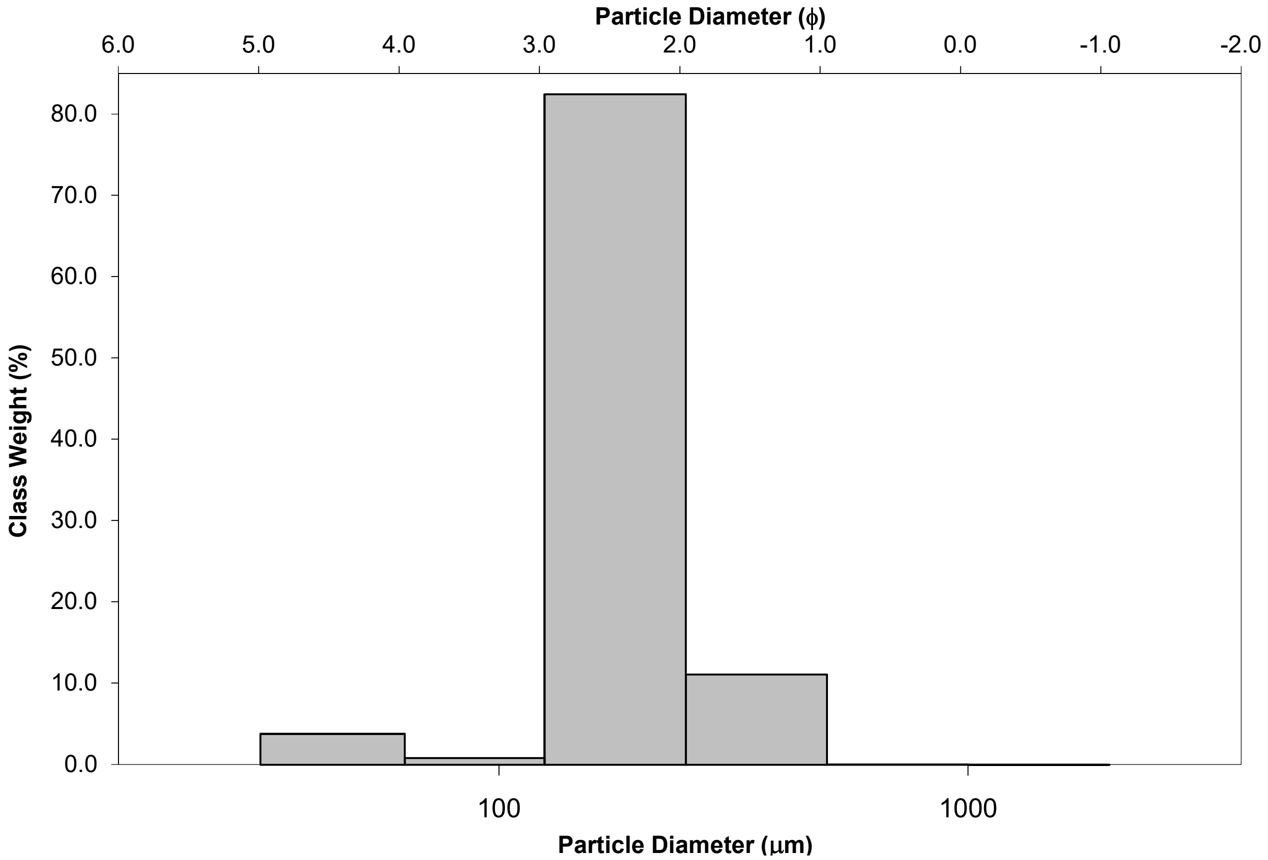
	μm	φ
MODE 1:	187.5	2.500
MODE 2:		
MODE 3:		
D_{10}:	130.5	1.880
MEDIAN or D_{50}:	181.6	2.461
D_{90}:	271.7	2.938
(D_{90} / D_{10}):	2.082	1.563
$(D_{90} - D_{10})$:	141.2	1.058
(D_{75} / D_{25}):	1.512	1.276
$(D_{75} - D_{25})$:	75.61	0.596

GRAIN SIZE DISTRIBUTION

GRAVEL:	0.0%	COARSE SAND:	0.0%
SAND:	96.1%	MEDIUM SAND:	11.3%
MUD:	3.9%	FINE SAND:	83.9%
		V FINE SAND:	0.9%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	3.9%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	0.0%	FINE SILT:	0.0%
V FINE GRAVEL:	0.0%	V FINE SILT:	0.0%
V COARSE SAND:	0.0%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic φ	Geometric μm	Logarithmic φ	Description
MEAN ($\bar{x}$):	202.9	180.1	2.473	181.6	2.461	Fine Sand
SORTING (σ):	71.52	1.445	0.531	1.356	0.439	Well Sorted
SKEWNESS (Sk):	2.716	-1.502	1.502	0.156	-0.156	Coarse Skewed
KURTOSIS (K):	31.88	10.07	10.07	1.072	1.072	Mesokurtic

GRAIN SIZE DISTRIBUTION



SAMPLE STATISTICS

SIEVING ERROR: 0.1%

SAMPLE IDENTITY: **Perfil-2**

ANALYST & DATE: Miguel, Jun 8th 2022

SAMPLE TYPE: Unimodal, Well Sorted

TEXTURAL GROUP: Sand

SEDIMENT NAME: Well Sorted Fine Sand

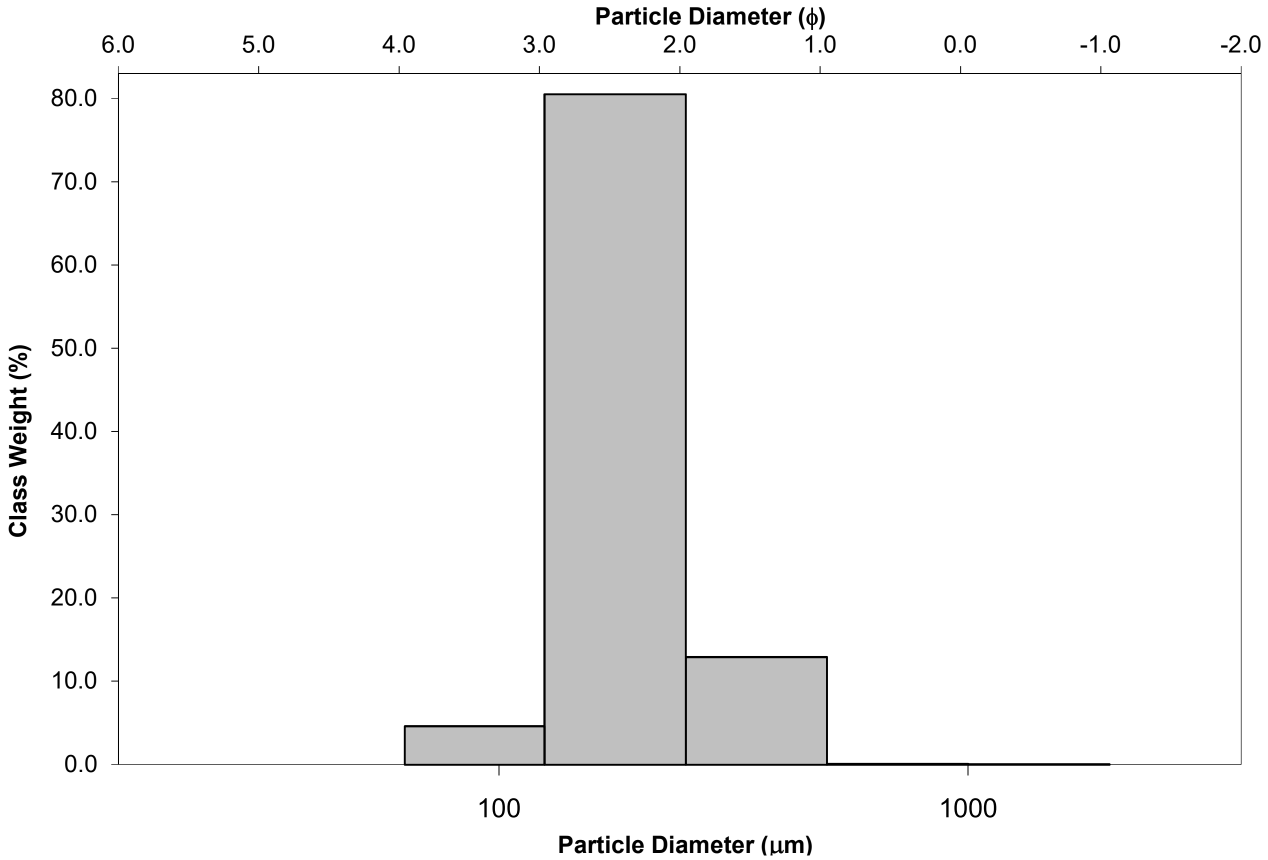
	μm	φ
MODE 1:	187.5	2.500
MODE 2:		
MODE 3:		
D_{10}:	130.8	1.745
MEDIAN or D_{50}:	183.4	2.447
D_{90}:	298.4	2.935
(D_{90} / D_{10}):	2.282	1.682
$(D_{90} - D_{10})$:	167.6	1.190
(D_{75} / D_{25}):	1.526	1.285
$(D_{75} - D_{25})$:	78.12	0.610

GRAIN SIZE DISTRIBUTION

GRAVEL:	0.0%	COARSE SAND:	0.1%
SAND:	100.0%	MEDIUM SAND:	13.2%
MUD:	0.0%	FINE SAND:	82.0%
		V FINE SAND:	4.7%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.0%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	0.0%	FINE SILT:	0.0%
V FINE GRAVEL:	0.0%	V FINE SILT:	0.0%
V COARSE SAND:	0.1%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic φ	Geometric μm	Logarithmic φ	Description
MEAN ($\bar{x}$):	209.5	188.1	2.410	183.4	2.447	Fine Sand
SORTING (σ):	79.02	1.343	0.426	1.370	0.454	Well Sorted
SKEWNESS (Sk):	4.794	0.856	-0.856	0.163	-0.163	Coarse Skewed
KURTOSIS (K):	60.66	6.864	6.864	1.096	1.096	Mesokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **Perfil-3**

ANALYST & DATE: Miguel, Jun 8th 2022

SAMPLE TYPE: Unimodal, Moderately Well Sorted

TEXTURAL GROUP: Sand

SEDIMENT NAME: Moderately Well Sorted Fine Sand

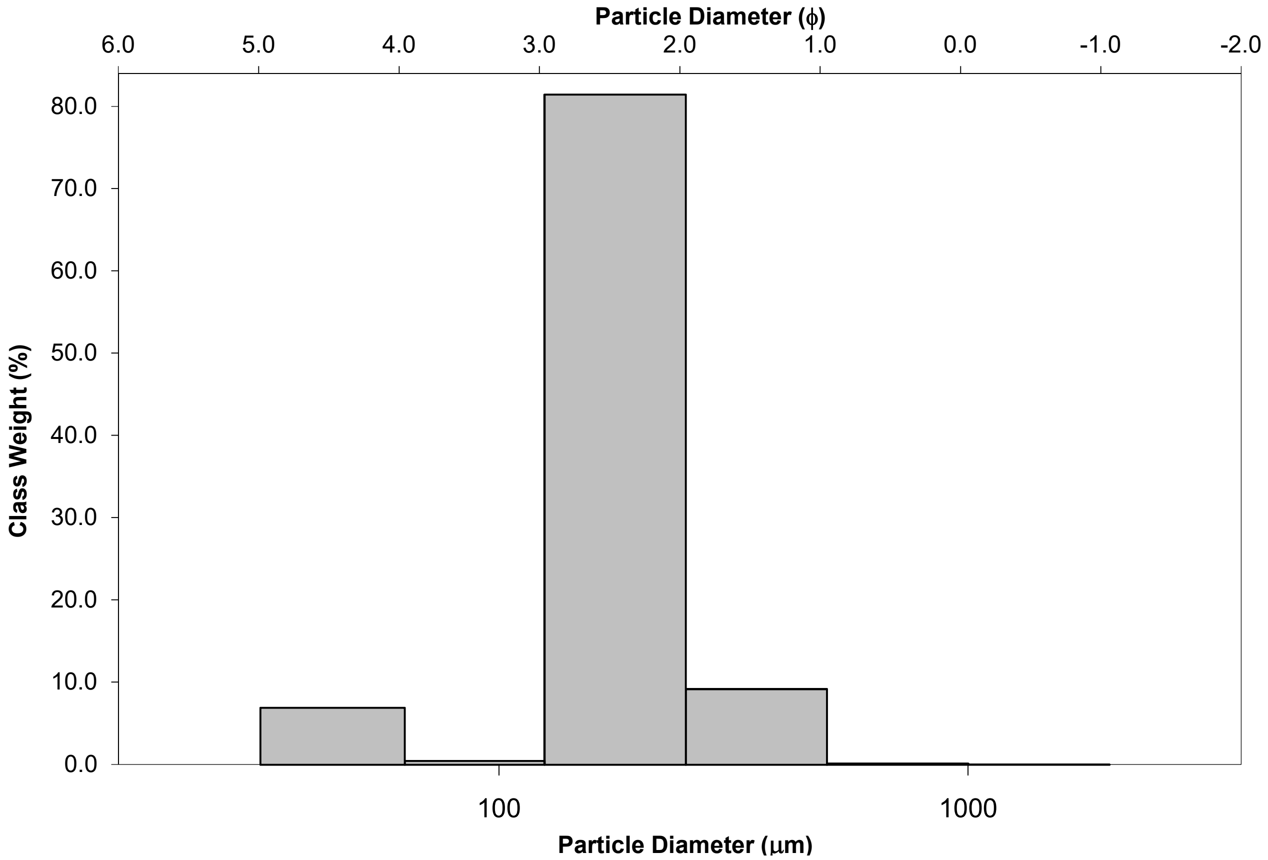
	μm	ϕ
MODE 1:	187.5	2.500
MODE 2:		
MODE 3:		
D_{10}:	127.4	2.005
MEDIAN or D_{50}:	178.2	2.489
D_{90}:	249.1	2.972
(D_{90} / D_{10}):	1.954	1.482
$(D_{90} - D_{10})$:	121.6	0.967
(D_{75} / D_{25}):	1.520	1.276
$(D_{75} - D_{25})$:	75.16	0.604

GRAIN SIZE DISTRIBUTION

GRAVEL:	0.0%	COARSE SAND:	0.2%
SAND:	92.9%	MEDIUM SAND:	9.4%
MUD:	7.1%	FINE SAND:	82.8%
		V FINE SAND:	0.6%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	7.1%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.1%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	0.0%	FINE SILT:	0.0%
V FINE GRAVEL:	0.0%	V FINE SILT:	0.0%
V COARSE SAND:	0.0%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	195.8	170.6	2.551	178.2	2.489	Fine Sand
SORTING (σ):	76.18	1.545	0.628	1.545	0.628	Moderately Well Sorted
SKEWNESS (Sk):	3.078	-1.640	1.640	-0.150	0.150	Fine Skewed
KURTOSIS (K):	39.25	7.850	7.850	1.892	1.892	Very Leptokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **Perfil-4**

ANALYST & DATE: Miguel, Jun 8th 2022

SAMPLE TYPE: Unimodal, Moderately Well Sorted

TEXTURAL GROUP: Sand

SEDIMENT NAME: Moderately Well Sorted Fine Sand

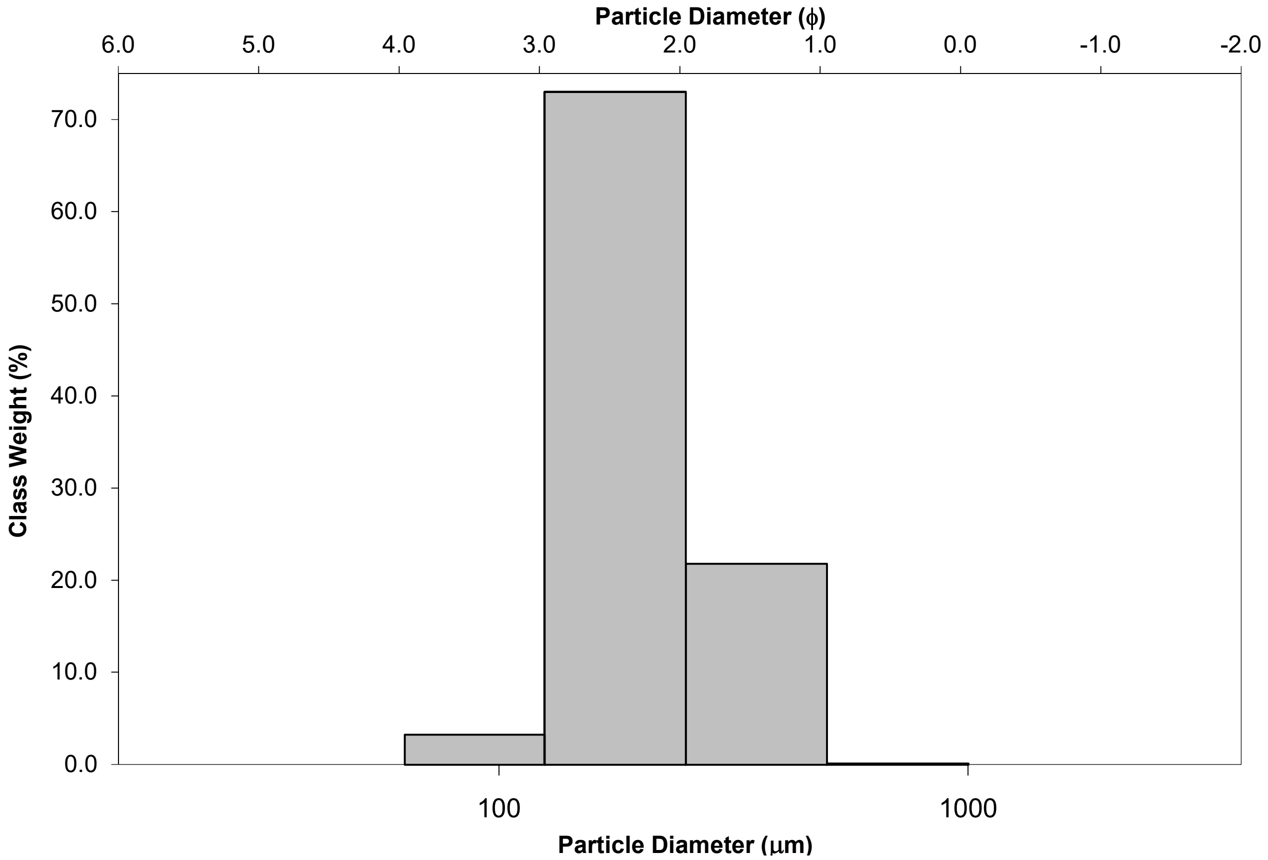
	μm	ϕ
MODE 1:	187.5	2.500
MODE 2:		
MODE 3:		
D_{10}:	133.1	1.443
MEDIAN or D_{50}:	193.2	2.372
D_{90}:	367.8	2.910
(D_{90} / D_{10}):	2.764	2.017
$(D_{90} - D_{10})$:	234.8	1.467
(D_{75} / D_{25}):	1.594	1.331
$(D_{75} - D_{25})$:	90.91	0.673

GRAIN SIZE DISTRIBUTION

GRAVEL:	0.0%	COARSE SAND:	0.2%
SAND:	100.0%	MEDIUM SAND:	22.2%
MUD:	0.0%	FINE SAND:	74.3%
		V FINE SAND:	3.3%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.0%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	0.0%	FINE SILT:	0.0%
V FINE GRAVEL:	0.0%	V FINE SILT:	0.0%
V COARSE SAND:	0.0%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	227.0	202.0	2.307	202.4	2.305	Fine Sand
SORTING (σ):	83.93	1.388	0.473	1.460	0.546	Moderately Well Sorted
SKEWNESS (Sk):	1.395	0.622	-0.622	0.246	-0.246	Coarse Skewed
KURTOSIS (K):	4.792	3.543	3.543	1.072	1.072	Mesokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **Perfil-5**   ANALYST & DATE: Miguel, Jun 8th 2022

SAMPLE TYPE: Unimodal, Moderately Well Sorted   TEXTURAL GROUP: Sand

SEDIMENT NAME: Moderately Well Sorted Fine Sand

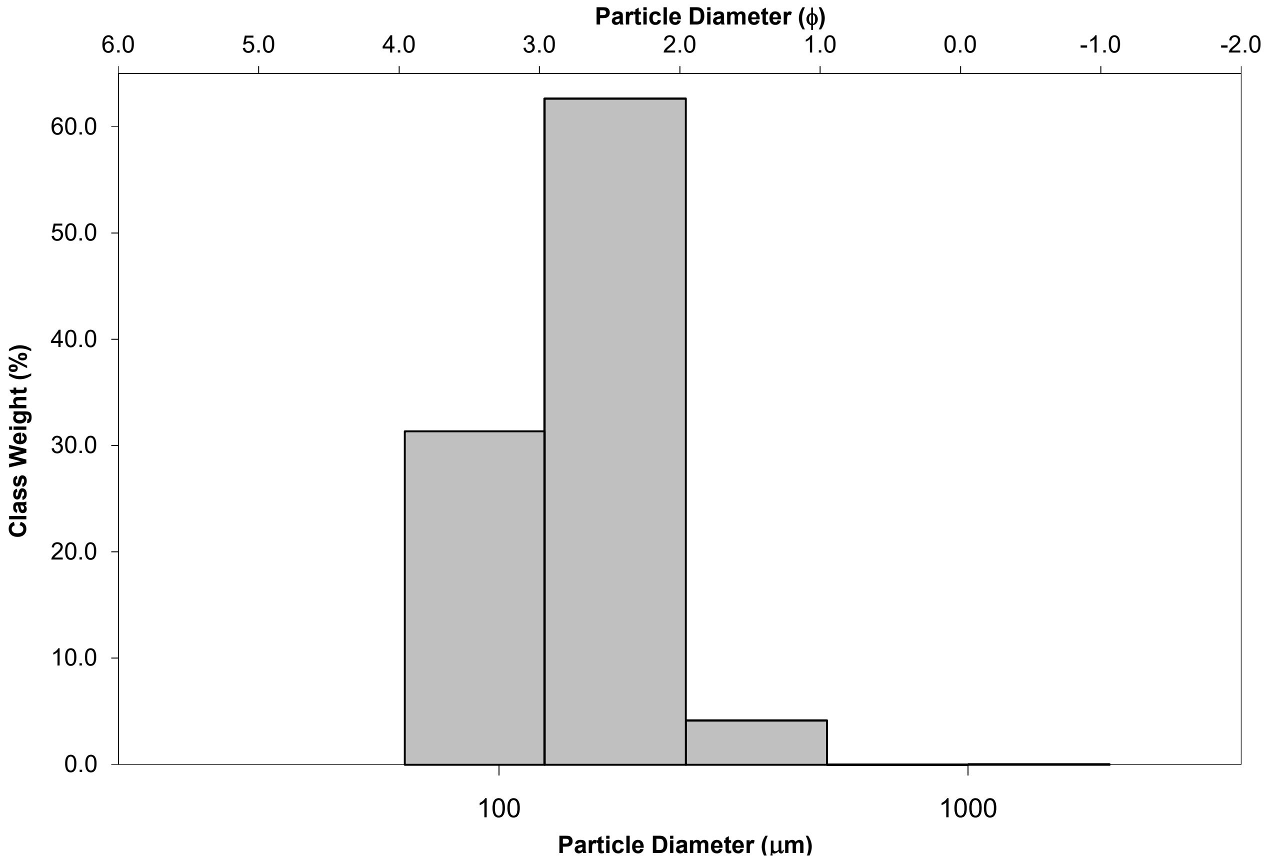
	μm	φ
MODE 1:	187.5	2.500
MODE 2:		
MODE 3:		
D_{10}:	78.22	2.088
MEDIAN or D_{50}:	152.5	2.713
D_{90}:	235.1	3.676
(D_{90} / D_{10}):	3.006	1.760
$(D_{90} - D_{10})$:	156.9	1.588
(D_{75} / D_{25}):	1.847	1.381
$(D_{75} - D_{25})$:	91.67	0.885

GRAIN SIZE DISTRIBUTION

GRAVEL:	0.0%	COARSE SAND:	0.0%
SAND:	100.0%	MEDIUM SAND:	4.3%
MUD:	0.0%	FINE SAND:	64.0%
		V FINE SAND:	31.7%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.0%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	0.0%	FINE SILT:	0.0%
V FINE GRAVEL:	0.0%	V FINE SILT:	0.0%
V COARSE SAND:	0.1%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic φ	Geometric μm	Logarithmic φ	Description
MEAN ($\bar{x}$):	166.7	146.6	2.770	144.1	2.795	Fine Sand
SORTING (σ):	69.72	1.451	0.537	1.519	0.603	Moderately Well Sorted
SKEWNESS (Sk):	4.780	0.011	-0.011	-0.207	0.207	Fine Skewed
KURTOSIS (K):	78.49	3.249	3.249	0.844	0.844	Platykurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **Perfil-6**

ANALYST & DATE: Miguel, Jun 8th 2022

SAMPLE TYPE: Unimodal, Moderately Well Sorted

TEXTURAL GROUP: Sand

SEDIMENT NAME: Moderately Well Sorted Fine Sand

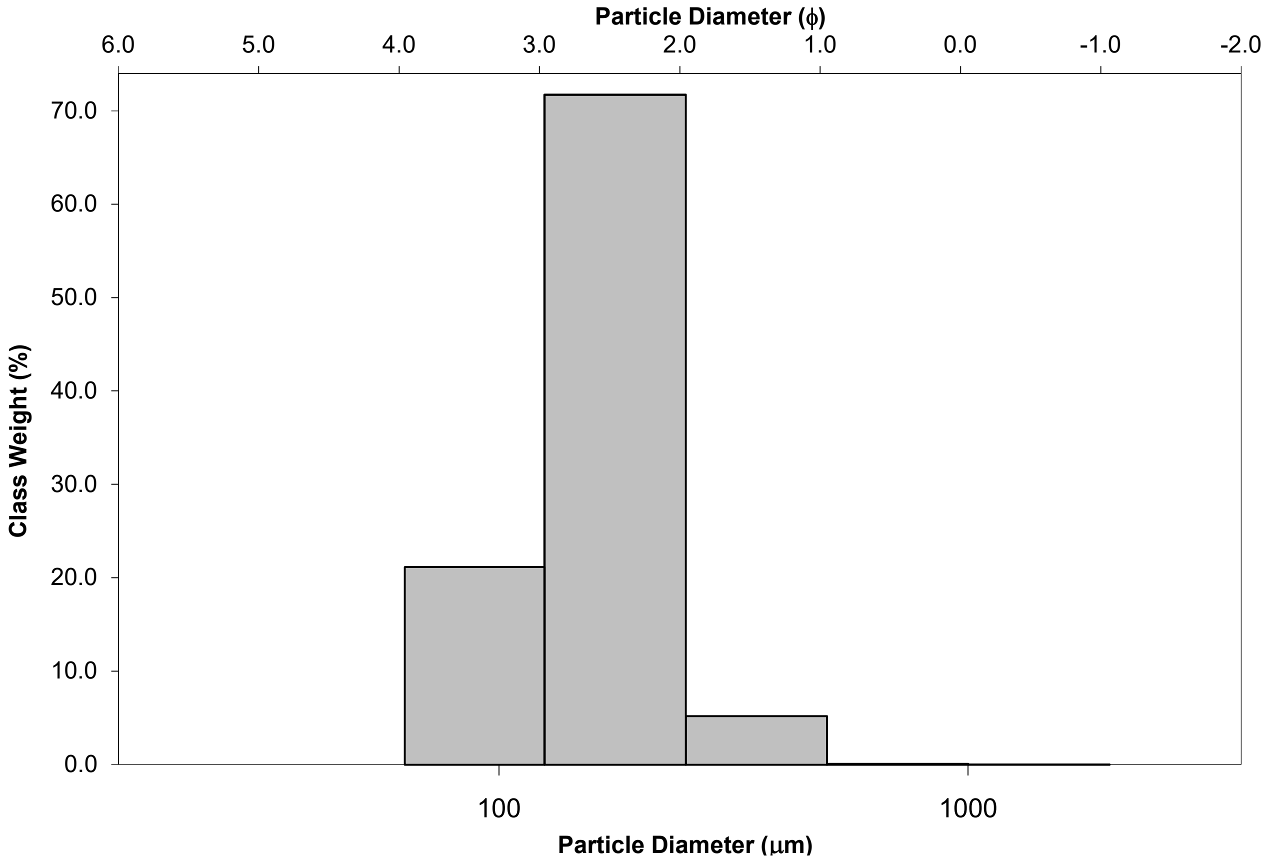
	μm	ϕ
MODE 1:	187.5	2.500
MODE 2:		
MODE 3:		
D_{10}:	86.84	2.062
MEDIAN or D_{50}:	164.0	2.608
D_{90}:	239.5	3.525
(D_{90} / D_{10}):	2.758	1.710
(D_{90} - D_{10}):	152.7	1.464
(D_{75} / D_{25}):	1.606	1.301
(D_{75} - D_{25}):	78.38	0.683

GRAIN SIZE DISTRIBUTION

GRAVEL:	0.0%	COARSE SAND:	0.1%
SAND:	100.0%	MEDIUM SAND:	5.3%
MUD:	0.0%	FINE SAND:	73.2%
		V FINE SAND:	21.3%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.0%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	0.0%	FINE SILT:	0.0%
V FINE GRAVEL:	0.0%	V FINE SILT:	0.0%
V COARSE SAND:	0.1%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	178.7	158.7	2.656	157.5	2.667	Fine Sand
SORTING (σ):	69.39	1.413	0.498	1.470	0.556	Moderately Well Sorted
SKEWNESS (Sk):	4.786	-0.129	0.129	-0.202	0.202	Fine Skewed
KURTOSIS (K):	73.87	4.388	4.388	1.107	1.107	Mesokurtic

GRAIN SIZE DISTRIBUTION



SAMPLE STATISTICS

SIEVING ERROR: 0.0%

SAMPLE IDENTITY: **Perfil-7**

ANALYST & DATE: Miguel, Jun 8th 2022

SAMPLE TYPE: Unimodal, Moderately Well Sorted

TEXTURAL GROUP: Sand

SEDIMENT NAME: Moderately Well Sorted Fine Sand

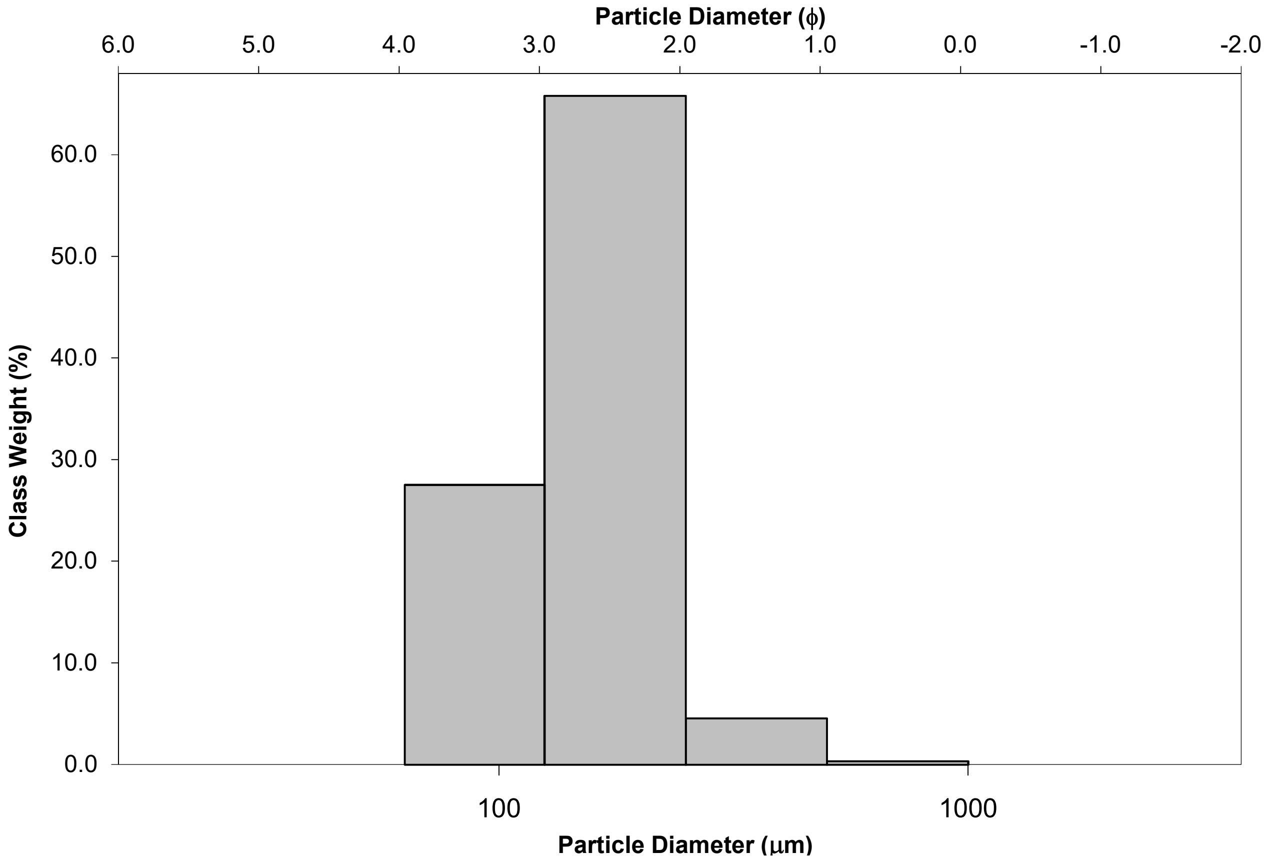
	μm	ϕ
MODE 1:	187.5	2.500
MODE 2:		
MODE 3:		
D_{10}:	80.61	2.074
MEDIAN or D_{50}:	157.2	2.669
D_{90}:	237.5	3.633
(D_{90} / D_{10}):	2.946	1.752
$(D_{90} - D_{10})$:	156.9	1.559
(D_{75} / D_{25}):	1.744	1.349
$(D_{75} - D_{25})$:	86.76	0.802

GRAIN SIZE DISTRIBUTION

GRAVEL:	0.0%	COARSE SAND:	0.4%
SAND:	100.0%	MEDIUM SAND:	4.7%
MUD:	0.0%	FINE SAND:	67.2%
		V FINE SAND:	27.8%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.0%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	0.0%	FINE SILT:	0.0%
V FINE GRAVEL:	0.0%	V FINE SILT:	0.0%
V COARSE SAND:	0.0%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	172.3	151.5	2.722	148.6	2.751	Fine Sand
SORTING (σ):	70.74	1.449	0.535	1.504	0.589	Moderately Well Sorted
SKEWNESS (Sk):	2.734	0.034	-0.034	-0.225	0.225	Fine Skewed
KURTOSIS (K):	19.97	3.582	3.582	0.928	0.928	Mesokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **Tipo Playa**

ANALYST & DATE: Miguel, Jun 8th 2022

SAMPLE TYPE: Unimodal, Moderately Well Sorted

TEXTURAL GROUP: Sand

SEDIMENT NAME: Moderately Well Sorted Fine Sand

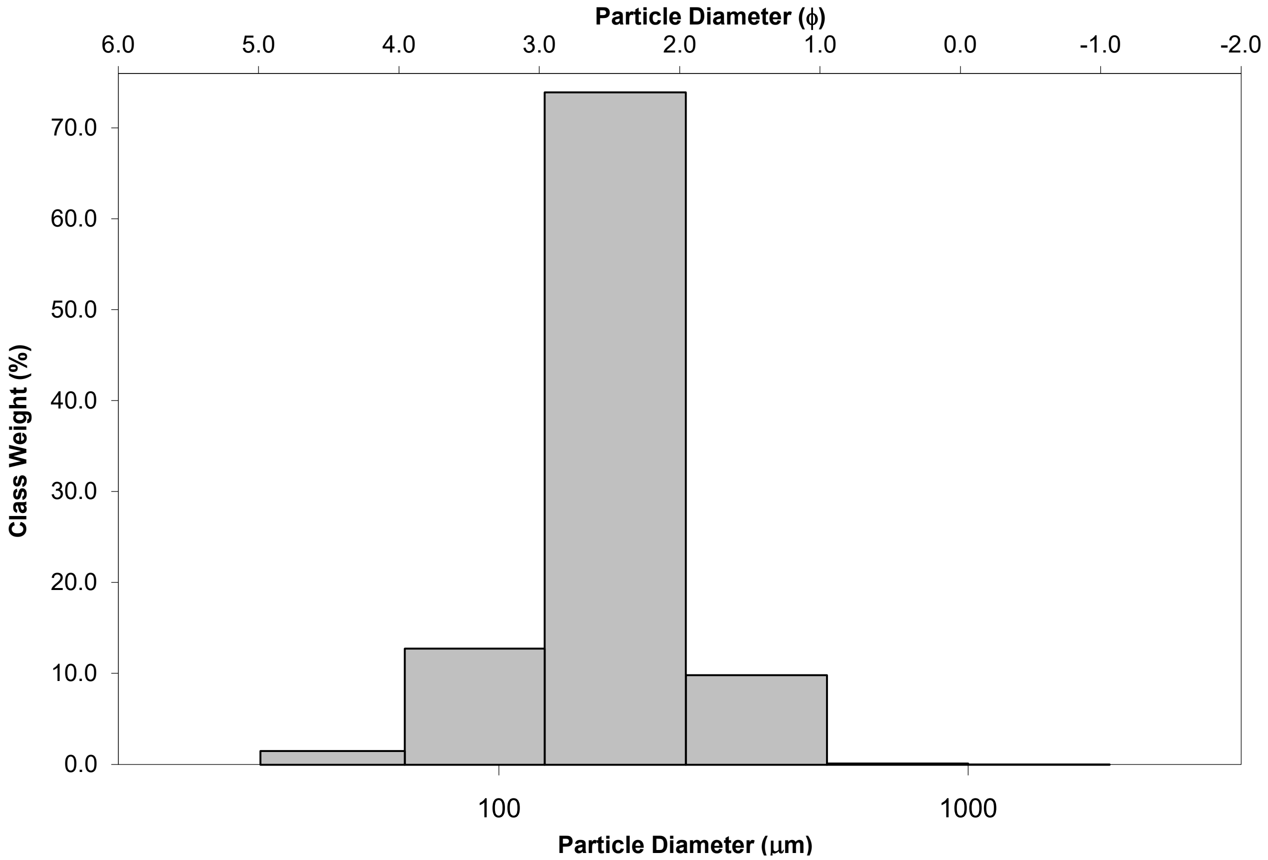
	μm	ϕ
MODE 1:	187.5	2.500
MODE 2:		
MODE 3:		
D_{10}:	98.55	1.979
MEDIAN or D_{50}:	173.4	2.528
D_{90}:	253.7	3.343
(D_{90} / D_{10}):	2.574	1.689
$(D_{90} - D_{10})$:	155.1	1.364
(D_{75} / D_{25}):	1.584	1.302
$(D_{75} - D_{25})$:	80.47	0.664

GRAIN SIZE DISTRIBUTION

GRAVEL:	0.0%	COARSE SAND:	0.1%
SAND:	98.4%	MEDIUM SAND:	10.0%
MUD:	1.6%	FINE SAND:	75.3%
		V FINE SAND:	12.9%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	1.6%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	0.0%	FINE SILT:	0.0%
V FINE GRAVEL:	0.0%	V FINE SILT:	0.0%
V COARSE SAND:	0.0%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	193.3	170.1	2.556	173.4	2.528	Fine Sand
SORTING (σ):	77.22	1.459	0.545	1.480	0.566	Moderately Well Sorted
SKEWNESS (Sk):	3.115	-0.518	0.518	-0.034	0.034	Symmetrical
KURTOSIS (K):	35.76	5.752	5.752	1.387	1.387	Leptokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **C1**

ANALYST & DATE: Miguel, Jun 8th 2022

SAMPLE TYPE: Unimodal, Poorly Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Fine Sand

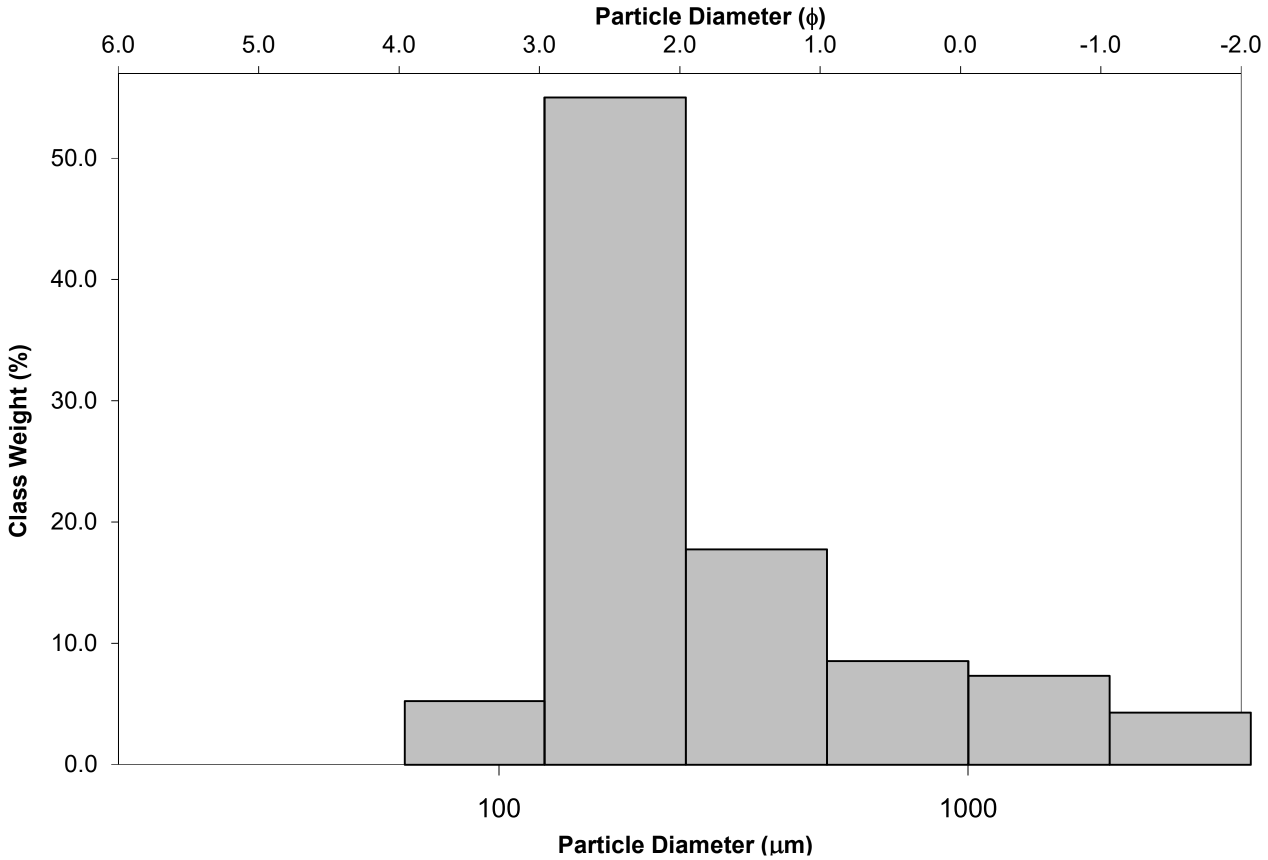
	μm	ϕ
MODE 1:	187.5	2.500
MODE 2:		
MODE 3:		
D_{10}:	132.8	-0.484
MEDIAN or D_{50}:	219.9	2.185
D_{90}:	1399.0	2.913
(D_{90} / D_{10}):	10.53	-6.013
(D_{90} - D_{10}):	1266.2	3.397
(D_{75} / D_{25}):	2.782	2.268
(D_{75} - D_{25}):	285.9	1.476

GRAIN SIZE DISTRIBUTION

GRAVEL:	6.2%	COARSE SAND:	8.5%
SAND:	93.8%	MEDIUM SAND:	17.7%
MUD:	0.0%	FINE SAND:	55.0%
		V FINE SAND:	5.2%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.0%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	0.0%	FINE SILT:	0.0%
V FINE GRAVEL:	6.2%	V FINE SILT:	0.0%
V COARSE SAND:	7.3%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	477.5	257.9	1.763	295.6	1.758	Medium Sand
SORTING (σ):	645.4	3.118	1.223	2.435	1.284	Poorly Sorted
SKEWNESS (Sk):	2.794	-1.590	-1.168	0.557	-0.557	Very Coarse Skewed
KURTOSIS (K):	10.53	12.23	3.501	1.200	1.200	Leptokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **C2**

ANALYST & DATE: Miguel, Jun 8th 2022

SAMPLE TYPE: Unimodal, Moderately Sorted

TEXTURAL GROUP: Slightly Gravelly Sand

SEDIMENT NAME: Slightly Very Fine Gravelly Fine Sand

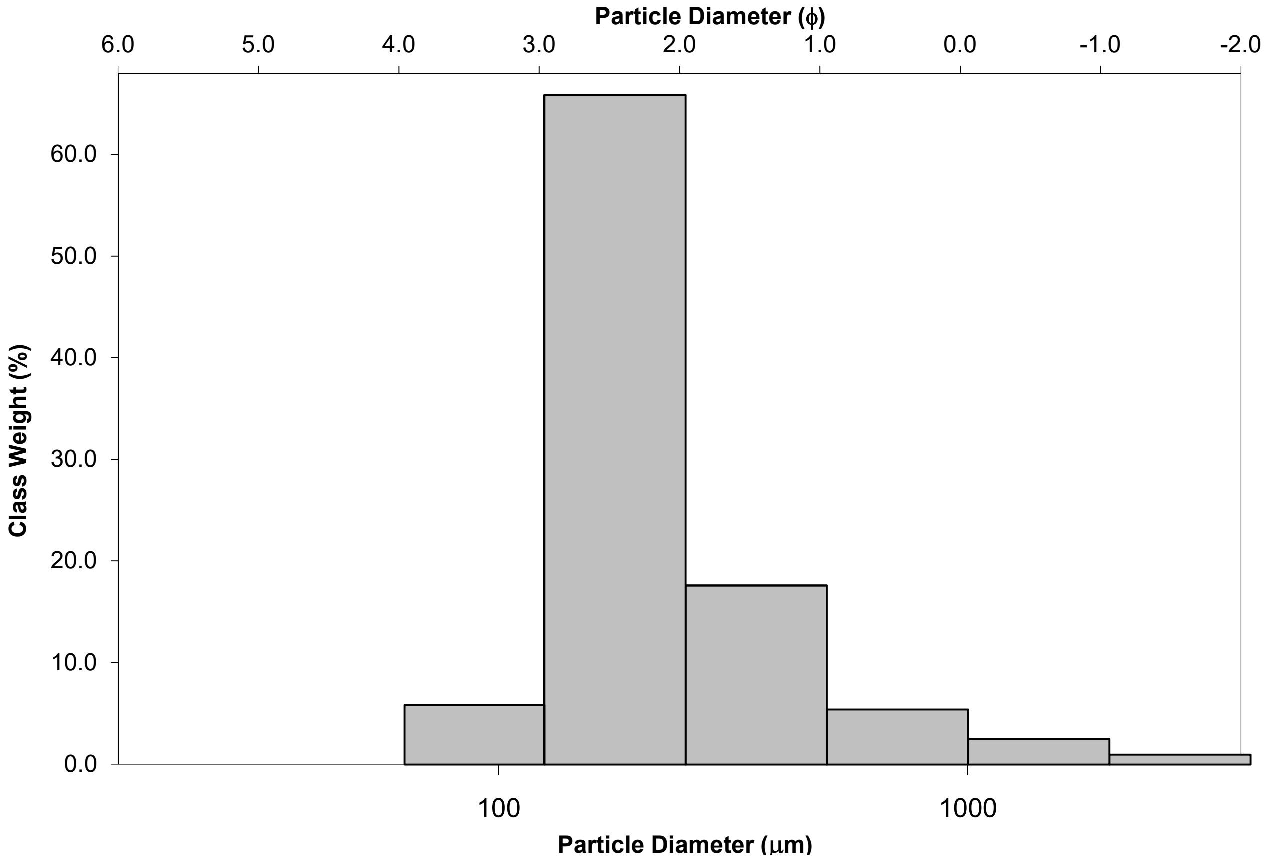
	μm	ϕ
MODE 1:	187.5	2.500
MODE 2:		
MODE 3:		
D_{10}:	130.5	1.033
MEDIAN or D_{50}:	197.5	2.340
D_{90}:	488.7	2.938
(D_{90} / D_{10}):	3.746	2.845
$(D_{90} - D_{10})$:	358.3	1.905
(D_{75} / D_{25}):	1.793	1.450
$(D_{75} - D_{25})$:	120.8	0.842

GRAIN SIZE DISTRIBUTION

GRAVEL:	1.4%	COARSE SAND:	5.5%
SAND:	98.6%	MEDIUM SAND:	17.9%
MUD:	0.0%	FINE SAND:	66.8%
		V FINE SAND:	5.9%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.0%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	0.0%	FINE SILT:	0.0%
V FINE GRAVEL:	1.4%	V FINE SILT:	0.0%
V COARSE SAND:	2.5%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	307.2	220.6	2.144	219.8	2.186	Fine Sand
SORTING (σ):	363.8	1.961	0.861	1.761	0.817	Moderately Sorted
SKEWNESS (Sk):	4.982	-0.606	-1.731	0.382	-0.382	Very Coarse Skewed
KURTOSIS (K):	32.84	19.13	6.751	1.435	1.435	Leptokurtic

GRAIN SIZE DISTRIBUTION



SAMPLE STATISTICS

SIEVING ERROR: 0.0%

SAMPLE IDENTITY: **C3**

ANALYST & DATE: Miguel, Jun 8th 2022

SAMPLE TYPE: Unimodal, Moderately Well Sorted

TEXTURAL GROUP: Slightly Gravelly Sand

SEDIMENT NAME: Slightly Very Fine Gravelly Fine Sand

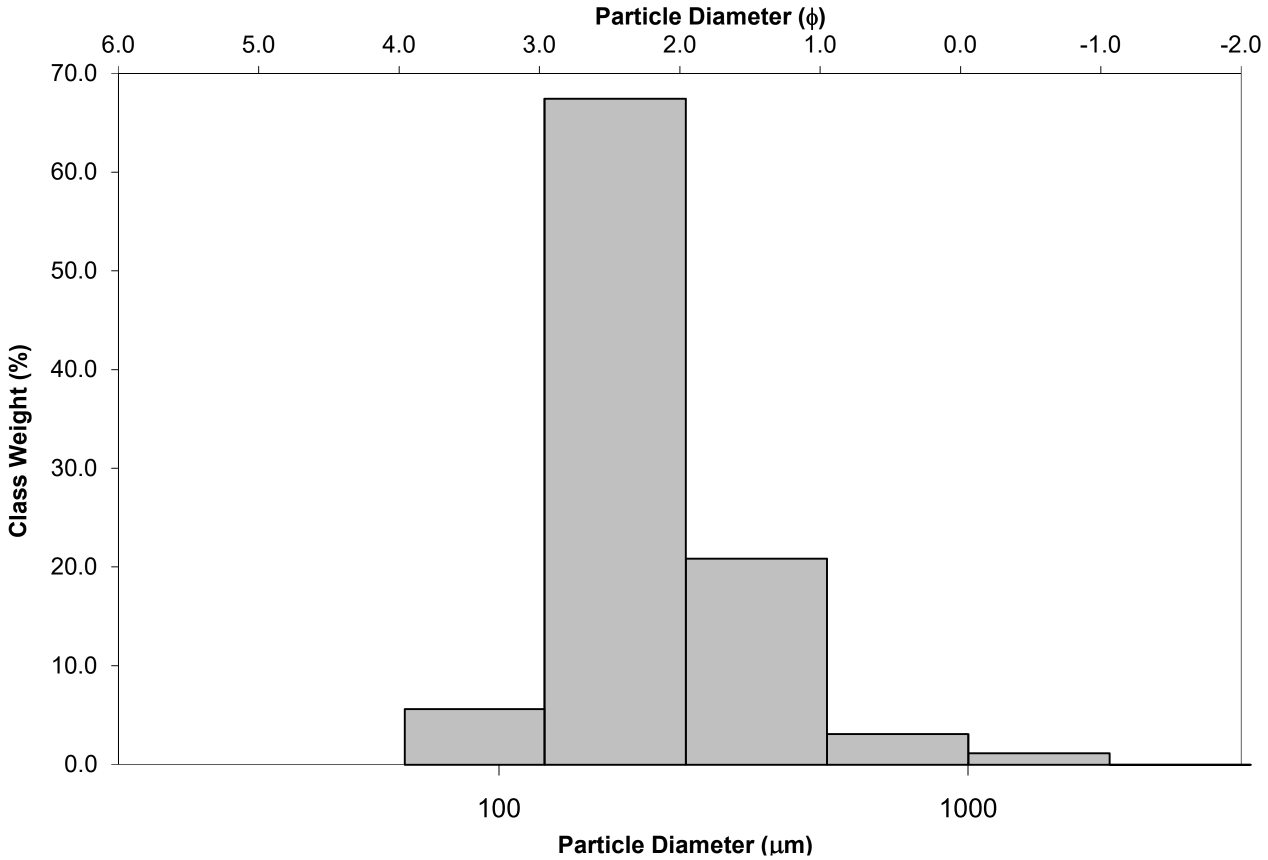
	μm	ϕ
MODE 1:	187.5	2.500
MODE 2:		
MODE 3:		
D_{10}:	130.6	1.263
MEDIAN or D_{50}:	195.5	2.355
D_{90}:	416.6	2.937
(D_{90} / D_{10}):	3.191	2.325
$(D_{90} - D_{10})$:	286.0	1.674
(D_{75} / D_{25}):	1.681	1.381
$(D_{75} - D_{25})$:	103.5	0.750

GRAIN SIZE DISTRIBUTION

GRAVEL:	0.0%	COARSE SAND:	3.2%
SAND:	100.0%	MEDIUM SAND:	21.2%
MUD:	0.0%	FINE SAND:	68.7%
		V FINE SAND:	5.7%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.0%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	0.0%	FINE SILT:	0.0%
V FINE GRAVEL:	0.0%	V FINE SILT:	0.0%
V COARSE SAND:	1.2%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	255.8	210.7	2.244	210.2	2.250	Fine Sand
SORTING (σ):	186.2	1.598	0.664	1.561	0.643	Moderately Well Sorted
SKEWNESS (Sk):	4.418	0.811	-1.326	0.255	-0.255	Coarse Skewed
KURTOSIS (K):	29.38	10.84	6.194	1.144	1.144	Leptokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **C4**

ANALYST & DATE: Miguel, Jun 8th 2022

SAMPLE TYPE: Unimodal, Moderately Well Sorted

TEXTURAL GROUP: Sand

SEDIMENT NAME: Moderately Well Sorted Fine Sand

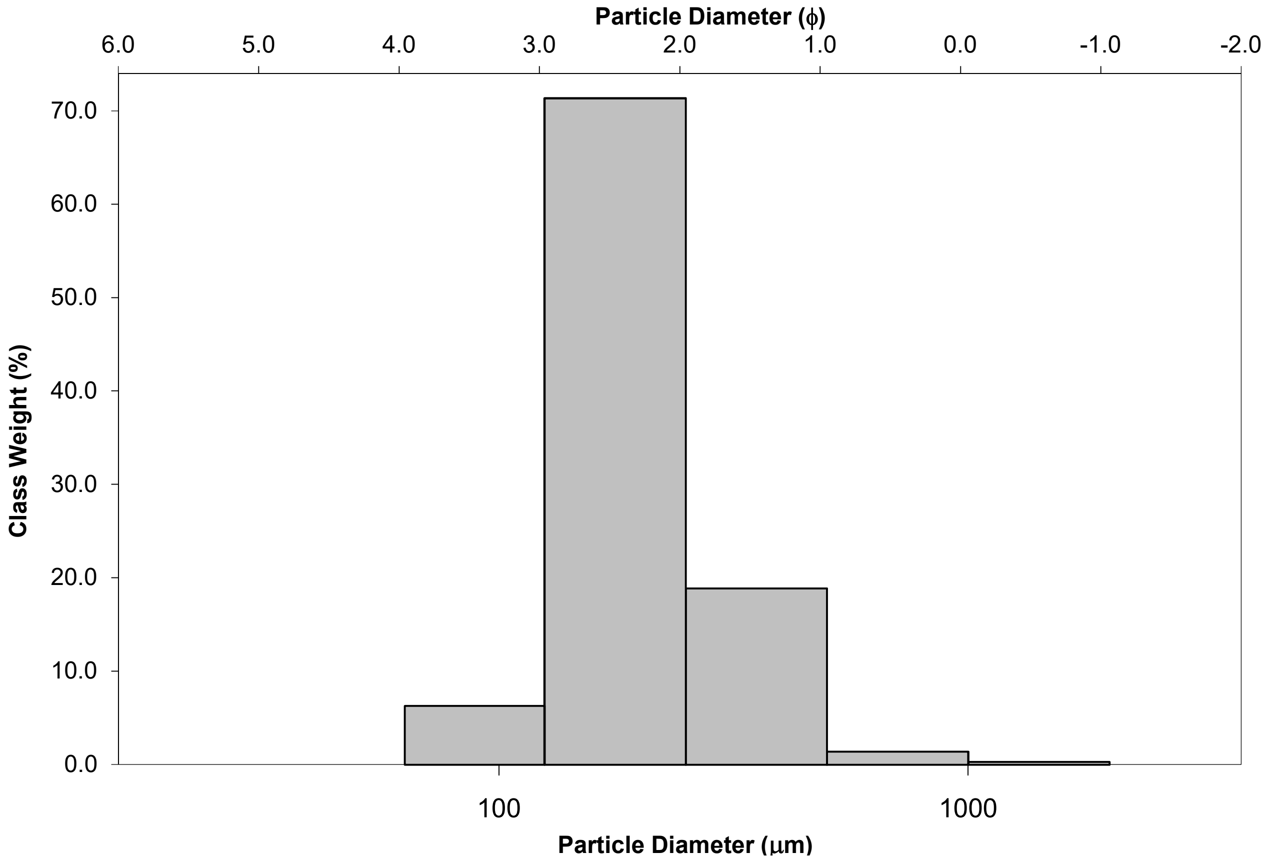
	μm	ϕ
MODE 1:	187.5	2.500
MODE 2:		
MODE 3:		
D_{10}:	129.4	1.429
MEDIAN or D_{50}:	189.6	2.399
D_{90}:	371.4	2.950
(D_{90} / D_{10}):	2.869	2.064
$(D_{90} - D_{10})$:	242.0	1.521
(D_{75} / D_{25}):	1.611	1.335
$(D_{75} - D_{25})$:	91.27	0.688

GRAIN SIZE DISTRIBUTION

GRAVEL:	0.0%	COARSE SAND:	1.4%
SAND:	100.0%	MEDIUM SAND:	19.2%
MUD:	0.0%	FINE SAND:	72.7%
		V FINE SAND:	6.3%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.0%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	0.0%	FINE SILT:	0.0%
V FINE GRAVEL:	0.0%	V FINE SILT:	0.0%
V COARSE SAND:	0.3%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	229.8	198.5	2.333	198.1	2.336	Fine Sand
SORTING (σ):	124.1	1.473	0.559	1.506	0.591	Moderately Well Sorted
SKEWNESS (Sk):	4.568	0.956	-0.956	0.188	-0.188	Coarse Skewed
KURTOSIS (K):	38.80	5.836	5.836	1.215	1.215	Leptokurtic

GRAIN SIZE DISTRIBUTION



SAMPLE STATISTICS

SIEVING ERROR: 0.0%

SAMPLE IDENTITY: **C5**

ANALYST & DATE: Miguel, Jun 8th 2022

SAMPLE TYPE: Bimodal, Poorly Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Fine Sand

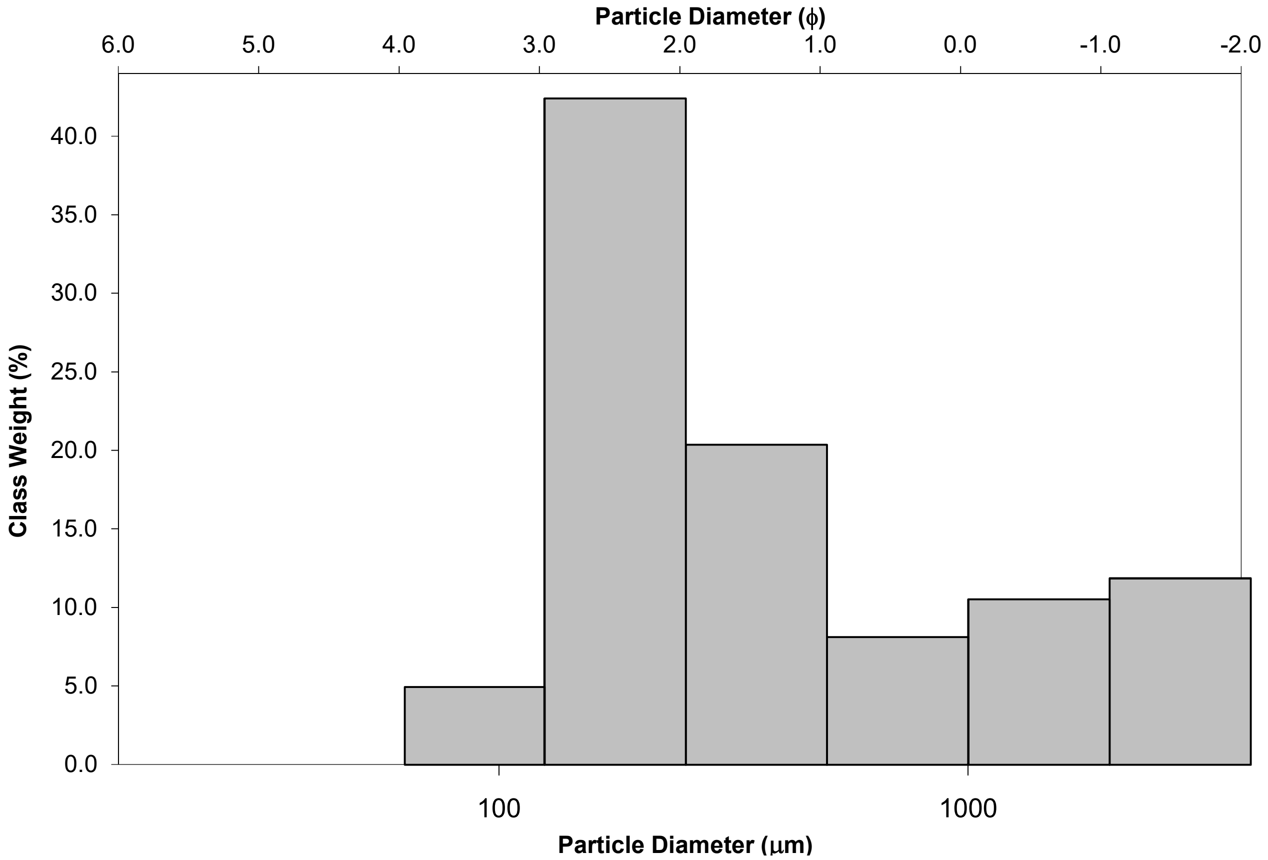
	μm	ϕ
MODE 1:	187.5	2.500
MODE 2:	3000.0	-1.500
MODE 3:		
D_{10}:	139.2	-2.404
MEDIAN or D_{50}:	352.7	1.504
D_{90}:	5291.9	2.845
(D_{90} / D_{10}):	38.01	-1.183
$(D_{90} - D_{10})$:	5152.7	5.248
(D_{75} / D_{25}):	10.69	-2.490
$(D_{75} - D_{25})$:	1787.1	3.418

GRAIN SIZE DISTRIBUTION

GRAVEL:	24.8%	COARSE SAND:	7.1%
SAND:	75.2%	MEDIUM SAND:	17.7%
MUD:	0.0%	FINE SAND:	36.9%
		V FINE SAND:	4.3%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.0%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	0.0%	FINE SILT:	0.0%
V FINE GRAVEL:	24.8%	V FINE SILT:	0.0%
V COARSE SAND:	9.2%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	640.5	163.2	1.173	583.3	0.778	Coarse Sand
SORTING (σ):	896.9	10.00	1.458	3.226	1.690	Poorly Sorted
SKEWNESS (Sk):	1.848	-1.271	-0.405	0.338	-0.338	Very Coarse Skewed
KURTOSIS (K):	5.097	3.797	1.919	0.440	0.440	Very Platykurtic

GRAIN SIZE DISTRIBUTION



SAMPLE STATISTICS

SIEVING ERROR: 0.0%

SAMPLE IDENTITY: **C6**

ANALYST & DATE: Miguel, Jun 8th 2022

SAMPLE TYPE: Unimodal, Moderately Sorted

TEXTURAL GROUP: Slightly Gravelly Sand

SEDIMENT NAME: Slightly Very Fine Gravelly Fine Sand

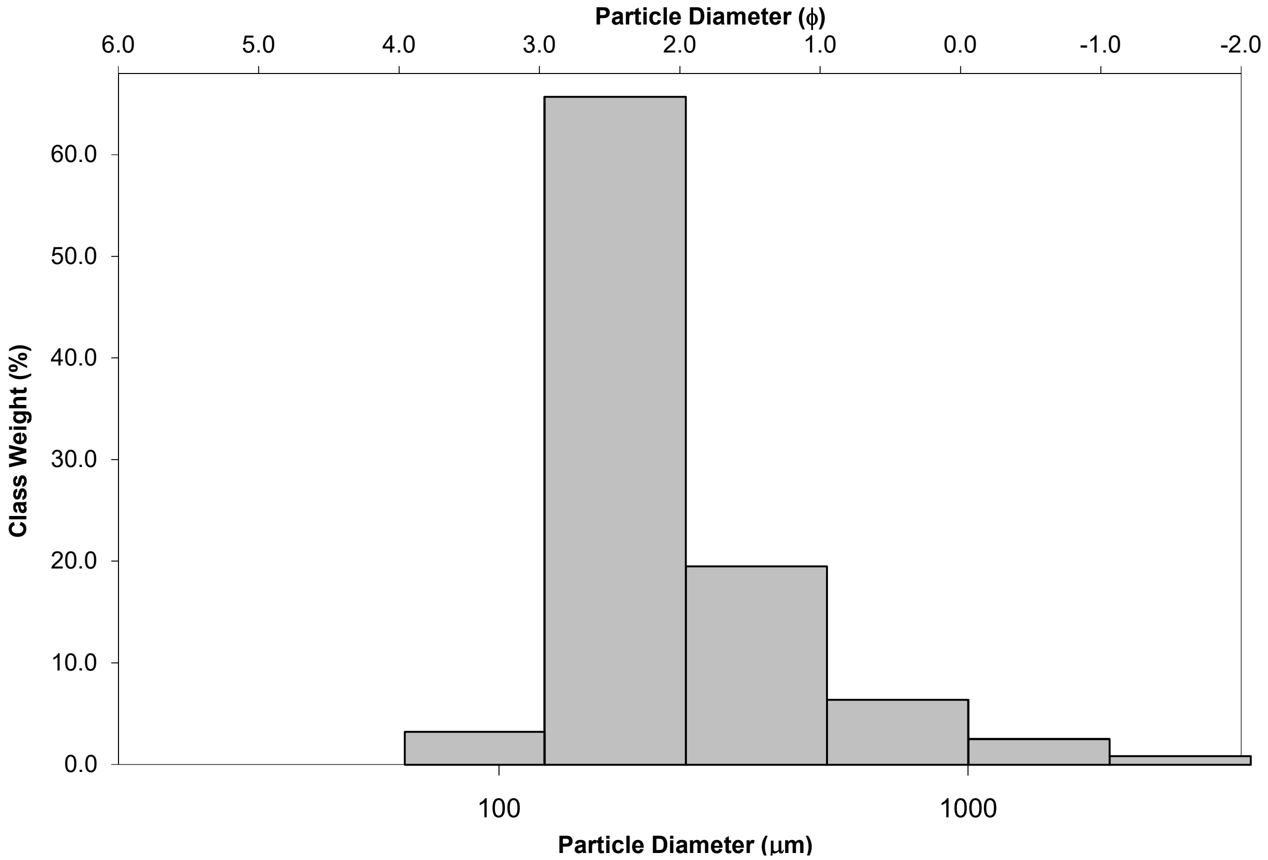
	μm	ϕ
MODE 1:	187.5	2.500
MODE 2:		
MODE 3:		
D_{10}:	134.1	0.994
MEDIAN or D_{50}:	203.0	2.301
D_{90}:	502.2	2.899
(D_{90} / D_{10}):	3.746	2.918
$(D_{90} - D_{10})$:	368.2	1.905
(D_{75} / D_{25}):	1.894	1.526
$(D_{75} - D_{25})$:	140.1	0.922

GRAIN SIZE DISTRIBUTION

GRAVEL:	1.0%	COARSE SAND:	6.5%
SAND:	99.0%	MEDIUM SAND:	19.9%
MUD:	0.0%	FINE SAND:	66.8%
		V FINE SAND:	3.3%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.0%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	0.0%	FINE SILT:	0.0%
V FINE GRAVEL:	1.0%	V FINE SILT:	0.0%
V COARSE SAND:	2.6%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	316.6	233.7	2.089	227.4	2.137	Fine Sand
SORTING (σ):	353.1	1.821	0.836	1.734	0.794	Moderately Sorted
SKEWNESS (Sk):	4.878	0.975	-1.751	0.418	-0.418	Very Coarse Skewed
KURTOSIS (K):	32.50	11.48	6.559	1.222	1.222	Leptokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **C7**

ANALYST & DATE: Miguel, Jun 8th 2022

SAMPLE TYPE: Unimodal, Moderately Well Sorted

TEXTURAL GROUP: Sand

SEDIMENT NAME: Moderately Well Sorted Fine Sand

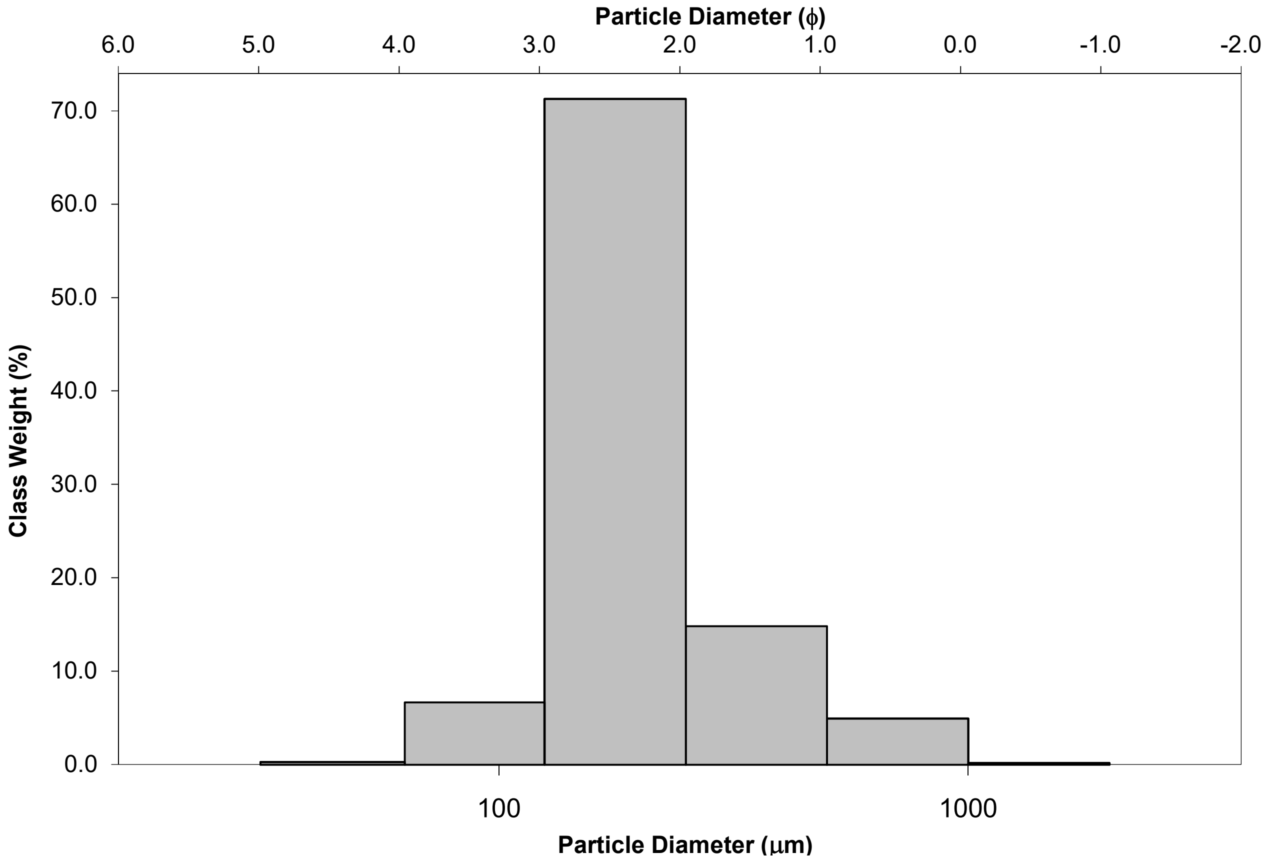
	μm	ϕ
MODE 1:	187.5	2.500
MODE 2:		
MODE 3:		
D_{10}:	128.6	1.315
MEDIAN or D_{50}:	188.4	2.408
D_{90}:	402.1	2.959
(D_{90} / D_{10}):	3.127	2.251
$(D_{90} - D_{10})$:	273.5	1.645
(D_{75} / D_{25}):	1.612	1.334
$(D_{75} - D_{25})$:	90.79	0.689

GRAIN SIZE DISTRIBUTION

GRAVEL:	0.0%	COARSE SAND:	5.0%
SAND:	99.7%	MEDIUM SAND:	15.1%
MUD:	0.3%	FINE SAND:	72.6%
		V FINE SAND:	6.7%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.3%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	0.0%	FINE SILT:	0.0%
V FINE GRAVEL:	0.0%	V FINE SILT:	0.0%
V COARSE SAND:	0.2%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	240.1	200.9	2.315	198.6	2.332	Fine Sand
SORTING (σ):	150.3	1.564	0.645	1.566	0.647	Moderately Well Sorted
SKEWNESS (Sk):	3.152	1.046	-1.046	0.218	-0.218	Coarse Skewed
KURTOSIS (K):	16.68	5.447	5.447	1.398	1.398	Leptokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **C8**

ANALYST & DATE: Miguel, Jun 8th 2022

SAMPLE TYPE: Unimodal, Poorly Sorted

TEXTURAL GROUP: Slightly Gravelly Sand

SEDIMENT NAME: Slightly Very Fine Gravelly Fine Sand

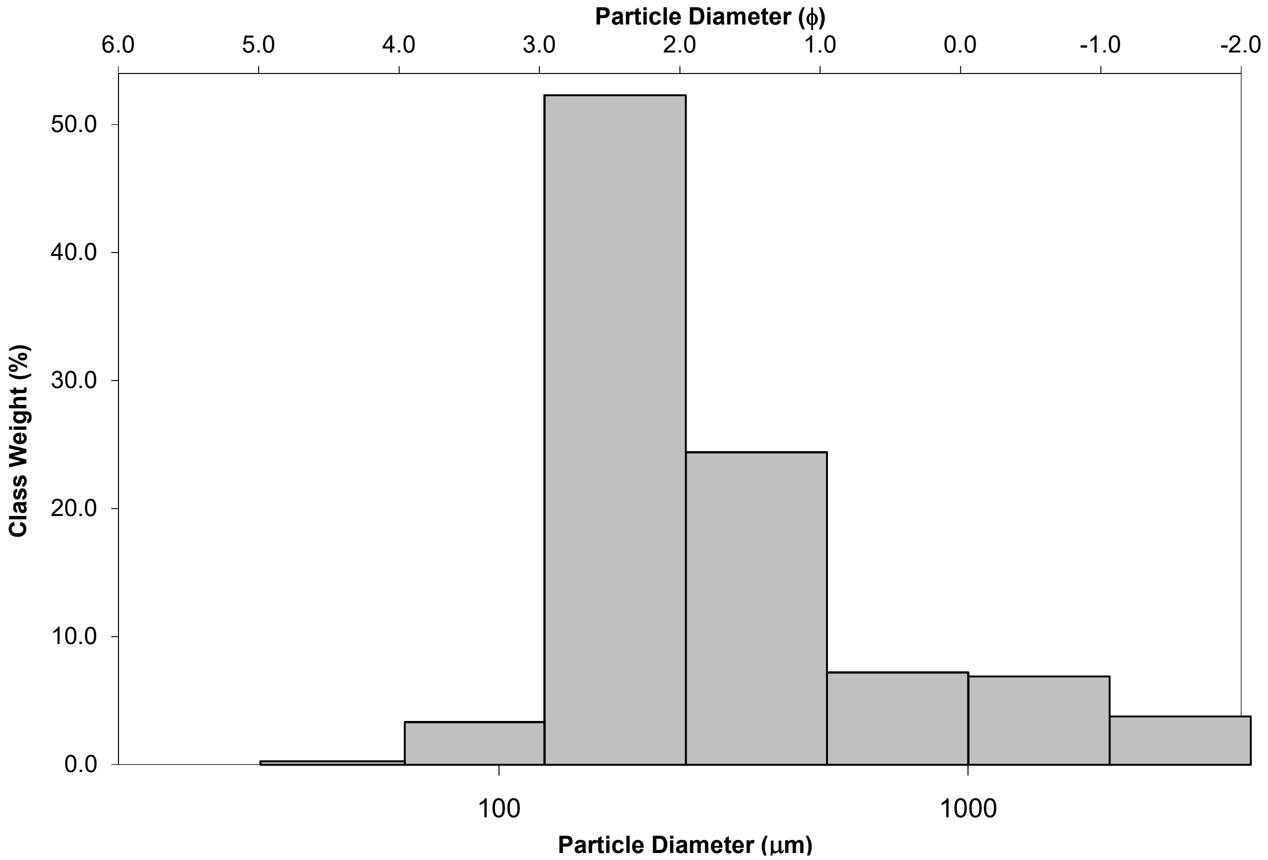
	μm	ϕ
MODE 1:	187.5	2.500
MODE 2:		
MODE 3:		
D_{10}:	135.9	-0.243
MEDIAN or D_{50}:	229.9	2.121
D_{90}:	1183.6	2.879
(D_{90} / D_{10}):	8.708	-11.840
$(D_{90} - D_{10})$:	1047.7	3.122
(D_{75} / D_{25}):	2.550	2.085
$(D_{75} - D_{25})$:	256.5	1.350

GRAIN SIZE DISTRIBUTION

GRAVEL:	4.7%	COARSE SAND:	7.3%
SAND:	95.0%	MEDIUM SAND:	24.6%
MUD:	0.3%	FINE SAND:	52.8%
		V FINE SAND:	3.3%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.3%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	0.0%	FINE SILT:	0.0%
V FINE GRAVEL:	4.7%	V FINE SILT:	0.0%
V COARSE SAND:	7.0%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	468.4	276.9	1.763	282.1	1.826	Medium Sand
SORTING (σ):	613.0	2.604	1.155	2.203	1.140	Poorly Sorted
SKEWNESS (Sk):	2.966	-1.002	-1.227	0.487	-0.487	Very Coarse Skewed
KURTOSIS (K):	11.71	12.90	3.964	1.194	1.194	Leptokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **C9**

ANALYST & DATE: Miguel, Jun 8th 2022

SAMPLE TYPE: Unimodal, Moderately Well Sorted

TEXTURAL GROUP: Slightly Gravelly Sand

SEDIMENT NAME: Slightly Very Fine Gravelly Fine Sand

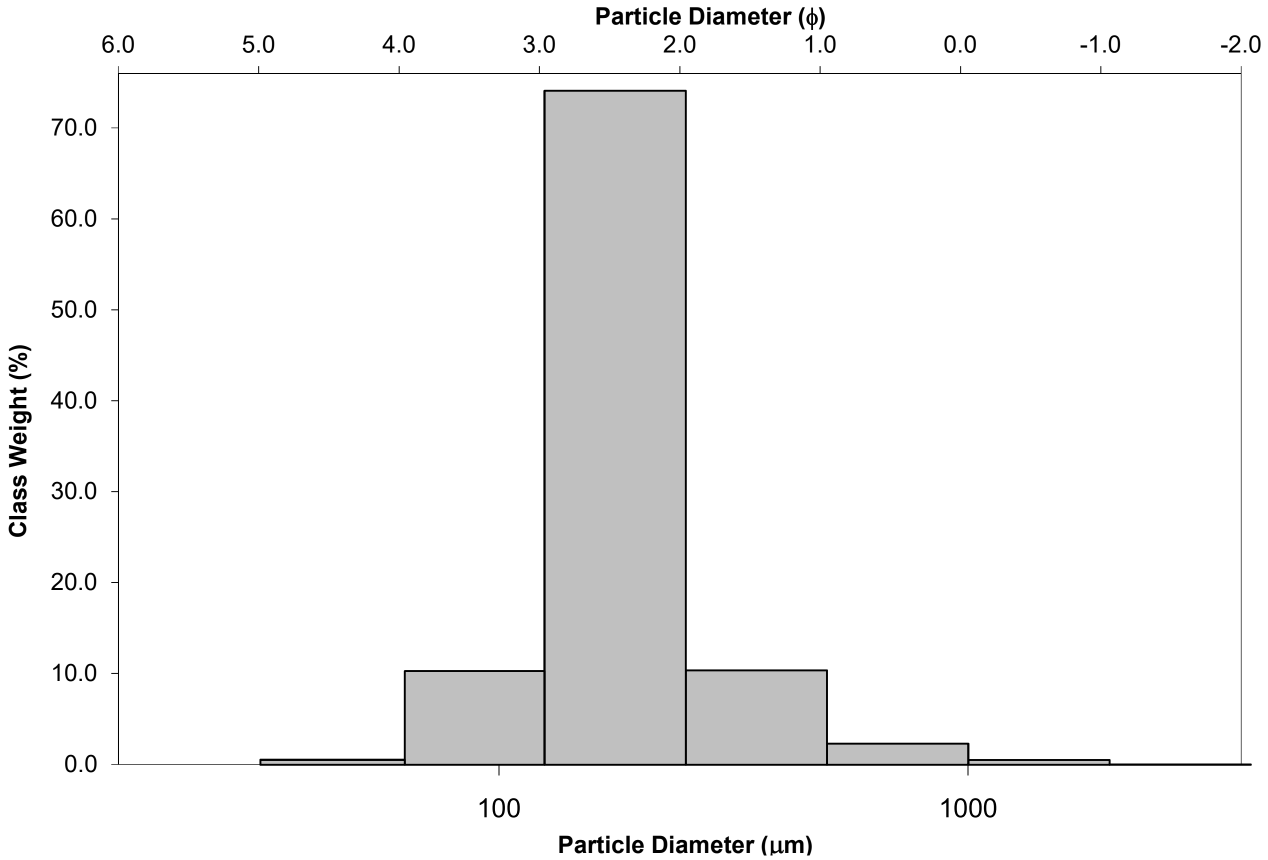
	μm	ϕ
MODE 1:	187.5	2.500
MODE 2:		
MODE 3:		
D_{10}:	117.4	1.655
MEDIAN or D_{50}:	179.0	2.482
D_{90}:	317.5	3.090
(D_{90} / D_{10}):	2.703	1.867
$(D_{90} - D_{10})$:	200.0	1.435
(D_{75} / D_{25}):	1.583	1.308
$(D_{75} - D_{25})$:	82.99	0.663

GRAIN SIZE DISTRIBUTION

GRAVEL:	0.1%	COARSE SAND:	2.4%
SAND:	99.3%	MEDIUM SAND:	10.6%
MUD:	0.6%	FINE SAND:	75.4%
		V FINE SAND:	10.4%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.6%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	0.0%	FINE SILT:	0.0%
V FINE GRAVEL:	0.1%	V FINE SILT:	0.0%
V COARSE SAND:	0.6%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	218.2	182.8	2.441	179.0	2.482	Fine Sand
SORTING (σ):	154.1	1.582	0.620	1.502	0.587	Moderately Well Sorted
SKEWNESS (Sk):	6.361	-0.640	-1.121	0.045	-0.045	Symmetrical
KURTOSIS (K):	69.19	23.64	8.033	1.473	1.473	Leptokurtic

GRAIN SIZE DISTRIBUTION



SAMPLE STATISTICS

SIEVING ERROR: 0.0%

SAMPLE IDENTITY: **C10**

ANALYST & DATE: Miguel, Jun 8th 2022

SAMPLE TYPE: Bimodal, Poorly Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Fine Sand

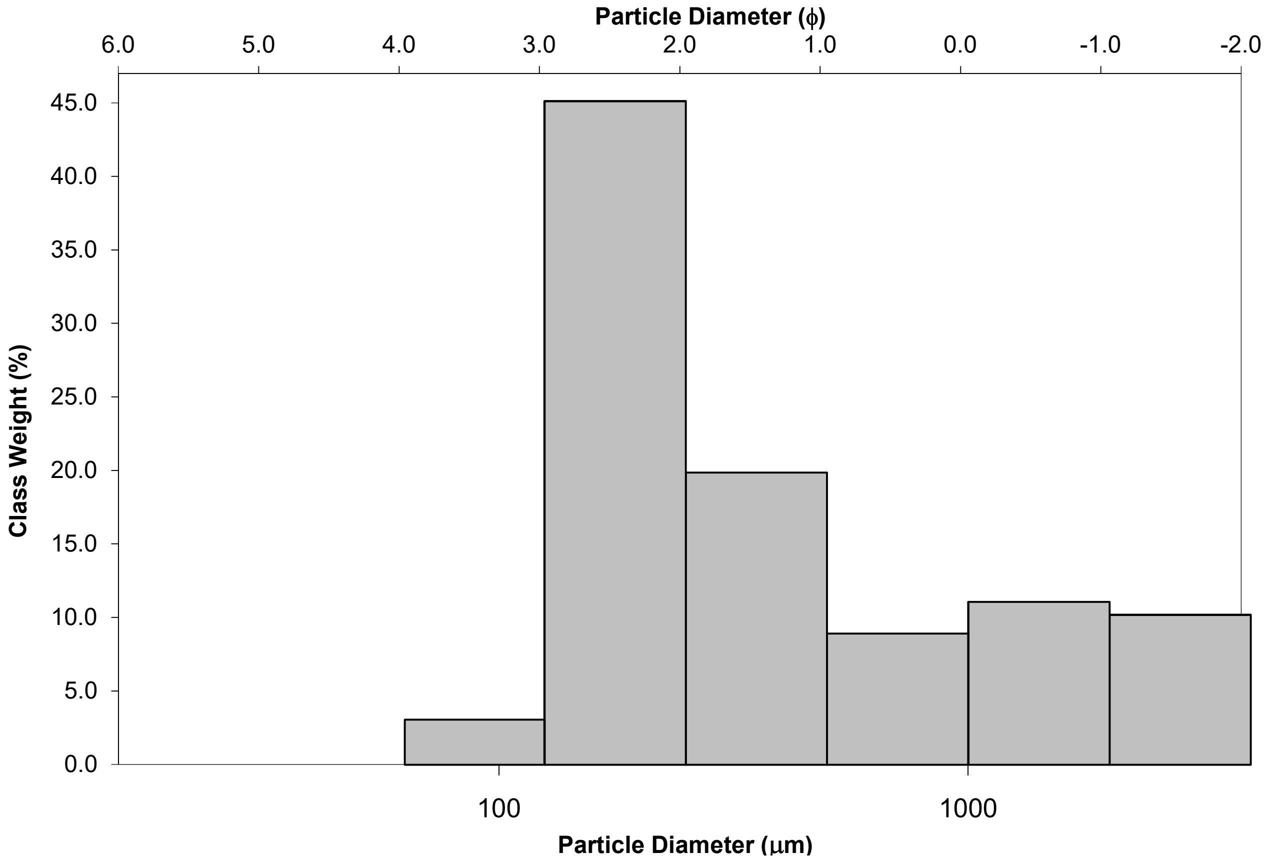
	μm	ϕ
MODE 1:	187.5	2.500
MODE 2:	1500.0	-0.500
MODE 3:		
D_{10}:	140.3	-1.686
MEDIAN or D_{50}:	293.9	1.767
D_{90}:	3216.9	2.833
(D_{90} / D_{10}):	22.93	-1.681
$(D_{90} - D_{10})$:	3076.6	4.519
(D_{75} / D_{25}):	6.426	-12.307
$(D_{75} - D_{25})$:	971.1	2.684

GRAIN SIZE DISTRIBUTION

GRAVEL:	16.6%	COARSE SAND:	8.5%
SAND:	83.4%	MEDIUM SAND:	18.8%
MUD:	0.0%	FINE SAND:	42.7%
		V FINE SAND:	2.9%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.0%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	0.0%	FINE SILT:	0.0%
V FINE GRAVEL:	16.6%	V FINE SILT:	0.0%
V COARSE SAND:	10.5%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	664.0	251.8	1.296	456.4	1.132	Medium Sand
SORTING (σ):	868.3	5.987	1.425	3.040	1.604	Poorly Sorted
SKEWNESS (Sk):	1.858	-1.712	-0.643	0.484	-0.484	Very Coarse Skewed
KURTOSIS (K):	5.221	6.768	2.133	0.670	0.670	Very Platykurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **C11**   ANALYST & DATE: Miguel, Jun 8th 2022

SAMPLE TYPE: Unimodal, Moderately Well Sorted   TEXTURAL GROUP: Slightly Gravelly Sand

SEDIMENT NAME: Slightly Very Fine Gravelly Fine Sand

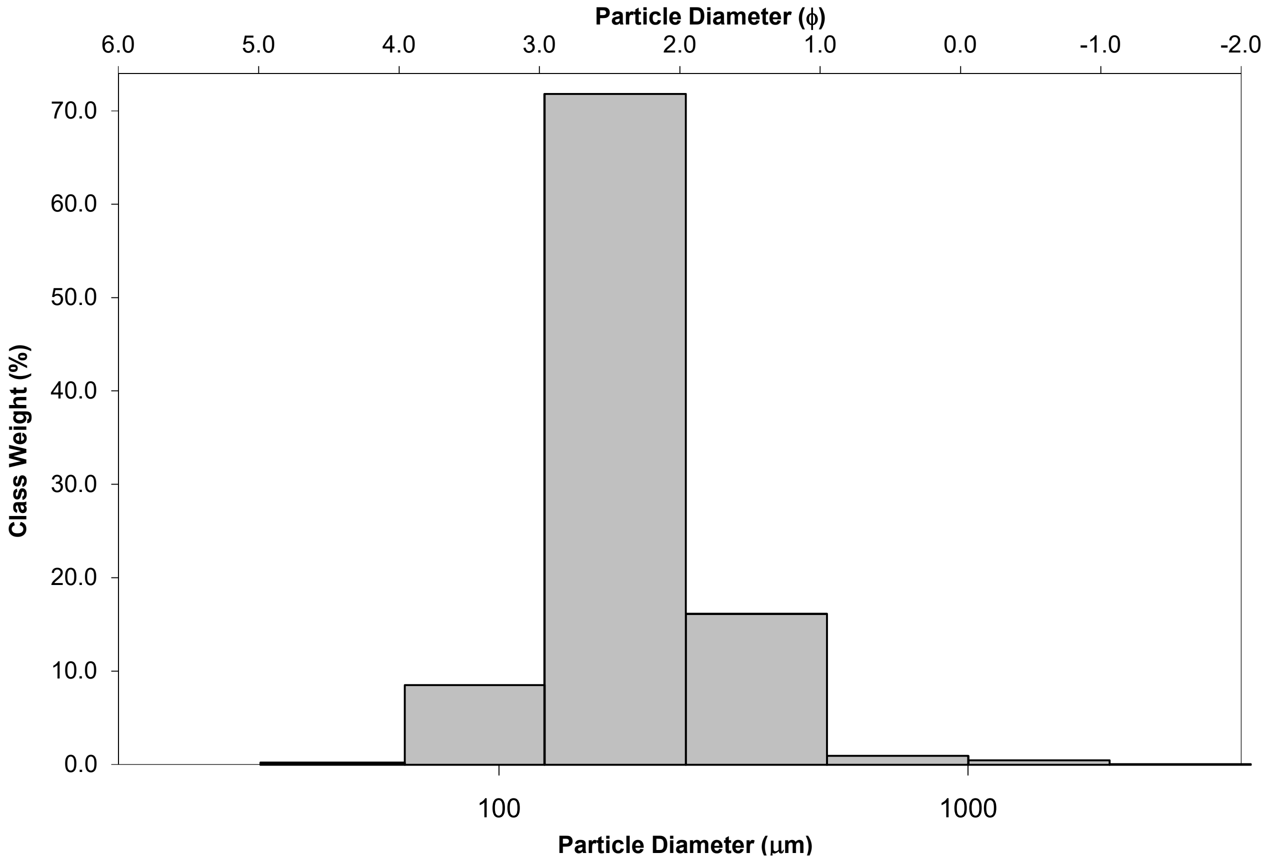
	μm	ϕ
MODE 1:	187.5	2.500
MODE 2:		
MODE 3:		
D_{10}:	126.4	1.514
MEDIAN or D_{50}:	184.6	2.437
D_{90}:	350.2	2.984
(D_{90} / D_{10}):	2.771	1.971
$(D_{90} - D_{10})$:	223.8	1.470
(D_{75} / D_{25}):	1.606	1.326
$(D_{75} - D_{25})$:	88.27	0.683

GRAIN SIZE DISTRIBUTION

GRAVEL:	0.1%	COARSE SAND:	1.0%
SAND:	99.7%	MEDIUM SAND:	16.5%
MUD:	0.2%	FINE SAND:	73.2%
		V FINE SAND:	8.6%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.2%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	0.0%	FINE SILT:	0.0%
V FINE GRAVEL:	0.1%	V FINE SILT:	0.0%
V COARSE SAND:	0.5%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	223.8	191.0	2.389	188.7	2.406	Fine Sand
SORTING (σ):	148.1	1.499	0.584	1.509	0.594	Moderately Well Sorted
SKEWNESS (Sk):	7.845	1.001	-1.001	0.096	-0.096	Symmetrical
KURTOSIS (K):	106.1	7.700	7.700	1.338	1.338	Leptokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.1%

SAMPLE STATISTICS

SAMPLE IDENTITY: **C12**

ANALYST & DATE: Miguel, Jun 8th 2022

SAMPLE TYPE: Bimodal, Poorly Sorted

TEXTURAL GROUP: Sandy Gravel

SEDIMENT NAME: Sandy Very Fine Gravel

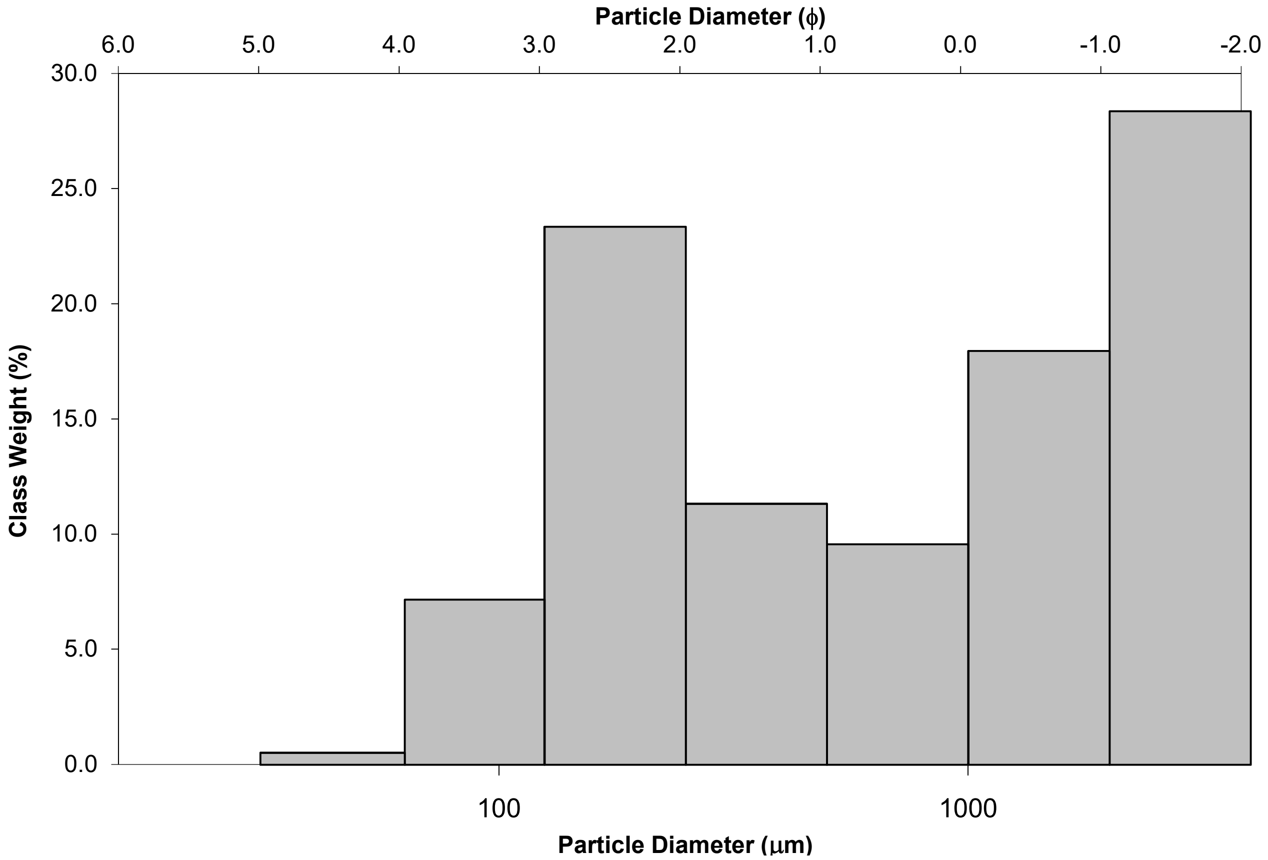
	μm	ϕ
MODE 1:	3000.0	-1.500
MODE 2:	187.5	2.500
MODE 3:		
D_{10}:	143.8	-2.714
MEDIAN or D_{50}:	1463.0	-0.549
D_{90}:	6559.7	2.798
(D_{90} / D_{10}):	45.61	-1.031
$(D_{90} - D_{10})$:	6415.9	5.511
(D_{75} / D_{25}):	14.00	-1.112
$(D_{75} - D_{25})$:	3239.7	3.807

GRAIN SIZE DISTRIBUTION

GRAVEL:	43.4%	COARSE SAND:	7.8%
SAND:	56.1%	MEDIUM SAND:	9.2%
MUD:	0.4%	FINE SAND:	18.9%
		V FINE SAND:	5.7%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.4%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	0.0%	FINE SILT:	0.0%
V FINE GRAVEL:	43.4%	V FINE SILT:	0.0%
V COARSE SAND:	14.5%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	1040.9	177.8	0.452	918.4	0.123	Coarse Sand
SORTING (σ):	1172.5	17.23	1.595	2.969	1.570	Poorly Sorted
SKEWNESS (Sk):	0.813	-0.957	0.439	-0.765	0.765	Very Fine Skewed
KURTOSIS (K):	2.011	2.495	2.004	0.397	0.397	Very Platykurtic

GRAIN SIZE DISTRIBUTION



SAMPLE STATISTICS

SIEVING ERROR: 0.0%

SAMPLE IDENTITY: **C13**

ANALYST & DATE: Miguel, Jun 8th 2022

SAMPLE TYPE: Unimodal, Poorly Sorted

TEXTURAL GROUP: Slightly Gravelly Sand

SEDIMENT NAME: Slightly Very Fine Gravelly Fine Sand

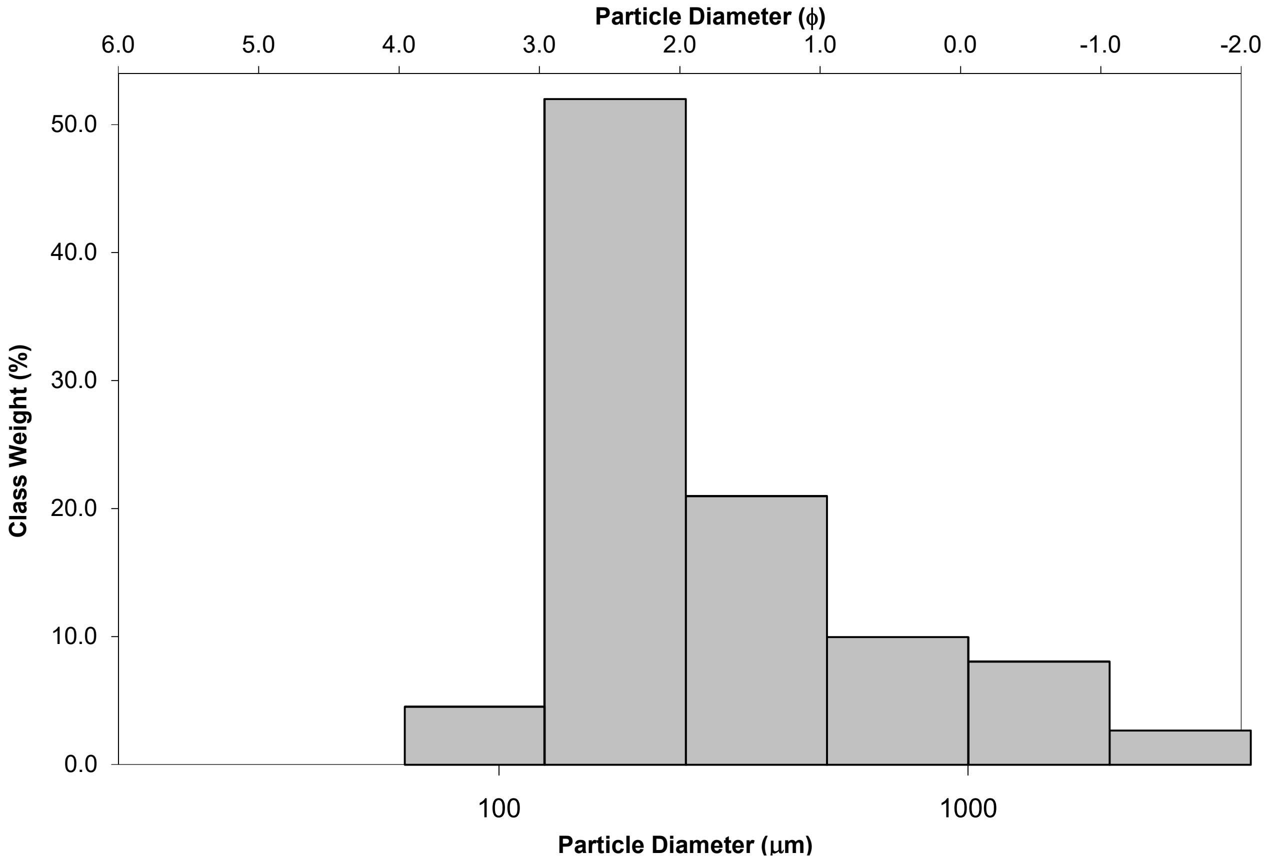
	μm	ϕ
MODE 1:	187.5	2.500
MODE 2:		
MODE 3:		
D_{10}:	134.3	-0.165
MEDIAN or D_{50}:	227.2	2.138
D_{90}:	1121.4	2.897
(D_{90} / D_{10}):	8.350	-17.530
$(D_{90} - D_{10})$:	987.1	3.062
(D_{75} / D_{25}):	2.724	2.240
$(D_{75} - D_{25})$:	282.0	1.446

GRAIN SIZE DISTRIBUTION

GRAVEL:	3.2%	COARSE SAND:	10.1%
SAND:	96.8%	MEDIUM SAND:	21.3%
MUD:	0.0%	FINE SAND:	52.7%
		V FINE SAND:	4.6%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.0%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	0.0%	FINE SILT:	0.0%
V FINE GRAVEL:	3.2%	V FINE SILT:	0.0%
V COARSE SAND:	8.2%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	463.1	285.3	1.765	288.5	1.793	Medium Sand
SORTING (σ):	566.1	2.408	1.150	2.222	1.152	Poorly Sorted
SKEWNESS (Sk):	2.891	-0.294	-1.110	0.496	-0.496	Very Coarse Skewed
KURTOSIS (K):	11.96	10.16	3.499	1.068	1.068	Mesokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **C14**

ANALYST & DATE: Miguel, Jun 8th 2022

SAMPLE TYPE: Unimodal, Moderately Well Sorted

TEXTURAL GROUP: Sand

SEDIMENT NAME: Moderately Well Sorted Fine Sand

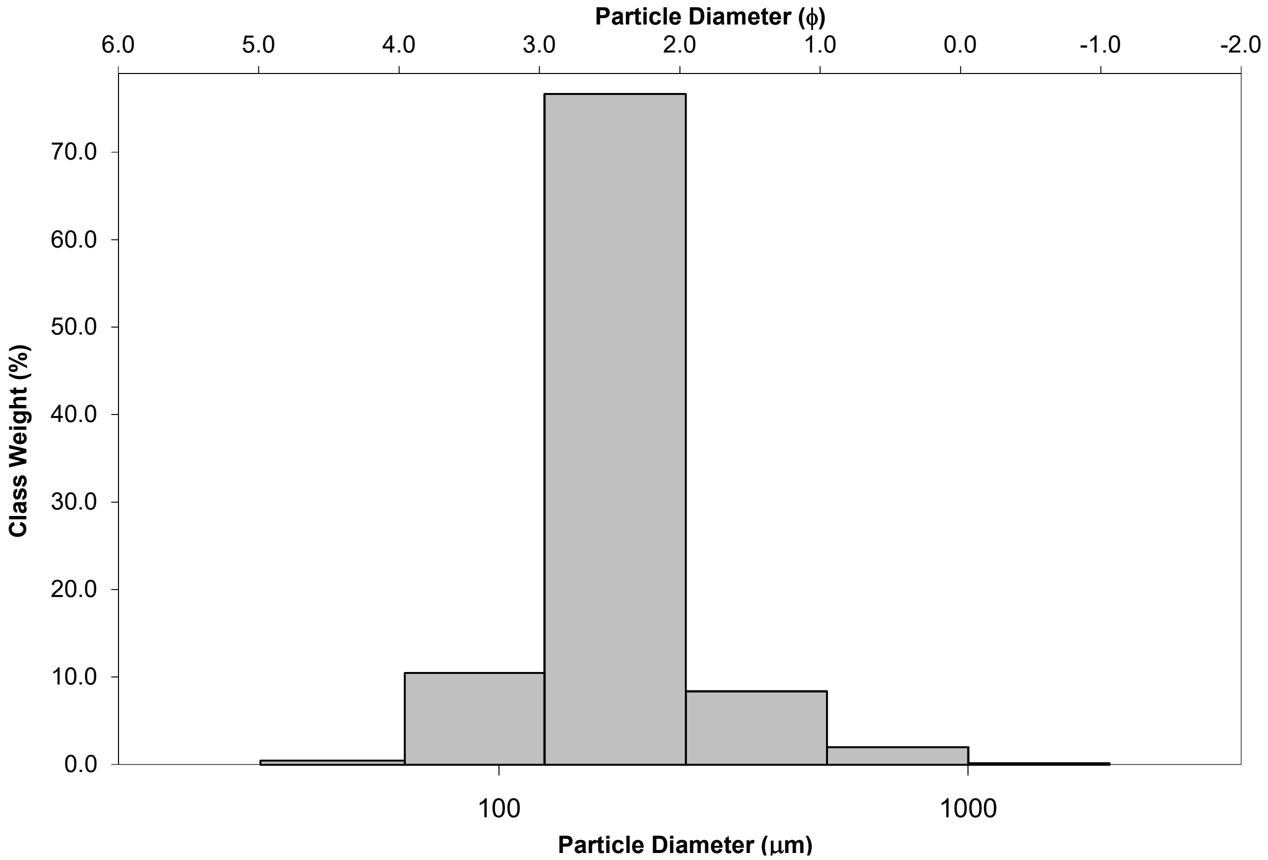
	μm	ϕ
MODE 1:	187.5	2.500
MODE 2:		
MODE 3:		
D_{10}:	116.4	1.906
MEDIAN or D_{50}:	176.5	2.502
D_{90}:	266.8	3.103
(D_{90} / D_{10}):	2.292	1.628
(D_{90} - D_{10}):	150.4	1.197
(D_{75} / D_{25}):	1.559	1.293
(D_{75} - D_{25}):	78.99	0.640

GRAIN SIZE DISTRIBUTION

GRAVEL:	0.0%	COARSE SAND:	2.1%
SAND:	99.5%	MEDIUM SAND:	8.6%
MUD:	0.5%	FINE SAND:	78.1%
		V FINE SAND:	10.6%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.5%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	0.0%	FINE SILT:	0.0%
V FINE GRAVEL:	0.0%	V FINE SILT:	0.0%
V COARSE SAND:	0.2%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	206.9	178.8	2.483	176.5	2.502	Fine Sand
SORTING (σ):	115.3	1.470	0.556	1.472	0.558	Moderately Well Sorted
SKEWNESS (Sk):	4.852	0.804	-0.804	0.025	-0.025	Symmetrical
KURTOSIS (K):	39.25	7.715	7.715	1.439	1.439	Leptokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **C15**

ANALYST & DATE: Miguel, Jun 8th 2022

SAMPLE TYPE: Unimodal, Moderately Sorted

TEXTURAL GROUP: Slightly Gravelly Sand

SEDIMENT NAME: Slightly Very Fine Gravelly Fine Sand

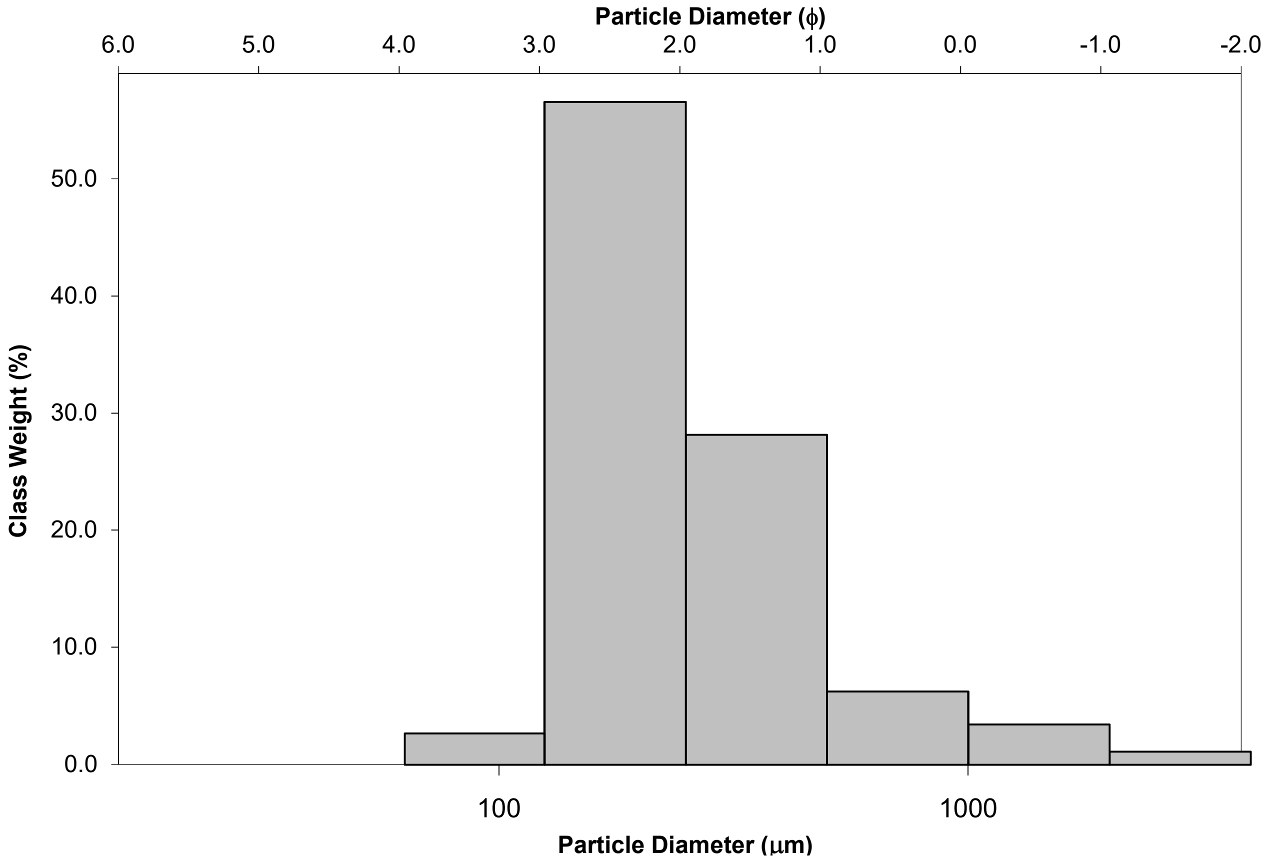
	μm	ϕ
MODE 1:	187.5	2.500
MODE 2:		
MODE 3:		
D_{10}:	136.5	0.833
MEDIAN or D_{50}:	220.9	2.178
D_{90}:	561.3	2.873
(D_{90} / D_{10}):	4.112	3.448
$(D_{90} - D_{10})$:	424.8	2.040
(D_{75} / D_{25}):	2.183	1.758
$(D_{75} - D_{25})$:	193.5	1.126

GRAIN SIZE DISTRIBUTION

GRAVEL:	1.2%	COARSE SAND:	6.4%
SAND:	98.8%	MEDIUM SAND:	28.7%
MUD:	0.0%	FINE SAND:	57.6%
		V FINE SAND:	2.7%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.0%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	0.0%	FINE SILT:	0.0%
V FINE GRAVEL:	1.2%	V FINE SILT:	0.0%
V COARSE SAND:	3.5%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	352.5	256.1	1.961	243.2	2.040	Fine Sand
SORTING (σ):	391.9	1.862	0.882	1.790	0.840	Moderately Sorted
SKEWNESS (Sk):	4.400	1.134	-1.510	0.362	-0.362	Very Coarse Skewed
KURTOSIS (K):	26.34	8.096	5.658	1.059	1.059	Mesokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **C16**

ANALYST & DATE: Miguel, Jun 8th 2022

SAMPLE TYPE: Unimodal, Moderately Well Sorted

TEXTURAL GROUP: Slightly Gravelly Sand

SEDIMENT NAME: Slightly Very Fine Gravelly Fine Sand

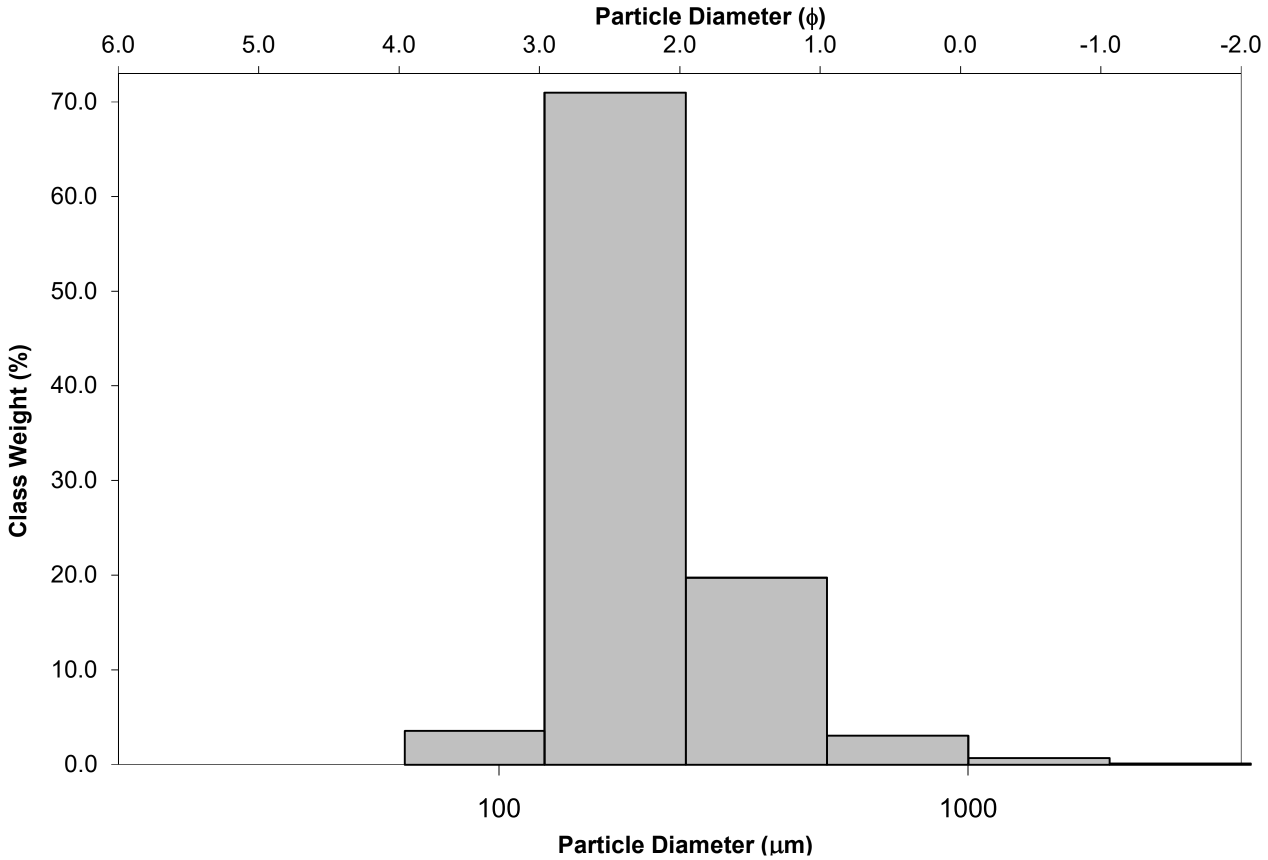
	μm	ϕ
MODE 1:	187.5	2.500
MODE 2:		
MODE 3:		
D_{10}:	132.9	1.298
MEDIAN or D_{50}:	195.1	2.358
D_{90}:	406.7	2.912
(D_{90} / D_{10}):	3.060	2.243
$(D_{90} - D_{10})$:	273.7	1.613
(D_{75} / D_{25}):	1.615	1.344
$(D_{75} - D_{25})$:	94.44	0.692

GRAIN SIZE DISTRIBUTION

GRAVEL:	0.1%	COARSE SAND:	3.1%
SAND:	99.9%	MEDIUM SAND:	20.1%
MUD:	0.0%	FINE SAND:	72.3%
		V FINE SAND:	3.6%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.0%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	0.0%	FINE SILT:	0.0%
V FINE GRAVEL:	0.1%	V FINE SILT:	0.0%
V COARSE SAND:	0.7%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	252.8	211.0	2.245	208.6	2.261	Fine Sand
SORTING (σ):	189.9	1.537	0.620	1.516	0.601	Moderately Well Sorted
SKEWNESS (Sk):	6.597	1.630	-1.630	0.296	-0.296	Coarse Skewed
KURTOSIS (K):	72.22	7.575	7.575	1.144	1.144	Leptokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **C17**

ANALYST & DATE: Miguel, Jun 8th 2022

SAMPLE TYPE: Unimodal, Moderately Sorted

TEXTURAL GROUP: Sand

SEDIMENT NAME: Moderately Sorted Fine Sand

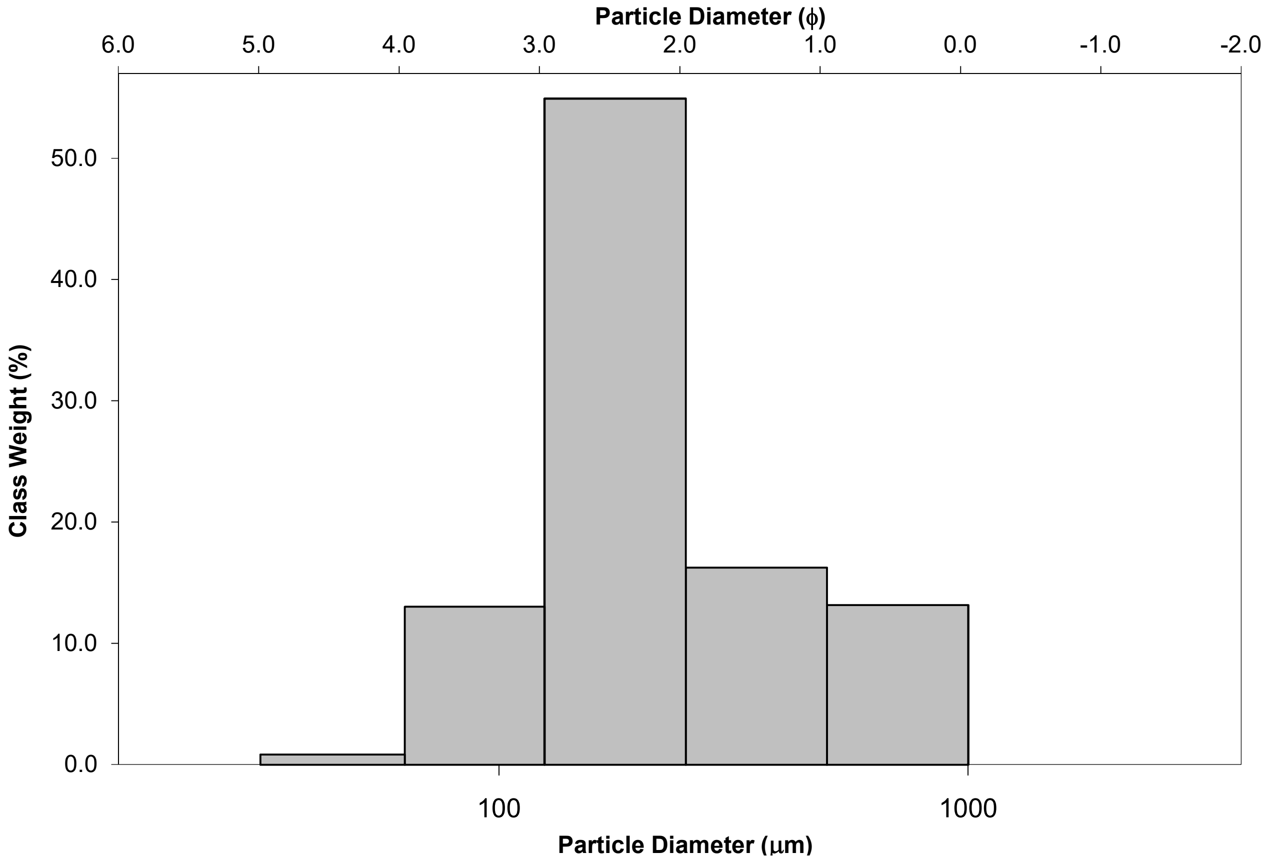
	μm	ϕ
MODE 1:	187.5	2.500
MODE 2:		
MODE 3:		
D_{10}:	101.4	0.745
MEDIAN or D_{50}:	195.2	2.357
D_{90}:	596.8	3.302
(D_{90} / D_{10}):	5.886	4.434
(D_{90} - D_{10}):	495.4	2.557
(D_{75} / D_{25}):	2.152	1.651
(D_{75} - D_{25}):	165.0	1.106

GRAIN SIZE DISTRIBUTION

GRAVEL:	0.0%	COARSE SAND:	13.4%
SAND:	99.1%	MEDIUM SAND:	16.6%
MUD:	0.9%	FINE SAND:	56.0%
		V FINE SAND:	13.1%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.9%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	0.0%	FINE SILT:	0.0%
V FINE GRAVEL:	0.0%	V FINE SILT:	0.0%
V COARSE SAND:	0.0%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	280.6	215.6	2.214	223.9	2.159	Fine Sand
SORTING (σ):	202.4	1.849	0.887	1.936	0.953	Moderately Sorted
SKEWNESS (Sk):	1.521	0.491	-0.491	0.265	-0.265	Coarse Skewed
KURTOSIS (K):	4.028	2.912	2.912	1.225	1.225	Leptokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **C18**

ANALYST & DATE: Miguel, Jun 8th 2022

SAMPLE TYPE: Bimodal, Poorly Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Fine Sand

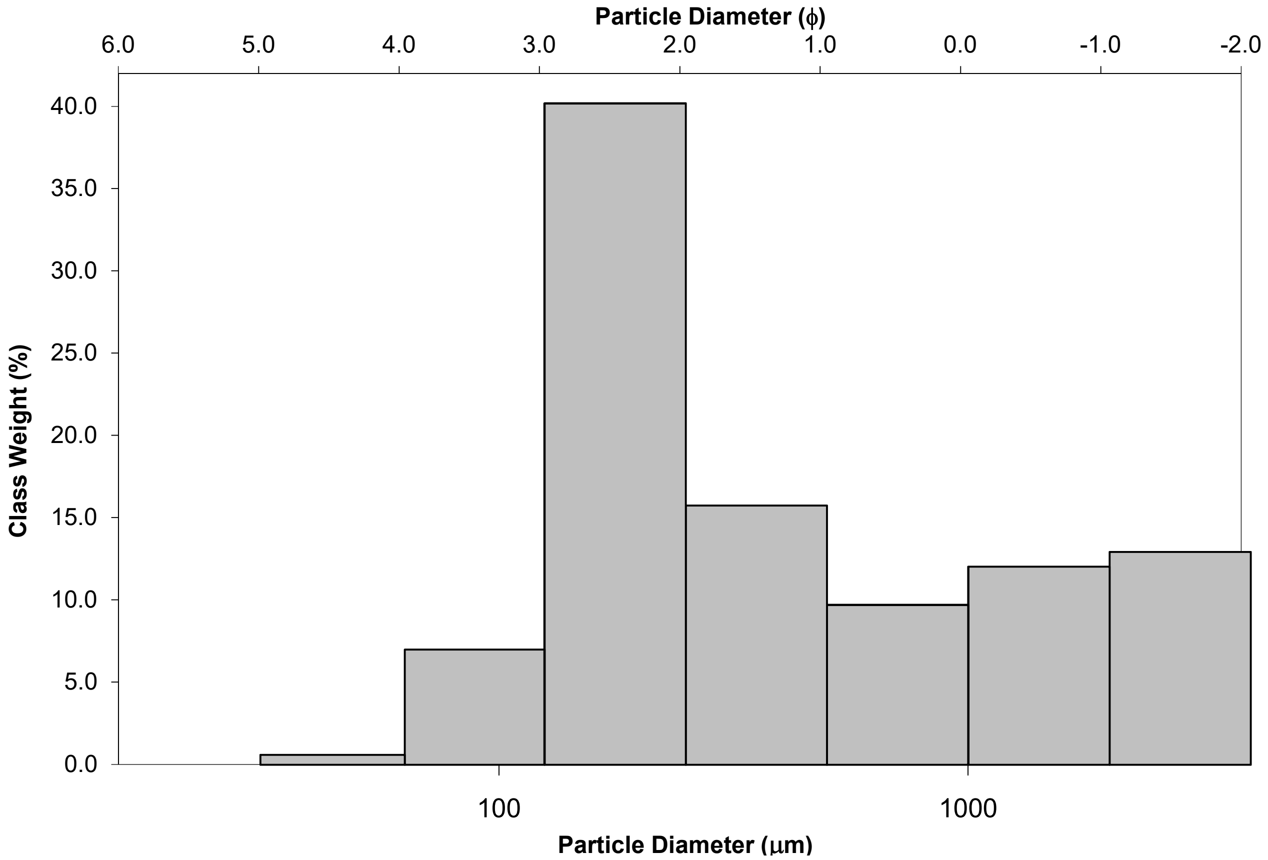
	μm	ϕ
MODE 1:	187.5	2.500
MODE 2:	3000.0	-1.500
MODE 3:		
D_{10}:	132.0	-1.848
MEDIAN or D_{50}:	321.5	1.637
D_{90}:	3599.0	2.922
(D_{90} / D_{10}):	27.27	-1.581
$(D_{90} - D_{10})$:	3467.0	4.769
(D_{75} / D_{25}):	8.583	-4.359
$(D_{75} - D_{25})$:	1319.6	3.102

GRAIN SIZE DISTRIBUTION

GRAVEL:	20.3%	COARSE SAND:	9.1%
SAND:	79.2%	MEDIUM SAND:	14.7%
MUD:	0.6%	FINE SAND:	37.6%
		V FINE SAND:	6.5%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.6%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	0.0%	FINE SILT:	0.0%
V FINE GRAVEL:	20.3%	V FINE SILT:	0.0%
V COARSE SAND:	11.3%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	732.2	244.2	1.221	494.5	1.016	Medium Sand
SORTING (σ):	944.4	6.996	1.556	3.286	1.716	Poorly Sorted
SKEWNESS (Sk):	1.596	-1.516	-0.381	0.357	-0.357	Very Coarse Skewed
KURTOSIS (K):	4.161	5.599	1.916	0.600	0.600	Very Platykurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **C19** ANALYST & DATE: Miguel, Jun 8th 2022

SAMPLE TYPE: Unimodal, Moderately Well Sorted TEXTURAL GROUP: Slightly Gravelly Sand

SEDIMENT NAME: Slightly Very Fine Gravelly Fine Sand

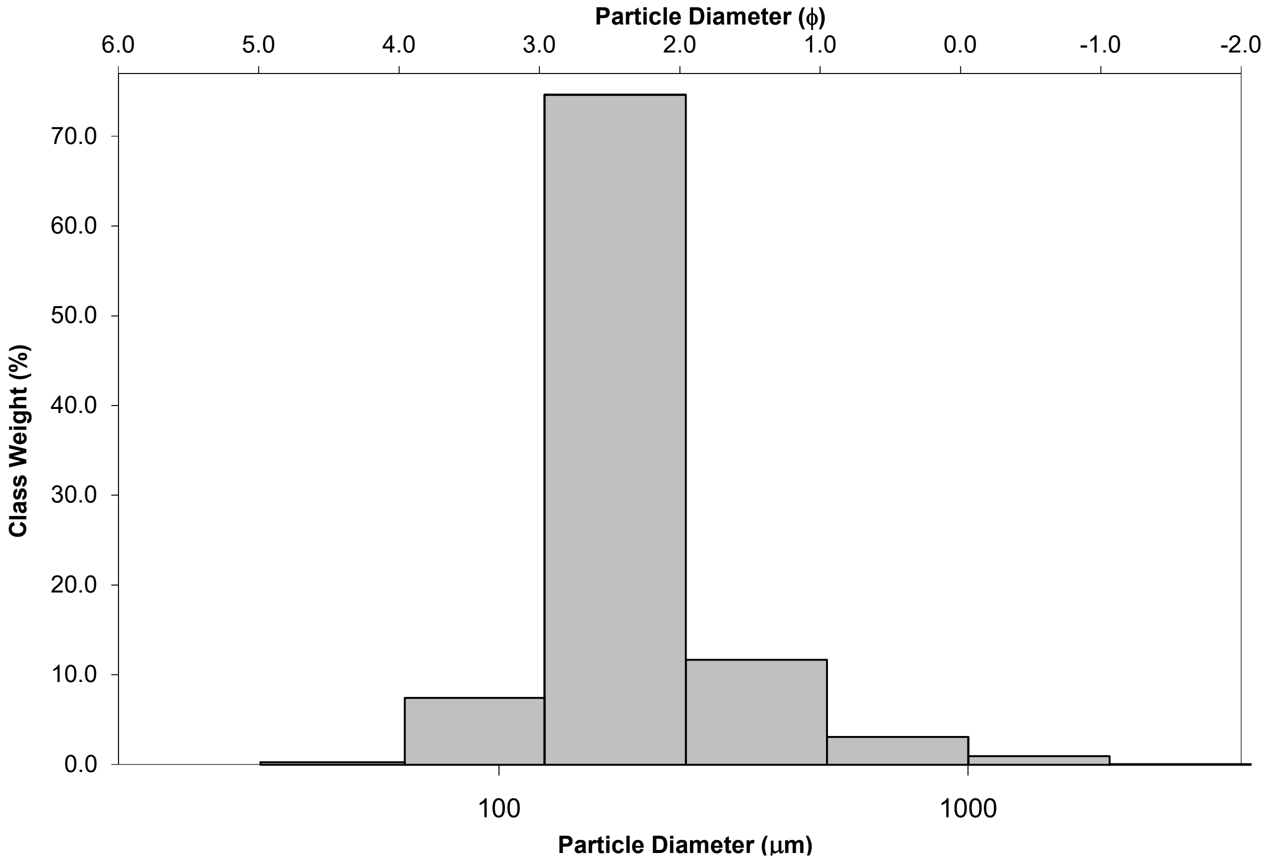
	μm	φ
MODE 1:	187.5	2.500
MODE 2:		
MODE 3:		
D_{10}:	127.5	1.485
MEDIAN or D_{50}:	183.6	2.445
D_{90}:	357.3	2.972
(D_{90} / D_{10}):	2.803	2.001
$(D_{90} - D_{10})$:	229.8	1.487
(D_{75} / D_{25}):	1.578	1.311
$(D_{75} - D_{25})$:	84.43	0.658

GRAIN SIZE DISTRIBUTION

GRAVEL:	0.1%	COARSE SAND:	3.2%
SAND:	99.6%	MEDIUM SAND:	11.9%
MUD:	0.3%	FINE SAND:	76.0%
		V FINE SAND:	7.5%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.3%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	0.0%	FINE SILT:	0.0%
V FINE GRAVEL:	0.1%	V FINE SILT:	0.0%
V COARSE SAND:	1.0%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic φ	Geometric μm	Logarithmic φ	Description
MEAN ($\bar{x}$):	234.8	193.9	2.367	184.0	2.442	Fine Sand
SORTING (σ):	185.5	1.562	0.643	1.491	0.576	Moderately Well Sorted
SKEWNESS (Sk):	5.807	1.540	-1.540	0.103	-0.103	Coarse Skewed
KURTOSIS (K):	53.22	8.410	8.410	1.438	1.438	Leptokurtic

GRAIN SIZE DISTRIBUTION



SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **Tipo**

ANALYST & DATE: Miguel, Jun 8th 2022

SAMPLE TYPE: Unimodal, Poorly Sorted

TEXTURAL GROUP: Gravelly Sand

SEDIMENT NAME: Very Fine Gravelly Fine Sand

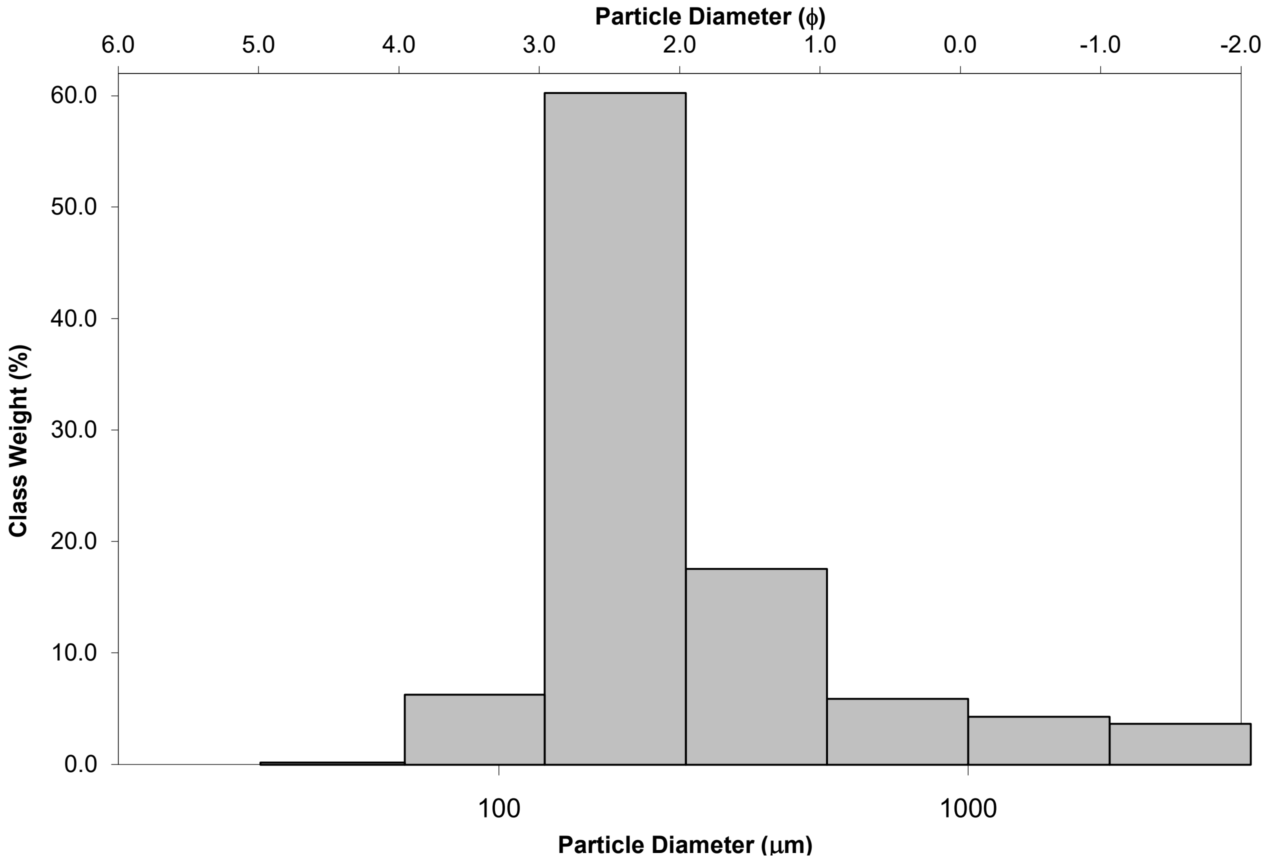
	μm	ϕ
MODE 1:	187.5	2.500
MODE 2:		
MODE 3:		
D_{10}:	130.4	-0.177
MEDIAN or D_{50}:	207.6	2.268
D_{90}:	1130.7	2.939
(D_{90} / D_{10}):	8.672	-16.584
(D_{90} - D_{10}):	1000.3	3.116
(D_{75} / D_{25}):	2.307	1.814
(D_{75} - D_{25}):	202.9	1.206

GRAIN SIZE DISTRIBUTION

GRAVEL:	6.5%	COARSE SAND:	5.9%
SAND:	93.3%	MEDIUM SAND:	17.4%
MUD:	0.2%	FINE SAND:	59.6%
		V FINE SAND:	6.2%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.2%
COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
FINE GRAVEL:	0.0%	FINE SILT:	0.0%
V FINE GRAVEL:	6.5%	V FINE SILT:	0.0%
V COARSE SAND:	4.3%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	400.3	215.8	1.929	250.0	2.000	Medium Sand
SORTING (σ):	585.4	3.286	1.139	2.277	1.187	Poorly Sorted
SKEWNESS (Sk):	3.438	-2.044	-1.412	0.501	-0.501	Very Coarse Skewed
KURTOSIS (K):	14.72	12.98	4.572	1.572	1.572	Very Leptokurtic

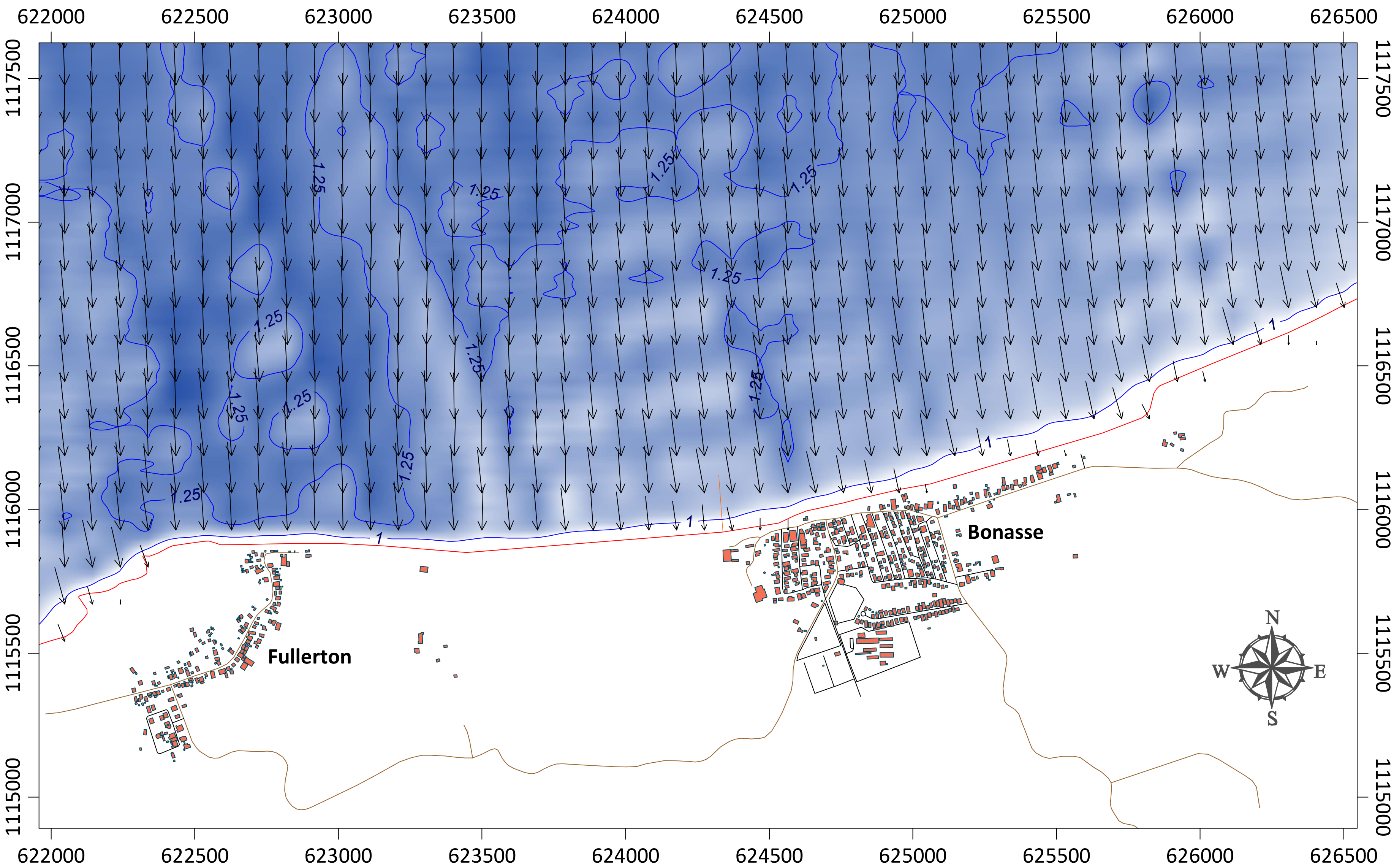
GRAIN SIZE DISTRIBUTION



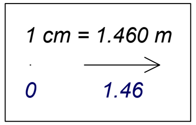
ANNEX 3

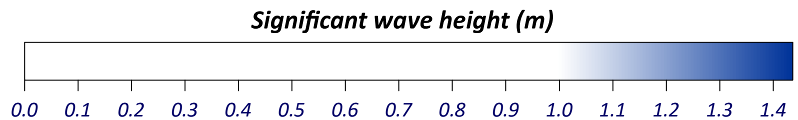
Results of mathematical modeling

Graph: Isolines and significant wave height vectors. Usual swell, north direction.

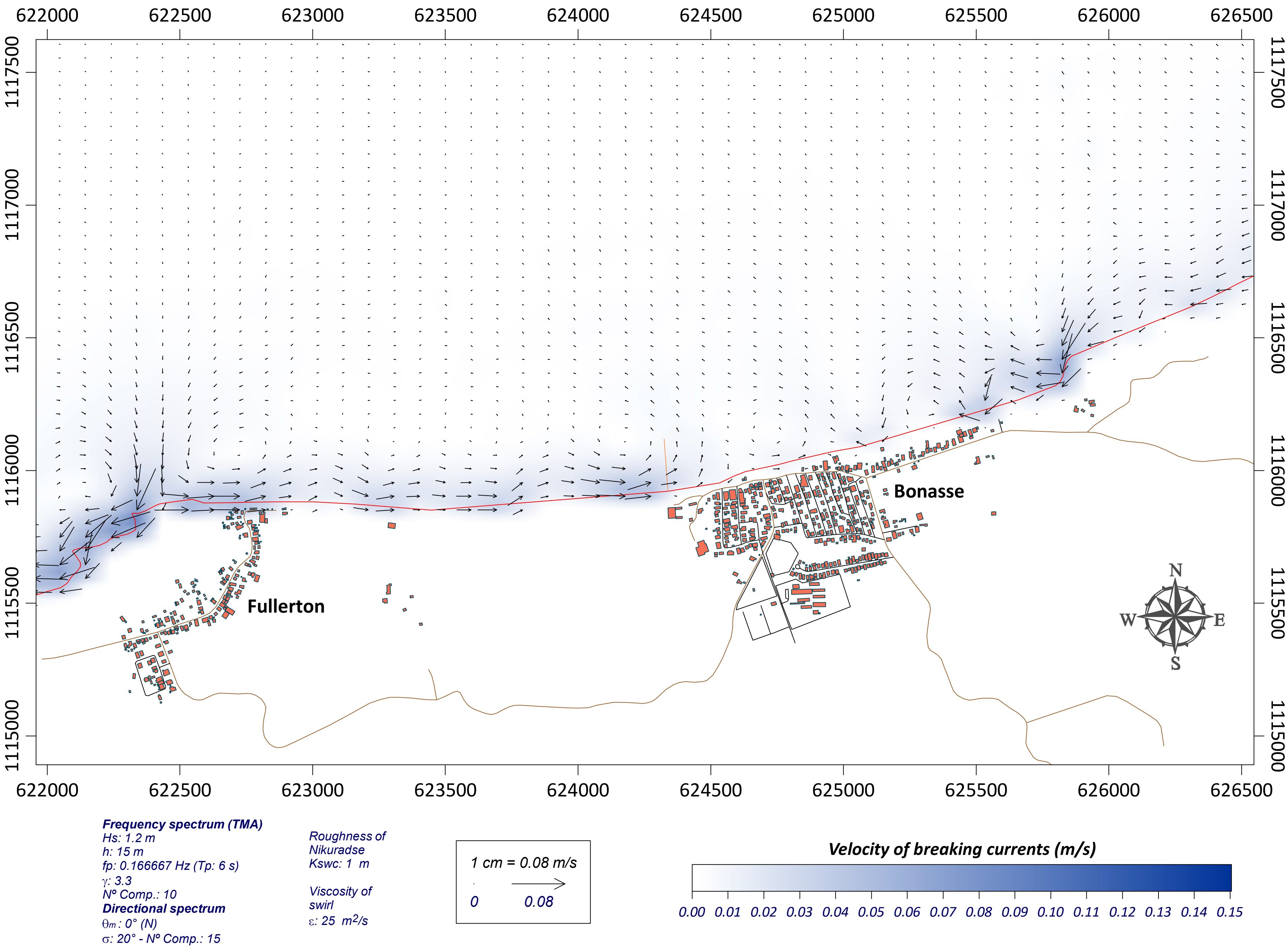


Frequency spectrum (TMA)
Hs: 1.2 m
h: 15 m
fp: 0.166667 Hz (Tp: 6 s)
γ: 3.3
Nº Comp.: 10
Directional spectrum
θm : 0° (N)
σ: 20° - Nº Comp.: 15

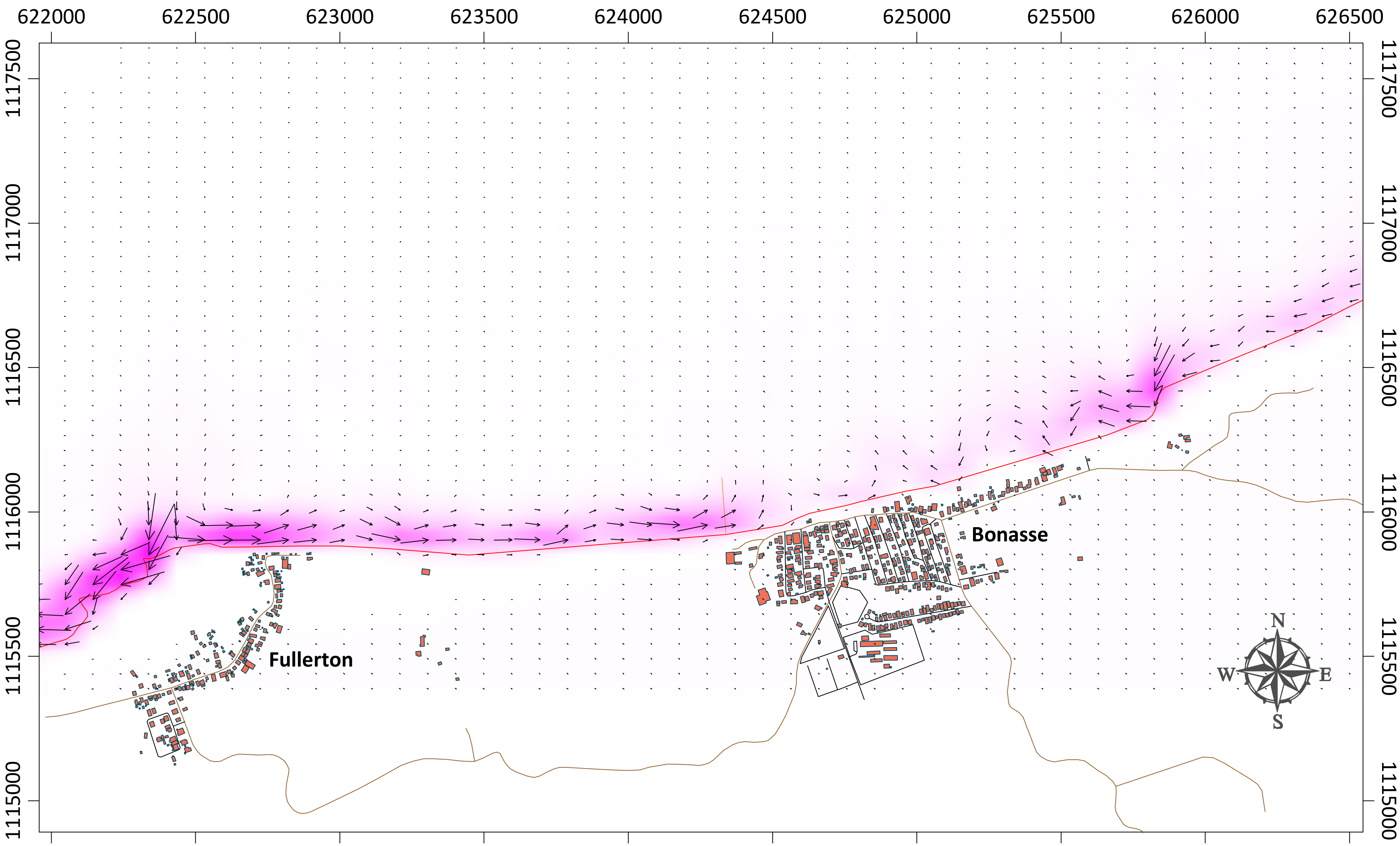




Graph: Vectors and magnitude of breaking currents. Usual swell, north direction.



Graph: Vectors and magnitude of sediment transport. Usual swell, north direction.



Frequency spectrum (TMA)
Hs: 1.2 m
h: 15 m
fp: 0.166667 Hz (Tp: 6 s)
γ: 3.3
Nº Comp.: 10
Directional spectrum
θ_m: 0° (N)
σ: 20° - Nº Comp.: 15

Roughness of Nikuradse
Kswc: 1 m

Viscosity of swirl
ε: 25 m²/s

D_{50}: 0.20 mm

Duration: 24.0 h

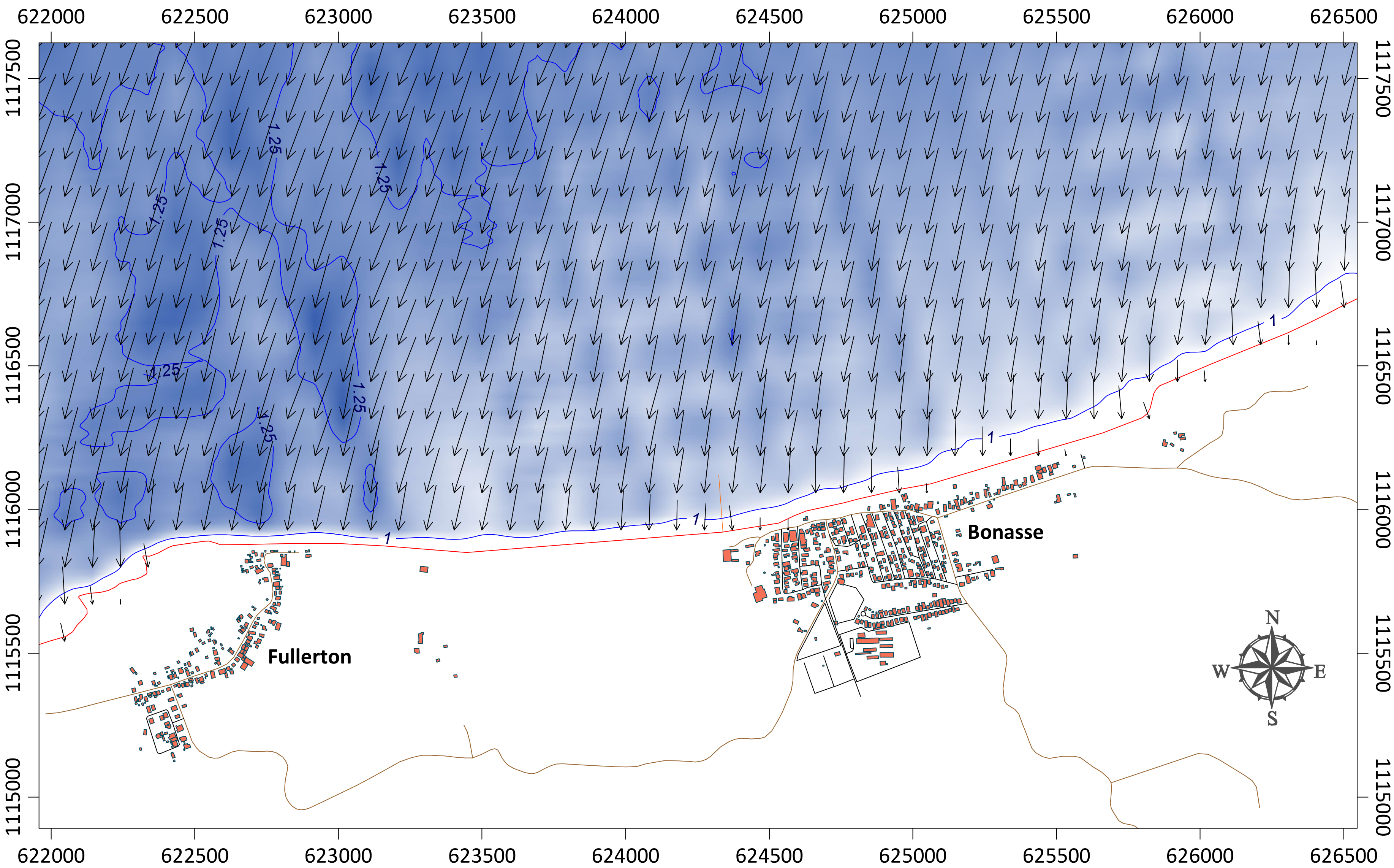
Formulation: Soulsby

1 cm = 0.040 m³/h/m.l.
0 0.04

Potential transport (m³/hour/m.l.)

0.00 0.01 0.01 0.01 0.02 0.03 0.03 0.04 0.04

Graph: Isolines and significant wave height vectors. Usual swell, north northeast direction.

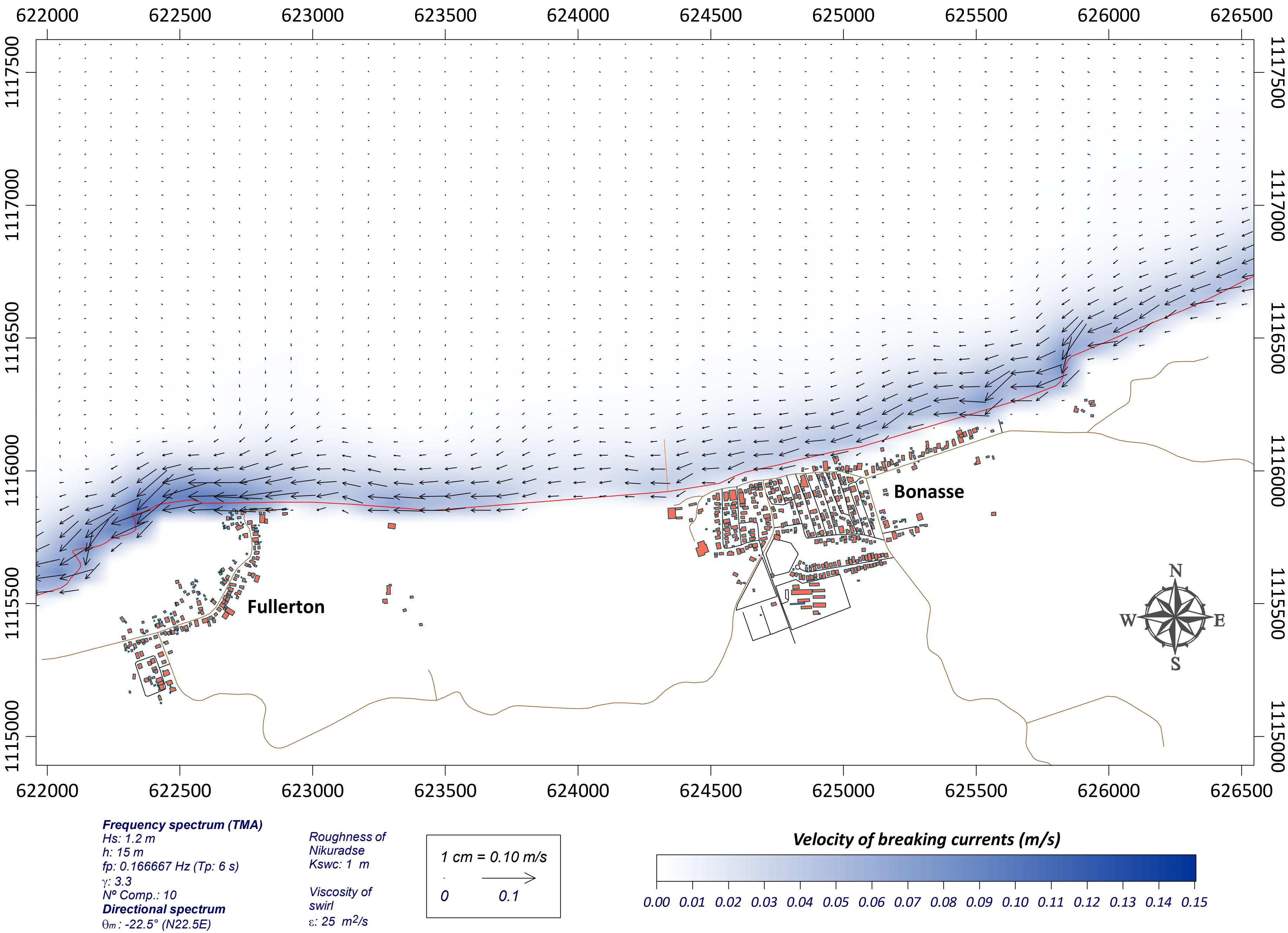


Frequency spectrum (TMA)
Hs: 1.2 m
h: 15 m
fp: 0.166667 Hz (Tp: 6 s)
γ: 3.3
Nº Comp.: 10
Directional spectrum
θm : -22.5° (N22.5E)
σ: 20° - Nº Comp.: 15

1 cm = 1.380 m
0 *1.38*

Significant wave height (m)
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4

Graph: Vectors and magnitude of breaking currents. Usual swell, north northeast direction.

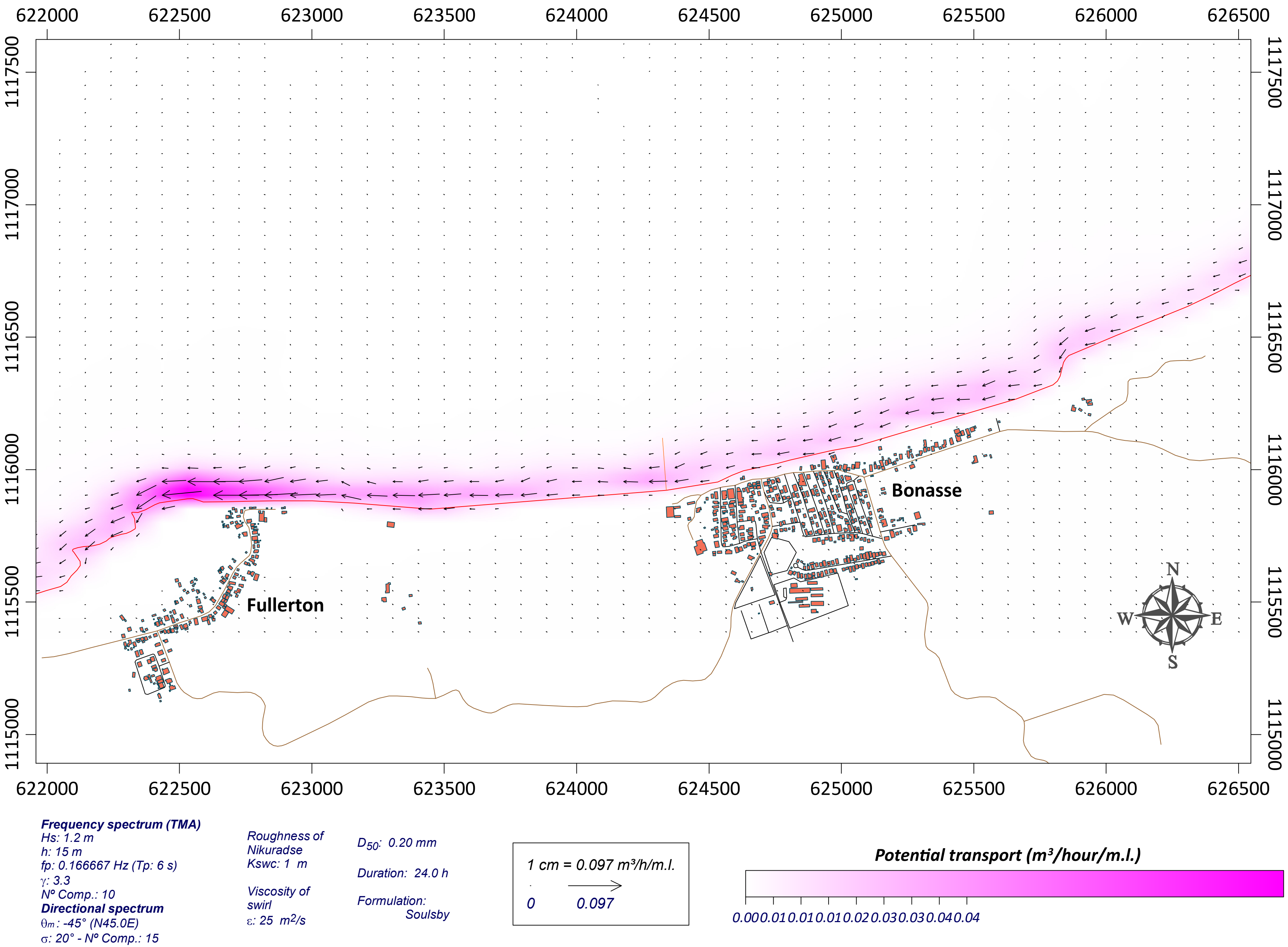


Frequency spectrum (TMA)
Hs: 1.2 m
h: 15 m
fp: 0.166667 Hz (Tp: 6 s)
γ: 3.3
Nº Comp.: 10
Directional spectrum
θm: -22.5° (N22.5E)
σ: 20° - Nº Comp.: 15

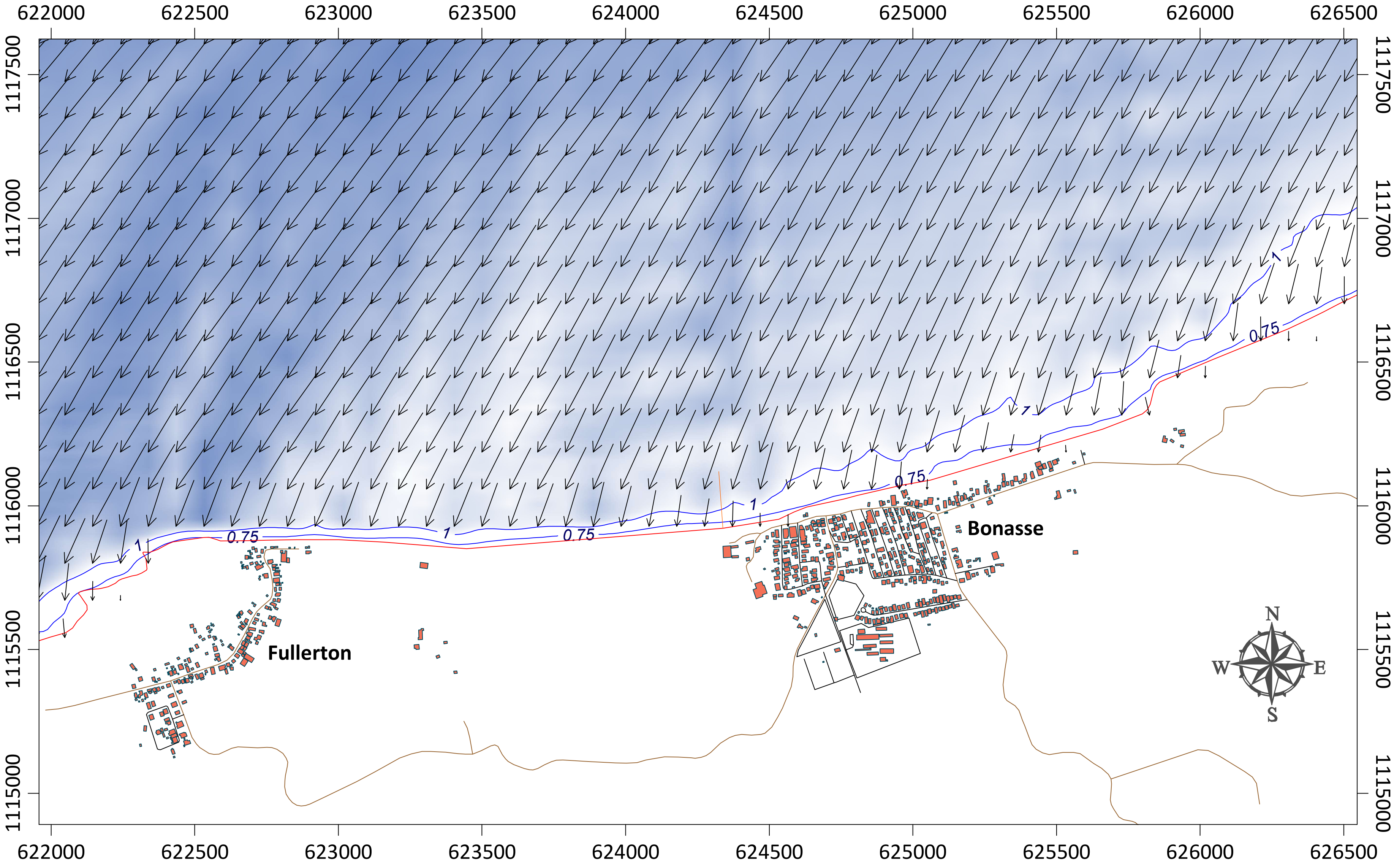
Roughness of Nikuradse
Kswc: 1 m

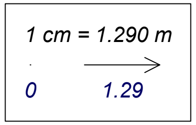
Viscosity of swirl
ε: 25 m²/s

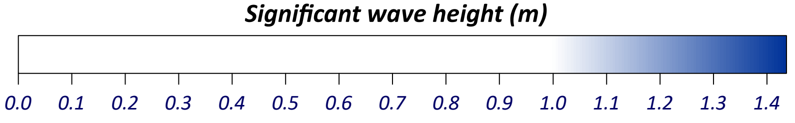
Graph: Vectors and magnitude of sediment transport. Usual swell, northeast direction.



Graph: Isolines and significant wave height vectors. Usual swell, northeast direction.

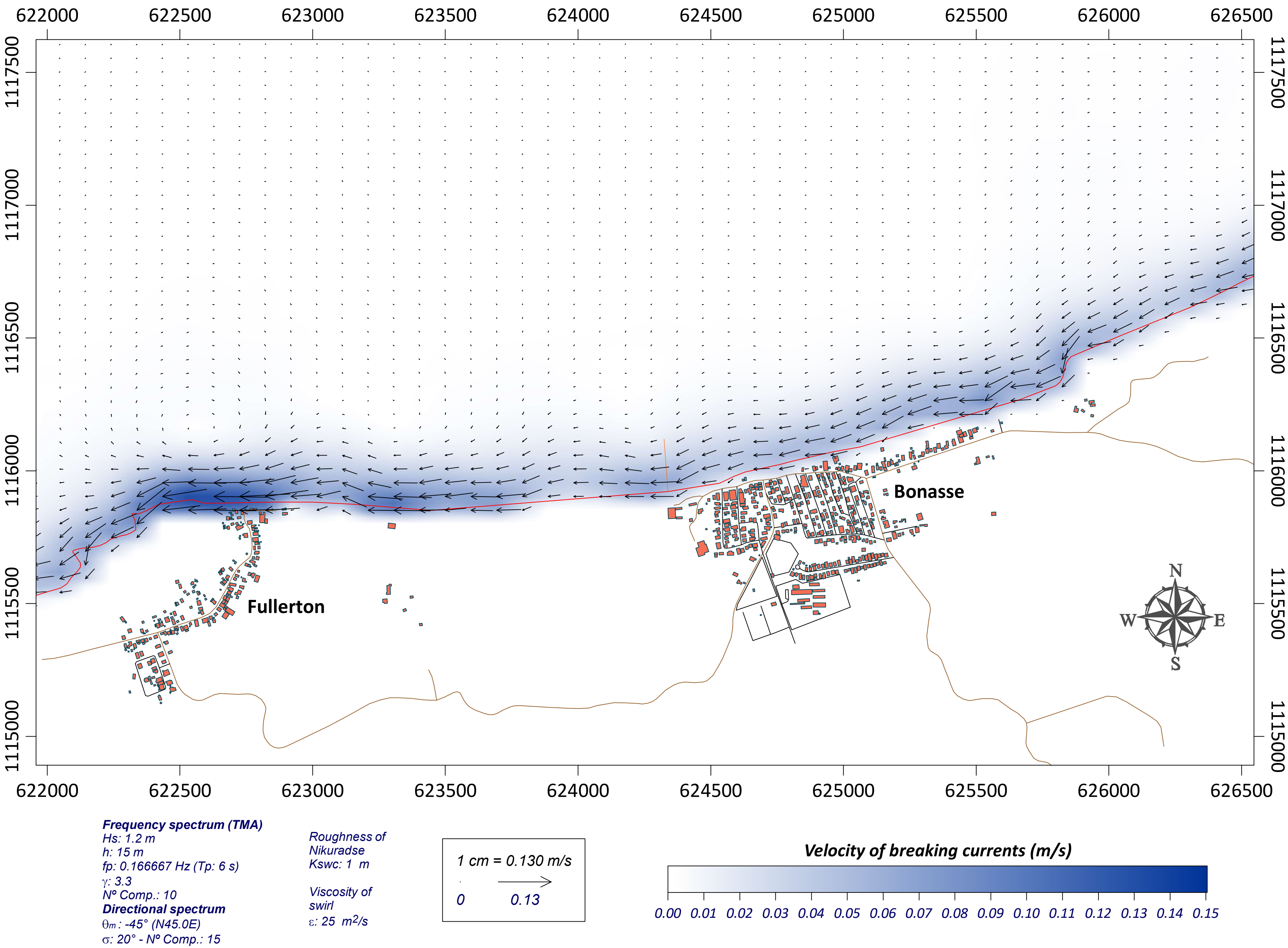




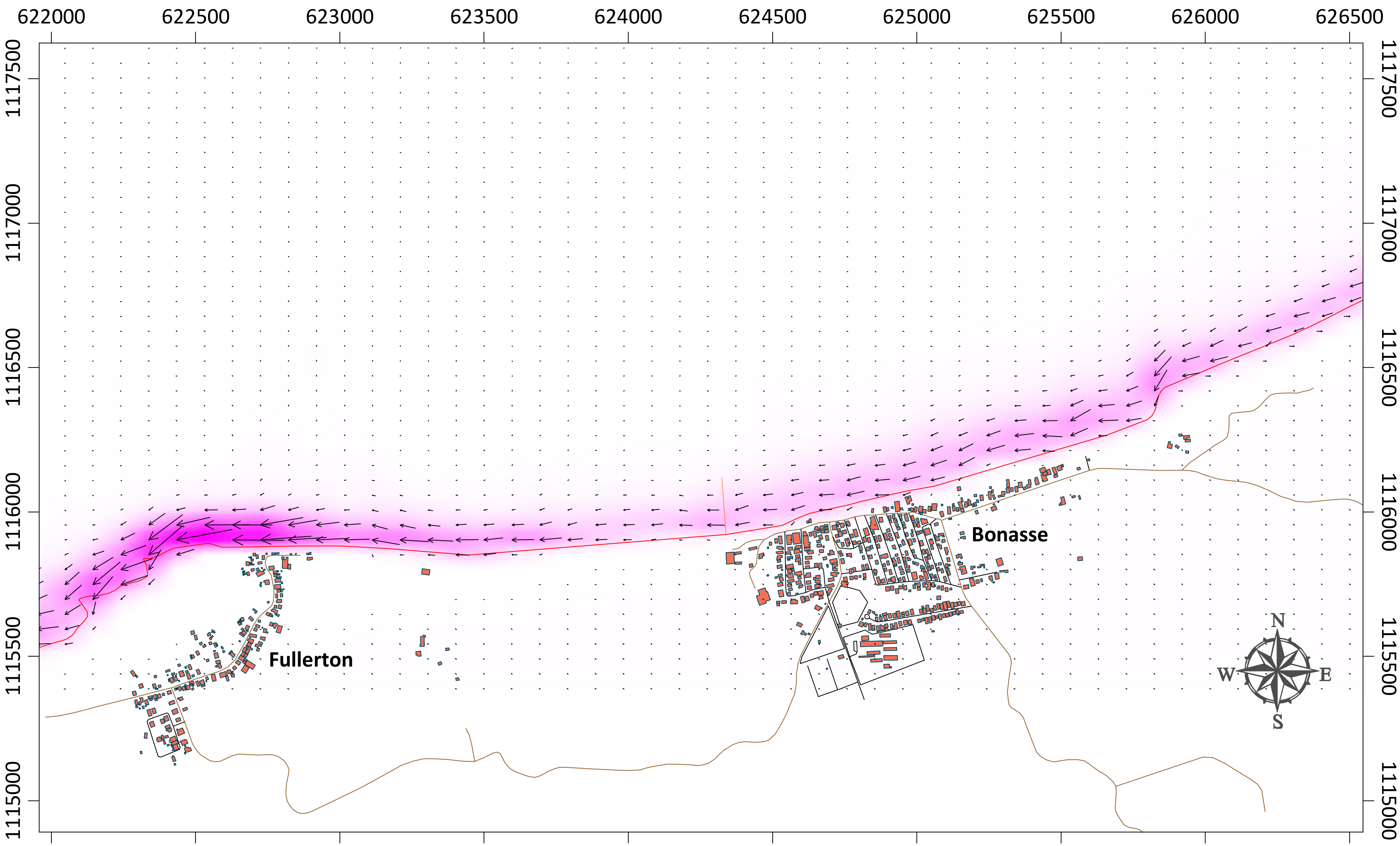


Frequency spectrum (TMA)
Hs: 1.2 m
h: 15 m
fp: 0.166667 Hz (Tp: 6 s)
γ: 3.3
Nº Comp.: 10
Directional spectrum
θm : -45° (N45E)
σ: 20° - Nº Comp.: 15

Graph: Vectors and magnitude of breaking currents. Usual swell, northeast direction.



Graph: Vectors and magnitude of sediment transport. Usual swell, north northeast direction.



Frequency spectrum (TMA)
Hs: 1.2 m
h: 15 m
fp: 0.166667 Hz (Tp: 6 s)
γ: 3.3
Nº Comp.: 10
Directional spectrum
θm: -22.5° (N22.5E)
σ: 20° - Nº Comp.: 15

Roughness of Nikuradse
Kswc: 1 m

Viscosity of swirl
ε: 25 m^2/s

D_{50}: 0.20 mm

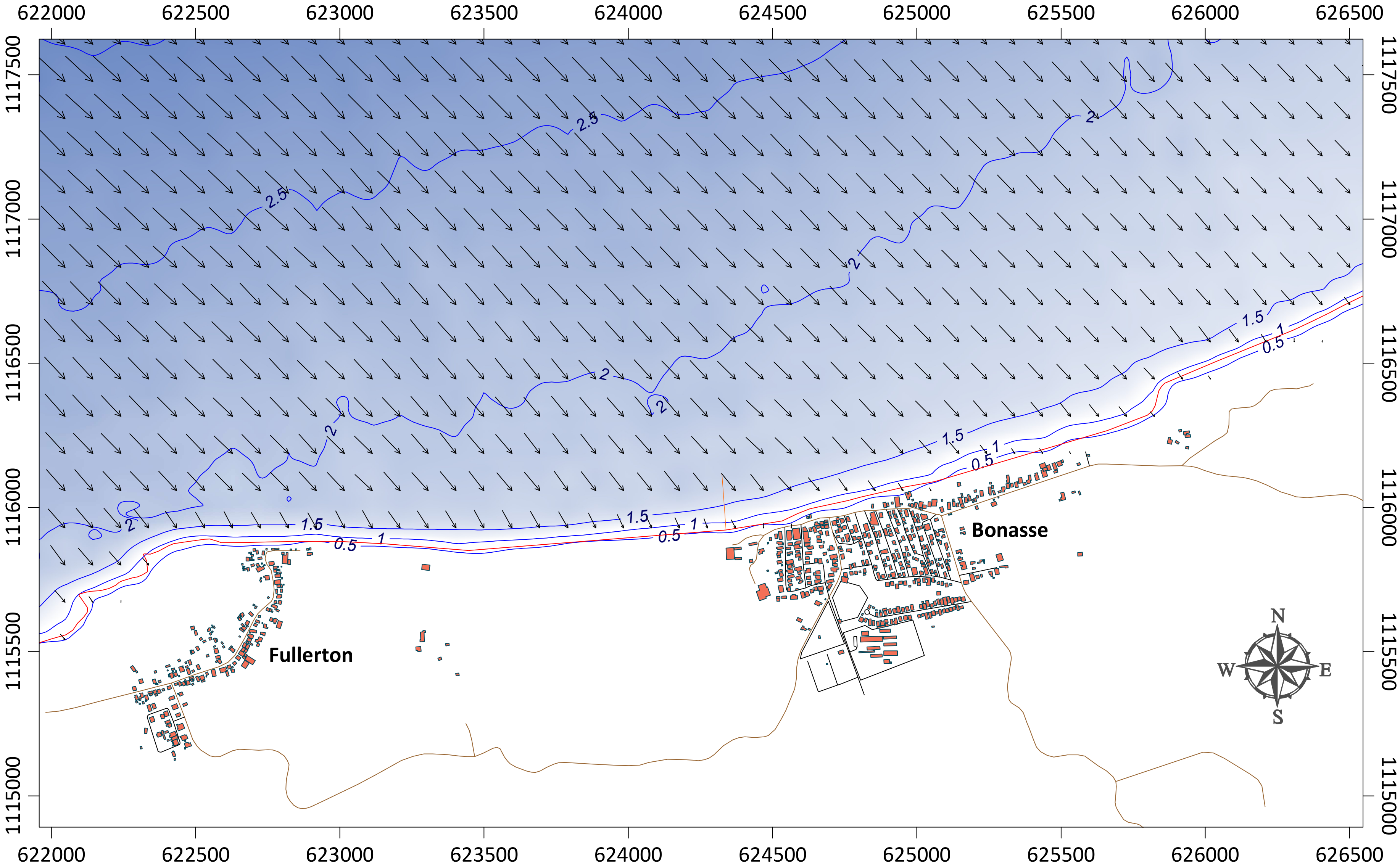
Duration: 24.0 h

Formulation: Soulsby

1 cm = 0.070 $m^3/h/m.l.$
0 0.07

Potential transport (m^3/hour/m.l.)
0.00 0.01 0.01 0.01 0.02 0.03 0.03 0.04 0.04

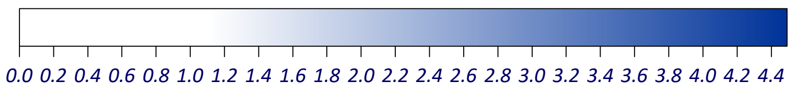
Graph: Isolines and significant wave height vectors. Tropical Depression swell, northwest direction.



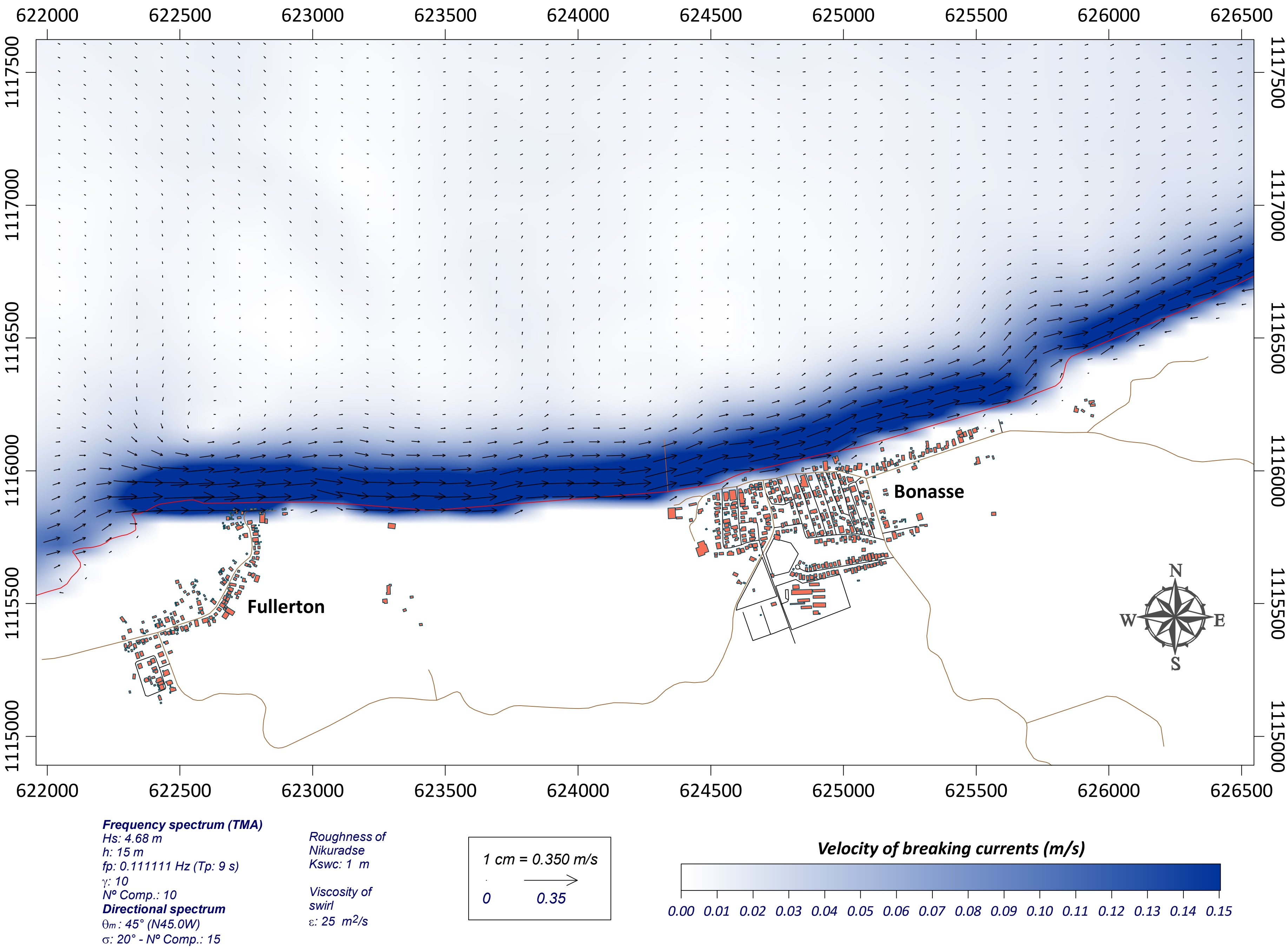
Frequency spectrum (TMA)
Hs: 1.3 m
h: 15 m
fp: 0.166667 Hz (Tp: 6 s)
γ: 3.3
Nº Comp.: 10
Directional spectrum
θm : 45° (N45.0W)
σ: 20° - Nº Comp.: 15

1 cm = 4.500 m
0 *4.5*

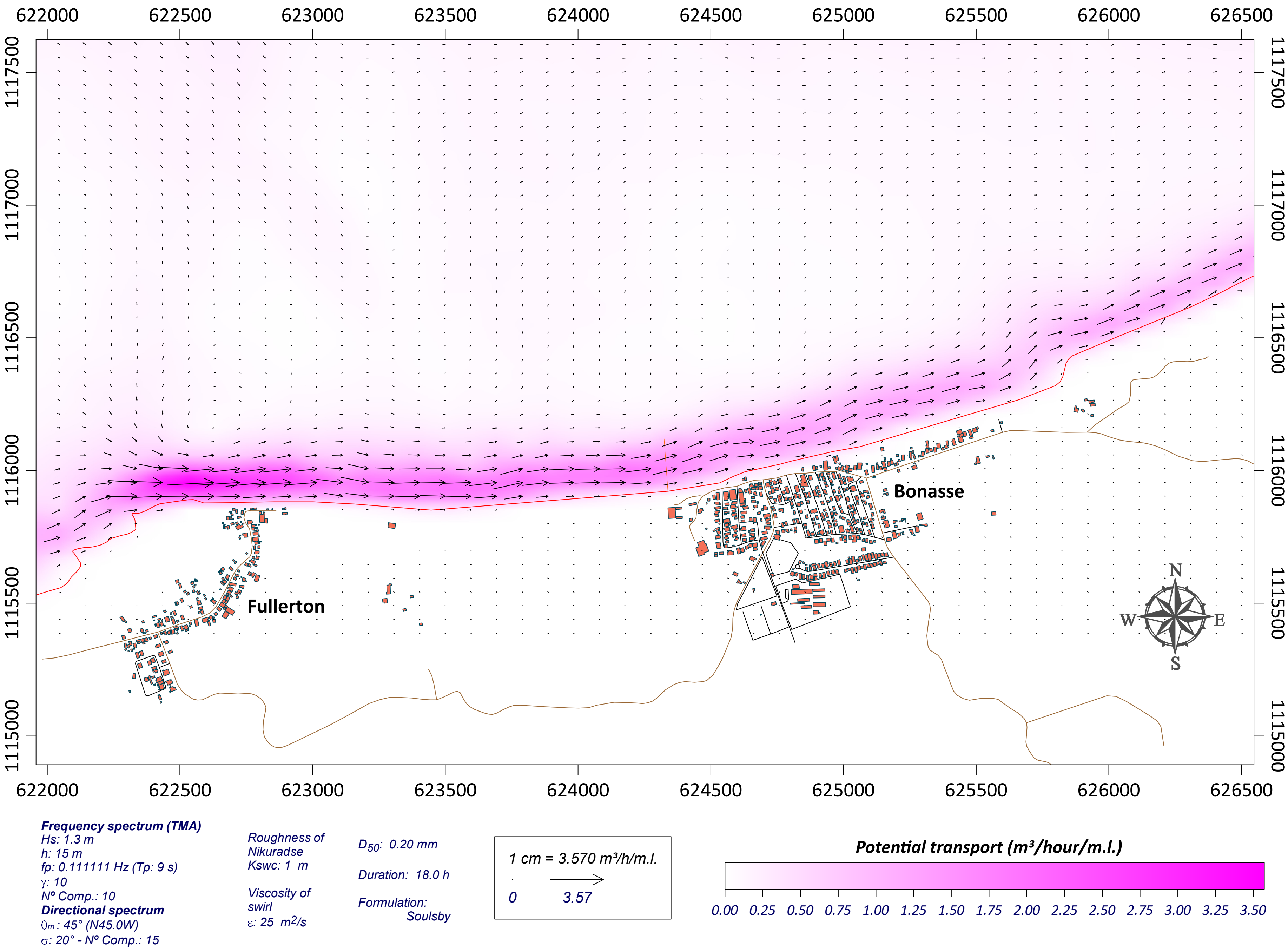
Significant wave height (m)



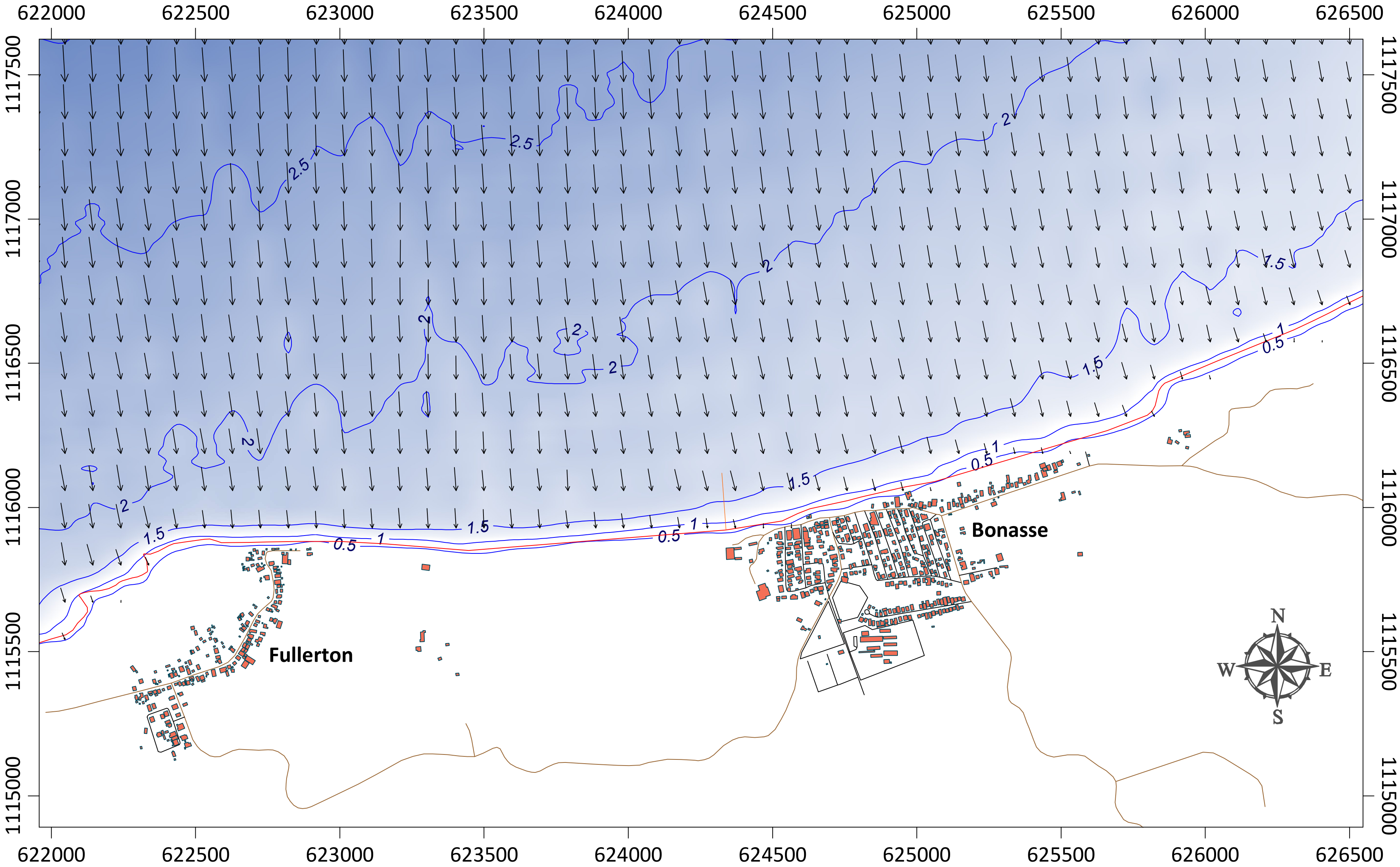
Graph: Vectors and magnitude of breaking currents. Tropical Depression swell, northwest direction.



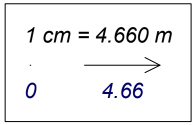
Graph: Vectors and magnitude of sediment transport. Tropical Depression swell, northwest direction.

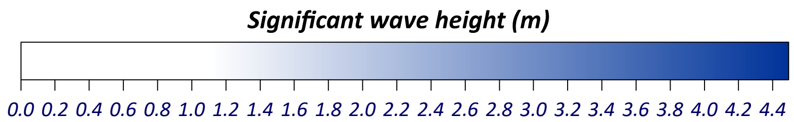


Graph: Isolines and significant wave height vectors. Tropical Depression swell, north direction.

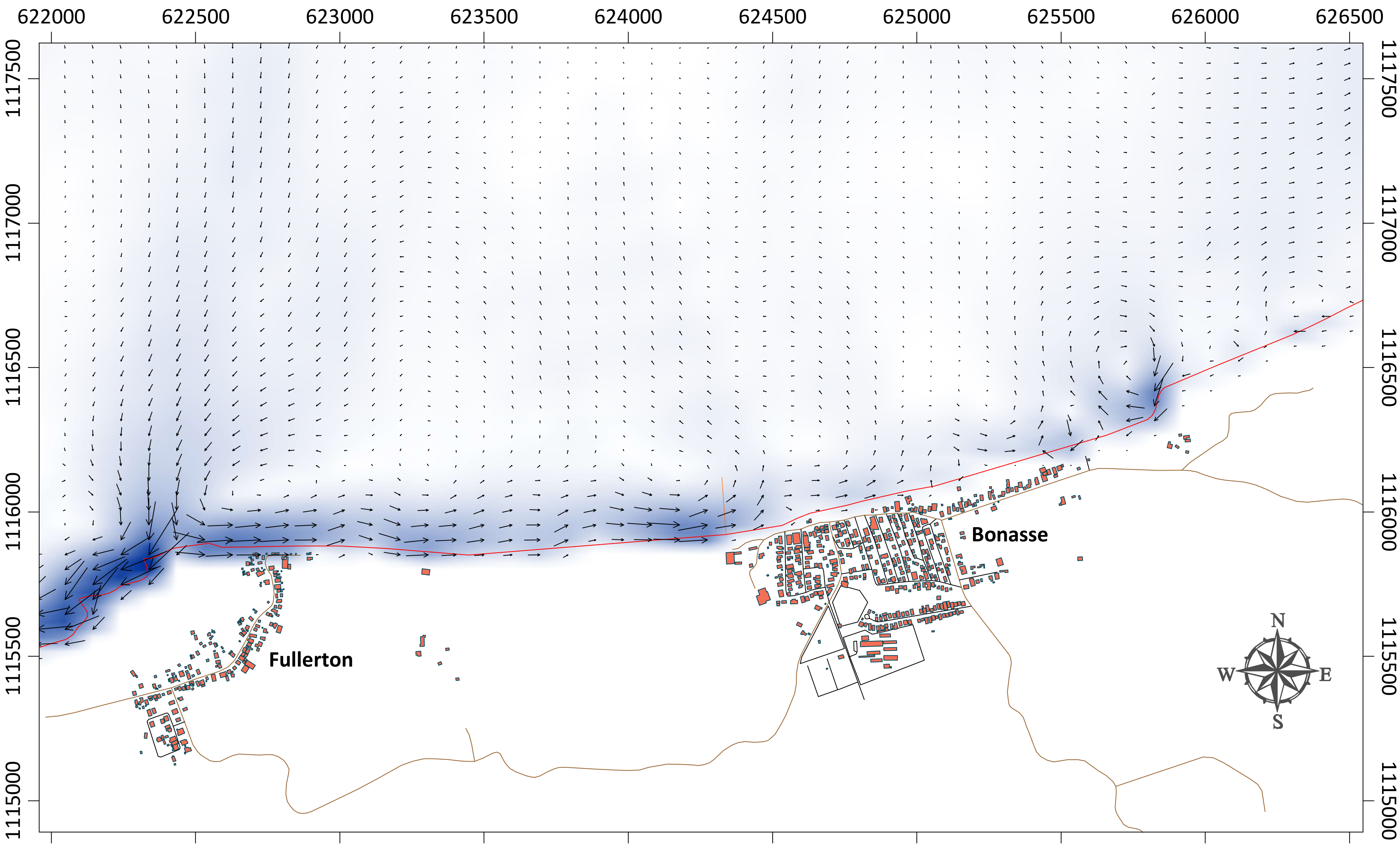


Frequency spectrum (TMA)
Hs: 4.68 m
h: 15 m
fp: 0.111111 Hz (Tp: 9 s)
γ: 10
Nº Comp.: 10
Directional spectrum
θm : 0° (N)
σ: 20° - Nº Comp.: 15





Graph: Vectors and magnitude of breaking currents. Tropical Depression swell, north direction.



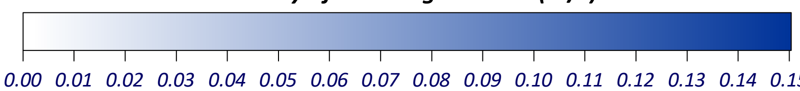
Frequency spectrum (TMA)
Hs: 4.68 m
h: 15 m
fp: 0.111111 Hz (Tp: 9 s)
γ: 10
Nº Comp.: 10
Directional spectrum
θm : 0° (N)
σ: 20° - Nº Comp.: 15

Roughness of Nikuradse
Kswc: 1 m

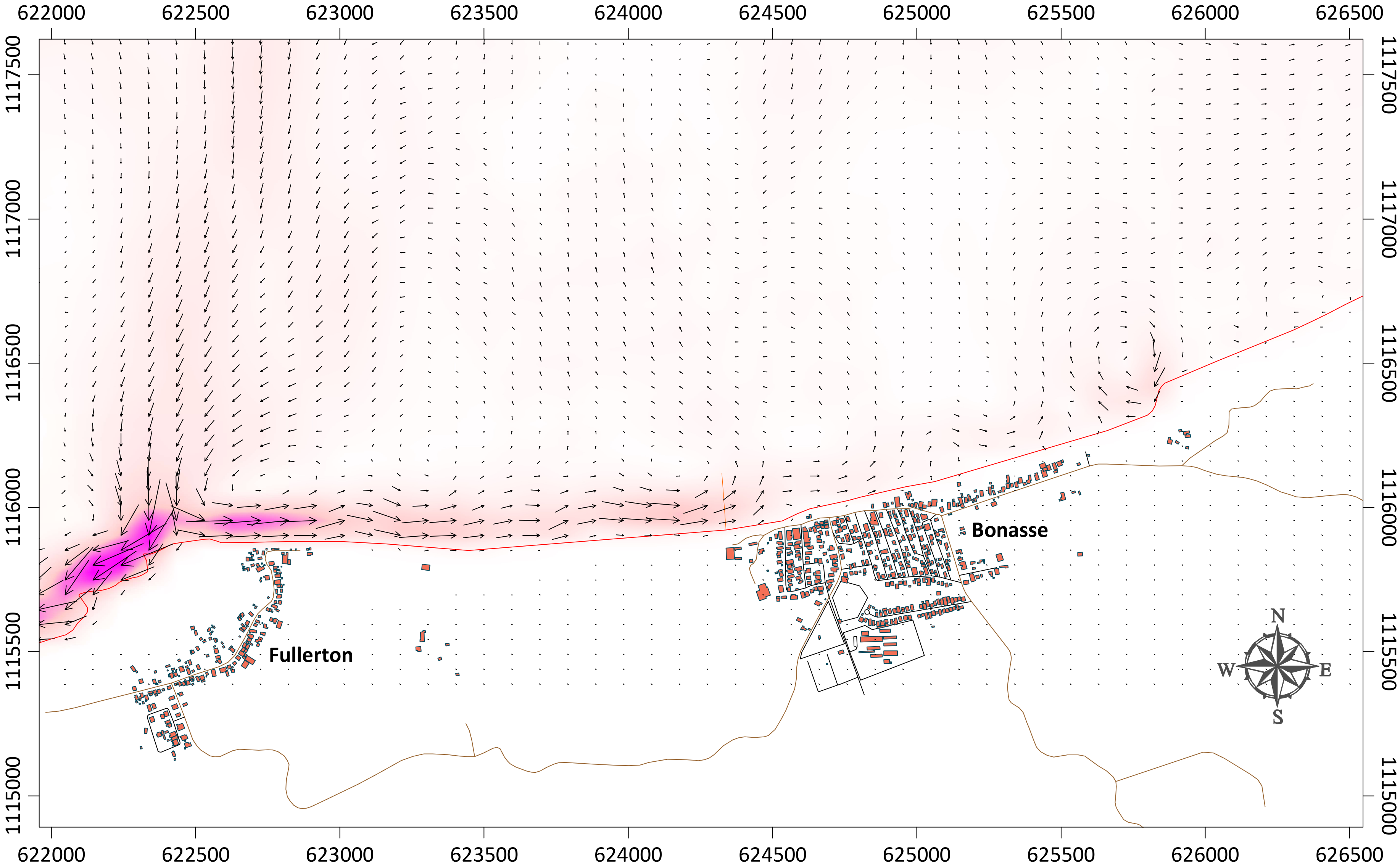
Viscosity of swirl
ε: 25 m²/s

1 cm = 0.160 m/s
0 *0.16*

Velocity of breaking currents (m/s)



Graph: Vectors and magnitude of sediment transport. Tropical Depression swell, north direction.



Frequency spectrum (TMA)
Hs: 1.3 m
h: 15 m
fp: 0.111111 Hz (Tp: 9 s)
γ: 10
Nº Comp.: 10
Directional spectrum
θm : 0° (N)
σ: 20° - Nº Comp.: 15

Roughness of Nikuradse
Kswc: 1 m

Viscosity of swirl
ε: 25 m²/s

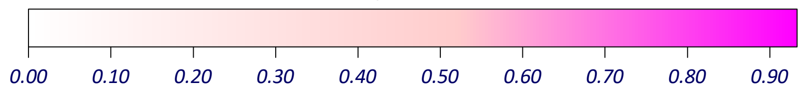
D_{50}: 0.20 mm

Duration: 18.0 h

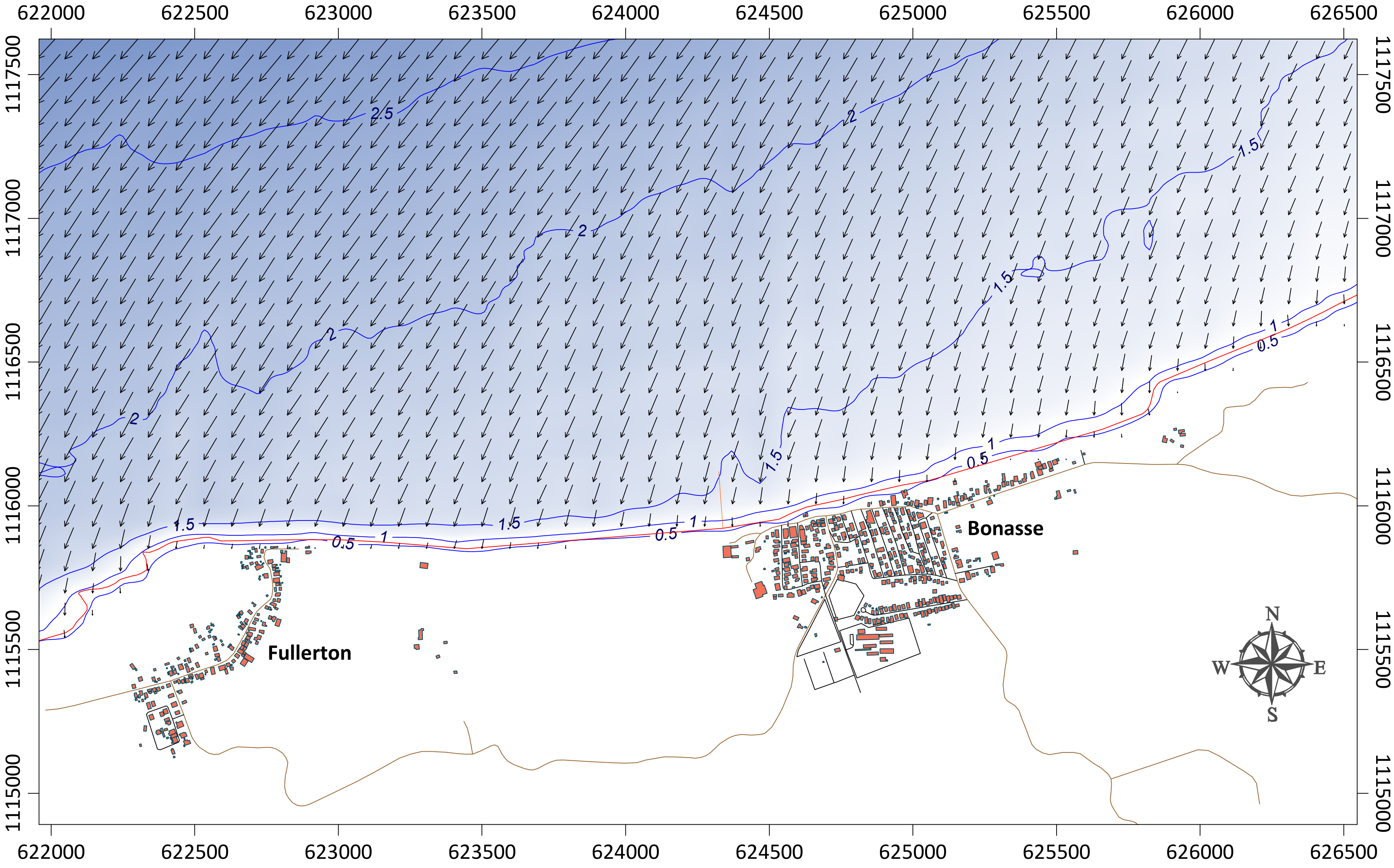
Formulation: Soulsby

1 cm = 0.930 m³/h/m.l.
0 0.93

Potential transport (m³/hour/m.l.)



Graph: Isolines and significant wave height vectors. Tropical Depression swell, northeast direction.

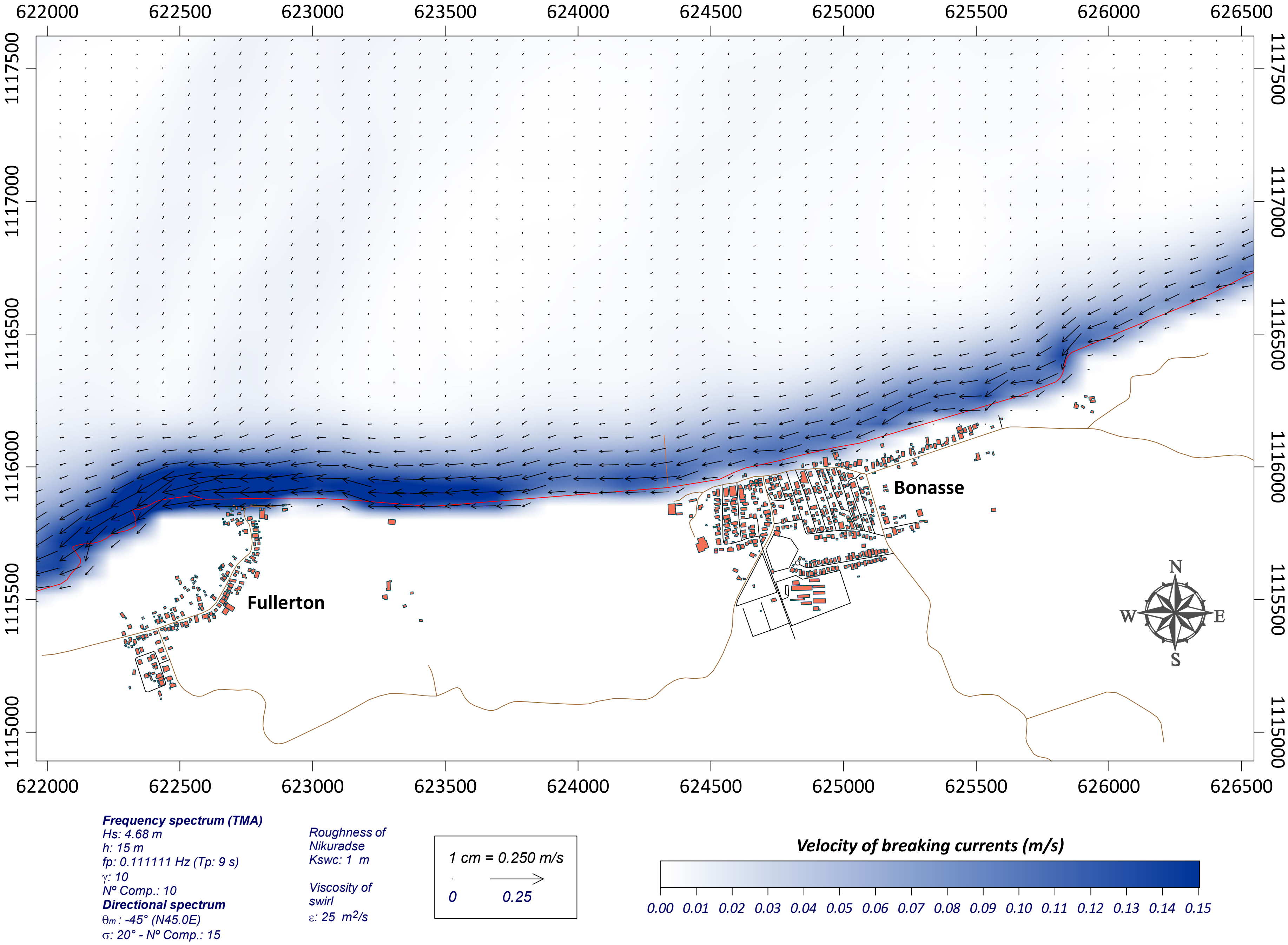


Frequency spectrum (TMA)
Hs: 4.68 m
h: 15 m
fp: 0.111111 Hz (Tp: 9 s)
γ: 10
Nº Comp.: 10
Directional spectrum
θm : -45° (N45.0E)
σ: 20° - Nº Comp.: 15

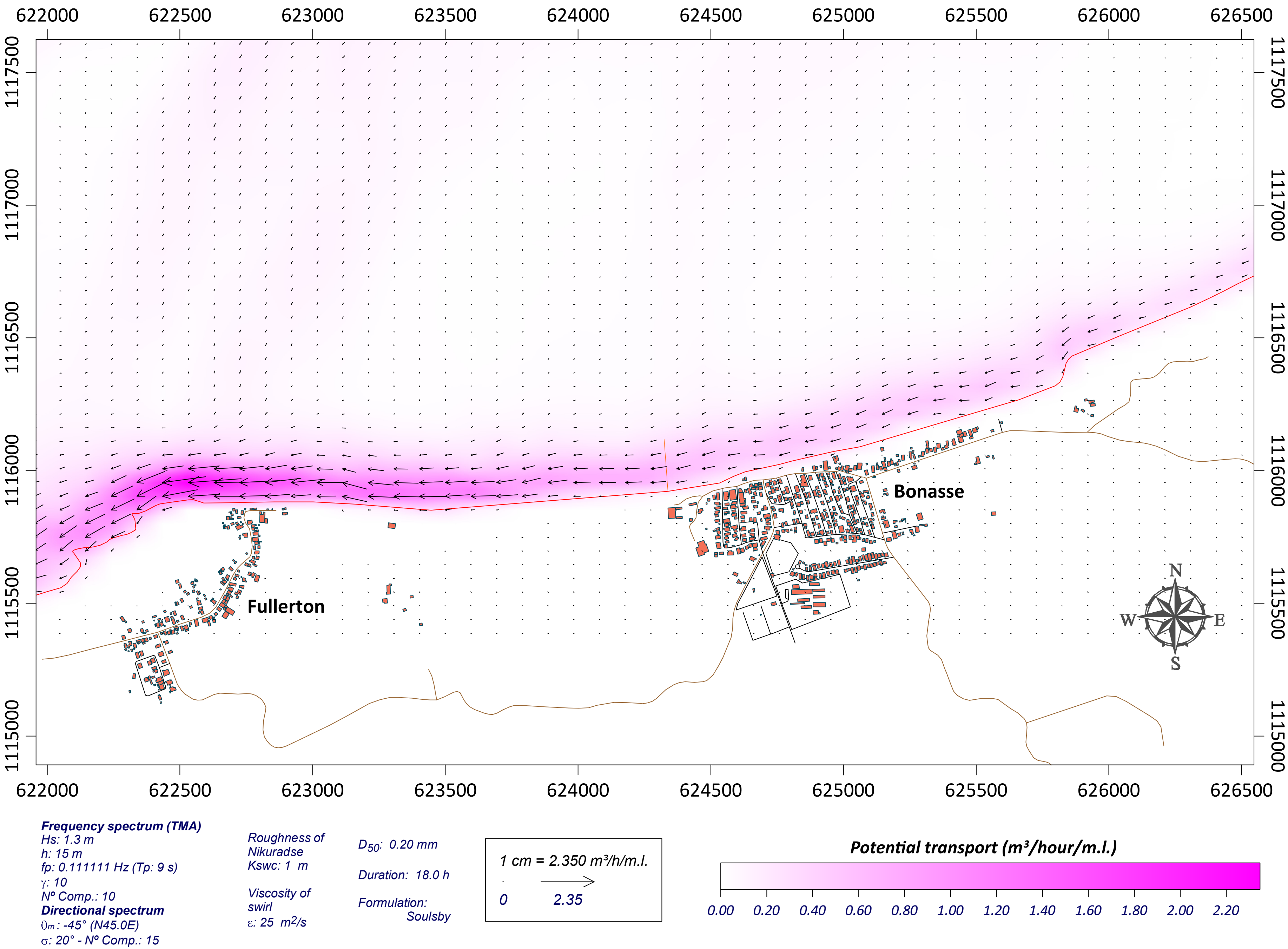
1 cm = 4.500 m
0 *4.5*

Significant wave height (m)
0.0 0.3 0.6 0.9 1.2 1.5 1.8 2.1 2.4 2.7 3.0 3.3 3.6 3.9 4.2

Graph: Vectors and magnitude of breaking currents. Tropical Depression swell, northeast direction.



Graph: Vectors and magnitude of sediment transport. Tropical Depression swell, northeast direction.



PLANS

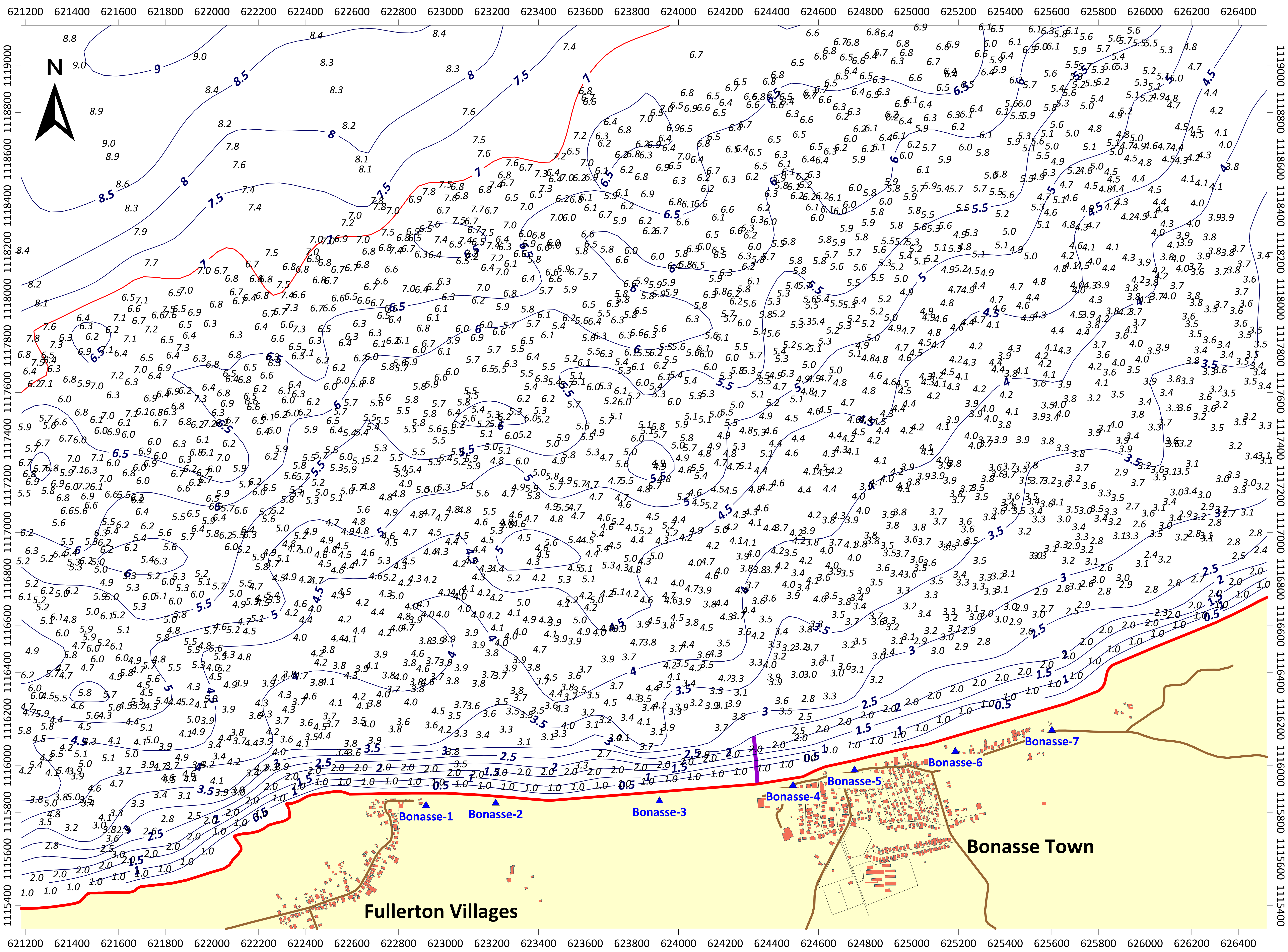
Plan 1. Bathymetry of the beach.

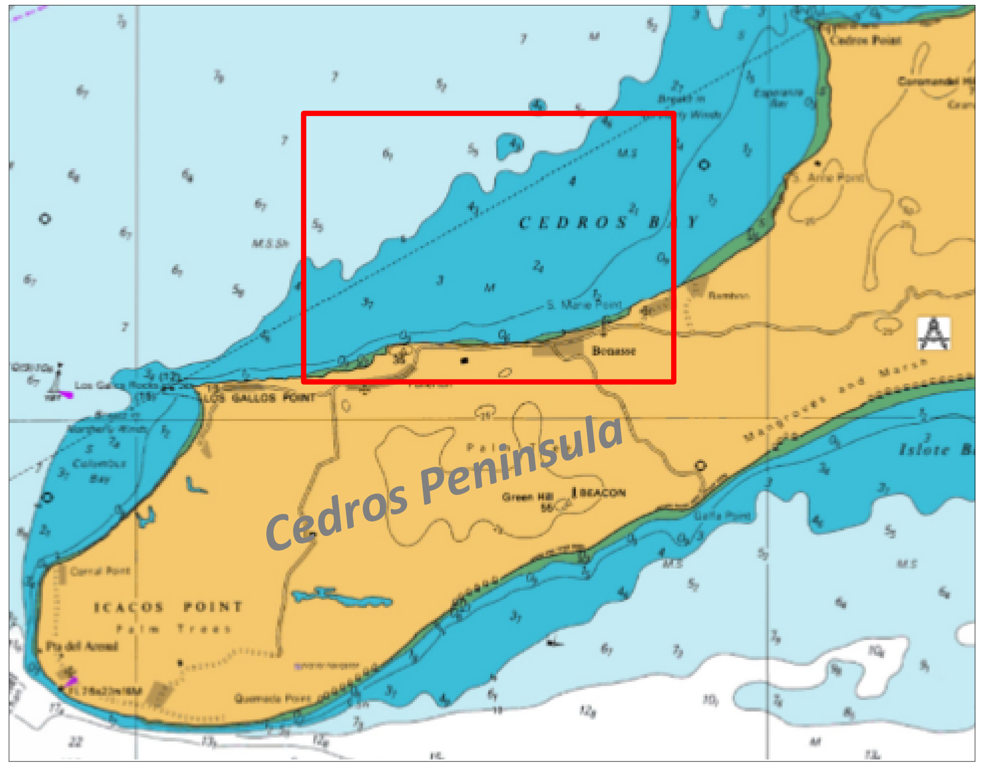
Plan 2. Bathymetry of the borrow area.

Plan 3. Grain size distribution of sands in the borrow area.

Plan 4. Design profiles for sand filling.

Plan 5. Execution of the works.





Symbology:

4.0	Isobaths
7.0	Isobath of 7 m
3.7	Depths
▲ Bonasse-2	Beach profiles
	Shoreline
	Pier

Distances scale (m)

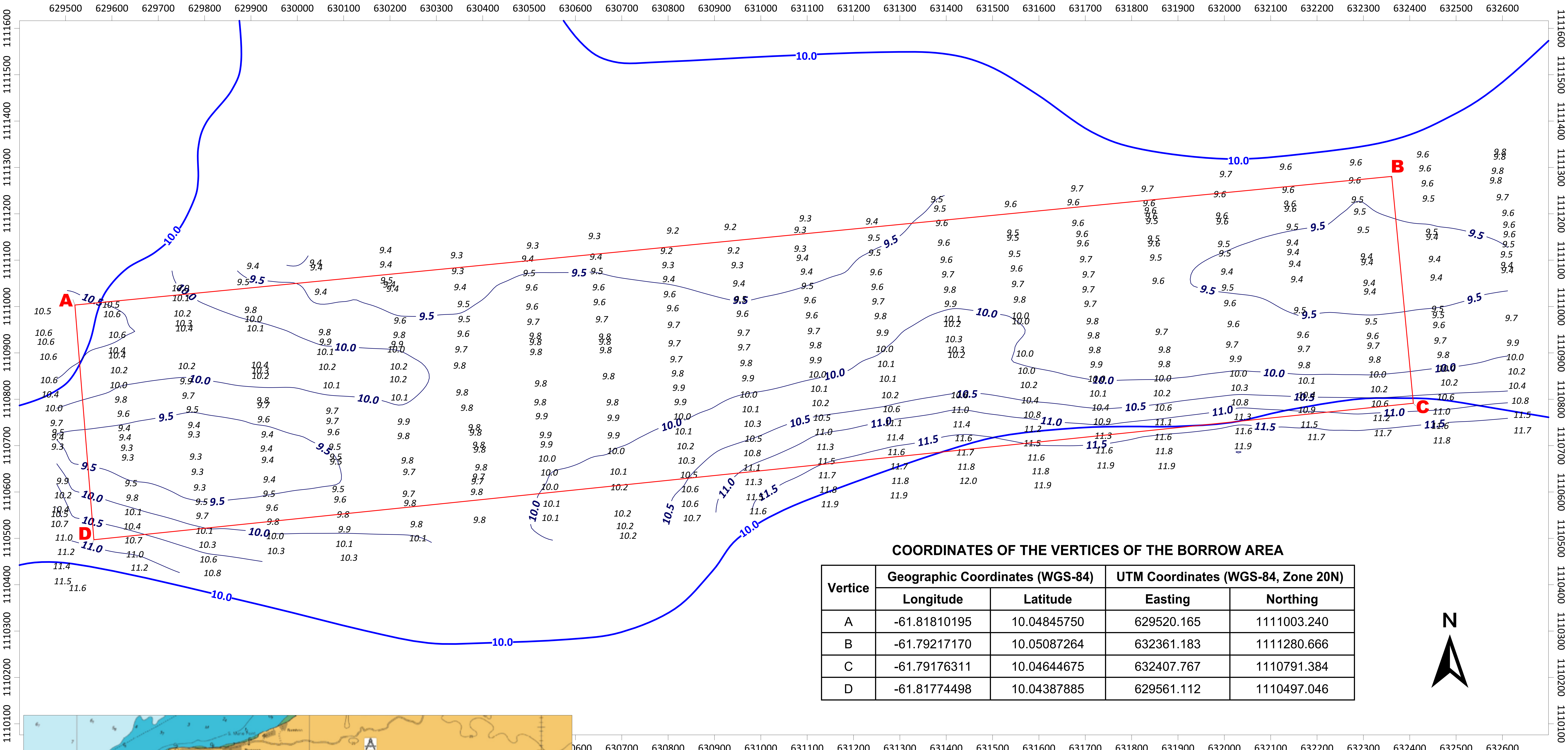
0 300 600 900 1200

Projection: Universal Transverse Mercator (UTM)
Datum: World Geodetic System 1984
Coordinate System WGS84 UTM zone 20N

Depths in meters, referred to mean sea level
Isobaths each 0.50 m.

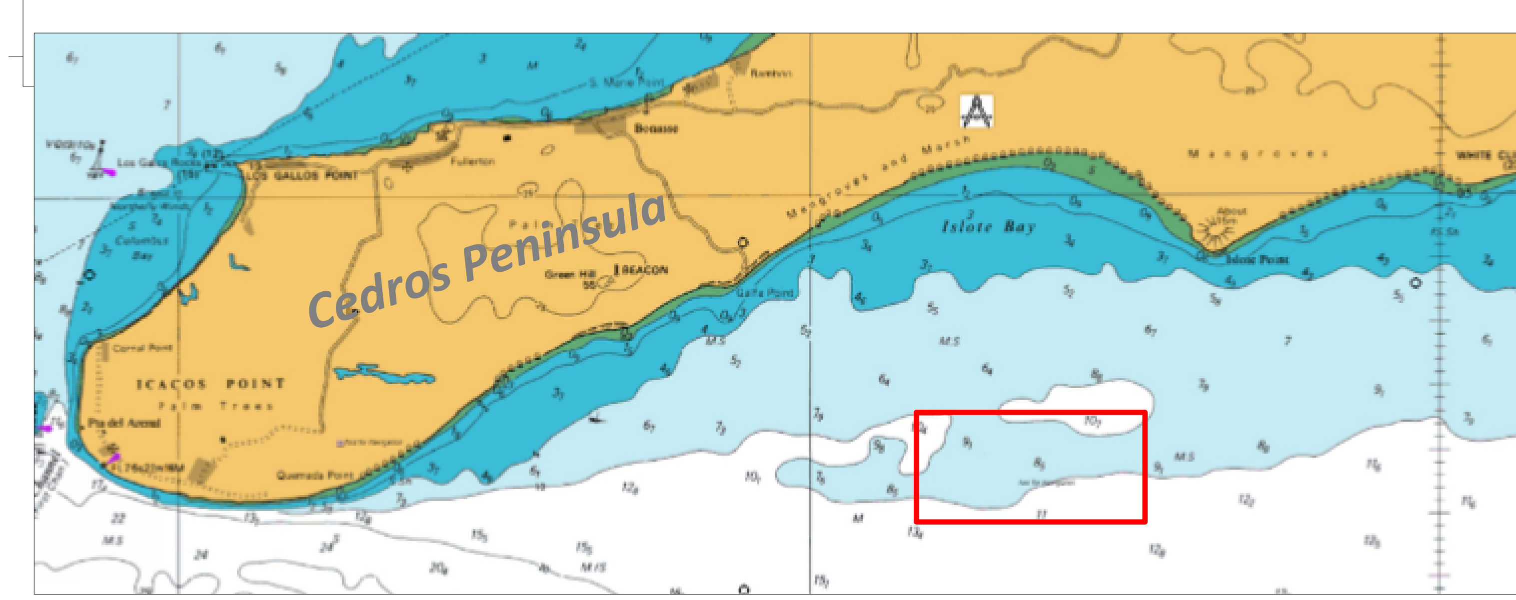
DO NOT USE as a Nautical Chart

GAMMA Tecnología y Medio Ambiente	MINISTRY OF SCIENCE, TECHNOLOGY AND ENVIRONMENT OF CUBA	
PROJECT MANAGER: MSc. Miguel Izquierdo Álvarez	PROJECT: PROJECT FOR THE REHABILITATION OF BONASSE BEACH, CEDROS BAY TRINIDAD AND TOBAGO	
MADE BY: MSc. Miguel Izquierdo Álvarez	TITLE: BATHYMETRY OF THE BEACH	
REVIEWED BY: MSc. Leonel I. Peña Fuentes		
DATE: August 2022	SCALE: 1 : 13000	PLAN: 1



COORDINATES OF THE VERTICES OF THE BORROW AREA

Vertice	Geographic Coordinates (WGS-84)		UTM Coordinates (WGS-84, Zone 20N)	
	Longitude	Latitude	Easting	Northing
A	-61.81810195	10.04845750	629520.165	1111003.240
B	-61.79217170	10.05087264	632361.183	1111280.666
C	-61.79176311	10.04644675	632407.767	1110791.384
D	-61.81774498	10.04387885	629561.112	1110497.046



Symbology:

- 10.5 — Isobaths
- 10.0 — Old nautical chart isobaths
- 10.2 — Depths
- A B C D — Borrow area

Distances scale (m)

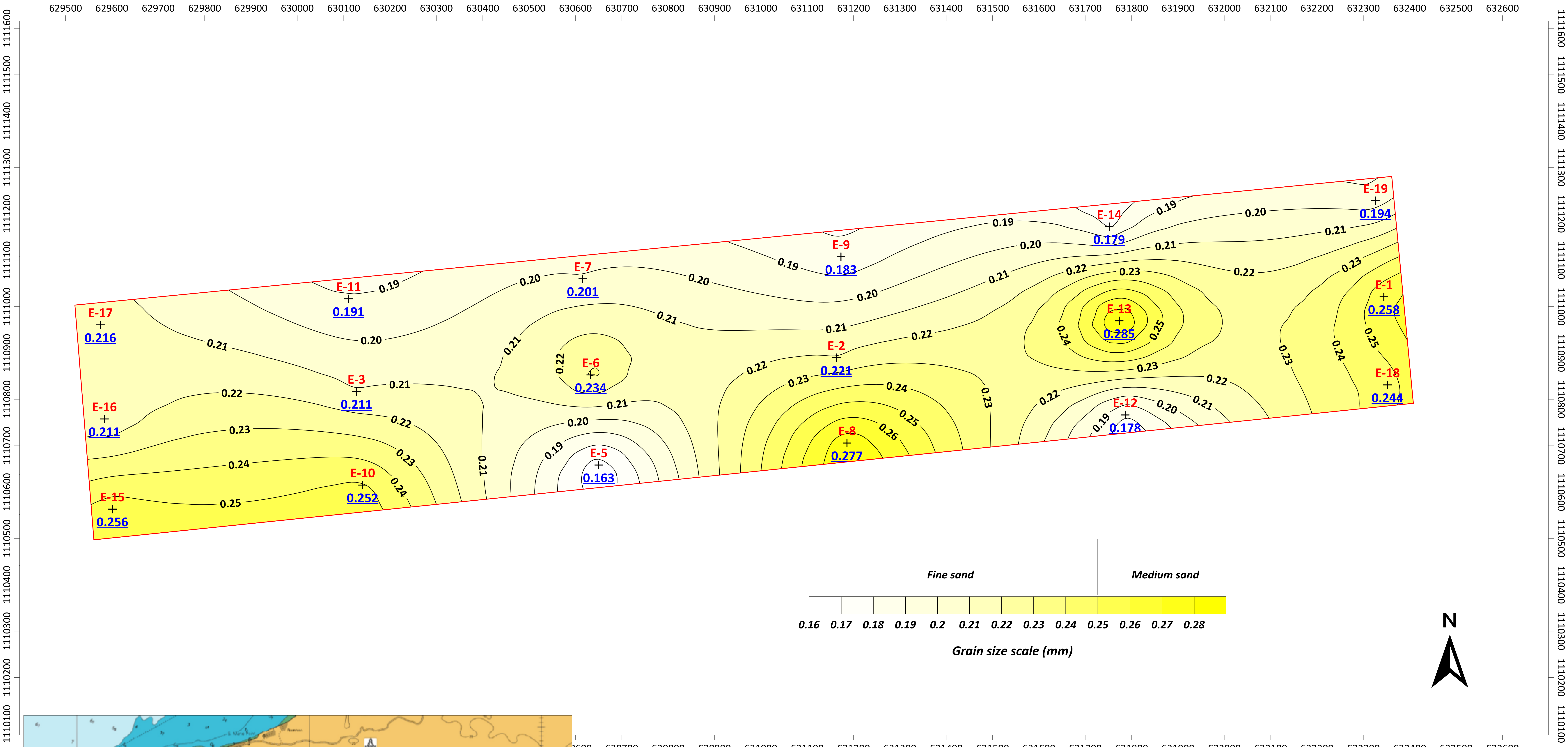
0 100 200 300 400

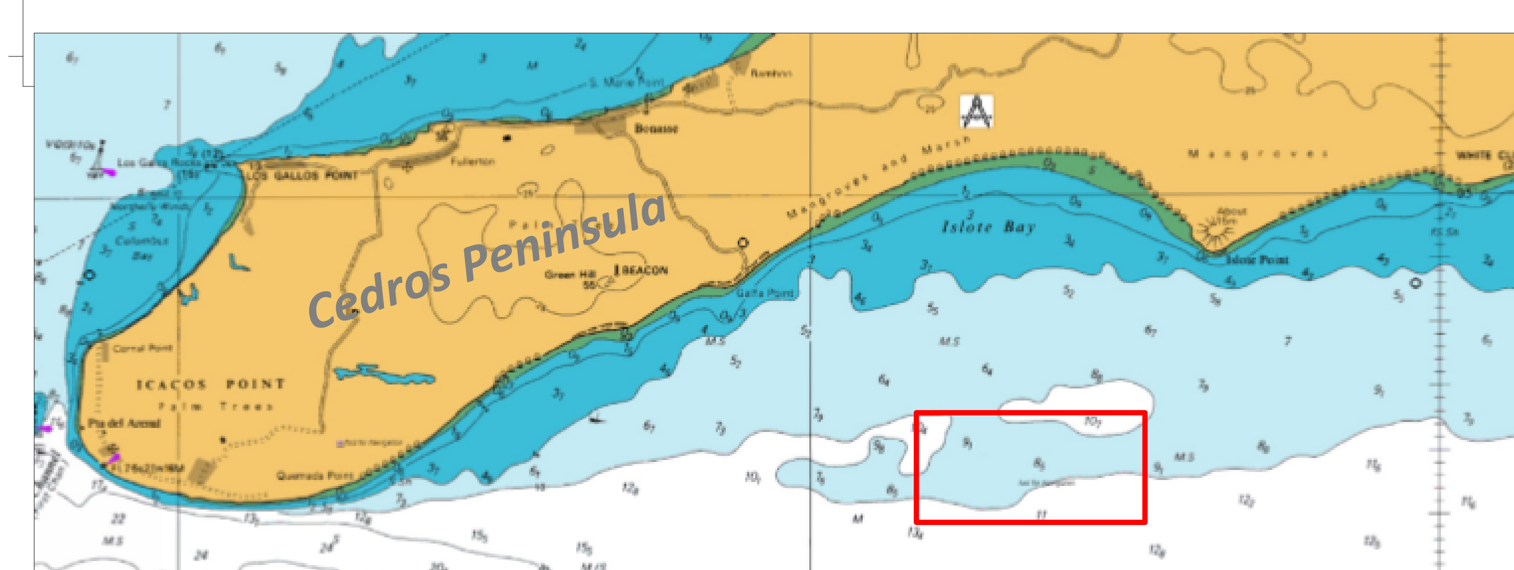
Projection: Universal Transverse Mercator (UTM)
Datum: World Geodetic System 1984
Coordinate System WGS84 UTM zone 20N

Depths in meters, referred to mean sea level
Isobaths each 0.50 m.

DO NOT USE as a Nautical Chart

GAMMA	MINISTRY OF SCIENCE, TECHNOLOGY AND ENVIRONMENT OF CUBA
PROJECT MANAGER: MSc. Miguel Izquierdo Álvarez	PROJECT: PROJECT FOR THE REHABILITATION OF BONASSE BEACH, CEDROS BAY TRINIDAD AND TOBAGO
MADE BY: MSc. Miguel Izquierdo Álvarez	TITLE: BATHYMETRY OF THE BORROW AREA
REVIEWED BY: MSc. Leonel I. Peña Fuentes	
DATE: August 2022	SCALE: 1 : 6000 — PLAN: 2





Symbology:

10.5 — Isolines of granulometry

E-32 + Sampling station

0.163 Granulometry at the station

A B C D Borrow area

Distances scale (m)

0 100 200 300 400

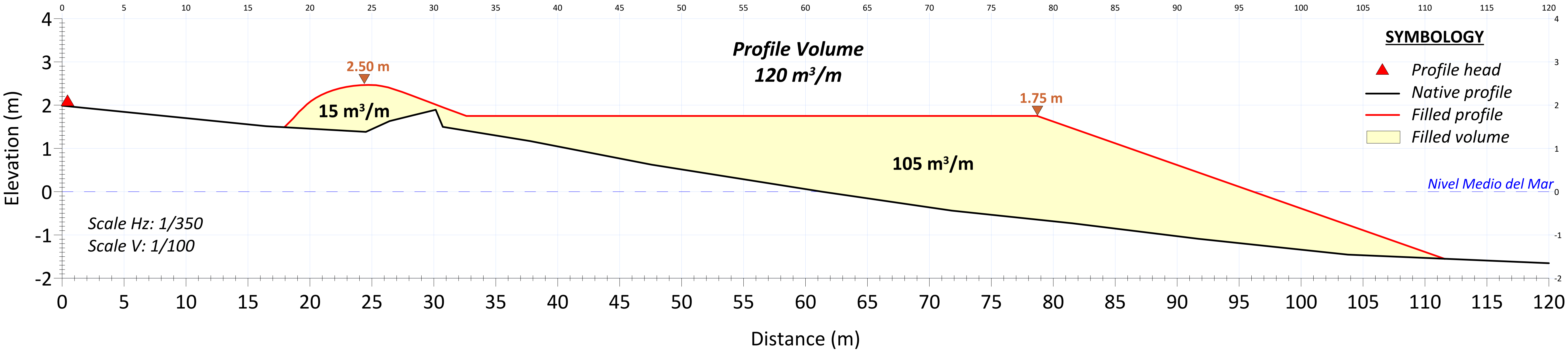
Projection: Universal Transverse Mercator (UTM)
Datum: World Geodetic System 1984
Coordinate System WGS84 UTM zone 20N

Isolines in millimeters

GAMMA	**MINISTRY OF SCIENCE, TECHNOLOGY AND ENVIRONMENT OF CUBA**
PROJECT MANAGER: MSc. Miguel Izquierdo Álvarez	**PROJECT:** PROJECT FOR THE REHABILITATION OF BONASSE BEACH, CEDROS BAY TRINIDAD AND TOBAGO
MADE BY: MSc. Miguel Izquierdo Álvarez	**TITLE:** GRAIN SIZE DISTRIBUTION OF SAND IN THE BORROW AREA
REVIEWED BY: MSc. Leonel I. Peña Fuentes	
DATE: August 2022	**SCALE:** 1 : 6000 — **PLAN:** 3

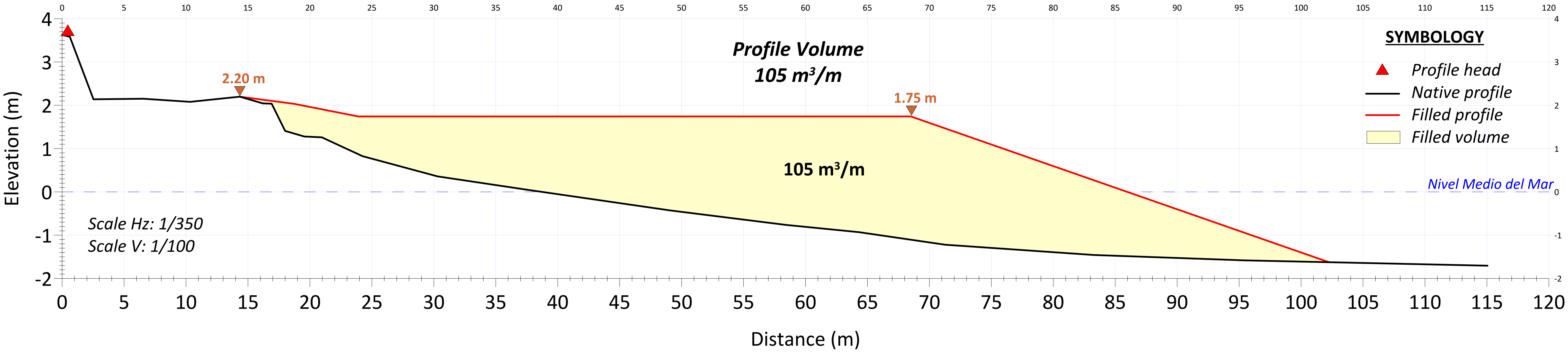
Beach Profile "Bonasse 1"

(Sector 2, Fullerton)



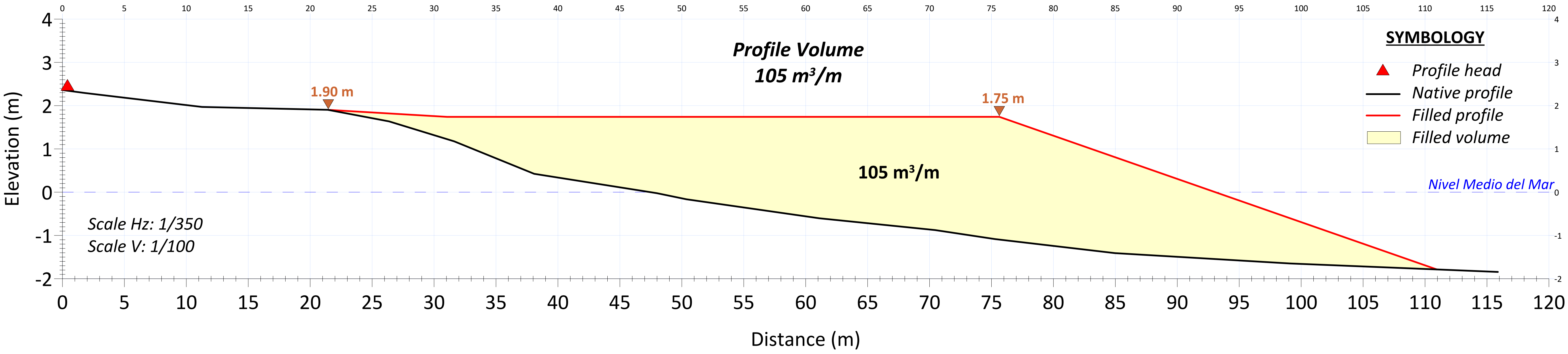
Beach Profile "Bonasse 3"

(Sector 2)



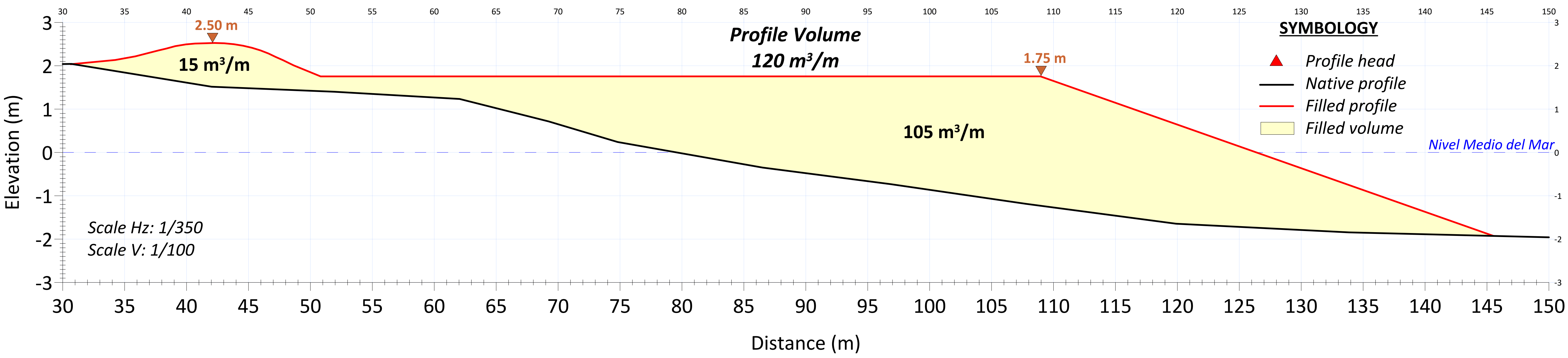
Beach Profile "Bonasse 5"

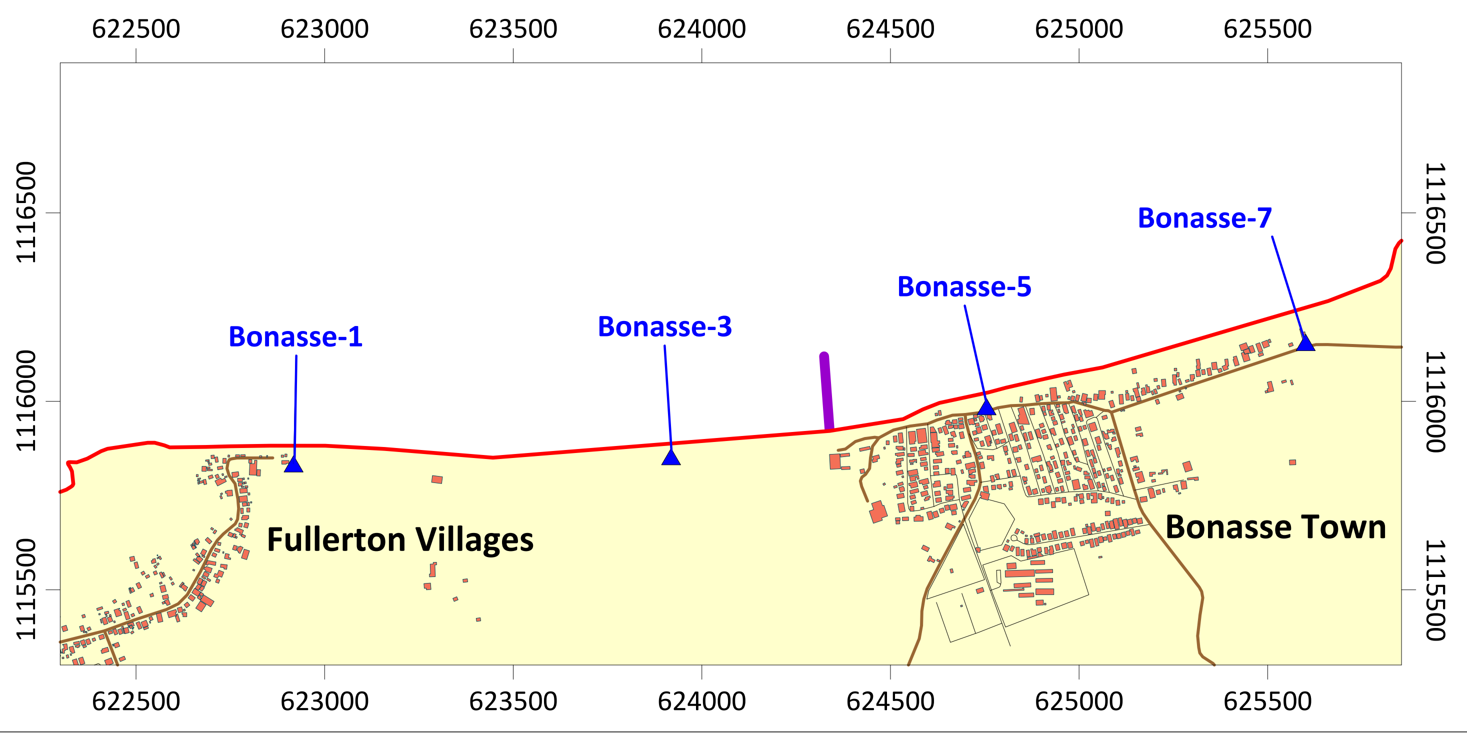
(Sector 1, Bonasse)



Beach Profile "Bonasse 7"

(Sector 1, Bonasse)

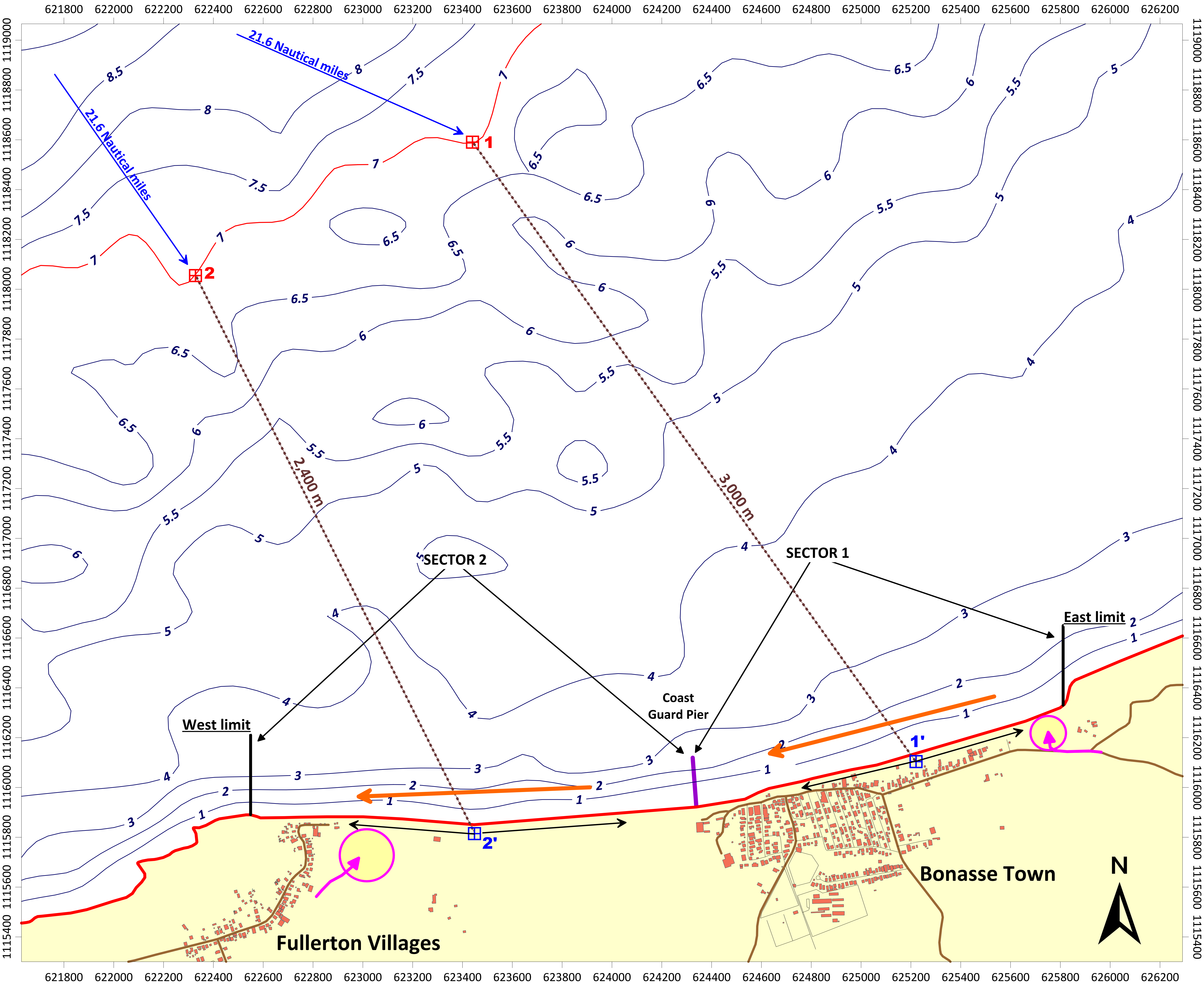




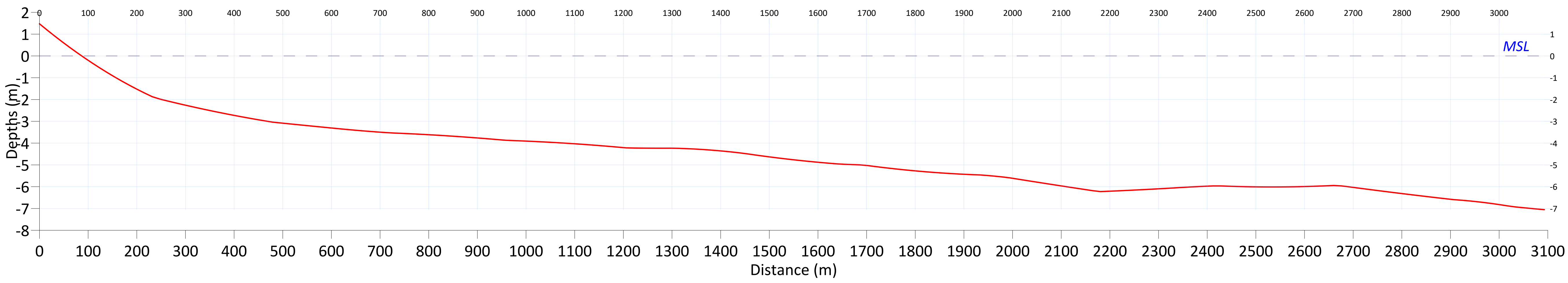
NOTES:

The cross sections correspond to the points that make up the network of beach profiles established by Inversiones Gamma S.A.

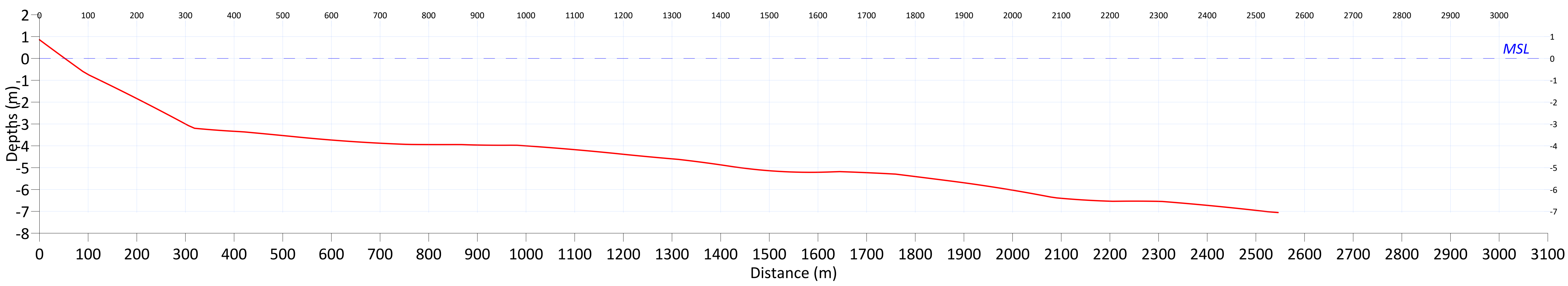
GAMMA	MINISTRY OF SCIENCE, TECHNOLOGY AND ENVIRONMENT OF CUBA
PROJECT MANAGER: MSc. Miguel Izquierdo Álvarez	**PROJECT:** PROJECT FOR THE REHABILITATION OF BONASSE BEACH, CEDROS BAY TRINIDAD AND TOBAGO
MADE BY: MSc. Miguel Izquierdo Álvarez	**TITLE:** DESING PROFILES FOR SAND FILLING
REVIEWED BY: MSc. Leonel I. Peña Fuentes	
DATE: August 2022	**SCALE:** GRAPHICS **PLAN:** 4

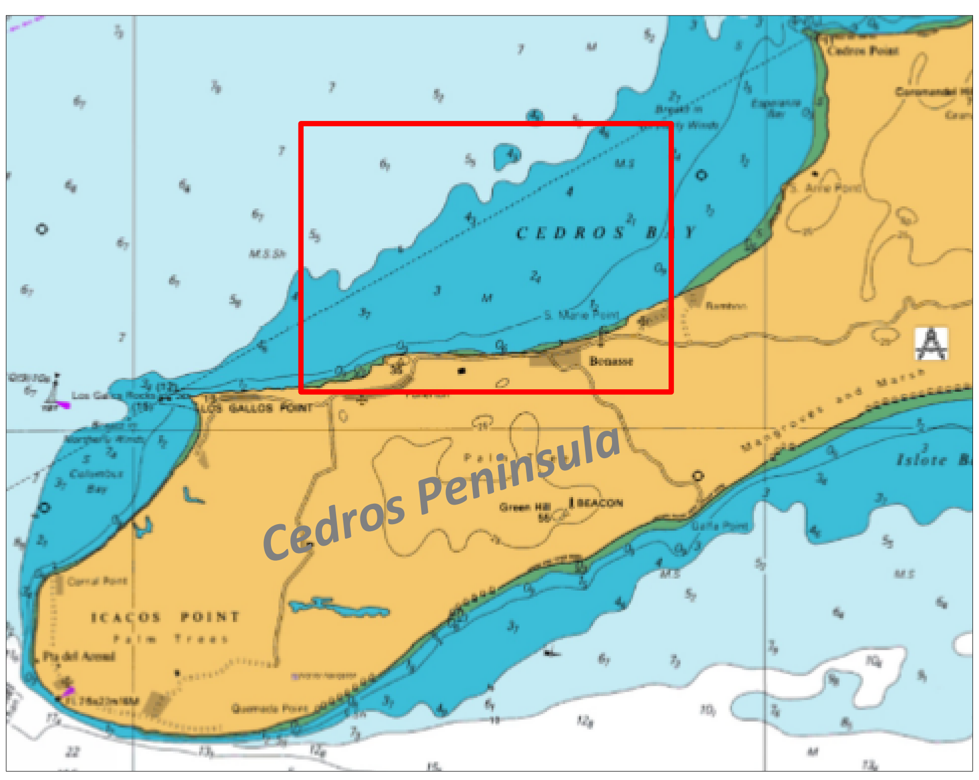


Cross section 1-1'



Cross section 2-2'





Symbology:

- 2 — Isobath
- 7 — 7m isobath
- Dredge connection point position
- Position of the pipeline on land
- Average sailing distance from the borrow area to the dredge connection point
- 2,570 m — Length of discharge pipe
- Direction of fill advance
- Pipe assembly/disassembly area and equipment access

Distance scale (m)

0 300 600 900 1200

Projection: Universal Transverse Mercator (UTM)
Datum: World Geodetic System 1984
Coordinate System WGS84 UTM zone 20N

Depths in meters, referred to mean sea level
DO NOT USE as a Nautical Chart

GAMMA	MINISTRY OF SCIENCE, TECHNOLOGY AND ENVIRONMENT OF CUBA
PROJECT MANAGER: MSc. Miguel Izquierdo Álvarez	PROJECT: PROJECT FOR THE REHABILITATION OF BONASSE BEACH, CEDROS BAY TRINIDAD AND TOBAGO
MADE BY: MSc. Miguel Izquierdo Álvarez	
REVIEWED BY: MSc. Leonel I. Peña Fuentes	TITLE: EXECUTION OF THE WORKS
DATE: Agosto 2022	SCALE: 1 : 13000 PLAN: 5

ELEMENTS INVOLVED IN THE DEGRADATION OF THE MORPHOLOGICAL, AESTHETIC AND FUNCTIONAL CONDITIONS OF THE BEACH IN SECTOR 2

SECTOR WITHOUT ANTROPIZATION (Less than 10%)

Although the sector retains its natural state and there is no human intervention, there is a significant erosion process, where the main signs of erosion are the presence of erosion scarps, falling trees, outcropping of old structures due to sand loss and the marked retreat of the shoreline, evidenced by the presence on the beachfront of morphological elements and vegetation that normally by its natural zoning, belongs to areas of dunes and post-dunes.

In the Fullerton section, where there is a certain degree of anthropization, there is occupation of the dune and the placement of defensive structures to protect against storm waves.

These elements affect the aesthetics of the beach, as well as the morphology of the profile, preventing the normal functioning of the beach, especially in times of storm wave impacts, which are normally dissipated by a morphologically complete and stable beach profile.

MEASURES FOR THE REHABILITATION AND PROTECTION OF BONASSE BEACH

SECTOR 2

COASTAL MANAGEMENT ACTIONS

Coastal management actions should be addressed to eliminate all sources of contamination and discharge of solid or liquid waste, as well as to ensure the physical integrity of the coastal environment, preventing new construction on the dunes and the beach, and removing all abandoned concrete structures that currently exist and that, by their nature, are incompatible with the proper functioning of the beach.

These management actions will also lead to the implementation of engineering measures aimed, on the one hand, at mitigating the effects of erosion and restoring the aesthetic and functional conditions of the beach and, on the other hand, at meeting the challenges posed by climate change and rising sea levels.

Short Term

Coastal cleaning and sanitation. Drainage management.

Medium Term

Removal of rigid structures. Drainage management.

Drainage management in the medium term will have two action fronts. On the one hand, monitoring the elimination of micro-dumps that have not yet been removed and, on the other hand, the execution of solutions for the control and sanitation of drainage discharges that are evacuated through the concrete structures (canals) present at both ends of Bonasse town, which discharge directly into the sea without any type of treatment.

The establishment of waste treatment plants, as well as a drainage system by means of main conductors and submarine outfalls, should be the object of assessment and projects that would make up the Bonasse Coast Master Plan.

MEASURES FOR THE REHABILITATION AND PROTECTION OF BONASSE BEACH

SECTORS 1 & 2

Medium term: Artificial Beach Nourishment

Artificial Beach Nourishment, as an advanced technique for beach recovery and/or maintenance, has shown satisfactory results worldwide, due to its undeniable benefits and advantages over other engineering alternatives, with regard to the conservation of natural beach conditions.

It basically consists of providing new volumes of sand to the beach, from a nearby borrow area, which allows the sediment lost due to the effect of erosion to be returned to the system in a short period of time. In addition, it allows the creation and/or recovery of spaces destined for recreational use or related to fishing, as well as providing the beach profile with the volumes of sand and the space necessary for its dynamic operation, thus also serving as a coastal defense.

Among its most notable advantages is the speed with which the profile is restored and the non-introduction of new structures in the coastal area, this being a friendly solution in harmony with the environment, as well as being aesthetically superior to the creation of rigid structures, such as groynes, breakwaters or jetties. It should be noted that its implementation does not compromise the application of other measures in the future, if necessary, since the basic morphology of the coastal sector is not modified, nor are costly and difficult-to-remove elements introduced.

BEFORE	DURING	AFTER

ELEMENTS INVOLVED IN THE DEGRADATION OF THE MORPHOLOGICAL, AESTHETIC AND FUNCTIONAL CONDITIONS OF THE BEACH IN SECTOR 1

HIGHLY ANTHROPIZED SECTOR

Water and sediment contamination due to unprocessed discharge into the sea from storm drains and liquid and solid waste from domestic activities.

These elements are sources of contamination that affect the aesthetics and functionality of the beach as a seaside resort, in addition to being potential generators of disease due to the increase of microorganisms that are harmful to human health.

Debris and abandoned concrete structures in the process of destruction.

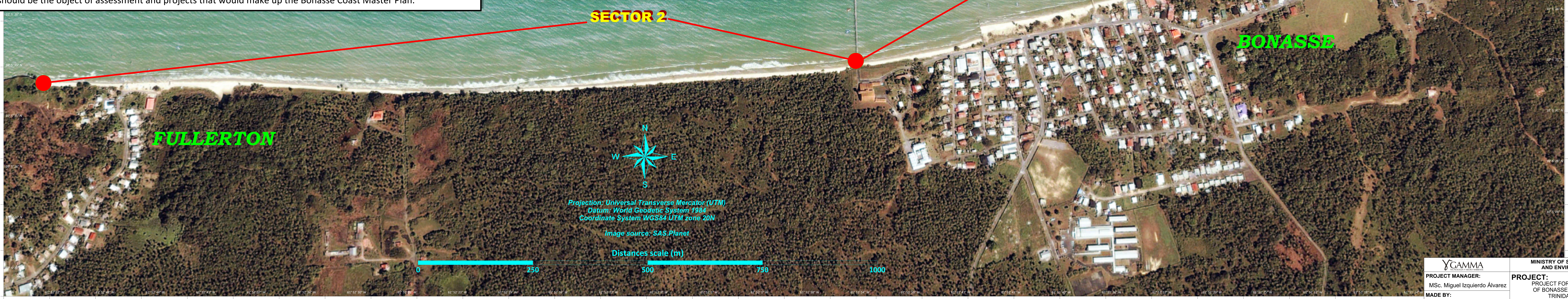
These elements affect the aesthetics of the beach; however, the main impact occurs in the morphology and functionality of the beach profile, favoring erosive processes in times of storms, which accelerate the loss of sediments from the emerged part of the beach.

Coastal erosion, where there are signs of erosion that undoubtedly indicate the unequivocal presence of this phenomenon, with an intensity that can be classified as moderate. These elements affect the aesthetics of the beach, as well as the morphology of the profile and the functionality of the beach.

Within these signs of erosion we find the formation of erosion scarps on the dune, destruction of walls and protective structures reached by the waves, as well as the reduction of the beach width that reflects the loss of dune sectors and the exposure to the sea of the shrub vegetation typical of post-dune areas.

The causes of erosion are mainly natural, associated with the sedimentary imbalance of the beach, as a result of the deficit in sediment inputs from the cliffs upstream, which causes more sediment to escape from the beach by the coastal currents than sediment that enters the beach from the cliffs, marking an irreversible erosive trend in a natural way.

It is understandable that actions to solve erosion problems should be oriented towards the elimination and/or mitigation of the causes that generate them and the execution of works that allow for the rehabilitation of eroded beach sectors.



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PROJECT MANAGER: MSc. Miguel Izquierdo Álvarez	PROJECT: PROJECT FOR THE REHABILITATION OF BONASSE BEACH, CEDROS BAY TRINIDAD AND TOBAGO
MADE BY: MSc. Miguel Izquierdo Álvarez	
REVIEWED BY: MSc. Leonel I. Peña Fuentes	TITLE: SUMMARY OF EXISTING BEACH CONDITIONS AND MEASURES TO BE IMPLEMENTED FOR BEACH REHABILITATION
DATE: March 2023	SCALE: 1 : 3500 — PLAN: 6